3.2.3 Soil Survey

(1) Introduction

The soil survey was carried out in two stages (FIG.3.2.4). The objectives of each stage are as follows:

Stage I

1) To analyse the present soil condition in the study area (Dauka, Wadi Mokhawrim, Shasr, Hanfeet and Quitbeet; Total: 418,100 ha) and draw the soil classification map.
2) To classify the land suitability and draw the land suitability classification map in order to select a promising area for agriculture development and a site for pilot farm plan.

Stage II

1) To evaluate the soil condition for establishing a guideline for agricultural development.
2) To evaluate the soil condition of the pilot farm site selected in the stage I through a detailed soil survey.

(2) Soil Survey

1) Methods

Stage I

. Review of previous survey results

Auger boring survey was conducted to review the previous soil surveys (Harza 1985, GDC 1986). The surveys covered the following eight areas, which are described in FIG.3.2.4.

Dauka	South Shasr
East Dauka	Hanfeet
Wadi Mokhawrim	North Hanfeet
Shasr	Quitbeet

. Survey in the JICA study area (South Dauka 1 & 2)

Pit-excavation and auger boring survey were adopted in the area.

. Selection of field survey points

The points were selected based on the landform analysed with aerial photographs (1:60,000) and satellite imageries (1:250,000).

. Criteria of soil classification and land suitability classification

FAO standard was applied for the classifications similar to the previous studies.

Stage II

In the pilot farm site of 50 ha area, a detailed field survey was carried out by making pit excavation and auger boring survey on about 100 m grid basis (density of survey points: about 1 point/ha). Around the pilot farm site and in the existing farms, supplementary survey was carried out with pit excavation and auger boring.

Total number of survey points and samples are as follows;

Type	Study Area		Pilot Farm Site	
	Survey points	Samples	Survey points	Samples
Pit Excavation	11	28	6	20
Auger Boring	102	146	50	95

Type of analysis, number of samples and the method of analysis are shown in TABLE 3.2.3.

2) Results

a) Soil conditions of the Study Area

1 Soil Classification of the Study Area

Most of the soils in the study area occur on limestone and marl of Tertiary System. These soils are constituted of eolian and aqueous sediments of the weathered material of these rocks.

The shallow soil (about 30 cm depth) is dominant in the study area, while the deep soil (more than 100 cm depth) is distributed only in a small area of wadi, alluvial fan and toeslope.

The natural vegetation is also poor. Only at few scattered locations, shrubs (Acacia ehrenbergiana etc.), herbs (Zygophyllum coccineum, Heliotropium kotschyi etc.) and grasses (Stipagrostic plumosa etc.) can be seen.

The soils are characterized into the following items:

Physical

. High bulk density
. Weak development of the soil horizon and structure
. Slightly sandy texture (loamy sand to sandy loam, low clay content)
. Low organic matter content

Chemical

. High pH 1:2.5 (7.0 - 8.8, mean 8.2, number of samples: 54)
. Slightly high EC 1:5 (0.1 - 10.0 mS/cm mean 0.9 mS/cm, number of samples: 54)
. Low cation exchange capacity (1.0 - 9.0 me/100 g)
. Low nutrient content
. High calcium carbonate content (20 - 78%)

In general, there is a tendency that EC and gypsum contents are higher in the southern part of the study area than the northern part. This tendency may be caused by geological formation. Rus formation, which contents gypsum, is distributed in the southern part of the study area. (See ANNEX 4 Hydrogeological Map of the Central Nejd)
As a result of this study, 6 soil groups and 16 sub-groups can be classified in the study area.
Area of each soil group is as follows:

Soil Group (FAO)	Extent of the study area	
1. Fluvisols	46,075 ha	(11.0%)
2. Yermosols	330,707 ha	(79.1%)
3. Solonetz	1,580 ha	(0.4%)
4. Solonchaks	2,480 ha	(0.6%)
5. Regosols	4,480 ha	(1.1%)
6. Lithosols	32,778 ha	(7.8%)
Total	418,100 ha	(100.0%)

Yermosols is dominant in the study area.
The extent of sub-groups in each study area is shown in TABLE 3.2.5. Also the soil classification map is shown in FIG.3.2.5.

a. Fluvisols

Soils of wadi in the study area are classified as Calcaric Fluvisols because of high $CaCO_3$ content: they are distributed in wadi and in active fan position.

Generally, pH (1:2.5) is about 8.0, and EC (1:5) is slightly high (0.4 to 0.5 mS/cm).

Calcaric Fluvisols covers an area of 46,075 ha (11.0%). This type of soil can be further classified into 5 sub-groups according to soil depth and soil texture. The shallow soil type (JC-S) is dominant in the area.

	Type		Texture	Depth (cm)	Area (ha)	%	Land Suitability
Fluvisols	Deep 1	(Jc-dl)	fine SL - SCL	> 100	40	-	S1
	Deep 3	(Jc-d3)	gravelly coarse S	> 100	3,710	0.9	S3
	Deep 4	(Jc-d4)	gravelly S - LS	> 100	2,850	0.7	N1
	Moderate Deep 2	(Jc-md2)	gravelly SL	50 - 100	4,735	1.1	N2
	Shallow	(Jc-s)	gravelly S - LS	30	34,740	8.3	N2
	Total				46,075	11.0	

b. Yermosols

Yermosols covers an area of 330,707 ha (79.1%). Soil in the study area are classified as Calcic Yermosols and Gypsic Yermosols.

Calcic Yermosols is the most widespread soil in the study area, covering an area of 307,585 ha (73.6%). The average of pH (1:2.5) is approximately 8.0, and the range of EC (1:5) is from 0.1 mS/cm to 0.2 mS/cm. Soil texture is sandy loam. This type of soil is classified into 5 sub-groups according to soil depth and soil texture. The shallow soil type (Yc-s) is dominant.

Gypsic Yermosols is mainly distributed in the hills and terraces in the southern part of the study area (especially in Hanfeet). It covers an area of 23,122 ha (5.5%). The range of pH (1:2.5) is from 7.0 to 8.0. The EC (1:5) is high (from 4.0 mS/cm to 5.0 mS/cm). The color is reddish (5YR).
This soil is classified into 2 sub-groups according to soil depth and soil texture.

	Type		Texture	Depth (cm)	Area (ha)	%	Land Suitability
Calcic Yermosols	Deep 1	(Yc-d1)	SL - L	> 100	16,130	3.9	S2
	Deep 2	(Yc-d2)	gravelly LS	> 100	5,450	1.3	SC2
	Moderate Deep 1	(Yc-md1)	SL coarse S	50 > 100	2,950	0.7	S2
	Moderate Deep 2	(Yc-md2)	gravelly SL	50 - 100	19,700	4.7	S3
	Shallow	(Yc-s)	SL	30	263,355	63.0	N2
Gypsic Yermosols	Deep	(Yy-d)	L	> 100	2,465	0.6	S3
	Shallow	(Yy-s)	gravelly SL	30	20,657	4.9	N2
	Total				330,707	79.1	

c. Solonetz (So-d)

The ESP (Exchangeable Sodium Percentage) is more than 15% in the natric B horizon and the salinity content is high.
Orthic Solonelz, deep (So-d), which has an orthic A horizon, is identified in the study area.

This soil occurs on the old alluvial formation deposited in only Wadi Thumrait catchment in Hanfeet. It covers an area of 1,580 ha (0.4%). Soil depth is more than 100 cm, and soil texture is loam. The sodium content of this soil is high.
The soil is marginally suitable (S3) for irrigated agricultural development because of its high sodium content in the solum.

d. Solonchaks

Orthic Solonchaks, moderate deep (Zo-md), which has an orthic A horizon, is identified in the study area.
This soil is distributed in the gravel terraces along the old alluvium in Hanfeet. It covers an area of 2,480 ha (0.6%). Soil depth is from 50 cm to 100 cm, and soil texture is gravel.
This soil is permanently not suitable (N2) for irrigated agricultural development because of its high salinity.

e. Regosols

Calcaric Regosols, deep (Rc-d), which has a calcic horizon, is identified in the study area. This soil is distributed in eolian deposit, alluvial terrace and fan positions in Dauka and Shasr. It covers an area of 4,480 ha (1.1%). Soil depth is more than 100 cm. Soil texture is unconsolidated sand. The water-holding capacity is low. This soil is marginaly suitable (S3) for irrigated agricultural development because of its sandy texture.

f. Lithosols

Lithosols, very shallow (L-vs), is identified in the study area. The soil is distributed in eroded gravel terraces and hills in Dauka, East Dauka, South Dauka-1, Quitbeet, Hanfeet, and South Dauka-2. It covers an area of 32,778 ha (7.8%). This soil is permanently not suitable (N2) for irrigated agricultural development due to its very shallow soil depth.

2 Land Suitability Classification in the Study Area

Land suitability classification, based on the evaluation of land resource potential, should be applied for land use planning, choice of crops and planning of irrigation system.

The land suitability classification in the reports of Harza (1985) and GDC (1986) adapted on the FAO system ("A Framework for Land Evaluation", FAO, 1976) and therefore the same FAO system is adapted in this report.

The land suitability classification, adopted for the study, is for irrigated agriculture development (TABLE 3.2.6).

There are two orders (Order S: Suitable, Order N: Not Suitable) and six classes (Class S1: Highly Suitable, Class S2: Moderately Suitable, Class S3: Marginally Suitable, Class Sc2: Conditionally Suitable, Class N1: Currently Not Suitable, Class N2: Permanently Not Suitable).

In addition to this, there are six limitations (x: soil texture, k: $CaCO_3$, d: soil depth, t: landform, s: salinity and n: sodium), as subclasses, in the study area.

The result of the land suitability classification is shown in TABLE 3.2.4. The extent of land suitability classification is shown in TABLE 3.2.7. The land suitability classification map is shown in FIG.3.2.6.

Order		Class	Extent in the study area	
S: Suitable	S1 :	Highly Suitable	40 ha	(0.01%)
	S2 :	Moderately Suitable	18,865 ha	(4.5%)
	S3 :	Marginally Suitable	30,620 ha	(7.3%)
	SC2:	Conditionally Suitable	5,450 ha	(1.3%)
N: Not Suitable	N1 :	Currently Not Suitable	2,850 ha	(0.7%)
	N2 :	Permanently not Suitable	360,275 ha	(86.2%)
		Total	418,100 ha	(100.0%)

The unsuitable lands cover an area of 363,125 ha (about 87% of the study area), and the suitable lands cover 54,975 ha (about 13%) area.

Highly suitable lands of 'S1' class and moderately suitable lands of 'S2' class cover only an area of 18,905 ha (4.5%).

The area of Class S1 land and Class S2 land which require no special soil inoculation are the promising lands to be selected for agricultural development.

3 Soil Condition of the Existing Farms

There are four existing farms in the study area. Those are Dauka, Shasr, Hailat Al-Rakah, and Quitbeet. In these farms, supplemental soil surveys were carried out with pit excavations and auger borings in order to gain the knowledge of soil conditions of the existing farms.

From the result of land suitability classification, it is found that Shasr's soil is relatively good, which is followed by and Hailat Al-Rakah, Dauka and Quitbeet. The farms in Quitbeet cultivate crops under the bad soil condition.

In general, many of the existing farms were established without considering the soil condition.

Results of the field surveys are as follows:

a. Dauka (Since 1985, Cultivated area: about 18 ha)

Soil depth is limited by hard platy limestone located at 50 cm depth. In the old small local farm, the water table is located at 50 cm depth and strong salinization was observed on the surface of the farm. Also, soil profiles are so wet that the weed (pharagmites sp.) which grow in the wet swampy land, has started to grow at the center of the farm.

Land suitability of the soils is classified as S3dx class. Under such water conditions adequate drainage system is necessary for such farms. Also the suitable soil (S2 class) is widely distributed at a distance of about 3 km north-west of the existing farm. If that area can be given with suitable irrigation facility then it will be better to shift the existing farms to the new area.

b. Shasr (Since 1973, Cultivated area: about 7 ha)

The soils of the area in general, is characterized of deep soil depth. The depth from surface to impermiable layer (hard limestone) is more than 5 m and the potential of natural drainage is high. Therefore, this land classified into a moderate suitability (S2k) for irrigated agriculture development. The soil of this area is the best among the existing farms. And the soils have no big problem for agriculture development.

c. Hailat Al-Rakah (Since 1980, Cultivated area: about 70 ha)

In general the old farms have relatively deeper soil depth (S2k-S3dk) than the new farms. Some new farms in the southern part are located in very shallow soil (N2dk) with limestone and marl being encountered at 20cm to 40cm in depth. Also the quality of irrigation water is getting worse.
The suitable area for agricultural development is only marginal and therefore adequate guidance of soil and water conditions should be necessary for a new settler in this area.

d. Quitbeet (Since 1980, Cultivated area: about 0.1 ha)

There are very small local farms in wadi and toeslope. The soil has very gravelly sand texture. The soil depth is limited by rounded gravel and stone located at 30 cm in depth. Land suitability classification comes under N2xd class. The soil condition is bad. And also the suitable land is very small and marginal. There is no potential for agriculture development.

b) Soil Conditions of the Pilot Farm Site

1 Environment

The pilot farm site is located approximately 150 km north of Salalah and about 1.5 km west of the national highway. This area is in the tributary area of a wadi and approx. 270 m above sea level. This area includes 432 ha of suitable lands (Class S2: land suitability classification) that stretches in east-west direction. And an area of 50 ha was chosen as the pilot farm site. Natural vegetation is poor. Plants cover less than 1%. There are only few grasses (Stipagrostic plumosa) and shrubs (Fagonia sp. etc.).

2 Soils

Soil map of the pilot farm site is shown in FIG.3.2.7.

General characteristics of the soil in the pilot farm site are as follows:

* The soil developed on the well weathered old alluvium in a wadi land form.

* The main soil is classified as Calcic Yermosols deep 1 (Yc-dl) in FAO, Typic Calciorthids in USDA. Also land suitability classification comes under S2k.

* Major soil depth is more than 1.5 m, although very shallow soil or lithic phase (0 - 30 cm in depth) is distributed on some parts with area less than 2 ha.

* Hard limestone (impermeable layer) is found at about 4 - 5 m in depth according to the observation of the wells (NJD2, NJD3) and the profile of the hand dug well which is located at about 2 km north-west of the pilot farm site.

* The organic matter content is very low. The structure of subsoil is massive.

* Soil texture is sand (S) to sandy loam (SL) in surface or subsurface horizon and sandy loam (SL) to silty loam (SiL) in subsoil. The silt content increases with depth.

* Consistency of the surface soil is loose in dry and moist. The subsoil is hard to very hard in dry, but become very friable to friable in moist.

* Cracking are developed well within the soil profile.

* The roots are few, but can be observed up to 1.0 to 1.5 m in depth.

* The pH (1:2.5) is not so high.

* The pH values in the surface or subsurface horizon are relatively high in north and south side. There is the same tendency in the subsoil horizon.

horizon	mean of pH value	range
surface or subsurface (0 - 25 cm)	8.3	7.7 - 8.6
subsoil (60 - 90 cm)	8.2	7.7 - 8.7

(Results of the Auger Boring)

* The EC (1:5) is relatively high in subsoil.

The EC values in the subsoil horizon are higher in the south side than the north side. And the EC values in the surface or subsurface horizon is generally low.

horizon	mean of EC value	range
surface or subsurface (0 - 25 cm)	0.19 mS/cm	0.06 - 0.87 mS/cm
subsoil (60 - 90 cm)	0.79 mS/cm	0.09 - 2.55 mS/cm

(Results of the Auger Boring)

* There is an inverse correlation between the pH and the EC.

* The gypsum rich soils, which have slightly reddish color, occur in the south side and their EC values are also relatively high.

* The reaction to dilute HCl is violent, and the content of calcium carbonate is high.

* Drainage is good according to the result of our intake rate test in the site. Also the impermeable layer (hard limestone) is located at a depth of about 4 to 5 m and therefore, the natural drainage potential should be high.

* According to our observation of stones and gravels on the surface, there is no clear evidence of active flooding such as over-turned stones and gravels. In addition to that, surface drainage into the pilot farm site are small area 41.7 sq.km., isolated from the big wadi, and cut by the main road. So there happens rare floods and even if it happens, not in appreciable scale.

3) Problems and the Countermeasures for the Agricultural development

a) Study Area

* The study area is dominated by shallow depth of soil with few locations of deep soil depth. Agricultural development should be carried out in the area, which have the deep soil profile (more than 1.0 m) and high potential of natural drainage. Shallow profile soil area should be avoided. If an agricultural development will be carried out in the shallow profile soil area, where the soil depth is limited by impermeable layer such as hard limestone, poor drainage and salinization hazard will occur similar to the old farm in Dauka.

* The soils in the study area have the following limitations for agriculture development:

. Very low organic matter
. High bulk density
. Low cation exchange capacity
. Low available nutrient (nitrogen, phosphorus, etc.)
. High calcium carbonate

But if sufficient water both in quality and quantity is available, the land classified as S1 and S2 land suitability class have relatively high potential for agriculture development.

* Total area of S1 and S2 class is estimated as 18,905 ha based on the survey results of Harza (1985)and GDC (1986). But according to our survey, the actual area may be less than 18,905 ha and such tendency is remarkable in Harza survey area. This may be because of the reason that Harza had to carry out the survey in 1985 without the exact land form map (scale 1:100,000) which was published only in 1986. So detailed soil survey should be carried out to make a more detailed agricultural development plan in the study area.

* Many of the existing farms were established without considering the soil condition such as the farm at Dauka and new farm at Hailat Al-Rakah. Some farms are suffering from the salinization due to poor drainage. In order to obtain high yield from these areas, it is necessary to lead the existing farm to carry out agriculture with suitable soil condition and soil management. Information on soil condition and suitable soil management for the existing farm will be helpful for the new settler.

* In a good soil area, relatively good vegetations are observed. So after this, when a big development will be carried out in such a place, an assessment survey for the natural ecosystem should be carried out before the development. It is important for this country to conserve the natural vegetation and the wild life as natural heritage.

b) Pilot Farm Site

The soils of the pilot farm site are good in the study area. But the soils are immature in terms of soil development and have a number of problems for agriculture development. Furthermore there is too little rain and is too hot in summer for the plants to grow. The problems and countermeasures of the soil are as follows:

1. Physical

<u>Problems</u>

. High bulk density
. Very low organic matter
. At the initial stage of the irrigation (within 4 to 6 months) crust occurs on the soil surface resulting in damage for the crops in the undeveloped soil of desert area (PDO FARM Report 1988)

<u>Countermeasures</u>

. Physical problems can be improved to a certain extent through the application of organic matter. Cultivations should be minimum in order to restrain the decomposition of organic matter.
. Shallow cultivation and frequent irrigation will control the crust formation.
. It seems that temperate crop species are vulnerable to the crust and the tropical species, especially Graminae (grasses, sorghums and millets) are less affected (PDO FARM Report 1988).
. Since the crust adversely affects the crops in the early irrigation period, tropical Graminae crops such as Rhodes grass is suitable as the reclamation crop.

2. Chemical

<u>Problems</u>

. High pH of surface soil in the north and south side of the site

- Though the EC (1:5) of surface soil is not high (mean: 0.19 mS/cm), irrigation will cause salinization problem in the long term.
- Relatively high calcium carbonate
- Low cation exchange capacity
- Low available nutrient (nitrogen, phosphorus etc.)

Countermeasures

- There was clear correlation between poor crop growth and pH greater than 8.5 (PDO FARM Report 1988).
  In order to lower the pH value acidic fertilizers like gypsum, sulfur, or ammonium sulfate should be applied. Concerning the salts, surface EC (1:5) is partially high (more than 0.5 mS/cm) in the site. In the short term soil salinity, however, will not cause a big problem since the soil permeability is good and the natural drainage potential is high. Besides the salts can be leached out easily with irrigation. But in the long term salinization problem will occur. And an adequate drainage system is necessary in the future. The scale and beginning time of drainage should be determined through the monitoring soil survey in the site.

- Fertilizer application is required, especially nitrogen, which should be applied frequently in a small quantity due to lack of available nutrient and low cation exchange capacity (poor nutrient holding capacity).
  At PDO FARM, liquid fertilizer of urea is injected through the irrigation system. And the amount of fertilizer application is large, 2,000 kg/ha/yr of N and 500 kg/ha/yr of P.

- In case of high pH, the trace elements such as Zn, Cu, Mn, Fe and B will become unavailable and hence the study of these elements is required.

3. General suggestions for the soil management

. Most of the surfaces in the study area are stable in natural stage being protected by a lag gravel, and moderately hard surface crust. Once a stable crust is disturbed by cultivation and so on, the sand erosion hazard will be occured, leading to serious deflation of topsoils and clogging of machinery. This problem can be lessened by careful management of soil surfaces under irrigation, step by step cultivation with small area, making windbreak fence and planting windbreak trees.

. From the viewpoint of inoculation of the soil, perennial Graminae (ex. Rhodes grass) and Leguminous (ex. Alfalfa) can be recommended as reclamation crops for the following reasons.

Perennial Graminae (ex. Rhodes grass)

This species grow fast, and soon can cover a bare land widely. Therefore this plant is effective to reduce the wind erosion of soil surface. Physical and chemical improvement of root zone can be obtained by the root distribution.

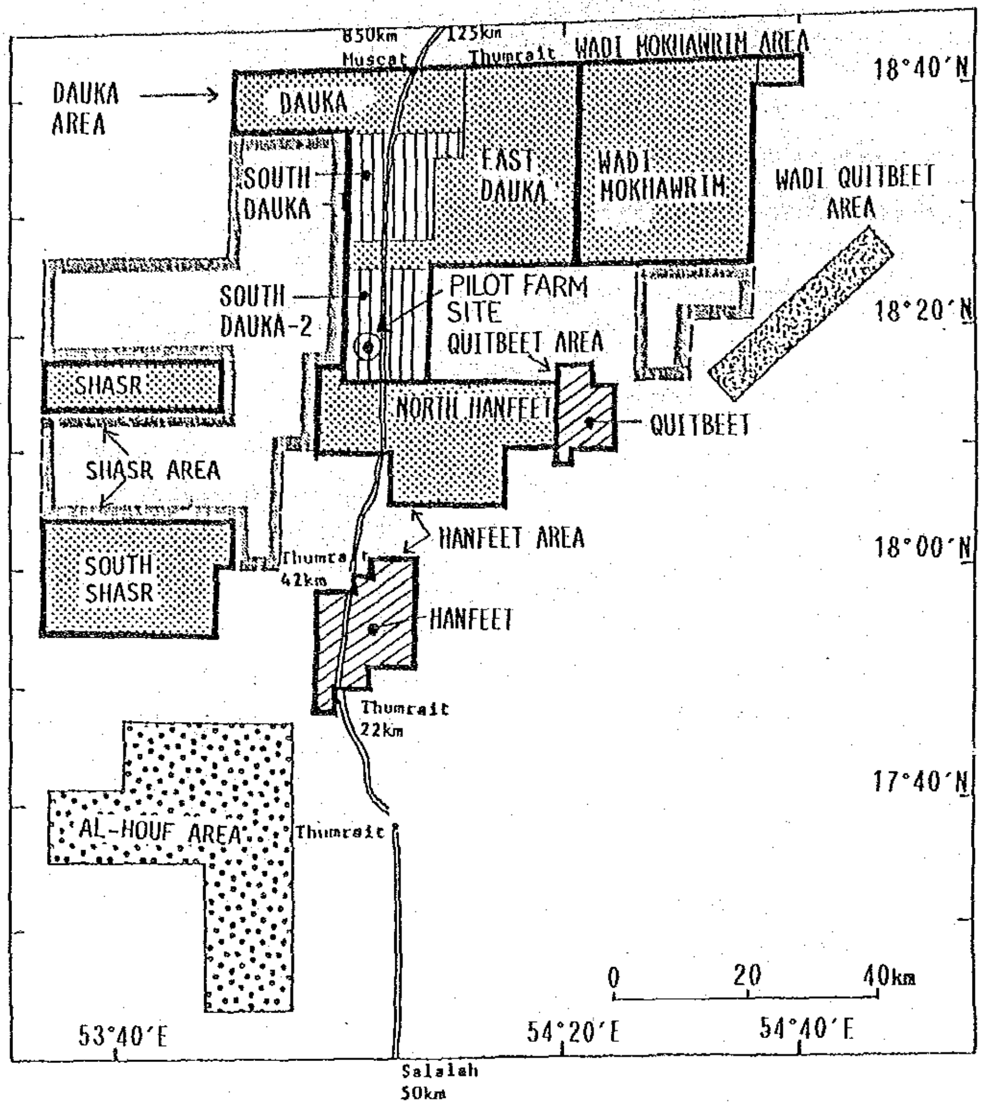
Leguminous (ex. Alfalfa)

It is useful as green manure for supply of organic matter and nitrogen fixation by its leguminous bacteria.

Rhodes grass and Alfalfa are suited for a desert area, because they have a high salt tolerance and a low water requirement.

. Since the site is an uncultivated desert area with few agricultural information, a monitoring research is necessary to grasp the relation between the soil condition and the yield, and to build up the technology of soil management.

FIG. 3. 2. 4 Location of Present and Previous Soil Survey Area



STUDY AREA

JICA SURVEY 1987

PREVIOUS STUDY

Groundwater Development Consultants Ltd(GDC) 1986
Preliminary soil survey of selected area around Hanfeet and Quitbeet in Nejd
Harza Engineering Company International.1985
Preliminary Soil and Groundwater Survey in Nejd

1:60.000 Soil Mapping

Reconnaissance study

Sir A.Gibb & Partners 1984
Preliminary Soil and Groundwater Survey

Ministry of Agriculture and Fisheries 1982
Soil Survey Reports on Wadi Muqshin,Wadi Quitbeet and Hanfeet,Nejd,Salalah Region.
Soil and Water Management Field Document No.6

TABLE 3.2.3 Soil Analysis Methods

Type of Analysis	Method	No. of Samples
Bulk density, oven dry	By using core Sample of 100cc	48
Distribution of three phases	Be calculated(∵ Soil 2.65g/cc)	48
Particle size analysis	gravel >2000 microns coarse sand 200 ~2000 microns fine sand 20~ 200 microns silt 2~ 20 microns clay < 2 microns	48
Texture	International system	48
Water paste saturation %	Volume of water added to soil at saturation	48
Calcium Carbonate ($CaCO_3$) %	By gravimetric loss of CO_2	48
Gypsum %	By increase in soluble Ca + Mg	48
Available Phosphorus (P) PPM	Colorimetric determination	48
pH(1:2.5)	1:2.5 Soil suspention	289
EC(1:5) mS/cm	1:5 Soil water extract	289
Total soluble salts (TTS) %	Be calculated (EC × 0.32)	48
Exchangeable cations (Ca, Mg, K, Na)	Ammonium acetate at pH 7.0	48
Cation exchange capacity (CEC)	Sodium acetate at pH 8.2	48
Exchangeable sodium percentage (ESP) %	Be calculated (Ex.Na/CEC × 100)	48
Soluble cations	By Flame photometry (K, Na) Titration with Versenate (Ca, Mg)	48
Soluble anions	Acid titration (HCO_3) Silver-nitrate titration (Cl) Precipitation as barium sulphate (SO_4)	48
Sodium adsorption ratio (SAR)	Be calculated $(Na^{+} \times [0.5(Ca^{2+}+Mg^{2+})]^{-0.5})$	48
Base saturation %	Be calculated (total Ex-cations/CEC×100)	48
Total nitrogen (N)	Semi-micro method	48
Organic matter	Walkley Method	48

The analyses were carried out by Soil and Water Laboratory-Salalah, MAF

TABLE 3.2.4 Soil Classification and Land Suitability Classification

Soil group FAO (1974)	Sup-group	Map code		Landform 1/	Soil Depth cm	Texture	Drainage	pH(1:2.5)	Land Suitability Unit 3/	Extent 4/ ha (%)
Fluvisols	Calcaric Fluvisols, deep 1	1	$Jc-d_1$	AT	> 100	Fine SL ~SCL	well	2/ 8.0	S1	40 (0.01)
	Calcaric Fluvisols, deep 2	2	$Jc-d_2$ 5/	W	> 100	gravelly LS~SL	well	8.0~8.5	S2k, S2xe	0 (0.0)
	Calcaric Fluvisols, deep 3	3	$Jc-d_3$	W	> 100	gravelly coarse S	Excessively drain	8.0~9.0	S3x	3,710 (0.9)
	Calcaric Fluvisols, deep 4	4	$Jc-d_4$	AF	> 100	gravelly S~LS	well	8.0	N1x	2,850 (0.7)
	Calcaric Fluvisols, moderate deep 1	5	$Jc-md_1$ 5/	W	50~100	SL	well	8.5	S3kd	0 (0.0)
	Calcaric Fluvisols, moderate deep 2	6	$Jc-md_2$	W-AF	50~100	gravelly SL	well	8.0	N2x	4,735 (1.1)
	Calcaric Fluvisols, shallow	7	Jc-s	W-AF	30	gravelly S~LS	well	8.0	N2xd	34,740 (8.3)
										46,075 (11.0)
Yermosols	Calcic Yermosols, deep 1	8	$Yc-d_1$	FA-W	> 100	SL~L	well	8.0	S2k	16,130 (3.9)
	Calcic Yermosols, deep 2	9	$Yc-d_2$	FA	> 100	gravelly LS	Excessively drain	8.0	Sc2x	5,450 (1.3)
	Calcic Yermosols, moderate deep 1	10	$Yc-md_1$	FM	50~100	SL	well	8.0	S2kd	2,950 (0.7)
	Calcic Yermosols, moderate deep 2	11	$Yc-md_2$	FR	50~100	gravelly SL	well	8.0	S3xd	19,700 (4.7)
	Calcic Yermosols, shallow	12	Yc-s	FA	15~30	SL	well	8.0	N2d	263,355 (63.0)
	Gypsic Yermosols, deep	13	Yy-d	AF	> 100	L	moderate well	8.0	S3s	2,465 (0.6)
	Gypsic Yermosols, shallow	14	Yy-s	ET	20~30	gravelly SL	well	8.0	N2xdt	20,657 (4.9)
										330,707 (79.1)
Solonetz	Orthic Solonetz, deep	15	So-d	FA	> 100	L	imperfect	8.0	S3h	1,580 (0.4)
Solonchaks	Orthic Solonchak, moderate deep	16	Zo-md	D	50~100	gravelly SL	moderate well	8.0	N2xdts	2,480 (0.6)
Regosols	Calcaric Regosols, deep	17	Rc-d	RAT	> 100	fine LS	Excessively drain	7.5 ~ 8.0	S3x	4,480 (1.1)
Lithosols	Lithosols, very shallow	18	L-vs	ET	< 10	SL	well	—	N2xd	32,778 (7.8)
										418,100 (100)

1/ Landform
- ET : Eroded gravel terraces and hills
- RAT: Recent alluvial terrace, outwashfan, eolian deposits
- AT : Alluvial toeslope
- AF : Alluvial fan
- FA : Flat plain on old alluvium
- FM : Flat plain on weathered marl
- FR : Flat plain on hard rock
- D : Degraded gravel terrace on bedrock plain
- W : Wadi

2/ pH paste

3/ S 3 x (See TABLE 3.2.6)
- S — Order
- 3 — Class
- x — Sub-class Limitation

4/ In case of complex soil units (ex. $Jc-md_2$ /Jc-s), the extent is calculated with even in each soil unit as follows; divide equally

$Jc-md_2$ /Jc-s 100ha → $Jc-md_2$ 50ha, Jc-s 50ha

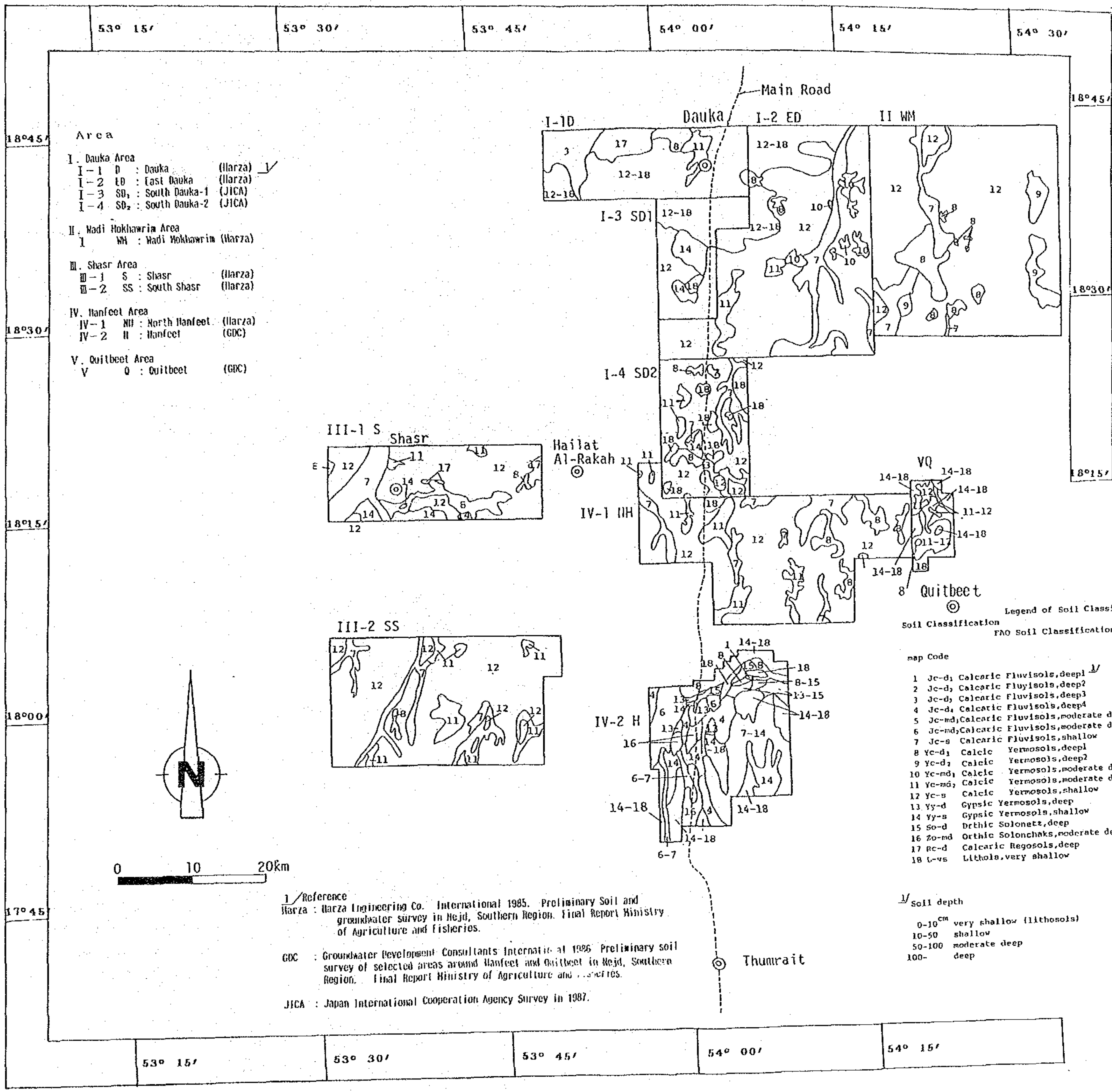
5/ $Jc-d_2$ and $Jc-md_1$ occur outside the study area.

TABLE 3. 2. 5 Extent of the Soil Classification Unit

Map Code	Soil code	Soil classification	Land suitability classification	DAUKA AREA: DAUKA ha	%	EAST DAUKA ha	%	SOUTH DAUKA 1 ha	%	SOUTH DAUKA 2 ha	%	WADI MOKHAWRIM AREA: WADI MOKHAWRIM ha	%	SHASR AREA: SHASR ha	%	SOUTH SHASR ha	%	HANFEET AREA: NORTH HANFEET ha	%	HANFEET ha	%	QUITBEET AREA: QUITBEET ha	%	Total ha	%
1	Jc-d1	Calcaric Fluvisols,deep 1	S1																	40	0.1			40	0.01
2	Jc-d2	Calcaric Fluvisols,deep 2	S2																					0	0.0
3	Jc-d3	Calcaric Fluvisols,deep 3	S3	3560	12.0					150	0.7													3710	0.9
4	Jc-d4	Calcaric Fluvisols,deep 4	N1																	2850	7.1			2850	0.7
5	Jc-md1	Calcaric Fluvisols,moderate deep 1	S3																					0	0.0
6	Jc-md2	Calcaric Fluvisols,moderate deep 2	N2																	4020	10.1			4020	1.0
7	Jc-s	Calcaric Fluvisols,shallow	N2			6850	9.1	330	2.0	2270	10.0	5610	6.7	3600	13.3	3640	6.3	8050	14.7					30350	7.3
8	Yc-d1	Calcic Yermosols,deep 1	S2	1430	4.8	820	1.1			620	2.7	5180	6.2	4180	15.5	150	0.3	2810	5.1	585	1.5	140	1.4	15915	2.6
9	Yc-d2	Calcic Yermosols,deep 2	Sc2									5450	6.5											5450	1.3
10	Yc-md1	Calcic Yermosols,moderate deep 1	S2			2640	3.5					310	0.4											2950	0.7
11	Yc-md2	Calcic Yermosols,moderate deep 2	S3	1120	3.8	2930	3.9			840	3.7			560	2.1	6460	11.1	5840	10.7			420	4.2	18170	4.3
12	Yc-s	Calcic Yermosols,shallow	N2	240	0.8	52300	69.5	6100	36.7	14430	63.3	57450	80.3	15600	57.8	47950	82.4	37900	69.4			1260	12.6	243230	58.2
13	Yy-d	Gypsic Yermosols,deep	S3																	1820	4.6			1820	0.4
14	Yy-s	Gypsic Yermosols,shallow	N2					1540	9.3	470	2.1			2480	9.2					5360	13.4			9850	2.4
15	So-d	Orthic Solonetz,deep	S3																	720	1.8			720	0.2
16	Zo-md	Orthic Solonchaks,moderate deep	N2																	2480	6.2			2480	0.6
17	Rc-d	Calcaric Regosols,deep	S3	3900	13.2									580	2.2									4480	1.1
18	L-vs	Lithosols,very shallow	N2					550	3.3	4020	17.6									390	1.0	2090	20.9	7050	1.7
6- 7	Jc-md2 /Jc-s	Calcaric Fluvisols,moderate deep 2 /Calcaric Fluvisols,shallow	N2																	1430	3.6			1430	0.3
7-14	Jc-s /Yy-s	Calcaric Fluvisols,shallow /Gypsic Yermosols,shallow	N2																	7350	18.4			7350	1.8
8-15	Yc-d1 /So-d	Calcic Yermosols,deep 1 /Orthic Solonetz,deep	S3																	430	1.1			430	0.1
11-12	Yc-md2 /Yc-s	Calcic Yermosols,moderate deep 2 /Calcic Yermosols,shallow	N2																			3060	30.6	3060	0.7
12-18	Yc-s /L-vs	Calcic Yermosols,shallow /Lithosols,very shallow	N2	19350	65.4	9760	90.4	8080	48.7															37190	8.9
13-15	Yy-d /So-d	Gypsic Yermosols,deep /Orthic Solonetz,deep	S3																	1290	3.2			1290	0.3
14-18	Yy-s /L-vs	Gypsic Yermosols,shallow /Lithosols,very shallow	N2																	11235	28.1	3030	30.3	14265	3.4
		Total		29600	100	75300	100	16600	100	22800	100	84000	100	27000	100	58200	100	54600	100	40000	100	10000	100	418100	100

(modification of Harza-1985, and GDC-1986)
Jc-d2 and Jc-md1 occur outside of the study area

FIG. 3. 2. 5
Soil Classification Map



Legend of Soil Classification

Soil Classification map Code		FAO Soil Classification	Soil Characterisitics
1	Jc-d₁	Calcaric Fluvisols,deep1 1/	deep loamy calcarious soil on AT 2/
2	Jc-d₂	Calcaric Fluvisols,deep2	deep sandy to loamy calcarious soil in W
3	Jc-d₃	Calcaric Fluvisols,deep3	deep gravelly coarse sandy calcarious soil in W
4	Jc-d₄	Calcaric Fluvisols,deep4	gravelly surface over old gravelly calcarious alluvium soil on AF
5	Jc-md₁	Calcaric Fluvisols,moderate deep1	moderate deep loamy calcarious soil in W
6	Jc-md₂	Calcaric Fluvisols,moderate deep2	moderate deep gravelly to loamy calcarious soil in W anf on AF
7	Jc-s	Calcaric Fluvisols,shallow	shallow gravelly sandy calcarious soil in wadi and on AF
8	Yc-d₁	Calcic Yermosols,deep1	deep sandy to loamy calcarious soil on FP
9	Yc-d₂	Calcic Yermosols,deep2	deep gravelly sandy calcarious soil on FP
10	Yc-md₁	Calcic Yermosols,moderate deep1	moderate deep loamy calcarious soil to weathered marl of FP
11	Yc-md₂	Calcic Yermosols,moderate deep2	moderate deep gravelly to loamy calcarious soil on weathered rock of FP
12	Yc-s	Calcic Yermosols,shallow	shallow loamy calcarious soil on weathered rock of FP
13	Yy-d	Gypsic Yermosols,deep	deep gypsic loamy calcarious soil on AF
14	Yy-s	Gypsic Yermosols,shallow	shallow gypsic gravelly loamy calcarious soil on ET
15	So-d	Orthic Solonetz,deep	deep loamy high alkali soil with natric B horizon on FT and in W
16	Zo-md	Orthic Solonchaks,moderate deep	moderate deep gravelly loamy high salinity soil on UP
17	Rc-d	Calcaric Regosols,deep	deep very young undeveloped calcarious soil on RAT
18	L-vs	Lithols,very shallow	very shallow loamy soil over lithic bedrock on ET

1/ Soil depth

0-10cm	very shallow (lithosols)
10-50	shallow
50-100	moderate deep
100-	deep

2/ Land form

AT : alluvial toeslope
W : wadi
AF : alluvial fan
EP : flat plain of old alluvium over weathered limestone
ET : eroded gravel terraces and hills
FT : flat terrain of old alluvial fan
UP : undulating gravel terraces on bedrock plain
RAT: recent alluvial terraces, outwash fans and deep eolian deposits

TABLE 3.2.6 Land Suitability Orders and Classes

Order	
S Suitable	: Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs without unacceptable risk of damage to land resources.
Class	
S1 Highly Suitable	: Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
S2 Moderately Suitable	: Land having limitations which in aggregate are moderately severe for sustained application of agiven use;the limitations will reduce roductivity or benefits and increase required inputs to extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to Class S1 land.
S3 Marginally Suitable	: Land having limitations which in aggregate are too severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs that this expenditure will be only marginally justified.
Sc2Conditionally Suitable	: Land having a conditional suitability for agriculture or they are limited to a special agriculture use.
Order	
N Not Suitable	: Land which has qualities that appear to preclude sustained use of the kind under consideration.
Class	
N1 Currently Not Suitable	: Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost;thelimitations are so severe as to preclude successful sustained use of the land in the given manner.
N2 Permanently Not Suitable	: Land having limitations which appear so severe as to preclude any possibilities of sustained use of the land in the given manner. FAO(1976)

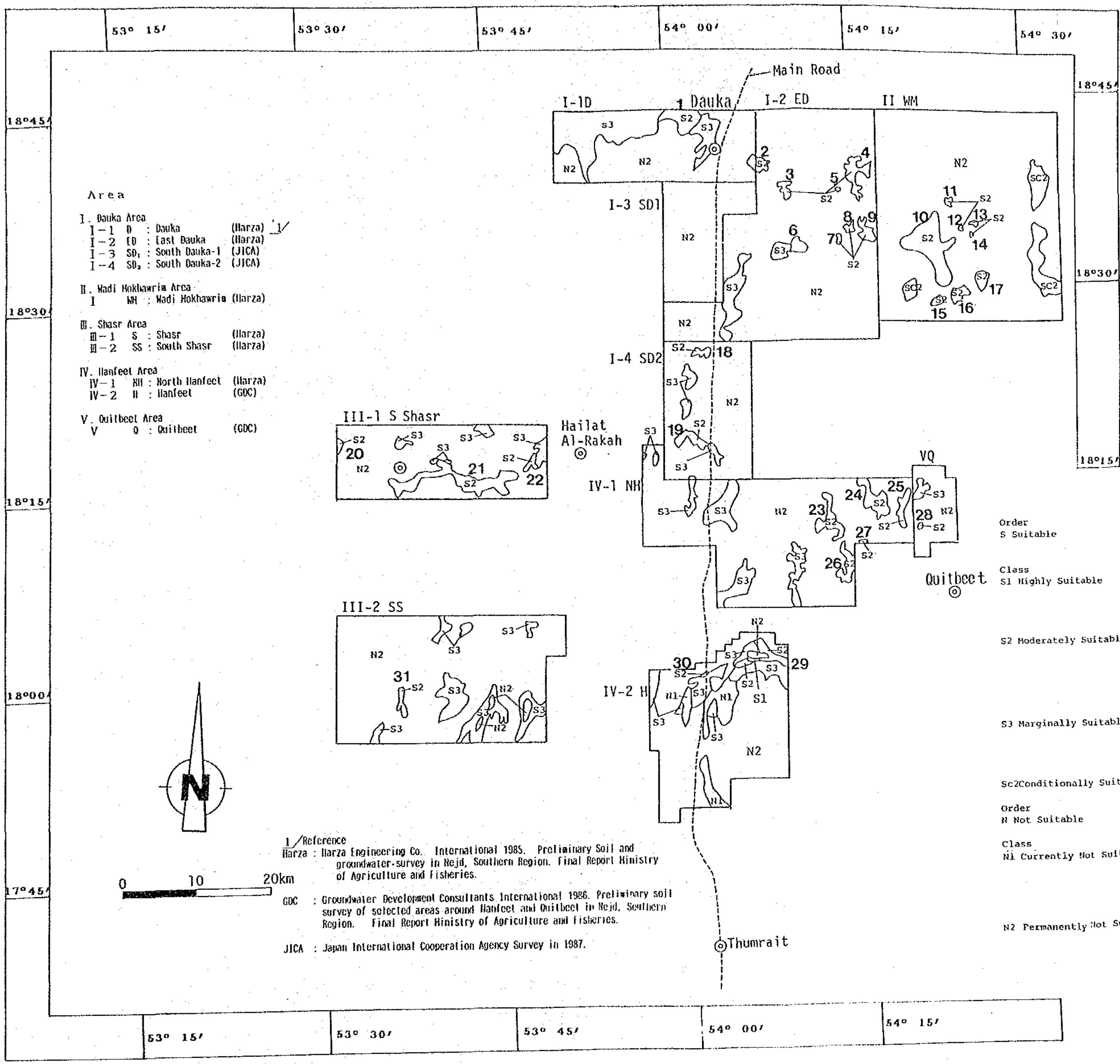
Sub-Class Limitation
x : coarse textures in the root zone, and associated low fertility
k : high calcium carbonate
d : effective depth of the soil limited by bedrock or very gravelly substrate
t : topographic limitation of sloping land on bedrock landforms and terraces
s : high salinity in part of the profile
n : high exchangeable sodium percentage in part of the profile GDC(1986)

TABLE 3. 2. 7 Extent of Land Suitability Classification

Order	Class	DAUKA AREA				WADI MOKHAWRIM AREA	SHASR AREA		HANFEET AREA		QUITBEET AREA	TOTAL
		DAUKA	EAST DAUKA	SOUTH DAUKA -1	SOUTH DAUKA -2	WADI MOKHAWRIM	SHASR	SOUTH SHASR	NORTH HANFEET	HANFEET	QUITBEET	
S	S1	–	–	–	–	–	–	–	–	40 (0.01)	–	40 (0.01)
	S2	1.430 (4.8)	3.460 (4.6)	–	620 (2.7)	5.490 (6.5)	4.180(15.5)	150 (0.2)	2.810 (5.1)	585 (1.5)	140 (1.4)	18.885 (4.5)
	S3	8.580(29.0)	2.930 (3.9)	–	990 (4.3)	–	1.140 (4.2)	6.460(11.1)	5.840(10.7)	4.260(10.7)	420 (4.2)	30.620 (7.3)
	Sc2	–	–	–	–	5.450 (6.5)	–	–	–	–	–	5.450 (1.3)
Sub Total		10.010(33.8)	6.390 (8.5)	–	1.610 (7.1)	10.940(13.0)	5.320(19.7)	6.610(11.4)	8.650(15.8)	4.885(12.3)	560 (5.6)	54.975(13.1)
N	N1	–	–	–	–	–	–	–	–	2.850 (7.1)	–	2.850 (0.7)
	N2	19.590(66.2)	68.910(91.5)	16.600 (100)	21.190(92.9)	73.060(87.0)	21.680(80.3)	51.590(88.6)	45.950(84.2)	32.265(80.6)	9.440(94.4)	360.275(86.2)
Sub Total		19.590(66.2)	68.910(91.5)	16.600 (100)	21.190(92.9)	73.060(87.0)	21.680(80.3)	51.590(88.6)	45.950(84.2)	35.115(87.7)	9.440(94.4)	363.125(86.9)
Total		29.600 (100)	75.300 (100)	16.600 (100)	22.800 (100)	84.000 (100)	27.000 (100)	58.200 (100)	54.600 (100)	40.000 (100)	10.000 (100)	418.000 (100)

(Modification of Harza-1985. and GDC-1986)

FIG. 3. 2. 6
Land Suitability Classification Map



1/Reference
Harza : Harza Engineering Co. International 1985. Preliminary Soil and groundwater-survey in Nejd, Southern Region. Final Report Ministry of Agriculture and Fisheries.

GDC : Groundwater Development Consultants International 1986. Preliminary soil survey of selected areas around Hanfeet and Quitbeet in Nejd, Southern Region. Final Report Ministry of Agriculture and Fisheries.

JICA : Japan International Cooperation Agency Survey in 1987.

S_1, S_2 Class Area

No.	Area (ha)		No.	Area (ha)	
1	1330	D 1330	18	190	SD_2 620
2	570[1]	ED 3560	19	430	
3	350		20	250	S 4180
4	1010		21	3830	
5	30		22	100	
6	120		23	820	NH 2810
7	290		24	1260	
8	180		25	250	
9	1010		26	430	
10	3720	WH 5490	27	50	
11	100		28	140	Q 140
12	90		29	540	H 620
13	80		30	80	
14	40		31	150	SS 150
15	240				
16	480		Total	18,900 ha	
17	740				

1/100ha of 570ha belongs to Dauka

Legend of land suitability classification

LAND SUITABILITY ORDERS AND CLASSES

Order
S Suitable : Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs without unacceptable risk of damage to land resources.

Class
S1 Highly Suitable : Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.

S2 Moderately Suitable : Land having limitations which in aggregate are moderately sever for sustained application of a given use; the limitations will reduce roductivity or benefits and increase required inputs to extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to Class S1 land.

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Sc2 Conditionally Suitable : Land having a conditional suitability for agriculture or they are limited to a special agriculture use.

Order
N Not Suitable : Land which has qualities that appear to preclude sustained use of the kind under consideration.

Class
N1 Currently Not Suitable : Land having limitations which may be surmountable in time but which cannot be corrected with exisiting knowledge at currently acceptable cost; thelimitations are so severe as to preclude successful sustained use of the land in the given manner.

N2 Permanently Not Suitable : Land having limitations which appear so severe as to preclude any posibilities of sustained use of the land in the given manner.

FAO(1976)

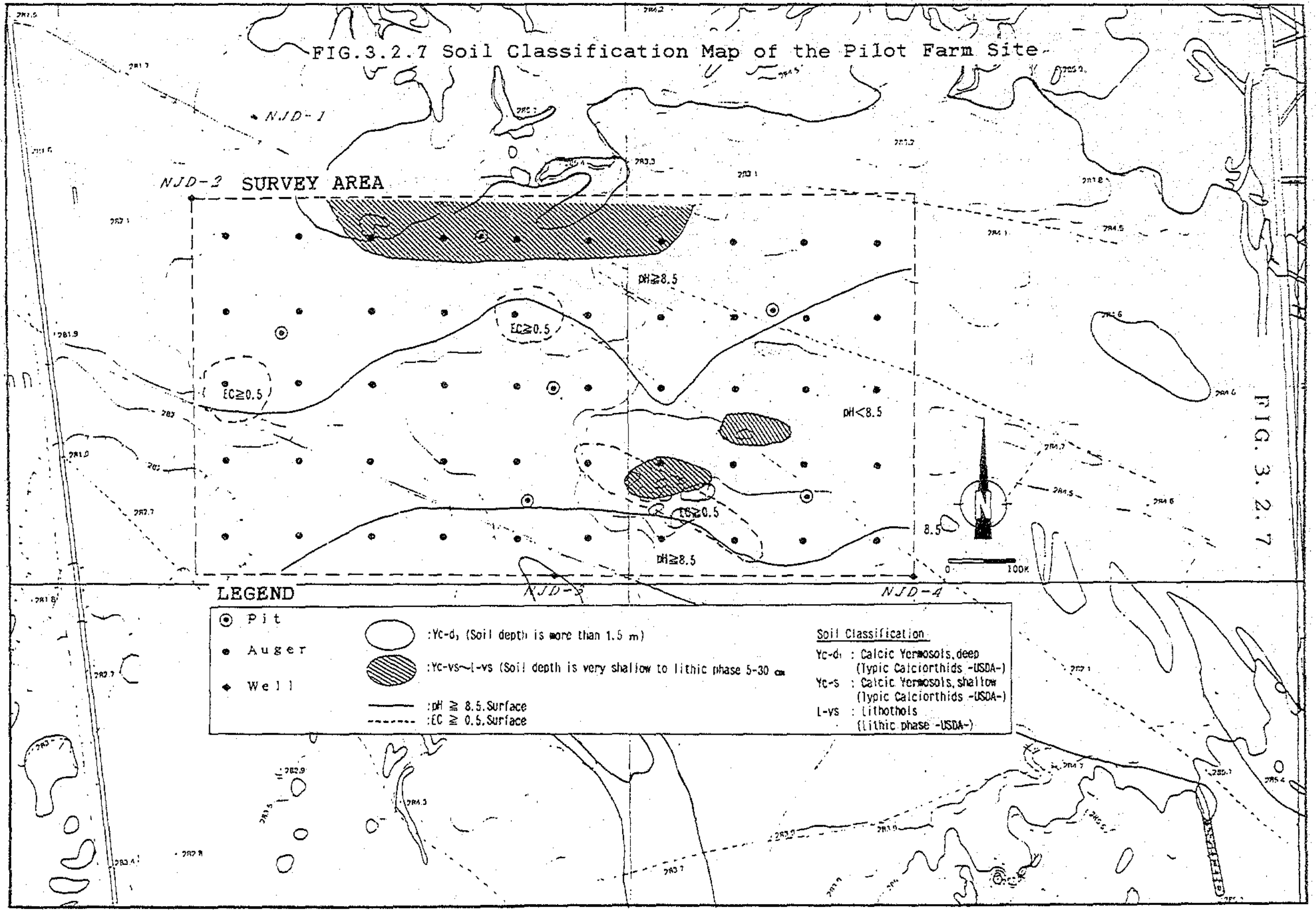
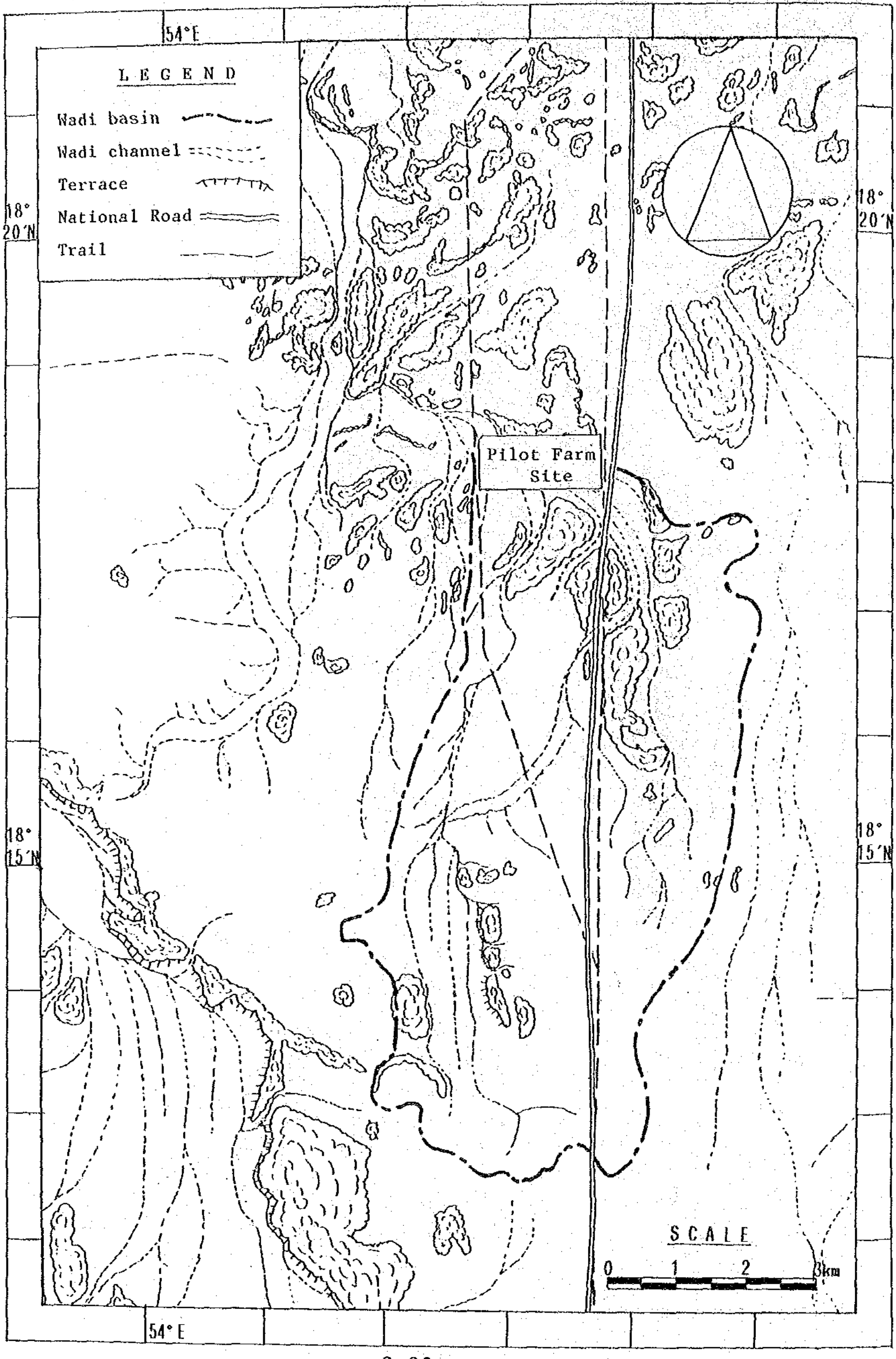


FIG.3.2.7 Soil Classification Map of the Pilot Farm Site

FIG. 3. 2. 8 Surface Drainages around the Pilot Farm Site



3.3 Agriculture

3.3.1 Agriculture in the Nejd

Nomadism of camel and goat has been the dominant agriculture activity in the Nejd, because the natural conditions of the area, consisting of sandy and soil desert, limit the crop cultivation. However, crops such as date-palm have been cultivated in limited areas adjoining the well and oasis.

Agricultural land has expanded rapidly in the 1980's with the development of hand-dug well and flowing well by the local people. Especially, its expansion by construction of wells with self investment in Hailat Al-Rakah, Dauka and Shasr show the intention of local people for the agriculture development in the area.

PDO desert farm with construction of a 40 ha pilot farm has been established in the Nejd in 1985 by the instruction of His Majestry Sultan Qaboos bin Said in order to determine crop cultivation under desert condition. The farm was expanded in 1987 by the establishment of a 60 ha centre pivot irrigator to achieve a sub-commercial scale production.

3.3.2 Agricultural Land Use and Farm Holdings

According to the field interview carried out in this study, 54 farms exist in the study area with a total area of 390 ha and most of the farmers have settled recently. This area excludes PDO desert farm of 100 ha area (TABLE 3.3.1). Among the 54 farms, only 20 farms of 128 ha area are registered and the others are not registered. Some farms are managed commonly by several families.

Among the total area of 390 ha, only 95 ha is actually cultivated, since most of the farms are in developing stage and at present they are unsuitable because of poor soil conditions caused by salinity hazard. Farm area selection criteria should be reviewed in accordance with the guideline which is proposed in this report.

The ratio of planted area of each crop in each farm is shown in TABLE 3.3.2.

(1) Fodder grass

Main fodder grass cultivated in the area is Rhodes grass; perennial grass, and alfalfa is also cultivated in a small area. The advantages of Rhodes grass cultivation in the area are as follows:

1) High marketing price and large demand
2) High yield
3) Easy to post harvest treatment
4) High tolerance for drought and salinity
5) Low labour requirement
6) Improve soil structure

Rhodes grass is the only crop cultivated on a large scale by using centre pivot irrigator in the PDO farm and Dauka . Its production is mainly sold to the local people. On the other hand, small farmers also produce Rhodes grass hay but it's mainly used for self-consumption.

Main variety of Rhodes grass in the area is Cv. Katambora and is harvested about 10 times per year and its yield registered by PDO farm is 40 - 45 ton/ha/year as dry matter.

Alfalfa is also cultivated in the area, however, its planted area is too small compared with Rhodes grass. It is because, alfalfa easily loose their leaves during post harvest treatment and transportation and its yield is about half as that of Rhodes grass; 15 - 17 ton/ha/year as dry matter.

The PDO farm investigates the introduction of Italian ryegrass to make up the low productivity of Rhodes grass during winter season.

(2) Vegetables

Many vegetables such as tomato, watermelon, eggplant, onion and cucumber are cultivated on a small scale and except watermelon, others are used for self-consumption. Main irrigation method for vegetable cultivation is furrow irrigation, however, sprinkler and drip irrigation systems are introduced by few farmers and the PDO farm. Application of compost is popular in the area.

(3) Fruits

Date-palm is the most popular fruits for cultivation in the area, which shares 87% of the fruits cultivated area, and lime and orange are also cultivated. However, most of the fruit trees are unmatured except in Shasr.

(4) Cereals

Cereals, wheat and barley etc., are cultivated in a small area, however, they are used only as hay or materials of green manure. According to the results of PDO farm trial, yield of barley is registered as 3.5 ton/ha, which is much higher than that of Oman average (2.38 ton/ha).

Average yields of the main agricultural area in Oman; Batinah Region and Salalah Plain, and the results of PDO farm cropping season trials are shown in TABLE 3.3.3. The table shows that the highest yields registered by PDO farm trials are almost same or higher except for alfalfa and egg plant comparing with these two agricultural regions. Especially, the yields of Rhodes grass and tomato, which are the high tolerance crops for the drought and salinity, register much higher than those in the two regions. It can be shown that the potential for agricultural development in the Nejd is high by the introduction and the extension of appropriate technology.

3.3.3 The Existing Situation of Agriculture

(1) Hailat Al-Rakah

42 farm holdings are ascertained in Hailat Al-Rakah. The average farm holding size and the cultivated area are 6.6 ha and 1.7 ha respectively. The main crop is Rhodes grass, which shares 50% of the total cultivated area. Its product is mainly used for self-consumption however, a small amount of the product is sold in the market. Other crops cultivated in the area are date and vegetables such as tomato, watermelon, onion and egg plant etc. Most of their products are used for self-consumption.

Shallow wells are used as the irrigation water resource. However, the quality and quantity of irrigation water is low because of its high electric conductivity. Besides it easily induces saline toxicity. Furrow irrigation system is mainly applied in the area, but sprinkler and drip irrigation systems are also introduced by a few farmers for forage crop and vegetables. Organic fertilizers such as dry dung of livestock are most popular in this area but chemical fertilizers such as urea are also applied for Rhodes grass. Agricultural machines such as tractor and binder assisted by the government are rented for the farmers but few farmers have their own machines. Most of the land owners are out of their farm and agriculture depends on foreign labour force.

(2) Dauka

Farmland in Dauka can be divided into two farms; one farm of 42 ha was established in 1985 and consists of 4 households. The other farm of 18 ha is a modernized one established in 1988. Both of these farms are using the water from a flowing well.

In the farm established in 1985, the average farm holding per farmer is 10.5 ha and the average cultivated area is only 1.0 ha. The main crop is Rhodes grass, which shares 40% of the total cultivated area and the others are date-palm and vegetables such as sweet potato, tomato, egg plant and cucumber.

However, their yield is low because of the shallow soil depth and poor drainage. Furrow irrigation is widely used in the area, however, sprinkler and drip irrigation systems are introduced by a few farmers for forage crop and fruits respectively. Agricultural machinery is not yet introduced in the area. Application of organic fertilizer is extended but chemical fertilizer is also applied by a few farmers.

The farm area established in 1988 is equipped with centre pivot irrigation system and the main crop is Rhodes grass covering an area of 13.5 ha. Tractor and binder are used for cultivation and organic and chemical fertilizers are applied. Here also, the agriculture depends on foreign labour force.

(3) Shasr

Shasr has been popular as an oasis and is distributed with old well. There are two farms using these water resources; one is managed by six farmers in the existing village and the other is out of the village. New wells are also developed in recent years and two farmers are doing cultivation using these wells. Total farmland of the area is 52.5 ha, of which only 7.4 ha is cultivated. The farm in the village mainly cultivate date-palm sharing 60% of the total cultivated area and the others are vegetables and forage crops. The other farmers cultivate mainly vegetables sharing 40% of the total cultivated area. Furrow and border irrigation systems are applied and agricultural machine is not introduced in the area. Application of manure is extended but chemical fertilizer is not applied in the area.

(4) PDO Desert Farm

PDO desert farm has been established in 1985 by the instruction of His Majesty Sultan Qaboos bin Said. Main objective of the farm is to evaluate the possibility of irrigated agriculture in the interior desert, particularly:

a) to determine the crops which could be grown in the desert and which might be economically and socially desirable in terms of Oman's agricultural strategy, and
b) to examine further large scale development options which might be warranted.
c) in mid-1987 a goat meat production evaluation exercise was added.

Total farm land area is 100 ha and the main research activities are as follows:

1. Introdution of crop and cultivation experiment.
2. Soil management
3. Observation of groundwater level
4. Efficient fattening of goat
5. Soil survey
6. Observation of meteorological data

Forage crop cultivation, mainly Rhodes grass, shares 95% of the total farm land, and vegetables and fruits are also cultivated. Rhodes grass hay is sold to nomads and market. Other products are mainly consumed by the people who live in the oil camp adjoining the farm.

3.3.4 Cropping Pattern

Natural conditions of the Nejd are much different from Batinah Region and Salalah Plain, which are famous for farming in Oman. Therefore, the existing agricultural technology of these areas can not be applied to the area directly. The agricultural technologies such as cropping system have not been established in the area. Crop cultivation period is much different between each farmer. Therfore, crop yield in the area is low.

However, cropping season trials of vegetables, such as tomato and cucumber, have been started by PDO farm since 1986 (FIG.3.3.1) and FIG.3.3.2 shows appropriate cropping season for each crop in the area, in which the yield is between the highest and half of it.

TABLE 3.3.1 Number and Area of Farms in the Study Area

Area	Number of Farms	Agricultural Land ha	Arable Land ha	Mean Agricultural Land ha/farm	Mean Arable Land ha/farm
Hailat Al-Rakah	42	277.0	69.9	6.60	1.66
Dauka	5	60.0	17.6	12.00	3.52
Shasr	4	52.5	7.4	13.12	1.85
Quitbeet	3	0.1	0.1	0.03	0.03
Sub-total	59	389.6	95.0	7.21	1.76
PDO Farm	1	100.0	92.0	–	–
Total	55	489.6	187.0	7.21	1.76

Note : JICA Team survey Feb.,1989

TABLE 3.3.2 Ratio of Planted Area for Each Crop

(Unit : %)

Area	Forage Crop	Vegetables	Fruits	Others	Total
Hailat Al-Rakah	47.9	23.9	28.2	0	100.0
Dauka	86.0	9.0	2.8	2.2	100.0
Shasr	11.4	26.0	47.5	15.1	100.0
Quitbeet	50.0	0	50.0	0	100.0
Weighted Ave.	52.1	25.0	21.3	1.6	100.0
PDO Farm	94.6	1.1	4.3	0	100.0

Note : JICA Team survey Feb.,1989

TABLE 3.3.3 Crop Yield Comparison

(Unit : ton/ha)

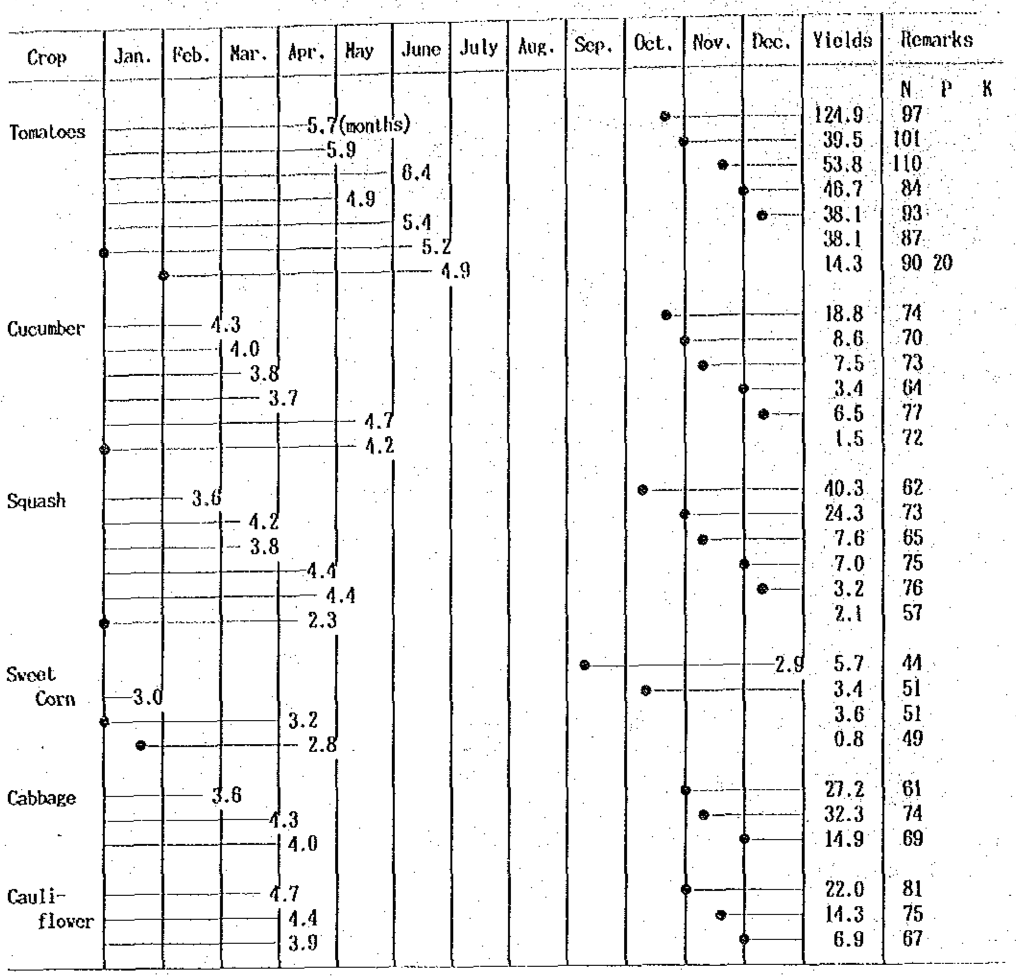
Area	Cabbage	Cucumber	Egg-plant	Squash	Tomato	Watermelon
Batinah *	28.6	17.8	19.0–28.5	16.6–21.4	28.1	23.8
Southern *	33.1	28.0	20.0	5.2	20.0	21.9
PDO Farm **	14.9–32.3	1.5–18.8	11.8–13.1	2.1–40.3	38.1–124.9	23.9

(Unit : ton/ha/year)

Area	Alfalfa	Rhodes grass
Batinah *	90.0–200.0 ***	180.3 ***
Southern *	160.0 ***	118.5 ***
PDO Farm **	83.3–94.4 ***	229.1–244.5 ***

Source : * Economic Development Prospects for the Southern Region, 1986
** PDO : A Report on Project Development, March 1988
Note : *** Green Matter

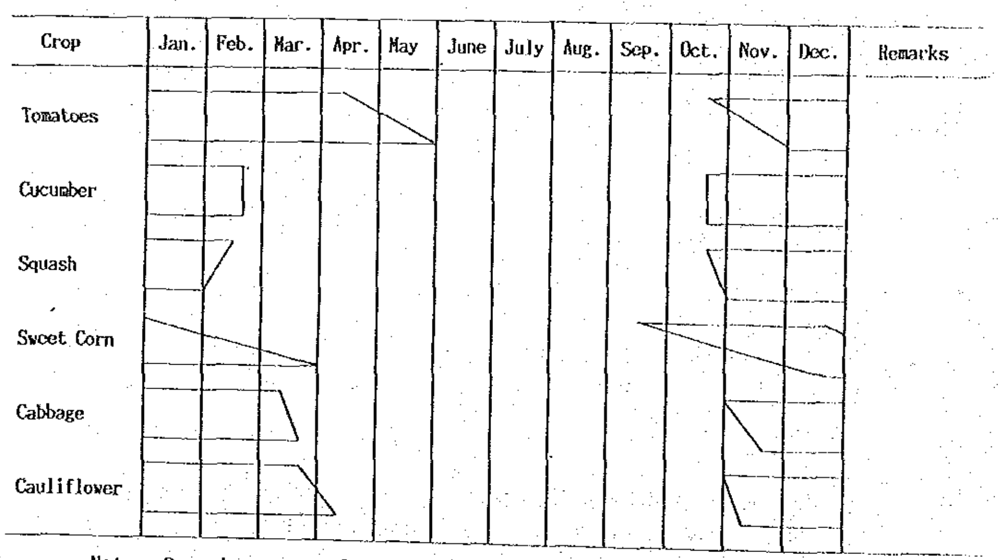
FIG.3.3.1 Results of PDO Experimental Farm on the Cropping Period



Notes : Yields — ton / ha
N,P,K --- Fertilizer, g / plant

Source : PDO, The Desert Agricultural Project,
A Report on Project Development to March 1988, April 1988

FIG.3.3.2 Proposed Cropping Period for Vegetables



Note: Cropping season for the yield between highest and half of it.
Source: PDO, The Desert Agricultural Project,
A Report on Project Development to March 1988, April 1988

According to the results, difference of cropping season affect much to their yield. Generally, appropriate seeding time in the area is from October to November. If the seeding time is delayed, the crop will be damaged by low temperature during the winter season in the seedling period and yield will be much decreased. Crop cultivation is very difficult during the summer season affected by high temperature.

However, a few crops such as okra and watermelon are cultivated during the season.

3.3.5 Agricultural Input and Machinery

(1) Organic Fertilizer

Oman's government attaches importance to organic fertilizer and gives an aid of 25% as supplemental fund. Therefore the organic fertilizer such as cattle dung and fowls dung is used 1 or 2 ton per ha for sowing bed in each farm. Most organic fertilizer is dried, packed and transportated from the Jabal or Salalah. Camel dung is used as self-supporting organic fertilizer. Wheat and barley are cultivated in the PDO farm and used as green manure.

(2) Chemical Fertilizer

Only one third of the farmers applies chemical fertilizer in the area. Main fertilizers available in the area are urea, ammonium sulphate, super phosphate and compound fertilizer (15-15-15). Amount and method of fertilizer applied by the PDO farm are shown in TABLE 3.3.4.

Quick-acting fertilizers such as ammonium sulphate and super phosphate are used for sowing bed and basal dressing. And, liquid fertilizer is applied for topdressing. Split application method is adapted by the farm, since the cation exchange capacity of soils is low. Application of potassium fertilizers is not popular in the area since the irrigation water contains much potassium.

(3) Disease and Insect Damage

Main disease and insect damages and their countermeasures in PDO farm are shown in TABLE 3.3.5.
Period of high humidity may encourage fungal pests. The damages caused by birds, foxes and snakes are also observed in the farm.

(4) Agricultural Labor Force and Farm Machinery

Most of the farmland owners live in Salalah or Thumrait, and agriculture in the area depend on foreign labour force. However in Shasr, some farmland oweners do agricultural production by themselves. Average number of employment per farm is from one to two.

The most wide spread agricultural machine used by small farmers in the area is small sprayer. In Hailat Al-Rakah, tractors and balers, which are aided by the government, are shared by the farmers. Modernized farms in Dauka are well equipped with agricultural machinery; two tractors and others are used for harvesting and cultivation.

TABLE 3.3.4 Fertilizer Input

	Nitrogen (N)	Method	Phosphorus (P205)	Method
Perennial Grasses	2,000kg/Y	83kg/2W	400kg/Y	100kgX3-4T
Alfalfa	200kg/Y	2-4T	500kg/Y	200kgX3-4T
Sorghum, Millet	70kg/M		150kg/M	
Cereals	50kg	in seedbed	125kg	in seedbed
	70kg/4W,70kg/8W			
Vegetables	20g Urea/Plant/W		20g /Plant	

Y=Year M=Month W=Week T=Times

Source:The Desert Agricultural Project, A Report on Project Development to March 1988, April 1988

TABLE 3.3.5 Fungal Diseases and Insect Pests

1)- Fungal Diseases

Fungal	Septoria	Mildew	Late blight	Early Blight
Crop	Wheat	Barley	Potatos	Tomatos
Counter-measure	Hi-spor 45	Colixin	Mancozeb need quick action	Polyram-Combi and Calilxin

2)- Insect Pests

Insect Pests	Aphids	Spider	Green Mite	Tarsonemid Aphids	Caterrpillars Mite
Crop	Wide range	Melons	Veg.,Cereals	Cucumbers	Alfalfa,Tomato Okra,Melon
Counter-measure	Dimethoate Malathion	Torque	Dimethoate, Malathion,etc.	Torque	Ripcord

	Mealy Bugs	Shoot Flies	Melon Flies	Stem Borer
Crop	Date palms	Phodes grass, Cereals	Melon	Maize
Counter-measure	Dimethoate	Ripcord, Diamethoate	Dimethoate	Ripcord

Source:The Desert Agricultural Project, A Report on Project Development to March 1988

3.3.6 Marketing for Farm Products

(1) Price of Agricultural Product

Every week the Public Authority for Marketing Agricultural Produce publish the price of agricultural product in a newspaper. Average of their products in 1987 are shown in the TABLE 3.3.6.

(2) Circulation of farm products

The circulation of main farm products in the southern region is described as follows:

1) Fodder grass

Natural grassland in the Jabal has no enough capacity for the present livestock population.
At present the grasslands cultivated is only one-fourth of the requirement against 100,000 cattles raised in the area. Shortage of fodder grass is supplemented by local feed and fodder grass purchased from Salalah plain and north. However it causes increase of the production expence.

It is estimated that every year 45,000 ton of local feed and 16,000 ton of fodder grass is supplied from Salalah plain and 2,000 ton is supplied from Sohar which is 1,200 km away from Salalah.

Main fodder grass is Rhodes grass and its hay is sold at a price of 0.1 R.O./kg. The fodder grass is purchased either from Dhofar Cattle Feed Company (DCFC) or directly from farmers and is transported using trucks. It is also sold at a temporary market. The herd owners in Salalah go and purchase it at the PDO farm in monsoon season, since the supply of the fodder grass is shorter during the season.

Although there is a plan to reduce the cattle population in the Jabal from 100,000 to 50,000 by the livestock destocking program, a stable supply of the fodder grass will be indispensable for the conservation of the Jabal grasslands. In this regard, the fodder grass production is much expected in the Nejd.

Source: Livestock Marketing Study in the Southern Region, PAMAP, 1987

2) Vegetables and Fruits

In Oman, vegetables and fruits are mostly imported. On the other hand, coconut, banana and papaya cultivated in the Salalah plain are shipped to the northern region of Oman. The farm products shipped to the northern region are collected processed and shipped by PAMAP. However most of the farm products are sold to private merchants and PAMAP deal with them a little.

3.3.7 Agricultural Supporting Services

(1) Research and Extension

Agricultural institutions in Oman are shown in TABLE 3.3.7. One institution for each of agriculture, animal husbandry and production farm are established in the southern region.

The main services of agricultural extension are suppling of seeds, fertilizers and agricultural chemicals, rental of agricultural machinery and extension of technology. 38 extension offices are established in Oman, of which five offices are distributed in the southern region.

However, there is no organization related to agriculture in the Nejd. Livestock quarantine office is planned to be established in Thumrait.

(2) Circulating Organization of Farm Products

The PAMAP is responsible for the distribution of agricultural products. It was established in 1981 and the main objectives are as follows:

1. To encourage farmers to increase production.
2. To ensure the availability of products in the local market in the required quantities and reasonable rates.

Main roles of the PAMAP are as follows:

1. To provide a link between farmers and the trade
2. To provide marketing outlet
3. To improve the distribution system on the quantity and quality of produce

The headquarter of the organization is at Muscat. The marketing network consists of a Central Distribution Centre at Ghallah and five regional distribution centres at Salalah, Nizwa, Sohar, Sumayil and Ibra.

Twelve collection centres are also set up in whole Oman. Among these centres, a collection and distribution centre and a banana packing plant are established at Salalah.

(3) Agricultural Credit

The Oman Bank for Agriculture and Fisheries was established in 1981. The main role of the Bank is the provision of finance for development projects in the agricultural and fisheries sector. The loans granted between 1983 and 1987 is shown in TABLE 3.3.8.

5,409 loans worth of R.O.16.3 million are distributed during the period. In this loans for the establishment of new farm, improvement of existing farm and mechanization of farm share 48%, 21% and 17%, respectively, and these three agriculture sector share 85% of the total loans. The figure shows that the agricultural development is given the highest priority. However, only 2.1% of the total loan is invested in the southern region.

TABLE 3.3.6 Price Comparison between Local Products & Imported Crops

(P A M A P 1987 average)

Crops	Local Products(R.O./kg)	Inported Crops(R.O./kg)
Tomato	0.207	0.173
Cucumber	0.253	0.295
Watermelon	0.111	0.104
Onion	0.080	0.084
Banana	0.163	0.383
Lime	0.254	0.354
Date-palm	0.318	0.350

TABLE 3.3.7 Agricultural Research Station and Extension Centre

	Whole Country	Southern Region
Research Station		
Agriculture	5	1
Animal Husbandry	3	1
Production Farm	8	1
Extension Centre	38	5
Nursery	4	2

Source: Statistical Year Book, 1988

TABLE 3.3.8 O.B.A.F Financing Record by Purpose

Unit : R.O. 1,000

Purpose of Loan	1983－1987 Total			1983－1987 Average	
	Number	Value	(Va.%)	Number	Value
Farm Improvement	492	3472	(21.3)	98.4	694.4
Establishment of New Farms	646	7845	(48.0)	129.2	1569.0
Farm Mechanization	4035	2811	(17.2)	807.0	562.2
Livestock	7	23	(0.1)	1.4	4.6
Agro. Industries and Marketing	3	533	(3.3)	0.6	106.6
Fisheries	220	1070	(6.6)	44.0	214.0
Large Projects	6	577	(3.5)	1.2	115.4
Total	5409	16331	(100.0)	1081.8	3266.2

Source : Sultanate of Oman, Statistical Year Book, 1988

CHAPTER-4

GROUNDWATER RESOURCES

CHAPTER 4 GROUNDWATER RESOURCES

The groundwater survey of this project was carried out along the procedure presented in FIG.4.1.1 as a flow-chart.

Achieved results were published in the reports at each project stage. This chapter discusses the whole results in a comprehensive way.

4.1 Groundwater Survey

4.1.1 Review of Preceding Surveys

Groundwater Survey in the Nejd is still at the preliminary level. This situation is due to the great areal extent, ca. one third of the total territorial area, where modern industrial activities like oil field development and highway construction has been set out rather recently.

There were two significant surveys on the groundwater carried out so far, following the works of restricted scale and accuracy, done by Sir W. Halcrow and Partners (1976), Sir A. Gibb and Partners (1984) and Harza (1985).

One of them was made by PDO (Petroleum Development Oman) in its concession area. This survey was a compilation work of the water resources surveys, which were conducted as an auxiliary part of oil exploration. It contains the Nejd consisting a section in the report; D. H. Parker, 1985, The Hydrology of the Cainozoic Aquifers in the PDO Concession Area, Sultanate of Oman, PDO Report. In the report eastern portion of the Nejd is covered, but most of the central and all of the western Nejd are excluded. However, the groundwater system extends beyond the geographical and administrative boundary, forming a large scale flow system, so the report provides important informations in order to conceive the whole feature of the regional groundwater occurrence.

As the present report manages a flow system which discharges in the north eastern area far beyond the Nejd boundary, the major survey area of the PDO report confirms an indispensable part.

The PDO report can be appreciated as an idealistic report which covers sufficient span of survey items, starting from aquifer hydraulics, hydrogeology, hydrochemistry and environmental isotope studies. Although, most of the bore holes were drilled as production wells, resulting in an insufficient areal density of observation points. The density decreases when particular aquifers are considered. In addition, there is no description whether the structure of the wells are perfect as observation wells.

In short PDO report provides an important conception for the large scale regional groundwater system in the Nejd and adjacent area, but does not contain sufficiently detailed data for the relatively localized area like the project's one.

The other of the two is the PAWR (Public Authority for Water Resources) survey.

During the period of 1984-1986 PAWR drilled groundwater exploration bore holes at the thirteen points in the almost identical area of the present project. The results of each bore hole survey were edited in a report.

The target geologic formations were Tertiary and the maximum drilling depth reached 492 m. Drilled wells are maintained as observation wells.

It was an epoch making matter that thirteen points were drilled for purely scientific purposes in ca. 15 thousand km^2 of the Nejd. Consequently the present project intended to supplement the PAWR surveys and to level-up the survey quality. In case of PAWR drillings, the bore holes were finished to make themselves specialized in measuring the potential head of the particular aquifer.

They paid efforts to minimize the interference between the aquifers caused by the drilling works. The areal density of the exploration wells are not enough still in such a great virgin area for scientific survey, nevertheless the disposition designed by PAWR helps succeeding survey projects greatly to position their own survey points. At the same time newly acquired data are to be integrated in a meaningful way into the already established greater frame.

PAWR had conducted environmental isotope studies on the groundwaters in nation-wide scale almost in the same period of its Nejd groundwater survey. The results on the Nejd groundwaters were presented in the report: PAWR, 1986, Origin and Age of Groundwater in Oman - Study of Environmental Isotopes, PAWR Report PAWR 86-7.

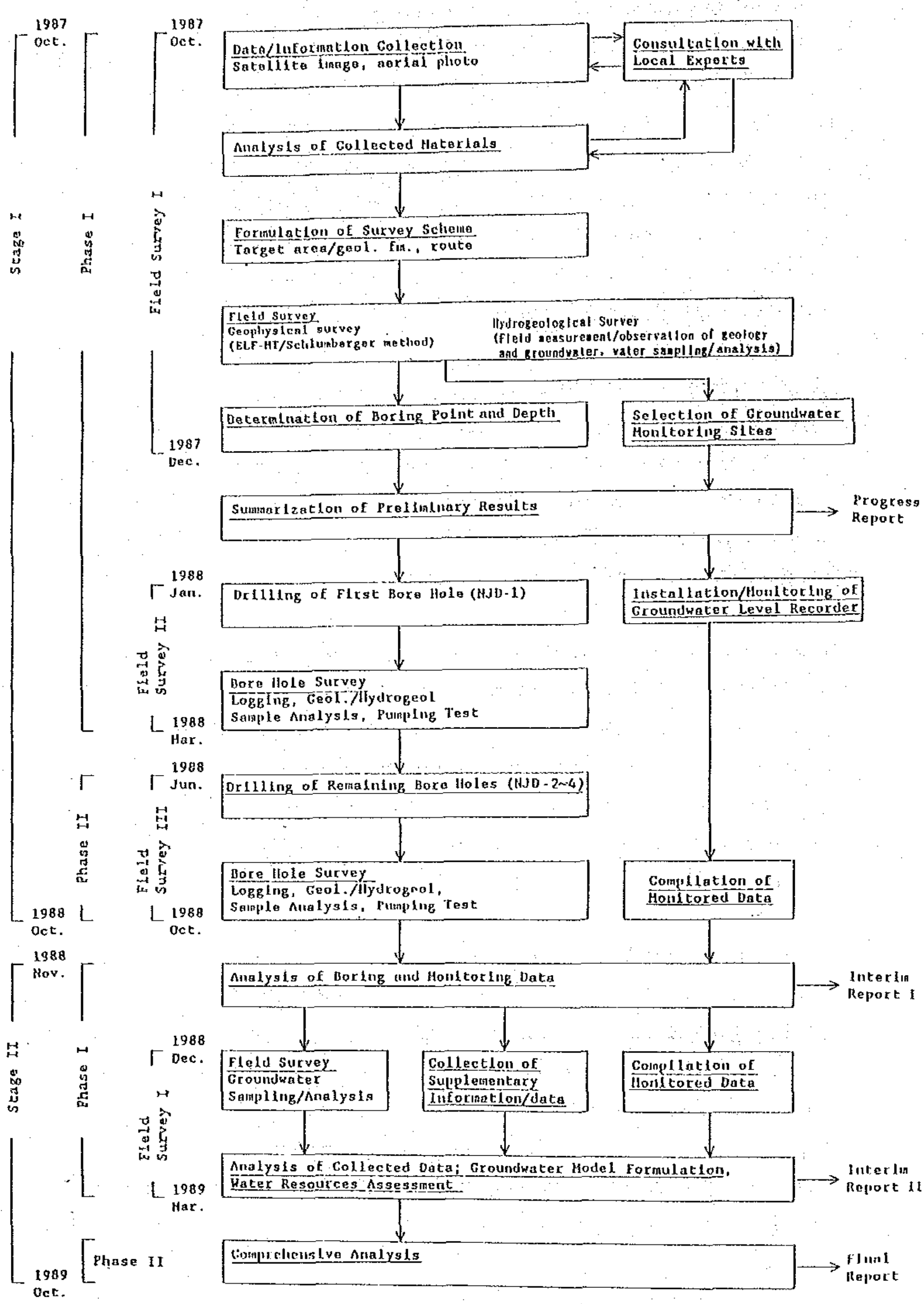
This study disclosed some significant aspects of the groundwater and presented several confining factors to the water resources development in the Nejd. According to the study lower UER aquifer, the target aquifer of the present project, bears groundwater of low level carbon-14 throughout the area and the groundwater ages were computed more than 10 thousand years.

The oxygen and hydrogen isotope ratios of Lower UER water were discovered different from those of rain and groundwater of the Dhofar Mountains, which had been regarded as the recharging area of the aquifer. These facts strongly suggested the Nejd groundwater disconnected from the present hydrologic cycle. Eventually the groundwater resources are apt to be believed finite without any current recharge.

PAWR can be said to have established a regional survey scheme to which any following project shall contribute their results, including environmental isotope survey. The survey scheme will clarify the water resources and inter-aquifer correlations with increasing accuracy and details.

The present project was formulated with positive consideration of the above and included environmental isotope study as a significant element.

FIG. 4. 1. 1 Work Flow Chart of Groundwater Survey



4.1.2 Hydrogeology

By the substantial co-operation of the Directorate General of Petroleum and Minerals in the Southern Region (DGPMS), a hydrogeological map of 1:250,000 scale was drawn over the project area. The map is attached to this report in the pocket.
TABLE 4.1.1 is the stratigraphical division, recently compiled by the directorate, for the Palaeogene formation in the Nejd.

The basement of the Nejd is Pre-Cambrian, but the most of the outcropping rocks are sedimentaries of Hadhramaut group from Palaeocene to Eocene.

Underlying Mesozoic formations are regarded as not having good prospect for the groundwater resources.

The Tertiary formations are divided into the following four formations from the lower to the upper horizon.

a) Umm Er Radhuma (UER) formation

a-1) Lower UER formation

The formation belongs to Palaeocene and early Eocene, and consists of limestone with some shale, which was formed in the shallow marine environment of transgressive period.

The bottom of the formation is of aquiclude strata, known as Shammar Shale, which separate Tertiary formation from the Mesozoic. The most promising aquifer is believed to exist at the top of this lower UER, where cavities and burrows develop to form karstic structure.

a-2) Upper UER formation

The formation consists of limestone of shallow marine environment, containing chert nodules and silica geodes, originating from Eocene in transgressive stage. At the top karstic structures develop to form aquifers.

Aquifers are sometimes poor in water quality and quantity. They are subordinate to the Lower UER aquifers.

b) Rus formation

The formation consists of marl, dolostone and laminated massive gypsum of shallow evaporitic marine environment in regressive stage of Eocene, lacking in fossils.

Aquifers are poor in water quality and quantity.

c) Dammam formation

The formation consists of limestone of shallow marine environment in transgressive stage of Eocene, containing large fossils.

Aquifers are poor in general, but promising ones were occasionally discovered in the north as small scale shallow aquifers.

d) Aydim formation

The formation composes the top of the local Eocene formation, outcropping only on the crests of Qamr and Qara Mountains which are the western and central part of the Dhofar Mountains.

It consists of limestone and dolostone of shallow marine origin, containing large fossils.

As the aquifer develops mainly in the carbonate rocks, it is presumed that some fracture structure may be related. Fracture could be caused by faults and/or synclinal structures. These structures may produce lineaments at the ground surface.
The regional aquifers in the Nejd develop in a monoclinal structure which dips moderately to the north with the above-mentioned characteristic surface features, indicating inner geologic structures.

Prior to the field survey, general reconnaissance was made through the composite satellite pictures of 1/250,000 with their interpretation charts (MAF, Earth Satellite Corporation, 1982), aerial pictures of 1/60,000 (MD, 1983), and topographical map of 1/100,000 (MD, UK, 1985), and 1/250,000 (MD, UK, 1975).

Through the reconnaissance work, lineaments of SW-NE and SSE-NNW trends were detected. In the survey area SW-NE trend was recognized to be prevailing (see Hydrogeological Map of the Central Nejd). The detected lineaments could be identified as steep slope zone of bare rock with concentrated wadi courses or specifically oriented wadi courses.

We have to acknowledge with thanks that geologists of MPM kindly provided opportunities for us to discuss on the lineaments in relation to the underlain geological structures.

According to the existing geological data, SW-NE structural trend coincides with the great structures, called the Ghudun-Butabul High and the Murbat-Kuria Muria High, which develop in the Pre-Cambrian and overlying Palaeozoic and Mesozoic erathems. Survey area extends just over the Ghudun-Butabul High and the lineaments are closely positioned above the faults in the Khasfah Flank which is the northern flank of this particular high structure. The ever performed seismic surveys, however, have not picked up any proofs which indicate the Khasfah Flank faults to reach the overlying Tertiary system. MPM geologist commented that there was no negative facts against the assumption of "Neotectonism" along the Khasfah Flank/Ghudun-Butabul High. A structural sketch map is presented in FIG.4.1.2 and 4.1.3.

In addition the regional geostructures were compiled from the informations provided by the DGPMS.

There extends a large regional geostructural conditions drawn in FIG.4.1.4.

The regional geostructure seems to be strongly related to the abbysal structure in Arabian Sea.

The Alula-Fartak fracture zone, one of the large transform faults along the Arabian Sea Rift, appears to develop on the same trending line with the SW-NE lineaments.

There are UER cutcrops (south west coast) on the same line.

In the terrestrial part, the trough of Tertiary isopach contours is again found coninciding with the lineaments direction.

The Tertiary isopach can be regarded as approximately identical with the Terriary base depth contours, for the Nejd relief is extremely flat particularly in the north, and Tertiary outcropping is dominant there. FIG.4.1.4 indicates another trough of the Tertiary base, which initiate at the northern slope of the Dhofar Mountains, trending eastward.

TABLE 4.1.1 Palaeogene Stratigraphy of the Nejd

Age			Stratigraphy			Lithology
Palaeogene	Eocene	Priabonian — Bartonian	Hadhramaut Group	Aydim Fm.	Haluf Mb.	Green and yellowish marl with micritic and biocalcarentic limestone with large molluscs and echinoderms.
					Tagut Mb.	Yellowish biocalcarentic limestone, biocalcarentic and micritic limestone with abundant corals at the top, large molluscs, green clay and marl at the base.
					Moosak Mb.	
					Heiron Mb.	
		Early Bartonian — Middle Lutetian		Dammam Fm.	Uyun Mb.	Thin-bedded, nodular, grey to pink bioclastic limestone with large molluscs, scarce corals.
					Qara Mb.	Massive-bedded, nodular, bioclastic limestone with large molluscs.
					Andhur Mb.	Yellowish shale with intercalations of white to yellowish bioclastic limestone, green marl and coquina with oyster at the base.
		Early Lutetian — Late Ilerdiam		Rus Fm.	Gahit Mb.	Laminated partly recrystallized white challky dolomite collapse breccia, chert beds with marl and bioclastic limeston at the top. Laminated gypsum with intercalations of biocalcarenite and bedded chert and flint.
					Aybut Mb.	Highly recrystallized collapse breccia and chalky dolomite with bedded chert and flint.
	Palaeocene	Middle Ilerdiam — Late Thanetian		Umm Er Radhuma Fm.	Mudayy Mb.	Thin-bedded, white to yellowish micritic dolomite with bedded nodular chert, silica geodes, abundant small echinoderms.
					Hasik Mb.	Massive to thin-bedded, nodular, grey to whitish, bioclastic limestone with shale and thin intercalation at the top, marl with nautiloids at the base.
					Atayr Mb.	

(Based on DGPMS. MPM Data)

FIG. 4. 1. 2

FIG. 4. 1. 2 Structural Sketch Map of the Nejd

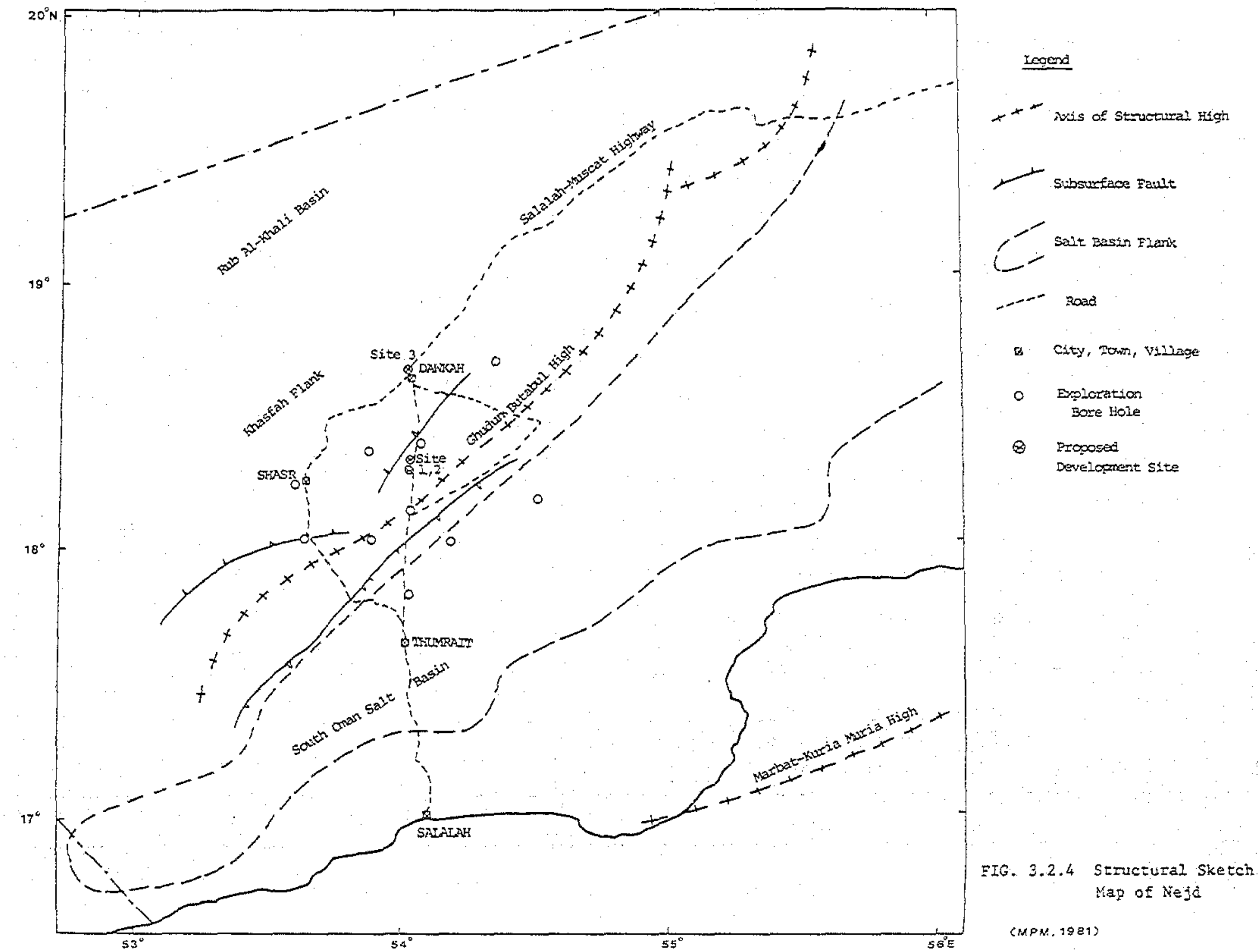


FIG. 3.2.4 Structural Sketch Map of Nejd

(MPM, 1981)

FIG. 4. 1. 3 Geological Cross-Section of the Nejd

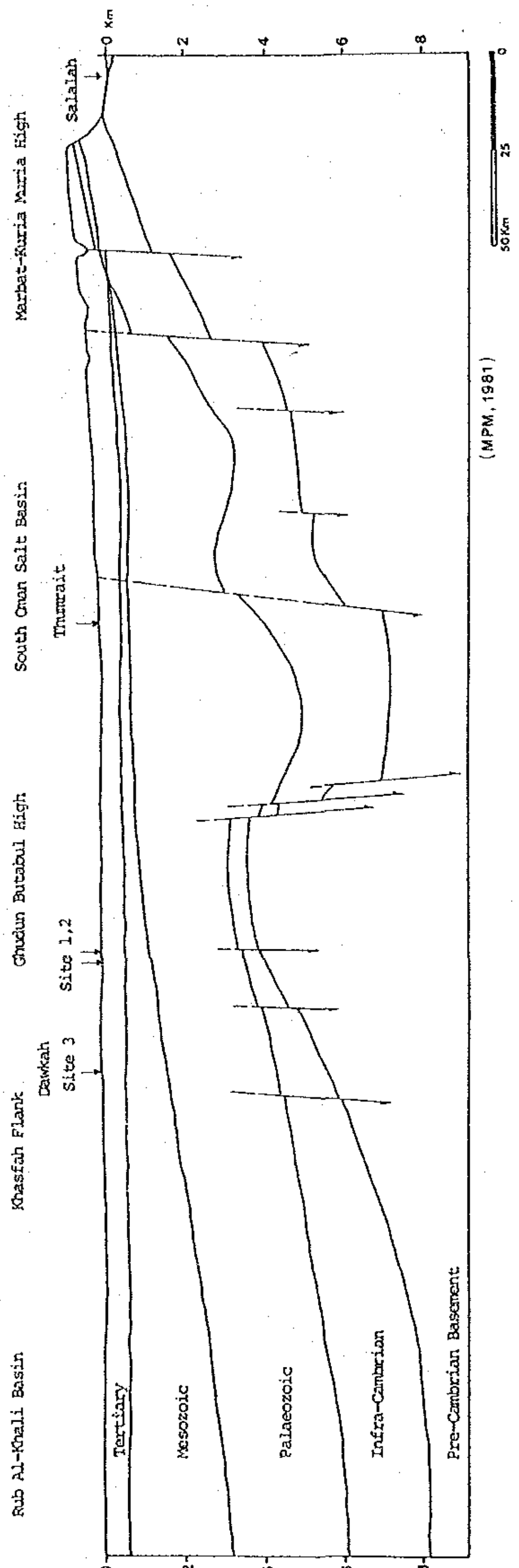


FIG. 4. 1. 4 Geostructural Conditions around Umm Er Radhuma Aquifers in the Nejd

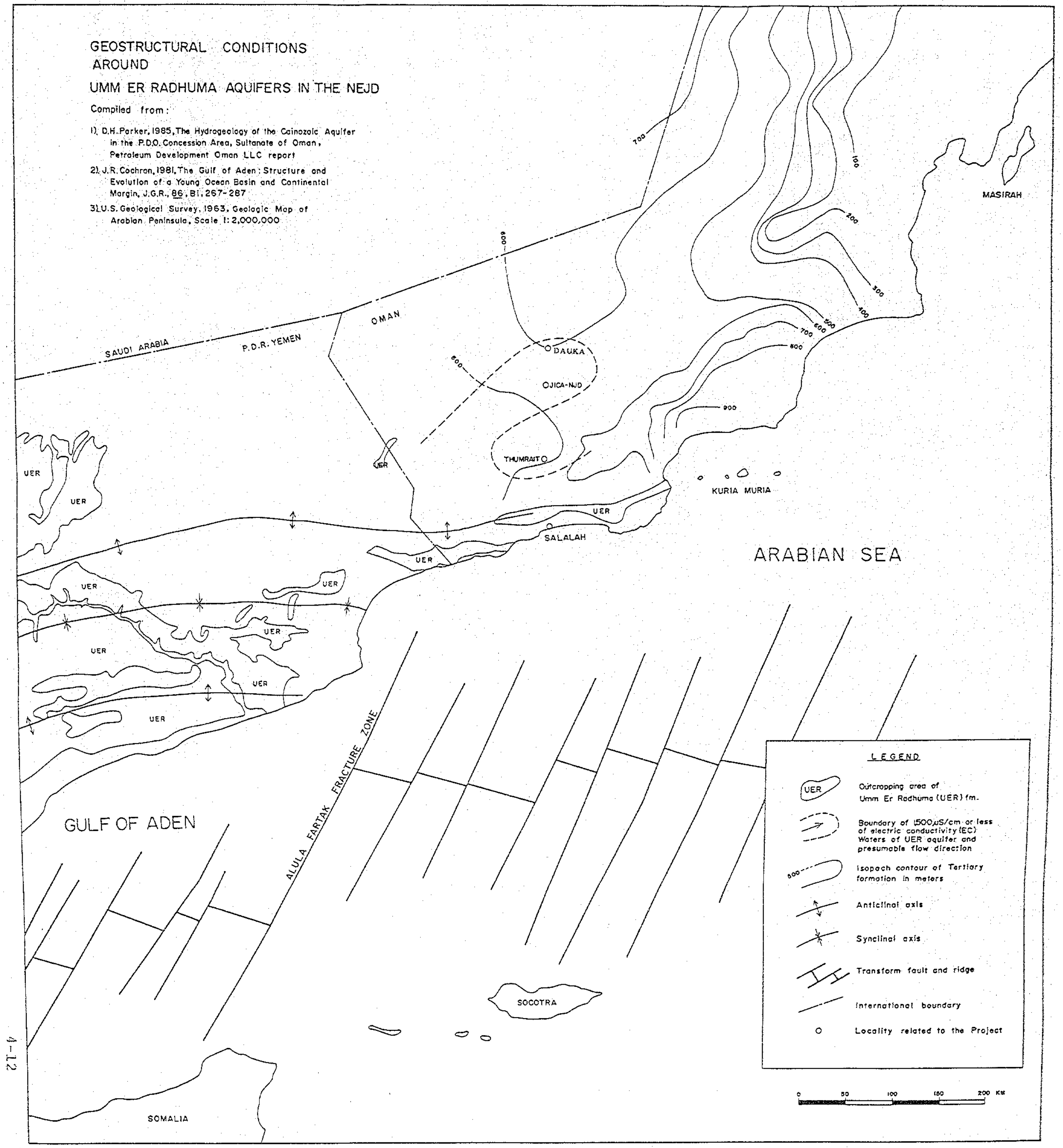


FIG. 4. 1. 4

4.1.3 Groundwater Hydrology

In the present project four bore holes (NJD-1, 2, 3, 4) were drilled at the proposed pilot farm site in the most prospective development area. Drilling positions are shown in FIG.4.1.5. Through these bore holes pumping tests were carried out for the most promising aquifer and aquifer properties were calculated. At the same time bore hole loggings, recovery of cutting and core samples for the micropalaeontological analysis, and water samples for hydrochemical analyses were made through them.

(1) Aquifer Division

Following aquifer divisions were determined through the present bore hole exploration considering PDO and PAWR works.

Four aquifers were discriminated for the project area in the Nejd by PAWR and the present survey.

<u>Zone A: Dammam formation and Rus formations, 0-140 m</u>

Generally good water quality of EC less than 2,000 μS/cm, except for some high salinity water of more than 10,000 μS/cm in the Rus formation. Mostly consisting of shallow and young waters, but the total resource amount is not appreciable. Some waters are in confined condition.

<u>Zone B: Upper part of upper UER formation, 140-270 m</u>

Large transmissivity can be encountered. There are some good quality waters but the water quality of the marly part of the formation is degraded, more than 2,000 μS/cm. Mostly in confined condition.

<u>Zone C: Top of lower UER formation, 270-310 (?) m</u>

This aquifer develops extensively in the Nejd. Quality is good with EC around 1,500 μS/cm. Due to the chemically reduced condition, hydrogen sulphide is contained. The aquifer is confined and produces flowing wells in the north (see the Hydrogeological Map attached).

Zone D: Lower UER formation, 310 (?) m -

Both quality and quantity is poorer than Zone C. EC exceeds 2,000 μS/cm and tends to increase with the depth.

A diagrammatic summary is given in FIG.4.1.6, extracting a general features from the available informations and data from the bore holes drilled by the project.

For the more detailed understandings of the lower UER aquifer, a composite diagram (FIG.4.1.7) was drawn, using columnar geological section and several bore hole loggings of NJD-1 bore hole.

Among the loggings, so called TV logging is the intra-hole observation by a small submersible TV camera.

By the TV logging extensive karstic cavities were directly observed. Some of them were so large that the diameters exceed one meter. The observed karstic cavities are plotted in the column beside the geological one.

Cavities distribute in good coincidence with the relating characteristics of drilling rate, bore hole caliper, natural gamma radiation level, formation electric resistivity and formation porosity.

TV logging enables to determine the level and thickness of the karstic aquifer with better accuracy due to the direct visual observation.

Presented below are the aquifers confirmed,

	Depth (m)	Water Quality (μS/cm)
Rus formation	45 - 55	2,000 - 5,000 or more
Upper UER formation	140 - 170	4,000
Lower UER formation	280 - 310	1,500
	370 -	

(2) Groundwater Flow System and Hydrochemical Aspect

Potentiometric groundwater heads and EC values of Zone C were measured by the observation wells drilled by PAWR and this project. Their regional distribution is printed in the Hydrogeological Map attached.

The contour patterns indicate prevailing flow direction of SW-NE in the map. The results are in conformity with radio carbon dating of Zone C waters measured by PAWR and estimated regional groundwater flow regime presented by PDO.

This flow system also agrees with our previously proposed Four-flow-zone System (FIG.4.1.8) based on PAWR groundwater datings. The regional geostructure discussed in the preceding section 4.1.2 is another supporting fact.

Major chemical components analysed for Zone I waters were plotted in a Piper's trilinear diagram (FIG.4.1.9(1)). In Zone-I change of the chemical property is traceable from upstream to downstream. Mg^{++}/Ca^{++} ratio tends to increase downstream and indicate desolution of cations from dolomite ($CaMg(CO_3)_2$), one of the major minerals of the Zone C aquifer.

Same diagram was plotted for flow Zone II, III and IV, and the diagram (FIG.4.1.9(2)) depicted differenciations for these Zones from Zone I in the anion contents. In the diagram sulphate ion of Zone II/III water decreases more than that of Zone I water, but in Zone IV water sulphate increases remarkably. This tendency is an additional supporting point for the flow zone system. By the way Zone I water seems to be modified generally into non-carbonate hardness type waters which is typical for fossil groundwater elsewhere in the world.

Stable isotopes of Zone C groundwaters presented another differenciation. $^{18}O/^{16}O$ and D/H ratio of Zone I, II and IV waters are close to each other but those of Zone III waters are appreciably deviated from the formers (FIG.4.1.10). These ratios generally reflect climatic conditions in which the water is extracted from the hydrologic cycle. So the differences in these ratios indicate the differences in the recharge area and/or recharge period. These Nejd waters are also different from Salalah Plain groundwaters which are currently recharged by the rains on the Dhofar Mountains. Consequently Zone C waters do not seem to contain any recharge waters from the Mountains.

Radio active hydrogen, i.e. tritium, is found at very low level in all Zone C waters. This is a substantial aspect that even mixing of local modern waters does not occur.

Radio carbon contents of project site groundwater from Zone C was measured to be 7.82 pmC which is quite close to the level of 8.24 pmC at the PAWR observation well ZA035301AA of Zone C. PAWR determined the dating at this well as 18-24 thousand years, so the dating at the project site well belongs to the same dating group.

Hydrochemical data are compiled in Appendix with other related data already published by other institutions.

(3) Aquifer Properties

Hydraulic properties of Zone C aquifer determined by pumping tests at NJD-1, 2, 3 and 4 sites are presented in TABLE 4.1.2.

Similar values are computed by NJD-1, 2, 3 pumping tests, but NJD-4 tests does not produce consistent results at its observation wells. The presumable reason shall be discussed later. The representative hydraulic coefficients are to be around 4,000 m^2/day for transmissivity and 4×10^{-5} for storage coefficient.

Storage coefficient lies within the typical range for confined aquifer.

There appeared strong draw-down effect caused by the existence of aquifer boundaries in every constant-discharge pumping test at the project site. Typical diagrams are presented in FIG.4.1.11(1) and (2). The analytical diagrams were drawn by Cooper-Jacob method which provided such effect as several discrete change of linear gradient. FIG.4.1.11(1) shows such phenomenon. When pumping starts in a aquifer with boundaries, potentiometric water level around it behaves as if there are wells of same pumping rate beyond the boundaries at a mirror symmetrical position. Let r_0 the distance between the observation well and the pumping well and t_0 the required time to get ΔS drawdown at the observation well, then similar terms, r_1 and t_1, can be defined for the imaginary wells depicted in the diagram.

Following equation is derived:

$$r_1 = r_0 \sqrt{\frac{t_1}{t_0}}$$

The position of the imaginary well is to be determined by plural observation well configuration. Consequently the boundary can be drawn as a mirror plane between the pumping well and the imaginary well.

However, the observed diagram shown in FIG.4.1.11(2) cannot provide analysable pattern due to the excessive boundary effect.

Boundaries determined by the analysable data are presented in FIG.4.1.12. The position and direction of these boundaries seems to be alligned in admissible coincidence with the hydrogeological structure estimated through geophysical and geological explorations:
The boundary position is located in the vicinity of high and low resistivity boundary determined by the ELF-MT electro-magnetic survey and its direction is SW-NE in good accordance with the local groundwater flow direction and geostructural allignment.
The detected boundaries suggest Zone C aquifer developing in zonal pattern.

(4) Groundwater Level

Potentiometric levels and their fluctuation of Zone C aquifer were observed at the eleven existing wells and four newly drilled wells in the project area.

Regional flow system was detected to be SW-NE by the potentiometric contour map (see Hydrogeologic Map attached), and the gradient was calculated as 9×10^{-4}. At the proposed pilot farm site same direction was confirmed through the static water level observation in the four new wells, but the gradient was 2.2×10^{-4} (FIG.4.1.13).

The long-term trend of the regional potentiometric heads were estimated as -15 - -30 cm/yr through the observation during the project period of 1987 - 1989.

The automatically recorded hydrographs at the six wells showed typical earth-tidal phenomenon in which water levels oscillated with the amplitude of ca. 5 cm. This oscillation have to be considered when static levels are to be measured temporarily. These findings are presented in the attached Hydrogeological Map.

Above-mentioned facts seem to support the zonal flow system of fossil groundwater in Zone C aquifer, namely, the fossil water is flowing without current recharge through the confined aquifer in a quite large scale. The flow direction follows regional major geological structure and the water level proceeds a sustained decline. The potentiometric gradient characterised by such a declining head in fossil ground system is called the residual gradient in fossil groundwater.

TABLE 4. 1. 2

TABLE 4.1.2 Hydraulic Constants of Project Site Aquifer

PUMPED WELL	OBSERVATION WELL	TRANSMISSIVITY (m^2/day)				STORAGE COEFFICIENT($\times 10^{-5}$)		
		COOPER JACOB	THEIS TYPE CURVE	RECOVERY	AVERAGE	COOPER JACOB	THEIS TYPE CURVE	AVERAGE
NJD－1	NJD－1	—	—	3360	3360	—	—	—
					3.4×10^3			—
NJD－2	NJD－2	—	—	3130	3130	—	—	—
	NJD－1	3790	3900	3860	3850	4.47	3.65	4.06
	NJD－3	4690	3900	4930	4510	4.17	5.97	5.07
					3.8×10^3			4.6
NJD－3	NJD－3	—	—	3950	3950	—	—	—
	NJD－1	4940	4090	4650	4560	4.54	5.64	5.09
	NJD－2	4940	3440	4400	4260	3.71	5.27	4.49
					4.3×10^3			4.8
NJD－4	NJD－4	—	—	4370	4370	—	—	—
	NJD－1	4370	4620	4750	4580	2.04	2.78	2.41
	NJD－2	4750	5860	3640	4750	2.41	3.82	3.12
	NJD－3	5570	6630	4840	5680	6.82	7.87	7.35
					4.8×10^3			4.3
LOCAL AVERAGE					4.1×10^3			4.6

FIG. 4. 1. 5 Layout of Well Sites

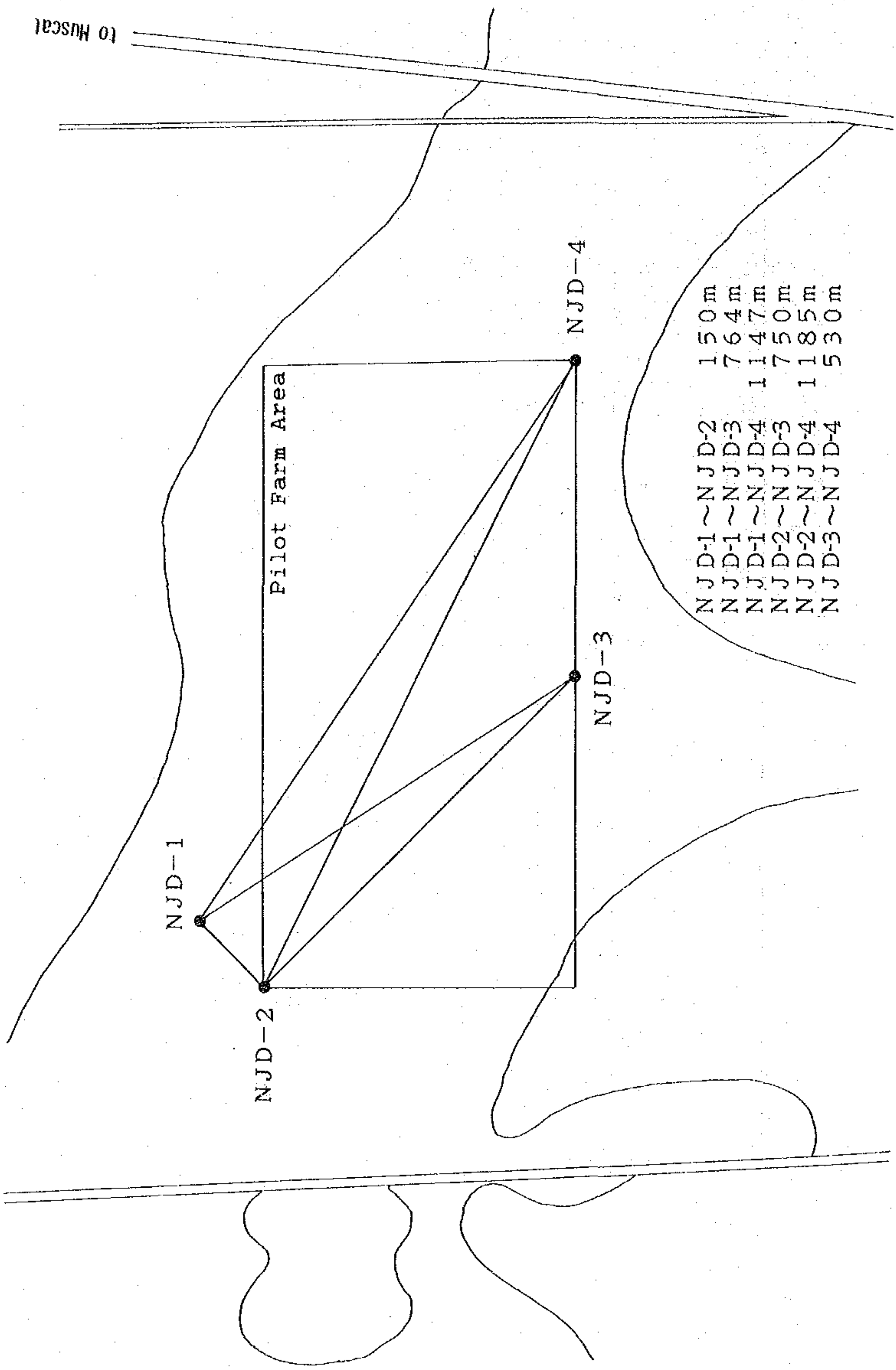


FIG. 4. 1. 6 Schematic Description of Tertiary Aquifers, Estimated for the Survey Area

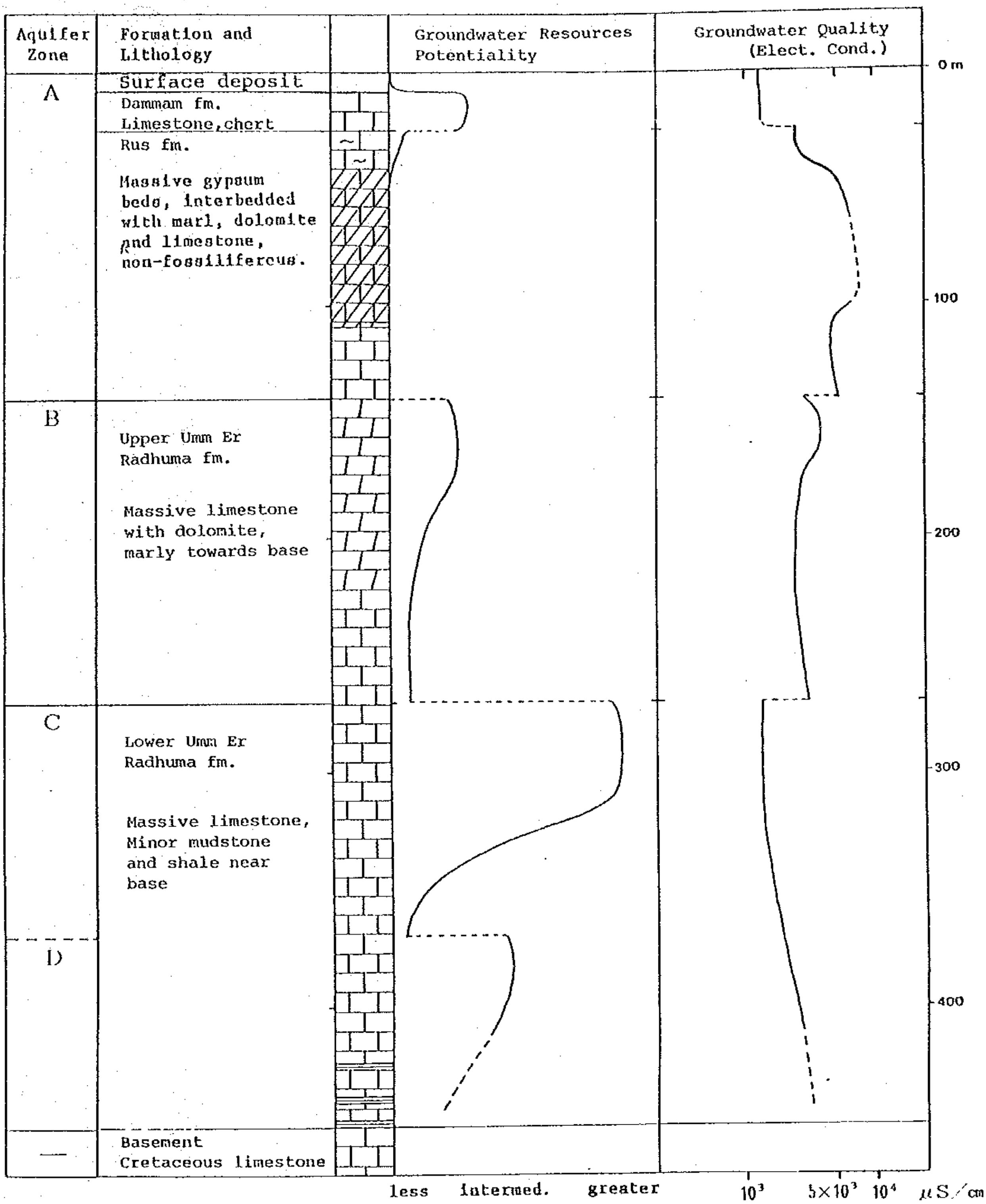


FIG. 4. 1. 7 JICA Observation Well NJD-1, Bore Hole Logging of Lower UER

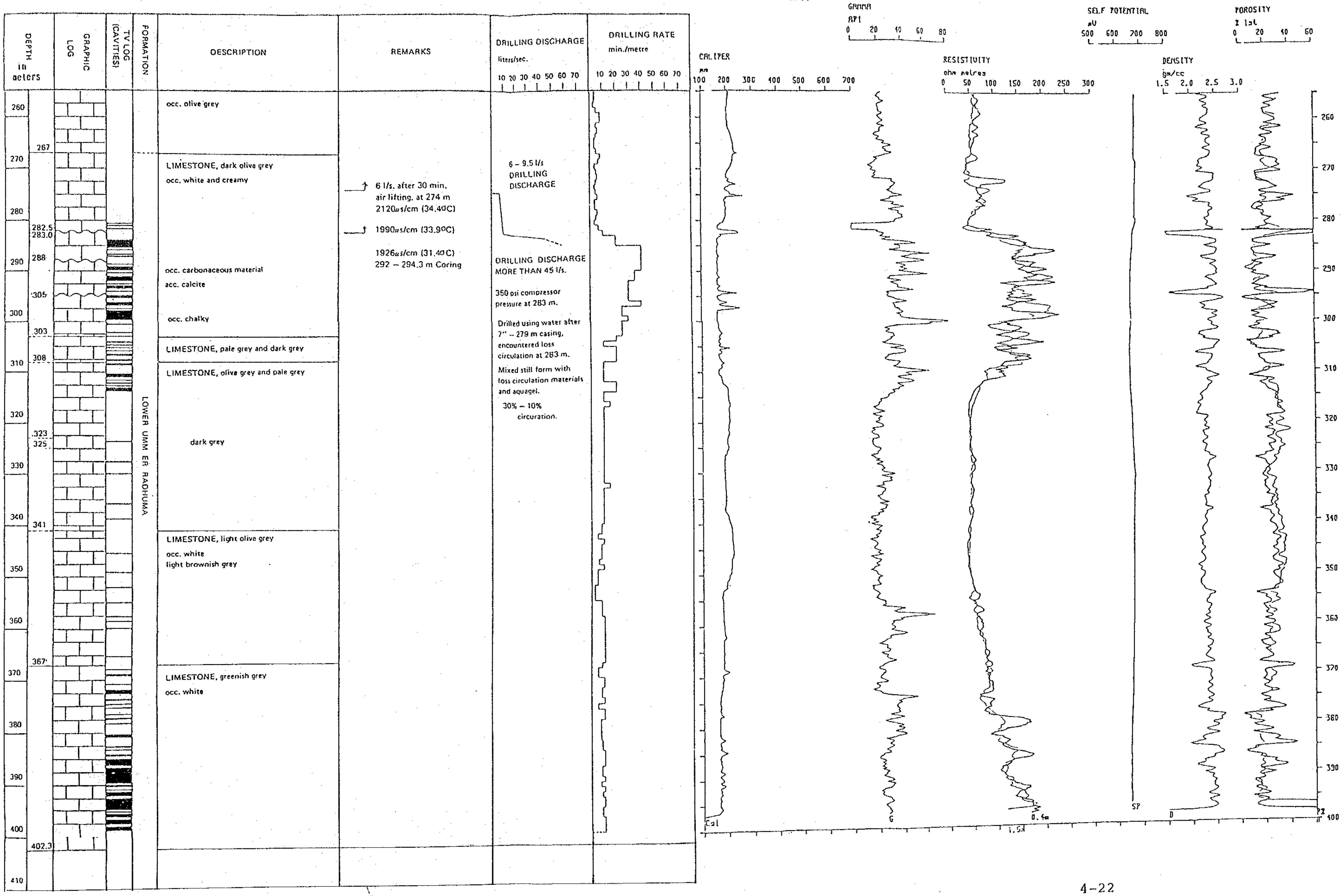
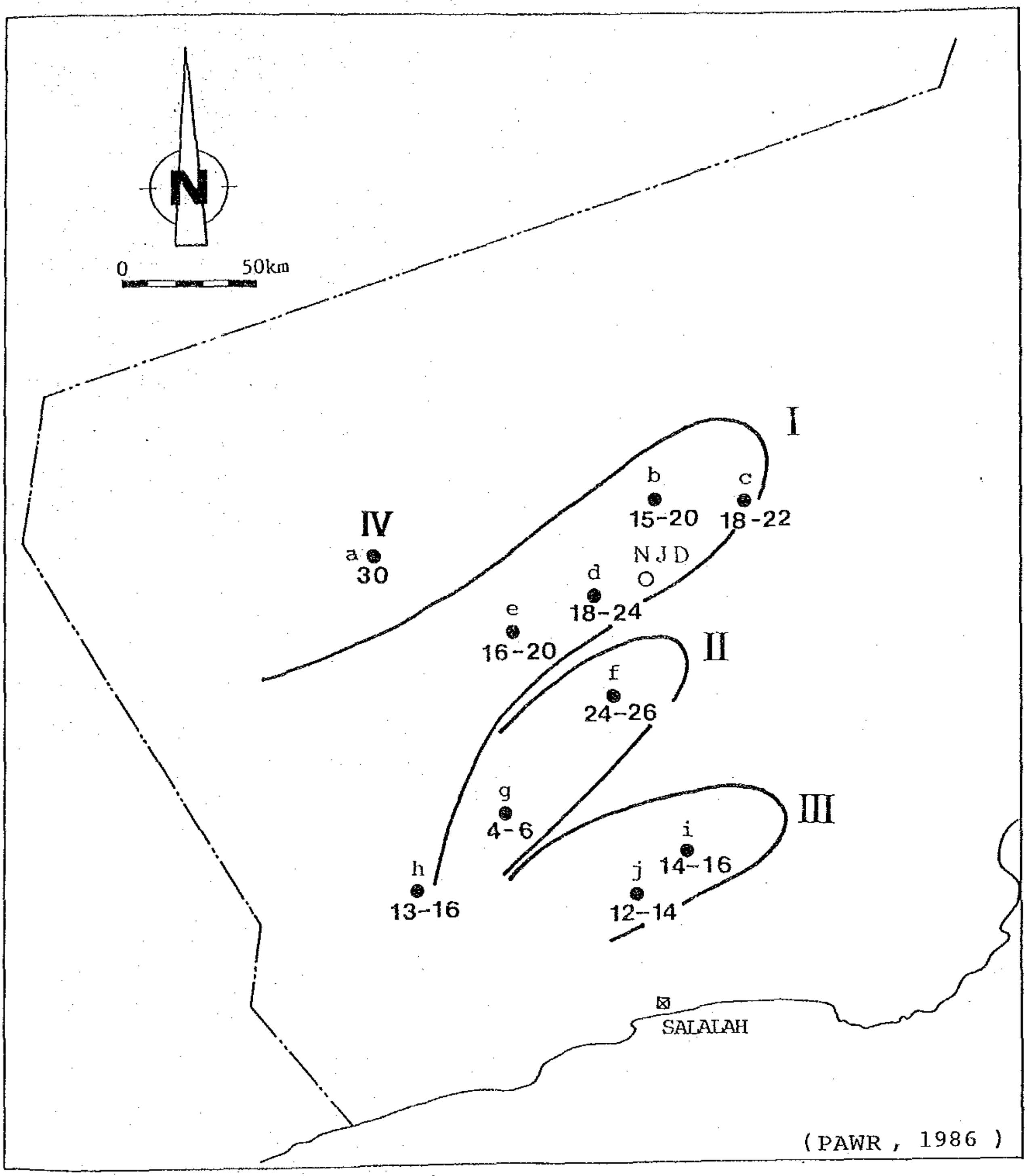


FIG. 4.1.8 Groundwater Dating(unit:1000years) and Flow Zones in the Nejd



Bore Hole Identification

a. YA243224AA	d. ZA035301AA	g. YV752600AA
b. AF961640AA	e. YA715978AA	h. YV424419AA
c. BF263460AA	f. ZV099779AA	i. BE045200AA
		j. AE827602AA

FIG. 4. 1. 9(1) Piper's Trilinear Diagram of Zone Ⅰ Groundwaters

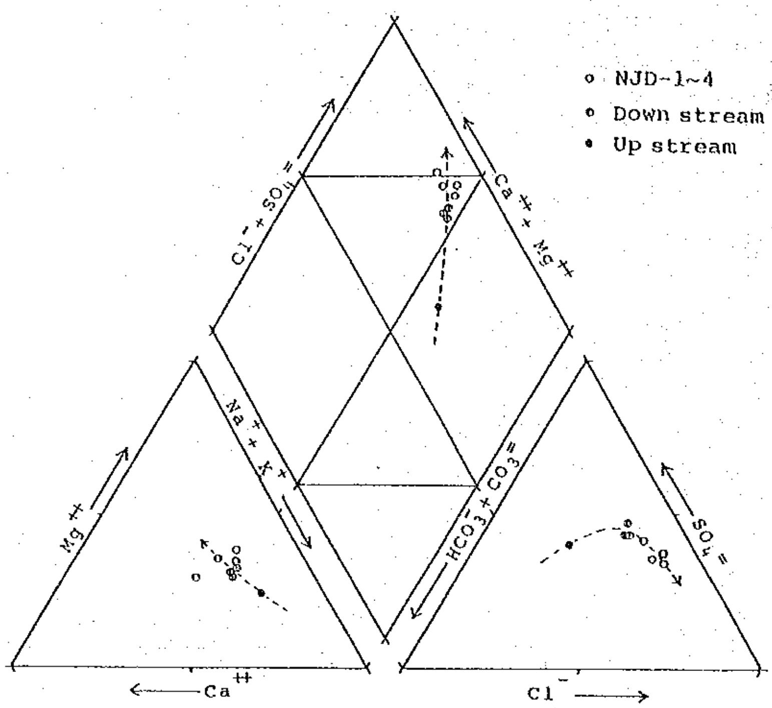


FIG. 4. 1. 9(2) Piper's Trilinear Diagram of Zone Ⅱ、Ⅲ and Ⅳ Groundwaters

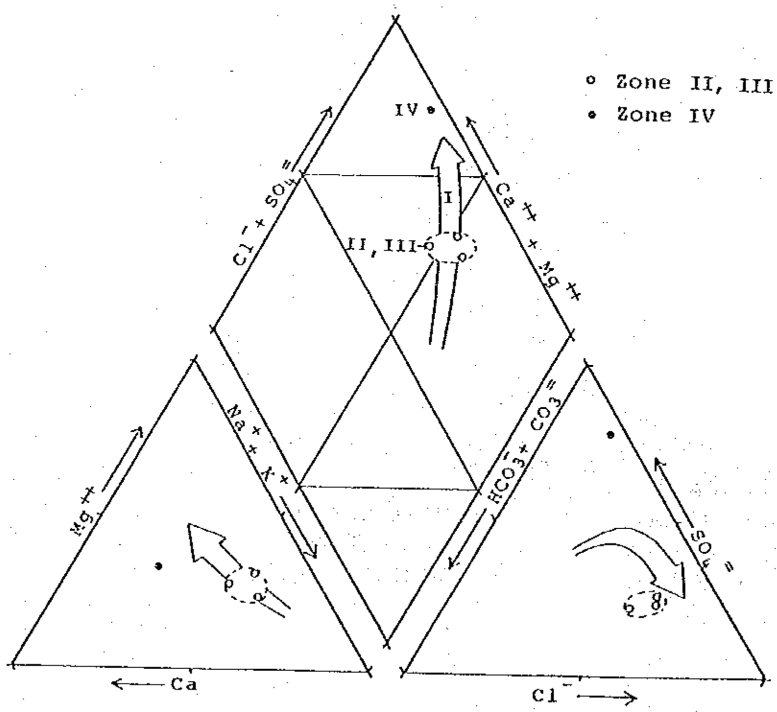


FIG. 4. 1. 10

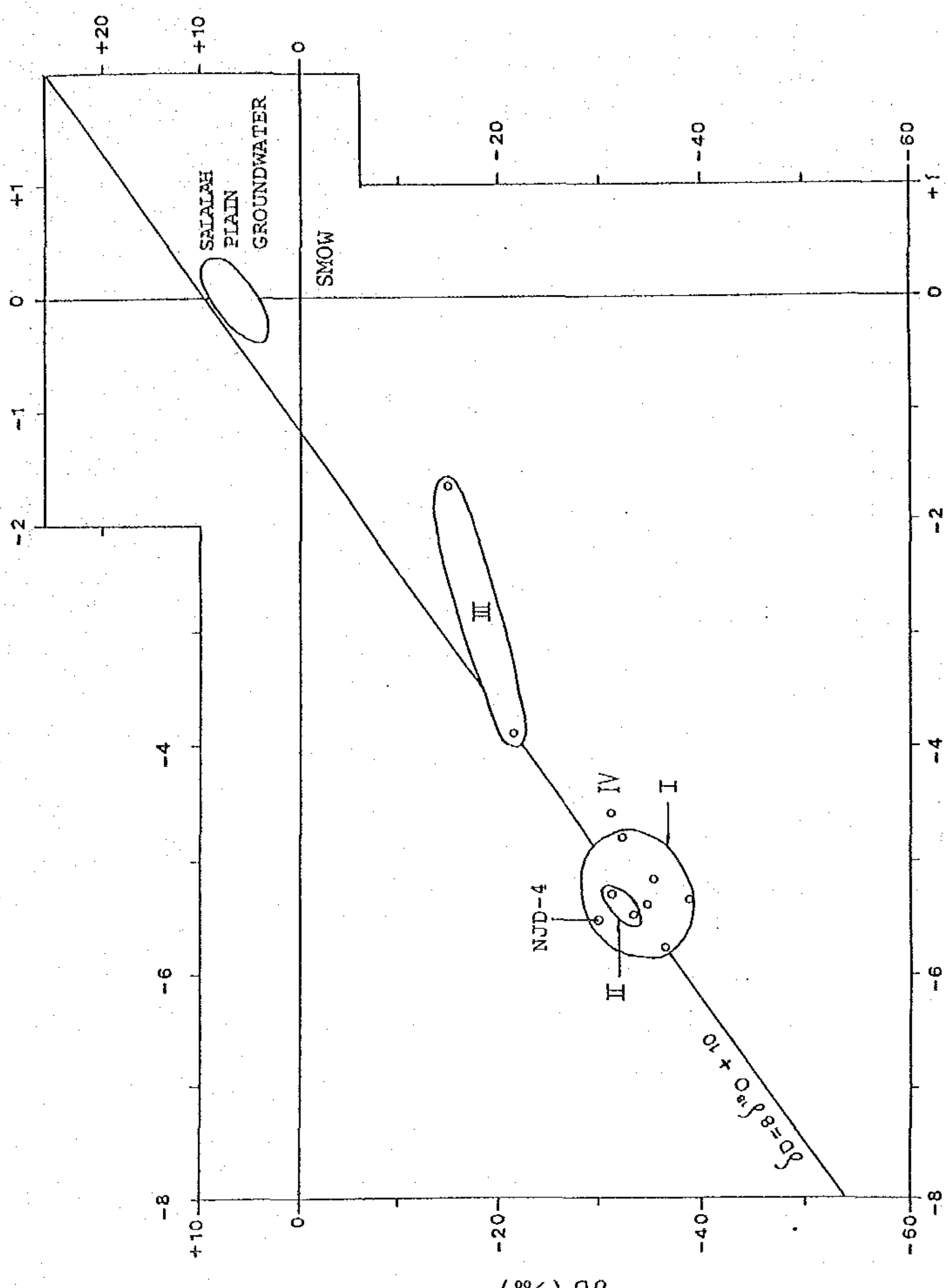


FIG. 4. 1. 10 Oxygen-18 and Deuterium Contents of UER Groundwaters

FIG. 4. 1. 11(1) s-t Plots of Constant Discharge Test at NJD-3

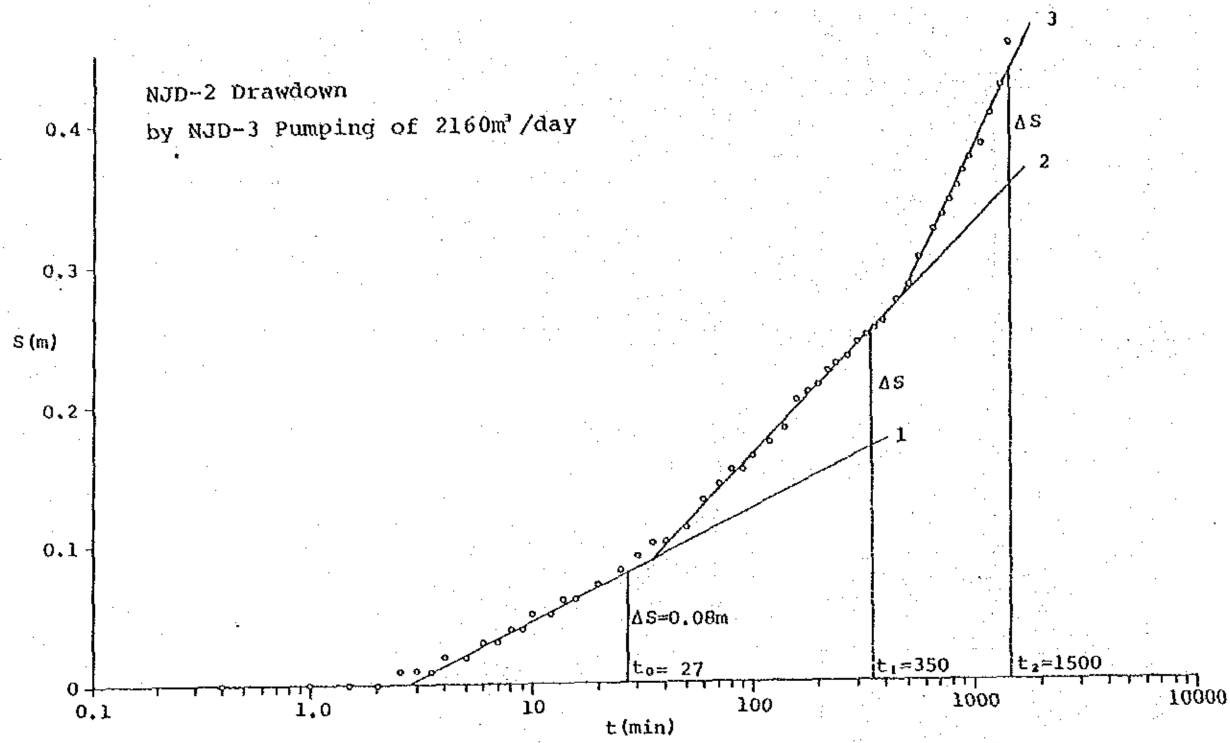


FIG. 4. 1. 11(2) s-t Plots of Constant Discharge Test at NJD-4

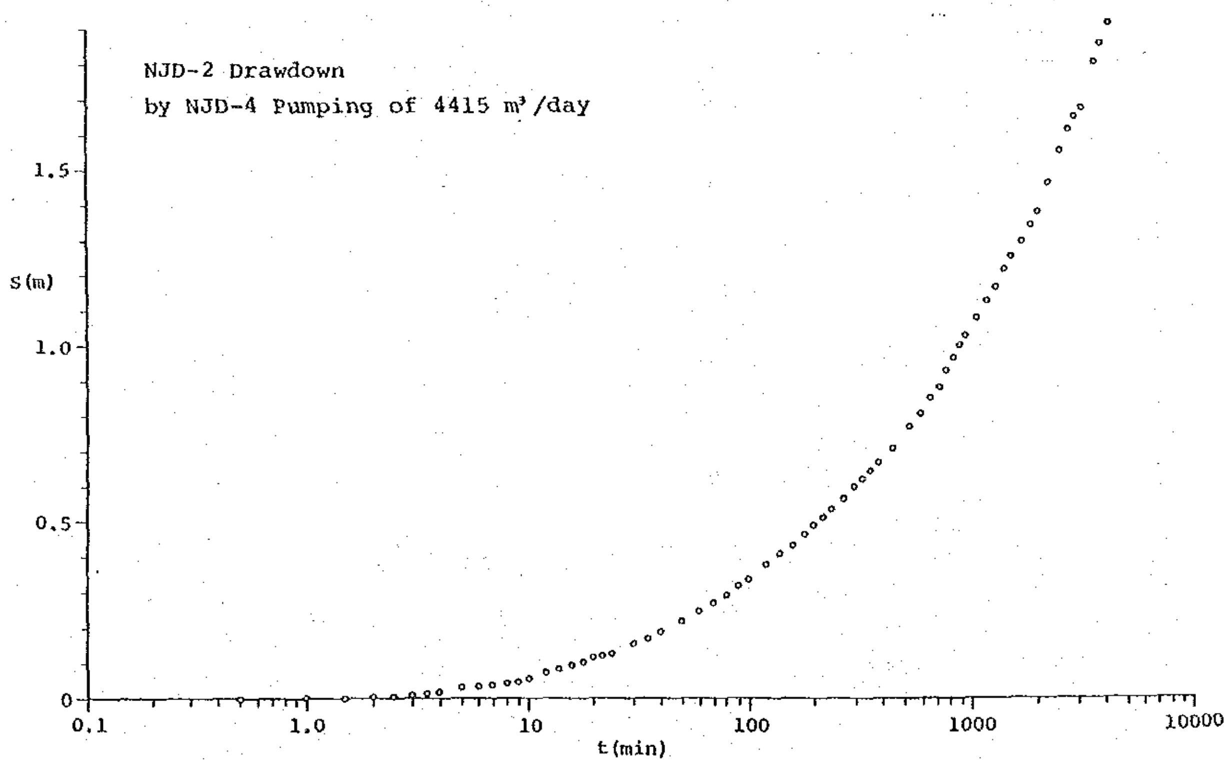
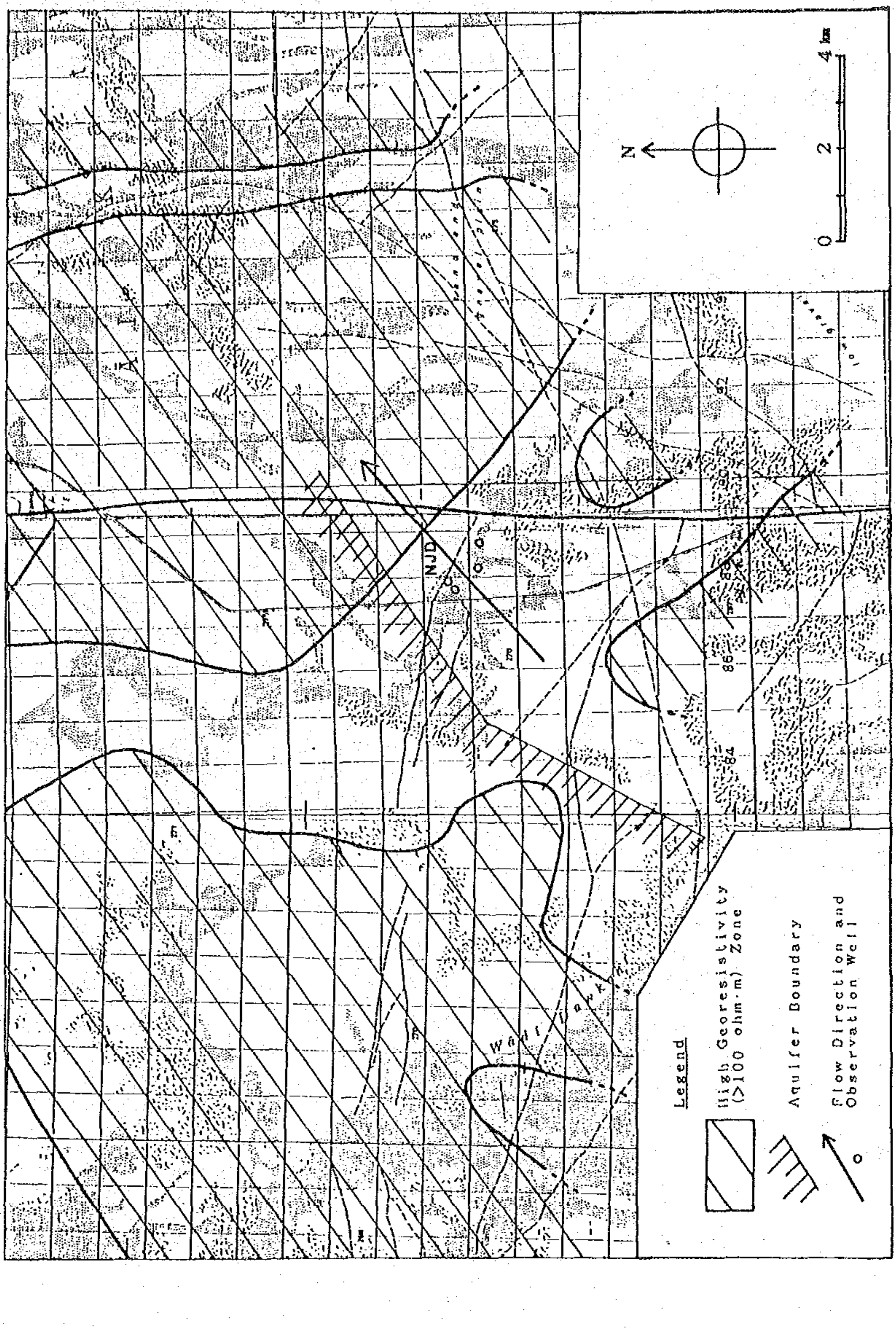


FIG. 4. 1. 12

FIG. 4. 1. 12 Estimated Horizontal Aquifer Boundary in the Project Site



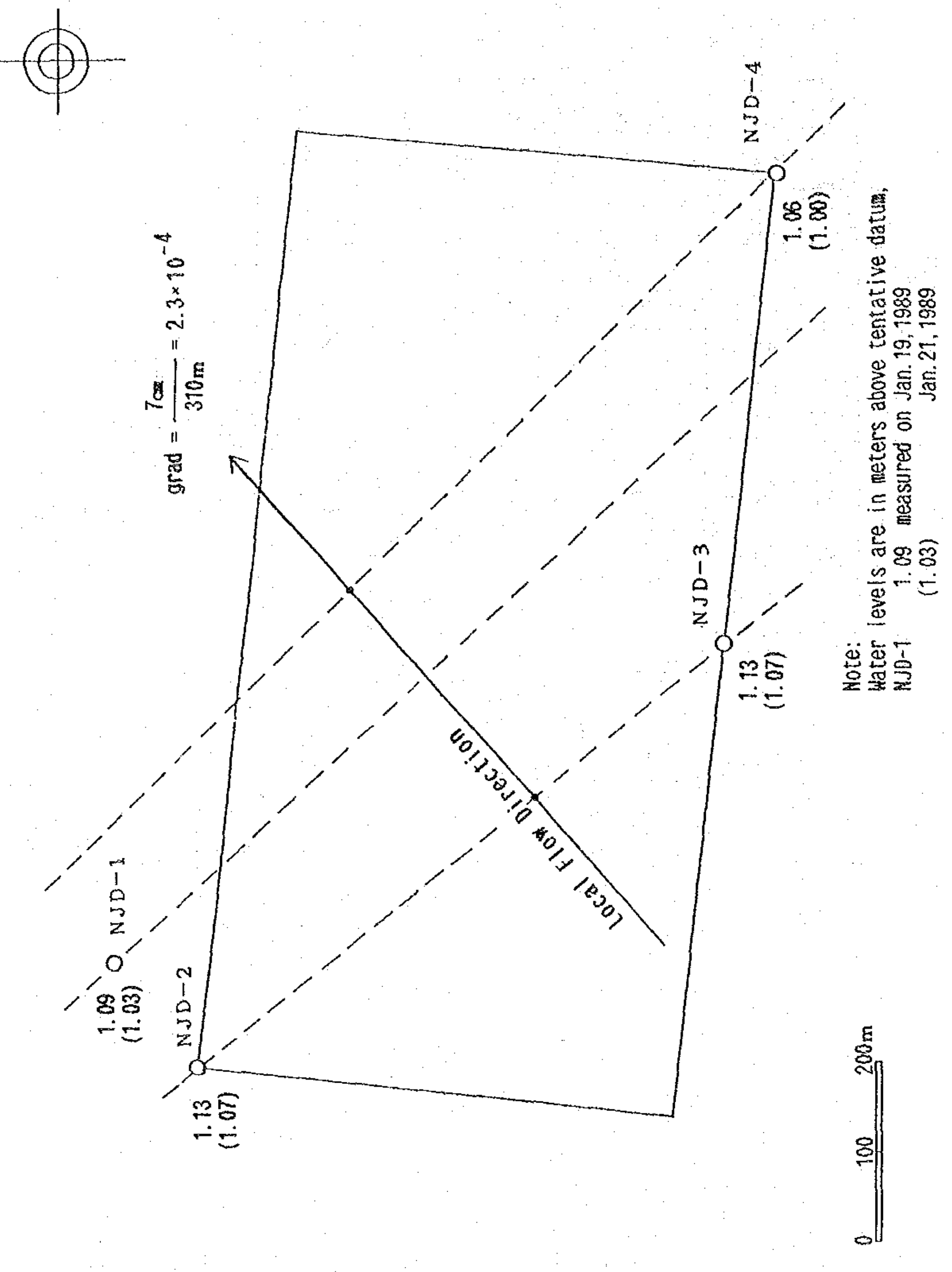


FIG. 4. 1. 13 Piezometric Contours of Lower UER Aquifer in Project Site.

4.2 Electric Prospecting

4.2.1 Outline

(1) Background

It is reported that the aquiferous formation in the Nejd is of Palaeogene limestone lying almost flat.

According to the existing data transmissivity varies widely, indicating the uneven distribution of groundwaters.

The groundwater is presumably concentrated in the zone with certain geological structures such as anticlines, faults, and fissures, in which solution channels or karstic structure may develop.

As such uneven distribution of groundwater may result in the diversity of ground resistivity, electric prospecting, with a detection depth of 500 m, was adopted for the present survey to detect the groundwater distribution.

(2) Method

Two prospecting methods, i.e. ELF-MT and Schlurmberger, were applied in stages to cover the widespread area of the Nejd within a limited period.

For the first stage, the ELF-MT method, was selected as the regional mapping method. This method can be easily practiced to determine the general trend of the local ground resistivity.

For the second stage, the Schlumberger method was applied to analyse vertical components of resistivity anomalies which were detected by the first stage.

1) ELF-MT method

This method (Extremely Low Frequency Magneto-Telluric method) utilizes the electromagnetic waves (Schumann resonance), which always exist on the earth, as the signal source.

By measuring the change in the electric and magnetic fields mutually orthogonal on the surface of the ground, the apparent resistivity of the point is obtained. The applicable frequencies are 8 Hz (the fundamental frequency) plus its harmonics. In this case only the frequency of 8 Hz was applied.

The apparent resistivity (ρ_a) is calculated by the following equation:

$$\rho_a = \frac{1.25 \times 10^5}{f} \left(\frac{Ex}{Hy}\right)^2 \quad \text{(Ohm.m)}$$

Ex : Electric field

Hy : Magnetic field

f : Frequency (Hz)

The depth of exploration is usually given by the skin depth (σ) of the electromagnetic field:

$$\sigma = 500 \sqrt{\frac{\rho}{f}} \quad \text{(m)}$$

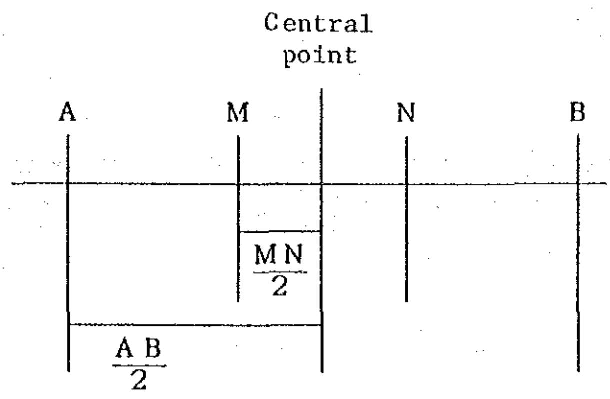
ρ : Resistivity of the ground (Ohm·m)

f : Frequency (Hz)

When the average resistivity of the earth is 8 Ohm·m, the skin depth (σ) is calculated as 500 m.

2) Schlumberger Method

The configuration of electrodes are shown in the following figure:



In the above figure, electrode A and B are transmitter poles and electrode M and N are receiver poles.

The resistivity structure along the vertical direction down in the ground from the central point can be analized by using the combination of the apparent resistivity ρ_a (Ohm·m) and the distance AB/2 (m) varying from 6 to 1,500 m.

The apparent resistivity (ρ_a) is calculated by the following equation:

$$\rho_a = K \times \frac{V}{I} \quad \text{(Ohm·m)}$$

V : Receiving voltage (V)

I : Transmitting current (A)

$$K = \pi \times \{ (\frac{AB}{2})^2 - (\frac{MN}{2})^2 \} / MN$$

There are two analysing methods: the standard curve matching method and the model calculation method. In this survey, the latter method was applied, using a computer.

(3) Geology and Geological Structure of the Area

Geology of the area is composed of the base rock of Precambrian and sedimentary rocks of Palaeozoic to Tertiary. The base rock is mainly gneiss and sedimentary rock consists mainly of limestone with some sandstone, shale and mudstone. Thin fluvial deposits are found along the wadi course.

According to the MPM's data, the geological structure of this area develops along SW-NE direction (see FIG.4.1.3 and FIG.4.1.4).

The target aquifer of this survey work lies in Umm Er Radhuma formation (hereinafter refered to as UER fm.) of Palaeogene and is almost horizontal in the area.

(4) Limitation of the Survey Area

Although the ELF-MT is an easy method, survey period was not long enough to cover the entire area. Therefore, it was necessary to limit the size of the survey area.

Because of this limitation, the Landsat Image analysis was carried out to extract the lineaments of SW-NE direction, which passes through Southern Dauka. If this lineament is a fault, it may be a hopeful sign that groundwater is concentrated there. According to the PAWR report, water wells, drilled on or around a lineament, were usually successful.

Southern part of Dauka, near the highway, is also located near the southern boundary of flowing well zone. So, further survey works were concentrated in this area.

4.2.2 Result of Survey

(1) Results of Survey by ELF-MT Method

FIG.4.2.1 shows the distribution of apparent resistivity determined by the field survey.

More than 10 measuring lines were surveyed.

Electric prospecting was carried out in the five designated places (Dauka, Wadi Mokhawrim, Shasr, Quitbeet and Hanfeet). In addition, south of Dauka and Hailat Al-Rakah, both located at the center of the project area, were surveyed.

The value of apparent resistivity was in the range from 10 to 3000 Ohm·m.

Hereinafter, resistivities more than 100 Ohm·m will be treated as high apparent resistivity; anything less than this is low.

1) The distribution of high and low apparent resistivities were surveyed at each place.

2) As for the general tendency, the apparent resistivity tends to be high on the gravel hills and low along the Wadi.

3) South of Dauka, located in the central part of the survey area, around the highway junction to Hailat Al-Rakah, low apparent resistivity zone was found. The central part and the southern part of the low anomaly showed a direction of SE-NW which may correspond to the fault in the basement rock.

4) The northern side of this low apparent resistivity zone is connected to the wider low apparent resistivity zone of SW-NE direction. Along southern boundary of this wider low apparent resistivity zone and the high resistivity zone a lineament of SW-NE was located.

5) The distribution of these apparent resistivity zones shows a direction of SW-NE which is same as the main trend of the geological structures in this area, suggesting wider geological structures.

For example, the location of the low apparent resistivity zone found in Wadi Mokhawrim corresponds to the location of above mentioned lineament and connects with the wider low apparent resistivity zones in southern Dauka and Shasr. This feature suggests the possibility of the presence of a big low apparent resistivity zone with a SW-NE direction.

Similarly, the low apparent resistivity zones found at Quitbeet and Hanfeet may possibly be connected to each other and having an SW-NE direction. At the same time, high apparent resistivity zone, found at Quitbeet and Hanfeet, may possibly be connected to each other and to other high zones at southern Dauka to form a big high apparent resistivity zone with the SW-NE direction.

(2) Result of Survey by Schlumberger Method

In order to analyse the vertical distribution of resistivity at the point of apparent resistivity anomaly, obtained by ELF-MT method, Schlumberger method was applied.

Fourteen surveying points were explored.

The location of the surveying points are shown in FIG.4.2.1 and the results of analysis are shown in FIG.4.2.2(1), (2). The Vertical Electric Sounding (VES) curve and analysed results are shown in Appendix.

In FIG.4.2.2(1), (2), the geological columns of the existing wells are also shown. Each well is connected by straight lines since the geological structure of the Tertiary in this area seems to be simple and flat.

1) Correlation with the Existing Data of Groundwater to the Survey Points

a. Correlation of Existing Well W5 (ZA035301AA) with Surveying Point No.10

This is a flowing well located 7 km north of Hailat Al-Rakah.

A volume of 14.3 lit./sec of groundwater comes from the boundary between upper UER fm. and lower UER fm. (hereinafter referred to as U/L Boundary) at the depth of 240 m. In addition, another aquifer joins the above with a water quantity of 1 lit./sec at the depth of 166 m. Surveying point No.10 is located about 100 m east of well W5.

Upper UER fm. is divided into two resistivity zones; low and high. Above mentioned two aquifers and lower UER fm. are grouped into the high resistivity zones.

b. Correlation of Existing Well WA3 (AF920700AA) with Surveying Point No.11

This well was drilled when the national highway was constructed. It has an aquifer in Rus fm. with a depth of 48 m and another in the upper UER fm. with a depth of 154 m.

These two aquifers were analysed to hold one low resistivity zone. The lower part of the low resistivity zone becomes a high resistivity zone; the same is analysed in the well W5.

c. Correlation of Shallow Wells at Hailat Al-Rakah with Surveying Point No.9

At Hailat Al-Rakha, many shallow wells, with a depths of more or less 15 m, were excavated, and farms were developed by applying irrigation from these wells.

The surveying point is located between two agricultural farms and about 300 m from a shallow well.

As the results of analysis, two strata with low resistivity have been found. One is very shallow, and the other is located in a deeper place near U/L Boundary.

The VES curve at this surveying point, the value of apparent resistivity (ρ_a) did not increase substantially even where the distance between electrodes (AB/2) was increased. Therefore, intermediate but not high resistivity zones were analysed even at lower UER fm.

2) Survey Works of the Proposed Site for the Pilot Farm

a. Site 1: Surveying Point Nos.2, 13 and 8

Site 1 is located in a Wadi in southern Dauka which belongs to the southern part of a low apparent resistivity zone found by ELF-MT method. A considerable amount of soil is accumulated there.

Surveying point No.13 is located near the center of the site. No.2 is at southeastern edge of the site and No.8 is about 4 km to the southwest.

At these surveying points, the results of analysis show the presence of the low resistivity zone at deeper levels including U/L Boundary.

And at surveying points No.2 and No.13, in a zone from ground surface to the intermediate depth, there are only intermediate resistivity zones without low resistivity zones.

b. Site 2: Surveying Points Nos. 3 and 4

This site is located near the northern end of a low apparent resistivity zone that includes Site 1.

Surveying points No.3 and No.14 are in the area of Site 2.

The results of analysis shows both surveying points of Nos.3 and 14 are mainly of intermediate and high resistivity except for a thin layer of low resistivity zone located at the shallow level correcponding to Rus fm.

At survey point No.3, lower UER fm. does not show high resistivity, but low resistivity.

c. Surveying Points Nos.5, 6 and 12

These surveying point are located around the Site 2.

No.5 is 4 km to the northeast, No.6 is 3 km to the west and No.12 is 8 km to the north of Site 2.

The results from surveying point No.6 is quite similar to that of surveying point No.3. It has intermediate resistivity up to the depth of U/L Boundary.

The results from surveying point No.12 is same as for No.11.

d. Site 3: Surveying Points Nos. 4 and 7

This area is located in the low apparent resistivity zone found by ELF-MT method near Dauka. Surveying point No.7 is located at the center of Site 3, and No.4 is 5 km away from No.7 to the southeast.

Rus fm. at the both surveying points, Nos. 4 and 7, turned out to be low resistivity zones. A surveying point No.4, there is a low resistivity zone at the low level of upper UER fm.
In case of No.7, it has intermediate resistivity down to its deeper portion.

3) Other Surveying Point (No.1)

This point is analysed as a intermediate resistivity zone at the level corresponding to Dammam fm. Upper UER fm. is analysed as a low resistivity zone, and U/L Boundary is a zone having less resistivity than upper UER fm.

Lower UER fm. is analysed as an intermediate resistivity zone.

4) Commentary

The resistivity of the ground is mainly controlled by formation porosity and groundwater quality.

The groundwater at the Nejd has electric conductivity around 2,000 S/cm.

Thus, if an aquifer is thick enough in regard to its depth, it may be detected as a low resistivity stratum. For example, in case of well WA3, two aquifers in upper UER fm. are analysed as low resistivity zones. The shallow well aquifers at Hailat Al-Rakah are also analysed as low resistivity zones.

On the other hand, at the flowing well W5, any low anomaly was not detected perhaps due to the thin aquifer thickness.

At surveying points Nos. 8 and 13 of Site 1, no low resistivity zone was analysed at the shallow depth. This coincides with the fact that a shallow well excavated in the area failed to find any groundwater.

At many surveying points, upper UER fm. zones tend to be divided into low and high resistivity zones, while lower UER fm. is often analysed as high resistivity zone.

This tendency coincides with the previously reported fact that there are number of good aquifers in upper UER fm., but less aquifers in lower UER fm.: There is more solution channels or karstic structure in upper UER fm. than in lower UER fm.

However, aquifers at U/L Boundary are used to be good. In case low resistivity zone is analysed near this boundary or in lower UER fm., aquifers may develop with extensive solution channels.

Since at Site 1, 2 and 3 low resistivity zones had been analysed at U/L Boundary or even in lower UER fm., successful hit into groundwater can be said very possible.

Actually an excellent aquifer was hit at the Project Site in Site 1.

For the wide range groundwater survey ground resistivity mapping is regarded as effective. In particular ELF-MT method is less costly and less time-consuming. In addition, this method can discriminate shallow and deep zones when multi-frequency probe is to be applied.

In the further stage of groundwater exploration this method should be taken into positive consideration.

FIG. 4. 2. 1 Apparent Resistivity Map by ELF-MT Method (8Hz)

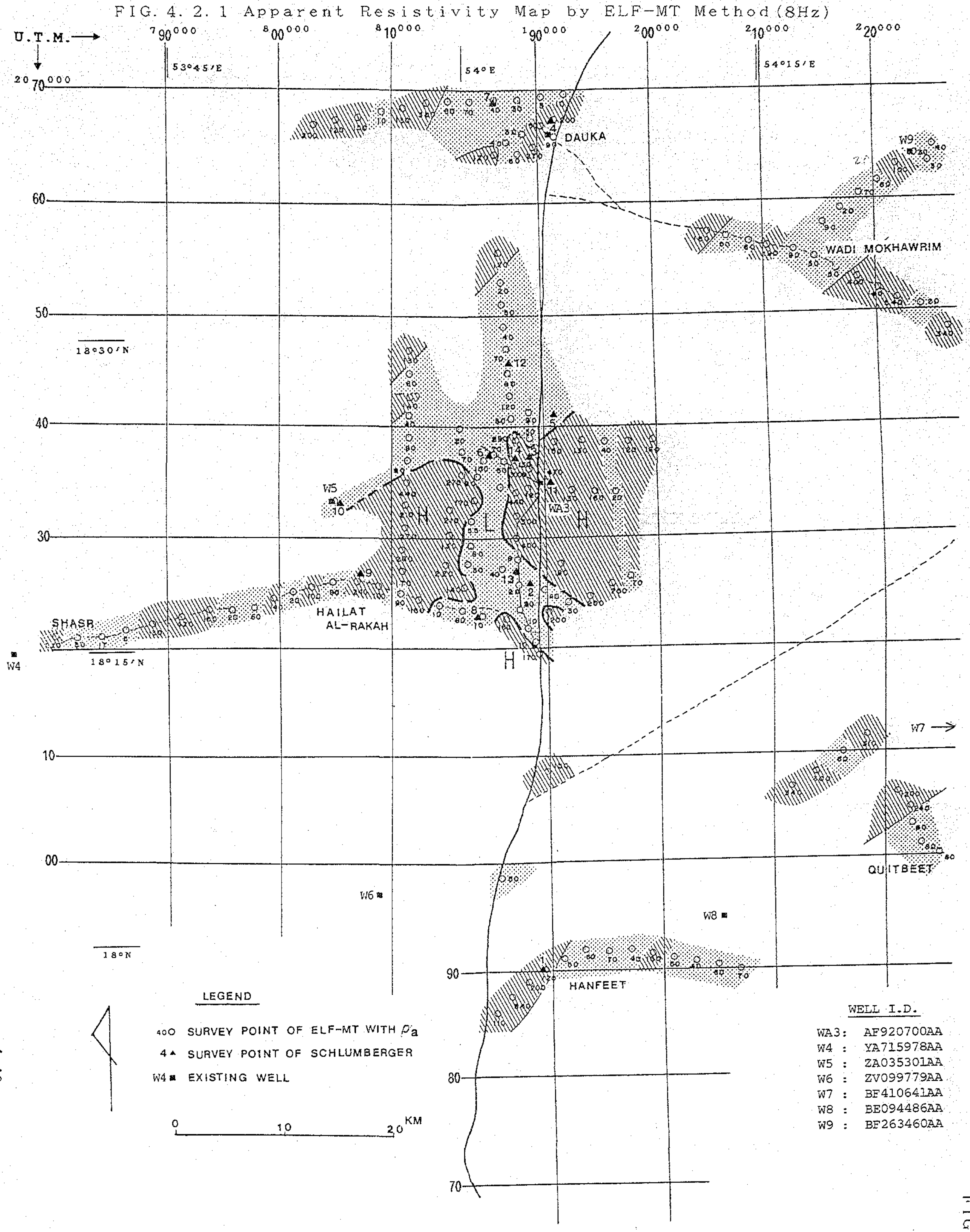


FIG. 4. 2. 2(1) Resistivity Profile by Schlumberger Method (W4-W5-WA3-W9)

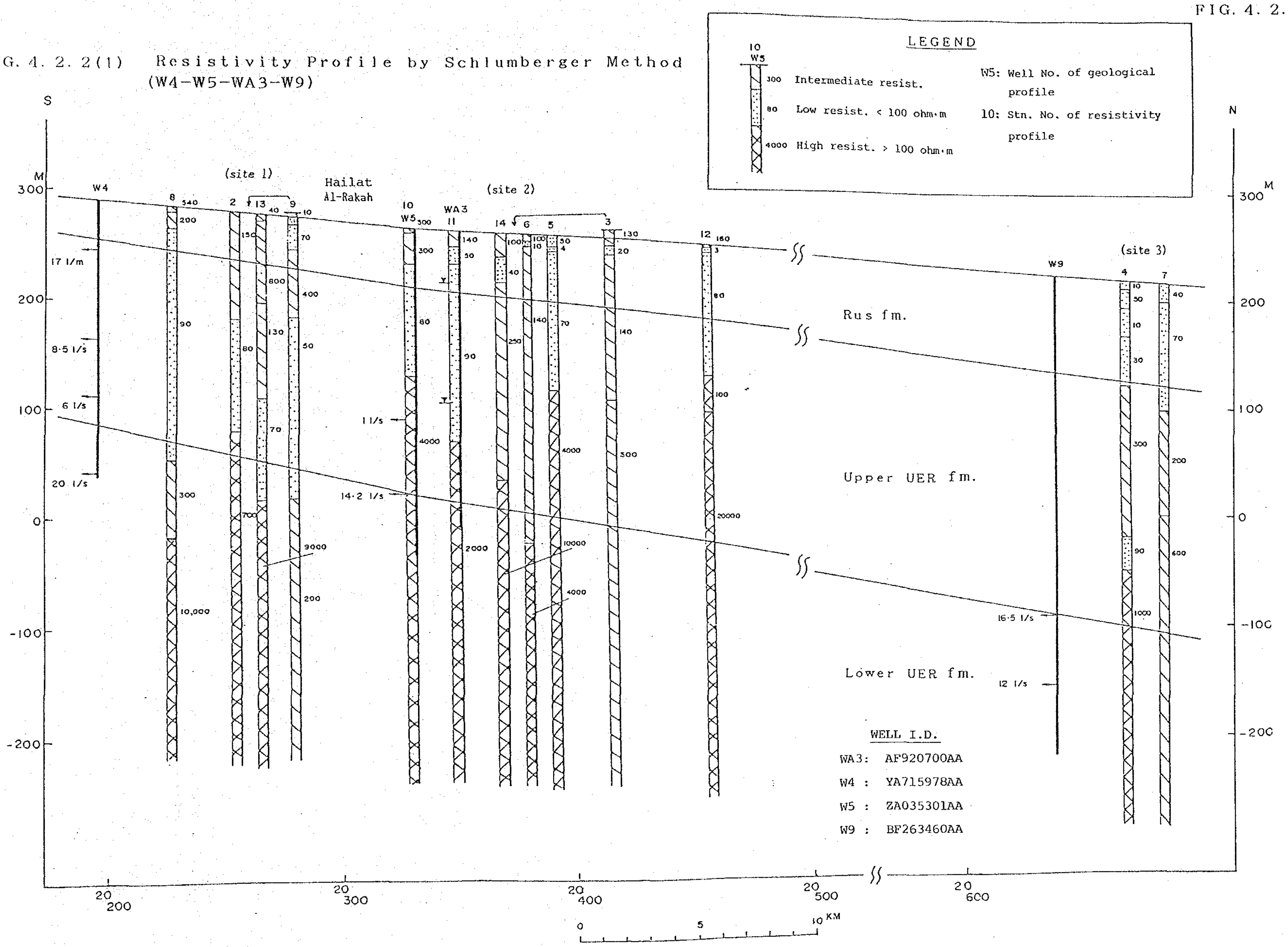
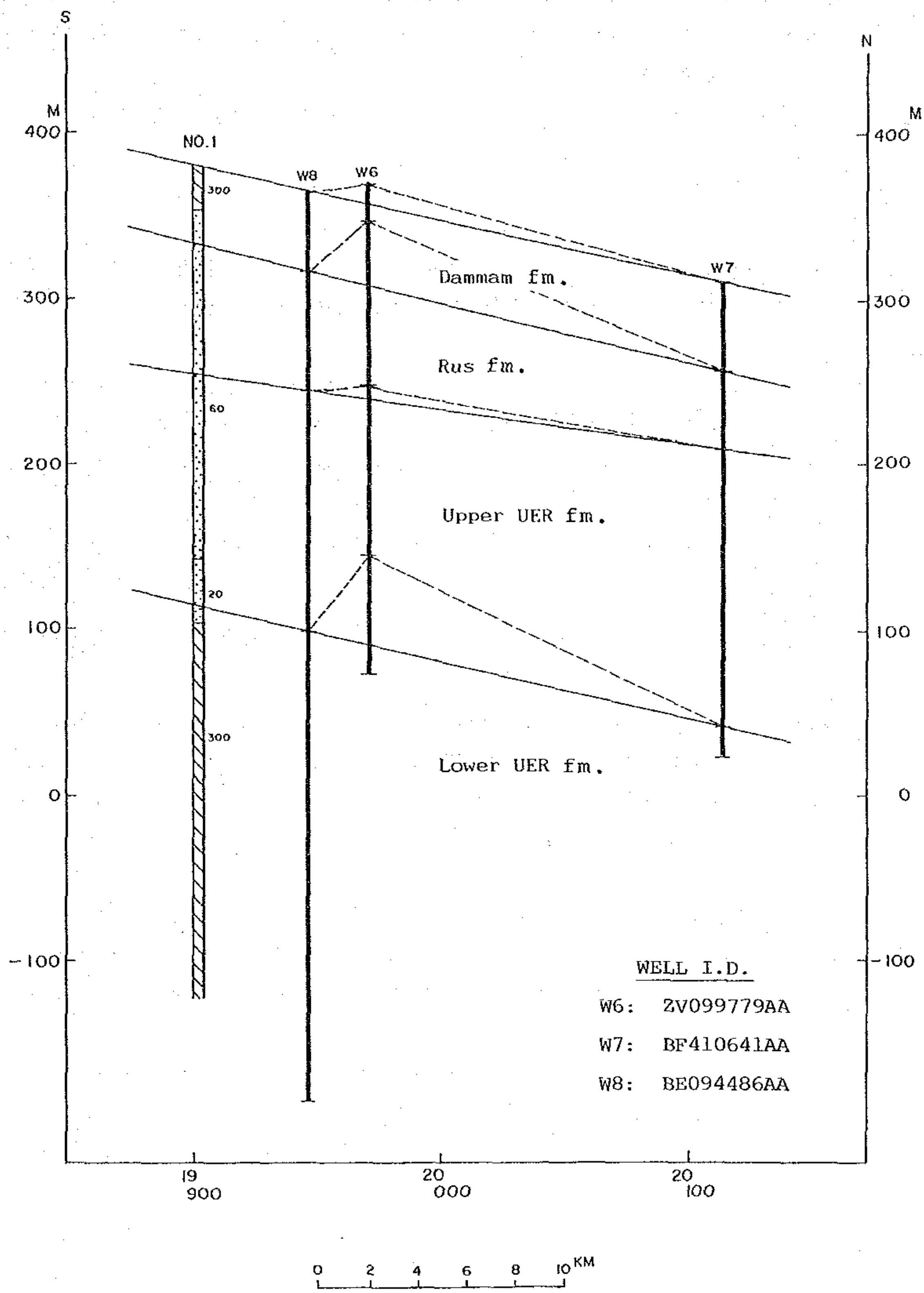


FIG. 4. 2. 2(2) Resistivity Profile by Schlumberger Method (W8-W6-W7)



4.3 Exploration Drilling Works

4.3.1 Outline

In order to evaluate groundwater with a view of developing agriculture in the Nejd and secure the water source for the planned Pilot Farm, two observation wells and two test wells were drilled in a promising area.
Well structures are so designed as to achieve above mentioned aims.

(1) Well Drilling Schedule and Method

Exploration drilling works were designed and practiced as specified in the following table. Details are given in Appendix.

Specification of Exploration Drilling Works

Study Phase	Well No.	Well type	Depth (m)	Borehole Dia. (mm)	Casing Dia. (mm)
Phase I (1987)	NJD-1	Observation Well	400	152-444	178-245
Phase II (1988)	NJD-2	Test Well	350	216-610	245-340
	NJD-3	Observation Well	350	152-444	178-245
	NJD-4	Test Well	350	216-660	245-340

Based on the results of the preceding groundwater investigation, drilling works were planned down to lower UER formation which held fairly good water in quality and quantity for irrigation purpose. The details are as follows.

1. Test Well : Test well shall be converted into production well, once farming will start at the site.
350 meter depth was required in order to secure necessary water resource from lower UER formation for the production pumpage in the future.

2. Observation well: The same depth as test well was designed for long term observation of groundwater.

The drilling were undertaken by a local contractor and supervised by the study team.

(2) Arrangement of Well Locations

Arrangement of four wells (FIG.4.1.5) were made as the followings.

1) The location of two test wells were decided by the farm design since they are scheduled to be converted into production wells. The location was set to keep the largest inter-well distance in order to minimize interference to each other.

2) The configuration of test wells and observation wells was decided to be applicable to pumping tests and groundwater observation. The groundwater flow of SW-NE direction, estimated by hydrogeological investigation, was taken into consideration.

(3) Drilling Method and Well Structure

1) Drilling Method

Wells were drilled by foam-air drilling with tricone bit driven by a truck mounted rotary table rig.

2) Well Structure

The well specifications (drilling depth and diameter) were made based on the depth of main aquifer and future utilization plan of each well. The well structure (casing program) was designed after the following points, extracted from the drilling experiences of local contractors:

The geology mainly consists of limestone with some marly horizons. At several levels solution cavities or fissures develop. Some of them form aquifers but not always of sufficient quantity and quality. Due to these conditions there are thief zones to which groundwater leaks from other aquifers. The major aquifer is located in lower UER formation with a high piezometric pressure.

For the development of lower UER aquifer, some countermeasures are required in order to prevent leakage to thief zone or mixing from saline aquifers (PAWR Report 86-I-13).

At the present project work the annular bore hole space was cemented at the troublesome horizon to prevent the groundwater mixing between upper and lower aquifers.

(4) Well Construction Work

1) General Outline of Work Items

a) Drilling work

- Drilling of observation well (NJD-1, NJD-3) Sole dia. 6"
- Drilling of test well (NJD-2, NJD-4) Sole dia. 8 1/2"

b) Appurtenant work

- Borehole geophysical logging
- Sampling of geological specimens and micro-fossil specimens
- Pumping test (Step discharge test, constant discharge test)
- Fencing work

2) Details of Construction Work

a) Drilling work

Drilling depth, drilling diameter and casing installation depth of each well are given in Appendix.

b) Borehole geophysical logging

The following geophysical loggings were carried out at each well prior to the casing installations.

Temperature logging
Electric conductivity logging
Caliper logging
Natural gamma logging
Electric-resistivity logging
Self-potential logging
Flow logging
Neutron logging
Density(gamma-gamma) logging

Temperature logging, electric conductivity logging and flow logging were done after completion of all drilling works.
In addition TV logging was carried out at every bore hole.

c) Sampling

Cutting samples were collected at every one meter depth during drilling. However, in the range of lost circulation drilling, cuttings were collected at every 10 meters depth. Core samples were collected at the following depths.

NJD-1	144.0 - 147.0m,	240.0 - 242.5m
	292.0 - 294.3m,	400.0 - 402.3m

NJD-2	90.0 - 93.0m,	185.0 - 187.0m
	274.0 - 276.3m,	297.0 - 300.3m
	315.0 - 318.3m,	350.0 - 353.2m
NJD-3	46.0 - 47.97m,	100.0 - 102.0m
	200.0 - 203.0m,	265.0 - 267.5m
	285.0 - 287.5m,	305.0 - 307.2m
NJD-4	20.0 - 22.46m,	40.0 - 42.85m
	130.0 - 133.0m,	260.0 - 263.0m
	280.0 - 283.0m,	290.0 - 293.0m
	300.0 - 303.0m,	310.0 - 313.0m

d) Micro-fossil analysis

The analysis was entrusted to BRGM (Bureau de Recherches Geologiques et Minieres) in France.

Micro-fossil analysis was done on the cutting samples and core samples as shown below.

NJD-1	145.70 m	Core sample
	159 - 160 m	Cutting sample
	187 - 188 m	Cutting sample
	219 - 220 m	Cutting sample
	242.50 m	Core sample
	264 - 265 m	Cutting sample
	275 - 276 m	Cutting sample
	292.60 m	Core sample
	349 - 350 m	Cutting sample
	402.30 m	Core sample

NJD-2	274.00 m	Core sample
NJD-3	267.00 m	Core sample
NJD-4	20.30 m	Core sample
	40.00 m	Core sample
	130.50 m	Core sample
	262.00 m	Core sample

e) Pumping test

After the completion of each well, step discharge test and constant discharge test were carried out by a submersible pump.

Well configurations for pumping test are as follows,

Pumping well	Observation well
NJD-1	Single well test
NJD-2	NJD-1, NJD-3
NJD-3	NJD-1, NJD-2
NJD-4	NJD-1, NJD-2, NJD-3

(5) Work Execution

Executed works are recorded as in FIG.4.3.1(1), (2).

FIG. 4. 3. 1 (1) Drilling Record of NJD-1

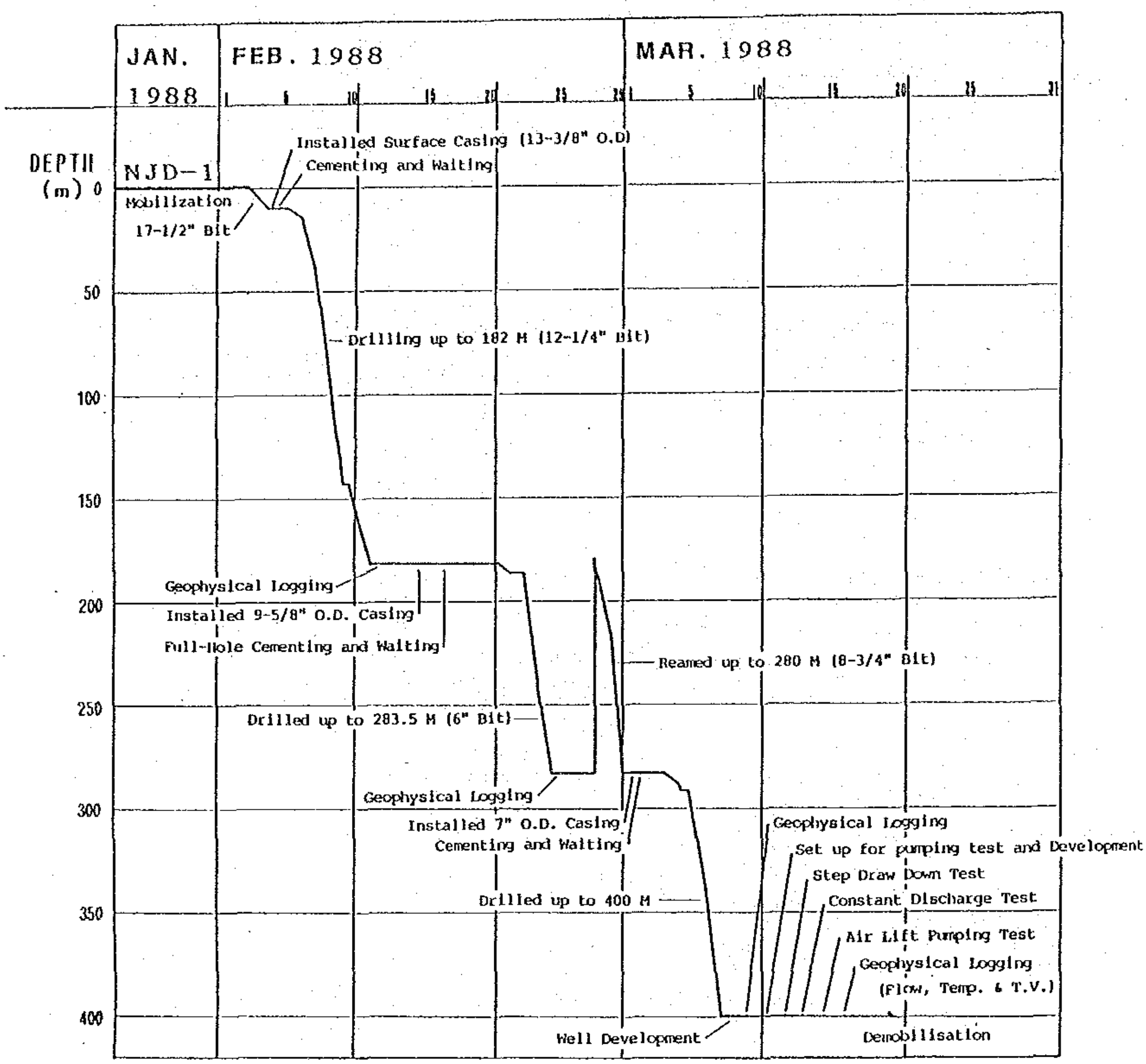
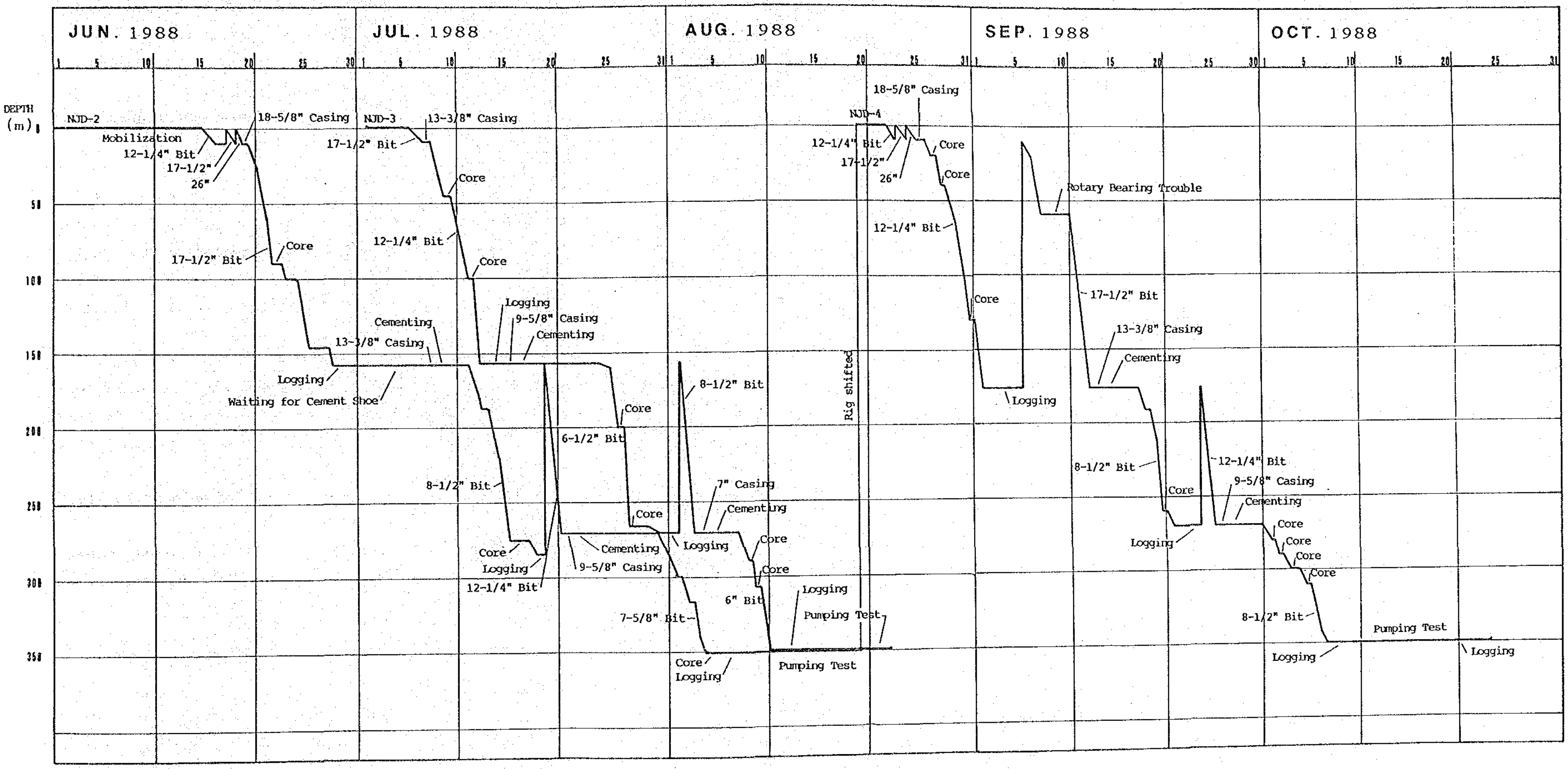


FIG. 4. 3. 1(2) Drilling Record of NJD-2, 3 and 4

FIG. 4. 3. 1(2)



4.3.2 Result of Borehole Investigation Works

(1) Geology of Borehole

Geological columnar section were compiled with several other drilling records, and presented in Appendix. Similar geologic conditions were found at each drilled point through the examinations of the occurrences of geologic formation and geophysical loggings. However, eminent fissure zone at 140 m depth were common for NJD-1 to NJD-3 bore holes but for NJD-4.

Geologic horizons were determined as follows.

0 - 30 m	Dammam fm.
30 - 140 m	Rus fm.
140 - 270 m	Upper UER fm.
270 - 400 m (Bottom of NJD-1 borehole)	Lower UER fm.

(2) Result of Borehole Logging

The results of borehole loggings are shown in Appendix.
Loggings show good correlations to each other and some characteristic features were confirmed in good coincidence with those of existing wells (PAWR observation well).

(3) Result of Pumping Test

Pumping test data of each well are given in Appendix, and summaries are presented in TABLE 4.1.2 and TABLE 4.3.1.

TABLE 4.3.1 Step Discharge Test Results

*120minutes discharge for one step

WELL No.	Q		s	Q / s
	(liter/sec)	(m³/day)	(m)	(m³/day)
NJD-1	4	346	0.17	2035
	6	518	0.38	1363
	8	691	0.69	1001
	10	864	1.08	800
NJD-2	11.4	985	0.27	3648
	23.2	2005	1.22	1643
	34.8	3002	2.20	1365
	43.8	3780	3.17	1192
	62.3	5384	5.92	909
NJD-3	5	432	0.09	4800
	10	864	0.42	2057
	15	1296	0.96	1350
	20	1728	1.64	1054
	25	2160	2.31	935
NJD-4	10.1	873	0.11	7936
	20.1	1737	0.645	2693
	30.0	2592	1.42	1825
	39.9	3447	2.315	1489
	58.1	5020	4.22	1190