controlled in data sets, called the INI-FILE–for General Parameters–and the TRY-FILE–for Basin Parameters. All kinds of parameters to be defined in the model and their meanings are referred to operation manual.

b) Fixed Model Parameters on Surface System

They are 21 basins covering whole area, consisting eight basins covering mountain area and 13 basins laid on Bahada plain. However, three sub-basins have verification data obtained from wadi gauging stations during the period from 1976 to 1995. Trial runs to verify the reliability of the of the surface system model was consequently, performed for these three sub-basins. As a result, a three-layered tank model was determined for basins No. 1 to No. 8 located in the mountain area. Four to five-layered tank structures were identified in the Bahada plain area corresponded to No. 9 to 21. All of fixed models are illustrated in Figure 1.5.3.

c) Fixed Model Parameters of Sub-surface System

Prior to conducting the trial run of Sub-surface system, all parameters evolving Surface System had been finalized and the amount of groundwater recharge was calculated. In the Sub-surface system, this amount was treated as the first income to the Sub-surface system. Thus the verification of Sub-basin model was treated only by operating sub-surface parameter correlated to aquifer coefficients such as permeability, storage coefficients and leakage. These parameters were modified one direction at a time, aquifer by aquifer, and so forth, until the model came to match the verification data within a tolerable error range. There were six sets of verification data, thus the verification of these parameters was completed in these six sub-basins. The fixed parameters are shown in Figure 1.5.4.

1.5.4. Groundwater Balance

(1) Existing Works

Evaporation from coastal sabkha has been estimated to equivalent to 8% of the rainfall (Pike 1970). Evaporation has been recorded since 1968 from standard pans in five locations and conversion factors calculated for estimating potential evapotranspiration rates for Date palms, Alfalfa and vegetable crops. Measurements at farms indicate that irrigation water is applied in practice at rates far exceeding the theoretical cropping requirements calculated from these evapotranspiration estimates. The previous study (HALCROW and Partners, 1969) presents a tentative water balance between rainfall, surface flow, groundwater recharge and groundwater extraction indicating the withdrawal of groundwater from storage. The data are based on the years 1966–68 in the Al Ain area, which were particularly dry. Against an estimated volume of 5,280 MCM for the alluvial aquifers, an overdraft of the order of 200 MCM would draw on some 4% of the total storage.

While in the Study area, the groundwater draft was reported by IWACO (1986) as amounting to 147 MCM/a based on 1985. This would be correlative with about seven times the average groundwater recharge, which is estimated to be 21.7 MCM/a.

(2) Current Hydrologic Balance

In the Study Area, the data for the hydrologic balance for the 19 years from 1977 to 1995 was analyzed given the current circumstances. The period of analysis was divided into two parts consisting of first 9 years from 1977 to 1985 and the second 10 years from 1986 to 1995. In the first period, the model identification was performed only by the flood record, while in the second period, the verification of model was modeled against both the flood record and groundwater hydrograph. In following paragraph, the model identification and their result of hydrologic balance in current condition are described.

a) Identification of Model

The identification for model was carried out through a comparison between the calculation result and the verification data. Both sets of results for the Surface System and the Sub-surface System mutually coincided with in a certain measure of success, as shown in Figure 1.5.5 and 1.5.6. In the Surface System, there was a little difference between both, consequently, the precision of the model was judged as good enough to reproduce their flood pattern by means of the rainfall record. In the Sub-surface System, although the calculation was not in accord with such an abrupt change in the real groundwater hydrograph, it was also concluded to be useful in analyzing the hydrologic balance in Study Area.

b) Hydrologic Balance in Current Situation

The hydrologic balance reproduced during 1977 to 1995 is present in Table 1.5.1 and Figure 1.5.7 and their average is shown in Figure 1.5.8.

A Summary of current hydrologic balance in the comparison with the previous IWACO study (1986) is shown in the following table.

Summary of Current Hydrologic Balance made by JICA and IWACO

Study Team	JICA			IWACO		
Duration (Year)	average of 1977-1995			1985		
Basin Area (km^2)	1,826			4,290		
	Depth (mm)	Volume (MCM)	(%)	Depth (mm)	Volume (MCM)	(%)
Basin Rainfall	155.1	288.3	100.0	112.6	483.0	100.0
Evapotranspilation	143.3	261.6	92.4	104.9	449.1	93.2
Surface Runoff	0.2	0.4	0.1	2.8	12.0	2.5
GW Recharge	11.9	21.7	7.7	5.3	22.7	4.7
GW Runoff	10.4	19.0	6.7	1.7	7.2	1.5
WG Draft	14.8	26.9	9.5	55.6	238.7	49.4
Balance	-13.5	-24.7	-8.7	-57.7	-246.7	-51.2

- Hydrologic Balance in Surface System

Prior to calculating the groundwater balance, all parameters in the surface system were fixed through identification and the surface hydrologic balance for 19 years in the Study Area was calculated on the basis of rainfall data. During this 19 years period, the rainfall in the area was estimated to be 155 mm/a, and out of this, the 143 mm/a was lost by evapotranspiration. The 12 mm of remainder was allocated to the other items, of which 0.2 mm went to surface runoff, 12 mm to groundwater recharge and -0.3 mm/a of storage balance in Surface System. The variation in annual rainfall was large, hence the draught which aggravated the shortfall in the groundwater recharge and even the surface runoff often took place. However in wet years, or even in drought years followed by a wet year, a large amount of evapotranspiration, often exceeding the amount of rainfall often took place. The ratio of groundwater recharge to rainfall is calculated to be up to 10% in the wet years.

- Hydrologic Balance in Sub-surface System

The groundwater recharge was calculated to be 12 mm (22 MCM) in average for 19 years. In contrast to this, values of 15 mm (27 MCM) for the groundwater draft and 10 mm (19 MCM) for the groundwater runoff were calculated. This expenditure, totaled with the groundwater draft and the groundwater runoff, is twice in excess of the budget in the groundwater balance, consequently the shortfall has been met by the depletion of groundwater storage. The groundwater storage during this 19 year period decreased 412 MCM, that was in a rate of 22 MCM/a as shown in Figure 1.5.7.(2). Over the past five years, from 1990 to 1995, there has been a remarkable reduction of groundwater resources. It has continued through the rainy years, so that the groundwater recharge has increased compared with previously. However, the amount of groundwater draft drastically increases in this time, it has been reached up to twice the before. Accordingly, there has been still negative balance with big loss of the storage.

- Comparison with the Existing Study of Hydrologic Balance

IWACO consultant made a groundwater balance study for the Northern Emirates inclusive of the Central Agricultural Region in 1985. The result of study for the Central Region is summarized in the table above with that of JICA's study.

The area under the IWACO's study was covered an area of 4,290 km^2 inclusive of Structural Plain upto Gulf coast, Bahada Plain and the related mountain catchment in all the Central Agricultural Region. Whereas, the area under the JICA's study covers an area of 1,826 km^2, only Bahada Plain from Falaji Al Mualla in the north to Fili inthe south and its mountain catchment within the Central Region.

IWACO estimated the groundwater abstraction of some 62 MCM for the domestic water supply within their study area inclusive Awir, Bidai, Shunuf, Tawi Rashid, Manama and others which are out of JICA's area. While, JICA study team estimated that in its area at 2 MCM inclusive of Falaj Al Mualla, Dhaid, Mileiha and others.

A significant discrepancy in both studies was taken place in the estimate of groundwater abstraction for irrigation. IWACO's estimate at 179 MCM/a in 1985 was drived based on the total gross farm area of 7,674 ha, a crop water requirement of 3.2 mm/day and an irrigation effeciency of 0.45. The JICA team estimated that at 52 MCM/a in 1995 based on the total net cropping area of 4,584 ha (the gross area is 6,181 ha) and the actual irrigation application of 33 m^3/day/ha (3.3 mm/day) which was drived by the sample farm survey made by the team and other previous experiments and other conditions.

A further discrepancy in both the studies was the methodology of study as well. IWACO applied a method in the conventional equation filling necessary components drived by a number of assumptions. As previously stated, the JICA team adopted a mathematical simulation model. The parameters of model were verified and defined by the actually investigated aquifer structure and the hydrologic behavior in the time-series observatory records of daily rainfall, groundwater hydrographs, floods and so forth.

(3) Simulation Cases

For the purpose of evaluation of groundwater resources, following four cases were applied to the predictive Study.

Case	Amount, Strength and Location of Wells of Groundwater Draft	Marginal Groundwater Head on Basin Management	Groundwater Augment Facility
Case1	1. Maintain amount (1995) of current groundwater draft. 2. Maintain current pumping strength and well location.	1. Economical marginal depth of pumping: set on 300 m as pumping depth.	out of consideration.
Case 2	1. Maximum amount of groundwater draft on marginal Groundwater head. 2. Optimum strength and well location to obtain the maximum.	1. Maintain groundwater head in the current dynamic condition: set on 100 m as a pumping depth.	- ditto -
Case 3	- ditto -	- ditto -	Groundwater recharge trench.
Case 4	- ditto -	- ditto -	Groundwater recharge trench and detention dam.

The target aquifers in this simulation were set on both the Upper and Lower Aquifer and the extraction from the aquifer was controlled by a marginal head defined according to the above conditions respectively. It is known as a "controlled head" and the extraction stops when this head reaches to this definition. It resumes when the head recovers this position. In this simulation. "the control head" was determined based on the economic condition. If the pumping will be made from the deeper than 300 m, the cost for pumping would be very high. The estimation for this situation gives the cost of 7.9 Dhs/m^3, which is nearly equal to that of the alternative water resources as mentioned below. On the country, the 2.0 Dhs/m^3 was introduced from the result of Case 2 water, which is pumped from a depth of less than 100 m. This cost also can bear comparison with that of tap water, which costs as much as 1.7 to 6.7 Dhs/m^3. When the pumping was done within 100 m deep, the cost for the pumping was secured economically.

1.5.5. Evaluation of Groundwater Resources

(1) Introduction

The evaluation of groundwater Resources in the Study Area was made through the aforesaid simulation study comprised of Cases 1-4. Case 1 was performed by predicting the timing of exhausting the groundwater resources and the evaluation of mining yield from the basin as well. Case 2 was conducted to obtain an indication of the sustainable yield in the Study Area. Case 3 and 4 were completed to evaluate the use of artificial facilities to augment the groundwater recharge designed in the Study Area. These results obtaining under above cases are described below.

(2) Mining Yield (Case 1)

The forecast covered the 100 years from 1996-2095. It was simulated under a mining yield in which the extraction was as large as the 54 MCM/a of the present level of consumption was made with the 300 m of the control depth. The parameters related to rainfall and the evaporation potential to be input in model was repeatedly substituted by the data of 1977-1995.

The results drawn in Figure 1.5.9 to 1.5.11. indicate that a serious water shortage is imminent. The Upper Aquifer is like to run dry first, it will become apparent in 2003. By 2010, the shortage will covers over the Lower Aquifer, even down to depths of 300 m. Finally, the whole Study Area will pass into a chronic state by 2040. At the same time, the potential of groundwater draft to be pumped up will drop down to 22 MCM/a, which is considered as same amount as the potential of groundwater recharge.

In this case, the groundwater basin will dry up (i.e. it reaches to the economic margin for pumpage, 300 m deep) within 45 years unless some countermeasure, such as restricting the amount of groundwater withdrawal, is enforced immediately.

(3) Sustained Yield (Case 2)

The simulation covers the 38 years from 1996-2033. The amount of withdrawal was given by a values ranging from the current level to the sustained yield. The 100 m of the control level giving a economic pumpage cost were also applied. By the trial run to process the parameter, the amount of withdrawal for each year was determined by the maximum amount to be extracted without any shortage. If the pumping exceeds this maximum amount, the groundwater head decreases down to the control level at some part of the simulated basin. As other parameter, the actual record of rainfall, the evaporation potential dated 1977-1995 was repeatedly used. The result is shown in Figure 1.5.12 to 1.5.14.

From 1995-2015, the amount of groundwater withdrawal starts gradually decreasing, and from this time onward, a constant extraction is maintained, The groundwater balance also becomes stable in this period. The hydrological balance on their budget and expense, of which are 21.7 MCM/a of groundwater recharge, the 2.2 MCM/a of groundwater runoff and 19.5 MCM/a of groundwater withdrawal, were preserved for the long term. Simultaneously, the "Sustainable Yield" was also introduced as the sustained amount on pumpage level. The 19.5 MCM/a of groundwater withdrawal was assumed as "Sustainable Yield" in the Study Area.

This Case prevented the groundwater going below serious levels exceeding 100 m which would have happened if groundwater withdrawal had not been cut back to achieve a "Sustainable Yield", within 20 years (1996-2015).

(3) Recharge Trench (Case 3)

The case was performed to evaluate the effect of the groundwater recharge trench. Using the current model which derived its parameters from the result of infiltration experiments, the effectiveness to be derived from the designed trench was simulated. In the actual work, the degree of this effect was assumed by a difference between the calculation in Case 3 and that of the current model. The facility configuration adopted in this case was three sites located at three wadis along Wadi Siji, Wadi Khadrah and Wadi Shoukah with 1 km long respectively. For other input parameter such as rainfall and evapotranspiration, the actual observation data from 1977 to 1995 were applied. The result is shown in Table 1.5.2. and Figure 1.5.15.

The 22.01 MCM/a of groundwater recharge was calculated from Case 3 whereas 21.67 MCM was calculated from the current model. Accordingly, the balance between both was obtained as 0.3 MCM/a as the effectiveness of groundwater recharge trench.

(4) Recharge Trench and Detention Dam (Case 4)

This case is also conducted for evaluating the groundwater augment facility. A combination plan composed of the groundwater trench and the detention dam was planned in this case. The current model was modified by setting the parameter related to this combination plan to analyze their facility effectiveness. These dams were designed at three sites of Wadi Siji with the capacity of 2..46 MCM, Wadi Khadrah with 3.28 MCM and Wadi Shoukah with 2..46 MCM respectively. The capacity of out-let was assumed to be one tenth of dam capacity. Furthermore, the scale of recharge trench was set as 1 km long as large as that of Case 3. The actual observation data from 1977 to 1995 was used for rainfall and evaporation potential for the model parameter. The result is shown in table 1.5.2 and Figure 1.5.16.

For all the Study Area, the total amount from this case was calculated as 23.64 MCM/a. On the other hand, 21.67 MCM/a was taken from the current model. Hence, The discrepancy between both came to be a effectiveness when this facilities was constructed.

(5) Conclusion

The groundwater recharge is estimated as 21.67 MCM/a in the Study Area, and the sustainable yield was evaluated as 19.5 MCM/a. Moreover, the timing of dried-up is at 2040 within 45 years from the present when the mining yield was set as 54 MCM/a of the current situation. The effect of the groundwater trench was obtained as 0.3 MCM/a when three facilities (@1 km long, 3 sites) were constructed at major wadis. Furthermore by the combination plan with detention dams (3 sites on three major wadis) and groundwater trenches (@11 km long, 3 sites) was planned, the increase of groundwater recharge was estimated as 1.97 MCM/a in whole the Study Area.

1.6. Groundwater Development Plan

1.6.1. Potentiality of Groundwater Resources Development

(1) Potentiality of Groundwater Resources in the Study Area

The resources in the Study Area have been sustained by three types of aquifers, the Upper Aquifer, Lower Aquifer and Fissure Water. The Upper Aquifer is composed of Pleistocene to Holocene sediments and has been widely utilized for the irrigation from ancient times. However, the area utilized has shrink to far from the mountain side due to its low yield resulting in over-drafting especially in the center of the Dhaid.

The rapid development from the lower aquifer has progressed in the last 10 years and has resulted in a serious drawdown in the groundwater head. Furthermore, Fissure Water wells, in spite of their high yield levels, have only a restricted distribution. In the Study Area, Fissure Water is found out at only three localities, which are the faulting zone running along Jabal Mileiha, the structural zone extended from the west of Diba zone and the thrust-faulting zone running in the W–E trend along the boundary area of the Oman Mountains and the Bahada Plain. The resource of Fissure Water is essentially provided from the Upper and Lower Aquifer, mainly by the Upper Aquifer, consequently, the Fissure Water itself does not have high reserve potentiality. In addition to this, the existence of an deeper aquifer below the 600 m is not likely given the observation data collected in the Study, moreover the salinity of water tends to be higher compared with the shallower horizon.

Taking all the above conditions into account, all the groundwater to be developed in the Study Area likely originates from only two aquifers, the Upper Aquifer and the Lower Aquifer. Furthermore, the restricted part in the lower aquifer in the undeveloped area have some potential for the groundwater development.

The predictive analysis (refer to the result of Case 1) was made on a case which a groundwater extraction as large as the current level was maintained till the groundwater head dropped below 300 m deep. Exhaustion, regarded the necessity of pumping from below 300 m deep, will begin in 2003 at Upper Aquifer, and later extend to the whole aquifer at 2010. The dried-up of Lower Aquifer commenced at 2023 and covers all aquifer till 2040. In other words, the all groundwater resources to be pumped economically in the Study Area had been mined up to 2040.

This estimation was made based on the concept of "mining yield" expressed by the total quantity of non-renewable groundwater in the groundwater basin and pumpage in view of economic factor. When the 54 MCM/a of present pumpage continued to the future, the available amount to be utilized decreased to 22 MCM/a. Furthermore, this value still drops to only 10 MCM/a in the drought year.

As countermeasure to be enforced in the future, the concept for "sustained yield" was introduced to avoid the tragic outcome of this simulation result. To form a groundwater development plan that takes account of the various phenomenon in the Study Area, following basic course was mapped out

- The groundwater draft is set according to a renewable yield or sustained yield,
- The gradual shifting of pumpage is to be planned from the present yield to the sustained yield,
- The control head is to be set on a realistic level of 100 m deep,
- The pumping level restricted to the control head is to be maintained in/after the duration of shifting of pumpage.
- Prevention of saline water intrusion from the downstream
- Prevention of pumpage at the area influenced by saline water.

Case 2 modeled under the above basic courses gave the 19.5 MCM/a as the sustained yield which was the one third of present amount of 54 MCM/a. The smooth shifting down of groundwater withdrawal to the 19.5 MCM/a was achieved within the 20 years in the simulation. If the target was set to a period longer than 20 years, the groundwater head may drop beyond the control head in some places in the Study Area. The appropriate yield obtained in respective year is given as below.

Year	1995	1997	1999	2001	2003	2005	2007	2017
Groundwater Draft (MCM)	54	51	45	36	34	27	22	19.5

(2) Integrated Groundwater Augmentation Plan

Two plans, consisting of (1) Groundwater Recharge Trenches and (2) A combination plan with Groundwater Recharge Trenches and Detention Dams, are recommended as groundwater augmentation facilities. These measures produced sufficient effect if they are located along the wadi Siji, Wadi Khadrah and Wadi Shoukah. The effectiveness for respective plans is set out in the following table.

Groundwater Augmentation Facility	Basic Items for facility	Effectiveness for groundwater Recharge
Groundwater Recharge Trench	3 Sites (Wadi Siji, Wadi Khadrah, Wadi Shoukah) Depth; 6 m, Length; 1 km	Total 0.3 MCM/a
Groundwater Recharge Trench + Detention Dam	3 Sites (Wadi Siji, Wadi Khadrah, Wadi Shoukah) Reservoir Capacity 2.46 MCM/s (W. Siji) 2.46 MCM/s (W. Khadrah) 3.28 MCM/a (W. Shoukah)	Total 1.97 MCM/a

The maximum effect, as large as 1.97 MCM/a was realized as a result of the combination facility plan featuring Groundwater Recharge Trenches and Detention Dams. If this amount of 1.97 MCM/a was added to the 19.5 MCM/a of the sustained yield, the total amount of 21.5 MCM/a would be available for utilization in the Groundwater Development Plan in the Study Area.

(4) Water Cost

Water cost was evaluated in two conditions, the natural yield, and the artificial yield produced by groundwater augment facility. Natural yield, refers to the sustained yield maintained due to the groundwater recharge from the surface. Therefore, the extraction from this resource can be made only from the Upper Aquifer. The pumpage can only be made with submersible pumps with the in-take level at 100 m deep from tubewells deepened up to 150 m.

On the other hand, the costs relating to the artificial yield are evaluated from both sides as groundwater augmentation facility and related pumpage costs as well. The respective water cost is given as follows.

Type of Facility	Water Cost (Dhs/m^3)	Components of Applied Facility
Water Well and Pump for withdrawal		
(Depth: 75m)	1.5	Well Depth = 100 m, Pump Cap. = 7900 m^3/a, H = 76m, kW = 1.1
(Depth: 100m)	2.0	Well Depth = 150 m, Pump Cap. = 7900 m^3/a, H = 148m, kW = 2.2
(Depth: 200m)	3.0	Well Depth = 250 m, Pump Cap. = 7900 m^3/a, H = 214m, kW = 3.7
(Depth: 300m)	7.9	Well Depth = 350 m, Pump Cap. = 7900 m^3/a, H = 328m, kW = 7.5
Groundwater Trench	7.5	Wadi Siji, Wadi Khadrah, Wadi Shoukah (3 sites @ 1 km = 3 km)
Groundwater Trench + Detention Dam	10.5	Groundwater Trench: Wadi Siji, Wadi Khadrah, Wadi Shoukah (3 sites @ 1 km = 3 km) Detention Dam: Wadi Siji, Wadi Khadrah, Wadi Shoukah (3 sites)
Pipe Line for Desalinated Water	10.1	Pipe Line: Sharjah-Dhaid, Desalinated Water: 1.25$/m^3

1.6.2. Management of Groundwater and the Monitoring System

The purpose of Groundwater Monitoring System is to monitor for the wasteful mining of limited groundwater resources. Consequently, the range of observation must cover all parts of the Study Area, and records must be kept long-term and in full. In addition, observation data must be closely linked to the management model, for immediate evaluation of present status or reserves.

The Database must be kept up to date with the data obtained from the monitoring system so that users can browse their data whenever they need it. The information to be entered into the Database refers only to a collection of data that is related to a particular topic or purpose. These would be the results of farm surveys, well records, rainfall and flood records and even the landowner's address and employees lists; each of these collections is stored in various forms of spread sheets and document files and are not used one in relation to another. Furthermore it requires a function whereby the user may extract only the necessary information from the basic data.

The management model, as a mater of course, need to be built to include all hydraulic information from the groundwater basin. The model out put following actual observation should provide figure for each respective block, and should the actual amount pumped be greater than the planned rate, a definite warning regarding the exhaustion of the groundwater resources must be issued.

(1) Groundwater Monitoring System

In the Study Area 12 observation wells were set up between 1977–1995 by MAF, and well records have produced very serviceable data since the start of observations. Even with some absent or inaccurate data, the original charts obtained from the record are stored in full at the MAF library. The observation by the meteorological and hydrologic station have been performed over an extended period.

The monitoring system included these existing observatory stations was organized to related to the model of groundwater balance in this Study. The model was then revitalized as a management model to control the groundwater basin in the Study Area.

(2) Management and Organization of Monitoring System

The sections implementing actual observation are different depending on the items to be recorded. Meteorological records, hydrological records and groundwater withdrawal data are separately collected by different sections. This surveying system is also adopted in the plan for the Groundwater Monitoring System. From the view point of alert system for the over-pumping from the groundwater basin, the collected data must be controlled with a closely relation between the Database System and Management Model. Paying attention to this function in the groundwater management, the Database itself is to be filled up by all the observatory data, and so must be administered in a unified way. However, the operating work to input data is conducted by respective observer by own responsibility. Furthermore, the Database must be used not only by the unifying sector, but should also be open to the every sections to browse overall data, including data on other items entered by other persons.

(3) Observation

The observation items in the Monitoring System is as follows (refer to Figure 1.6.1) :

Meteorological Item:	Rainfall, Temperature, Wind direction, Wind velocity, Sunshine
Hydrologic item:	Surface Runoff
Groundwater item:	Groundwater Head, Water Quality (Ec, Temperature, pH)
Groundwater Use:	Groundwater Withdrawal

For adequate records to be gathered for use in the Groundwater Monitoring System, supplementary stations must be set up in vacant areas that are not currently covered by the existing stations are required. In order to automate the routine work of observation, a transducer or the automatic recorder is to be applied.

a) Meteorological Observation

There are 10 stations included Gyle and Marbat Stations in the Study Area. Out of 10, only two are meteorological stations and other are all rain-gauge stations. The network of existing stations has an uneven distribution and the most of stations are located in the mountain areas as part of the planned dam projects in the Wadi Siji, Wadi Khadrah. In addition to this, the rainfall data has been taken from showers and the results from different sites do correspond well. In spite of these characteristics shown in the rainfall, there is no observation station at the southern area or in the Bahada Plain of the Study Area. For these vacant areas, five rain-gauges are to be newly installed under the plan. For meteorological stations, two of the existing stations are to be set as Monitoring System.

b) Hydrological Station

In the Study Area, there are six wadi-gauges which are still functioning in the present. However, all six stations are concentrated at the planned dam sites. In the monitoring plan, four new stations are to be set up in four other wadis--Wadi Dhaid, Wadi iqubah, Wadi Hamdah, Wadi Shoukah--and two stations are planned for the Bahada plain. Twelve stations in total, six new ones and six existing stations are planned to be built as part of a more comprehensive monitoring system.

c) Groundwater

There are six groundwater observatories around the Study Area, but the most of the stations are set only in the major farming area such as Mileiha and Dhaid. Moreover, most of these wells are not designed to observe the groundwater head of lower aquifer. Consequently, measurement has been made only in the upper aquifer, with the exception of only two wells. Even in the seven stations drilled during the Study, only one well has a screen deep enough to measure the groundwater head of the lower aquifer. In the planned Monitoring System, three stations for observing the groundwater head of lower aquifer and five stations for measuring the water quality are to be planned. The former stations locate the east of Fili, the west of Hamdah and the north of Dhaid. The later stations are to be set at Falaj Al Mualla, Dhaid, Wishah, Khadrah, Mileiha and Bahayis and Fili.

A total of 22 sites, with 17 stations capable of monitoring the the groundwater head of upper aquifer, six of monitoring the lower aquifer and five stations to measure the water quality, are to be built into the Monitoring System. The observations in these wells, which includes the boreholes and test wells in the Study, and other planned wells, are to make by the use of transducers and automatic recorders with data loggers. Furthermore, the execution of a ground level survey is also required for all wells, not only the newly installed ones, but also the existing wells.

d) Groundwater Utilization for Irrigation

To operate the management model, comprehensive and accurate estimates of groundwater withdrawal for irrigation must be made in every few years. For this purpose, basic data, such as pumping rate, farming area and farm inventory are to be gathered anew through field surveys. The installation of flow meters is planned for 20 typical farms to obtain the flow rate, and the aerial photography should be conducted to determine the latest data on farmed areas. All the data obtained from survey smust be categorized in the Database as required.

(4) Cost of Materials and Machinery for Observation

The rough estimation for the materials and machinery related to newly installed observatories is given as follows:

Facility	Unit	Amount (US$)
Meteorological Station	L.S.	53,500
Hydrological Station	L.S.	64,200
Groundwater Station	L.S.	687,400
Groundwater Withdrawal	L.S.	38,400
Total	L.S.	843,500

(5) Cost of Operating Organization and O&M of Facility

Both the operating organization and O&M of facility are managed under MAF who is handling the existing observation network. The cost related to all above items is as follows:

Item	Unit	Amount (US$)
O&M Groundwater Monitoring System	L.S.	42,200
O&M Database System	L.S.	2,800
Aerial Photography (every 5 years)	L.S.	6,000
Well Inventory Survey (every 5 years)	L.S.	20,900
Total	L.S.	71,900

1.6.3. Database Plan

It is required that all users including observers, the database manager and the operator of management model can easily access a database to utilize the necessary information for maintaining the groundwater monitoring system. A small-scaled computer network so called as LAN, Local Area Network, is convenient for this puropose. Five sets of machines, including servers and terminals are planned to deal with all the tasks related to groundwater monitoring. Four terminals used for the input of data are set at the meteorological section, the hydrological section, the irrigation section and the groundwater and dam section, and one sever controlling the database and to manage the basin model is to be set up at the groundwater and dam section.

A conventional Relational Database, adapted to hydrological and groundwater purposea, would form the basic application of this Database System. The software must be accessible to both the basin model constructed in the Study and GIS system described below.

(1) Database

The data of the farm and well inventory is stored on the spread sheet; groundwater quality analysis in an ASCII file, soil analysis and other irrigation and farming records in the form of a data-sheet. From these various types of data, the user can extract only necessary information from the basic data. Conventional commercially available software adapted to the groundwater management functions using a Relational database would be sufficient.

(2) Management Model

The model for the groundwater balance constructed in the Study is used as the management model by a devise of model parameter. To input the parameter related to the future plan, the model may predicts a hydrological situation on a given condition. On the other hand, the model must be verified by the latest observation data to improve the precision of the model.

(3) Geographical Information System (GIS)

On the basis of Orthophoto Image, the aerial photography is conducted in every several years to estimate the groundwater withdrawal through calculation the farming area. For this uses, the GIS would be functionary introduced to drawn the image map, trace of changes of farming area and visualize the observation data.

(4) Cost for Database Construction

The cost for construction of Database described above is as follows:

Item	Unit	Amount (US$)
Hardware of Survey and Terminal	L.S.	52,000
LAN and database Software	L.S.	1,500
Construction of LAN	L.S.	2,000
Total	L.S.	55,500

1.7. Infiltration Experiment

1.7.1. Set Up and Method

(1) Location of Test Pits

The Study Team carried out the field works to determine the infiltration rates of the wadi-bed on the Bahada plain. The site for field works are located on the gravel plain where the mountain wadi run off exists. These wadi areas are situated on the east end of the Study area. The testing sites, DW1 on the wadi Siji, DW2 on the wadi Khadrah, and DW3 on the wadi Shoukah, are shown in Figure 1.7.1. The groundwater table of these sites (15 to 35 meter below the ground level) are relatively shallow and that they are expected to contribute under groundwater recharge.

(2) Water Source

Because of there is no water supply system at the testing sites, the water was supplied by tanker from the well in the nearby farms. On the site, two water tanks with a total capacity of 22m^3 were installed, together with one additional tanker as standby, providing an amount of 30 m^3 of water for each test. In order to maintain a constant hydrostatic pressure on the water flowing into the test pits, a multistage centrifugal pump with a delivery of up to 1.13 m^3/min. was installed directly after the water tanks. Water volume from tanks was calculated by the tank gauge readings at each period.

(3) Test Pit Layout

The test pits had square dimensions of 1.5 m (pits of three different depths–1.5 m, 3.0 m, and 6.0 m–each 1.5 m square) were excavated and backfilled with a natural filter gravel with grain size not exceeding 3/4" for each testing site. Layout of testing devices is shown in Figure 1.7.2.

(4) Experiment Program

Water discharge and tank gauge had been recorded at each time after the pump began to supply water to the pit. When the water level in pit reached a certain level, the pump was controlled to maintain the constant head in the pit.

1.7.2. Infiltration Rate

(1) Test Result

The record of test which is the permeability from pit on each measurement period is shown in Figure 1.7.3.~12. The vertical axis (x-axis) means permeability and the horizontal axis (y-axis) means a reciprocal number of square root of time. By the linear approximation method a linear line is drawn on these x-y plotted graphs. When the time is approaching the infinite (x (0), the y value is reaching the "Steady State Infiltration Rate." The following table summarizes the result of the test. In the table, "Infiltration Rate: Test" is the average infiltration rate of infiltration test; it is the calculated value by dividing the accumulated infiltration by the testing period.

Table 1.7.1. The Result of Constant Head Test
-Infiltration Rate and Head-

Infiltration Pit	Depth of Test Pit (m)	Steady State Infiltration Rate (m^3/sec)	Infiltration Rate : Test (m^3/sec)	Head (m)
DW1-1	1.5	0.0089	0.0100	1.15
DW1-2	3.0	0.0183	0.0175	1.67
DW1-3	6.0	0.0259	0.0270	4.20
DW2-1	1.5	0.0017	0.0017	1.09
DW2-2	3.0	0.0040	0.0040	1.43
DW2-3	6.0	0.0029	0.0029	2.22
DW3-1	1.5	0.0005	0.0015	1.07
DW3-2 (T1)	3.0	0.0031	0.0031	1.20
DW3-2 (T2)	3.0	0.0023	0.0110	2.47
DW3-3	6.0	0.0165	0.0165	3.49

Both steady state and test infiltration rate are increasing with pit head. Most test cases follow this tendency except DW2-2. The table implies that the infiltration rates of DW1 site are relatively large and the rates of DW3 are small as compared with the rate in equivalent head.

(2) Analysis of Test

At the wadi bed of testing site, several layers which consists of gravel layer, sand layer, and silt layer are found. Therefore, the site must have an un-isotropy. As the first step of analysis, the isotropic hydraulic conductivity was calculated by the following equation.[1]

[1] The standard survey method for soil nature; "Dositsu Chosa-ho by Dositsu Kogaku-kai in Japanese (p.335, eq.8.24)"

$$k=\frac{2.3Q}{2\pi h^2}\left[\log_{10}\left\{\frac{h}{r_0}+\sqrt{1+\left(\frac{h}{r_0}\right)^2}-1\right\}\right] \quad \text{---(Eq.1.7.1.)}$$

The above equation represents the column pit. Therefore, the diameter r_0 with 0.846 which is the diameter of circle with equivalent cross section was applied to calculate hydraulic conductivity for the rectangular parallel-piped pit. The 10 sets of permeability and head data that the site test gave an input in Eq. 1.7.1. and the hydraulic conductivity for each case is shown in the Table 1.7.2.

Table 1.7.2. Isotropic Hydraulic Conductivity: K (m/sec)

Wadi		Depth of Test Pit (m)			Ave. by Site
		1.5	3.0	6.0	
Siji	DW1	0.00004487	0.00014497	0.00018623	0.00012536
Khadrah	DW2	0.00000536	0.00002050	0.00001858	0.00001481
Shoukah	DW3	0.00000346	0.00003118	0.00022442	0.00007234
	DW3*		0.00003029		
Ave. by Depth		0.00001790	0.00005674	0.00014308	0.00007099

* Result of an additional test of depth 3.0m in DW3.

The above table shows that the difference of hydraulic conductivity in the same testing site implies the un-isotropy of the infiltration on the wadi bed. Therefore, the following relation is found between isotropic hydraulic conductivity calculated and un-isotropic hydraulic conductivity which consists of vertical conductivity k_V and horizontal conductivity k_H.

$$k_V \leqq k \leqq k_H \quad \text{--- (Eq.1.7.2.a)}$$

(or $$k_V \geqq k \geqq k_H \quad \text{--- (Eq.1.7.2.b))}$$

The result of experiments does not describe the infiltration rate of both the vertical and the horizontal directions. However, assuming that vertical-infiltration is the flow from pit bottom and horizontal-infiltration is the flow from pit wall, the hydraulic conductivity with 1.5 m pit in the Table 1.7.2. is the closest to vertical un-isotopic hydraulic conductivity because the portion of infiltration for vertical direction becomes larger than other case. Therefore, the infiltration rate of both directions can be obtained by the following equation[2] and applying k value of 1.5 m pit as the hydraulic conductivity for

[2] Darcy eqation.

vertical direction.

$$Q_v=(1.5)^2 \times k_v \times \frac{h_1}{h_0} \quad \text{---(Eq.1.7.3)}$$

In the above equation, Q_v is infiltration rate for vertical direction, h_0 is the distance from groundwater table to the pit bottom, and h_1 is the distance from groundwater table to water level in the pit. The horizontal infiltration rate Q_H is found by the subtraction of Q_v from total infiltration rate Q. The following table shows the comparison of vertical and horizontal infiltration rate. In the table, q_v and q_v show the average infiltration rates per unit area for vertical and horizontal directions, respectively.

Table 1.7.3. Comparison of Vertical and Horizontal Infiltration Rate

Infiltration Pit	Infiltration Rate (m^3/sec)			Infiltration Rate per Unit Area (m^3/sec)	
	Total Q	Vertical Q_V	Horizontal Q_H = Q-Q_V	Vertical q_V	Horizontal q_H
DW1-1	0.00890000	0.00010590	0.00879410	0.00004707	0.00127451
DW1-2	0.01830000	0.00010862	0.01819138	0.00004828	0.00181551
DW1-3	0.02590000	0.00012327	0.02577673	0.00005479	0.00102289
DW2-1	0.00170000	0.00001245	0.00168755	0.00000553	0.00025803
DW2-2	0.00400000	0.00001260	0.00398740	0.00000560	0.00046473
DW2-3	0.00290000	0.00001298	0.00288702	0.00000577	0.00021674
DW3-1	0.00050000	0.00000840	0.00049160	0.00000373	0.00007657
DW3-2 (T1)	0.00310000	0.00000856	0.00309144	0.00000381	0.00042937
DW3-2 (T2)	0.00230000	0.00000939	0.00229061	0.00000417	0.00015456
DW3-3	0.01650000	0.00001080	0.01648920	0.00000480	0.00078745
Ave.	0.00841000	0.00004130	0.00836870	0.00001835	0.00065004

If the Darcy's law is applied, the infiltration rate per average unit area for both vertical and horizontal direction are shown by the following equations:

$$q_V = (H/L_V) \cdot k_V \quad \text{--- (Eq.1.7.4.a)}$$
$$q_H = (H/L_H) \cdot k_H \quad \text{--- (Eq.1.7.4.b)}$$

In the equation above L_V is the pass of infiltration from pit bottom and L_H is the pass of infiltration from pit wall to groundwater table. Assuming that L_V is equal to L_H because distance from pit bottom to water table is much further than depth of water level in pit, the following equation Eq. 1.7.5. is transposed from Eq.1.7.4.a and b.

$k_H/k_V = q_H/q_V$ --- (Eq. 1.7.5.)

Inputting k_V, q_H, and q_V to Eq. 1.7.5. brings the horizontal hydraulic conductivity k_H in the following table. In this table, k_H is 20 to 160 times larger than k_V.

Table 1.7.4. Un-Isotropic Hydraulic Conductivity
Comparison of Vertical and Horizontal Conductivity

Infiltration Pit	Hydraulic Conductivity k (m/sec)			k_H/k_V (%)
	k (isotropic assumption)	k_V (vertical)	k_H (horizontal)	
DW1-1	0.00004487	0.00004487	0.00121505	2708%
DW1-2	0.00014497	0.00004487	0.00168742	3761%
DW1-3	0.00018623	0.00004487	0.00083771	1867%
DW2-1	0.00000536	0.00000536	0.00024990	4662%
DW2-2	0.00002050	0.00000536	0.00044485	8299%
DW2-3	0.00001858	0.00000536	0.00020133	3756%
DW3-1	0.00000346	0.00000346	0.00007095	2051%
DW3-2 (T1)	0.00003118	0.00000346	0.00039033	11281%
DW3-2 (T2)	0.00003029	0.00000346	0.00012818	3705%
DW3-3	0.00022442	0.00000346	0.00056742	16399%
Ave.	0.00007099	0.00001645	0.00057931	3521%

1.7.3. Evaluation of Infiltration

On the pit wall, there are several sedimentation layers which are caused by floods. Because magnitude of floods were different, component and width of each layer were also different. Therefore, actual horizontal infiltration rate is different in the each depth and it is difficult to know what the actual horizontal infiltration rate is due to its depth.

By the following estimated, hydraulic conductivity was found and applied to the rational or empirical equation to calculate the permeability of recharge trench in this study. And efficiency of recharge trench is evaluated by computer simulation with synthetic storage model. In this study, efficiency of recharge trench with 1.5 m width, 6.0 m depth, and 1,000 m extension is going to be analyzed.

(1) Infiltration Rate with Isotropic Assumption

Because the pit water level of 6 m pit is closer to the dimension depth, the hydraulic conductivity of 6 m pit with isotropic assumption will be applied. The following is the infiltration loss equation[3] for a channel. In this equation, B represents trench width and H as trench depth.

$$Q = (B + 2H) \times k \qquad \text{--- (Eq.1.7.6.)}$$

The following table indicates the dimensions of the trenches and the infiltration rate calculated under Eq.1.7.6. Wadi Shoukah's infiltration rate with 0.303 m^3/sec is the largest wadi Siji's site as the second and 10 times larger than that in wadi Khadrah's site.

Table 1.7.5. Infiltration Rate of Recharge Trench with 1,000 m Length
—Eq.1.7.6. with k of Isotropic Assumption—

		Recharge Trench (m)			Infiltration Rate	
Wadi	k (m/sec)	Width	Depth	Length	(m^3/sec)	(m^3/day)
Siji	0.00018623	1.5	6.0	1,000	2.5141	217,218
Khadrah	0.00001858	1.5	6.0	1,000	0.2508	21,669
Shoukah	0.00022442	1.5	6.0	1,000	3.0297	261,766
Ave.	0.00014308	1.5	4.5	1,000	1.9315	166,884

(2) Infiltration Rate with Un-Isotropic Assumption

To obtain an infiltration rate with an un-isotropic assumption, the vertical and horizontal hydraulic conductivity of 6 m pit, which are k_V and k_H calculated in the previous section, are applied in the Darcy equation. The following table shows the infiltration rate with k_V and k_H.

Table 1.7.6. Infiltration Rate of Recharge Trench with 1,000 m Length
—Eq. 1.7.5. with k_V and k_H of Un-Isotropic Assumption—

	Hydraulic Conductivity (m/sec)		Infiltration Rate (m^3/sec)		Infiltration Rate Q	
Wadi	k_V	k_H	Q_V	Q_H	(m^3/sec)	(m^3/day)
Siji	0.00004487	0.00083771	0.0886	13.2270	13.3155	1,150,462
Khadrah	0.00000536	0.00020133	0.0097	3.1789	3.1886	275,496
Shoukah	0.00000346	0.00056742	0.0087	11.3484	11.3570	981,245
Ave.	0.00001790	0.00053549	0.0356	9.2514	9.2870	802,401

Compared to the infiltration rate of isotropic assumption (Table 1.7.5. refers), the infiltration rate of un-isotropic assumption is 3 to 10 times larger than that of isotropic assumption. In selecting the model, the un-isotropic approach is more adaptable than the

[3] The standard survey method for soil nature; "Dositsu Chosa-ho by Dositsu Kogaku-kai in Japanese (p.335, eq.8.24)"

isotopic approach in view of the nature of the assumptions mentioned above.

(3) Efficiency of Recharge Trench

Using the computer simulation with synthetic storage model, developed groundwater by the recharge trench was analyzed. In the simulation, infiltration rate with isotropic assumption was applied because it might bring an optimistic result by choosing a larger infiltration rate. Past record of wadi flood discharge was used in simulation, based on the data obtained from 1977 to 1995.

The yearly infiltration rate of each site are shown in the following table. The average yearly permeability of Siji trench with 386,189 m^3/year is the largest while that of Shoukah trench with 343.421 m^3/year as second. The Khadrah trench with an average yearly permeability of 35,679 m^3/year or only 10% of these two trenches. As the effect of these three trenches, the computer simulation indicates an additional groundwater recharge with 300,000 m^3/year.

Table 1.7.7. Annual Recharge of Three Trenches

	Infiltration (m^3/year)		
year	DW1 (w.Siji) site	DW2 (w.Khadrah) site	DW3 (w.Shoukah) site
1977	188,600	0	122,700
1978	42,700	0	27,800
1979	195,600	0	133,100
1980	0	0	0
1981	0	0	0
1982	2,012,800	210,200	2,034,600
1983	84,000	0	55,500
1984	0	0	0
1985	0	0	0
1986	0	0	0
1987	523,800	0	354,600
1988	1,116,100	229,300	1,015,300
1989	476,200	0	381,000
1990	979,700	130,000	927,900
1991	0	0	0
1992	0	0	0
1993	1,190,200	108,400	1,101,100
1994	0	0	0
1995	527,900	0	371,400
Ave.	386,189	35,679	343,421

Table 1.4.1 Aquifer Coefficient

Major Aquifer	Well	Area Name	SWL 1985(m)	S/P m3/hr/m	T m2/day	S/C %	EC mS/m2	TDS ppm
Upper Aquifer	GP-2	F'Al Mualla	26	1	3	-	19	-
	MF-1	Masfut	8	6	172	-	6	-
	GP-7	S.E.Mileiha	21	3	88	-	-	-
	B-1	N.Ikdedir	-	-	-	-	22-30	-
	B-2	N.E.Mileiha	-	-	-	-	11-20	-
	OW2	Khuderah	-	-	16	0.16	-	-
	PW2	Khuderah	-	0	3	-	-	1190
	GP-17	S.W.Dhaid	34	10	110	-	22.3	-
	GP-10	S.E.Dhaid	12	4	264	0.12	25	-
	GP-10A	S.E.Dhaid	12	4	264	0.12	18	-
	GWR4	Dhaid	-	-	-	-	-	-
	GP-1	Manamah	18	<1.8	8	0.60	7	-
	GP-1A	Manamah	18	<1.8	8	0.60	-	-
	GP-3	Manamah	19	1	6	0.60	12	-
	GP-3A	Manamah	19	1	6	0.60	15	-
	OW4	F'Al Mualla	-	-	-	-	-	-
	GP-13	N.Tawi Suhai	-	dry	-	-	-	-
	GWR2	F'Al Mualla	-	-	-	-	-	-
	GP-19	F'Al Mualla	24	dry	-	-	-	-
	GP-14	Siji	19	6	230	-	13	-
	PW3(municipality well)	Khuderah		1	12	-	-	-
			AVERAGE	3	85	0.40	14	1190
			MIN.	0	3	0.12	6	1190
			MAX.	10	264	0.60	25	1190
Lower Aquifer	PW5	Fali	-	0	5	-	-	1420
	OW3	Khuderah	-	-		-	-	
	PW3	Khuderah	-	-	1	0.33	-	970
	GP-15	S.E.Dhaid	14	5	-	-	24	
	PW1	Dhaid East	-	1	8		1000-2800	440
	GP-18	Dhaid	32	low	-	-	28	-
	GP-16	East Dhaid	23	2	120	0.25	-	-
	GP-16A	East Dhaid	23	2	120	0.25	6	-
			AVERAGE	2	51	0.28	19	943
			MIN.	0	1	0.25	6	440
			MAX.	5	120	0.33	28	1420
Fissure Water in Upper Aquifer	GP-11	E.Jabal Faiyah	9	28	480	-	151	-
	GP-6	Mileiha	18	29	1166	2.40	-	-
	GP-6A	Mileiha	18	29	1166	2.40	24	-
	PW4b	Manamah	-	24	290	-	-	450
			AVERAGE	28	776	2.40	87	450
			MIN.	24	290	2.40	24	450
			MAX.	29	1166	2.40	151	450

Table 1.4.2. Estimation of Groundwater Draft for the Irrigation

Number of Sub-Basin	Area for Calculation Unit	Farming Area (Unit, ha)	Farming Area (Sub-Basin, ha)	Estimated Pumping rate	Groundwater Draft (1000xm4/a)	Groundwater Draft (100xm4/a)
8-	I	25.86		148	1,148	
	II	39.33		148	1,746	
			65.19			2,895
9-	I	217.15		64	4,169	
			217.15			4,169
10-	I	10.44		40	125	
	II	4.29		133	171	
	III	20.98		133	837	
	IV	18.93		133	755	
	V	25.28		148	1,122	
			79.93			3,012
11-	I	157.13		64	3,017	
	II	316.11		14	1,328	
	III	4.00		40	48	
			477.23			4,392
12-	I	257.06		40	3,085	
	II	9.86		72	213	
	III	45.19		40	542	
			312.10			3,840
13-	I	14.64		40	176	
	II	121.70		40	1,460	
	III	10.54		14	44	
			146.88			1,680
14-	I	43.04		40	516	
	II	93.40		72	2,017	
	III	276.58		40	3,319	
	IV	53.38		72	1,153	
			466.40			7,006
15-	I	15.52		38	177	
	II	240.57		38	2,742	
	III	124.43		38	1,419	
	IV	64.31		38	733	
			444.83			5,071
16-	I	374.86		31	3,486	
	II	211.29		7	444	
	III	42.55		40	511	
			628.70			4,440
17-	I	256.96		7	540	
	II	146.20		7	307	
	III	96.72		38	1,103	
	IV	25.18		38	287	
	V	39.14		40	470	
			564.19			2,706
18-	I	156.05		31	1,451	
	II	580.78		20	3,485	
			736.83			4,936
19	I	26.45		31	246	
	II	296.78		31	2,760	
	III	69.58		31	647	
	IV	223.39		7	469	
	V	391.84		7	823	
			1008.04			4,945
20	I	18.15		31	169	
	II	44.11		31	410	
			62.26			579
21	I	201.43		31	1,873	
	II	102.86		31	957	
			304			2,830
			5,514	2,177	52,501	52,501
			-	49	-	3,821

Table 1.5.1 Hydrologic Balance of the Study Area in the Current Condition

Groundwater balance in Current Condition (1977-1994) Area: 1825.9 km2 Unit: mm

Year	Area Rainfall	Evapo-transpiration	Surface Runoff	Groundwater Recharge	Balance (Surface System)	Groundwater Runoff	Groundwater Draft	Balance (Sub-surface System)	Balance (Surface + Subsurface)
1977	219.3	214.1	0.0	7.1	-1.9	16.9	1.3	-11.1	-13.0
1978	124.3	124.4	0.0	4.2	-4.3	15.2	1.4	-12.4	-16.7
1979	177.6	140.0	0.0	3.3	34.3	14.3	1.6	-12.6	21.7
1980	106.7	135.9	0.0	5.2	-34.4	13.6	5.1	-13.5	-47.9
1981	87.1	86.1	0.0	1.5	-0.5	12.7	5.1	-16.3	-16.8
1982	385.4	338.0	0.1	42.6	4.7	13.2	5.9	23.5	28.2
1983	179.3	173.9	0.0	9.1	-3.7	12.9	7.9	-11.7	-15.4
1984	110.6	109.5	0.0	1.7	-0.6	11.8	8.6	-18.7	-19.3
1985	25.9	25.5	0.0	0.9	-0.5	10.7	13.2	-23.0	-23.5
1986	92.4	91.3	0.0	0.9	0.2	9.6	13.5	-22.2	-22.0
1987	153.1	143.6	0.0	6.0	3.5	8.7	15.4	-18.1	-14.6
1988	211.6	163.8	3.8	44.2	-0.2	9.7	16.9	17.6	17.4
1989	132.1	124.0	0.0	4.4	3.7	9.0	20.4	-25.0	-21.3
1990	219.8	187.7	0.1	36.4	-4.4	8.3	22.2	5.9	1.5
1991	71.7	71.4	0.0	2.8	-2.5	7.3	24.5	-29.0	-31.5
1992	143.3	139.7	0.0	2.1	1.5	6.2	26.6	-30.7	-29.2
1993	186.5	142.6	0.4	41.8	1.7	6.8	29.7	5.3	7.0
1994	61.9	61.5	0.0	3.6	-3.2	5.9	31.4	-33.7	-36.9
1995	259.0	249.4	0.0	7.8	1.8	4.5	29.6	-26.3	-24.5
Total	-	-	-	-	-4.8	-	-	-252.0	-256.8
Average	155.1	143.3	0.2	11.9	-0.3	10.4	14.8	-13.3	-13.5

Groundwater balance in Current Condition (1977-1994) Area:1825.9 km2 Unit: MCM

Year	Area Rainfall	Evapo-transpiration	Surface Runoff	Groundwater Recharge	Balance (Surface System)	Groundwater Runoff	Groundwater Draft	Balance (Sub-surface System)	Balance (Surface + Subsurface)
1977	400.4	390.9	0.0	13.0	-3.5	30.9	2.4	-20.3	-23.7
1978	227.0	227.1	0.0	7.7	-7.9	27.8	2.6	-22.6	-30.5
1979	324.3	255.6	0.0	6.0	62.6	26.1	2.9	-23.0	39.6
1980	194.8	248.1	0.0	9.5	-62.8	24.8	9.3	-24.6	-87.5
1981	159.0	157.2	0.0	2.7	-0.9	23.2	9.3	-29.8	-30.7
1982	703.7	617.2	0.2	77.8	8.6	24.1	10.8	42.9	51.5
1983	327.4	317.5	0.0	16.6	-6.8	23.6	14.4	-21.4	-28.1
1984	201.9	199.9	0.0	3.1	-1.1	21.5	15.7	-34.1	-35.2
1985	47.3	46.6	0.0	1.6	-0.9	19.5	24.1	-42.0	-42.9
1986	168.7	166.7	0.0	1.6	0.4	17.5	24.6	-40.5	-40.2
1987	279.5	262.2	0.0	11.0	6.4	15.9	28.1	-33.0	-26.7
1988	386.4	299.1	6.9	80.7	-0.4	17.7	30.9	32.1	31.8
1989	241.2	226.4	0.0	8.0	6.8	16.4	37.2	-45.6	-38.9
1990	401.3	342.7	0.2	66.5	-8.0	15.2	40.5	10.8	2.7
1991	130.9	130.4	0.0	5.1	-4.6	13.3	44.7	-53.0	-57.5
1992	261.7	255.1	0.0	3.8	2.7	11.3	48.6	-56.1	-53.3
1993	340.5	260.4	0.7	76.3	3.1	12.4	54.2	9.7	12.8
1994	113.0	112.3	0.0	6.6	-5.8	10.8	57.3	-61.5	-67.4
1995	472.9	455.4	0.0	14.2	3.3	8.2	54.0	-48.0	-44.7
Total	-	-	-	-	-8.8	-	-	-460.1	-468.9
Average	283.3	261.6	0.4	21.7	-0.5	19.0	26.9	-24.2	-24.7

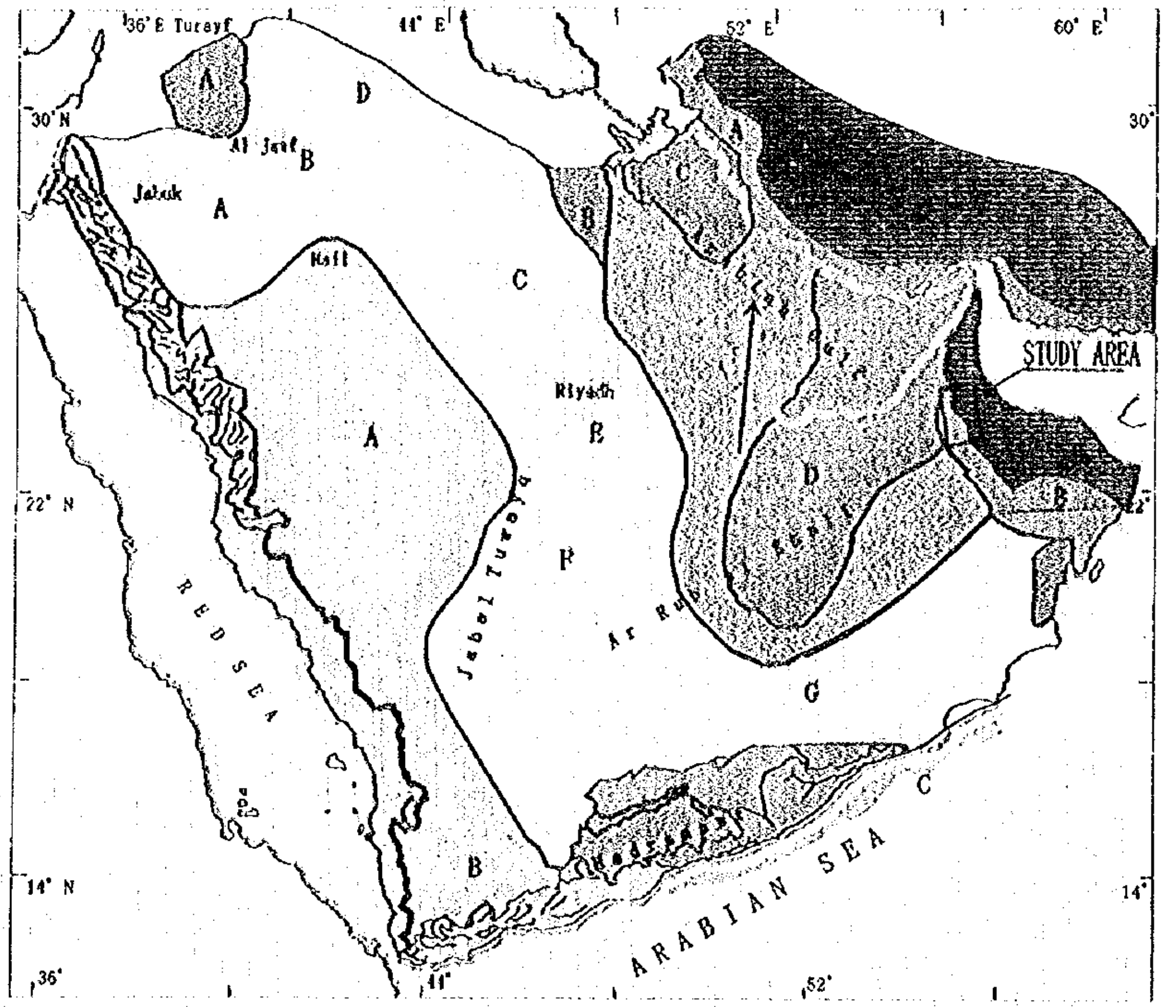
Table 1.5.2 Result of Case 3 and 4

(unit : mm)

Year	Present Condition				1000m Trench				Dam + 1000m Trench			
	Area Rainfall	Evapotranspiration	Groundwater Recharge in Study Area	Surface Runoff from Study Area	Area Rainfall	Evapotranspiration	Groundwater Recharge in Study Area	Surface Runoff from Study Area	Area Rainfall	Evapotranspiration	Groundwater Recharge in Study Area	Surface Runoff from Study Area
1977	219.28	214.14	7.06	0.02	219.28	214.01	7.19	0.02	219.28	212.05	9.18	0.02
1978	124.27	124.40	4.15	0.01	124.27	124.37	4.17	0.01	124.27	123.73	4.81	0.01
1979	177.63	139.96	3.27	0.02	177.63	139.92	3.44	0.02	177.63	139.39	4.30	0.02
1980	106.73	135.89	5.21	0.01	106.73	135.80	5.16	0.01	106.73	135.24	5.39	0.01
1981	87.10	86.14	1.47	0.00	87.10	86.14	1.47	0.00	87.10	85.92	1.68	0.00
1982	385.38	337.96	42.60	0.11	385.38	337.01	43.62	0.11	385.38	334.43	46.35	0.11
1983	179.25	173.89	9.10	0.02	179.25	173.84	9.08	0.02	179.25	172.85	9.94	0.02
1984	110.55	109.49	1.74	0.01	110.55	109.49	1.73	0.01	110.55	109.23	1.97	0.01
1985	25.92	25.52	0.86	0.00	25.92	25.52	0.86	0.00	25.92	25.49	0.88	0.00
1986	92.44	91.34	0.86	0.00	92.44	91.34	0.86	0.00	92.44	91.25	0.94	0.00
1987	153.05	143.59	6.04	0.02	153.05	143.31	6.34	0.02	153.05	142.59	7.07	0.02
1988	211.56	163.78	44.22	3.75	211.56	163.49	44.80	3.48	211.56	163.25	48.28	0.23
1989	132.08	124.00	4.43	0.02	132.08	123.76	4.85	0.02	132.08	123.02	5.89	0.02
1990	219.76	187.67	36.42	0.07	219.76	187.32	36.59	0.07	219.76	186.00	37.72	0.07
1991	71.66	71.39	2.81	0.00	71.66	71.39	2.78	0.00	71.66	71.34	2.71	0.00
1992	143.33	139.69	2.14	0.01	143.33	139.69	2.14	0.01	143.33	139.44	2.40	0.01
1993	186.52	142.59	41.78	0.44	186.52	142.15	42.26	0.44	186.52	141.05	43.43	0.43
1994	61.94	61.47	3.58	0.00	61.94	61.47	3.54	0.00	61.94	61.38	3.57	0.00
1995	259.02	249.40	7.78	0.04	259.02	249.08	8.12	0.04	259.02	247.76	9.49	0.04
Total	2947.47	2722.31	225.52	4.55	2947.47	2719.10	229.00	4.28	2947.47	2705.41	246.00	1.02
Average	155.13	143.28	11.87	0.24	155.13	143.11	12.05	0.23	155.13	142.39	12.95	0.05

(unit : 1000m³)

Year	Present Condition				1000m Trench				Dam + 1000m Trench			
	Area Rainfall	Evapotranspiration	Groundwater Recharge in Study Area	Surface Runoff from Study Area	Area Rainfall	Evapotranspiration	Groundwater Recharge in Study Area	Surface Runoff from Study Area	Area Rainfall	Evapotranspiration	Groundwater Recharge in Study Area	Surface Runoff from Study Area
1977	400383.4	390998.2	12890.9	36.5	400383.4	390760.9	13128.2	36.5	400383.4	387182.1	16761.8	36.5
1978	226904.6	227142.0	7577.5	18.3	226904.6	227087.2	7614.0	18.3	226904.6	225918.6	8782.6	18.3
1979	324334.6	255563.0	5970.7	36.5	324334.6	255479.9	6281.1	36.5	324334.6	254512.2	7851.4	36.5
1980	194878.3	248121.6	9512.9	18.3	194878.3	247957.2	9421.6	18.3	194878.3	246934.7	9841.6	18.3
1981	159035.9	157283.0	2684.1	0.0	159035.9	157283.0	2684.1	0.0	159035.9	156881.3	3067.5	0.0
1982	703665.3	617081.2	77783.3	200.8	703665.3	615346.6	79645.8	200.8	703665.3	610635.7	84630.5	200.8
1983	327292.6	317505.8	16615.7	36.5	327292.6	317414.5	16579.2	36.5	327292.6	315606.8	18149.4	36.5
1984	201853.2	199917.8	3177.1	18.3	201853.2	199917.8	3158.8	18.3	201853.2	199443.1	3597.0	18.3
1985	47327.3	46597.0	1570.3	0.0	47327.3	46597.0	1570.3	0.0	47327.3	46542.2	1606.8	0.0
1986	168786.2	166777.7	1570.3	0.0	168786.2	166777.7	1570.3	0.0	168786.2	166613.4	1716.3	0.0
1987	279454.0	262181.0	11028.4	36.5	279454.0	261669.7	11576.2	36.5	279454.0	260355.1	12909.1	36.5
1988	386287.4	299045.9	80741.3	6847.1	386287.4	298516.4	81800.3	6354.1	386287.4	298078.2	88154.5	420.0
1989	241164.9	226411.6	8088.7	36.5	241164.9	225973.4	8855.6	36.5	241164.9	224622.2	10754.6	36.5
1990	401259.8	342666.7	66499.3	127.8	401259.8	342027.6	66809.7	127.8	401259.8	339617.4	68872.9	127.8
1991	130844.0	130351.0	5130.8	0.0	130844.0	130351.0	5076.0	0.0	130844.0	130259.7	4948.2	0.0
1992	261706.2	255060.0	3907.4	18.3	261706.2	255060.0	3907.4	18.3	261706.2	254603.5	4382.2	18.3
1993	340566.9	260355.1	76286.1	803.4	340566.9	259551.7	77162.5	803.4	340566.9	257543.2	79298.8	785.1
1994	113096.2	112238.1	6536.7	0.0	113096.2	112238.1	6463.7	0.0	113096.2	112073.7	6518.5	0.0
1995	472944.6	455379.5	14205.5	73.0	472944.6	454795.2	14826.3	73.0	472944.6	452385.0	17327.8	73.0
Total	5381785.5	4970665.8	411777.0	8307.8	5381785.5	4964804.7	418131.1	7814.9	5381785.5	4939808.1	449171.4	1862.4
Average	283251.9	261614.0	21672.5	437.3	283251.9	261305.5	22006.9	411.3	283251.9	259989.9	23640.6	98.0



STABLE REGION

ARABIAN SHIELD

- Western Arabian Shield — A
- Yemen-Aden Plateau — B
- Southern Arabian Shield — C

ARABIAN CONTINENTAL SHELF

INTERIOR HOMOCLINE

- Tabuk Segment — A
- Hail Arch — B
- Northern Tuwayq Segment — C
- Widyan Basin Margin — D
- Central Arabian Arch — E
- Southern Tuwayq Segment — F
- Hadramawt Segment — G

BASINS

- Sirhan-Turayf Basin — A
- Dibdibba Basin — B
- Northern Arabian Gulf Basin — C
- Rub al Khali Basin — D

MOBILE BELT

MOUNTAINS

- Zagros Mountain — A
- Oman Mountains — B

FORELANDS

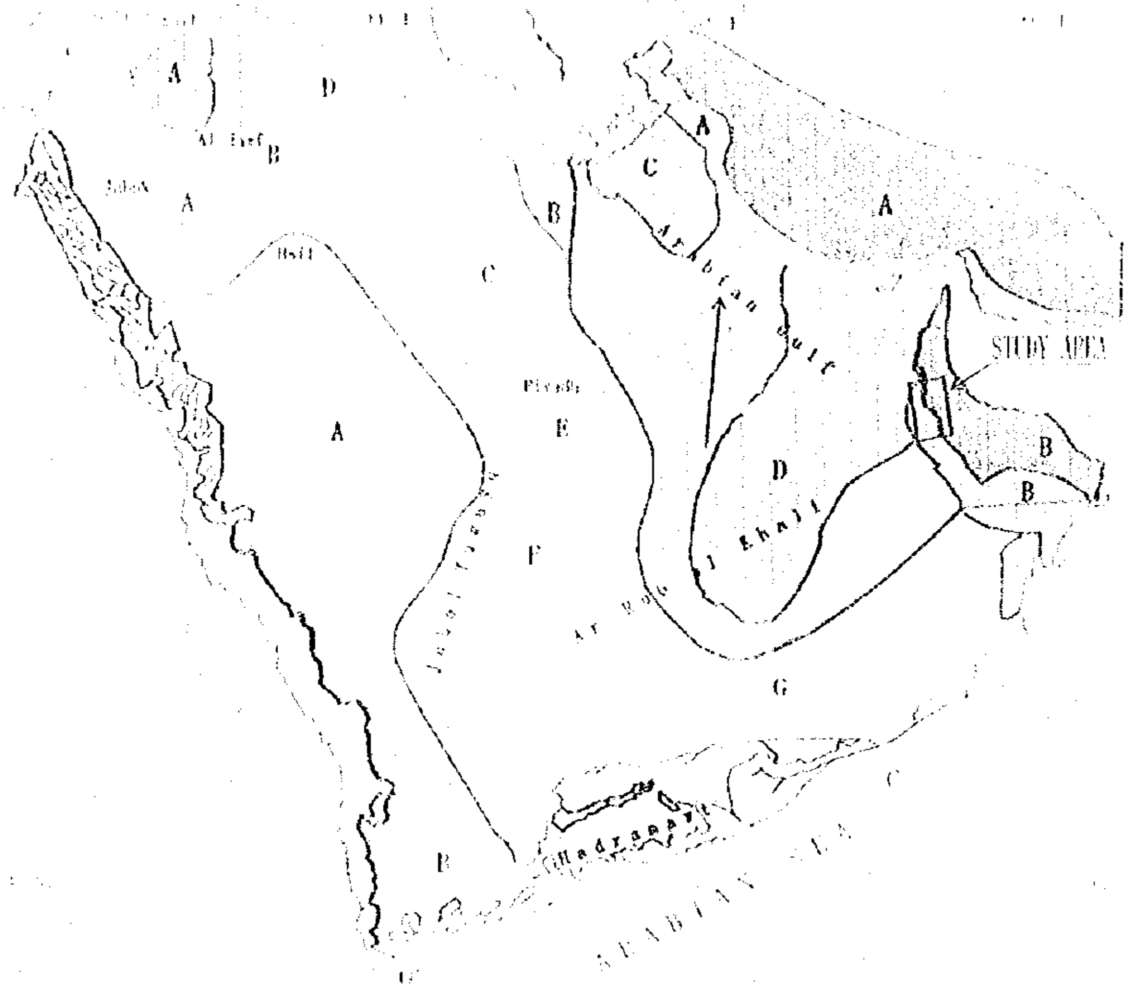
- Zagros Mountains Foreland — A
- Oman Mountains Foreland — B

HUOF-HAUSHI SWELL

QATER ARCH

INTERIOR PLATFORM

Figure 1.2.1 Geologic Structure of Arabian Peninsula



STABLE REGION

ARABIAN SHIELD

Western Arabian Shield A
Yemen-Aden Plateau B
Southern Arabian Shield C

ARABIAN CONTINENTAL SHELF

INTERIOR HOMOCLINE
Tabuk Segment
Hail Arch A
Northern Tuwayq Segment B
Widyan Basin Margin C
Central Arabian Arch D
Southern Tuwayq Segment E
Hadramawt Segment F G

BASINS
Sirhan-Turayf Basin A
Dibdibba Basin B
Northern Arabian Gulf Basin C
Rub al Khali Basin D

MOBILE BELT

MOUNTAINS

Zagros Mountain A
Oman Mountains B

FORELANDS

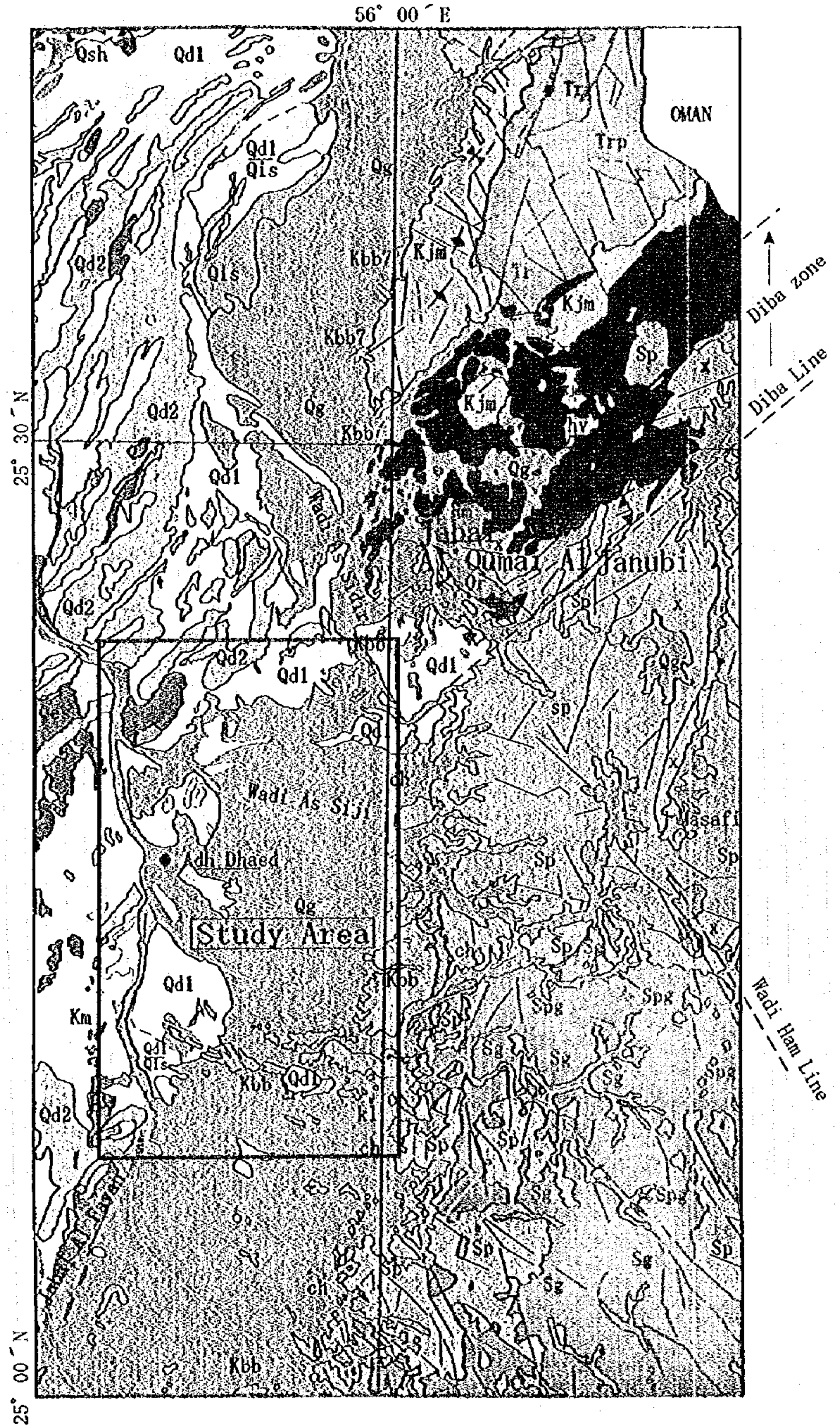
Zagros Mountains Foreland A
Oman Mountains Foreland B

HUOF-HAUSHI SWELL

QATER ARCH

INTERIOR PLATFORM

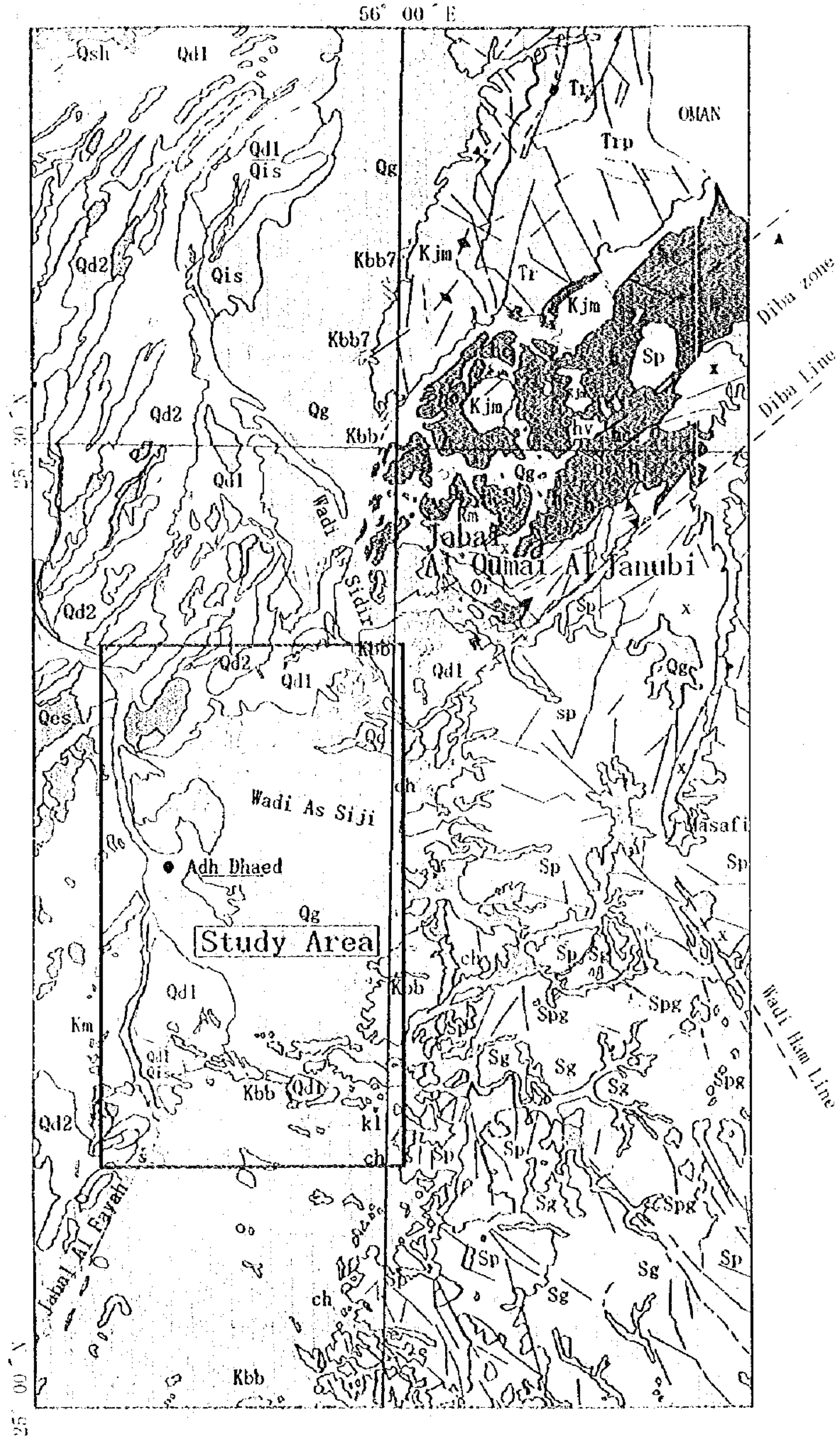
Figure 1.2.1 Geologic Structure of Arabian Peninsula



Autochthonous and Par-Autochthonous units				
Qg	Fluviatile deposits	Boulders gravel,sand and silt in drainage Channels and minor undifferentiated terrace deposits.Terrace and piedmont gravel beds,scree and outwash fans.Boulder to gravel size debris in a fine grained matrix,in places well cemented,local sand and silt interbeds	Holocene	QUATERNARY
Qcs	Coastal sabkhah	Calcareous silt,muddy sand with considerable salt content, salt crusts,flooded by storm and spring tides	Pleistocene and Holocene	
Qis	Inland sabkhah	Silt and muddy sand,flooded by wadi or rising ground water		
Qes	Desert plain deposits	Lag gravels,locally sand or silt,from low-lying flat or gently undulating surface with isolated dunes.May include areas of thin eolian sand cover,sabkhah		
Qd1	Eolian sand	Low dunes		
Qd2	Eolian sand	High dunes		
Kbb	Boulder beds	Pebbles,cobbles and boulders,principally of brown chert, gabbroic and ultrabasic rocks in a siliceous limestone matrix	?	
Kl	Limestone	White to buff,fine grained,porous,nodular weathering,contains fragments of chert,basic and ultrabasic rocks	Upper Cretaceous	JURASSIC to CRETACEOUS
Km	Maastrichtian Limestone	Brown,purplish,grey and white fossiliferous limestone,locally with nodular varieties,limestone conglomerata and reef deposits. Occasional chert bands and nodules.Minor interbeds of marl,mudstone and shale.Local thich basal conglomerate in Jabal Al Fayah area		
KJm	Musandam Group	Grey,massive to well bedded limestones,locally oolitic, fossiliferous,dolomitic with chert nodules		
	Elphinstone Group	Limestone,dolomitic limestone,dolomite,shale,marl, siltstone,sandstone,local chert and conglomerate(Tr)	Lower Jurassic to Lower Cretaceous	PERMO-TRIASSIC
Tr Trp	Ru'us Al Jibal Group	Dolomite,dolomitic and argillaceous limestone and occasional shale(Trp)	Mid-Permian to Triassic	
	Ramaq Formation	Limestone,dolomite,sandstone,marl and local shales outcropping in Jabal Al Qumar Al Janubi(Rm)	Ordovician	ORDOVICIAN
	Rann quartzite Formation	Quartzitic sandstone and shale	Upper Cretaceous to Pre-Permian	
Allochthonous units				
Sg	Gabbros	Coarse grained leucocratic and melanocratic varieties, commonly layered and with minor serpentinite zones; breccias,microgabbroic and pegmatitic types occur locally		
Spg	Gabbros and ultrabasics	Complex zones of gabbro with intermixed ultrabasic rocks		
ch Sp	Ultrabasics	Peridotite,serpentinized peridotite and serpentinite, locally banded.Magnesite and thin chrysotile veins widespread. Serpentinite generally highly tractured.Silicified alteration products(ch)hatched		
Hawasina series				
X	Metamorphics	Quartzite,quartz schist,quartz mica schist,chloritic schist, bands of brown,buff and White crystalline mable.Local calc silicate rocks include amphibolite and epidote schist		
	Chert/limestone facies	Maroon and greenish grey chert commonly well bedded,grey brown and white limestone,occasional green/grey and maroon shale,local volcanics(h) Larger areas of chert(hc)		
hv	Volcanics	Mainly dark green intermediate and basic lavas, vesicular, locally porphyritic and in places with pillow structures, agglomerate and ? tuff beds		

Geological boundary
Geological boundary,approximate
Dip and strike of atrata
Anticline
Syncline
Fault or fracture(mark on downthrow side)
Fault or fracture,inferred or approximate
Thrust fault(barbs point to overthrust rocks)
Wadi
Town

Figure 1.2.2 Geologic Map adjacent to the Study Area



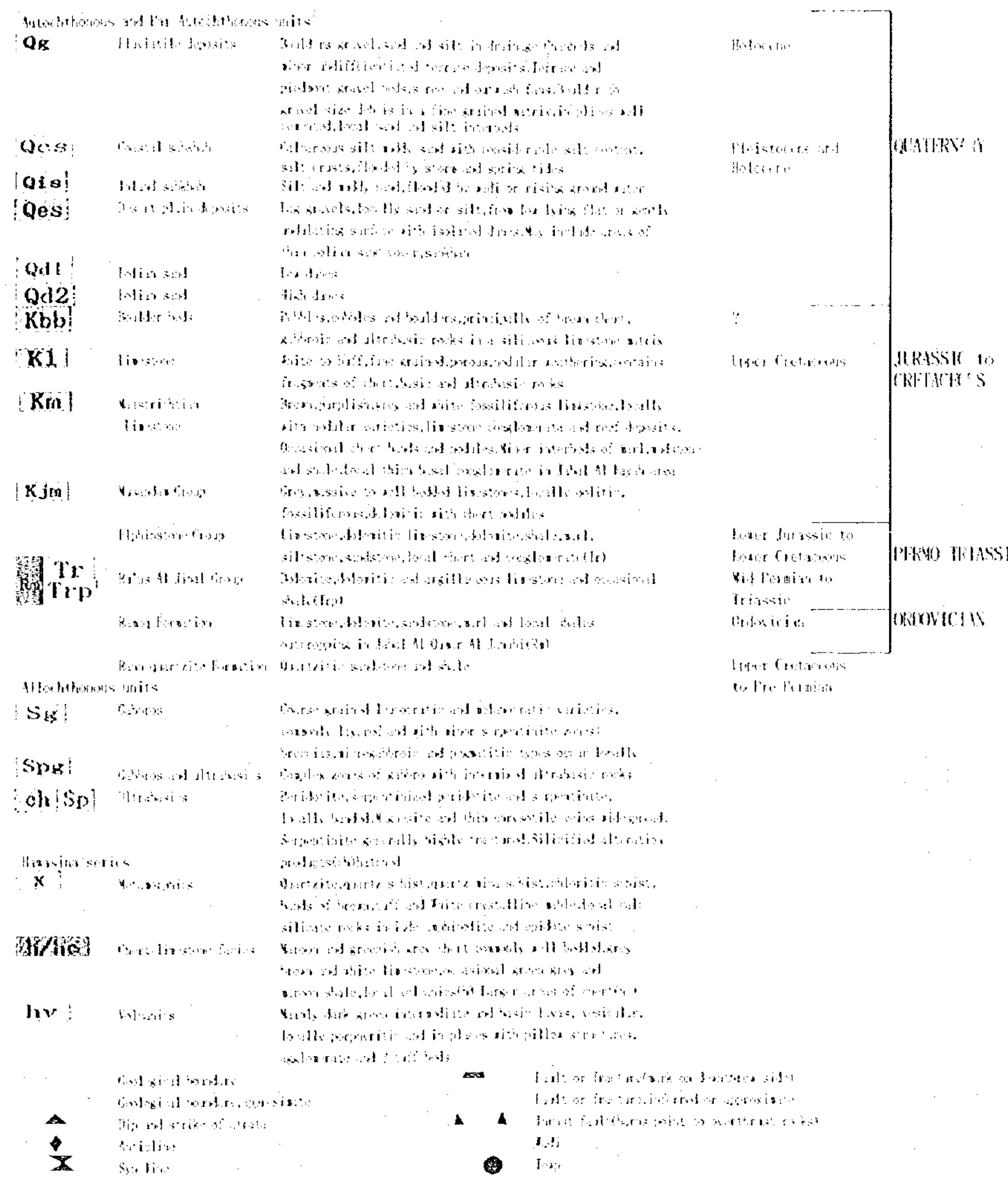


Figure 1.2.2 Geologic Map adjacent to the Study Area

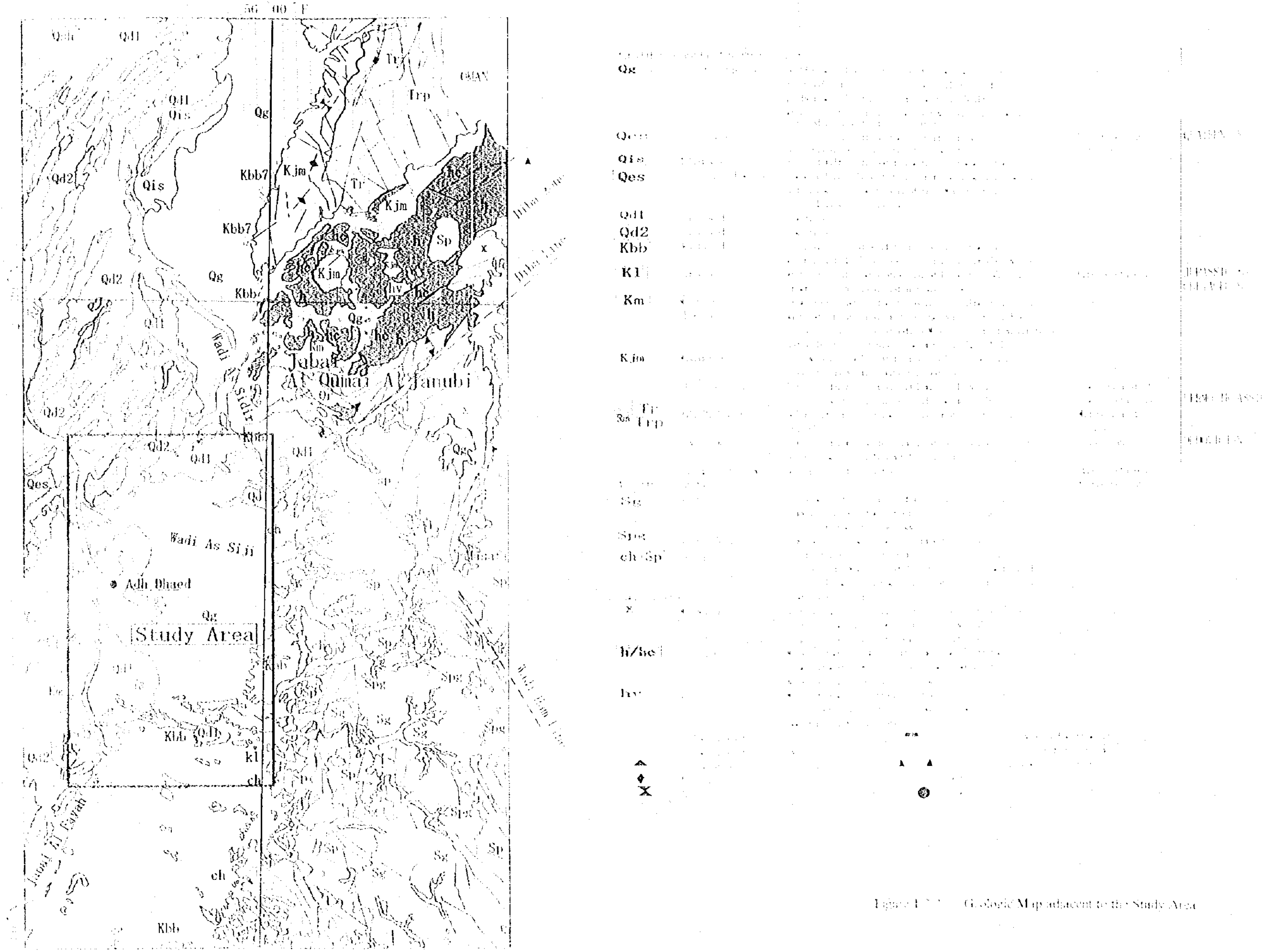


Figure I-?-? Geologic Map adjacent to the Study Area

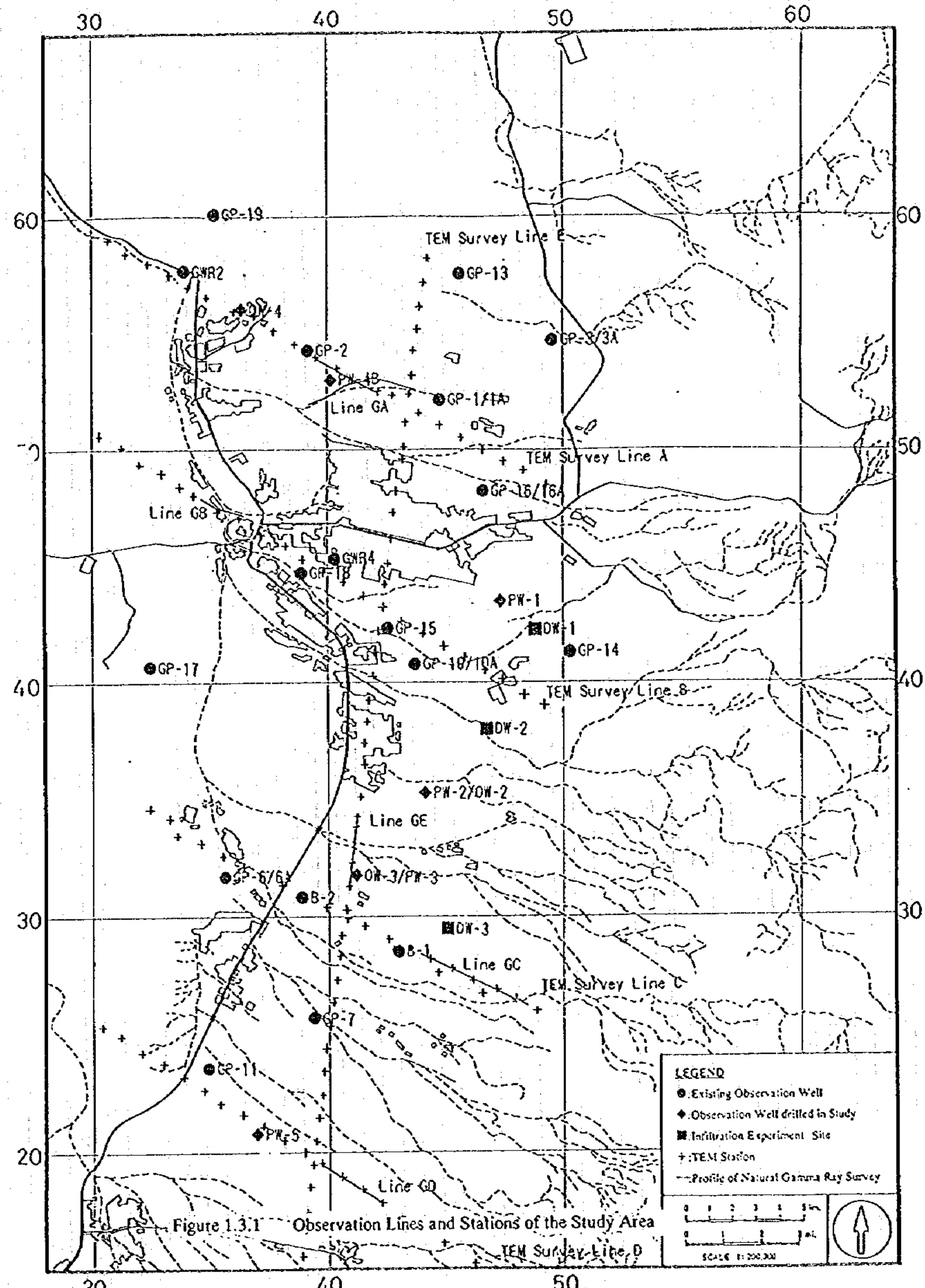
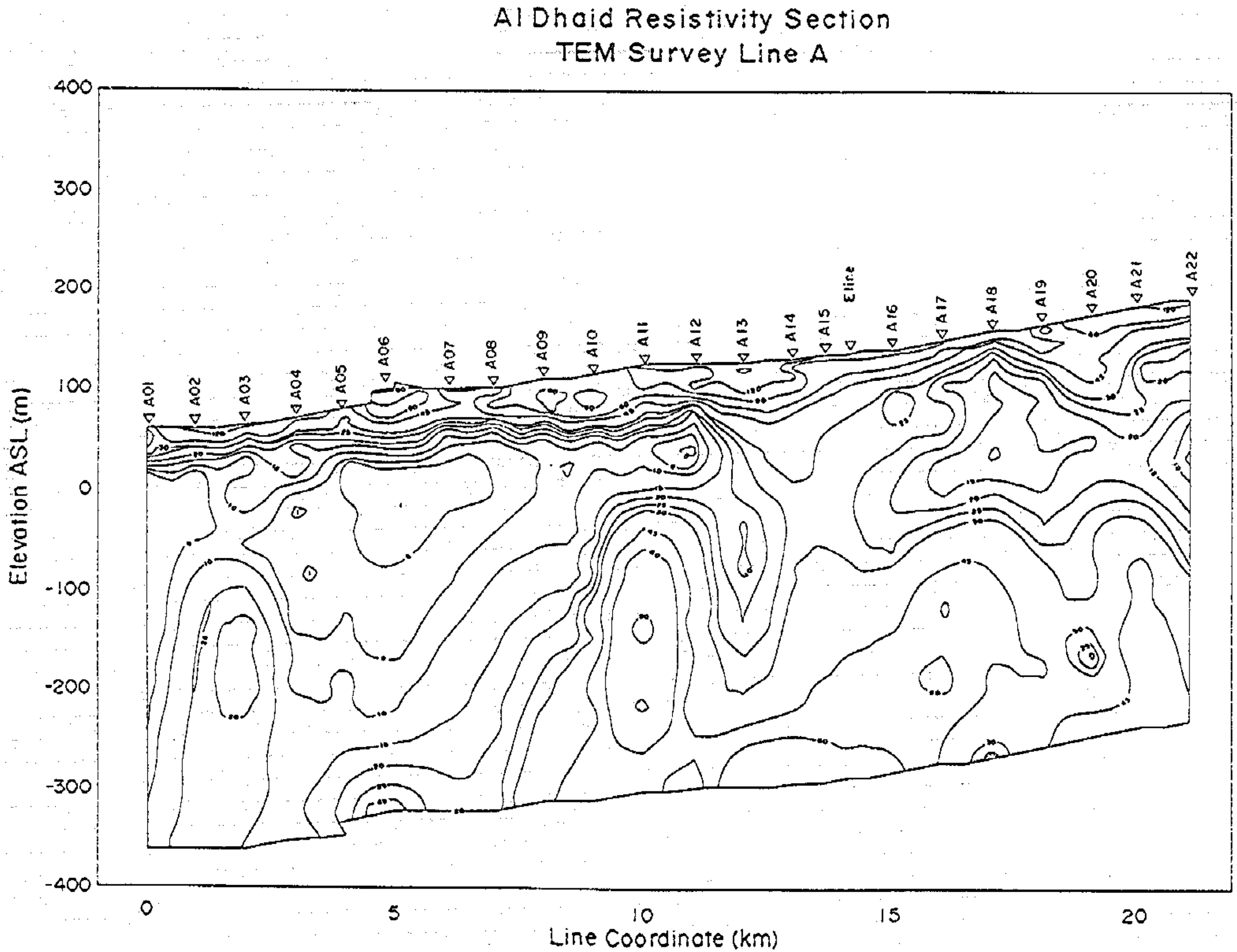


Figure 1.3.1 Observation Lines and Stations of the Study Area



Location: Al Dhaid Plain, United Arab Emirates
Date of Field Survey: April-June, 1995
Equipment: Geonics PROTEM/EM-47,EM-57
Interpretation Software: TEMIX-GL/GLIMGDX/WINSURF

Figure 1.3.2 Al Dhaid Resistivity Section TEM Survey Line A

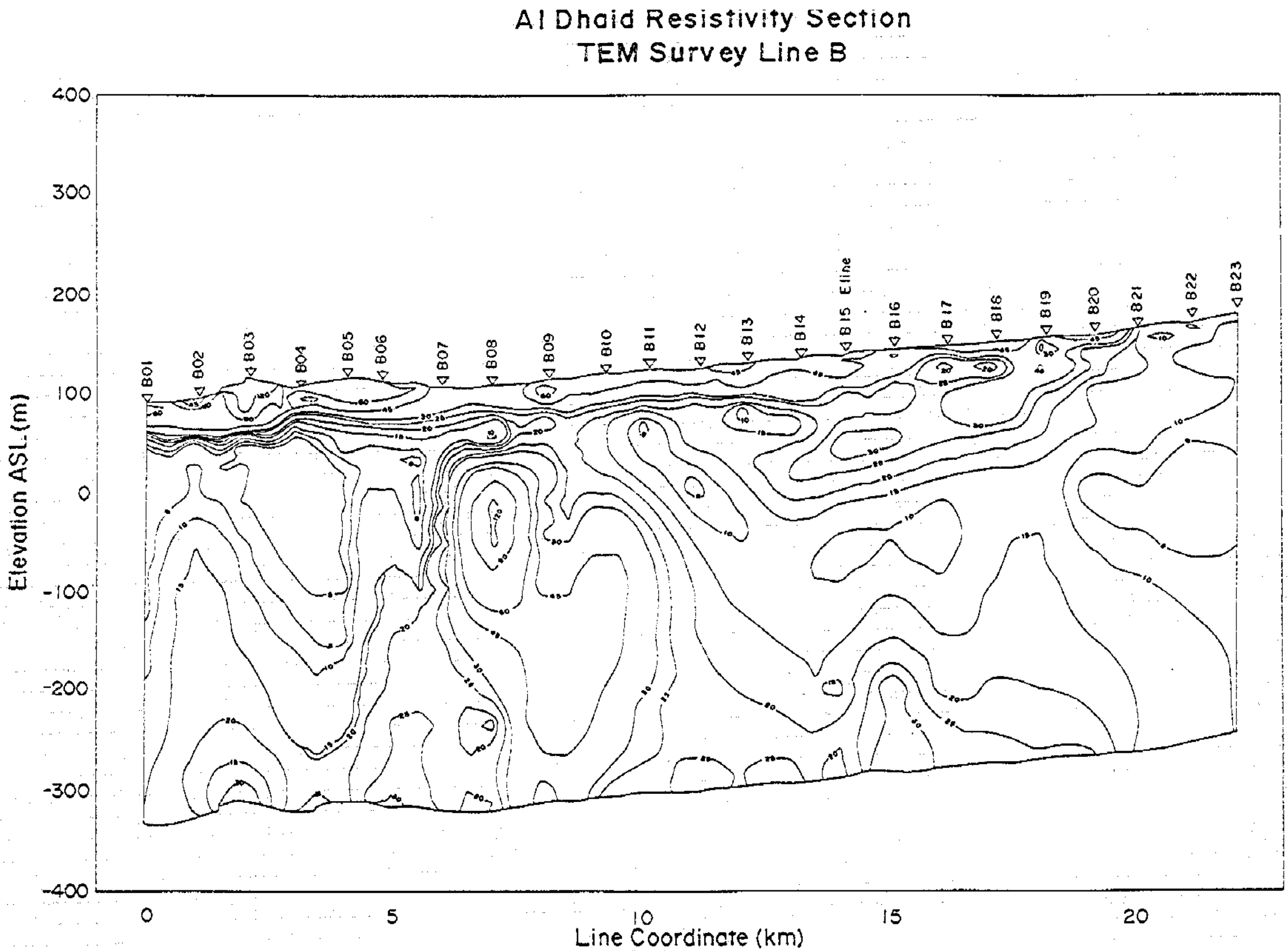


Figure 1.3.3 Al Dhaid Resistivity Section TEM Survey Line B

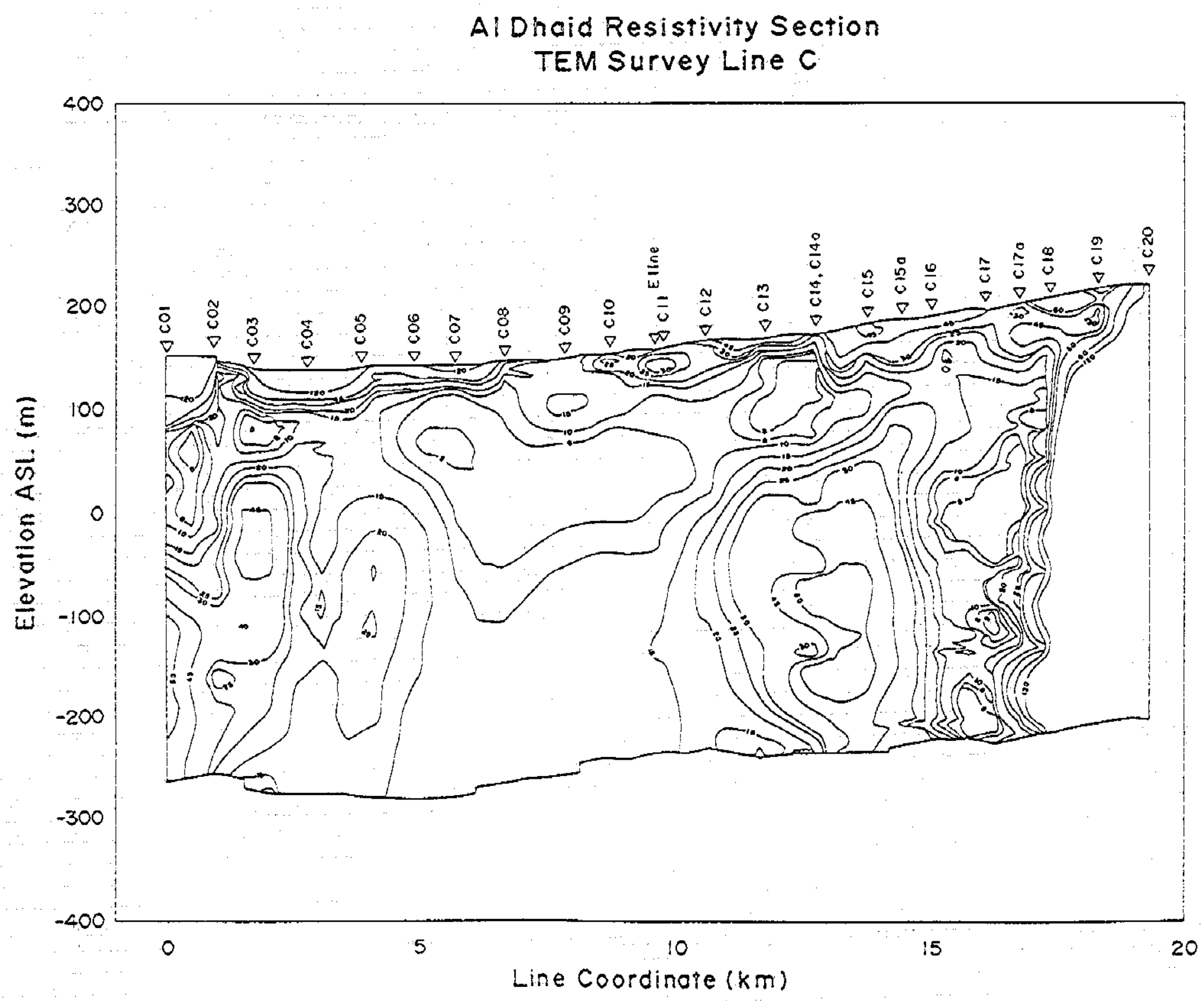


Figure 1.3.4 Al Dhaid Resistivity Section TEM Survey Line C

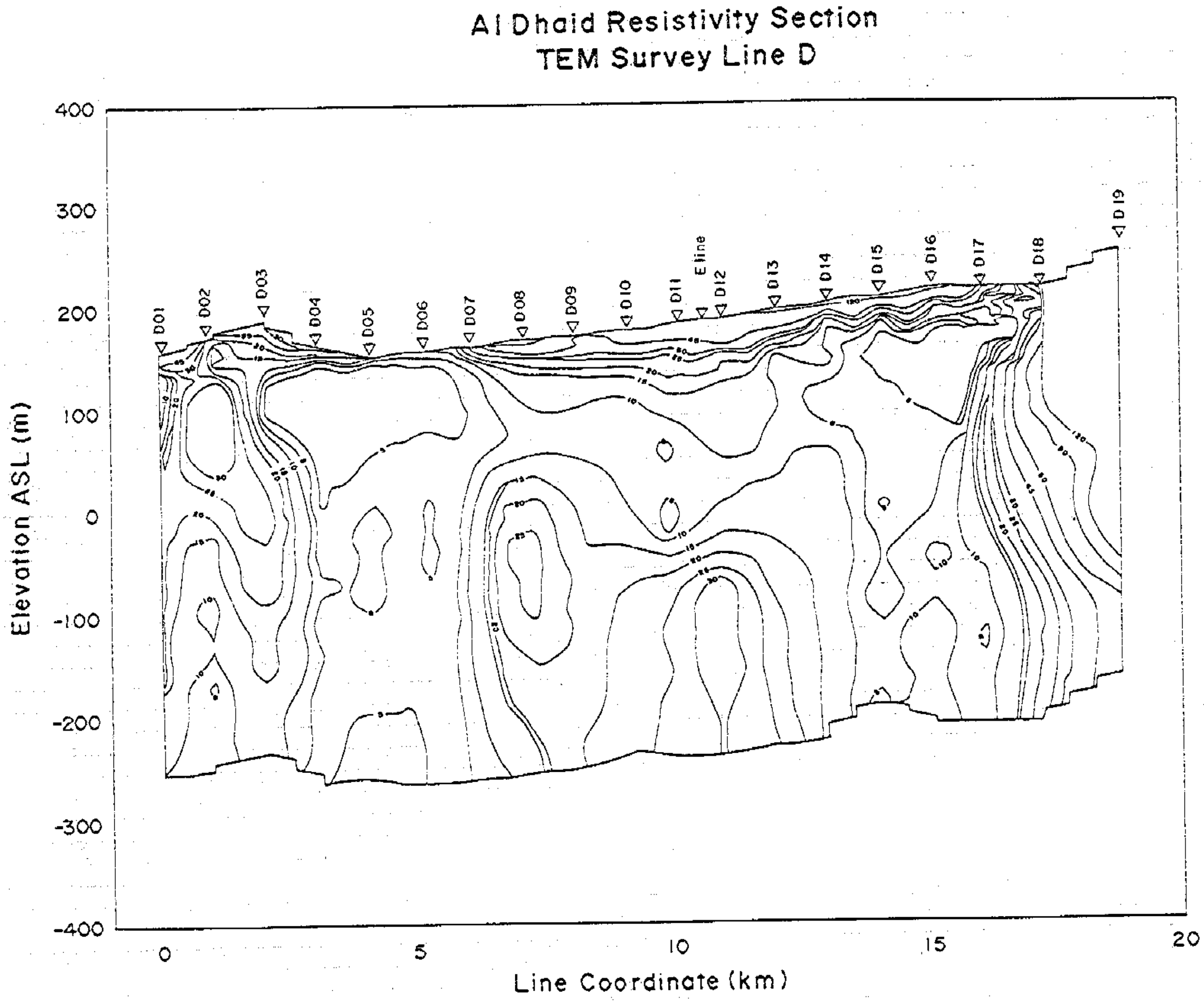


Figure 1.3.5 Al Dhaid Resistivity Section TEM Survey Line D

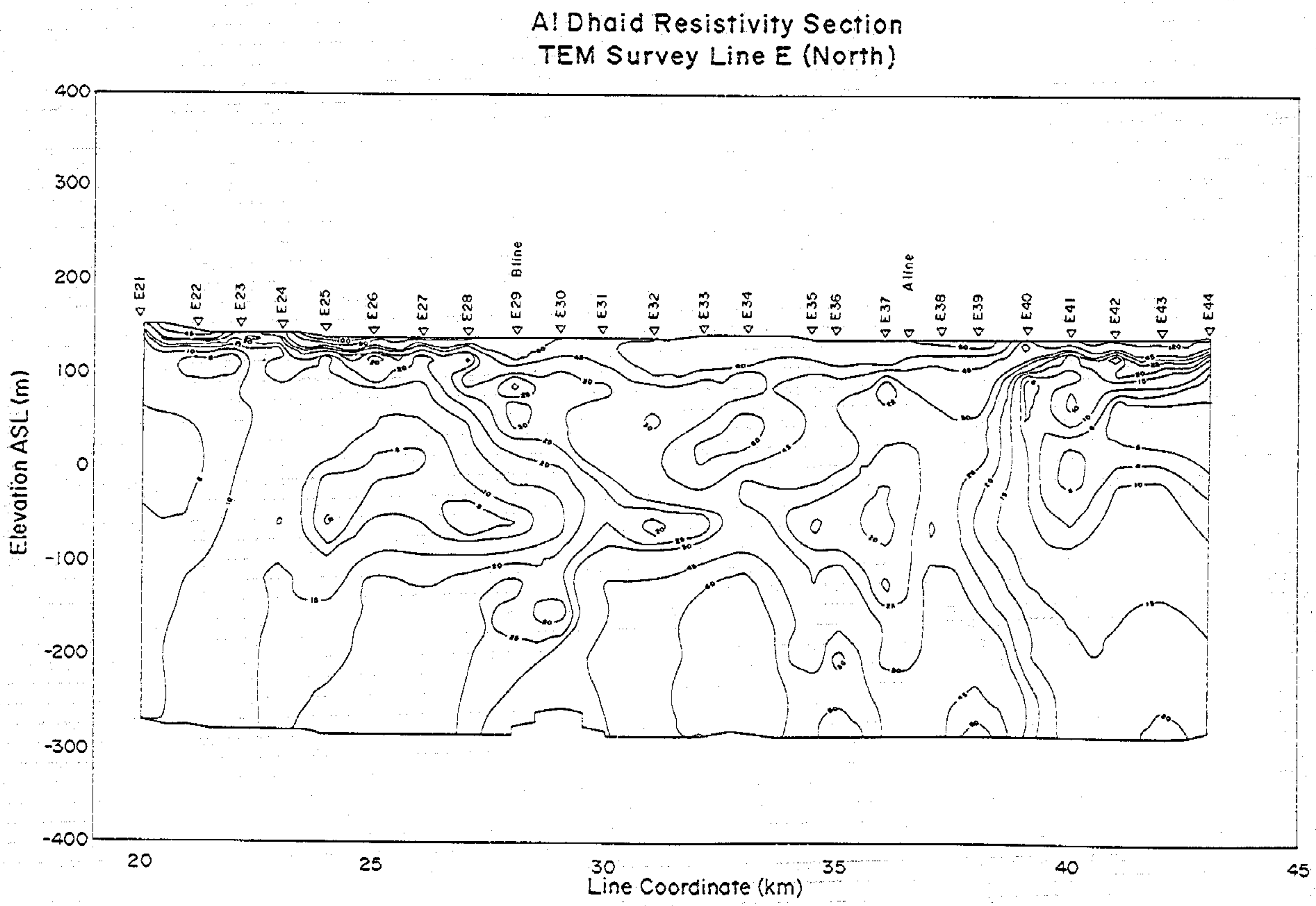


Figure 1.3.6 Al Dhaid Resistivity Section TEM Survey Line E(South)

Al Dhaid Resistivity Section
TEM Survey Line E (South)

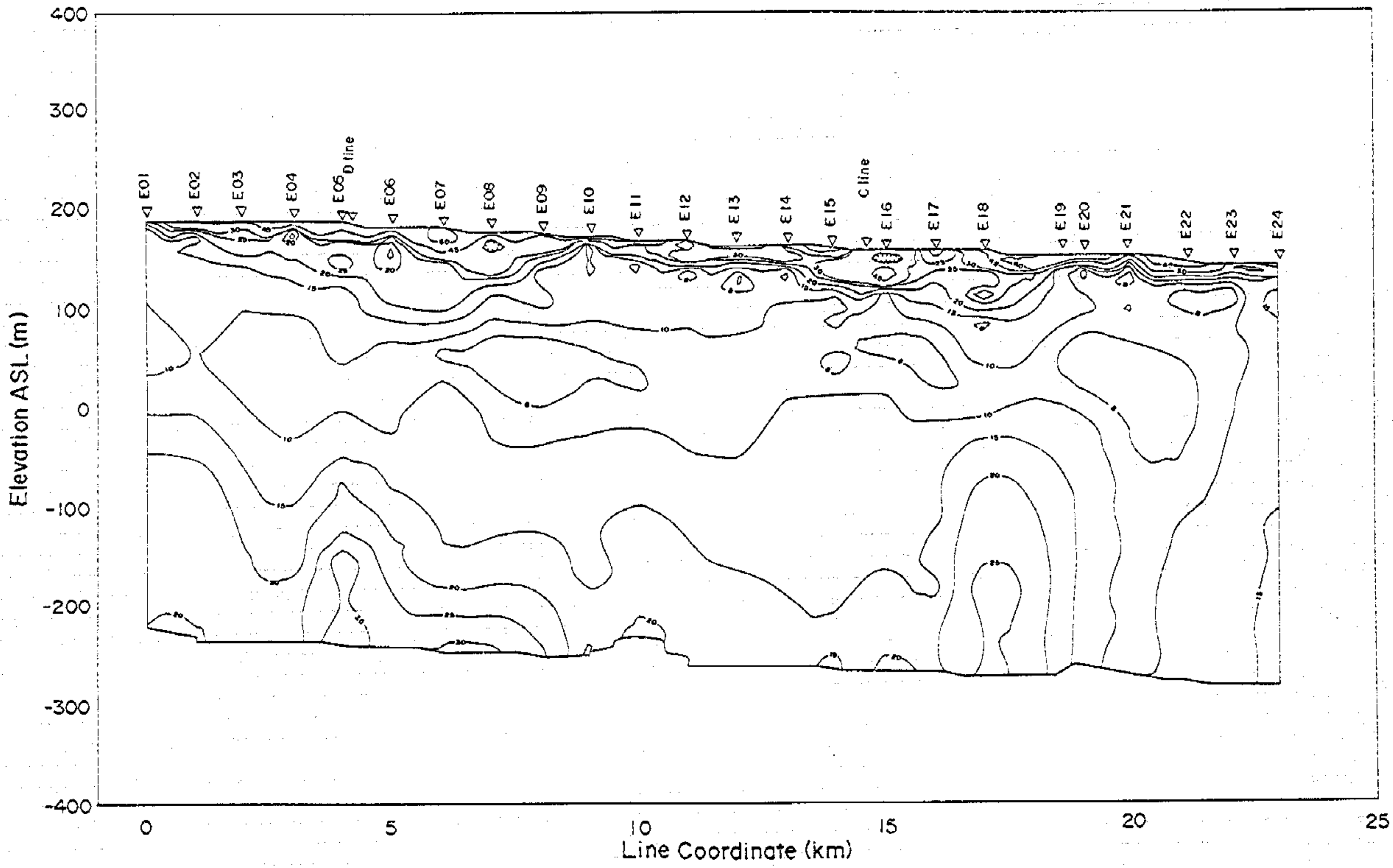


Figure 1.3.7 Al Dhaid Resistivity Section TEM Survey Line E(North)

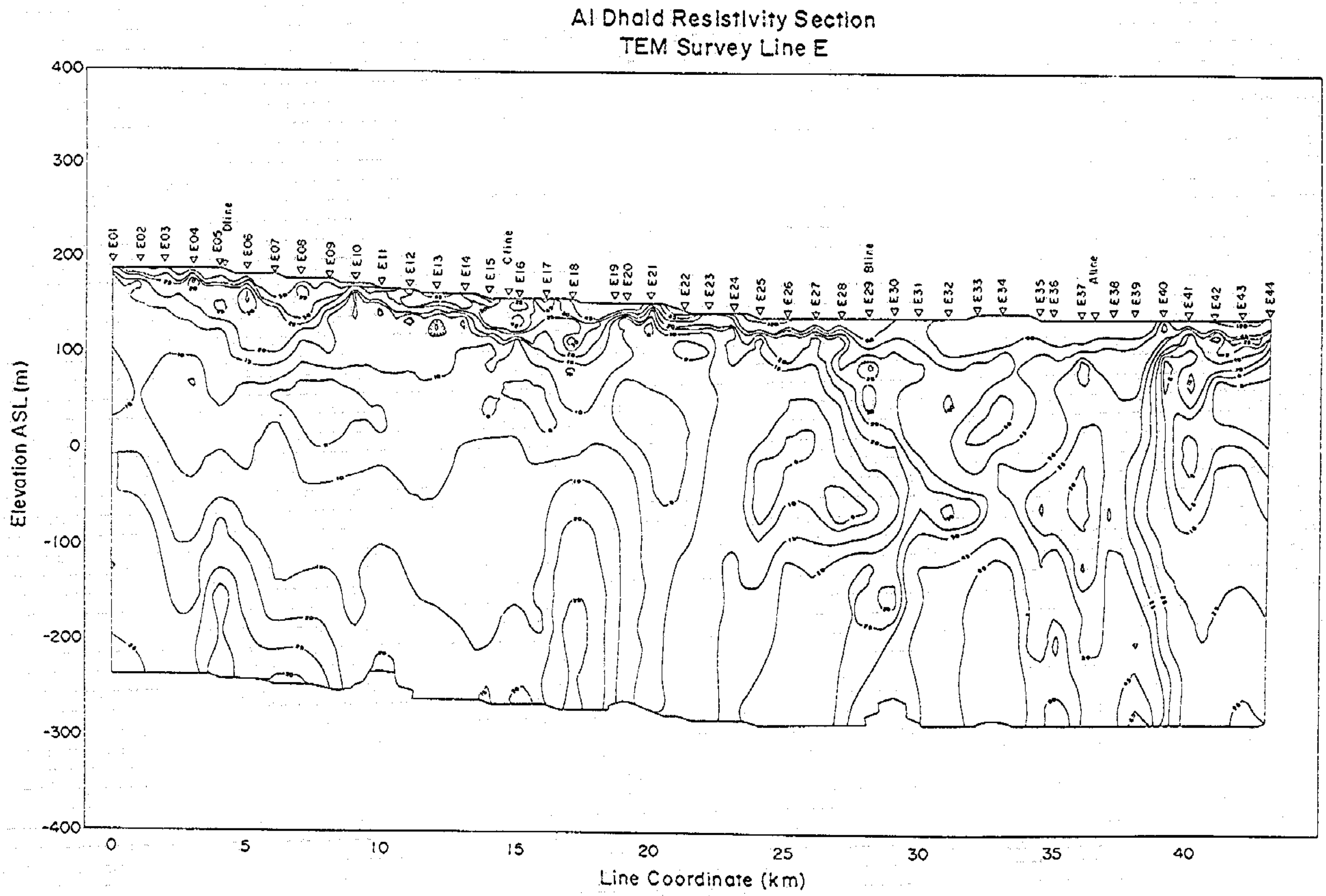


Figure 1.3.8 Al Dhaid Resistivity Section TEM Survey Line E(South and North)

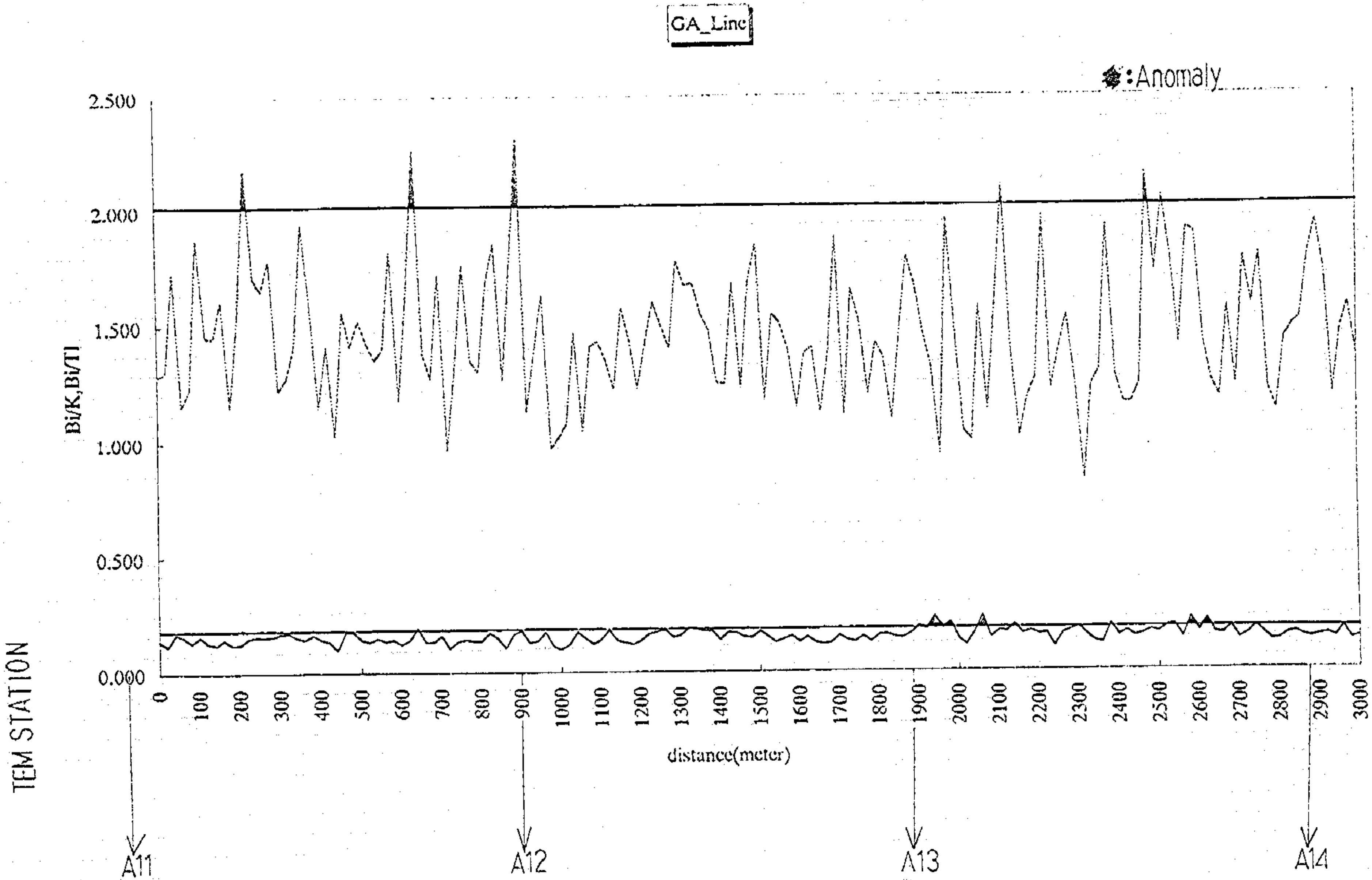


Figure 1.3.9 Result of Natural Gamma Survey Line GA

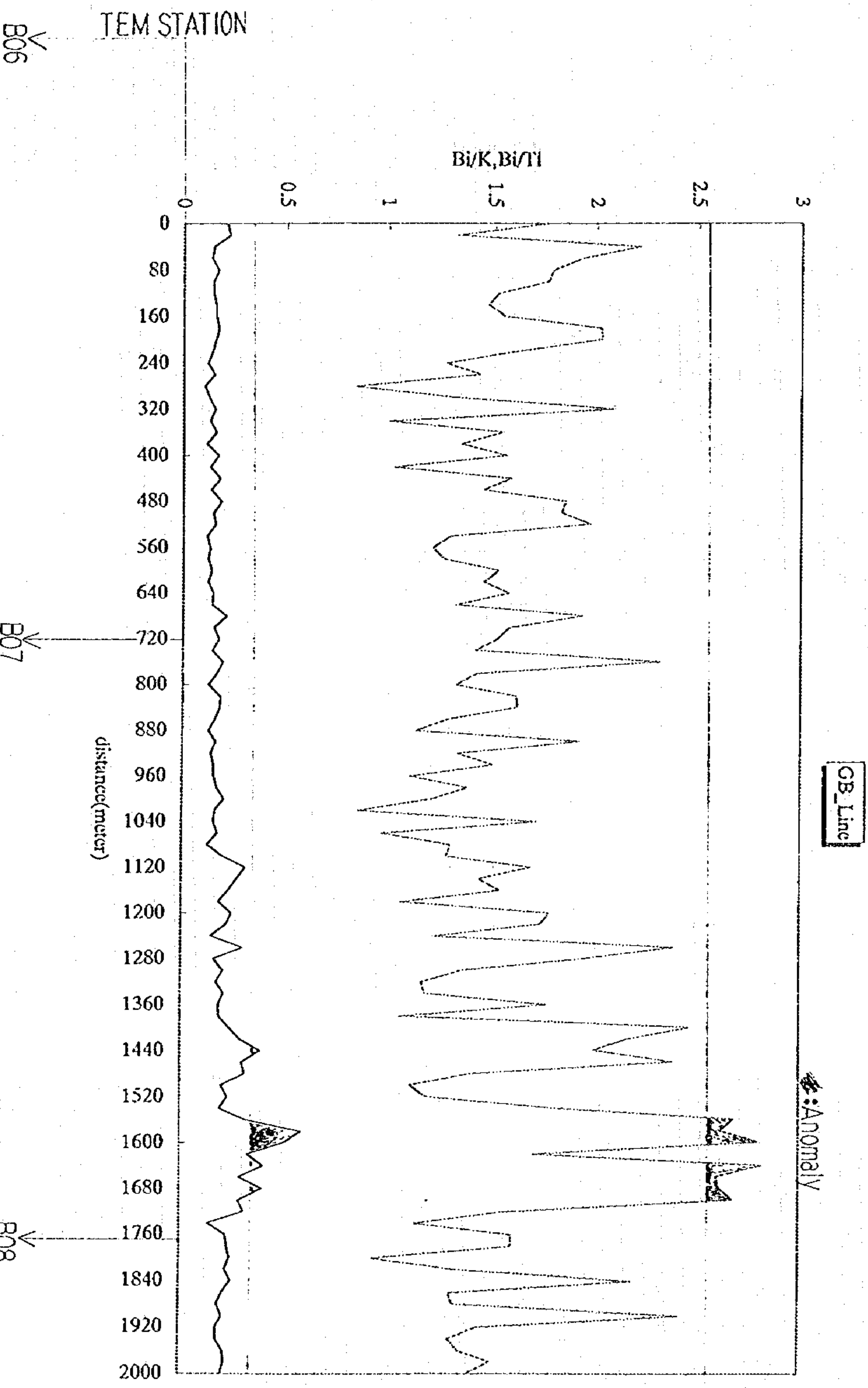


Figure 1.3.10 Result of Natural Gamma Survey Line GB

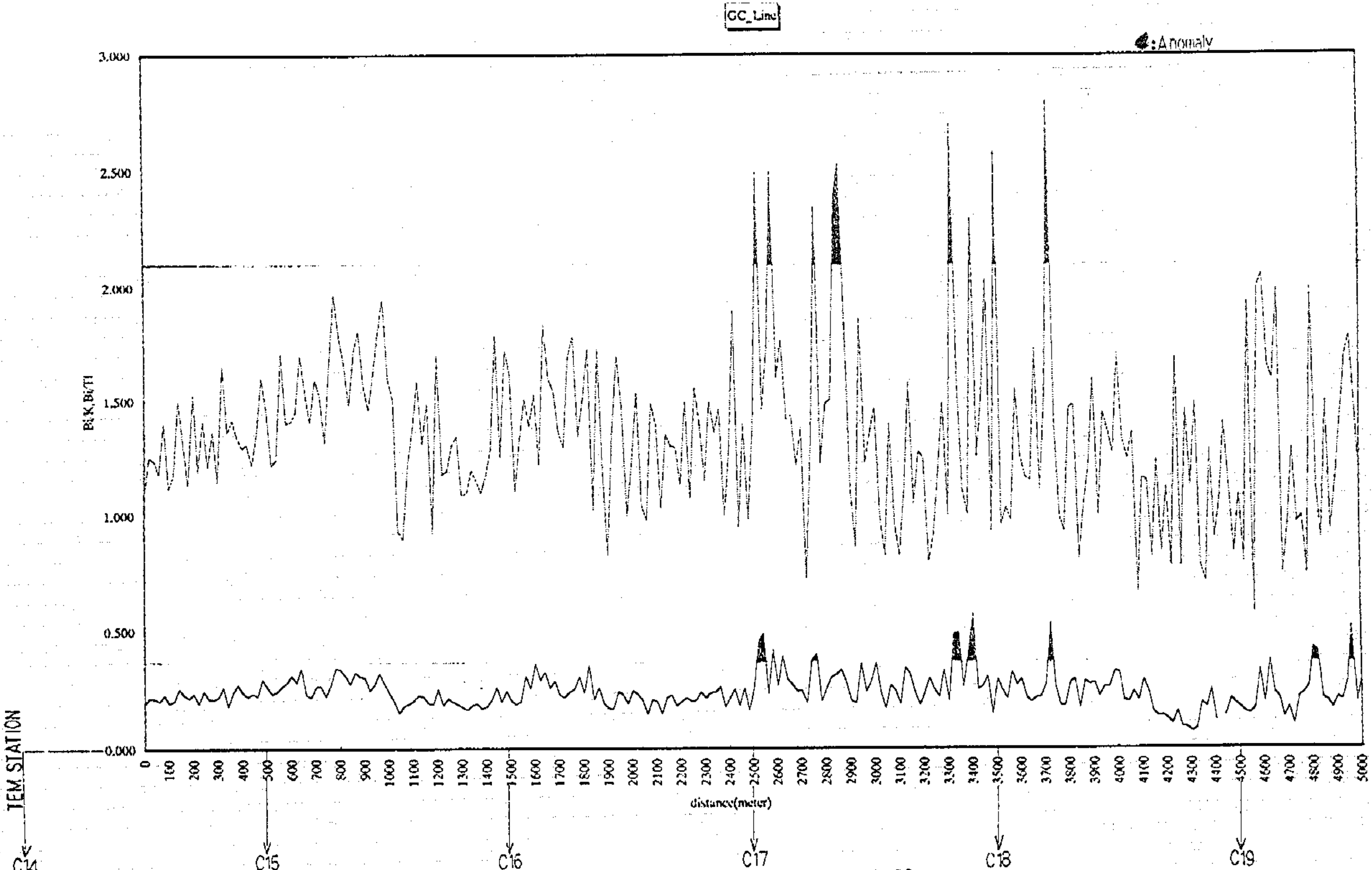


Figure 1.3.11 Result of Natural Gamma Survey Line GC

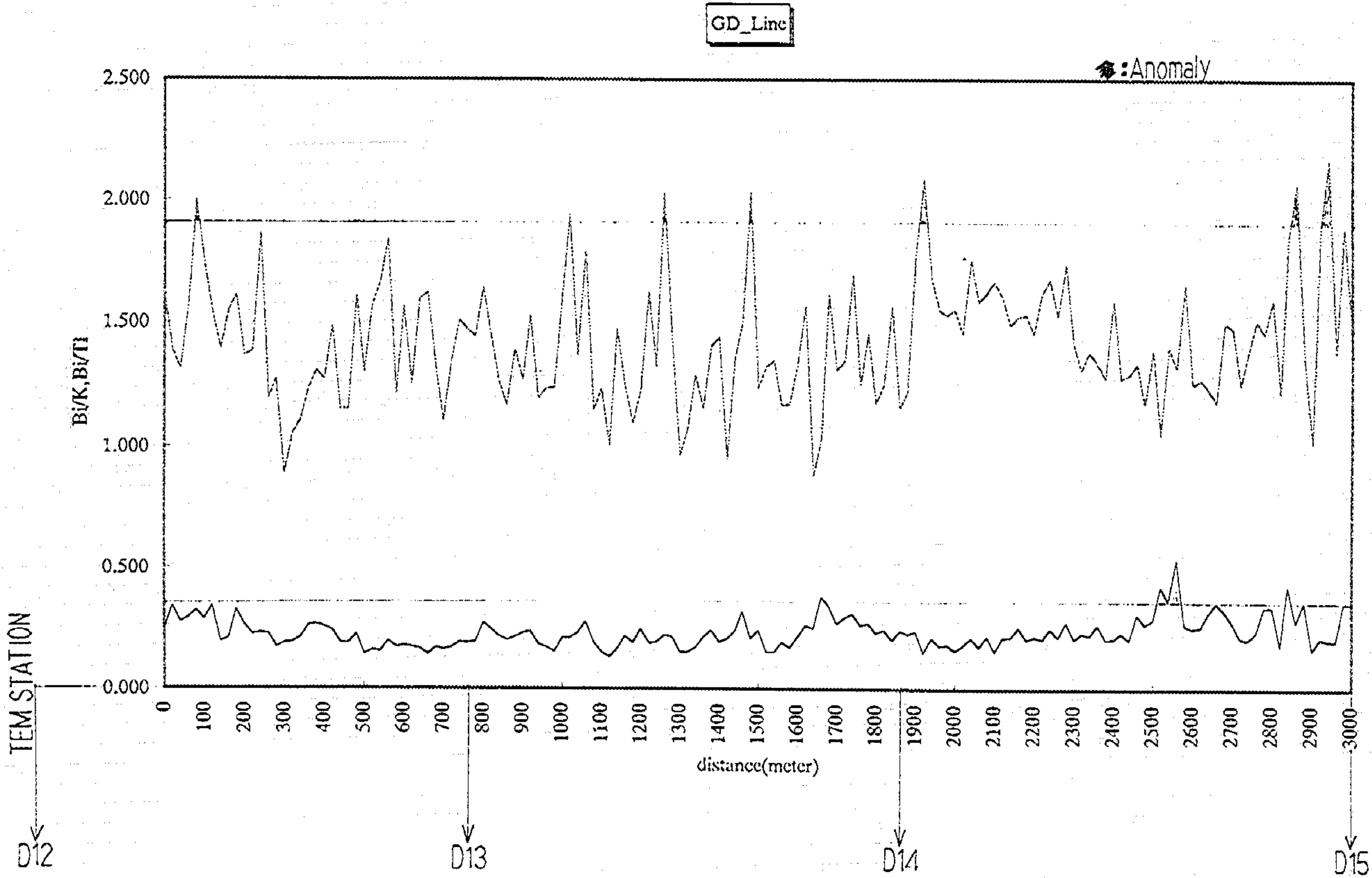


Figure 1.3.12 Result of Natural Gamma Survey Line GD

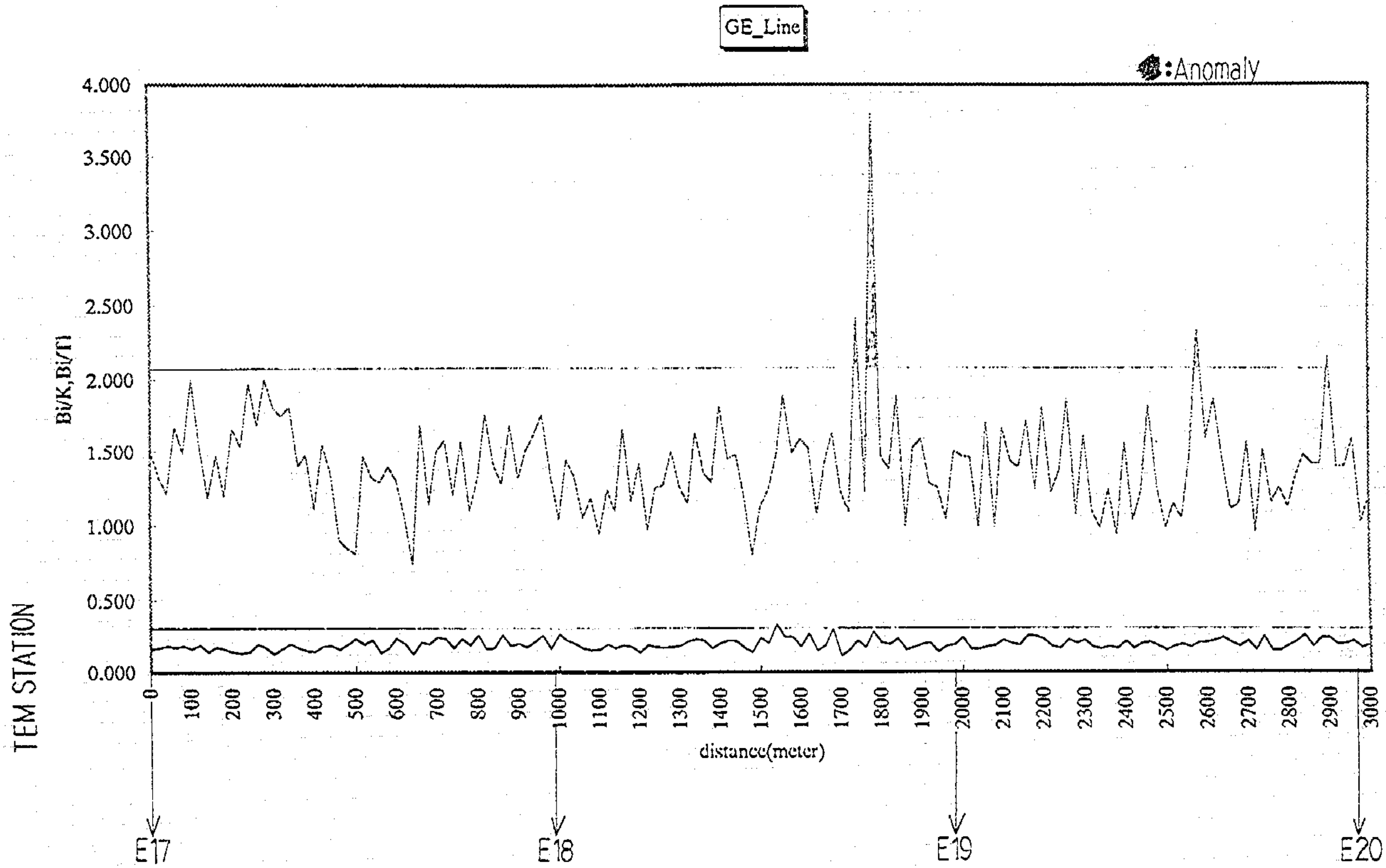
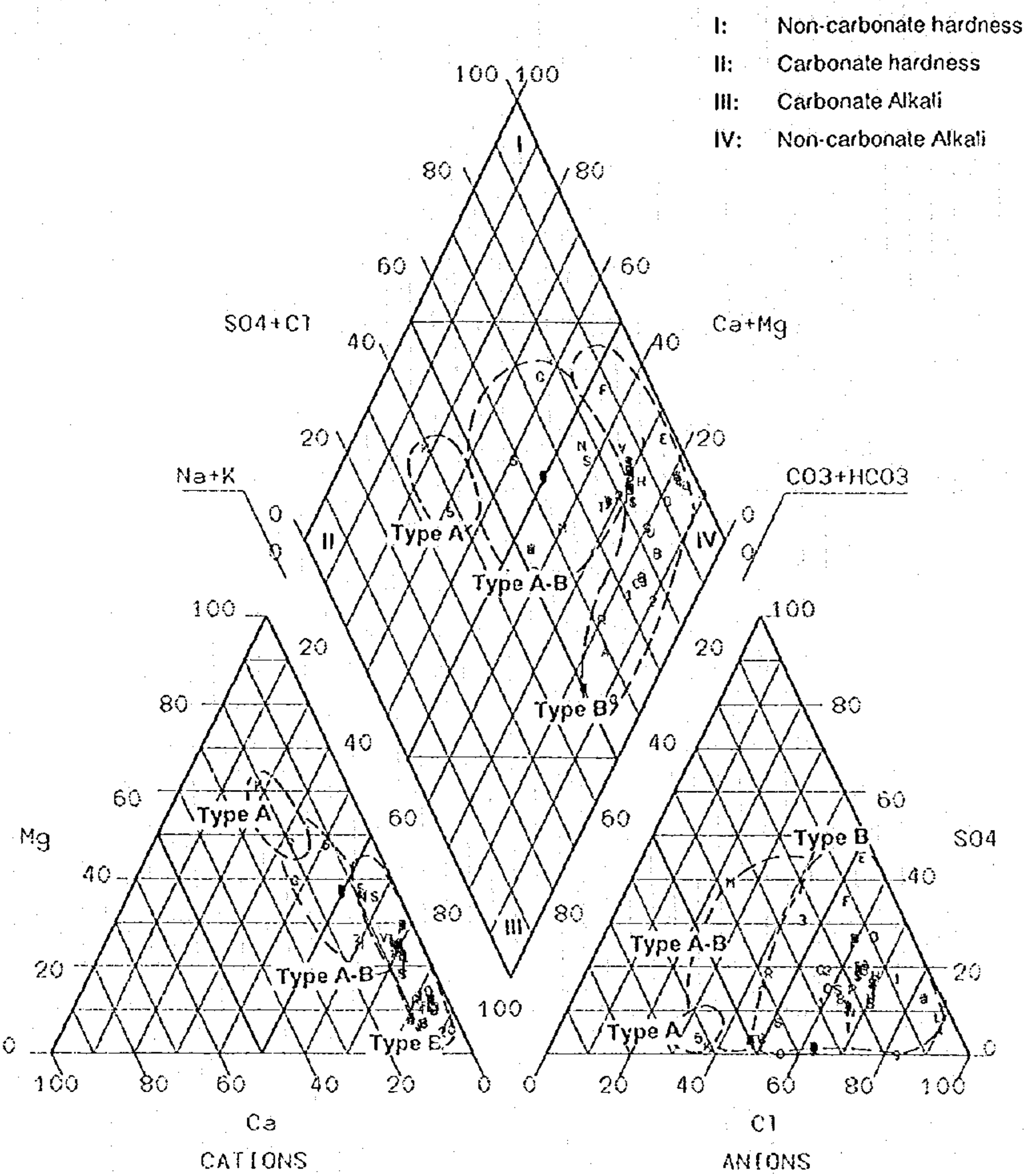


Figure 1.3.13 Result of Natural Gamma Survey Line GE



Type A: Aquifer in Oman Mountain

Type B: Aquifer in Bahada Plain

Type A-B: Contamination of type A with type B

Figure 1.3.14 Groundwater Quality (Piper Diagram)

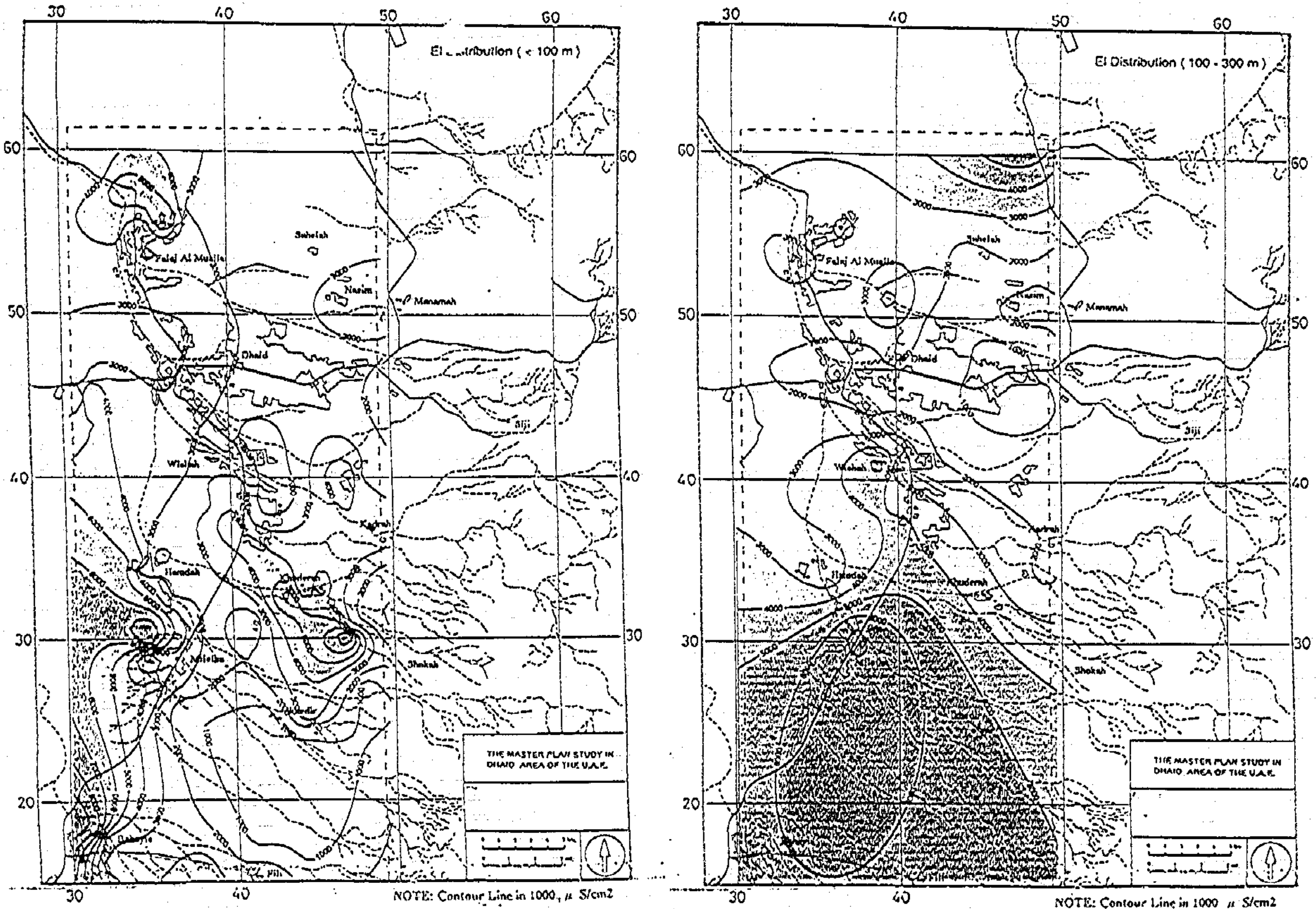


Figure 1.3.15 Distribution of Electric Conductivity

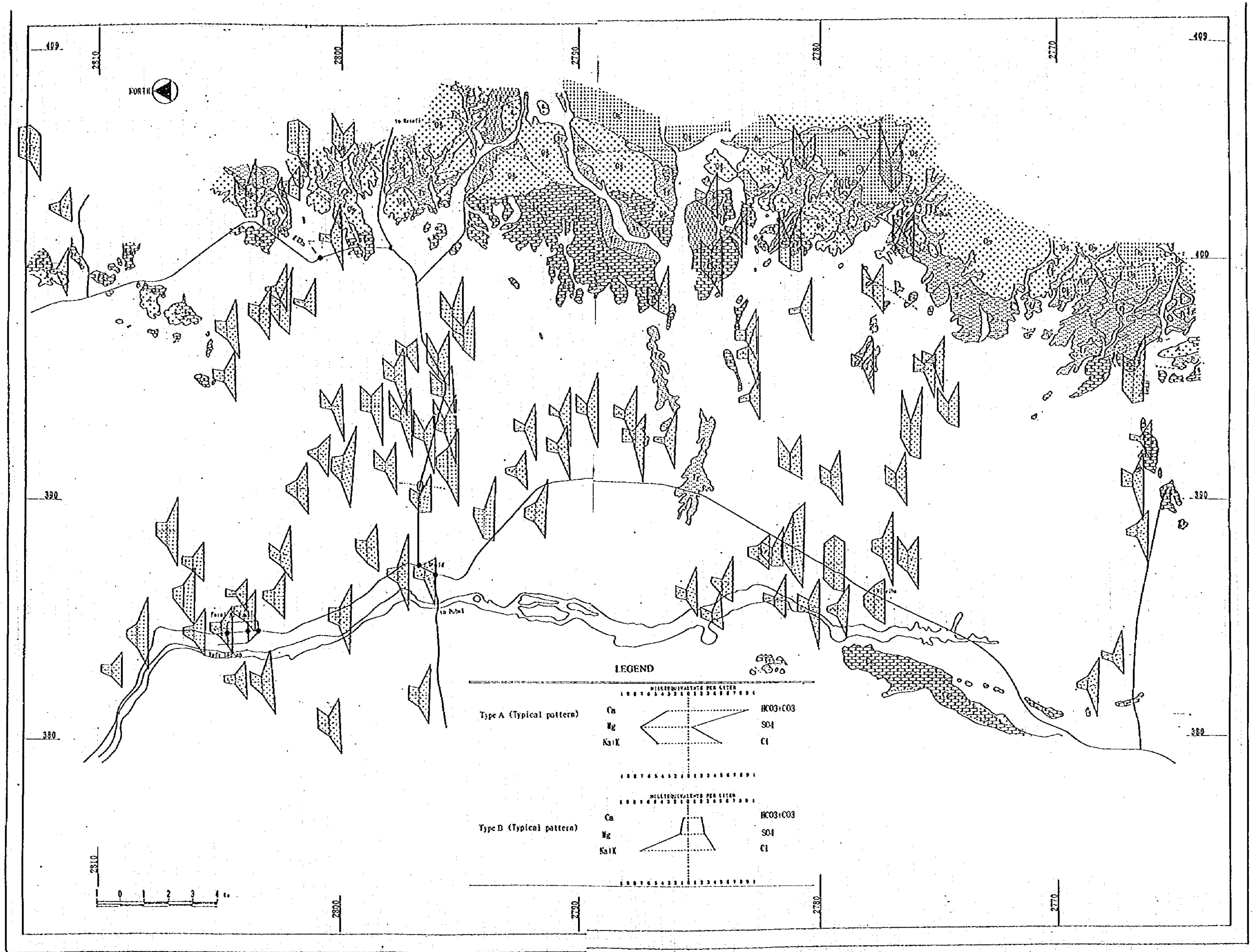
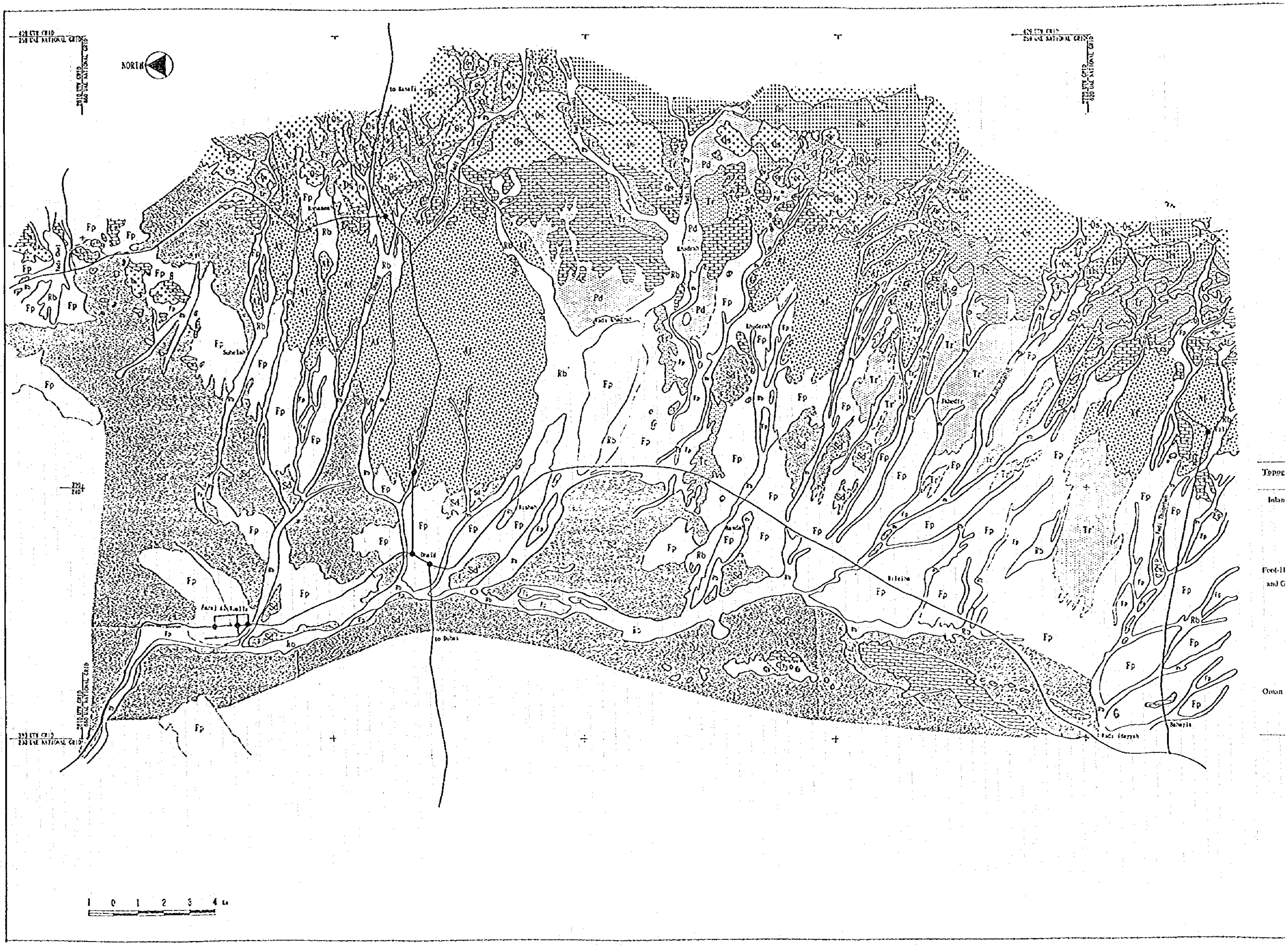


Figure 1.3.16 Groundwater Quality (Stiff Diagram)



NORTH
Fp
Rb
Sd
Pd
Tr
to Dubai
Topog
Inlan
Oman

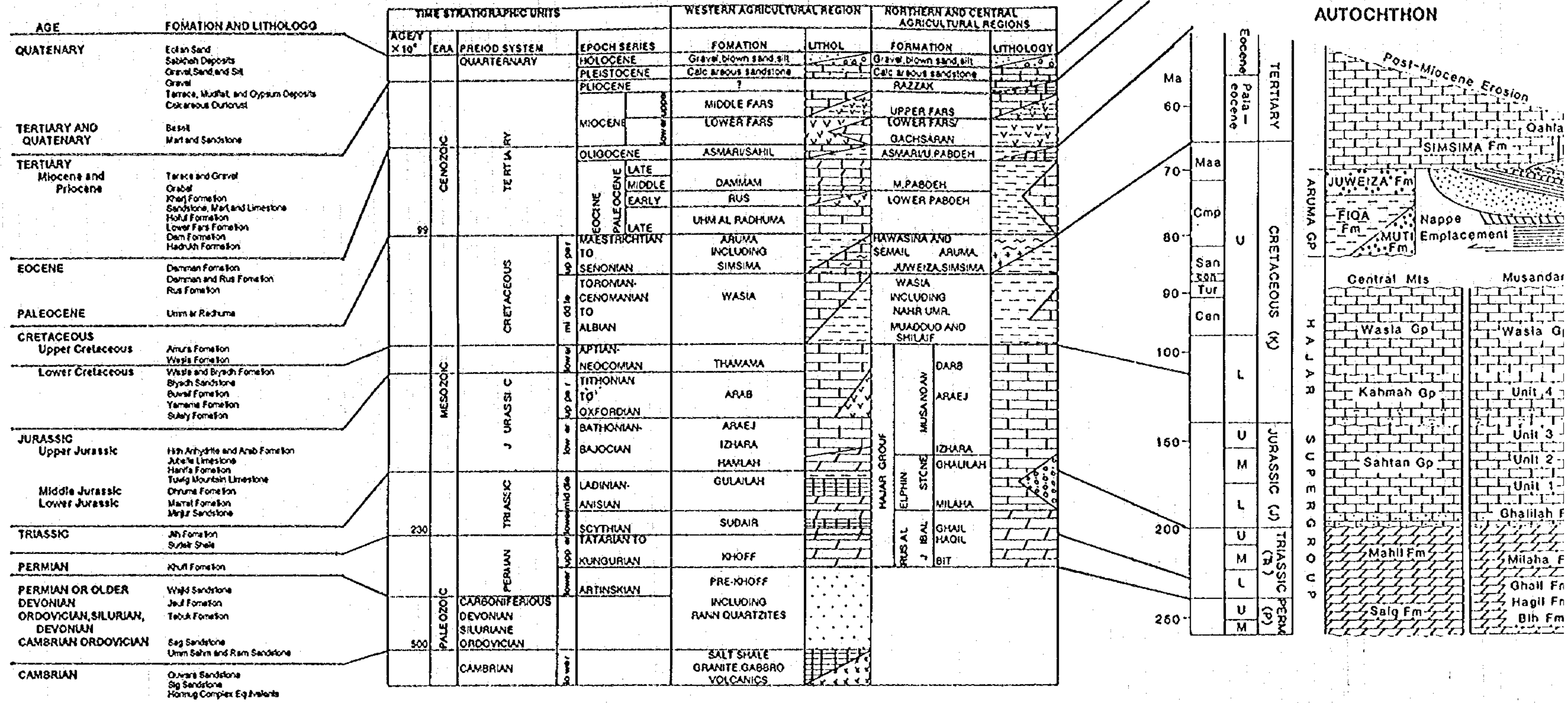
Topographical Division	Geomorphologic Symbols	Land Form Type	Geologic Symbols	Geological Unit
Inland Plain and Sand Dune	Af	[Af]Alluvial Fan(old /dissected)		[Al]Superficial Deposit(Recent alluvial gravel, sands and screen)
	Af	[Af]Alluvial Fan(new/active)		
	Fp	[Fp]Flood Plain,		
	Rd	[Rd]River Bed(active wadi)		
	Sd	[Sd]sand dune and trough		
Foot-Hill Highland and Gravel Plain	Tr	[Tr]Trace(or Dissected) Limestone and carbonates	T Qh T	Neoautochthonous Unit (Maastrichtian-Tertiary Sediment): [Jw]Juweiza Formation [Qh]Qahlah Formation and/or [Uar] Umm al Radhuma Formation and/or [Esh] Eocene shale and/or [Fa] Far Formation [UFa] Terrace Deposites(Cemented ravel)/Upper Far Formation
	Pd	[Pd]Pediment Plain		
Oman Mountain Range		Erosional Slope	Os	[Os]Semail Ophiolite Sequence
			Os	Allochthonous Unit(Batinah Complex) :Hayabi Complex and/or Hawasina Assemblages

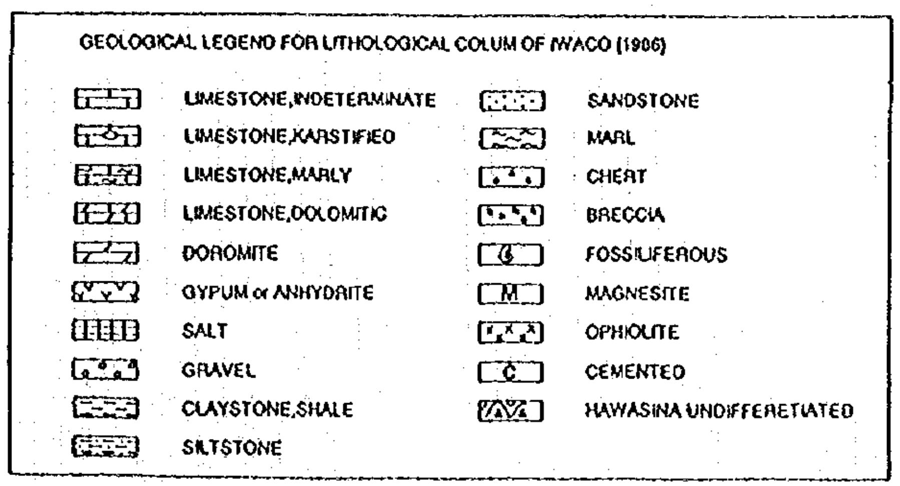
Figure 1.4.1 Geomorphologic Map of the Study Area

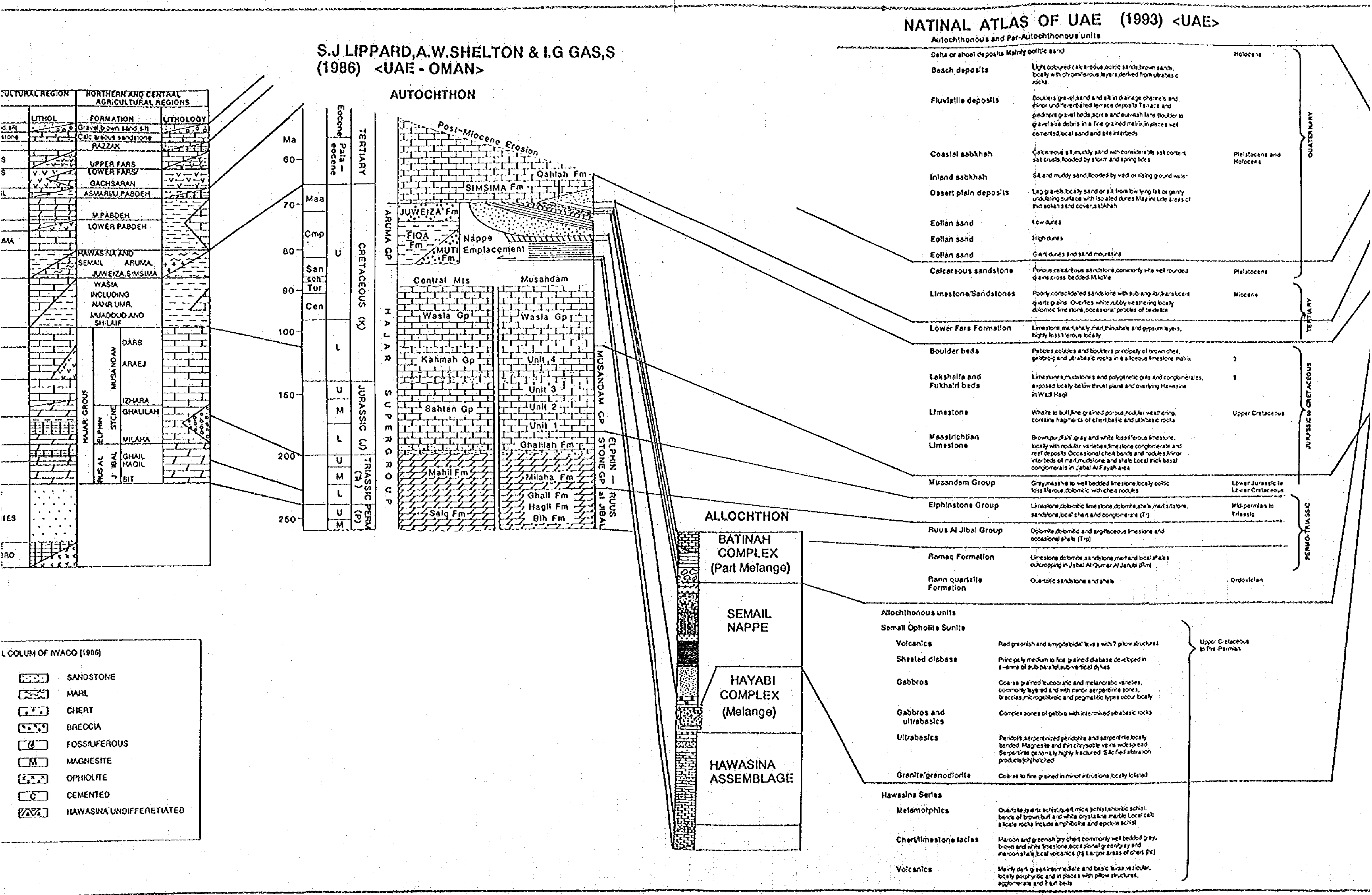
USGS(1963) <SAUDI ARABIA>

IWACO(1986) <UAE>

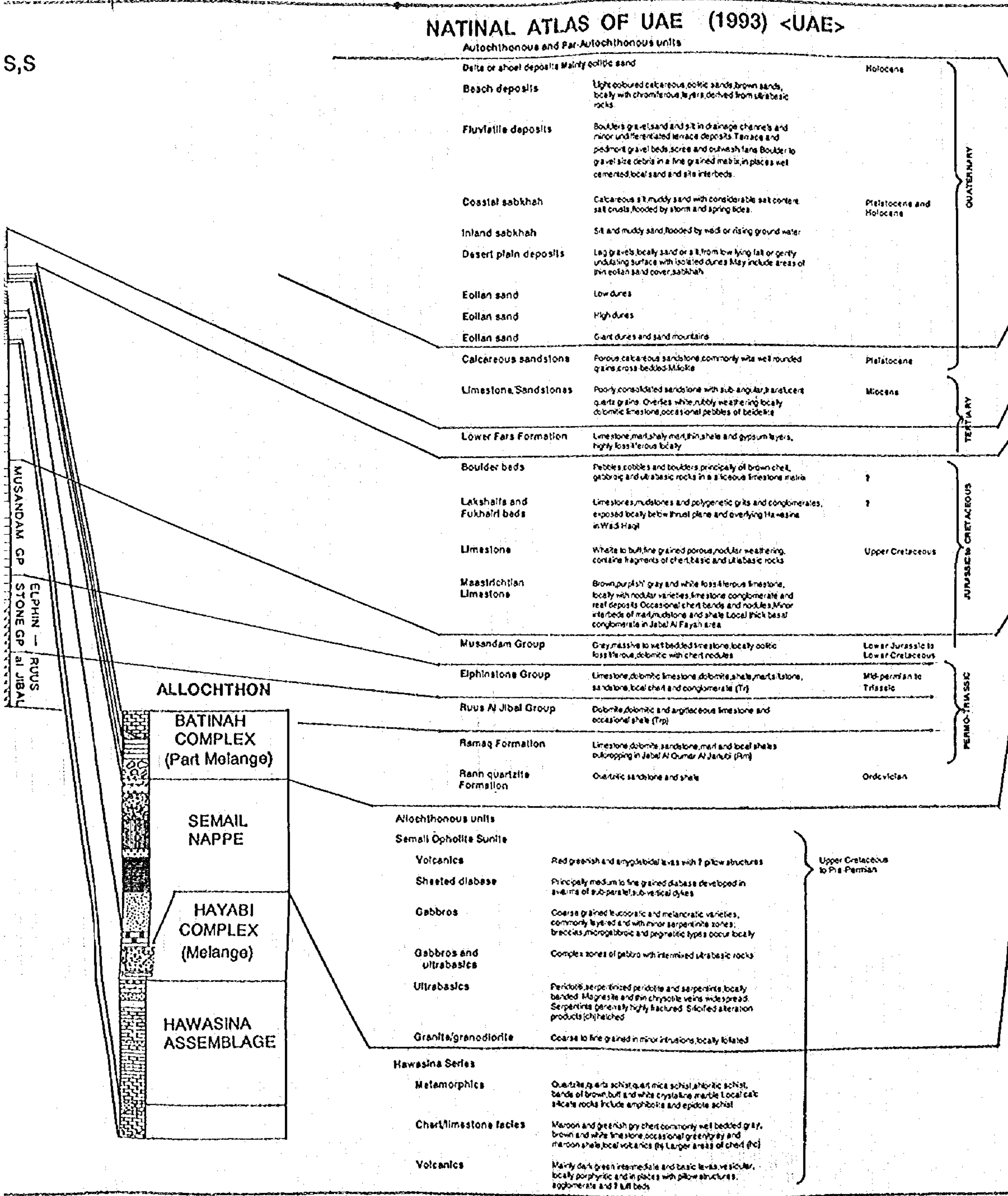
S.J LIPPARD, A.W.SHELTON & I.G (1986) <UAE - OMAN>






NATINAL ATLAS OF UAE (1993) <UAE>
S.J LIPPARD, A.W.SHELTON & I.G GAS,S (1986) <UAE - OMAN>
AUTOCHTHON
ALLOCHTHON
NORTHERN AND CENTRAL AGRICULTURAL REGIONS
FORMATION
LITHOLOGY
Gravel,brown sand,silt
Calcareous sandstone
RAZZAK
UPPER FARS
LOWER FARS
GACHSARAN
ASMARI/U.PABDEH
M.PABDEH
LOWER PABDEH
HAWASINA AND SEMAIL ARUMA,
JUWEIZA,SIMSIMA
WASIA INCLUDING NAHR UMR, MUADDUD AND SHILAIF
QARB
ARAEJ
IZHARA
GHAULAH
MILAHA
GHAIL
HAGIL
BIT
HAJAR GROUP
MUSANDAM
ELPHINSTONE
RUUS AL JIBAL
Ma
60
70
80
90
100
150
200
250
Eocene
Palaeocene
Maa
Cmp
San
Con
Tur
Cen
U
L
M
TERTIARY
CRETACEOUS (K)
JURASSIC (J)
TRIASSIC (R)
PERM (P)
ARUMA GP
HAJAR SUPERGROUP
Post-Miocene Erosion
Qahlah Fm
SIMSIMA Fm
JUWEIZA Fm
FIQA Fm
MUTI Fm
Nappe Emplacement
Central Mts
Musandam
Wasla Gp
Kahmah Gp
Sahtan Gp
Unit 4
Unit 3
Unit 2
Unit 1
Ghalilah Fm
Mahil Fm
Milaha Fm
Ghail Fm
Hagil Fm
Bih Fm
Saiq Fm
MUSANDAM GP
ELPHINSTONE GP
RUUS al JIBAL
BATINAH COMPLEX (Part Melange)
SEMAIL NAPPE
HAYABI COMPLEX (Melange)
HAWASINA ASSEMBLAGE
COLUM OF IWACO (1986)
SANDSTONE
MARL
CHERT
BRECCIA
FOSSILIFEROUS
MAGNESITE
OPHIOLITE
CEMENTED
HAWASINA UNDIFFERETIATED
Autochthonous and Par-Autochthonous units
Delta or shoal deposits Mainly oolitic sand
Holocene
Beach deposits
Light coloured calcareous,oolitic sands,brown sands, locally with chromiferous layers,derived from ultrabasic rocks.
Fluviatile deposits
Boulders gravel,sand and silt in drainage channels and minor undifferentiated terrace deposits Terrace and piedmont gravel beds,scree and outwash fans Boulder to gravel size debris in a fine grained matrix,in places well cemented,local sand and silt interbeds
Coastal sabkhah
Calcareous silt,muddy sand with considerable salt content salt crusts,flooded by storm and spring tides.
Pleistocene and Holocene
Inland sabkhah
Silt and muddy sand,flooded by wadi or rising ground water
Desert plain deposits
Lag gravels,locally sand or silt,from low lying flat or gently undulating surface with isolated dunes May include areas of thin eolian sand cover,sabkhah
Eolian sand
Low dunes
Eolian sand
High dunes
Eolian sand
Giant dunes and sand mountains
Calcareous sandstone
Porous,calcareous sandstone,commonly with well rounded grains,cross-bedded Miliolite
Pleistocene
QUATERNARY
Limestone/Sandstones
Poorly consolidated sandstone with sub-angular,translucent quartz grains. Overlies white,rubbly weathering locally dolomitic limestone,occasional pebbles of beidelite
Miocene
Lower Fars Formation
Limestone,marl,shaly marl,thin,shale and gypsum layers, highly fossiliferous locally
TERTIARY
Boulder beds
Pebbles,cobbles and boulders principally of brown chert, gabbroic and ultrabasic rocks in a siliceous limestone matrix
?
Lakshaifa and Fukhaird beds
Limestones,mudstones and polygenetic grits and conglomerates, exposed locally below thrust plane and overlying Hawasina in Wadi Hagil
?
Limestone
White to buff,fine grained porous,nodular weathering, contains fragments of chert,basic and ultrabasic rocks
Upper Cretaceous
Maastrichtian Limestone
Brown,purplish gray and white fossiliferous limestone, locally with nodular varieties,limestone conglomerate and reef deposits Occasional chert bands and nodules,Minor interbeds of marl,mudstone and shale Local thick basal conglomerate in Jabal Al Fayah area
Musandam Group
Grey,massive to well bedded limestone,locally oolitic fossiliferous,dolomitic with chert nodules
Lower Jurassic to Lower Cretaceous
JURASSIC to CRETACEOUS
Elphinstone Group
Limestone,dolomitic limestone,dolomite,shale,marl,siltstone, sandstone,local chert and conglomerate (Tr)
Mid-permian to Triassic
Ruus Al Jibal Group
Dolomite,dolomitic and argillaceous limestone and occasional shale (Trp)
Ramaq Formation
Limestone,dolomite,sandstone,marl and local shales outcropping in Jabal Al Qumar Al Janubi (Rm)
PERMO-TRIASSIC
Rann quartzite Formation
Quartzitic sandstone and shale
Ordovician
Allochthonous units
Semail Opholite Sunite
Volcanics
Red greenish and amygdaloidal lavas with ? pillow structures
Upper Cretaceous to Pre-Permian
Sheeted diabase
Principally medium to fine grained diabase developed in swarms of sub-parallel,sub-vertical dykes
Gabbros
Coarse grained leucocratic and melanocratic varieties, commonly layered and with minor serpentinite zones, breccias,microgabbroic and pegmatitic types occur locally
Gabbros and ultrabasics
Complex zones of gabbro with intermixed ultrabasic rocks
Ultrabasics
Peridotit,serpentinized peridotite and serpentinite,locally banded. Magnesite and thin chrysotile veins widespread. Serpentinite generally highly fractured. Silicified alteration products(ch)hatched
Granite/granodiorite
Coarse to fine grained in minor intrusions,locally foliated
Hawasina Series
Metamorphics
Quartzite,quartz schist,quartz mica schist,chloritic schist, bands of brown,buff and white crystalline marble Local calc silicate rocks include amphibolite and epidote schist
Chert/limestone facies
Maroon and greenish gry chert commonly well bedded gray, brown and white limestone,occasional greenish gray and maroon shale,local volcanics (h) Larger areas of chert (hc)
Volcanics
Mainly dark green intermediate and basic lavas,vesicular, locally porphyritic and in places with pillow structures, agglomerate and ? tuff beds

S,S



Geological Member in the Study Area

STRATIGRAPHIC UNITS	FORMATION CORRELATED	LITHOLOGY	RESISTIVE LAYER CORRELATED
HOLOCENE	[Al]Superficial Deposite(Reccent alluvial gravel,sands and screen)	Gravel,Gravel with sand and silt, partly cemented	LAYER I (AVG.100 ohm-m)
PLEISTOCENE-NEOGENE	[UFa]Razzak Formation or Post-Upper Far (Cemented sand and gravel)	Clay hard Limestone,Marl, Gravel, Limestone Gravel and Sandy.	LAYER II (AVG.50 ohm-m)
PALEOGENE	[Uar/Qh/Far]Umm al Radhuma,Qahlah,Far Formation [Esh/Far]Eocene shale, Far Formation	Shale,Limestone, Marl,Sandstone, Dolomite,Magnesite.	LAYER III (AVG.<10 ohm-m)
MAASTRICHIAN to PRE-PERMIAN	[Os]Semail Ophiolite Sequence	Semail Ophiolite.	LAYER IV (AVG.20 ohm-m)
MAASTRICHIAN SENOMANIAN	[Jw]Juweiza Formation	[JwS]Limestone with Melange Serpentinite, [JwG]Gravely Facies, [JwM]Marly & Shaley Facies, [JwD]Dolomitic Facies.	

Figure 1.4.2 Stratigraphical Correlation to the Study Area

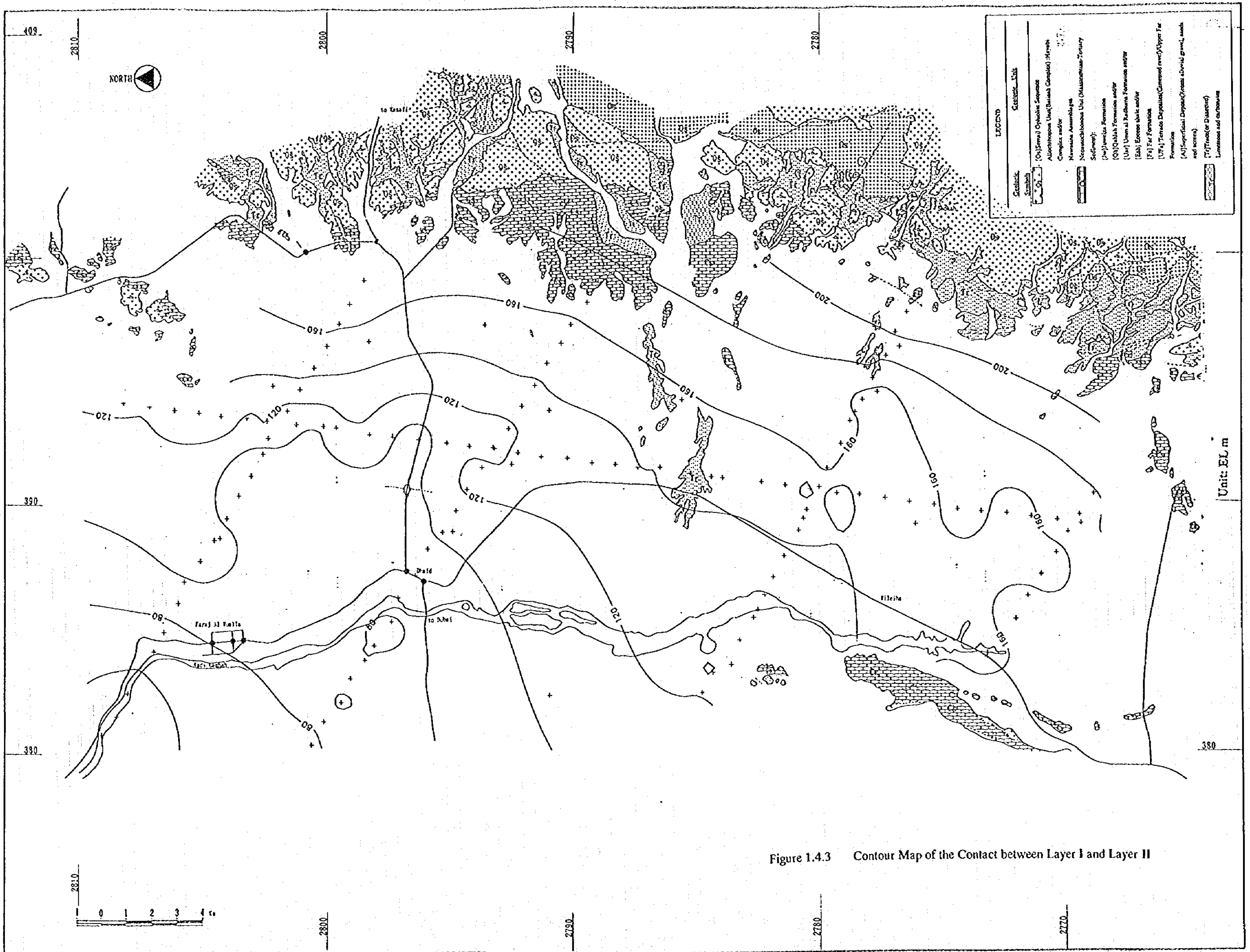


Figure 1.4.3 Contour Map of the Contact between Layer I and Layer II

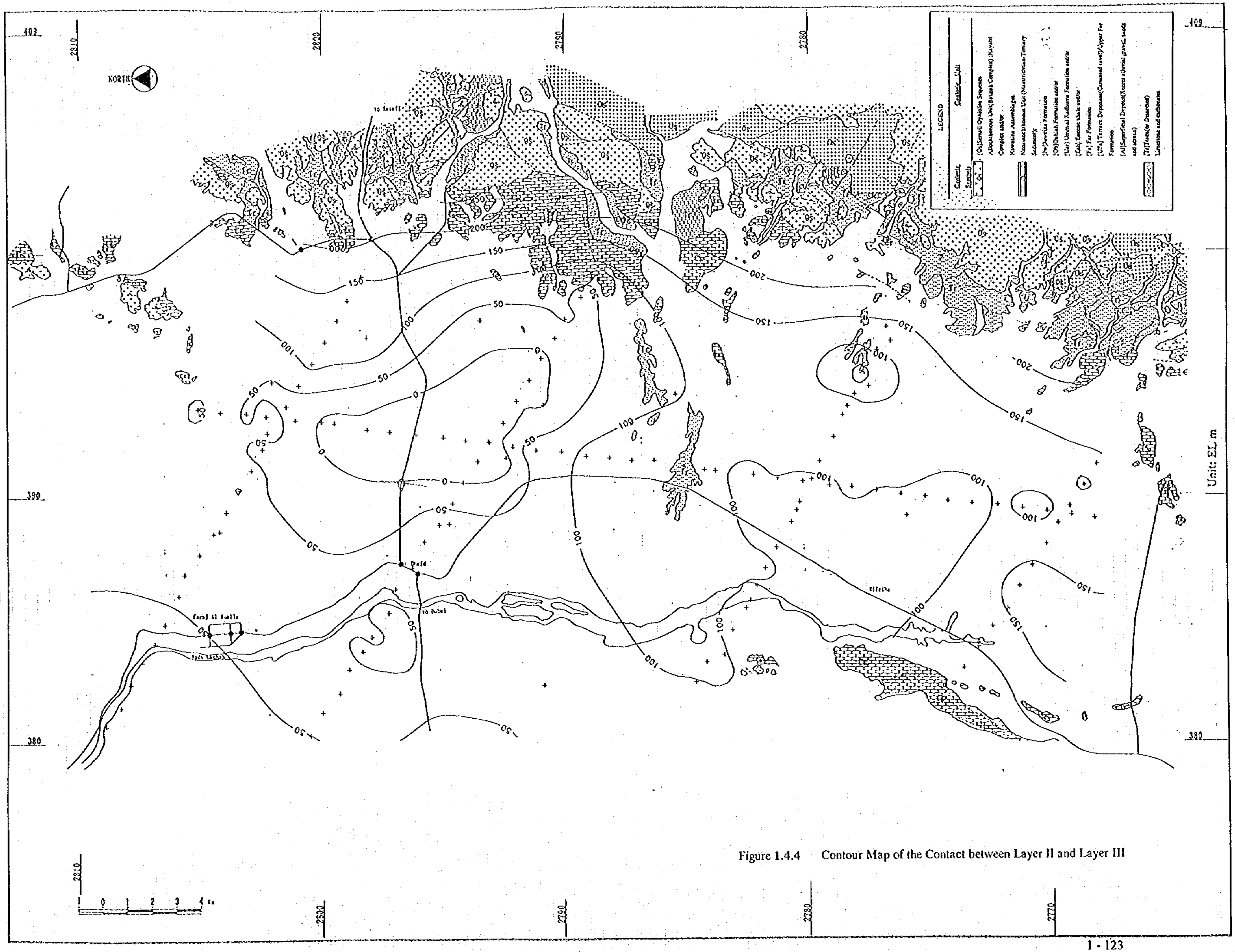


Figure 1.4.4 Contour Map of the Contact between Layer II and Layer III

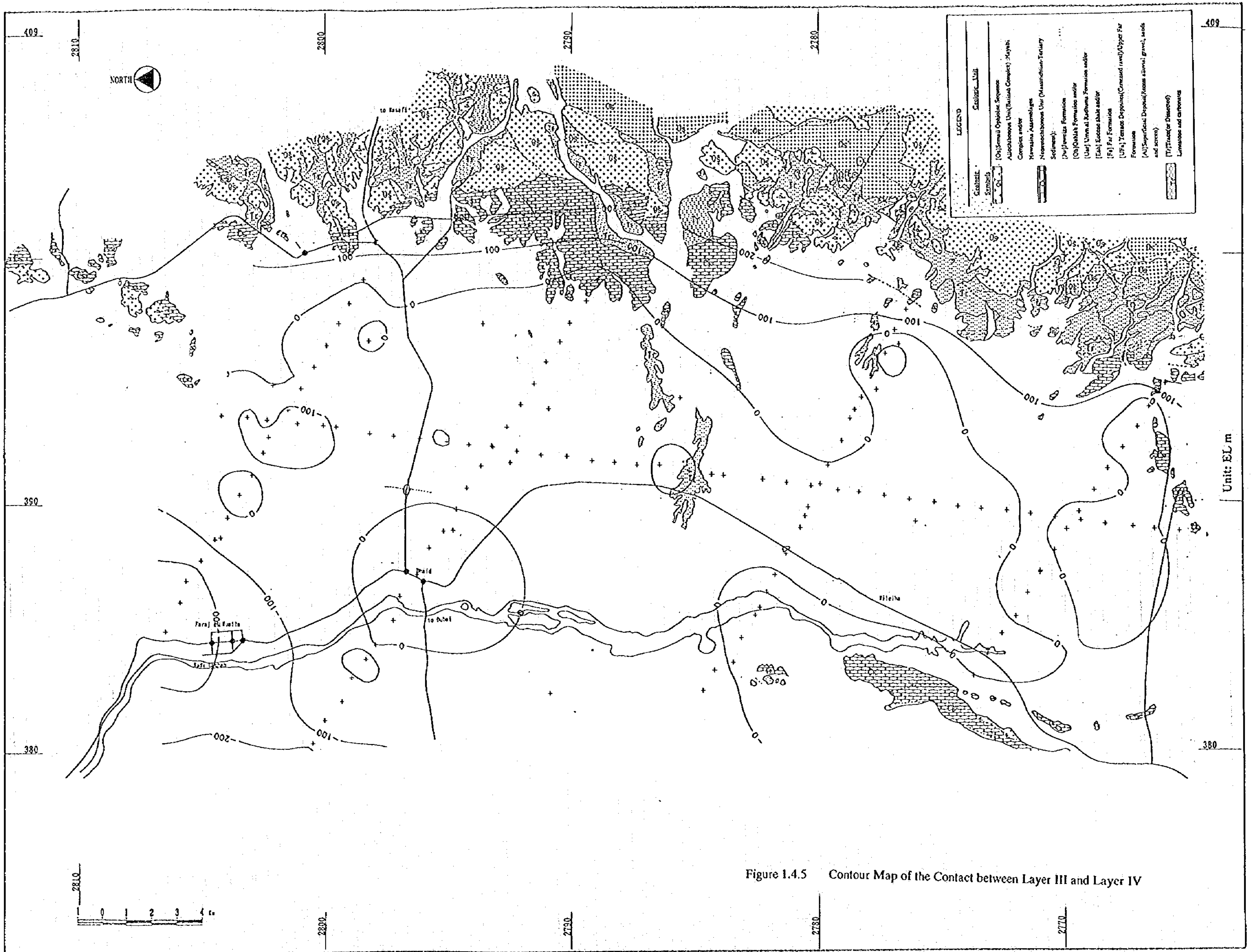


Figure 1.4.5 Contour Map of the Contact between Layer III and Layer IV

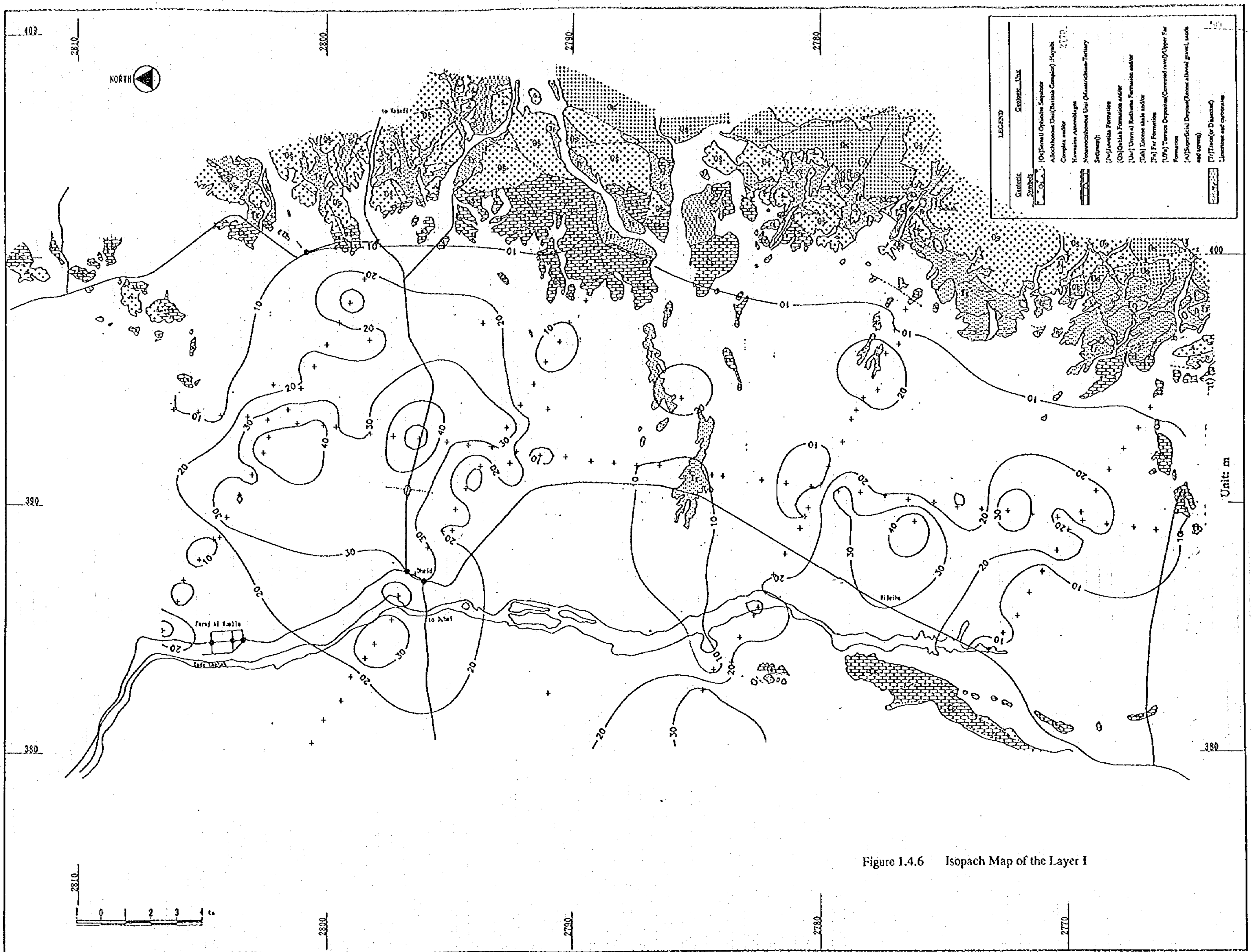


Figure 1.4.6 Isopach Map of the Layer I

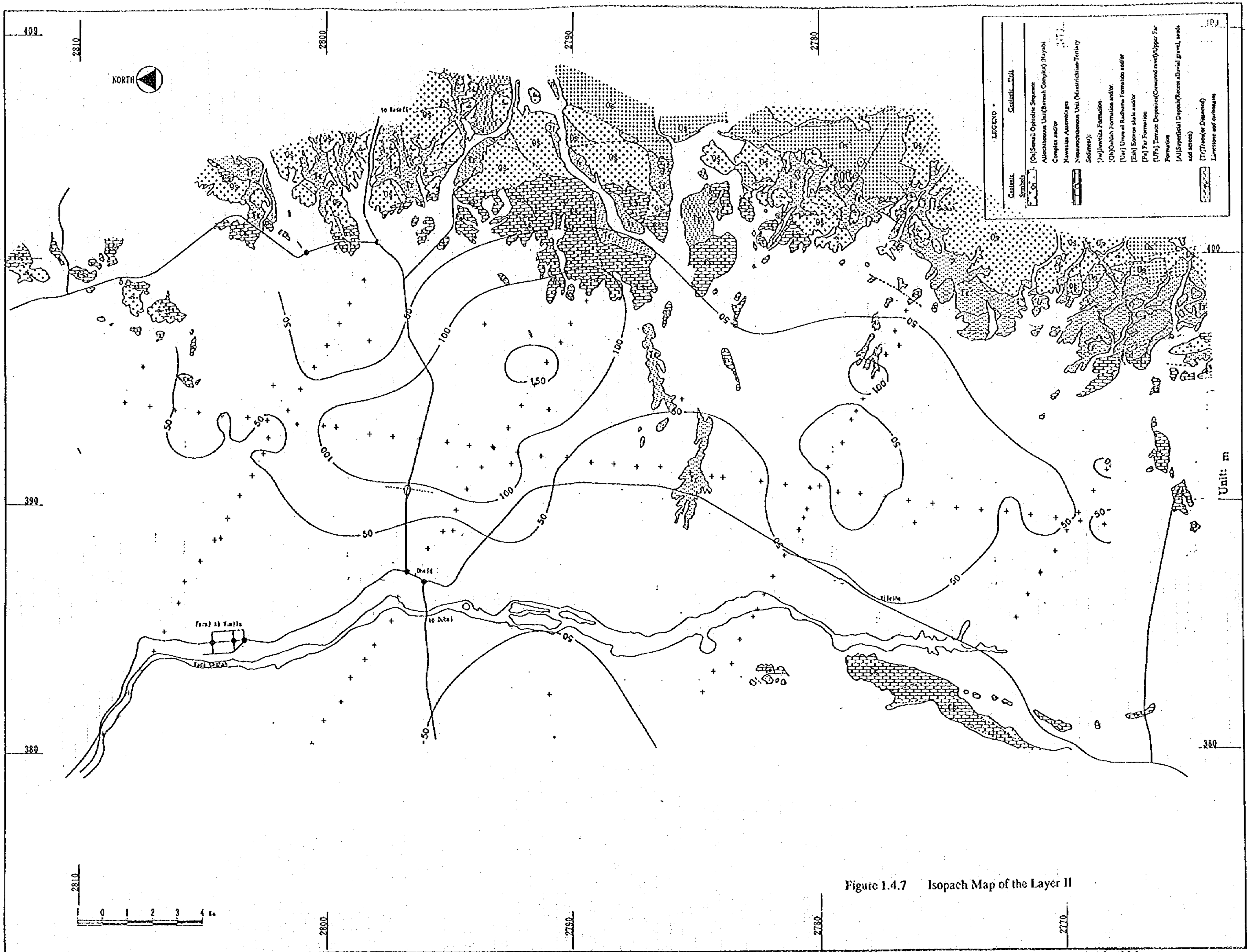


Figure 1.4.7 Isopach Map of the Layer II

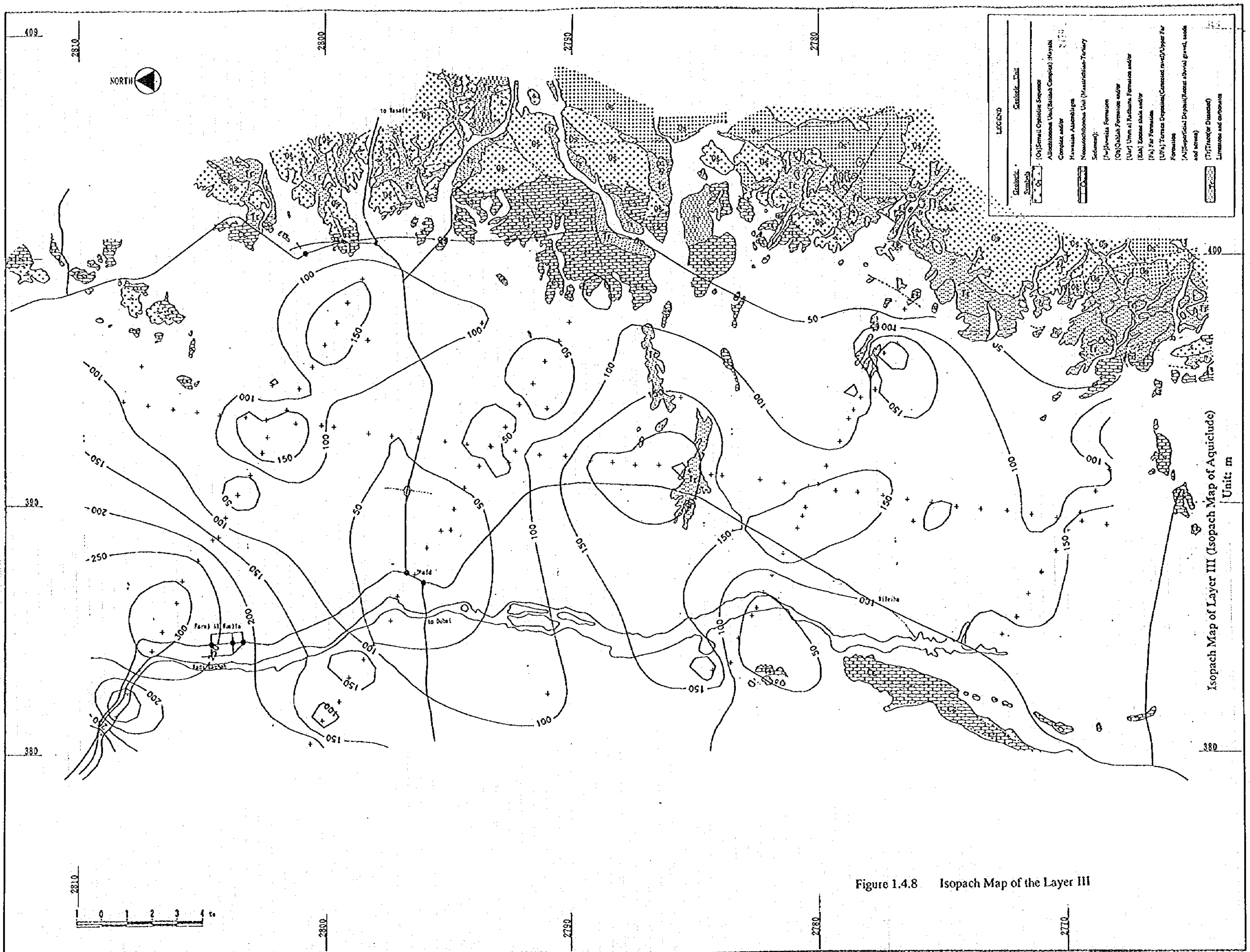
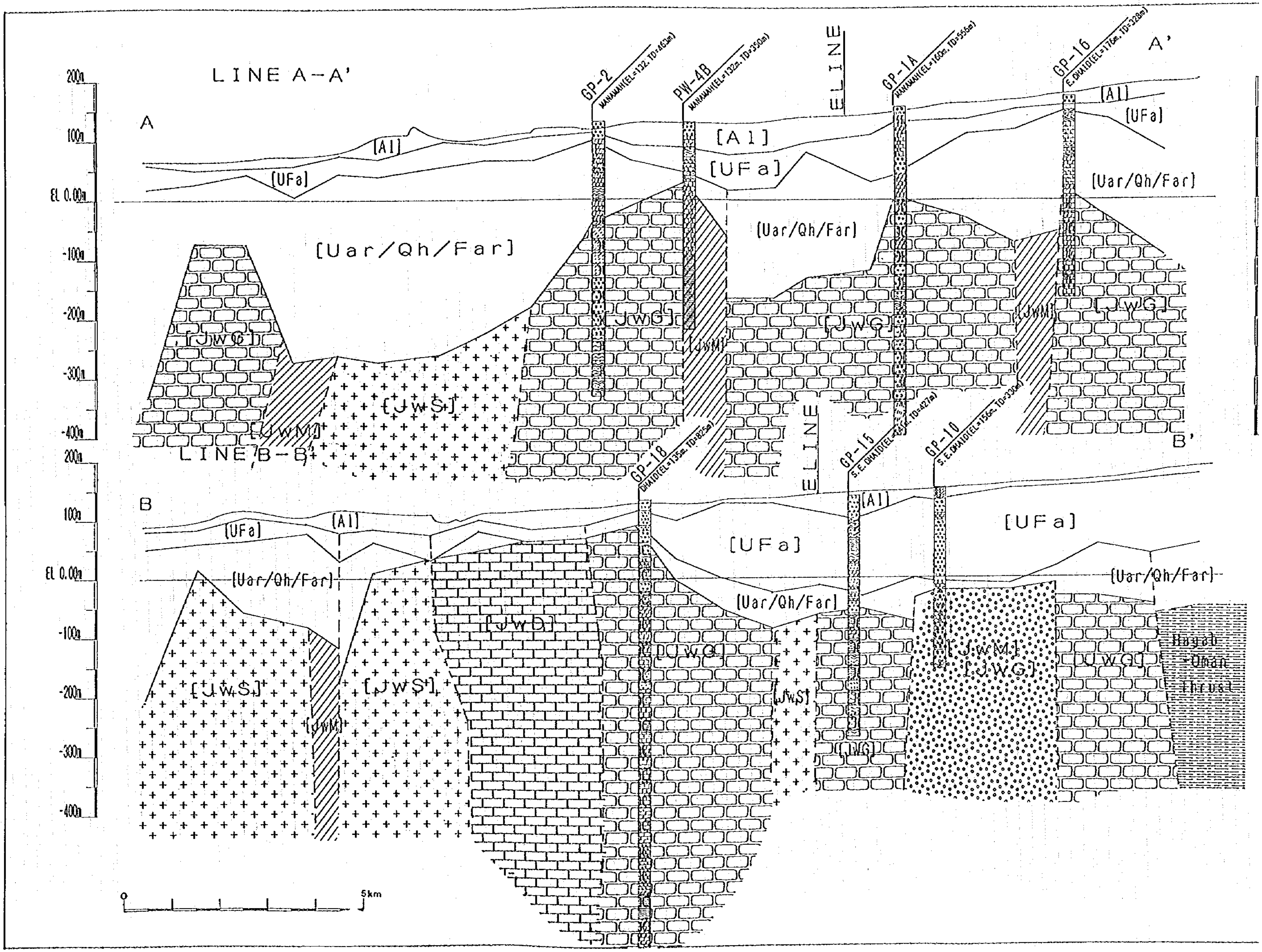


Figure 1.4.8 Isopach Map of the Layer III


LINE A-A'
A
A'
GP-2
MANAMAH(EL=132, TD=463m)
PW-4B
MANAMAH(EL=132m, TD=350m)
E LINE
GP-1A
MANAMAH(EL=160m, TD=556m)
GP-16
E.DHAID(EL=176m, TD=328m)
[Al]
[UFa]
[Uar/Qh/Far]
[JwG]
[JwM]
[JwS]
B'
LINE B-B'
B
GP-18
DHAID(EL=135m, TD=825m)
GP-15
S.E.DHAID
TD=427m)
GP-10
S.E.DHAID(EL=156m
[JwD]
[JwG]
[JwM]
[JwS]
Hayab
-Oman
Thrust
200m
100m
EL 0.00m
-100m
-200m
-300m
-400m
0
5km