STATE OF QATAR

THE STUDY ON DRAINAGE IMPROVEMENT PLAN, DOHA CITY

SUPPORTING REPORT

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JAPAN INTERNATIONAL COOPERATION AGENCY

PART : A Hydrogeology

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1. Introduction

1.1 Objective of the Study

As shown in Fig. 1.1.1 hydrogeological studies are the most important basic studies for solving the fundamental problems of drainage scheme for the areas requiring drainage. Studies include investigations of regional geological structure, hydrogeological characteristics and their distribution conditions.

As the most suitable and effective measure to cope with the rising groundwater level, a solution known as lateral drainage scheme has been selected as an urgent improvement measure. To carry out this scheme, two test work sites, one each at Wadi Musherib and Rayyan, were established. The effectiveness of the lateral drainage method was verified by the test work.

In consideration of the above-mentioned background, the two major objectives of the present hydrogeological study were as follows:

1 Clarification on all required hydrogeological conditions and geological structures of the study area for the purpose of preparing a groundwater drainage improvement plan.

2 Understanding the hydrogeological structures of the test work sites.

The hydrogeological study executed consisted of fieldwork, electrical soundings, geological observations of test work site excavation trench walls, core borings, and Lugeon tests. The results of the hydrogeological analyses are reflected in the basic concept of the drainage scheme.

1.2 Methodology

Basic propositions in drafting the drainage scheme are as follows:

1 As groundwater containers (vessels), understand the groundwater basins and clarify the water permeability, continuity, and thickness of the lower Dammam Formation.

2 Understand the structural distribution of fissures and vugs which cause the flow of water veins characteristic of the limestone region.

3 From the fact that water permeability has been assessed in two separate layers in the upper Dammam Formation according to the past studies, carry out a more highly accurate assessment of water permeability of the strata.

In order to solve the foregoing propositions, electrical soundings and Lugeon tests have been included in addition to geological survey, geological observations, and core logging.

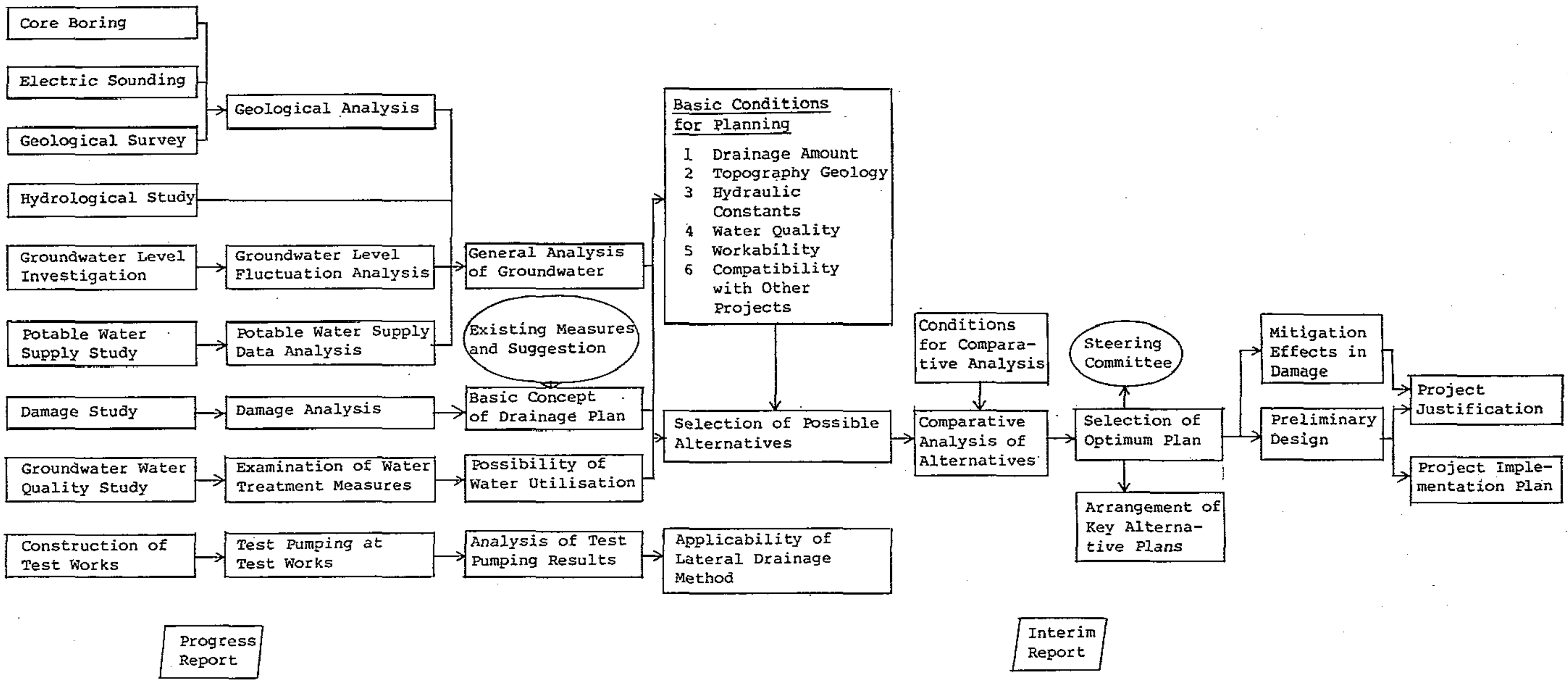


Fig. 1.1.1 Flow chart of the Study

1.2.1 Geological Survey

(1) Objective

By carrying out geological survey over an extensive area, the objective is to clarify the geological structures and distribution of layers in the entire study area. When this has been done, then the properties of the groundwater basins will be carified.

(2) Methodology

As the study area is topographically flat, weathering at the ground surface is quite severe. Therefore, when conducting geological survery, along with the investigation of wells located over a wide study area, geological obsevations of walls of exposed wells and cross sections of excavation at construction sites were carried out. As far as observations are concerned, analyses of water quality survey and water levels of wells were carried out in addition to geological observations of the outcrop surfaces.

1.2.2 Electrical Soundings

(1) Objective

With the aim of investigating the hydrogeological properties of the study area, electrical soundings were carried out at the test work sites of Wadi Musherib and Rayyan and the areas surrounding them.

(2) Methodology

In the study of the test work sites, the density of soundings was high in order to obtain a detailed clarification of the hydrogeological properties of the sites. However, for the area surrounding the test work sites, a relatively fewer number of soundings were taken in order to grasp the overall hydrologeological structure of the study area. In the present electrical sounding study, both the Schlumberger array method and Induced Poloarization method were employed.

a. Principle of electrical sounding

The resistivity is effective in estimating geological and underground structures because each facie possesses its own peculiar characteristics. The underground resistivity ( ) is expressed as =2 aV/I: where, = resistivity, a = sounding interval, V = potential difference and I = current. In the actual field condition, because the ground surface is invariably uneven and the resistivity will change in accordance with the properties of the ground surface, this resistivity is known as the apparent resistivity expressed as (<a>) where <a> = K x V/I: a = apparent resistivity, K = sounding value obtained at each point, V = potential difference, and I = current. An estimation of the underground conditions can be obtained from measurement of the apparent resistivity.

b. Schlumberger array method

Schlumberger array method is illustrated in Fig. 1.2.1. In the center of the AB current electrode line, the MN potential electrode is arranged. After fixing the MN distance, and then by increasing the AB distance, measurement of the apparent resistivity is carried out.

From these results, 1/2 the AB distance and the apparent resistivity are plotted on the double logarithmics paper and RS curve is drawn. From the RS curve, resistivity and thickness of each layer can be calculated. However, when resistivity of each layer is rather similar, accurate computation of the thickness of each layer becomes quite difficult.

In addition to Schlumberger array method, there is Wenner array method (1916), a method very similar to Schlumberger method, the only difference is that in the Wenner array method the MN distance of electrode array is 1/3 the AB distance. These two types of array methods are widely in use for structural analyses of sediments, analyses of groundwater, prospecting and confirmation of ores and their properties.

The apparent resistivity by Schlumberger array method is expressed by the following equation:

<a> = KxV/I

Where;

$K = 2 \quad / \, [\, (AB/2-MN/2)^{-1} - (AB/2+MN/2)^{-1}]$

<a>: apparent resistivity (ohm m)
K : Value determined at measurement points
V : potential difference (mV)
I : current (mA)
AB : current electrode distance (m)
MN : potential difference electrode distance (m)

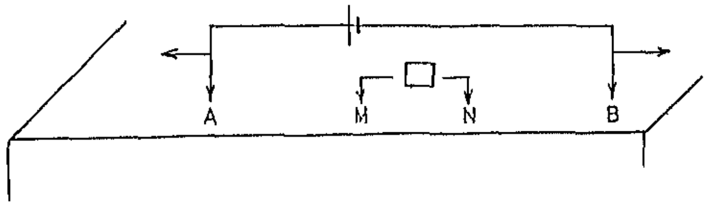


Fig. 1.2.1 Schlumber Array

c. Induced Polarization method

In areas where there are underground rocks, ore decomposition in the soil, clayish soil or buried metallic pipes, electric potential will not return immediately to "zero" even after power has been switched off. The potential will be reduced gradually; moreover, even after passing steady current, steady voltage will not be reached. This sort of phenomenon is observed over a period of few seconds. At times, after the current is turned off, the residual electric potential even after a few seconds may account for as much as 1% of value obtained as during the passing of power. This particular phenomenon is what has come to be known as the Induced Polarization (IP) phenomenon.

Making use of this phenomenon, study was carried out to determine the existence of cavities in limestone in the test work sites and to detect localized clay lumps and fracture zones. For the measurement with Induced Polarization method, highly accurate dipole-dipole array was employed. Dipole-dipole array is illustrated in Fig. 1.2.2.

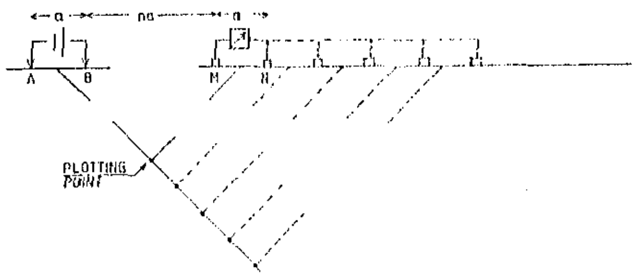


Fig. 1.2.2 Dipole-dipole Array

(3) Location and Quantity of Electrical Soundings by Schlumberger array method

(Max array interval AB/2=50 m or 100 m)

Musherib Test Work Site	46 Points
Rayyan Test Work Site	31 "
Surrounding Area of Rayyan Test Work Site	74 "
New District Area	36 "
Scheduled Site of Core Boring	33 "
TOTAL	220 Points

Induced Polarization Array Method (Array interval 5 m)

Musherib Test Work Site	200 m
Rayyan Test Work Site	300 m
Total	500 m

(4) Study Period

On-Site Study 22 Jan. 1981 - 19 Mar. 1981

(5) Equipment Used in the Study

Resistivity Measurement Equipment:
SYSCAL R2 (Made by BRGM in France)

1.2.3 Geological Observation of Trench Walls of Test Work Sites

(1) Objective

By carrying out observation of trench walls of the test work sites, the objective is to clearly understand the geological and hydrogeological conditions of the test work sites.

(2) Methodology

Besides investigating the conditions of strata by studying trench walls of the test work sites at both Wadi Musherib and Rayyan, geological observations were also carried out there with emphasis being paid to the locations of springs, fissures, and structural distribution of vugs. When conducting geological observations, grids of 1 m intervals were set up along both sides of the trench on the ground and the distances were measured. With this information, a detailed development schematic drawing at 1/100 scale was prepared.

This test can be carried out with a minimum of equipment. Over the top of a boring machine, simply arrange a wire rope from which a bucket is suspended. The bucket is constantly supplied with water so as to maintain a steady flow of water. To achieve the target pressure, the bucket is either raised or lowered by adjusting the rope.

Since the test was carried out in pace with the progress of boring, an air packet was used only at the top.

For measurement, the discharge every 2 min was read; 3 such measurements were taken and the average of the 3 was determined to be the discharge.

(3) Quantity

Musherib Test Work Site	13 Times (5 holes)
Rayyan Test Work Site	17 Times (5 ")
Surrounding Area of Rayyan Work Site	16 Times (3 ")
Total	46 Times (13 holes)

(4) Lugeon Value

In the Lugeon Test, as the test intervals are sometimes as much as approximately 5 m apart, there may be times when fissures may exist within the test intervals. For this reason, sometimes the direct evaluation of water permeability may become impossible.

In consideration of the above difficulty, in the present report, Lugeon value will be employed to carry out the evaluation of water permeability. Lugeon value is expressed as the water inflow in min per 1 m test interval length when injection pressure is maintained at 10 kg/cm^2. That is to say, 1 Lu could be expressed as follows:

1 Lu : ($1/min/1\ m/10\ kg/cm^2$.)

As hydrogeological condition in the test section is consistent with Darcy's law, the permeability of test section is expressed as follows:

$K = Q/2 \quad LP\ Ln(L/r)$ when $L>10r$

where
- k : Permeability(cm/sec)
- Q : Water inflow(cm^3/sec)
- L : Length of test section(cm)
- r : Radius of bore hole(cm)
- P : Pressure(g/cm^2)

From this theory, 1 Lu is defined as $1x10^{-5}$cm/sec(under the conditions; L=5m,P=10kg/cm^2,r=3.3cm,Q=5 /min).

1.2.4 Core Boring

(1) Objective

The core boring locations were selected as indicated in Fig. 1.2.3 in areas where there is no specific data available from previous study results and in places where there is a lack of proper information regarding groundwater observation holes.
From these results, in addition to making clear the geological structures of the entire study area and distribution of strata, an attempt was made for a clear understanding of the geological conditions of the Dammam Formation. Simultaneously, observation of groundwater level and sampling for analysis of water quality were carried out.

(2) Methodology

In order to understand in detail the underground structures of the test work sites, numerous densely concentrated borings were carried out.
Moreover, for the test work sites, in order to clarify the geological structures and distribution of strata, borings were carried out in the locations which were neglected in the past studies. The result of core logging is show in the appendix.
For core boring, a core tube of 77mm in diameter was employed. And for those expected to be used as observation holes in future, casings of 100 mm outside diameter were placed immediately below the ground surface.

(3) Quantity of Borings

The quantity of boring for the present study is indicated in Table 1.2.1.

1.2.5 Lugeon Test

(1) Objective

After selecting representative bore holes in the New District, test work sites and their surrounding areas, Lugeon Test was carried out.
From the Lugeon Test, a clear understanding of the accurate permeability of strata culd be obtained and reflected in the hydrogeological analyses.

(2) Methodology

In Japan, Lugeon Test is conducted with water conveyance pressure at between 1-10 kg/cm^2. However, the present test was conducted with low pressure of less than 1 kg/cm^2. In general, as pressure is increased, it is well known that test layer would more likely swell and fissures would grow bigger. Moreover, as the objective of the present test lies in understanding the water permeability of the layer, injection pressure for the test was held to low pressure. (Hydrostatic pressure)

Table 1.2.1 The Quantity of Core Boring

Hole No.	Depth (m)	Numbers of Lugeon Test	Location
LB-1	10.00	2	Musherib Test Work Site
LB-2	10.00	2	"
LB-3	10.05	2	"
TB-11A	30.15	6	"
TB-13A	10.00	1	"
LB-16	30.00	6	Rayyan Test Work Site
TB-27A	9.83	2	"
TB-31A	30.10	6	"
TB-32A	10.03	2	"
TB-43A	10.00	1	"
LB-4	30.00	6	
LB-5	20.05	-	
LB-6	30.07	6	
LB-7	30.00	-	New District
LB-8	20.00	-	"
LB-9	30.22	-	"
LB-10	30.00	4	
LB-11	30.00	-	
LB-12	30.00	-	
LB-13	30.00	-	
LB-14	30.00	-	
LB-15	30.00		
Total	500.50	46	

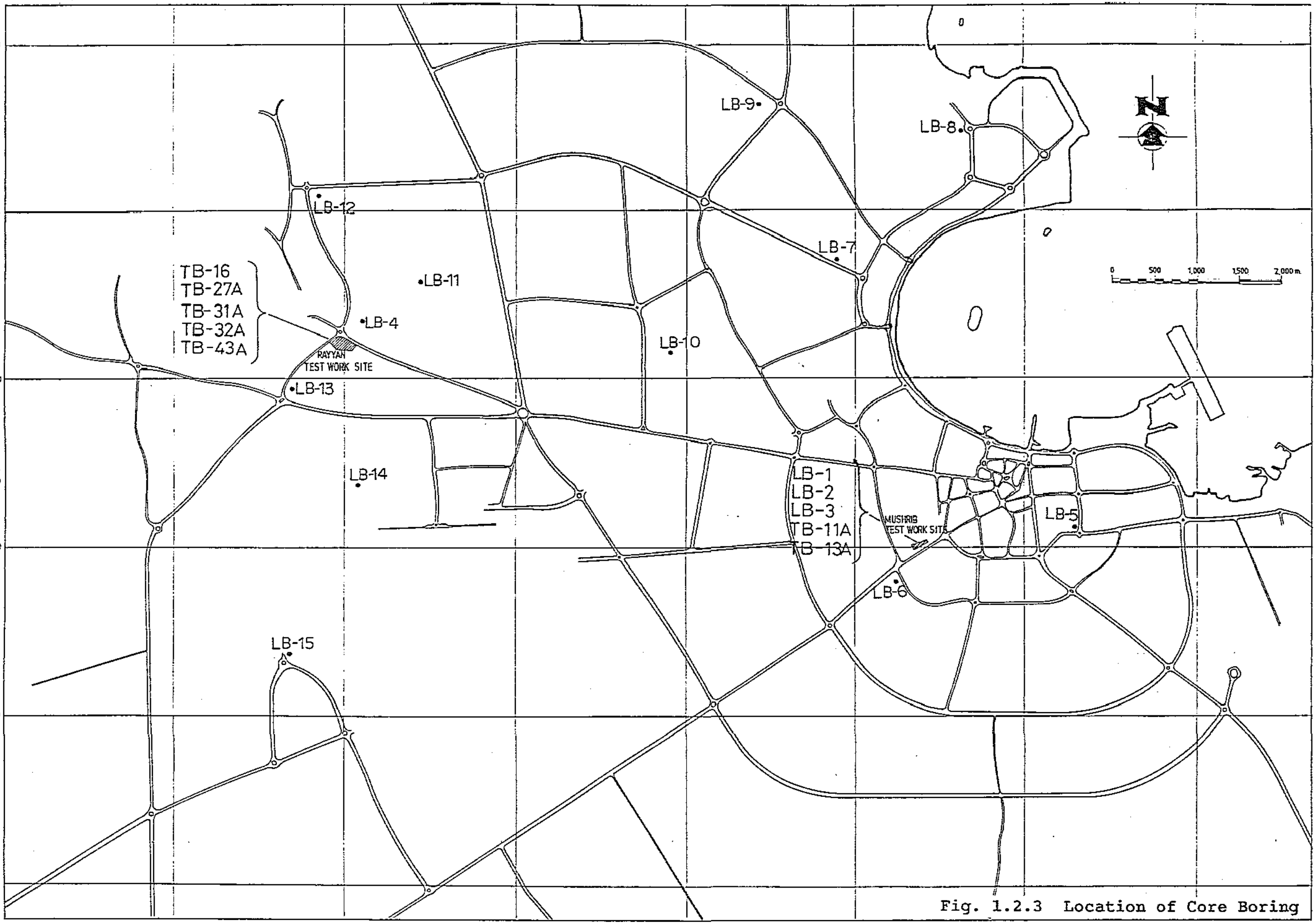


Fig. 1.2.3 Location of Core Boring

1.3 Progress of the Hydrogeological Study

As is shown in Table 1.3.1, the hydrogeological study consisting of geological survery, electrical soundings, and geological observations of the walls of the test work sites was carried out for the most part according to schedule; however, with respect to core boring in spite of the best efforts of the State of Qatar, drillings were executed nearly 3-4 months later than the original schedule as there was a delay in budget appropriation.

As far as the hydrogeological analysis is concerned, a preliminary result of analysis was prepared when the electrical soundings test was completed. As a result of the analysis, a decision was made to incorporate in the present study a Lugeon test which would make it possible to carry out the direct evaluation of water permeability between layers in addition to geological observations carried out through core boring.

At the expense of JICA, Lugeon Test was carried out using the core boring holes.

For the final hydrogeological analysis, owing to the aforementioned situation, although great limitation was placed on the term of work, the results of the Lugeon Test and core boring were reflected as much as possible in the preliminary analytical results.

The fact that core boring and Lugeon Test were carried out can only contribute, with great confidence, not just to the soundness of the drainage scheme's basic concept, but also to improvement in the accuracy of various numerical values of the scheme.

Table 1.3.1 Process of Hydrogeology

Times / Items	1986 JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	1987 JAN.
1. Geological survey													
2. Electrical soundings													
3. Geological observation of Trench Walls of Test Work Sites													
4. Core logging							Plan						
5. Lugeon Test							Plan						
6. Analysis of hydrogeology													

2. Topography

2.1 Introduction

The principal topographic feature of the Qatar Peninsula is the low to moderate reliefs of gently undulating low lying plains with the highest hills around 100 m in the southern part. According to the existing report (FAO 1982), the land mass of Qatar was reported to have been formed around the Tertiary Eocene time.

There are fold structures running in the N-S and NNW-SSE axes in the Qatar Peninsula. As if in harmony with these, gently rolling plains make up the topographic feature. The study area is situated in the eastern wing of the Qatar Central Pericline, possessing geological structure gently sloping toward the eastern side. In general, 2 series of basin topography are observed developed in the directions of NNW-SSE and ENE-WSW.

2.2 Topography of Study Area

As illustrated in the summit level map (Fig. 2.2.1), the topography of the study area can generally be divided into two major regions: 1) the extremely gentle upland of 8 - 16 m above sea level and 2) the coastal plain of less than 2 m above sea level.

In the upland, as illustrated in the summit level map, basin-shaped land extending in arc-shape toward NNW-SSE and another basin land extending nearly directly across it toward ENE-WSW can be acknowledged. Among these the most prominent topography which can be observed is the basin land in linear alignment in the direction of NNW-SSE along Garrafa-Rayyan-Markiyah-Abu Hamour-Naeejah. The lowest points of the basin land are 6 - 8 m above sea level which are anywhere between 6 - 8 m lower than their surrounding highland surface.

This basin land was not formed as a result of erosion process, but it is rather a conspicuous reflection of the geological structure and as such there is hardly any river system which drains to the sea.

In the boundary area between the highland lying in the west of the study area and the coastal plain lying in the east, an escarpment of 10 m in relative height is observed extending nearly due NNW-SSE.

According to a past report, this escarpment was thought to be part of a cylindrical collapsed cliff. Although the real cliff is observed in the vicinity of Doha Bay curving gently in an arc-shaped formation; however, in the northern region, since escarpment is seen extending in nearly over a straight line, it would be possible to conclude that it is eroded cliff or cliff of geological nature (fault cliff and/or fold terrace).

Moreover, in the city limits of Doha City two lowlands can be observed as shown in Fig. 2.2.2, one along Wadi Musherib and another in Montazah district. These two lowlands are presumed to be structural in nature as they compare closely with the geological structure of lower elevation layer.

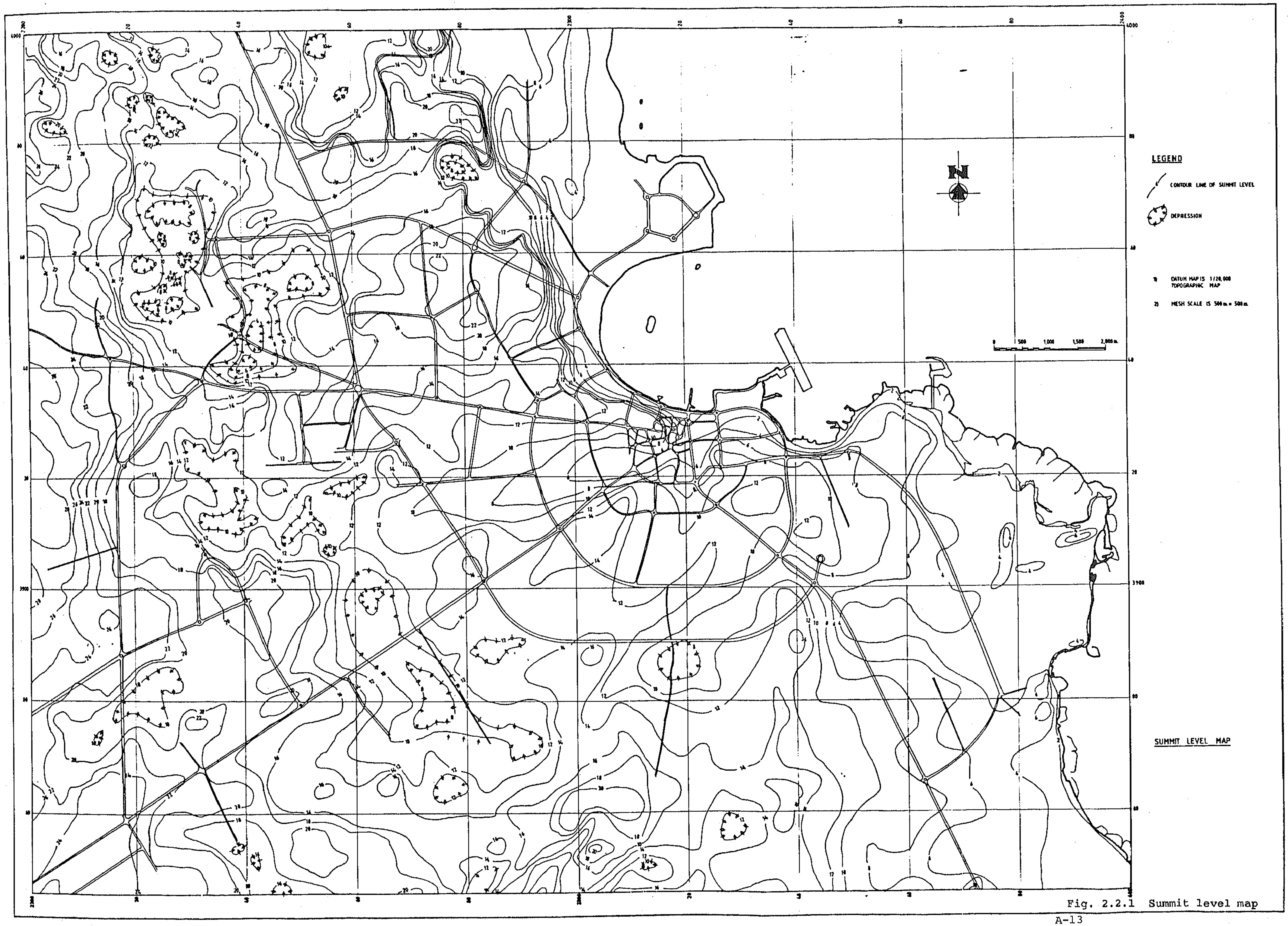


Fig. 2.2.1 Summit level map

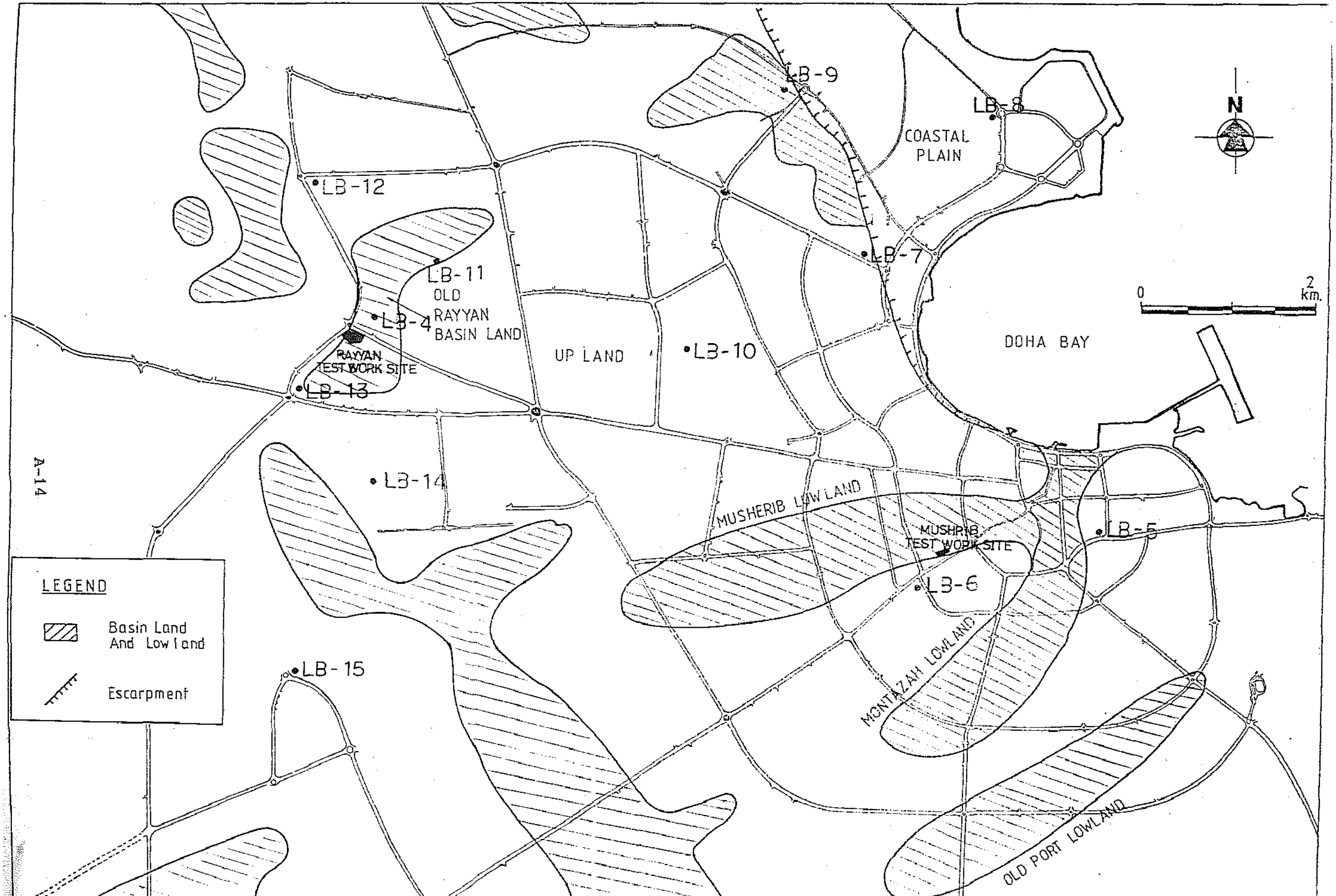


Fig. 2.2.2 Topographic Features of Study Area

Situated in the northwest section of the study area, the coastal plain, currently undergoing urban development, has variously been referred to as New District or West Bay. The coastal plain, a flat lowland of no more than 2 m above sea level (mostly less than 1 m), is a reclaimed land even today being filled with dredged sand and earth transported from the interior.

In the present report, a basin-shaped land without drainage to the sea shall be defined as "basin", while the one with drainage as "lowland".

3. Geology

3.1 Introduction

The Qatar Peninsula, for the most part, is composed of calcareous layer. The most ancient layer, situated at a depth of 1400 m below the ground surface, is of the Upper Jurassic which corresponds to the Arab Formation of Saudi Arabia. The Upper Jurassic formation is overlain in sequence by Cretaceous, Paleogene and Quaternary deposits.

In the Qatar peninsula, there are two fold structures along the axes of N-S and NNW-SSE. Related to these geological structures in the northern side of the central district of the peninsula is an accumulation of a seam of carbonate layers rich in shallow water sediments; in the southern side a sulfate layer rich in deep water sediments; and finally intercalated between the said two layers is a layer of residual sulfate facie.

An outstanding hydrologeological phenomenon, related to the aforementioned charactèristic of variations in lithofacies, is a depression formed as a result of leaching of sulfate found in the layer of sulfate facies distributed in the district. As this depression is related to the Midra Shale, the depression phenomenon is not very striking where Midra Shale is present, while it is rather conspicuous where Midra Shale is absent. Along the boundary facies, the dissolution scarp was formed as shown in Fig. 3.1.1.

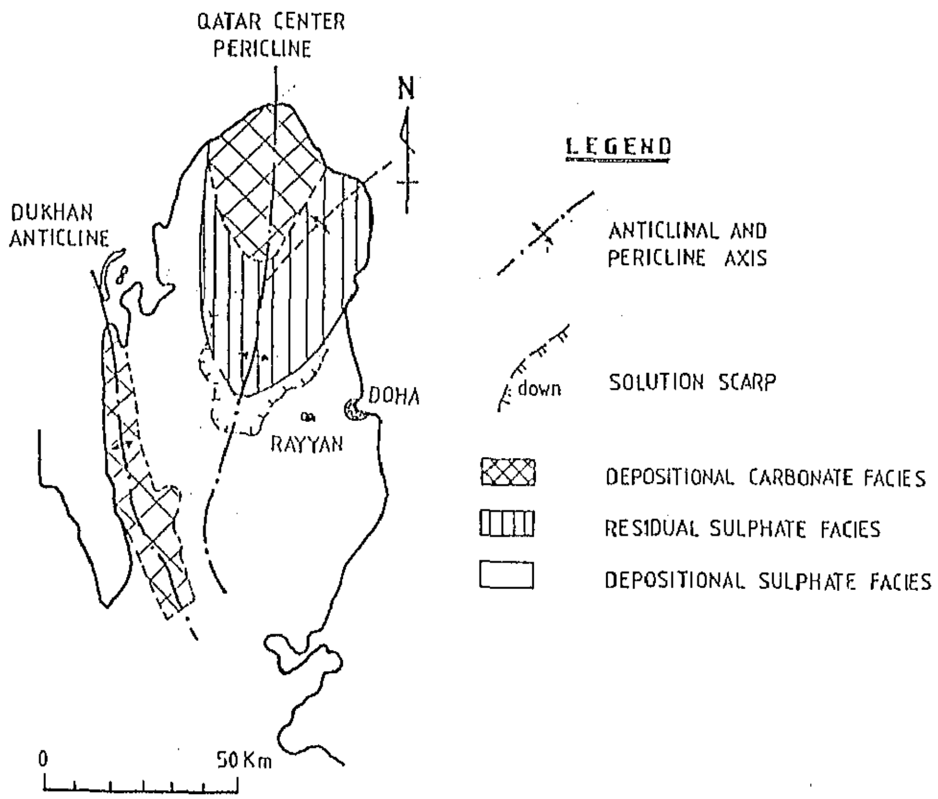


Fig. 3.1.1 Principal Geological Structure and Formation Facies Map
(*simplified from FAO, 1981, Fig. 3.13 and Fig. 3.10*)

3.2 Stratigraphy of Study Area

The sequence of geological layers observed in the study area is shown in Table 3.2.1. The critical layer in connection with the groundwater problem in Doha City is the Dammam Formation. As this is the aquifer, the present study's efforts shall be concentrated in this layer.

The Dammam Formation is made of 4 units, from the top: Simsima limestone, dolomite layer, Alveolina limestone layer, and Midra Shale. In terms of hydrogeology, it is composed of 3 zones: I) Upper Zone (severest weathered), II) Lower Zone (slightly weathered), and III) Midra shale. However, since the thickness of the Midra shale is not as thick as has been reported in the previous report and is intercalated with calcarenite and calcilutite, the second and third zones shall be together called the Lower Dammam Formation.

Moreover, in part of Rayyan district calcareous sandstone layer was observed on top of the Dammam Formation.

(1) Sandstone layer

The sandstone layer is observed distributed only in part of the New District and Rayyan in the study area. In both districts it is a calcareous sandstone layer.

The distribution of sandstone in the Rayyan area has been acknowledged by fieldwork and boring at LB-4. Thickness has been determined to be approximately 5 m. However, from the results of electrical soundings, the distribution is determined to be narrow, being confined to the Rayyan area only.

As the New District is overlain with a layer of fill sand, the distribution and accurate thickness of sandstone layer could not be ascertained; however, from boring at LB-8, appreciable concretion can be acknowledged.

(2) Upper Dammam Formation

The distribution of the Upper Dammam Formation throughout the entire study area has been acknowledged by fieldwork and by well study and is considered to be a generalized layer. This layer is mainly dolomitic limestone with accompanying limestone and sandy limestone.

From the results of boring, the top surface of this layer has been determined to be strongly weathered with well developed fissures which are filled with reddish-brown clay and other materials. However, toward the lower position the degree of weathering tends to weaken.

(3) Lower Dammam Formation

The Lower Dammam Formation is widely distributed in the study area. The contour of top of the Lower Dammam Formation is shown in Fig. 3.2.1. The elevation at the top surface of the Lower Dammam Formation is -10 to -15 m QND in the low lying areas, and in the surrounding areas, the elevation is around +5 m QND. The shape of the area is harmonious with the general characteristic topography of the area.

Table 3.2.1 Lithostratigraphic Sequence and Hydrogeological Significance

AGE	FORMATION	SUB FORMATION	MEMBER	THICKNESS (m)	LITHOLOGY	HYDROGEOLOGICAL SIGNIFICANCE
Oligocene	-	-	-	-	Absent; major unconformity	Period of diagenetic alteration of Simsima Limestone to Dolomite enhancing permeabilities.
Eocene	-	-	-	-	Absent; major unconformity	
- middle	Dammam	Upper Dammam	Simsima Limestone and Dolomite	30	Originally, very variable but basically chalky limestone. Diagenetic dolomite replacement general through of variable thickness (up to 10m).	Forms 80% of Qatar land surface. Both facies important aquifers where phreatic levels near surface in coastal belt etc.
	Dammam	Lower Dammam	Alveolina Limestone	1	E_1 marker; white compact fossiliferous chalky limestone	Lower Dammam, consisting largely of shale, has confining influence on Rus groundwater. Absence from northern 1/3 of Qatar of great recharge significance and controlling factor in removal of gypsum from underlying Rus Formation
Eocene - middle	Dammam	Lower Dammam	Midra Shale	10	Laminated, sub-fissile brown-yellow shale. Fossiliferous (sharks teeth) and with limonite and phosphate nodules.	(See above)
			Fhaihil Velates Limestone	1	White crystalline compact fossiliferous limestone	
Eocene - lower	Rus	-	Unit- 1 "Chalky Limestone"	25+		Anhydrite facies aquiclude,
			Unit- 2 "Anhydrite"	60+	Sulphate, Facies thick; anhydrite up to 50% with marl and some thin limestones.	
			Unit- 3 "Dolomitic Limestone"	? Abs		
Palaeocene	Umm er Radhuma	-	-	300+	Thick, alternating sequence of limestones and dolomites. Top 30-50m karstic dolomite. Marl content increasing downwards.	Upper unit excellent aquifer of very high storage coefficient and porosity. Remainder variable.

(After, Cavalier, 1970, IDTC 1980 and FAO, 1981)

From ASCO Report, 1983 Table 2.1

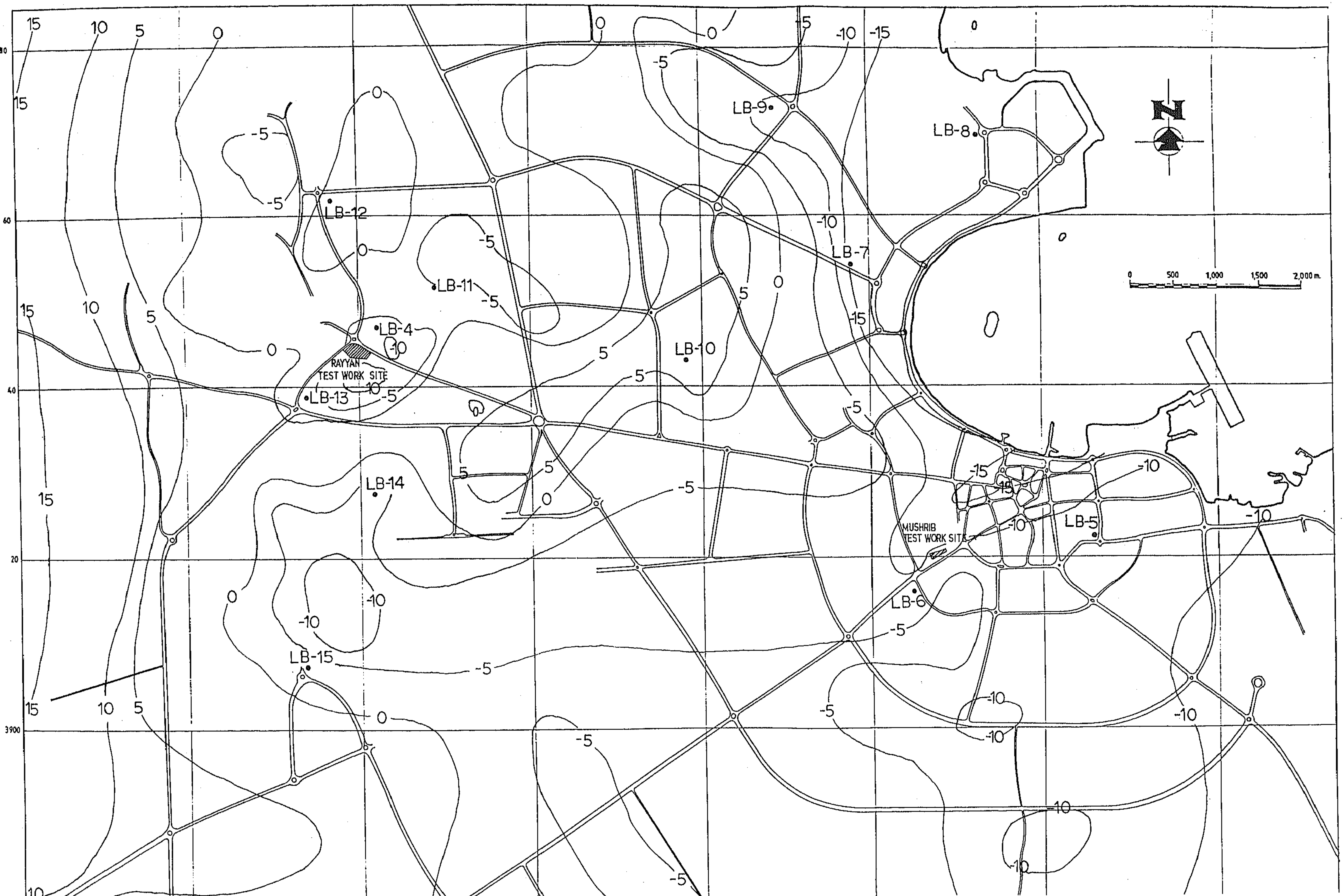


Fig. 3.2.1 Elevation of Top of Lower Dammam Formation (modified from ASCO Report, 1983, Fig. H/4.5)

The Lower Dammam Formation is mainly composed of dolomitic limestone, limestone and sandy-silty limestone with shale (*Midra Shale*) *interposed in* between.

Observed in the Midra Shale are from 1 to 4 layers of shale whose individual thicknesses are several centimeters. While it is thicker at the upper section of the Lower Dammam Formation, it becomes thinner towards the lower section. Also the horizontal continuity cannot be recognized to be by all means good. Moreover, numerous well developed horizontal fissures at intervals of several millimeters have been observed.

While dolomitic limestone forming the main feature of this formation is very conspicuous at the upper section, the change to sandy-silty limestone toward the lower section can be observed.

Moreover, anhydrite-gypsum can be frequently observed in the middle section of the formation in various shapes, some imbedded horizontally in layer shape, others irregularly imbedded in vein-like shape, and still others imbedded in mottled shape. Anhydrite is observed mostly imbedded in layer shape, while the trend is that gypsum is increasingly more likely to be observed in vein-like and mottled shapes. Some anhydrite in layer shape may be as much as 20 cm in thickness, but their continuity cannot be recognized.

(4) Rus Formation

The Rus Formation could not be confirmed in the present study. However, as can be recognized by boring carried out in the present study, the lower part of the Lower Dammam Formation changes to sandy-silty limestone with part of the section interposed with chalky limestone. This is rather quite similar to the lithofacies of Unit 1 of the Rus Formation. Moreover, since the Rus Formation is overlain apparently confirmably by the Lower Dammam Formation , the Rus Formation can be assumed to be present immediately beneath boring LB-6 and TB-31A of the present study.

Accordingly, armed with the results of the present study in addition to the results from the past studies, a surface contour map of the Rus Formation was prepared as shown in Fig. 3.2.2. The distribution of topographically low lands and the lower elevation surface of layers expressed as either "Depression" or "Low" seem to correspond.

3.3 Geological Structure of the Study Area

According to the observations of layers exposed in dug wells (Arabic Wells), a deformation of layers can be recognized at several points scattered within the Rayyan basin area. The deformation of these layers is presumed to preserve pre-depression structural elements. According to this, the directions of minor anticlial and synclinal axis, joints and minor faults are all aligned in the directions of depression topography in correspondence with the two directions of NW-SE and NE-SW to ENE-WSW. This phenomenon can only indicate the presence of tectonic movement somehow related to the structural elements incorporated in the layer in the district which includes the depressions located in the Rayyan area. From the fact that the alignment extends in the direction of tectonic line (fold axis, joint and fault), the formation of depression topography is certain to be related to the tectonic movement, and also indicates that it is regulated by geological structure.

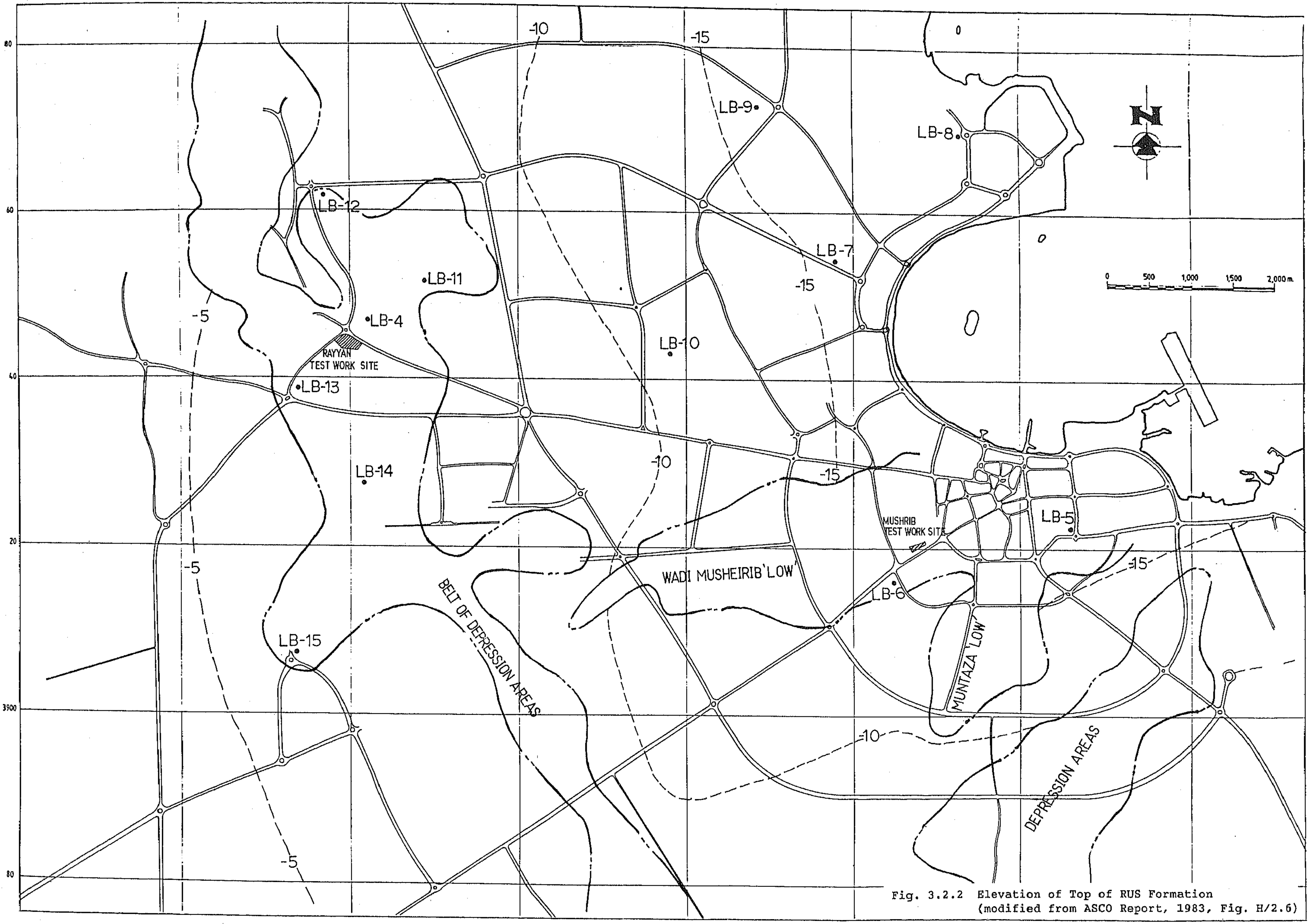


Fig. 3.2.2 Elevation of Top of RUS Formation
(modified from ASCO Report, 1983, Fig. H/2.6)

Besides, the thickness of the strongly weathered zone of the Upper Dammam Formation in the depression is quite substantial. This is presumed to be the result of weathering of the layer caused by infiltrating rain water after the formation of the tectonic line. The grade of weathering, being different depending on the extent of the tectonic line and differences in lithofacies, is presumed to have advanced selectively. Especially, leaching caused by seepage water is apt to take place in the layer located in the study area and adjacent environ. Advancing weathering in the upper part, as it were, hastens leaching deformation of the underlain layer in the lower part. The deformation in the lower section layer, in turn, causes deformation and collapse in the upper part layer, thus further hastening the weathering process. The repetition of these processes is presumed to have contributed toward the formation of depressions in the study area.

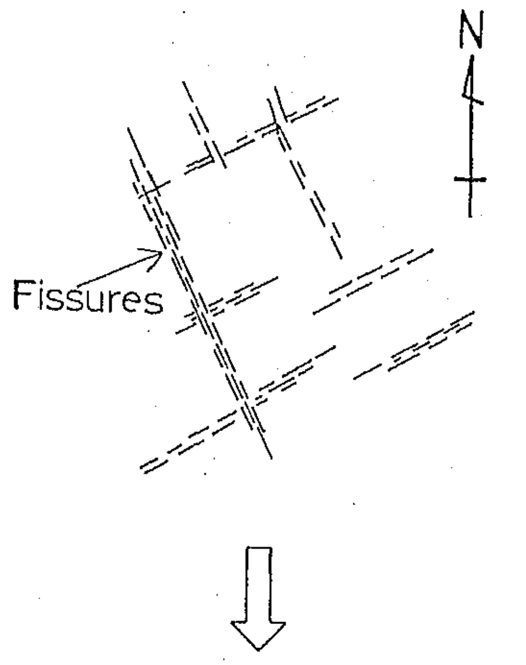
In consideration of the above-mentioned assumptions, the following process of geological structural development can be advanced as shown in Fig. 3.2.3.

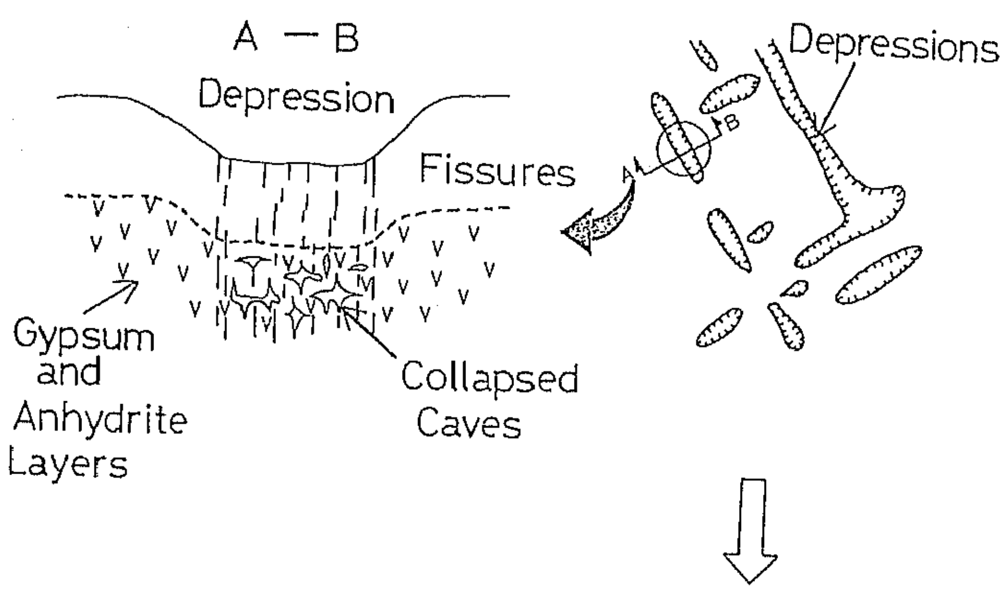
1) Fracture systems in the direction of NW-SE and NE-SW to ENE-WSW was formed.

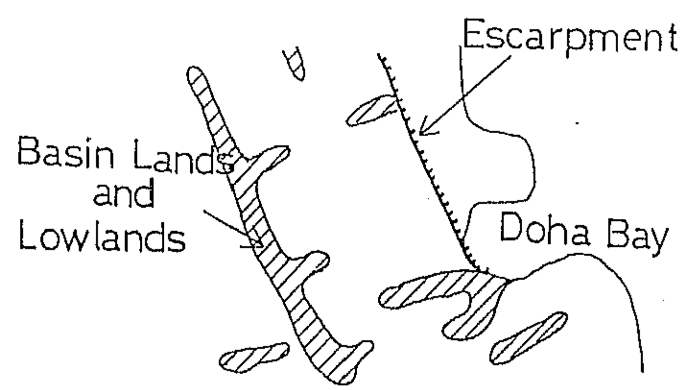
2) In order for groundwater to infiltrate and flow along the fractures region, anhydrites and other materials in this region had to be leached and cavities began to be formed, thus causing the formation of depressions along the feature.

3) Finally, the present condition of topography characterized by low lands and depressions aligned in the direction of the tectonic line was formed.

1) Formation of fissures system of NNE-SSE and ENE-WSW directions.
2) Groundwater flows along the fissure lines accelerated the dissolution of sulphate layers to create the depressions along the fissure lines.
3) Present topographic from with the distinctive features of regulated alignment of basins and lowlands.







※)Not to scale

Fig. 3.2.3 Development of Depression Structure

4 Hydrogeology

In terms of hydrogeology, the present study area can be divided into 3 layers from the top as I, II, and III. Layer I is composed of sand and severely weathered crust of Upper Dammam Formation. Layer II is composed of slightly weathered - fresh section of the Upper Dammam Formation. Layer III is composed of the Lower Dammam Formation. The characteristics of each of the three layers shall be described below.

4.1 Composition and Characteristics of Each Layer

(1) Layer I

This layer is composed of sand and strongly weathered zone of the Upper Dammam Formation. Although clay is interposed in the upper part of the Upper Dammam Formation, since fissures are dominant due to severe weathering, high permeability can be presumed. In the superficial layer in Rayyan, sandstone is distributed; because the degree of consolidation is low, and high water permeability can be presumed, in terms of hydrogeology, this layer shall not be classified as strongly weathered zone of the Upper Dammam Formation, but it shall be included in Layer I.

Although this layer is widely distributed throughout the entire area, the tendency is for it to be thick in the lowland, gradually becoming thin in the highland. This layer is thick in Musherib lowland and Rayyan basin. At the lowest elevation of the two areas, the thickness of Layer I reaches as much as 5-6 m, but in the surrounding areas, it thins out to 1-2 m. On the LB-13 coreboring located South-West of Rayyan area Layer I could not be observed.

(2) Layer II

This layer is composed of slightly weathered zone and fresh part of the Upper Dammam Formation. In the lower part of the Upper Dammam Formation, a fresh limestone layer can be seen because of weaker weathering; however, fissures in either the horizontal or perpendicular direction could be observed. However, water permeability is presumed to be somewhat less than that found in the severely weathered part.

Layer II has been observed distributed throughout the entire study area in 5-10 m thickness.

(3) Layer III

This layer is composed of the Lower Dammam Formation. The Lower Dammam Formation is interposed with layers of shale whose thicknesses range from 1 m to several centimeters. The water permeability in this layer is presumed to be less than either Layer I or Layer II.

4.2 Lugeon Test

With the objective of making quantitative determinations concerning water permeability of each layer, 46 Lugeon tests were carried out by using boreholes. In order to be able to make water permeability determinations which would be applicable to an extensive area, tests were carried out throughout the entire study area. Especially within the test work sites, a large number of tests were carried out towards the proper understanding of water permeability in detail.

The results of Lugeon test are shown in Table 4.2.1. In its entirety, the range of Lugeon values is quite extensive from several Lu to several hundred Lu. In terms of depths, the tendency is for them to become appreciably small but not noticeable.

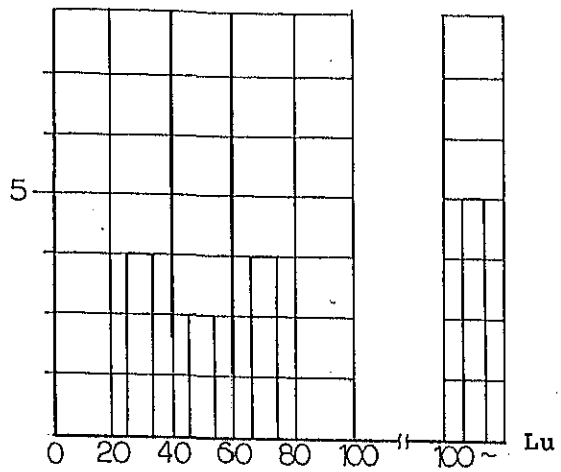
Fig. 4.2.1 is a summary of Lugeon values of Layers I to III, which were classified in accordance with geological information. From these results, the tendency of decreasing Lugeon values from Layer I to Layer III can be ascertained. In Layer I, Lugeon value (Lu) obtained through the Lugeon test was generally large with values greater than 20 Lu and there are no few instances where the values exceeded 100 Lu. In Layer II, there were few test values indicating 100 Lu, and in general it was smaller in comparison with Layer I. In Layer III, Lugeon value was less than 100 Lu and although the frequency of 20 Lu or less became bigger, this layer in terms of water permeability could be classified as an impermeable layer. This is corresponded with information obtained from boring results.

Table 4.2.1 The Results of Lugeon Test

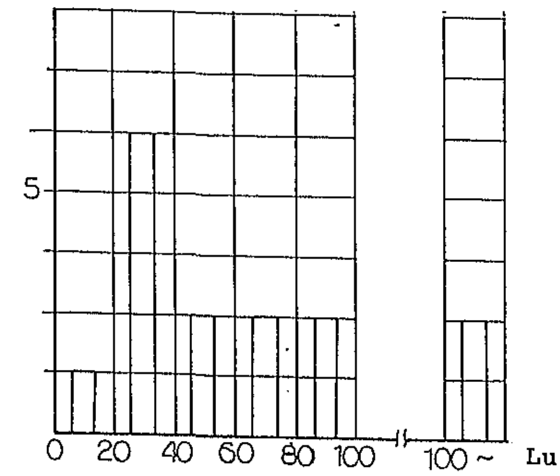
BH NO.	TEST NO.	DEPTH (m)	LUGEON VALUE
LB-1	1	3.40 to 6.26	30.0
LB-1	2	5.50 to 10.01	26.2
LB-2	1	3.00 to 5.40	49.0
LB-2	2	5.16 to 10.00	46.0
LB-3	1	4.10 to 5.90	237.5
LB-3	2	6.90 to 10.05	90.3
LB-4	1	3.85 to 6.68	73.6
LB-4	2	5.50 to 10.00	44.8
LB-4	3	10.00 to 15.04	55.8
LB-4	4	15.00 to 20.67	31.8
LB-4	5	20.00 to 25.23	37.1
LB-4	6	25.00 to 30.00	Very small
LB-6	1	3.00 to 5.05	67.4
LB-6	2	5.00 to 10.00	32.7
LB-6	3	10.00 to 15.00	29.9
LB-6	4	15.00 to 20.00	83.3
LB-6	5	20.00 to 25.80	19.6
LB-6	6	25.00 to 30.07	11.2

BH NO.	TEST NO.	DEPTH (m)	LUGEON VALUES
LB-10	3	10.00 to 15.00	63.8
LB-10	4	15.00 to 20.01	58.8
LB-10	5	20.00 to 25.00	35.5
LB-10	6	25.00 to 30.05	41.2
TB-11A	1	3.05 to 6.57	49.5
TB-11A	2	5.41 to 10.91	Very small
TB-11A	3	10.00 to 15.20	Very small
TB-11A	4	14.70 to 21.25	43.8
TB-11A	5	20.80 to 25.85	Very small
TB-11A	6	25.00 to 30.15	12.2
TB-13A	1	6.00 to 10.00	36.3
TB-16	1	2.0 to 5.0	263.5
TB-16	2	5.0 to 10.00	Very great
TB-16	3	10.00 to 15.00	206.8
TB-16	4	18.80 to 20.40	43.8
TB-16	5	19.00 to 25.85	68.1
TB-16	6	25.00 to 30.00	90.8
TB-27A	1	2.4 to 5.0	Very great

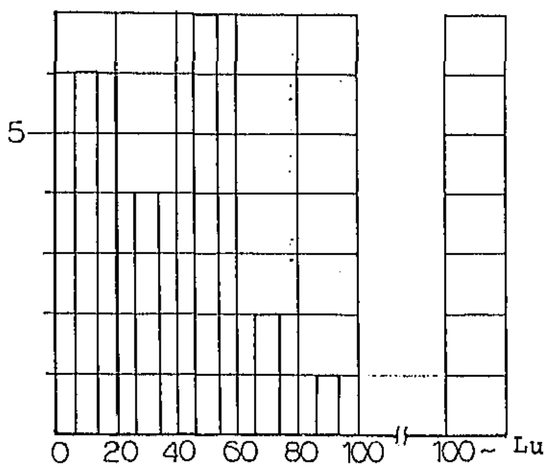
BH NO.	TEST NO.	DEPTH (m)	LUGEON VALUES
TB-27A	2	5.00 to 9.83	68.2
TB-31A	1	4.00 to 5.80	80.2
TB-31A	2	5.22 to 12.00	39.3
TB-31A	3	9.70 to 16.70	41.6
TB-31A	4	16.00 to 20.73	37.6
TB-31A	5	20.00 to 25.50	52.2
TB-31A	6	25.00 to 30.10	66.1
TB-32A	1	3.84 to 5.84	38.1
TB-32A	2	5.00 to 10.03	65.7
TB-43A	1	2.00 to 5.00	171.6



Layer I (n = 12)
Upper Dammam Formation
Strongly Weathered



Layer II (n = 14)
Upper Dammam Formation
Weakly Weathered



Layer III (n = 20)
Lower Dammam Formation

Fig. 4.2.1 Frequency of Each Lugeon Value in the Layer I to Layer III

4.3 Hydrogeology

Two groundwater mounds can be recognized in Doha City.

This is because the direction of elongation of the groundwater mound is due NW-SE in the northern part and due NE-SW in the southern part. This direction corresponds with the alignment of depression topography; in other words the geological structure. This phenomenon is schematically drawn in Fig. 4.3.1. The areas in which the shape of the mound has collapsed or has expanded, have large spaces between groundwater level contour lines and it is presumed that the underground permeability is high. In the study area, the groundwater table is situated in the I or II layer, the Upper Dammam formation where permeability is relatively high. Especially, the groundwater table is situated in the I layer.

As result of that, the shape of the groundwater table in the study area is well reflected on the hydrogeological structure.

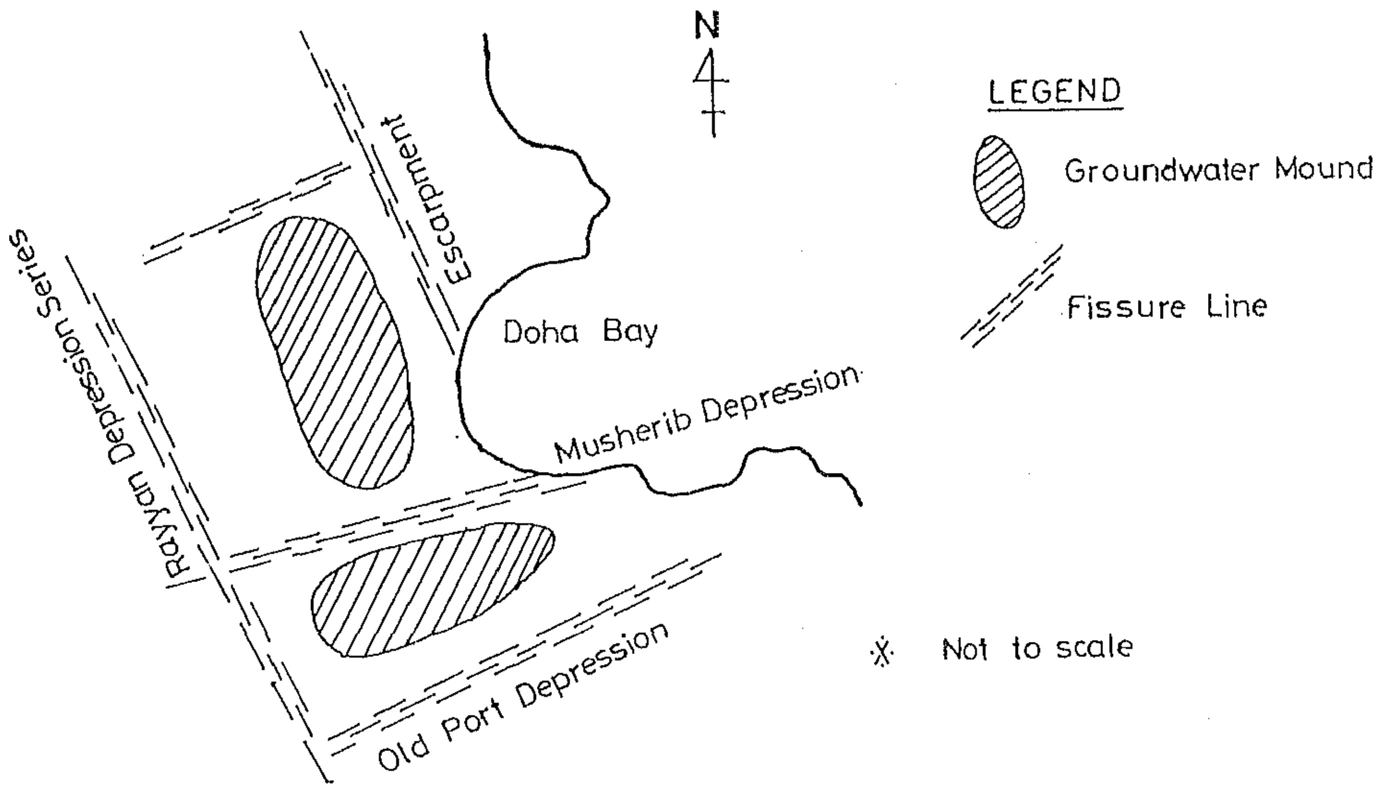


Fig. 4.3.1 Schematic Drawing of Relationship between Groundwater Mounds and Geological Structures

5. Hydrogeology of Study Area

The hydrogeological characteristics of Musherib area, Rayyan area, and New District area, which are the present study areas, shall be discussed in the following paragraphs.

The central position of each area, expressed in compliance with Qatar International Coordinates (QATZ), would be as follows.

i)	Musherib area	230 700 mE; 391 900 mN
ii)	Rayyan area	224 000 mE; 394 600 mN
iii)	New District area	230 200 mE; 397 650 mN

5.1 Wadi Musherib Area

Musherib area where electrical soundings were carried out is situated about central part in the Wadi Musherib lowland.

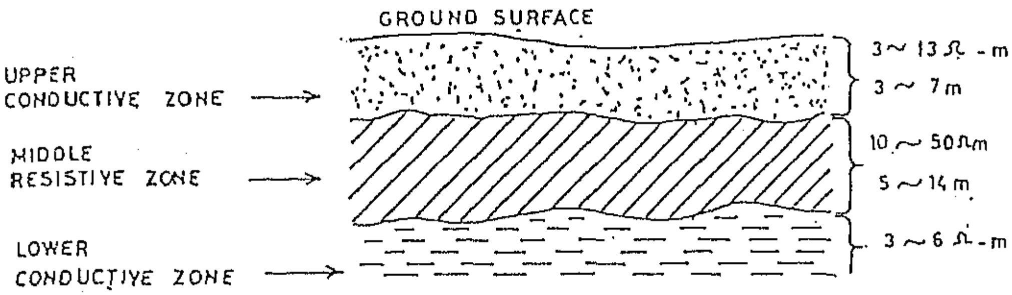


Fig. 5.1.1 Schematic Drawing of Electrical Soundings Results at Wadi Musherib Area

From the previous study of boring results, for structure foundation survey and so on, topsoil is extremely thin of less than 1 m thickness. The Upper Conductive Zone shown in the cross section of Fig. 5.1.1 is presumed to correspond to the upper weathered zone of the Upper Dammam Formation. This crust is the strongly weathered (diagenesis action) dolomitic limestone containing much clay. Although extremely low permeability is expected in the shallow part along the Musherib lowland, as a result of electrical soundings, very similar 3-layer structure in the other areas can be observed.

The Middle Resistive Zone is presumed to correspond to the relatively fresh lower layer with few fissures of the Upper Dammam Formation.

The Lower Conductive Zone corresponds either to Midra shale of the Lower Dammam Formation or adjacent formation.

As a result of the above, hydrogeological structure of the Musherib lowland could be considered in the following manner.

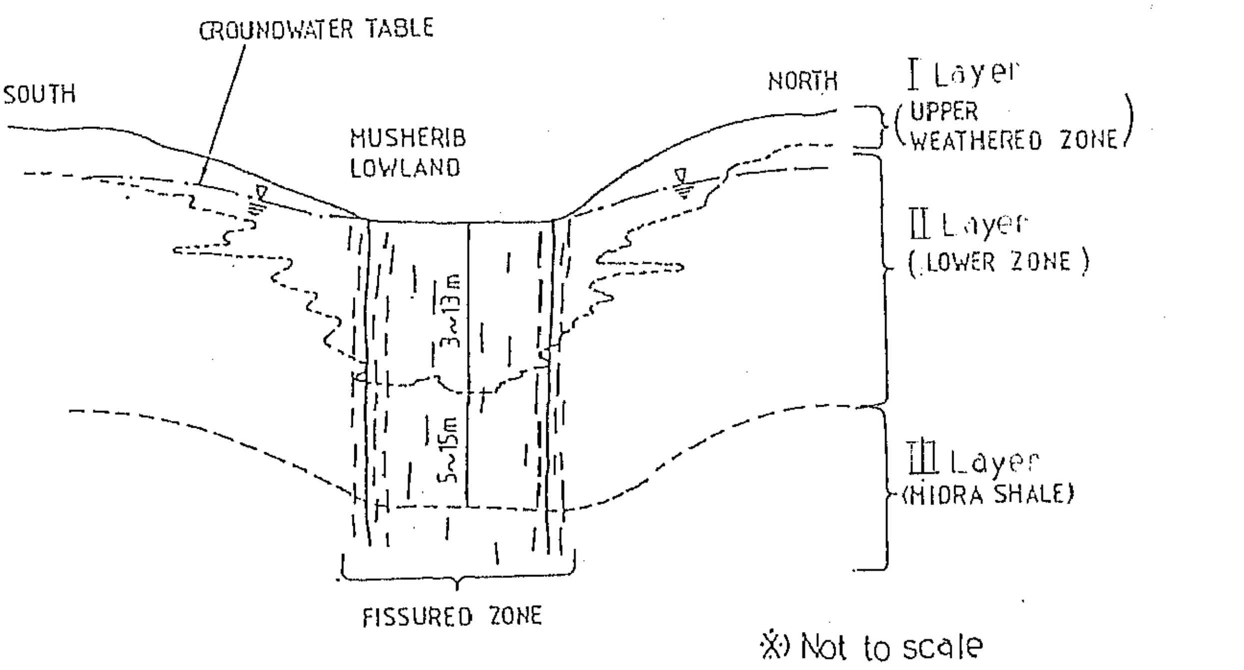


Fig. 5.1.2 Schematic Cross Section of Wadi Musherib Lowland

5.2 Rayyan Area

The Rayyan area is one of the group of depressions which extends NW-SE direction in the western part of Doha City. The elevation of the bottom of basin is the lowest, which is less than 6 m above sea level. The schematic drawing of this area is shown in Fig. 5.2.1.

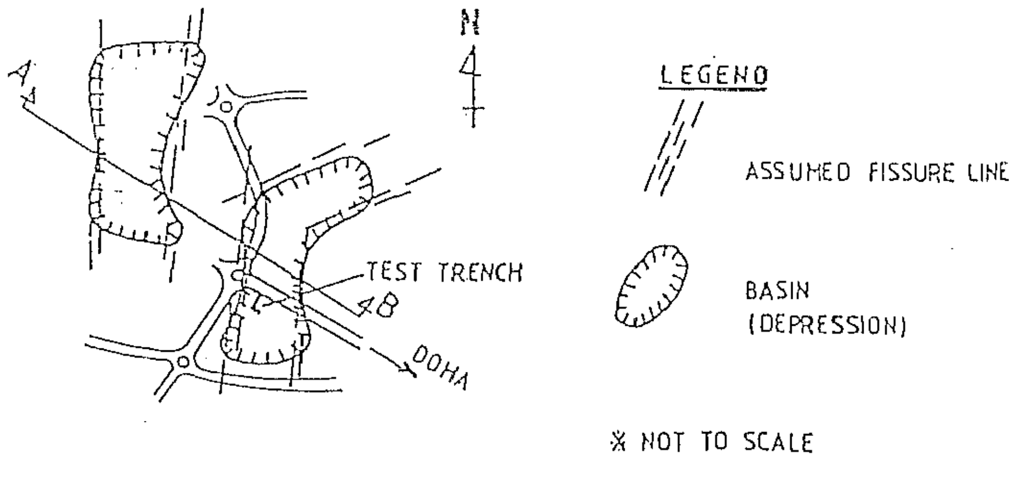


Fig. 5.2.1 Geotechtonical Feature of Rayyan Area Depression

The results of electrical soundings are shown in Fig. 5.2.2. Fig. 5.2.2 is the schematic cross section showing the features along A-B line of Fig. 5.2.1.

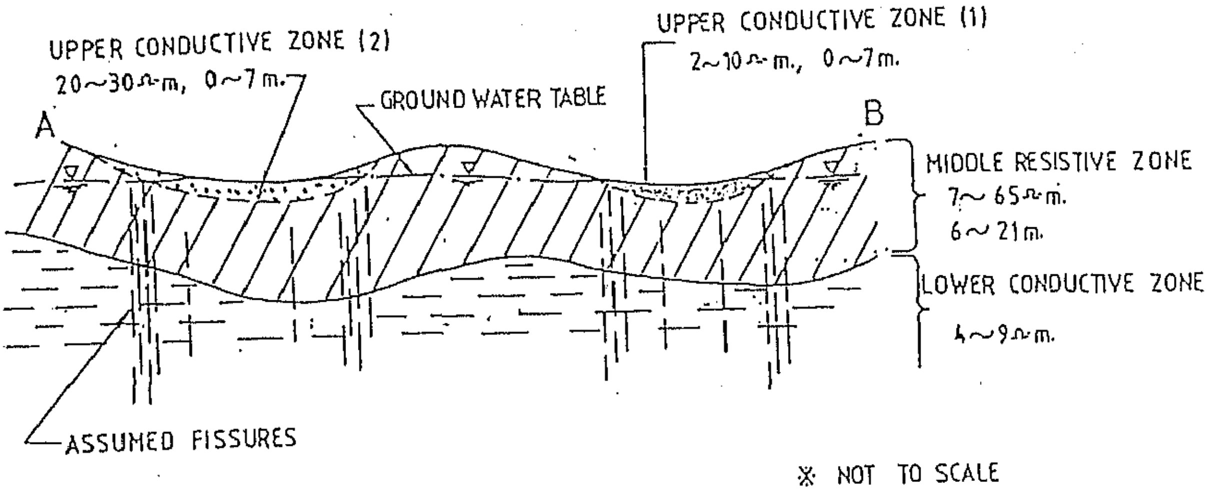


Fig. 5.2.2 Schematic Drawing of Electrical Sounding Results in Rayyan Area

The Upper Conductive Zone (1) is a conspicuously low resistive layer with resistivity value in the range between 2-10 ohm m. As a result of the on-site survery, it became clear that this layer is extremely brittle vesicular calcareous sandstone. This layer shows quite a high transmissivity coefficient and is distributed centrally in both depression areas with its thickness assumed to be in the neighborhood of 7 m at the maximum.

The Upper Conductive Zone (2), being similar to the Upper Conductive Zone of the Musherib presumed to be the superficial weathered zone of the Upper Dammam Formation, is dolomitic limestone containing much clay and fissures.

Being similar to the Musherib lowlands, the Middle Resistive Zone and Lower Conductive Zone are presumed to correspond, respectively, to relatively new Simsima dolomitic limestone with few fissures and the Lower Dammam Formation (Midra shale or its surrounding layer).

The geological structure and topography as hypothesized from the results of electrical sounding in the Rayyan area agree rather closely with the cross section. Moreover, a number of fracture systems presumed to have played an indirect role in the formation of depression areas can be recognized around the marginal zones of the areas.

5.3 New District Area

The New District area, a so-called Coastal Plain situated in the northern part of Doha City, is a lowland located on the eastern side of the escarpment which extends on NWN-SES direction. The results of electrical soundings carried out in this area are outlined in Fig. 5.3.1.

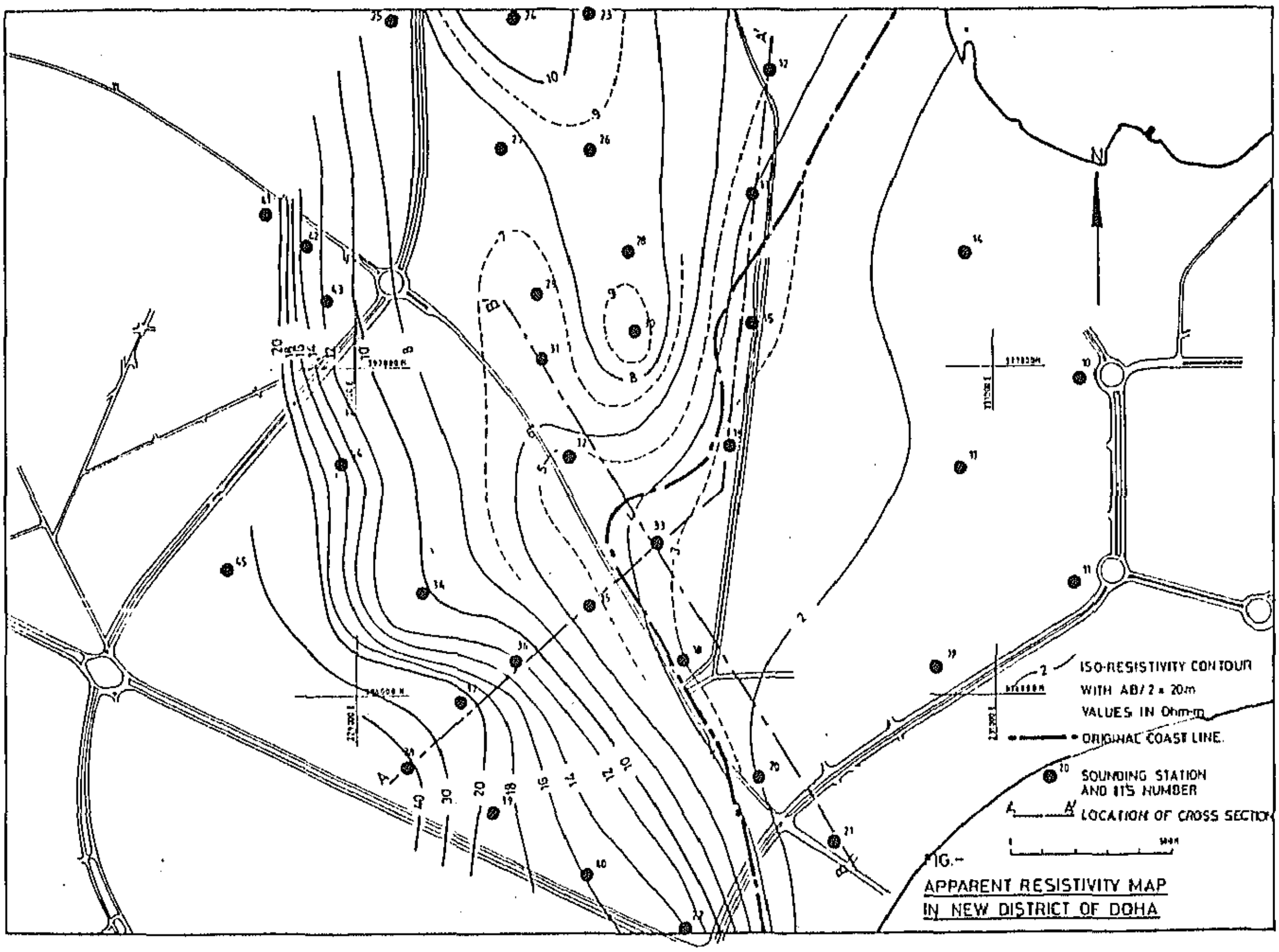


Fig. 5.3.1 Schematic Apparent Resistivity Map in New District Area of Doha

The results of Fig. 5.3.1, correspond well with the summit level map, the topography matches the mountain region as long as the value of apparent resistivity is 10 ohm m or greater. From the results of fieldwork, territories with apparent resistivity values of 10 ohm m or greater correspond with outcropping areas.

As there is infiltration of sea water of exceedingly low resistivity, it would be quite difficult to make proper estimations with respect to geological structure from the results of electrical soundings in the study area. It would be highly probable to find distributed the so-called Sabkha deposits which are extremely weak sediments from lagoon (N value, 1-2) high in salt concentration underneath the surface of the sea.

Bordering on the western limits of the New District area, the geological structure of the escarpment is thought to be not especially distributed depending on the results of electrical soundings carried out in this area, as shown in Fig. 5.3.2.

From the facts that: 1) this Escarpment extends in nearly the same alignment in the direction of a group of depression basins found in the inland, 2) though found to be few in number from the observation of joints in the excavation surfaces which cut across the cliff, a number of joints have been recognized extending in the same direction as that of the cliff, and finally 3) as the detection of a layer which seems to be dipping slightly to the east, the existence of fractures at the foot of this cliff in the same direction of the cliff could be considered a likely possibility.

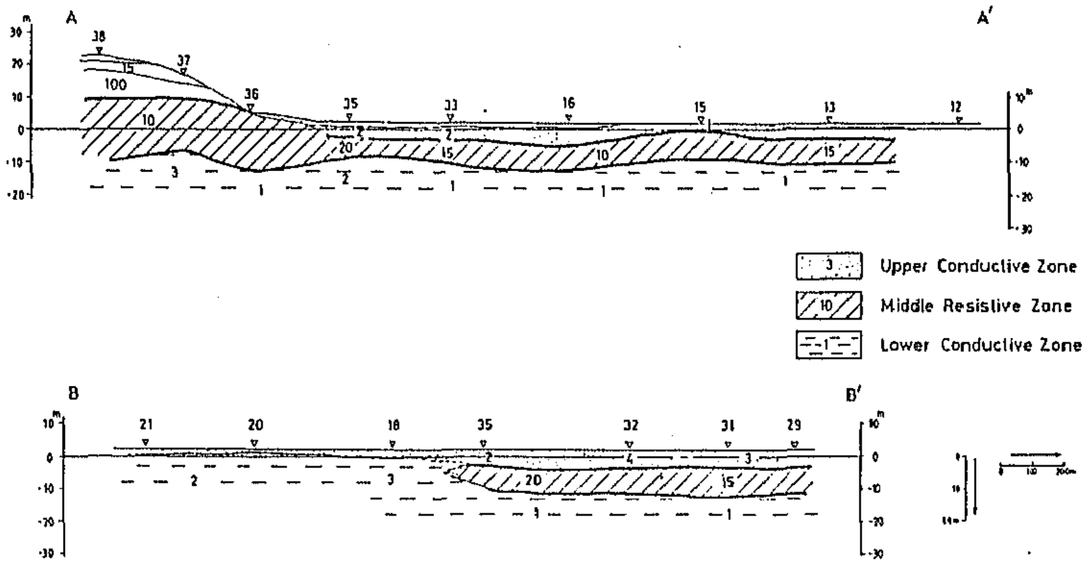


Fig.-
Resistivity Cross Section in New District

Fig. 5.3.2 Schematic Cross Section of New District Area

6. Hydrogeology of Test Work Sites

Test work was carried out in the two areas of Musherib and Rayyan. The Musherib test work site is located in the center of the Musherib area. Moreover, the Rayyan test work site is located at the lowest elevation in one of the two basins in the Rayyan area which is situated east of the other. The hydrogeological characteristics of the test work sites shall be discussed below.

6.1. Wadi Musherib Test Work Site

6.1.1 Results of Electrical Soundings

The locations of measurement lines and measurement point numbers are shown in Fig. 6.1.1. A resistivity vertical section schematic drawing using the apparent resistivity values was prepared. (See Fig. 6.1.2) The subsurface of the test work site can be divided into three sections: 1) Upper Conductive Zone, 2) Middle Resistive Zone, and 3) Lower Conductive Zone.

The results of IP method are shown in Fig. 6.1.3. From the results obtained by the IP method, in general, it is believed that cavities, caverns fissures and clay zone do not exist in the entire test work site.

6.1.2 Hydrogeological Condition of Wadi Musherib Test Site

In the Musherib test work site, 5 borings were carried out: LB-1, LB-2, LB-3, TB-11A and TB-13A (LB denotes long-term observation bore holes, while TB denotes temporary bore holes). These results are shown in Fig. 6.1.4.

The detailed development schematic drawing of the trench excavation wall surface is shown in Fig. 6.1.5.

The geology of the Musherib test work site consists of filling materials as overburden and dolomitic limestone as bedrock.

The bedrock of Musherib test work site is gray to white mottled dolomitic limestone and generally strongly weathered, as shown in Fig. 6.1.6. The bedrock is mostly clay of blueish green to reddish brown colour and in part it is brecciated structure interposed with a mixture of clay and unweathered rock fragments.

Fig. 6.1.1 Location Map in Wadi Musherib Test Site

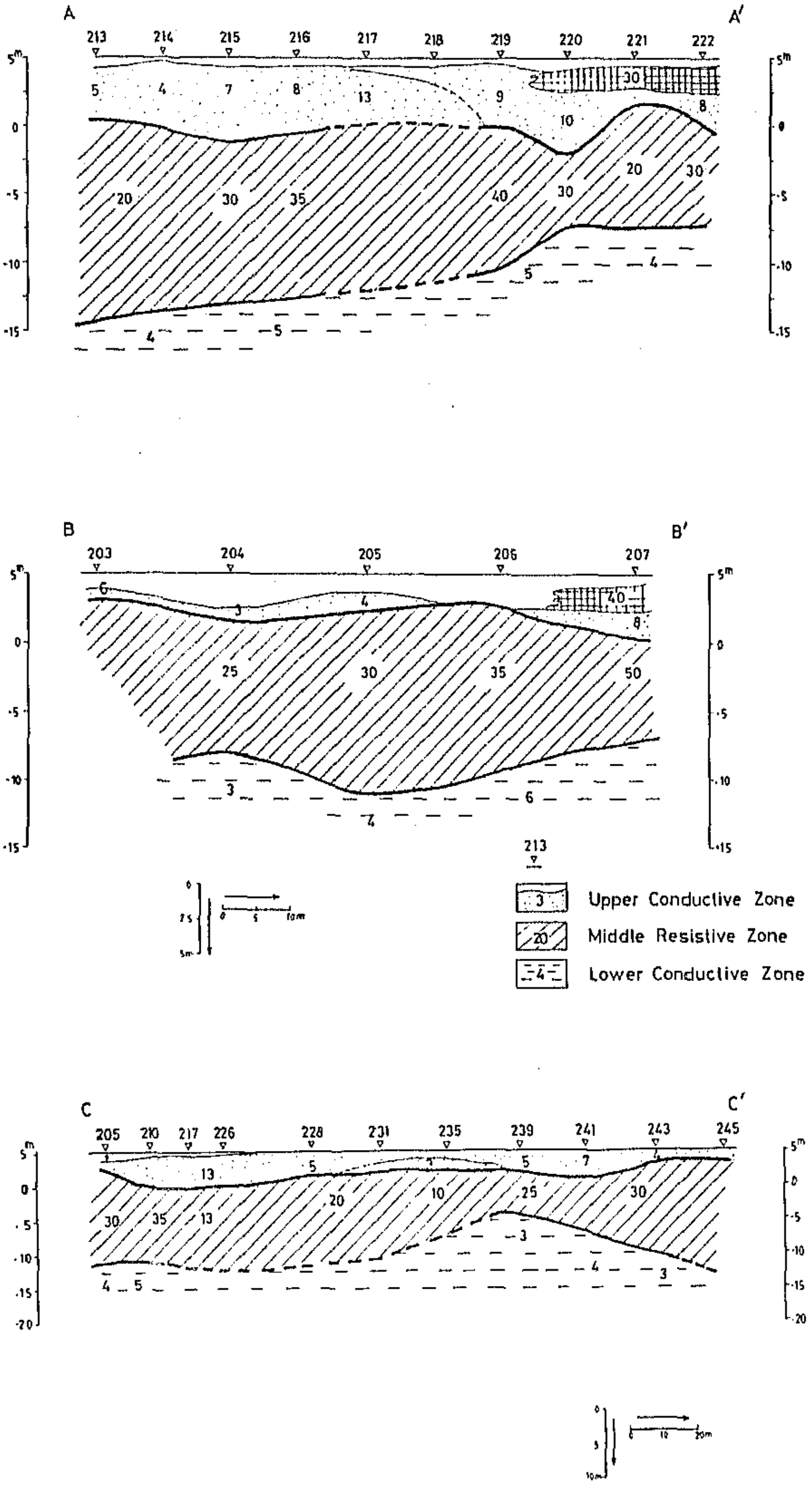


Fig. 6.1.2 Resistivity Cross Section in Wadi Musherib Test Site

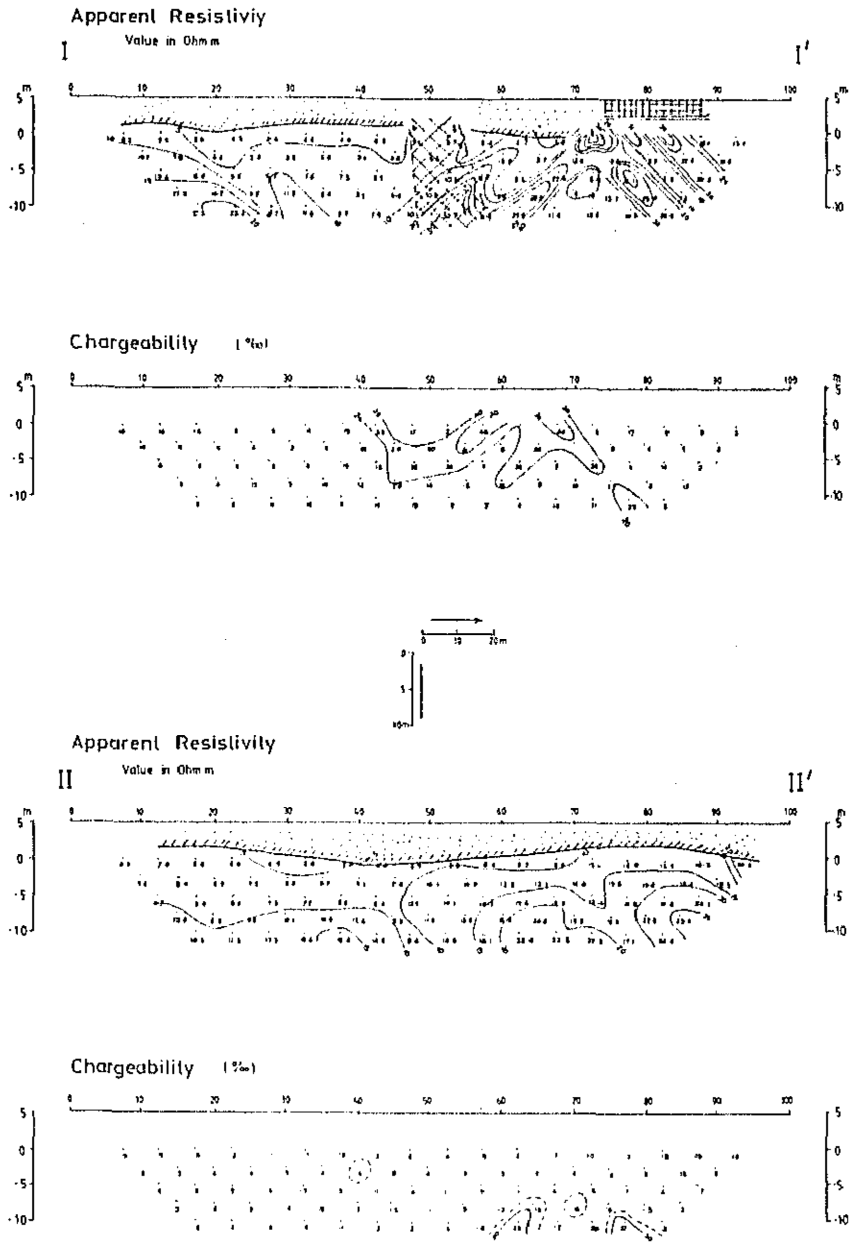


Fig. 6.1.3 IP Pseudo Section in Wadi Musherib Test Site

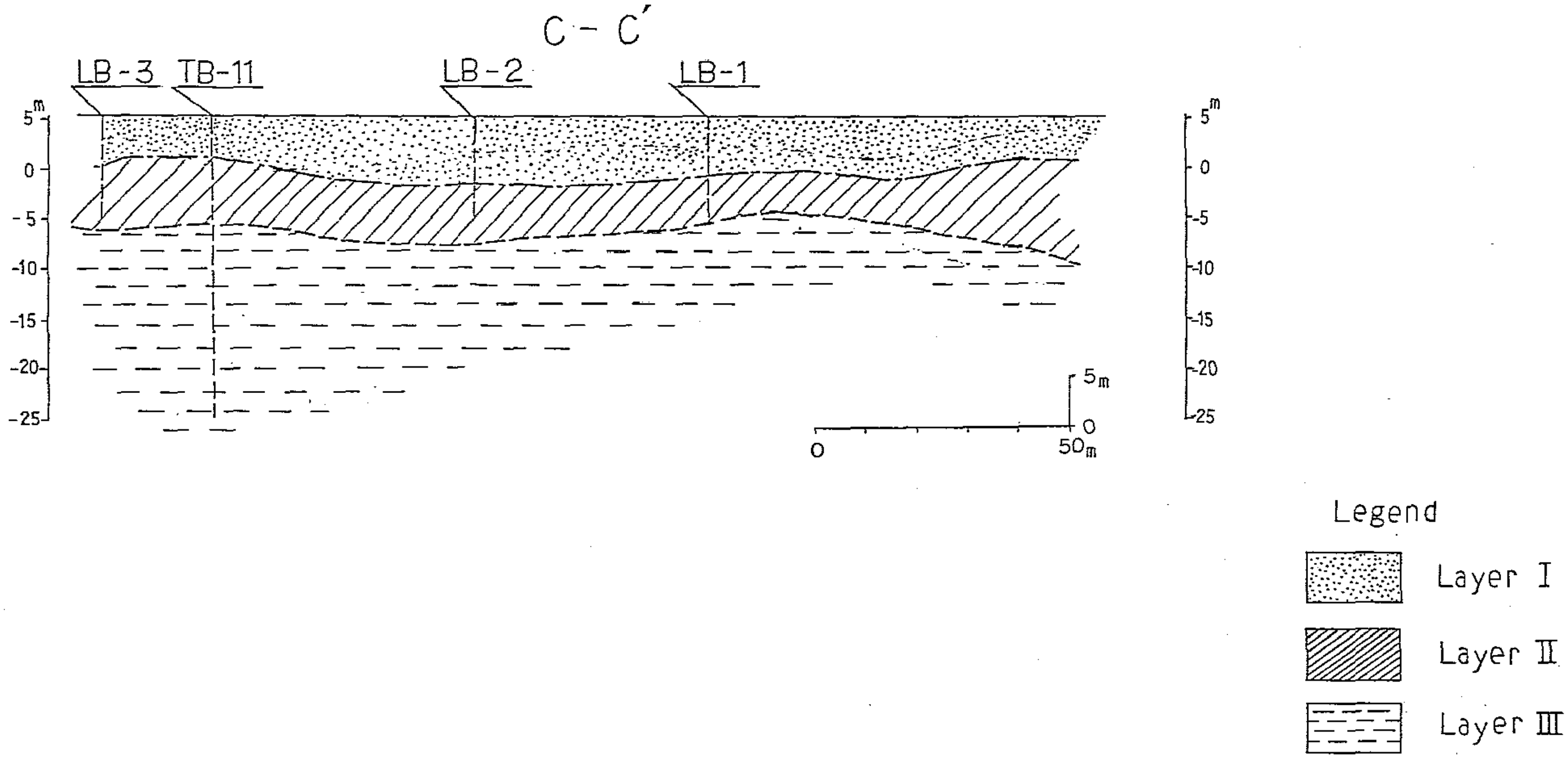


Fig. 6.1.4 Hydrogeological Cross Section of Wadi Musherib Test Site

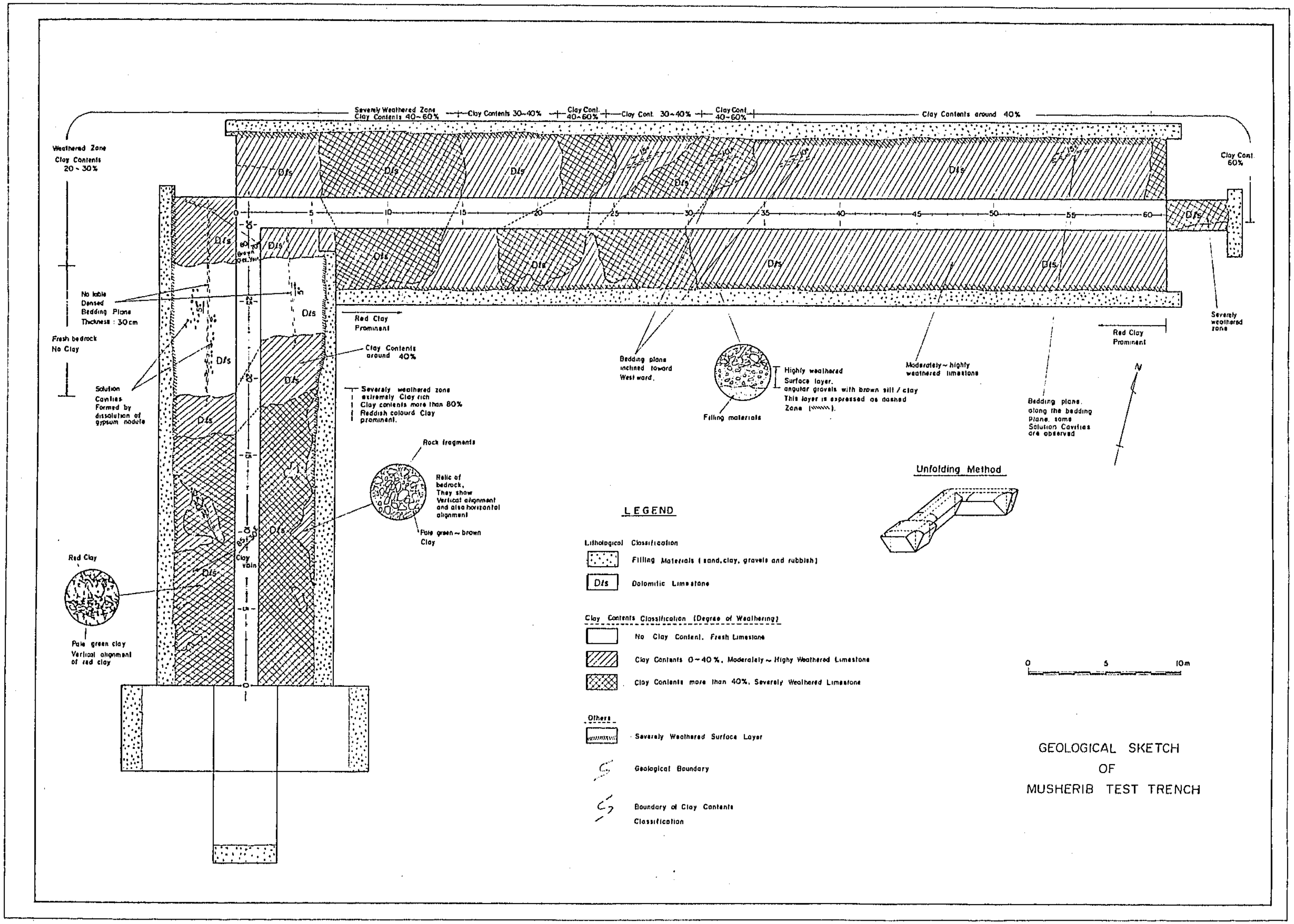


Fig. 6.1.5 Geological Sketch of Wadi Musherib Test Site

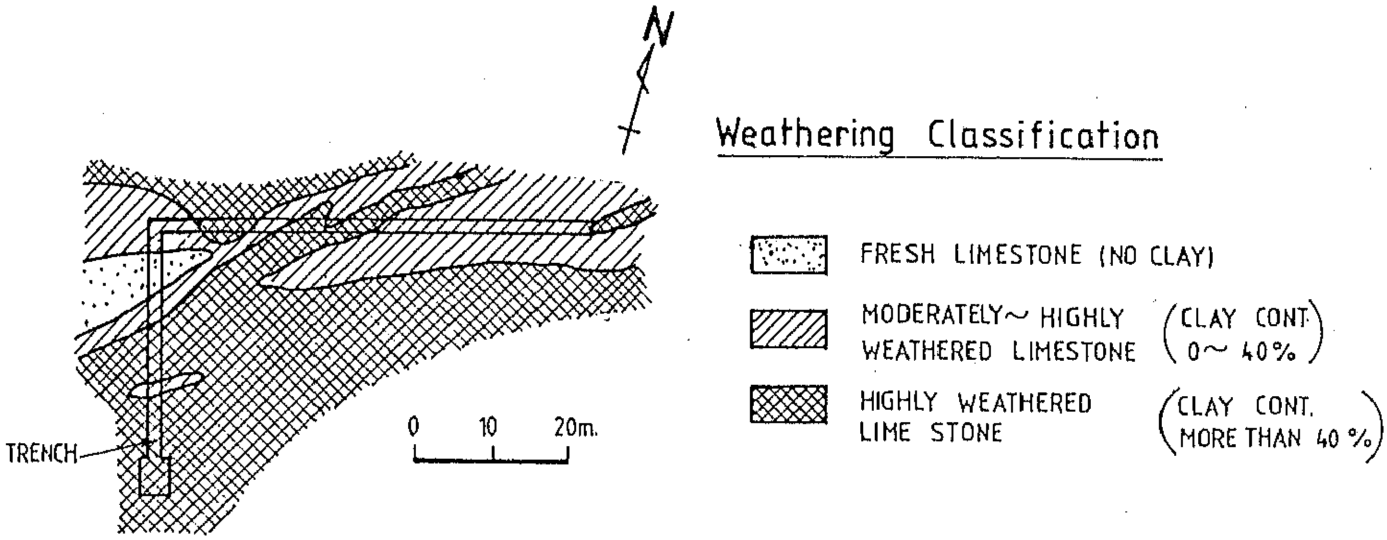


Fig. 6.1.6 Weathering Classification of Limestone of Wadi Musherib Test Site

In the fresh limestone, fossils are rarely observed and gypsum is present in nodular forms. As a large number of such gypsum nodules have dissolved, cavities of 1 to 5 cm have been created.

The filling materials are composed of sand, gravels, clay and waste materials which include rags, steel bars, concrete, plastics, etc. The thickness of the filling material is 1 to 1.5 m.

The characteristics revealed by a close observation of the weathering conditions in the trench shall be discussed below.

1) As is shown below, a collection of rock fragments are believed to be unweathered relics which are distributed vertically in the clay zone.

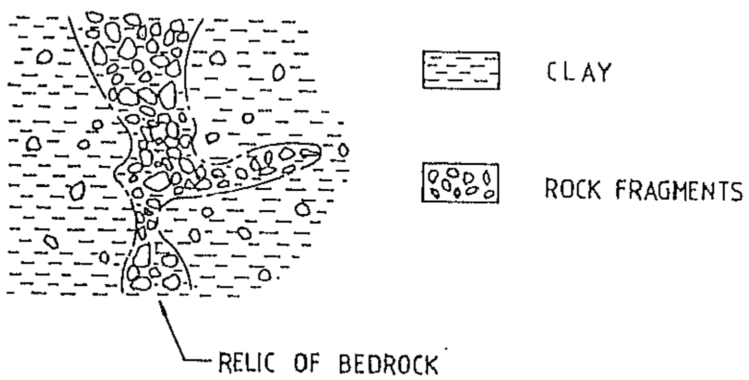


Fig. 6.1.7 Schematic Drawing of Vertical Alignment of Bedrock Relic

2) The direction of the weathered zone of the test work site shown as Fig. 6.1.7 is prominently due ENE-WSW-NE-SE. As has been stated in the preceding section, the weathering phenomenon suggests that it has all the more strongly been constrained by the linear structural elements in agreement with the direction of the Musherib lowland.

According to previous studies reports, the weathered zone is reported to get thicker along the Musherib lowland. In the lowland, the weathering phenomenon has advanced into depths along the fissures which had been formed previously.

The bedding plane of dolomitic limestone is due NE-SW direction and is dipping 10° to 15° toward NW. (This direction is toward the central Musherib lowland.)

Although no clear evidence exists of either fissure or fault in the test work site, vertical small-scaled lineament or clay veins could be observed in places. The vertical structural arrangement of weathering zone corresponds to the Musherib lowland which runs due ENE-WSE. Considering this, in the test work site, structural elements such as fissures have become quite difficult to recognize because of strongly weathering of dolomitic limestone.

At the longer leg of the trench, the groundwater has been observed spurting in large quantity. Also from the bedding planes and places where clay veins are present irregularly, spurting is observed in small quantity.

6.2 Rayyan Test Work Site

6.2.1 Electrical Soundings

The measurement line locations and measurement point numbers are shown Fig. 6.2.1.
A resistivity vertical section schematic drawing was prepared using the apparent resistivity values. (See Fig. 6.2.2) The subsurface of the test work site has been divided into 3 zones: 1) Upper Conductive Zone, 2) Middle Resistivity Zone, and 3) Lower Conductive Zone. The result of IP method are shown in Fig. 6.2.3.

As far as can be ascertained from the results of IP method, no cavities, caverns, fissure zones, or large clay lumps of any significance exist in the Rayyan test work site.

6.2.2 Hydrogeological Conditions of Rayyan Test Site

In the Rayyan test work site, 5 borings were carried out: LB-16, TB-27A, TB-31A, TB-32A, TB-43A. The results of boring at the Rayyan test work site is shown in Fig. 6.2.4.

A detailed development schematic drawing of the excavation wall surface of the trench is shown in Fig. 6.2.5.

The geology of the Rayyan test work trench consists of dolomitic limestone and topsoil.

According to the data on adjacent area, dolomitic limestone in the Rayyan test work site can be correlated to Simsima limestone and Dolomite Member of Upper Eocene. The dolomitic limestone is divided into two portions in terms of the degree of weathering.

The superficial dolomitic limestone has been strongly weathered turning in to white to gray clay containing limestone fragments in places. This portion, also containing much plant roots, is 0.5 to 2 m in thickness, with the average at 1 m. The stratification and joints could not be recognized.

This strongly weathered portion is underlain by strongly to moderately weathered dolomitic limestone which is composed of a hard limestone, dolomitic limestone layer and white-green clay layer. As these layers are found interposed in nearly horizontal manner, it can be presumed that these had been created along the original bedding plane of the dolomitic limestone.

In the strongly to moderately weathered portion, a weak stratification structure in the intervals of 5 to 30 cm can be observed.

The topsoil in the Rayyan test work site is composed of brown clay which contains silt and sand with gravel. The thickness of the topsoil is 10 to 15 cm. This layer is assumed to have been transported and deposited by wind (aeorian deposits).

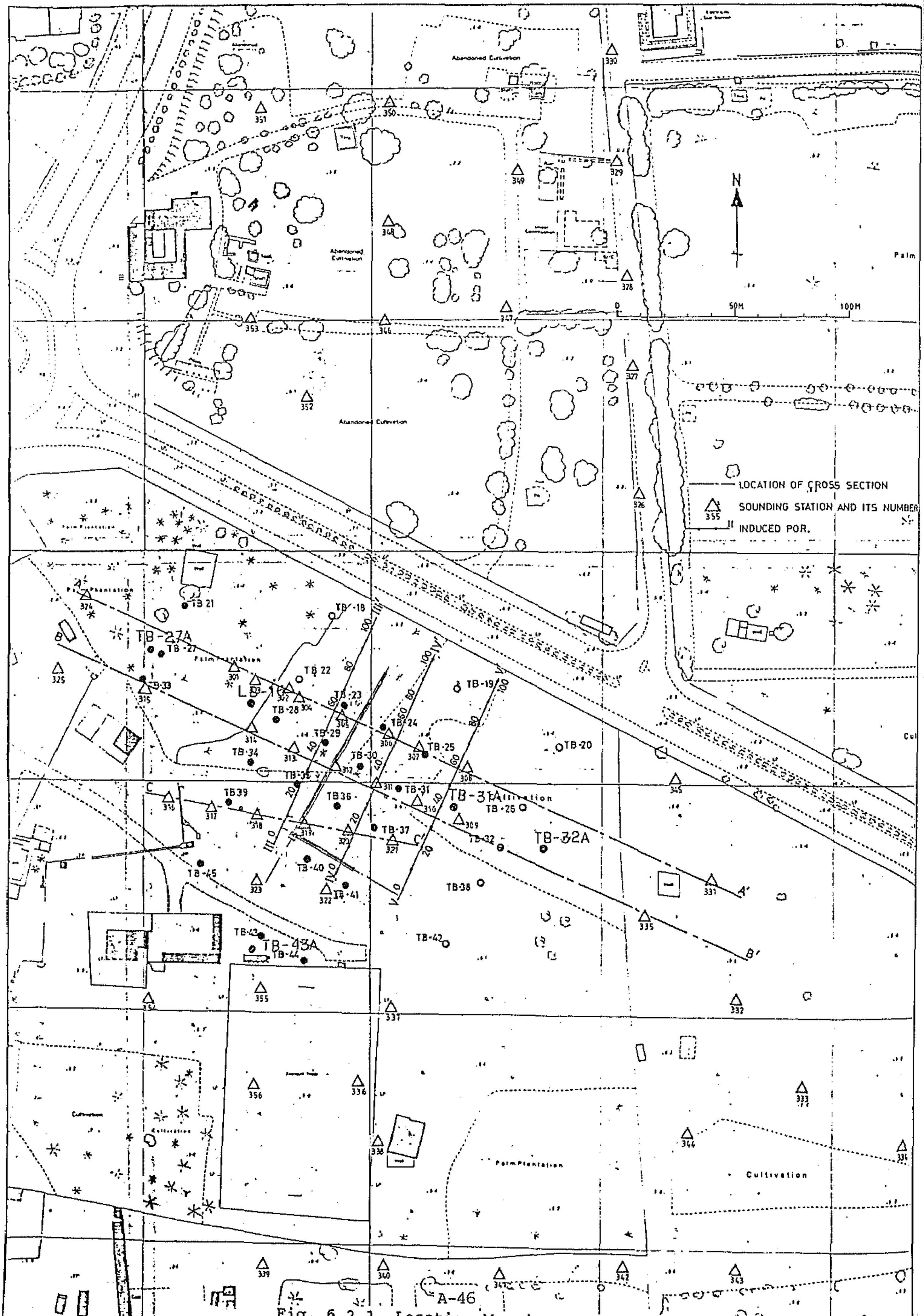


Fig. 6.2.1 Location Map in Rayyan Test Work Site

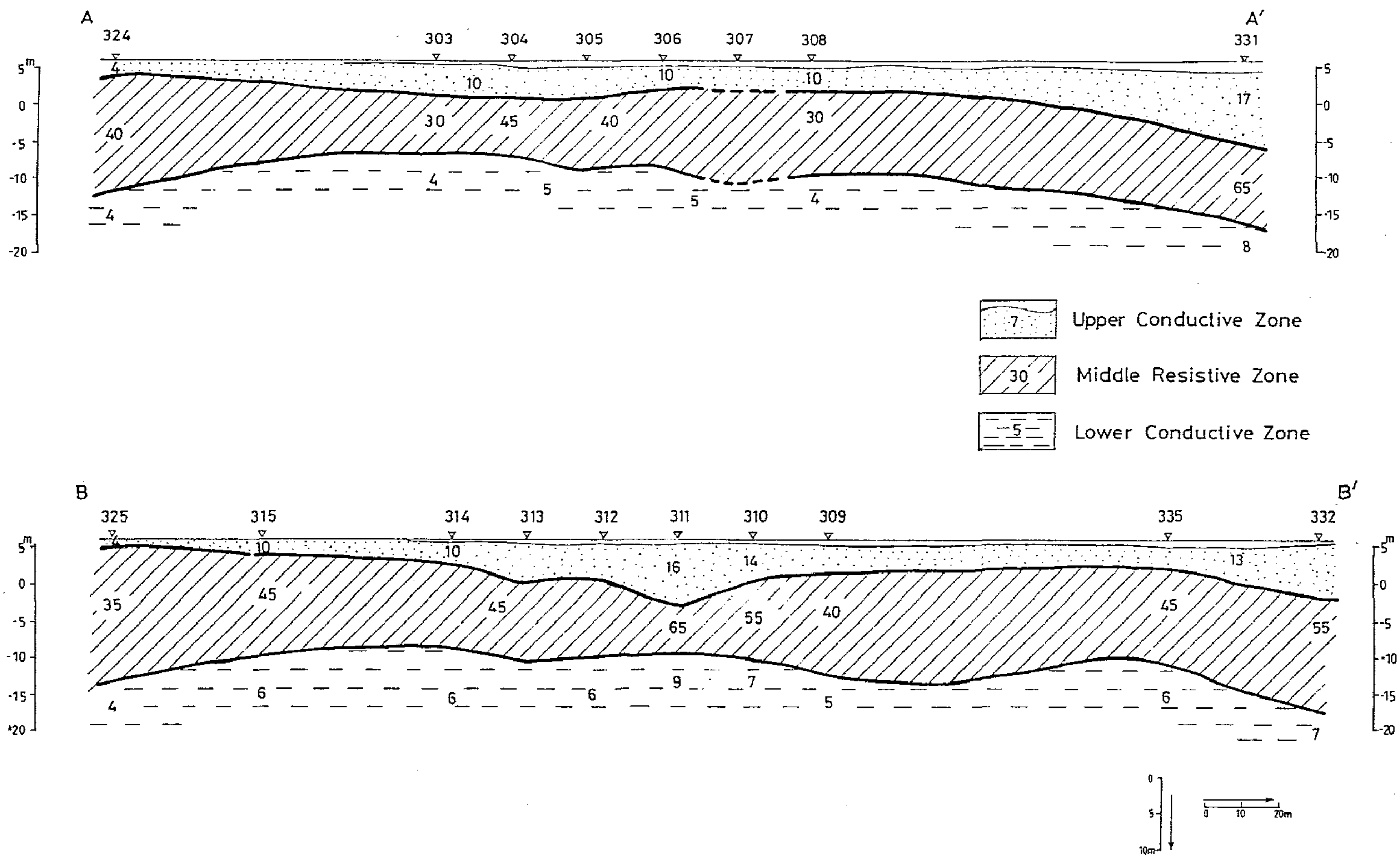


Fig. 6.2.2 Resistivity Cross Section in Rayyan Test Site

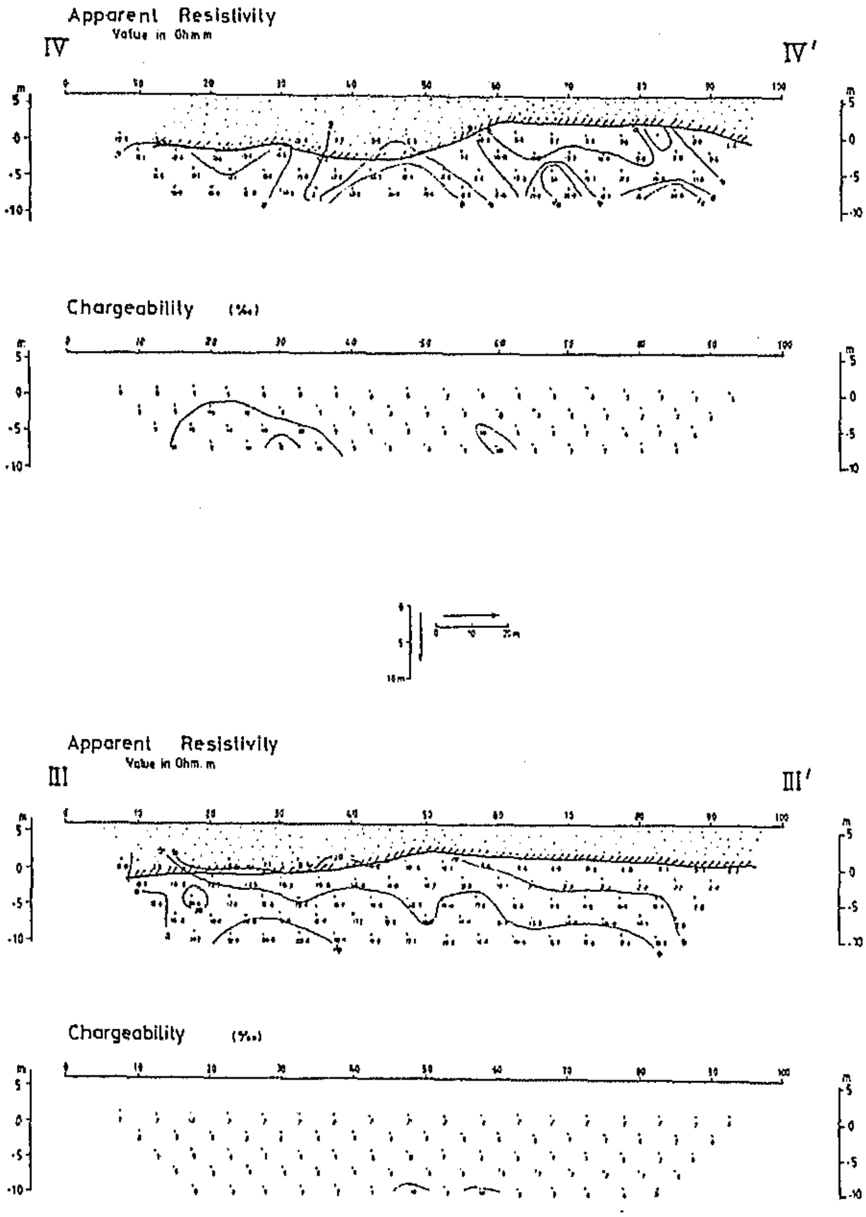


Fig. 6.2.3 IP Pseudo Section in Rayyan Test Site

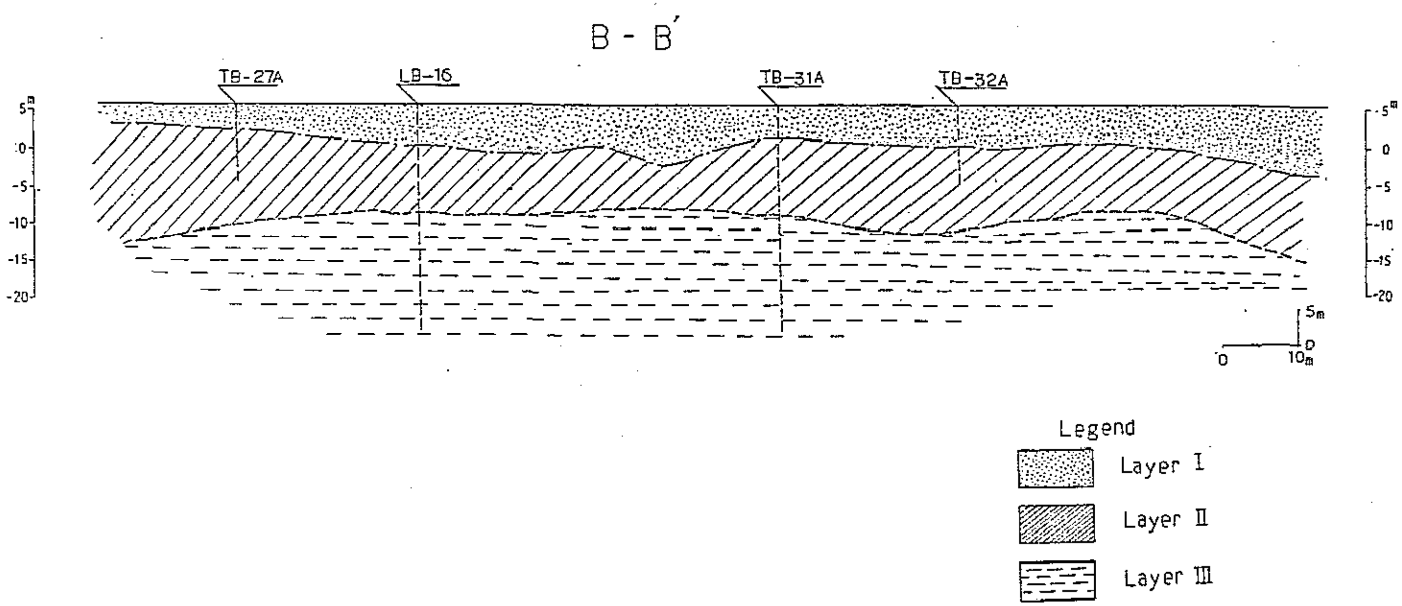


Fig. 6.2.4 Hydrogeological Cross Seciton of Rayyan Test Site

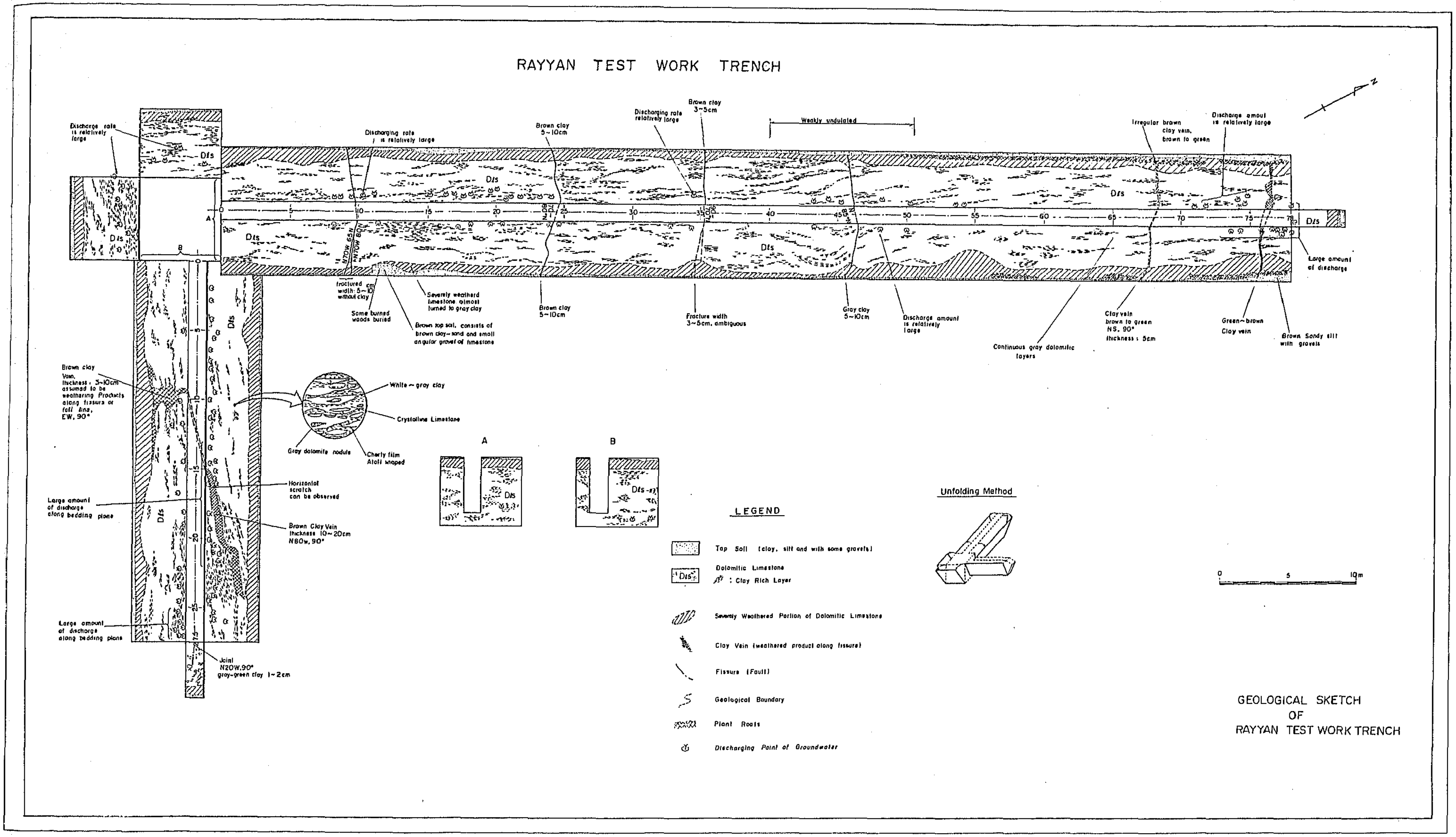


Fig. 6.2.5 Geological Sketch of Rayyan Test Work Site

In the Rayyan test work trench, 7 joints and minor faults were observed. All of them were small, with even the largest ones being not more than 10 cm in width. Along these joints, dolomitic limestone have transformed into gray to brown clay of several centimeters. It is quite characteristic that most of these joints and faults are nearly in the same direction (i.e. E-W to NW-ES).

In the trench, there were relatively large volume of groundwater flowout discharge at numerous locations. In terms of areas of water spurting, two classes can be identified: 1) spurting along the joints, and 2) spurting along the fissures. Especially numerous are water spurting out of the fissures along the minor axis of the trench. In case of water spurting along the joint surface, the quantity of flow increases as the joints get closer to the fissures. From these considerations, the following can be assumed.

a) The main flow of groundwater is along either the joints or bedding planes.

b) As far as the flow of groundwater is concerned, a more significant role is played by joints than the bedding planes.

Appendix
(Core Boring)

Legend

Symbolic Log

Subformation boundary

UD: Upper Dammam Formation

LD: Lower Dammam Formation

Packer test (Lu = (1/min/m/10 kgf/cm^2)

Symbolic Log

Gravel or/Concrete or Asphalt
(Grand surface materials)

Clay or silt

Sand stone

Limestone and/or dolomitic limestone

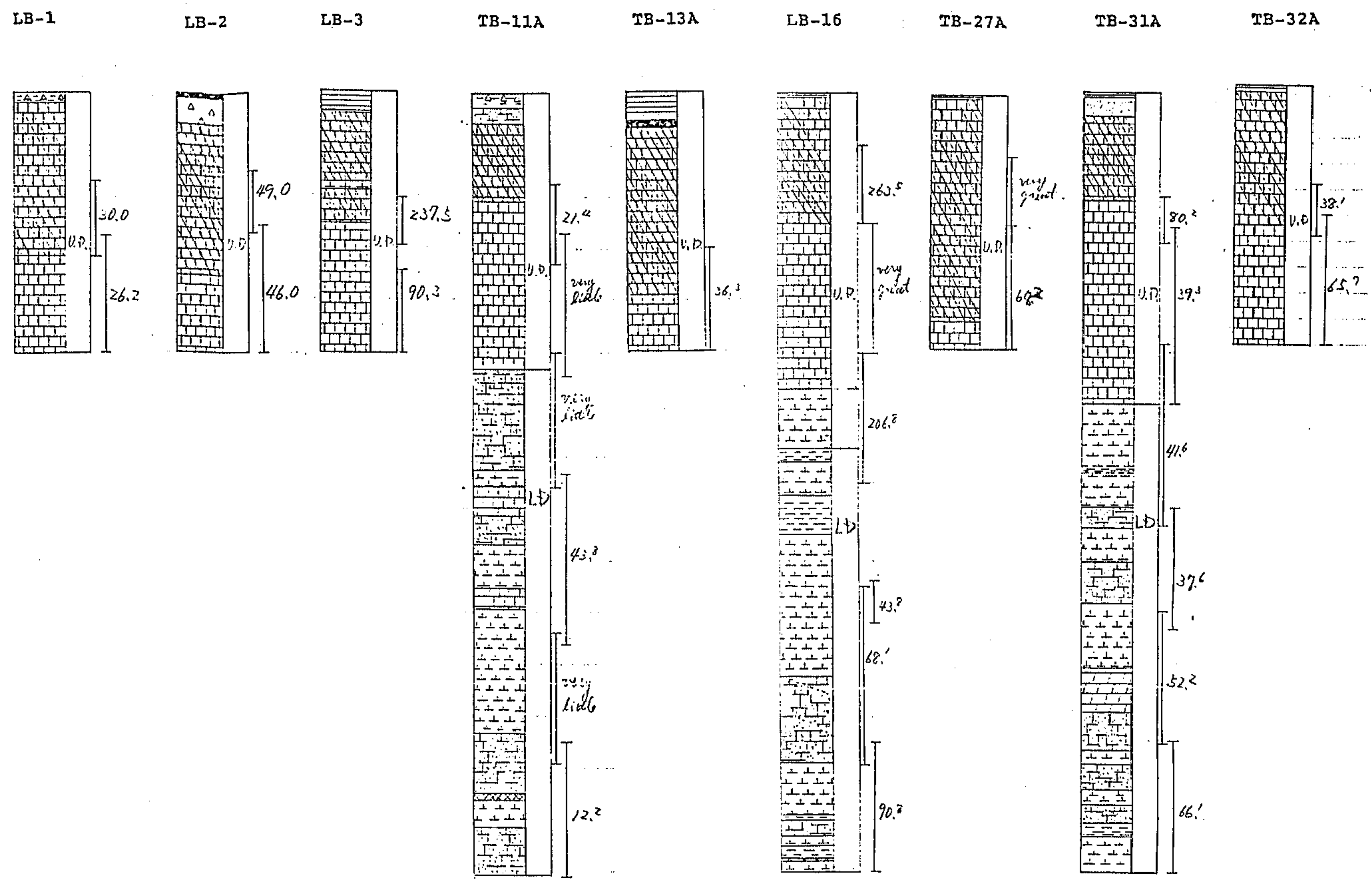
Calcilutite (Silty limestone)

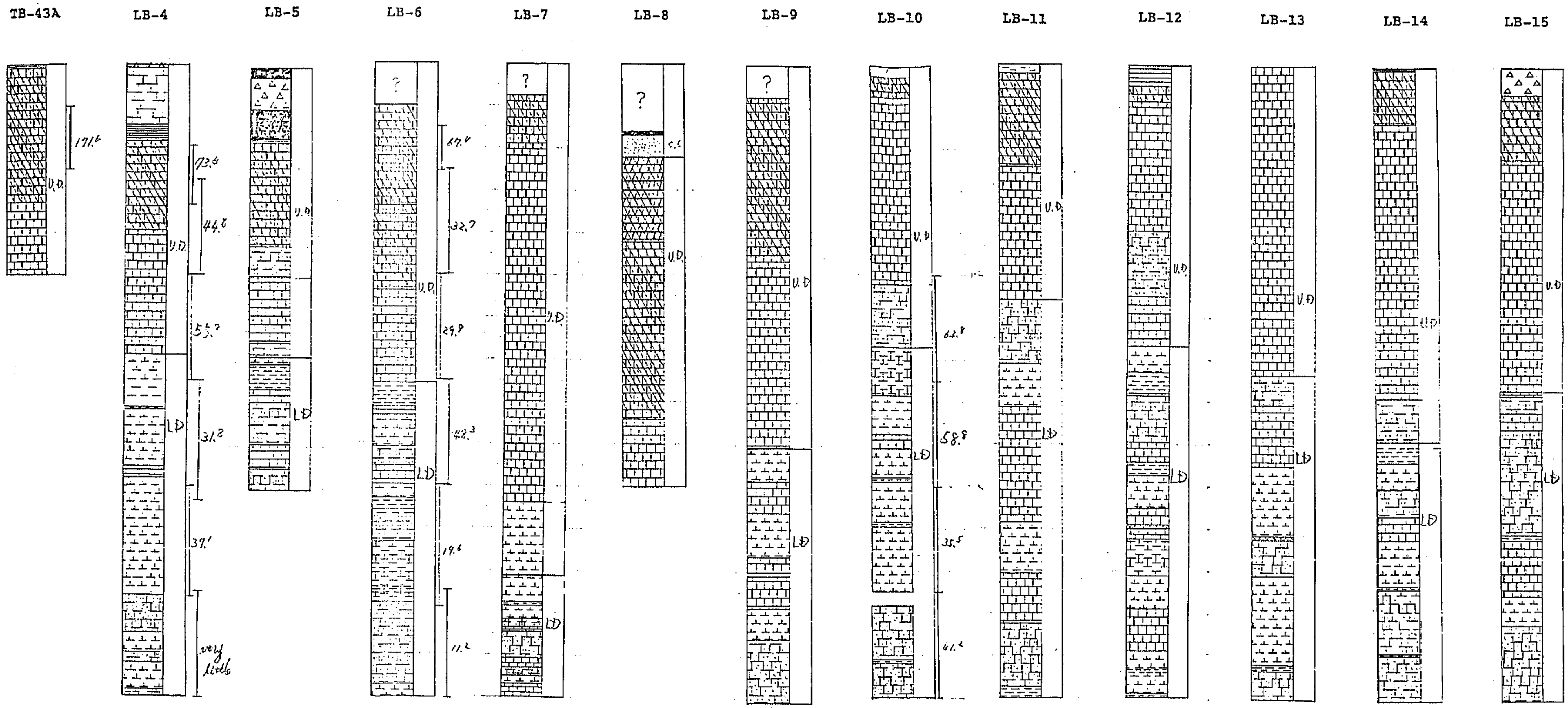
Calcarenite (Sandy limestone)

Dolomite

Shale

Chalk




TB-43A
LB-4
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PART : B Groundwater

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1. INTRODUCTION

Groundwater study is most important in order to understand the rising groundwater phenomena and it gives basic information to plan the divers countermeasures. This study mainly consists of the following objectives:

1 Renovation of groundwater contour map: 1986

2 Understanding of groundwater level rising rate

3 Understanding of different impacts to the groundwater recharge amount

- Meteological condition
- Potable water supply amount
- Waste water

4 Simulation of groundwater level from 1983 to 1986

- Wadi Musherib
- Rayyan

5 Forecasting of drainage amount in the project areas

- Wadi Musherib
- Rayyan

Taking into consideration the electric sounding and core boring results, numerical analysis was carried out by using quasi three dimensional model and its parameters were identified by trial and error method, based on the groundwater level simulation and discharge amount of Test Works.

Grid systems employed for Wadi Musherib and Rayyan are one and a half times bigger than previous study and the calculation was done by unsteady analysis using Finite Element Method.

These calculation results can supply much information for the urgent groundwater drainage improvement projects.

2. GROUNDWATER LEVEL

2.1 Groundwater Level Measurement

2.1.1 Field Reconnaissance

A groundwater level measurement plan was established after an inspection of MEW's monitoring wells and the policy of measurement was as follows:

- To understand groundwater level fluctuation behaviors in monitoring wells with the cooperation of MEW.

- To understand groundwater rising rate and area based on the ASCO study in 1983.

First one is being carried out continuously by MEW staff on a routine basis; second one was made by JICA staff and approximately 250 wells were investigated from Feb. 1st to Feb. 25th in 1986. Some checks of groundwater level were also carried out at the end of March.

The well classification and numbering system in the previous study by ASCO was respected in the JICA Study Team field reconnaissance. Well types are as follows;

- Dug well

- Existing drilled well

- Project well (drilled during ASCO 1983)

Remarks during JICA Study Team survey are as follows;

- Monitoring wells installed near schools have been filled by stones.

- Some borehole points have been lost due to road construction.

- Considerable number of wells cannot be measured due to pump installation.

- Wells inventoried in ASCO report, at present bear no trace of practical number except for mark of "Project well" and the identification is sometimes very difficult.

  ASCO does not cover all existing well points, and some well points have been newly added in this suvery.

2.1.2 Renovation of Groundwater Level Contour Map

By using ground level as parameter, each depth observation datum is transformed to groundwater level in QND. Ground level or datum point elevation for each well point is taken from "ASCO Report: Appendix: Site Summary".

Groundwater level contour map shown in Fig. 2.1.1 indicates that two groundwater mounds exist as interpreted in the previous study (ASCO);

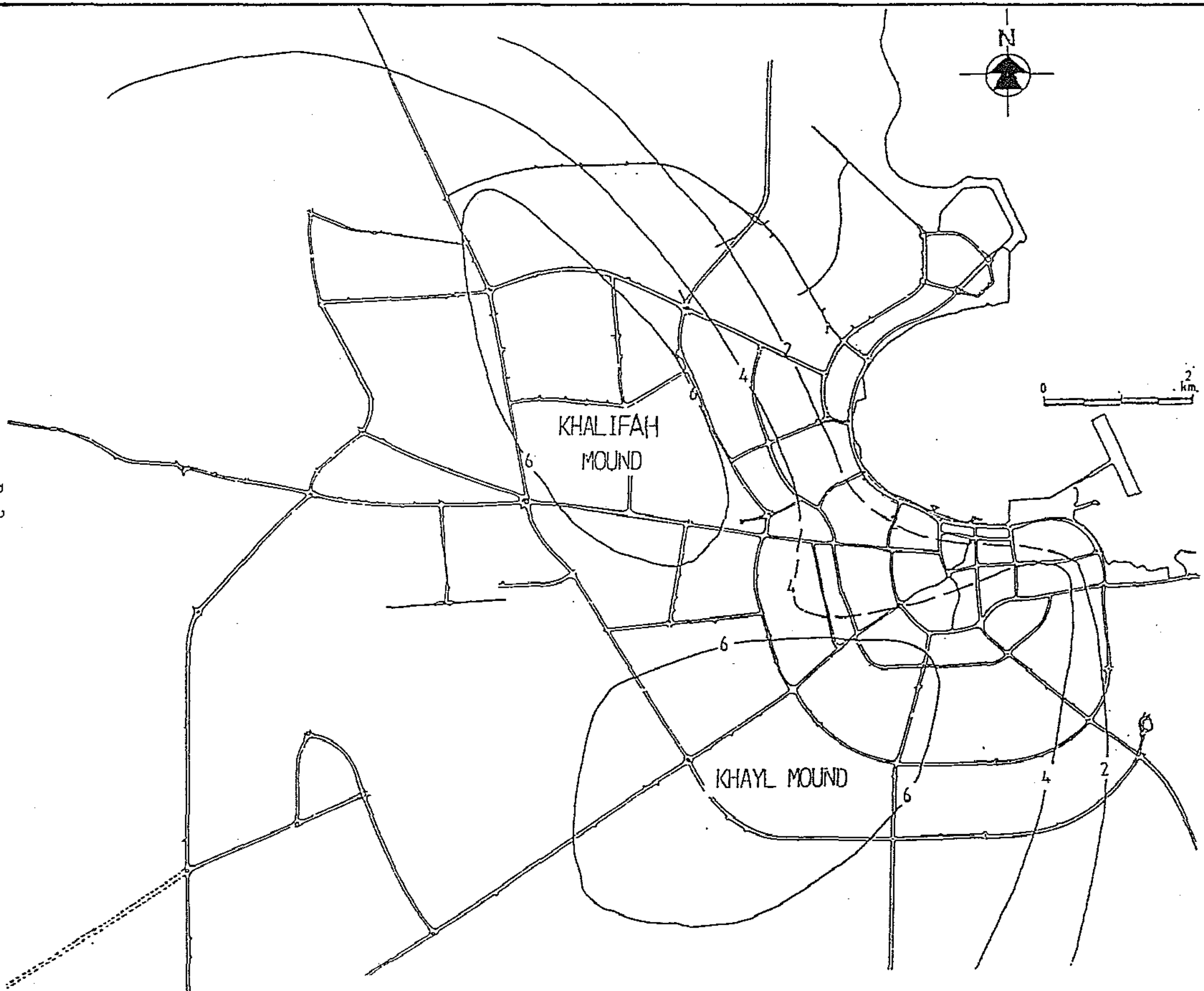


Fig. 2.1.1 Groundwater Table Elevation, February 1986 (Meters above Q.N.D.)

- One beneath Khalifah district (hereinafter referred to as Khalifah mound)

- Other beneath Khayl district (Khayl mound)

Wadi Musherib acts as natural drainage for both surface and groundwater. The groundwater level investigation of Wadi Musherib and its vicinity is complicated by the following two factors;

- Low density of measurement points

- High density of underground services, such as potable water supply system, telephone cables, sewerage, etc.

Therefore the JICA Study groundwater level contour map of the area within the 'C' Ring Road is estimated from general groundwater conditions.

From the view point of small scale time and space relationship, local and partial variations of groundwater levels will occur due to many specified and unspecified activities.

2.1.3 Groundwater Depth From Ground Surface

Depth to groundwater map as shown in Fig. 2.1.2 is obtained from the topographic analysis. Areas of shallow depth groundwater of less than 2m below surface can be grouped as follows;

a) Group 'A' ; Rayyan to Abu Hamour
b) Group 'B' ; Wadi Musherib
c) Group 'C' ; Montazah Low
d) Group 'D' ; Coastal Zone
e) Group 'E' ; Al Ahli Sports Club

In comparison with the previous study (ASCO 1983), Group 'A' area has extended seriously and the largest standing water now exists at Rayyan. The Groups 'B', 'C' and 'D' have nearly the same configuration as they had during the previous study and Group 'E' cannot be compared in detail as it has newly appeared.

2.1.4 Rate of Rising Groundwater Level

(1) Rise during last three years

In order to understand the recent rate of rise of groundwater levels during the last three years, the rate from Feb. 1983 to Feb. 1986 was calculated and its general configuration is shown in Fig. 2.1.3.

(2) The rate of groundwater level rise in Rayyan, where many well points exist, occurred in the range of 1.0 to 1.5 meters, and yearly rate is estimated to be 0.33 to 0.50 m.

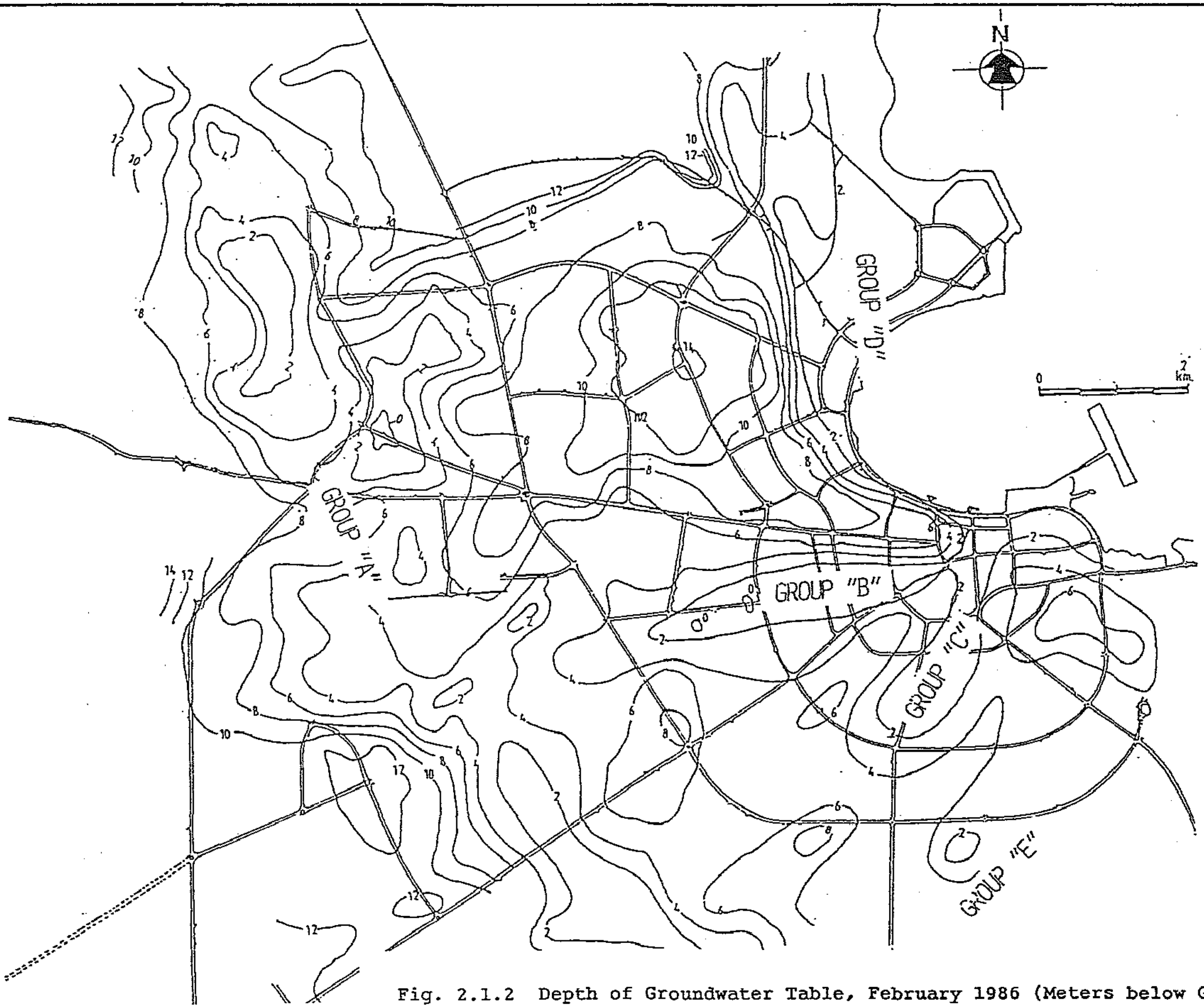


Fig. 2.1.2 Depth of Groundwater Table, February 1986 (Meters below G.L.)

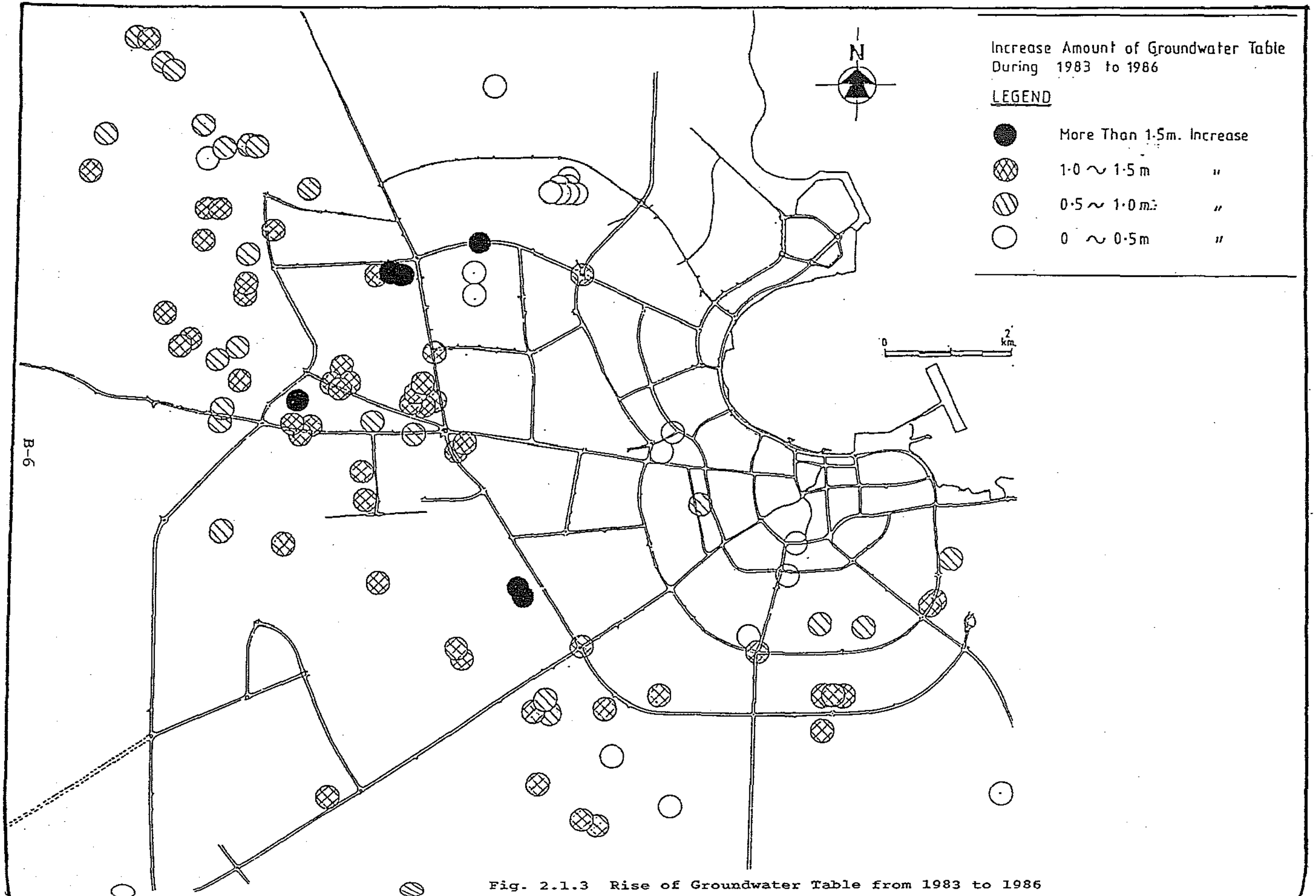


Fig. 2.1.3 Rise of Groundwater Table from 1983 to 1986

(3) Khalifah Groundwater Mound

Well points to measure the groundwater level in this area are low in distribution density and some of them have been destroyed by road construction or lost due to stone filling.

Data from well points observed in our investigation show no significant rise of groundwater level.

Taking into consideration the fact that the Khalifah area is already well urbanized and has had no important recent changes in land use, it can be understood that Khalifah groundwater mound has undergone no important extension.

(4) Wadi Musherib and its vicinity

The rate of rise of groundwater level in the area within 'C' Ring Road is not strong in comparison with the area out of 'C' Ring Road. Changes in groundwater level from Feb. 1983 to March 1986 are as follows;

- Rumailah Hospital	+ 0.15 m
- Banque de Paribas	+ 0.65 m
- MED Car Park	- 0.21 m
- MEW Stores	+ 0.25 m
- Montazah Park (2339-32)	+ 0.41 m

The western and southern areas between the 'C' and 'D' Ring Roads have demonstrated an important rise in height of 1.0 to 1.5 meter, similar to the Rayyan area.

(5) Khayl Groundwater Mound

Khayl Groundwater Mound is expected to expand rapidly in south-west (SW) direction.

The following suppositions are proposed;

- Groundwater recharge amount is rising due to the rapid urban development.
- In the south-western part, there is the possibility that groundwater will be partially supplied via the depression line from Rayyan-Abu Hamour.

(6) New District of Doha

There are very few wells to provide significant information. Assuming that Khalifah groundwater mound has shown no important recent extension, rising rate of groundwater level in New District seems to be less important than that in Rayyan area.

2.2 Factors Affecting Groundwater Rising

2.2.1 Hydrological condition

(1) Climatological characteristic at Doha International Airport

A climatological observation station is located at Doha International Airport and its observation items are as follows:

- Temperature
- Rainfall
- Relative humidity
- Wind speed
- Radiation
- Evaporation
- Others

There are several other rainfall observation stations but their observation data have not sufficient reliability as mentioned in the previous studies. One of the main reasons is the difficulty of maintenance of apparatus caused by the falling of suspended solids in air carried by strong wind.

Among above mentioned items, rainfall and evaporation are most important in the hydrological cycle. Evaporation is closely related to such factors as temperature, wind speed, relative humidity and radiation.

(i) Rainfall

Mean annual rainfall amount during the period of 1962 to 1985 is 75 mm. Mean monthly rainfall amount is more than 10 mm from December to March during the rainy season.

There is almost no rainfall from June to October.

The value of maximum rainfall in 24 hours is very random in its occurrence. Records showing more than 50 mm in 24 hours are as follows:

- May 1963 64.0 mm
- December 1964 80.1 mm
- January 1969 58.0 mm
- March 1982 66.5 mm

1986 rainfall information at Doha International Airport is as follows:

- Jan. 30 to Jan. 31 4.7 mm
- Feb. 6 to Feb. 7 7.4 mm
- Apr. 9 to Apr. 10 37.0 mm

According to the opinion of the Department of Meteorology, rainfall in Doha has particular characteristics, mentioned as follows:

a) Rainfall pattern can be recognized as thunderstorm, having high intensity of rainfall.

b) Rainfall does not occur uniformly. In particular case, there is rainfall in some places while there is no rainfall in the nearby vicinity.

c) As rainfall cloud is usually moved by the NW-SE wind, it is expected that a place located on the same NW-SE line has strong correlationship in rainfall amount.

(ii) Evaporation

Evaporation amount is measured by the following two methods:

a) Open Pond : 1976 to Present
b) Piche Pan : 1977 to Present

As open pond has much larger surface contact with atmosphere than Piche Pan, evaporation amount observed by open pond is some 60 to 70 percent of Piche Pan values. It seems that evaporation amount from the free water table such as standing water is very similar to that of open pond values.

(2) Meteological Observation at Rayyan

Meteological observation equipment were installed beside the Rayyan Test Work trench to understand the regional characteristics at Rayyan.

The following four equipment were installed for collecting local data during Test Work period at Rayyan site.

- Automatic rain gauge
- Automatic temperature, humidity and barometric pressure recorder
- Automatic wind direction and velocity recorder
- Evaporation pan

The meteological observation for the following items were carried out from the 1st June to the end of October.

- Temperature
- Humidity
- Barometric pressure
- Rainfall
- Surface wind direction and velocity
- Evaporation

The observation results from June to October 1986 are shown in Fig. 2.2.1 and Fig. 2.2.2.

With regard to the evaporation which is the most important factor during the Test Work Period, the observation results obtained at Rayyan show nearly the same configuration of variation characteristics as that of Doha Airport.

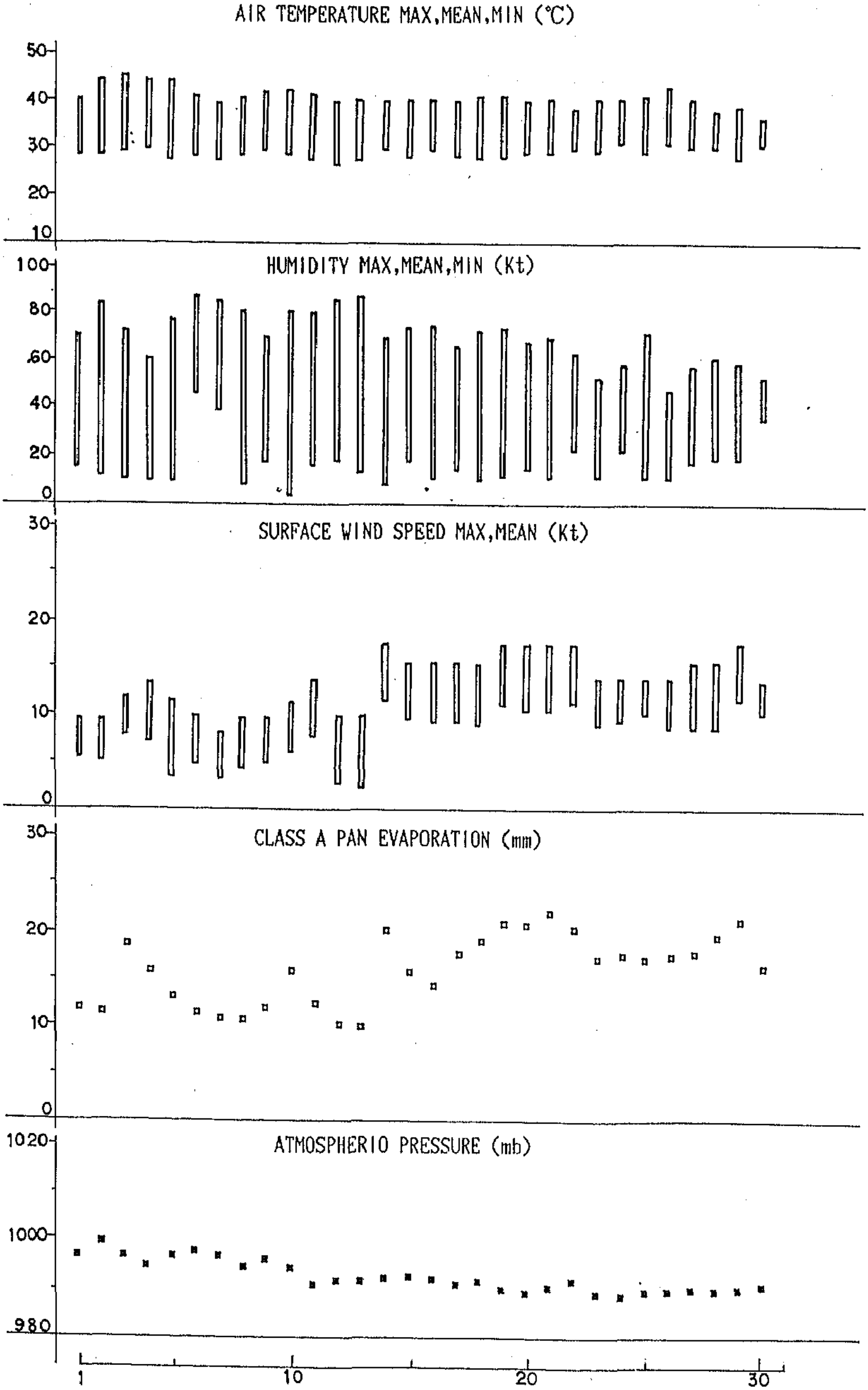


Fig.2.2.1 Meteological Observation at Rayyan : June

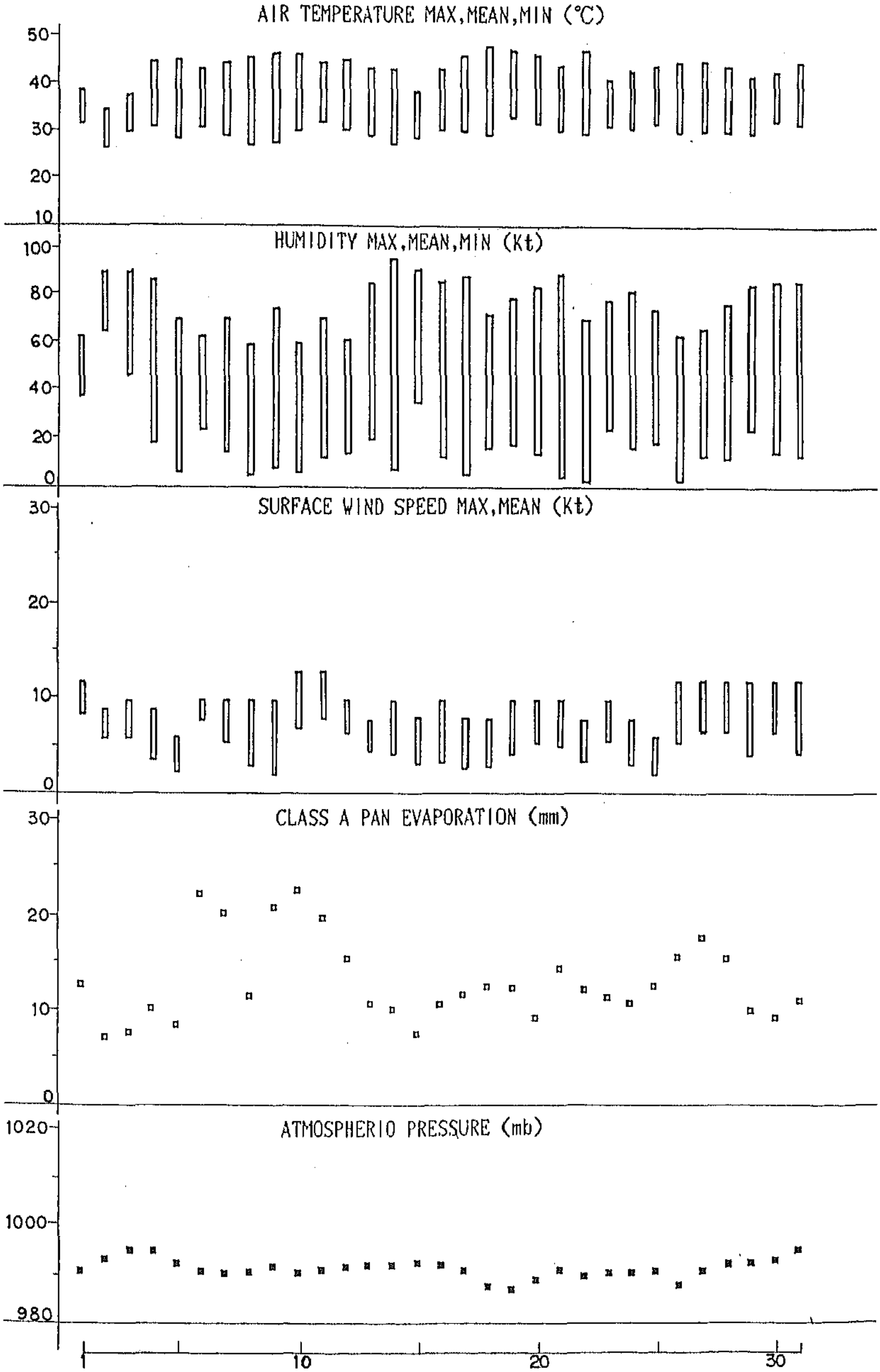


Fig.2.2.1 Meteological Observation at Rayyan : July

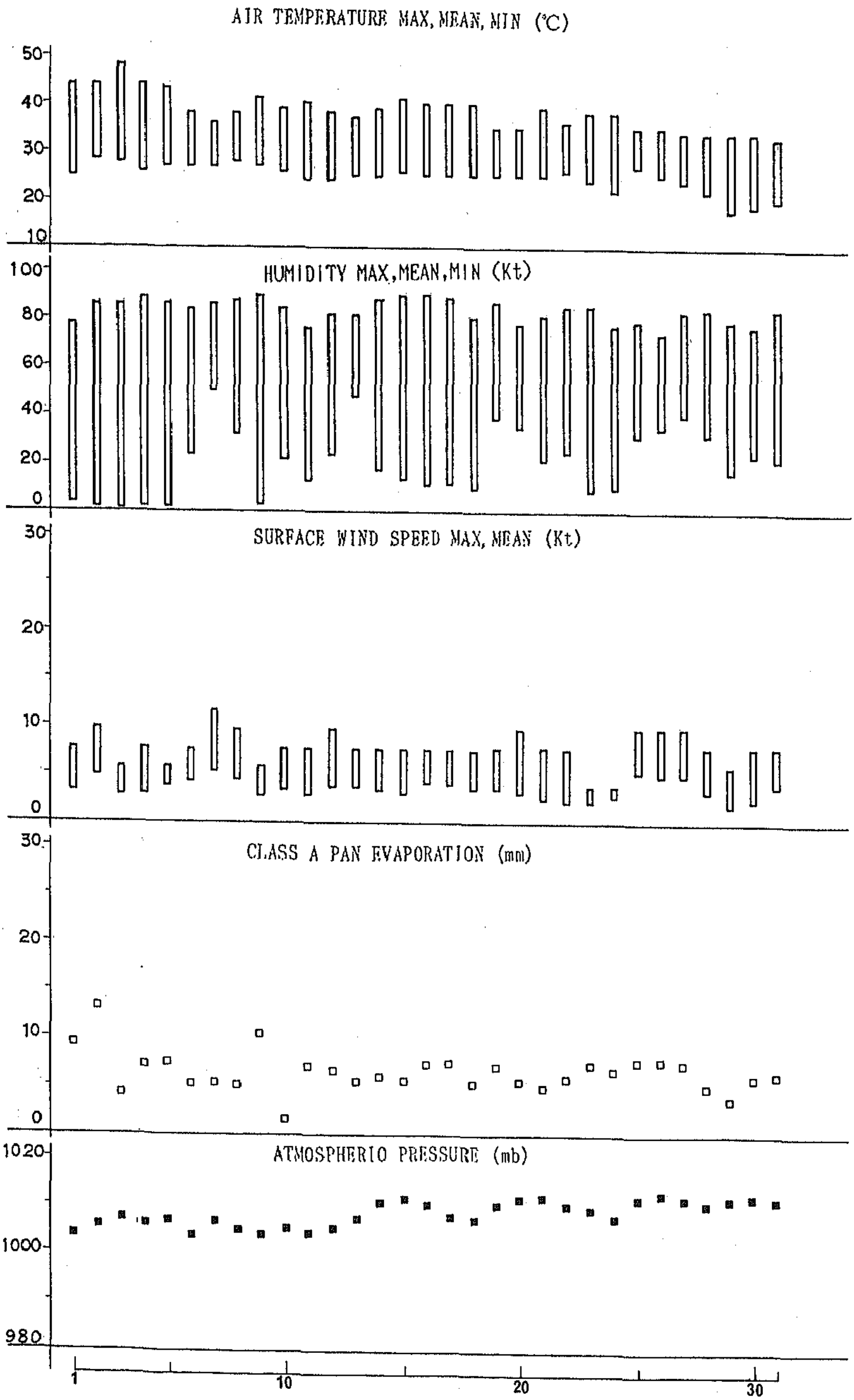


Fig.2.2.1 Meteological Observation at Rayyan : August

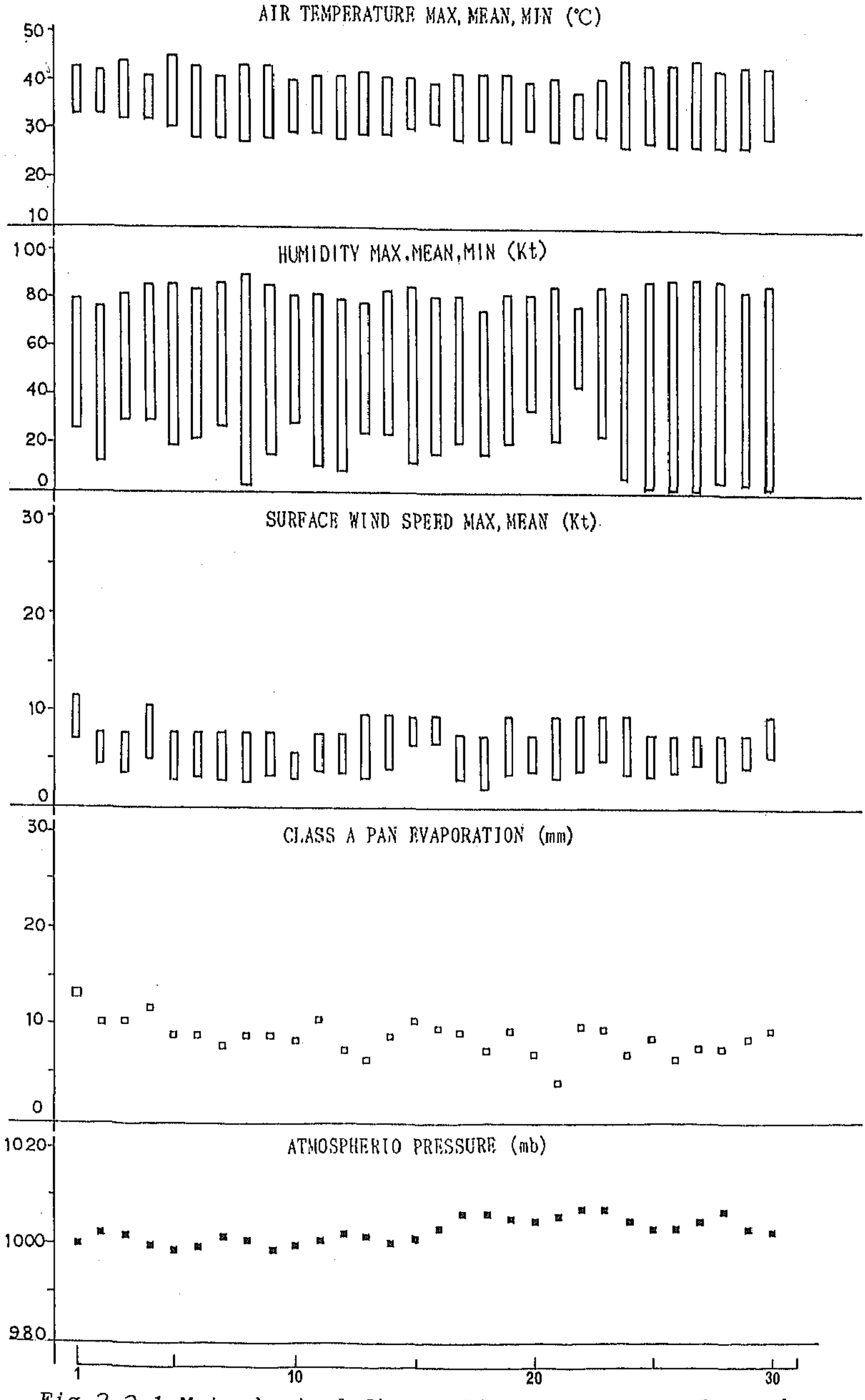
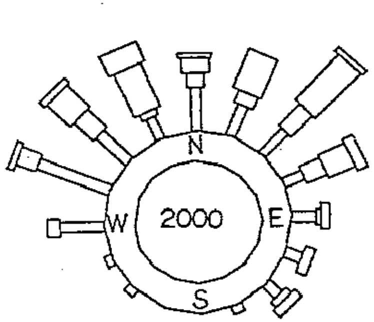
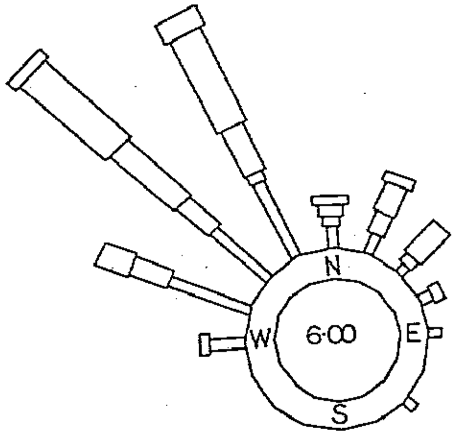


Fig.2.2.1 Meteological Observation at Rayyan : September



JUNE 1986
SURFACE WINDROSE (OLD RAYYAN)
TOTAL OBSERVATION =720
FIGURE IN CIRCLE: Percentage of calms
SEGMENT LENGTH(——)=10%
SEGMENT WIDTH

CLASS	BEAUFORT NO
01 TO 03Kts	1
04 TO 06Kts	2
07 TO 10Kts	3
11 TO 16KtS	4
17 TO 21KtS	5
22 TO 27Kts	6



JULY 1986
SURFACE WINDROSE (OLD RAYYAN)
TOTAL OBSERVATION =716
FIGURE IN CIRCLE: Percentage of calms
SEGMENT LENGTH( )=10%
SEGMENT WIDTH

CLASS	BEAUFORT NO
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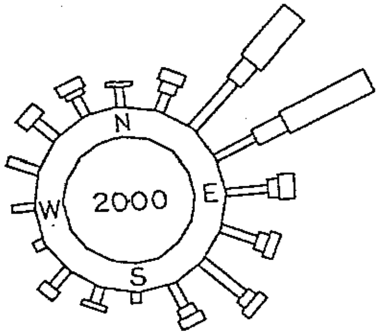
11 TO 16KtS	4
17 TO 21KtS	5



AUG 1986
SURFACE WINDROSE(OLD RAYYAN)
TOTAL OBSERVATION =744
FIGURE IN CIRCLE: Percentage of calms
SEGMENT LENGTH( )=10%
SEGMENT WIDTH

CLASS	BEAUFORT NO
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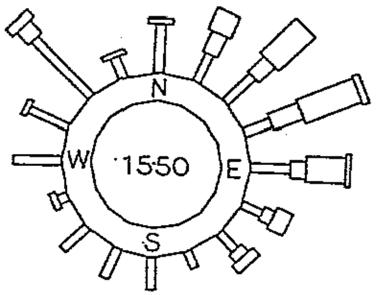
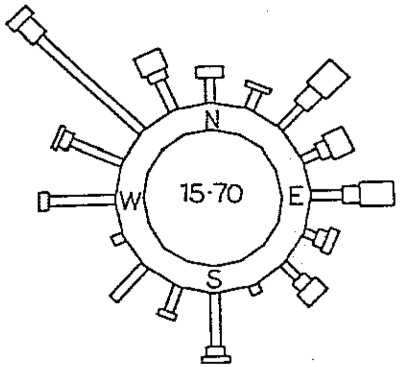
04 TO 06Kts	2
07 TO 10Kts	3
11 TO 16KtS	4



SEP 1986
SURFACE WINDROSE(OLD RAYYAN)
TOTAL OBSERVATION =720
FIGURE IN CIRCLE: Percentage of calms
SEGMENT LENGTH(——)=10%
SEGMENT WIDTH

CLASS	BEAUFORT NO
01 TO 03Kts	1
04 TO 06Kts	2
07 TO 10Kts	3
11 TO 16KtS	4



OCT 1986
SURFACE WINDROSE(OLD RAYYAN)
TOTAL OBSERVATION =744
FIGURE IN CIRCLE: Percentage of calms
SEGMENT LENGTH( )=10%
SEGMENT WIDTH

CLASS	BEAUFORT NO
01 TO 03Kts	1
04 TO 06Kts	2
07 TO 10Kts	3
11 TO 16KtS	4
17 TO 21KtS	5

Fig. 2.2.2 Wind Rose at Rayyan

2.2.2 Potable Water Supply

Basic data and information on the potable water supply were obtained with the collaboration of Telemetric Center (MEW). Data analysis procedure is as follows.

1) Arrangement of daily data
2) Calculation of monthly data and correlation
3) Graphic representation

The variation characteristics of the potable water supply amount, as shown in Fig. 2.2.3 can be summarised as follows;

1 Airport Reservoir had an important increase of supply amount from May 1983 to Feb. 1984, corresponding to the start of new supply area. From March 1984, the required additional amount was covered by the three other reservoirs; Old Salwa, New Salwa and Garrafa.

2 Supply system was reinforced and modified from time to time to respond to the water demand. In the recent three years, supply amount from these reservoirs between 1984 and 1986 are as follows.

   - Supply amount from Old Salwa, Airport and West Bay Reservoirs have been almost stable and have had no significant seasonal variation.

   - New Salwa and Garrafa have shown an increasing tendency and slight seasonal variation.

3 Correlation between the monthly inflow amounts of different reservoirs, given in Fig. 2.2.4, started to show positive relationship after the introduction of the new supply system in March, 1984.

4 Correlation between the monthly inflow amounts of different water towers given in Fig. 2.2.5 had no significant means from the results of multi-variable analysis.

2.2.3 House Connection

Influence of waste water from cesspits and septic tanks is also one of the important impacts on groundwater recharge amount. According to the suggestion of MPW that House Connection Project will be one of the powerful remedies to the rising groundwater problem, the map of the rate of rising roundwater level and house connection percentage was provided as shown in Fig. 2.2.6.

The areas where house connection is not advanced have high rates of rising groundwater level, but some areas where house connections have been installed still had a high rate of rising groundwater Level.

It will be difficult to define the efficiency of house connection as urgent countermeasure project.

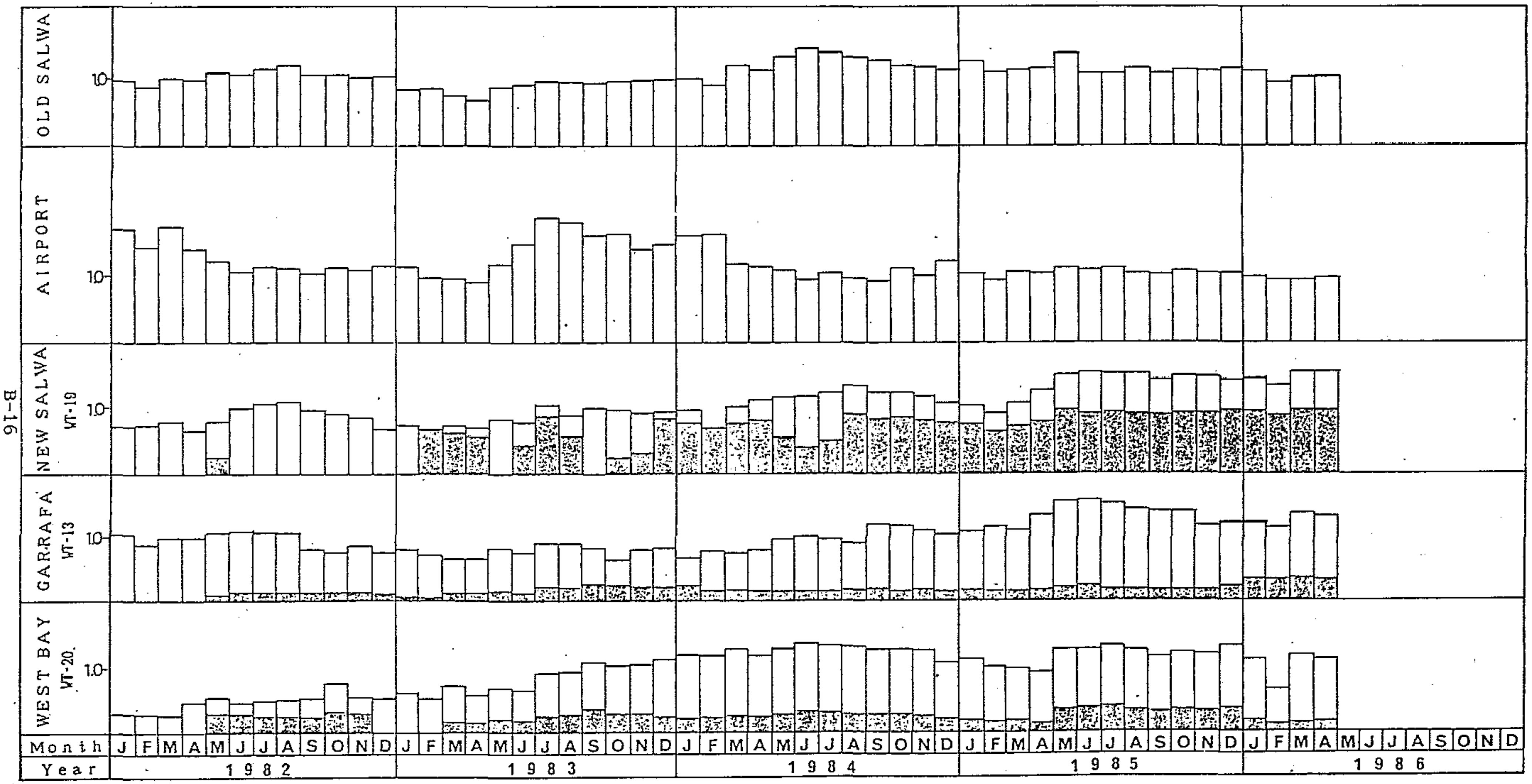


Fig. 2.2.3 Monthly Potable Water Supply Amount

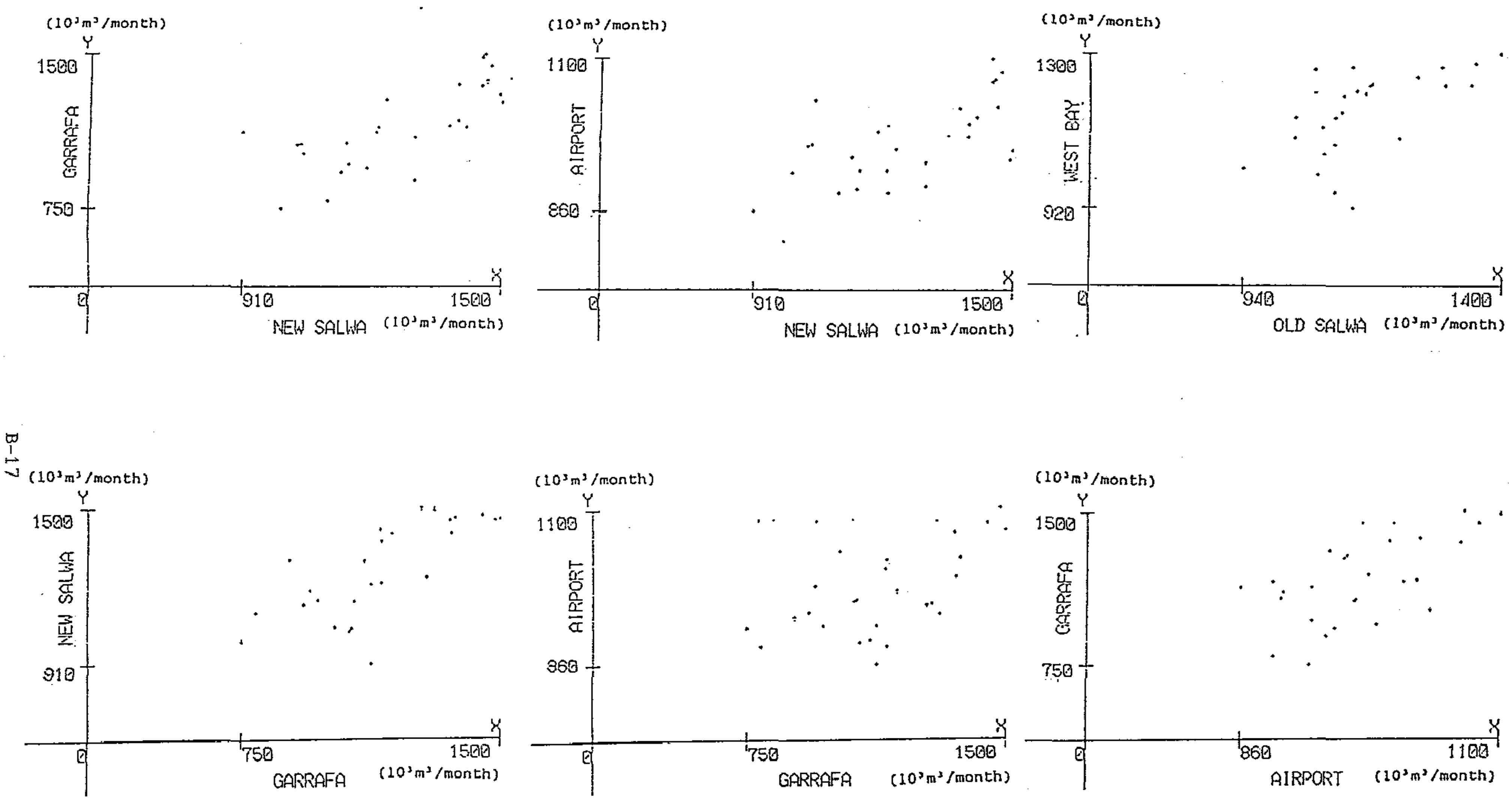


Fig. 2.2.4 Correlationship of Reservoir Inflow Amounts from March 1984 to April 1986

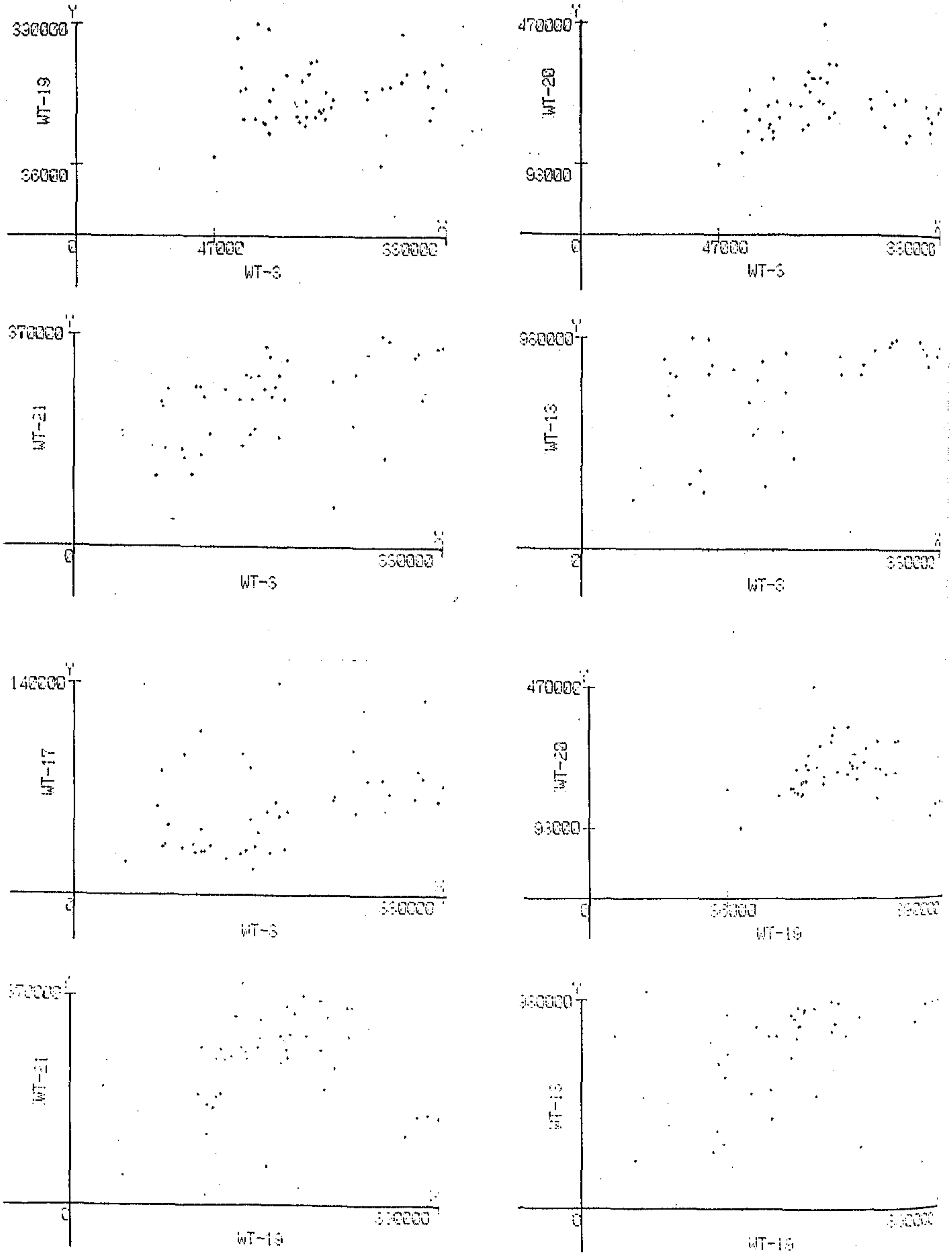


Fig. 2.2.5 Correlationship of Water Tower Inflow Amount

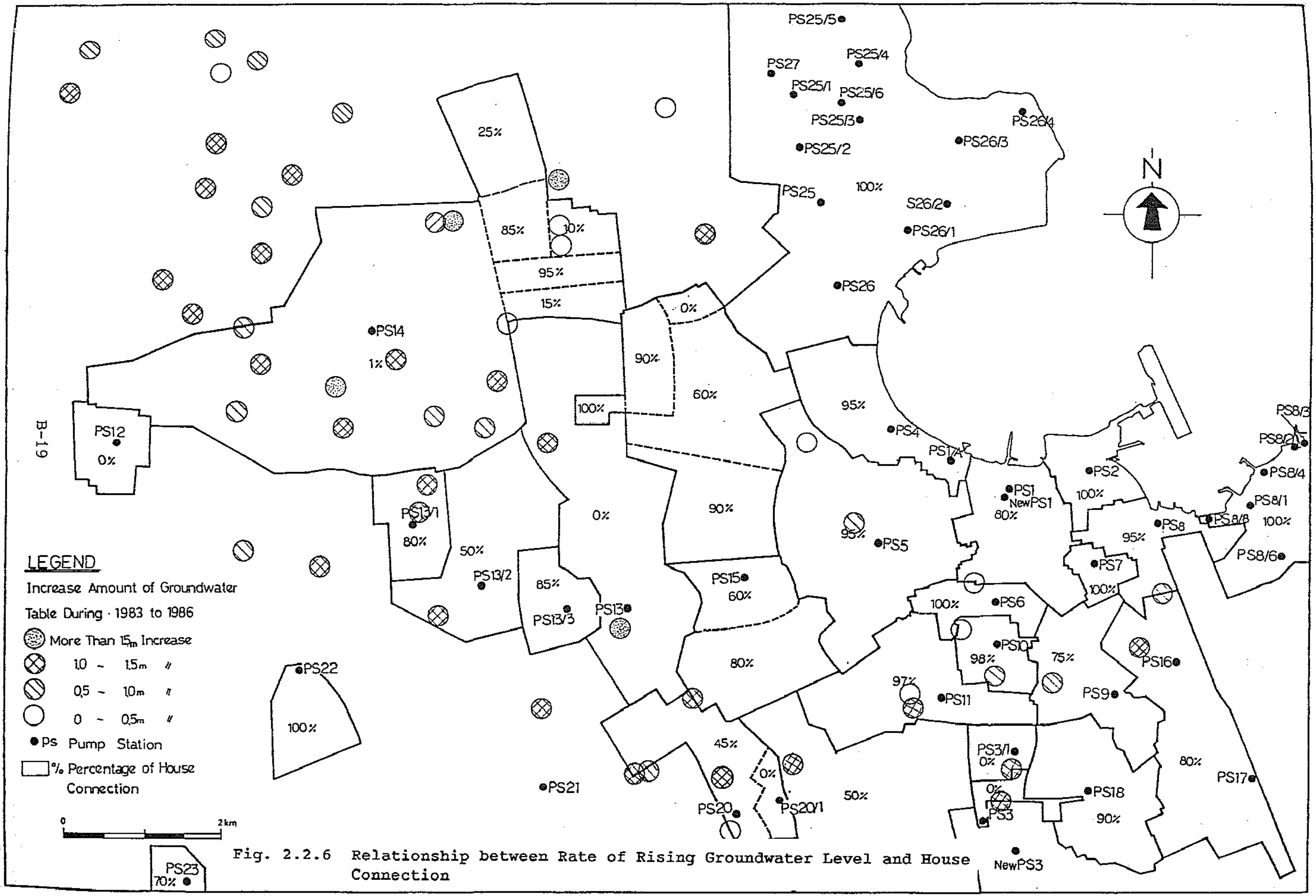


Fig. 2.2.6 Relationship between Rate of Rising Groundwater Level and House Connection

2.3 Groundwater Level Fluctuation

2.3.1 Graphical Analysis

Groundwater level observation results done by the Wellfield Section, MEW were used to grasp the characteristics of groundwater level fluctuation at each well.

Principal graphical representation is shown in Fig. 2.3.1 and the fluctuation characteristics can be summarised as follows.

- o Groundwater level at most wells is rising very gently and seasonal variation is only noticable at few wells.
- o Rainfall impact to the groundwater table is thought to be local and particular and not to be the principal cause of the recent rising groundwater level.

More detail information was given in the Supplement Report of Interim Report: Part A, A1 and A2, where

- A1 Groundwater Level Observation Data
- A2 Graphical Representation of Groundwater Level Fluctuation

2.3.2 Groundwater Level Fluctuation at Wadi Musherib

Wadi Musherib acts as a natural drain for surface water and groundwater situated between the Khalifah and Khayl groundwater mounds. As the Khalifah mound does not seem to be extending as before, the influence from the Khalifah Mound on Wadi Musherib is thought to be less important than that from the Khayl Mound. Khayl Mound has experienced a groundwater rise of 1.0 to 1.5 meter during last three years and the influence form Khayl upon Wadi Musherib becomes more important. This influence will be confirmed by the following facts obtained during our survey;

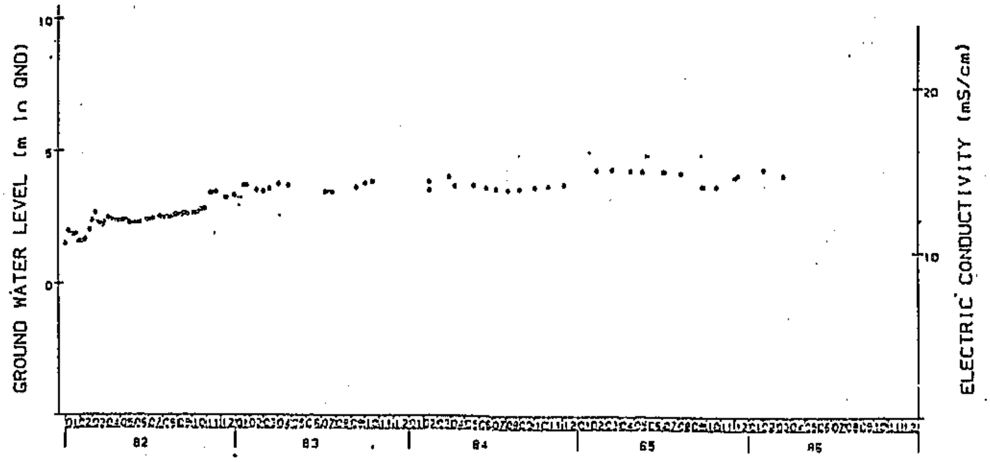
- Two standing water areas are located on the periphery of Khayl Mound and were still existing in April 1986.

  Telephone conduits act as drainage system where groundwater level is shallow. QNTS experience is that groundwater flows from Ramada Hotel towards Cable and Wireless Roundabout along Salwa Road and is the most important dewatering problem in Doha.

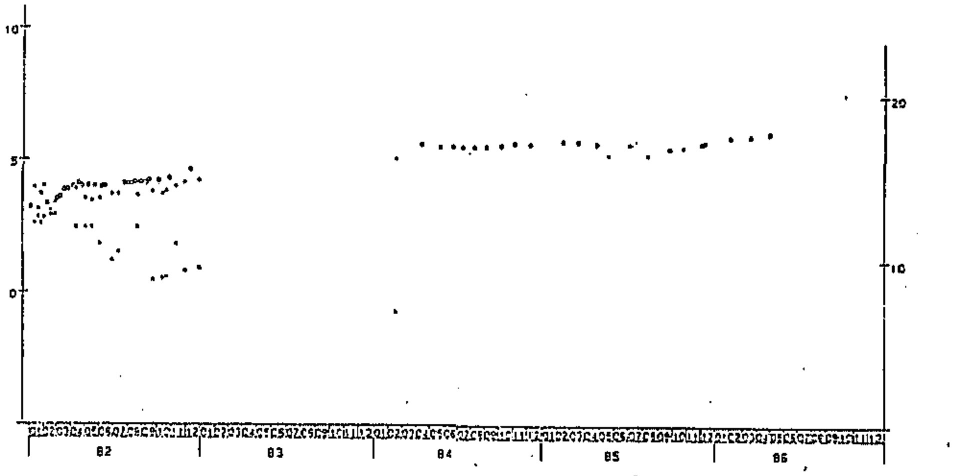
- It seems that urban development is expanding very rapidly in the Khayl area between 'C' and 'D' Ring Roads and consequently water consumption amount will be more important than before.

2.3.3 Groundwater Fluctuation at Rayyan

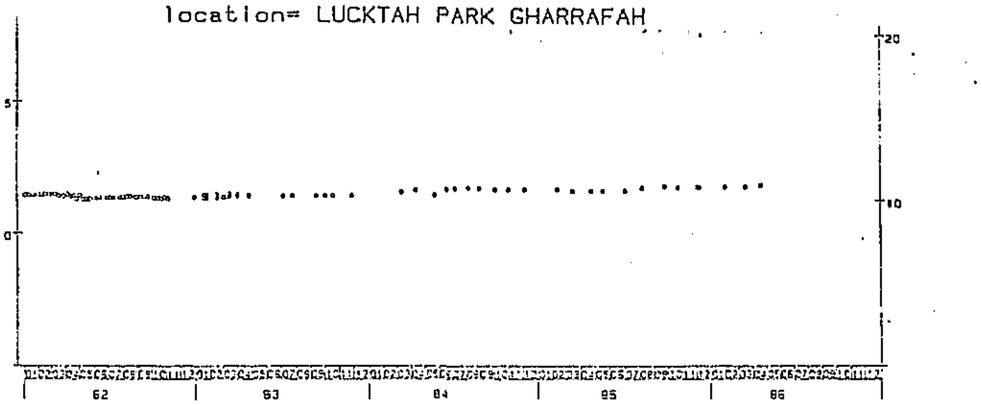
For groundwater level fluctuations from long term records and recent field reconnaissance covering the above mentioned items, the situation can be summarized as follows;



grid ref= 23709590 well number= 2239-GRF
location= GHARRAFAH RESERVOIR



grid ref= 25219610 well number= 2239-44
location= LUCKTAH PARK GHARRAFAH



grid ref= 26819946 well number= 2239-121
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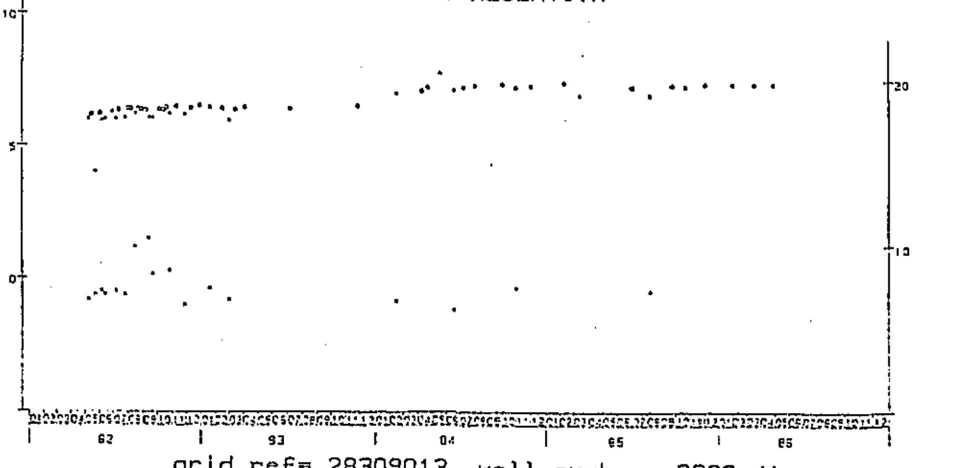
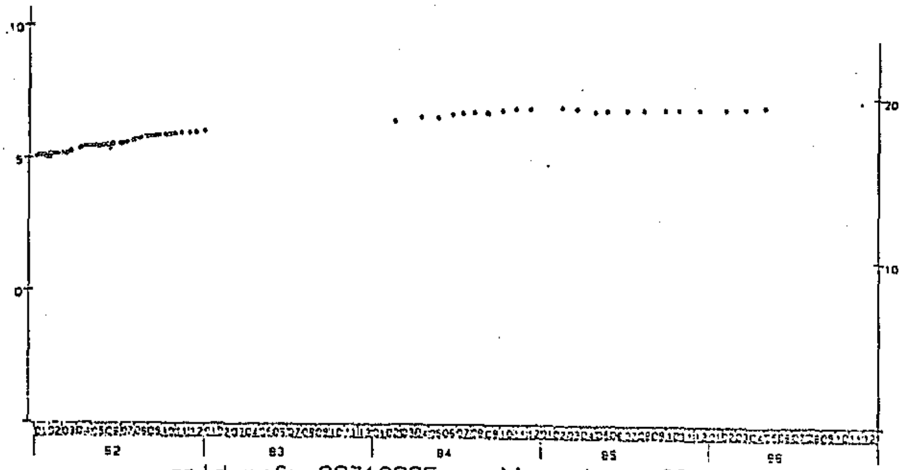
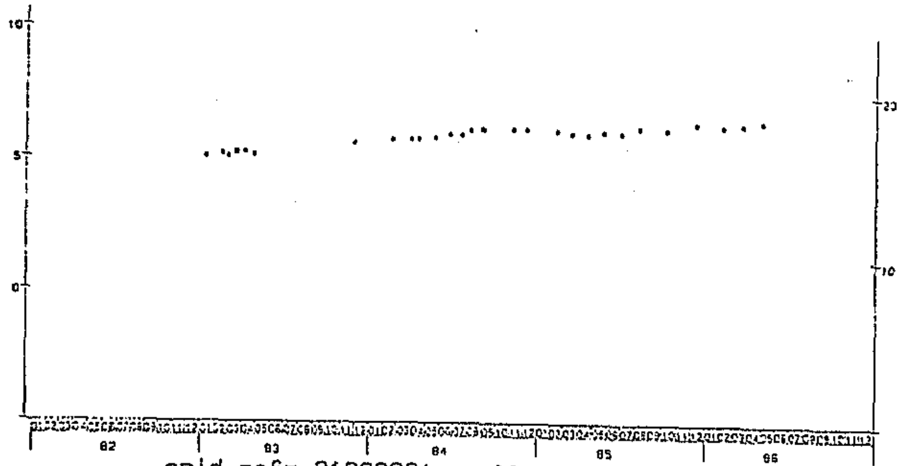


grid ref= 28309013 well number= 2239-41
location= FOOD CENTER ROUNDABOUT

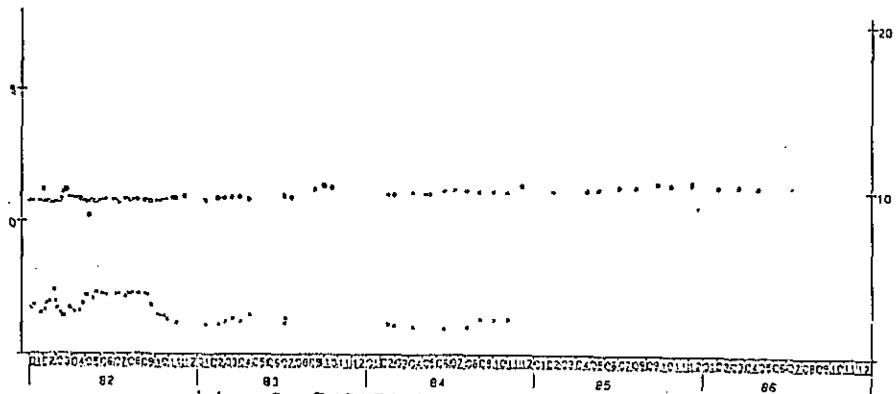
Fig. 2.3.1 Graphical Representation of Groundwater Level Fluctuation



grid ref= 29718935 well number= 2238-41
location= D RING ROAD FARM



grid ref= 31069021 well number= 2239-63
location= MONTAZA PARK OLD B/H



grid ref= 34219147 well number= 2339-26
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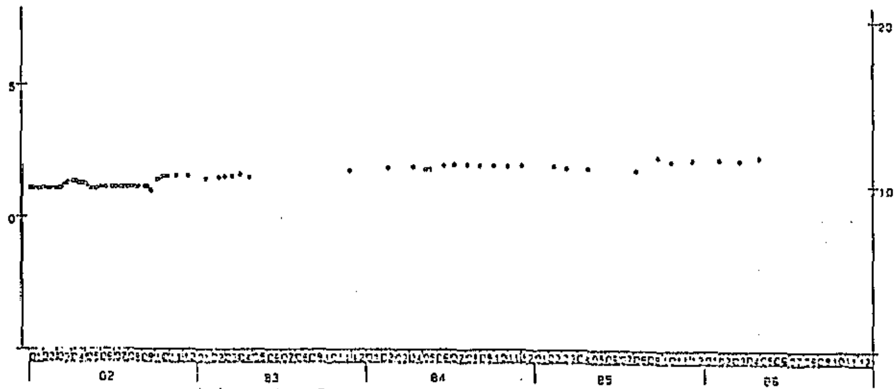

grid ref= 33689067 well number= 2339-2TD
location= ALMANA ROUNDABOUT

Fig.2.3.1 Continue

i) Before 1974 when Qatar did not enjoy a large income from Oil; intensive agricultural development occurred in the Rayyan area. According to MIA estimation, at that time the extraction amount by pumping was three times the natural recharge amount by rainfall. Such overpumping caused some sea water intrusion and the water quality deteriorated; subsequently when oil revenues increased and agriculture became less important; many farms were abandoned, and extraction amounts drastically decreased. Consequently groundwater levels recover year by year and are raised further by the introduction of recharge from potable water supplies.

ii) From the JICA study field reconnaissance, there are approximately 150 wells. Typical well is hand dug, some 10 m in width, 10 m in length and 5 m depth, having similar dimensions, as reservoir. Many dug wells have pump installation remains in one corner or at the middle part of one side.

It is probable that groundwater levels were lower than the bottom of dug well at the time of full agricultural development and some meters below sea level.

iii) Life style in Rayyan also changed with the provision of a sufficient water supply from desalination plant and progressed to a high water consumption western urban type. Recharge amount to groundwater due to this became higher than natural recharge by rainfall.

It is supposed that the first appearance of standing water occurred in the wet season of 1984/85, disappearing due to the strong evaporation conditions of the succeeding dry season. Standing water reappeared in the 1985/86 wet season.

From the JICA field reconnaissance, standing water is characterized as follows;

i) Standing water level has remained relatively constant from December 1985 to April 1986. Evaporation amount loss from standing water surface is continuously supplied by groundwater.

ii) After appreciable rainfall, standing water level becomes higher, but does not remain at the higher level.

iii) Salt accumulation is observed in shallow depth of standing water.

The recent rise in the groundwater table is attributed to the following causes;

i) Decrease of evapotranspiration amount due to the decline of agricultural activity, i.e. decrease of extraction amount by pumping also resulting in rise in groundwater table.

ii) Increase of recharge amount due to rising urban life style with high consumption of water.

3. NUMERICAL ANALYSIS

3.1 Numerical Analysis for Groundwater Level Simulation

The objectives of numerical analysis are first to well understand the rising groundwater behavior and second to obtain the basic information on drainage amount necessary to lower the groundwater level in the project areas.

3.1.1 Selection of Model

The hydrogeological studies developed upto the present are related to the characteristics of the shallow aquifer which is the direct cause of damage. In comparison, the information concerning deeper aquifers is very limited.

The applicability of the different simulation models is shown in Table 3.4.2. Quasi-three dimension model is the most adequate model to analyse the recent rising groundwater level and the other models are not suitable in this regard due to the insufficient basic hydraulic and hydrogeological information.

Table 3.1.1 Comparison of Simulation Models

	Quasi-Three Dimension Model	Multi-Aquifer Model	Three Dimension Model
Advantage	Multi-layers' horizontal flow can be represented and application is easy.	Leakage through aquifers is well represented.	Most detailed representation of groundwater phenomena is possible.
Disadvantage	Vertical flow element cannot be represented.	Accurate data for deep aquifers is necessary.	Node points are too many and accurate data supply is very difficult. Computing cost is expensive.

3.1.2 Mathematical Basis

i) Governing Equation

The governing equation of quasi-three dimensional plane model is derived form the continuity equation and dynamic equation according to the Dupuit-Forchheimer's assumption in which the vertical flow element is negligible.

The governing equation can be expressed as follows;

$$\nabla.(T\nabla h) = S\frac{\partial h}{\partial t} + q \quad .... \quad (3.2.1)$$

where,

T: Transmissivity
h: Hydraulic Head
S: Storage Coefficient
t: Time
q: Source Term

As the groundwater level varies in time, transmissivity for corresponding groundwater level is calculated by the sum of the product of permeability coefficient and saturated thickness of each aquifer.

$$T = \sum_i Ki \times Di \quad ....(3.2.2)$$

where,

K: Permeability Coefficient
D: Saturate Thickness
i: Subscript of the i th Aquifer

ii) Concept of Source Term

The following parameters effect the source term evaluation.

1 Groundwater evaporation varying with groundwater level
2 Groundwater extraction
3 Groundwater recharge
4 Local leakage through fractures and/or, into water vein system such as vugs, sewerage etc.

The source term can be expressed by the following equation.

$$q = Ev + Ex + Lt - \varepsilon \quad .... \quad (3.2.3)$$

where;

Ev : Groundwater Evaporation Amount
Ex : Groundwater Extraction Amount
Lt : Total Leakage Amount
ε : Groundwater Recharge Amount

Ev is calculated by the function of groundwater depth from surface. Ex and are estimated from the land use conditions and the previous study results of water balance. Lt almost corresponds to the inferred recharge.

iii) Initial and Boundary Conditions

Initial condition is given by the groundwater level contour map of 1983. Boundary condition is given by the linear interpolation of groundwater level of 1983 to 1986 level.