THE ARAB REPUBLIC OF EGYPT

NORTH SINAI GROUNDWATER RESOURCES STUDY
IN
THE ARAB REPUBLIC OF EGYPT

FINAL REPORT

EXECUTIVE SUMMARY

October 1992

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

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PREFACE

In response to a request from the Government of the Arab Republic of EGYPT the Government of Japan decided to conduct a study on North Sinai Groundwater Resources and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Egypt a study team headed by Dr. Kiyoo Kawada, Pacific Consultants International 9 times between Dec., 1988 and March, 1992.

The team held discussions with the officials concerned of the Government of Egypt, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

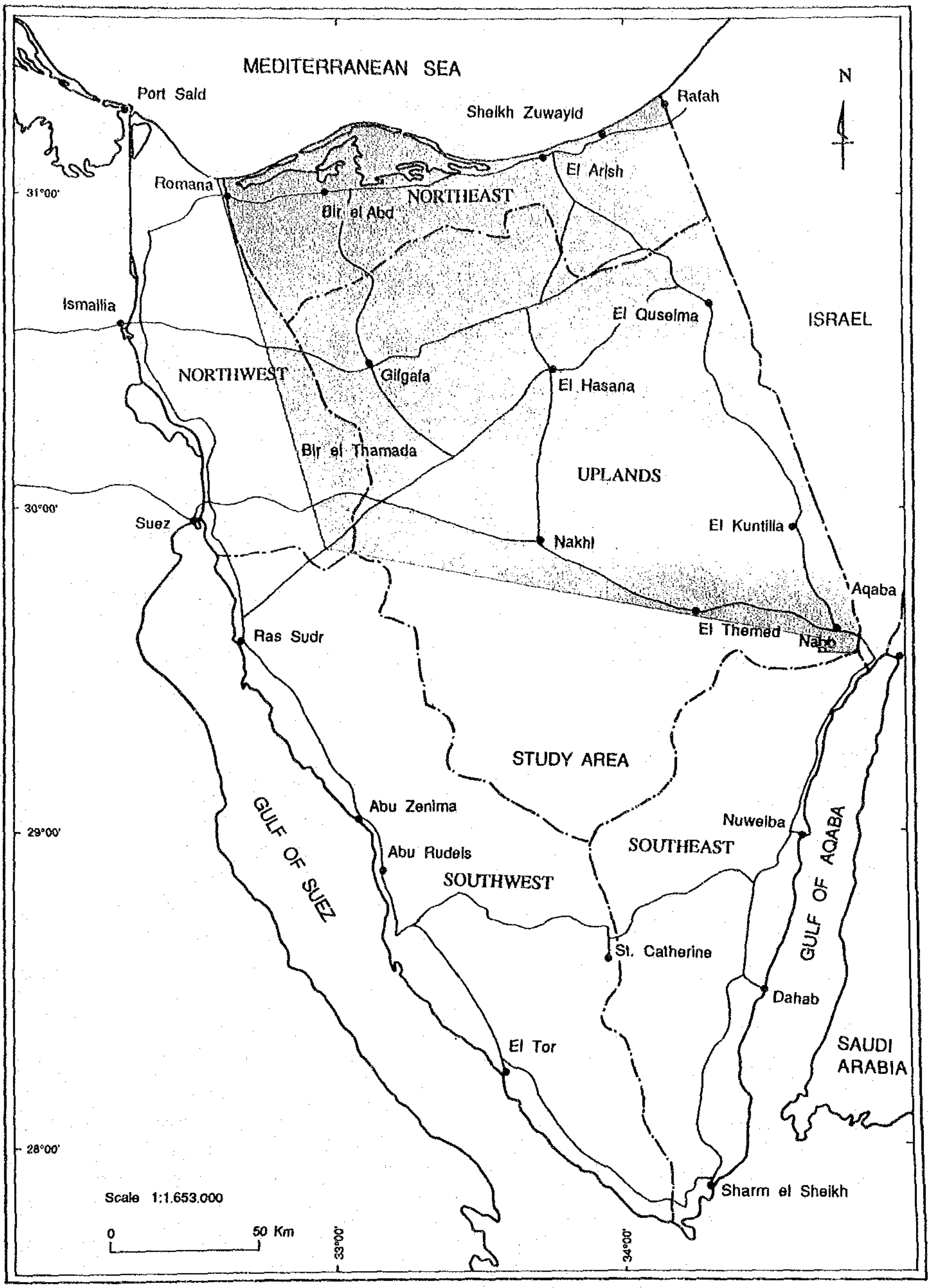
I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Arab Republic of Egypt for their close cooperation extended to the team.

October, 1992

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency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STUDY AREA

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1. INTRODUCTION

1-1 General

In response to the request of the Government of the Arab Republic of Egypt, the Government of Japan decided to conduct the North Sinai Groundwater Resources Study in the Arab Republic of Egypt within the framework of the Agreement of Technical Cooperation between the Government of Japan and the Government of Egypt, signed on June 15, 1988.

The Japan International Cooperation Agency (JICA), the official agency responsible for the implementation of technical cooperation programmes of the Government of Japan, undertook the study in close cooperation with the authorities concerned of the Government of Egypt.

The Research Institute for Water Resources (RIWR) has been the counterpart agency to the Japanese study mission and also acted as coordination body in relation with other relevant organization for the smooth implementation of the study.

In June and October, 1988, JICA dispatched missions to the Arab Republic of Egypt for the preliminary survey as well as discussion on the Scope of Work for the study. The Scope of Work was agreed upon between the Government of Egypt and the mission on September 1, 1988.

In accordance with the Scope of Work, this Final Report was completed based on the study undertaken during the period from December, 1988 to March, 1992.

This report consists of the Main Report associated with Hydrogeological Map and its Portfolio. Detailed technical matters are summarized in the attached Technical Report including five items: Well Survey, Fossil Analysis, Grain Size Analysis, Composite Column and Landform Classification.

1-2 Background

Egypt is mostly composed of desert. Only 3% of its land is cultivated, consisting mainly of the stretch of the alluvial plains of the Nile and its Delta. In order to cope with the increase in population and the development of the social economy in these surroundings, the Egyptian Government is being pressed into the development of the Sinai Peninsula which is assumed to have high potential for mineral, tourism and agricultural development. For this purpose, various kinds of international cooperation have been inaugurated.

The Sinai Peninsula extends over 61,000 km^2 and has a population of 200,000. Except for the northeastern part, it consists of desert land. The annual rainfall here is estimated at 60 - 100 mm, which is extremely low.

The development of surface water has been carried out in some districts by the construction of dams. However, the situation is clearly caught in difficulties. Therefore, the major water source in many places is groundwater. Although the Cretaceous and the Tertiary strata are assumed to be favorable aquifers, the distribution of these are still subject for further studies.

The future development of the water resources in Sinai will be centralized in the use of either groundwater or the pipeline from the Nile, and a number of researches have been launched by various international organizations. Among them, the Sinai Development Study was undertaken by Dames & Moore in 1985 and the Integrated Rural Development Project is under operation in cooperation with the Italian Government. In addition, RIWR has been conducting a water resource study with technical cooperation from the European Community (E.C.). RIWR also conducted the Groundwater Management Study of the coastal plain from El-Arish to the Rafah area (GMS).

As a systematic research on the Peninsula regarding the assessment of the groundwater resources has not yet been initiated, obstacles are left to the total development schemes.

Taking the above points into account, the Egyptian government decided to set up a water resource assessment project.

1-3 Project Area

The project area of this study covers the entire North Sinai Governorate extending over 26,000 km^2 (Fig. 1-1).

The area is completely covered by desert with gentle regional gradient toward the Mediterranean Sea in the North. Rocky mountains prevail over the area distributed by the Syrian Arc Movement.

2. OBJECTIVES

Objectives of the study are;

1) To construct a series of hydrogeological maps to evaluate groundwater potential for immediate usage of this precious resource,

2) To select priority areas for groundwater development, considering the water price to be incurred for project implementation,

3) To recommend the methodology of future groundwater development and

4) To perform technology transfer to Egyptian Government personnel during the course of the study.

3. PREVIOUS WORK

Various kinds of studies have been made in the study area on geology and hydrogeology published by Egyptian Geological Survey and Mining Authority and Israel Government.

In 1985, the final report of the Sinai Development Study (SDS) was released. This study was an integrated regional development study aimed at formulating the development framework for the entire Sinai Peninsula. The study described the future development target and strategy, including preliminary water resource assessment.

For integrated rural development in the Gebel Maghara area, the ongoing Gebel Maghara Rural Development Project (GMRDP) includes the hydrogeological study for obtaining a water source for the project during the early stage of the project (1988). Some wells were drilled which provided hydrogeological information on the aquifers in the limestone of the Jurassic and the Upper Cretaceous in the Gebel Maghara area.

In 1988, the Final Report of the Groundwater Management Study, Phase 1 was completed by RIWR. The objectives of the study were to evaluate the available groundwater resources in the area from El-Arish to Rafah and establish a monitoring system for the precious groundwater resources. The Phase 1 study carried out the compilation of existing hydrogeological information for further analysis and identification of the further necessary activities for attainment of the final target in the following phase.

In the Final Report of the Phase 1 study, most of the existing previous works on the area were reviewed and related discussions were held. This could be considered a remarkable output, as most of the existing well data of the Quaternary aquifers were reviewed and compiled in the appendix of the Report.

4. CONTENT OF STUDY

Although available data are abundant, the density of existing data is still insufficient considering the size of the study area which extends over 26,000 km^2. It is indispensable to obtain complete well data accompanied by lithology, stratigraphy and well logging information for the hydrogeological study. However, much of the existing well data is incomplete. In addition, available geological columns are also insufficient to draw a clear picture of subsurface conditions.

Therefore, a great deal of emphasis was placed on reviewing and reanalyzing the existing well data. Also, efforts were made to construct geological columns in the study area as the reference of reanalysis of the existing well data. The results were compiled as the composite geological columns (147 columns) as shown in Technical Report IV.

Considering the high possibility of geological formations to contain prospecting aquifer, the sandstone of the Lower Cretaceous is selected as one of the target formation. As a matter of fact this sandstone distributes over a broad area in the study area and its lithological nature is favorable to be an aquifer.

The Quaternary was also determined as another target formation since the Quaternary would be the most economic formation to develop wherever groundwater is available. In addition, the Quaternary aquifers along the Mediterranean coast from El-Arish to Rafah have been intensively utilized. Since the 1980s number of wells has rapidly increased which resulted in deterioration of aquifer so that it is an urgent matter to control groundwater pumpage rather than a resource assessment for future development.

Due attention has been paid to other formations, such as the Jurassic, the Upper Cretaceous and the Tertiary, wherever necessary. Considerable attention has been drawn to these target formations: the Lower Cretaceous and the Quaternary.

Major items undertaken during the study are summarized below:

4-1 Data Base

The existing and additionally obtained hydrogeological data are fed into the Base III according to the grid of each data location for data compilation and further analysis.

4-2 Landsat Image Analysis

In order to draw all the features of the study area, a satellite image analysis was undertaken. Interpreting the general characteristics of the computer processed colour image of the original data tapes, the following thematic maps were constructed to a scale of 1:250,000:

1) Lineaments,
2) Geological map,
3) Geomorphological map and
4) Vegetation and land use map.

4-3 Geological Investigation

The initial task was to pick up the contradictions found on the existing geological maps. For this purpose, field investigations were carried out to confirm the surface geology on key points. The output of these field surveys is reflected in the geological map.

A detailed geological survey was undertaken in 3,700 km^2 and 12 lithological columns were recorded. Two hundreds of samples were collected for micro-fossil analysis from the outcrops and test wells wherever it was necessary, since it is hardly possible to determine the stratigraphy through field observation of lithology where similar type of limestones encounter frequently (Technical Report II).

Results of these analysis were further worked out into the three dimensional distribution of the major formations; Isopach and contour maps of the major formations which may hold prospecting aquifers (Chapter 6, Main Report).

In this study, one of the target aquifers is the sandstone of the Lower Cretaceous, however the physical property of the strata is still open to question. In order to estimate the porosity and the homogeneity of the sandstone, grain analysis was adopted on more than 700 samples collected from eleven sites as shown in Technical Report III.

4-4 Geophysical Investigation

In order to supplement the geological information, geophysical prospecting was conducted at 600 points of shallow strata (200 m - 300 m) and at 50 points of deep strata: 1,000 m.

The survey lines were laid out to pass through the verification points where correlation of resistivity readings with lithology could be obtainable. However, inaccessibility due to deep desert sand and undefused land-mines were the limiting factor for the layout of the survey line.

In general, very low resistivities were detected from many different rock types *in situ* in the study area. It seems hard to find out a certain resistivity value corresponding to a specific type of lithology. Therefore, it is inevitable to integrate all available interrelated information of each specific section as well as verification of the reference point.

The resistivity profiles were further interpreted from a geological point of view to aid in the analysis of geological cross section (Chapter 6, Main Report).

Gravity prospecting was also applied to estimate the top surface of the basement (Chapter 6, Main Report).

4-5 Test Well Drilling

To obtain the most efficient output of aquifers in the study area, the target strata the Quaternary and the Low Cretaceous were determined. So that the first task of this study is to identify the hydrogeological conditions of these target strata.

Considerable attention had been drawn to the following two items in determining the test well locations in the Quaternary:

1) Confirmation of the extension of kurkar and
2) Confirmation of the existence of unexploited gravel layers and their extension of the gravel beds.

Based on interpretation of existing data, test well locations were determined and the precise locations were confirmed by the results of resistivity soundings. As a result, 11 test wells were drilled in various depth ranging from 40 m to 120 m. A total of 12 test wells for the Quaternary reached a cumulative drilling depth of 870 m.

General features of the Lower Cretaceous (distribution, thickness and depth to the top) were estimated by analysis of the geological investigation. The locations of the test wells to the Lower Ctretaceous were placed on some dome structure and the terrain where the main groundwater body is assumed moving in the deep sandstone. At the latter, two locations were sited: El-Bruk (799 m) and Arif El-Naga (900 m).

In addition, another six wells were drilled either in the sandstone of the Lower Cretaceous or the limestone of the Upper Cretaceous. The depth of these wells range from 300 to 400 m and the cumulative drilling depth is approximately 1,600 m.

The total drilling depth was approximately 4,200 m (Technical Report I) (Fig. 4-1).

4-6 Hydrological Study and Water Quality Analysis

A trial water balance analysis was made in SDS in 1985. As it only presented a crude approximation, it was required to obtain additional hydrometeorological information to improve its accuracy.

In this study, therefore, more attention has been drawn to the existing groundwater to figure out the general features of the groundwater in the study area in a more practical manner:

1) Updating of existing well information,
2) Analysis of data obtained from test wells,
3) Water level analysis and its behavior against pumpage,
4) Dating of selected groundwater samples, and
5) Water quality analysis of selected samples.

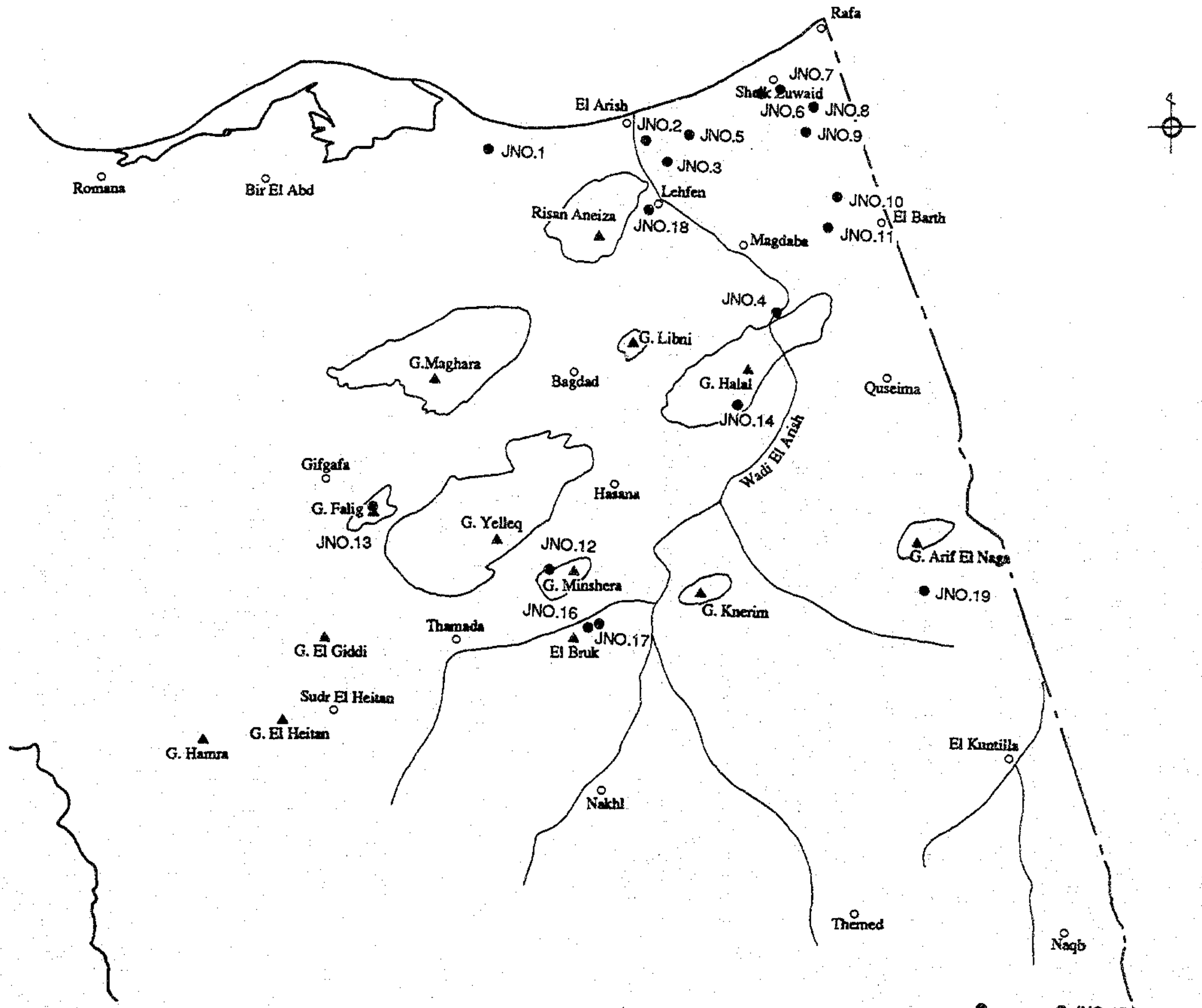

Fig .4-1 LOCATION OF TEST WELLS

5. GEOLOGY

The geological structure, distribution of major formations and their stratigraphy and lithology may have a direct affect on the hydrogeological conditions in the area. The stratigraphy of major geological formations was analyzed from a hydrogeological point of view.

5-1 Precambrian Rocks

In the southern part of the study area around Naqb, Precambrian rocks, consisting mainly of granite, gneiss and alkali rhyolites are distributed. The alkalirhyolite is a pale grey lava showing porphyritic texture.

The terrain of the Precambrian rocks forms steep mountains and has vastly different geomorphic features than those of younger rocks.

5-2 Paleozoic

The Paleozoic rocks crop out at Umm Bogma area in South Sinai. Sandstone is predominant in the area, but carbonate rocks can occasionally be seen. The thickness of this formation is estimated to be about 600 m in Central Sinai.

5-3 Mesozoic

5-3-1 Triassic

The Triassic outcrop is found only at the core of the dome structure at Gebel Arif El-Naga. It is classified into five formations:

1) The Lowermost Formation,
2) The overlying Formation,
3) Gevanim Formation,
4) Sharonim Formation and
5) Mohilla Formation.

It is assumed that the Sinai Peninsula spent most of the Triassic period in the shallow marine environment. This environment was governed by the Tethys Sea located in the northwest. During this period the sediments were accumulated on the tidal flats and deltas along the margin of the Tethys Sea.

5-3-2 Jurassic

The Jurassic formation outcrops at the dome structures in the study area. A complete Jurassic strata,.i.e.,from the Lower to the Upper, is observed at Gebel Maghara. Total thickness of this strata attains about 2,000 m. It is classified into six groups;

1) Masajid Formation
2) Safa Formation
3) Bir Maghara Formation
4) Shusha Formation
5) Rajabiah Formation
6) Mashabba Formation

These formations consist of sandstone, shale and limestone.

5-3-3 Cretaceous

5-3-3-1 Lower Cretaceous

The Lower Cretaceous formation in the study area is represented by the Malha Formation. It overlies unconformably on the Jurassic rocks and is overlain by the Cenomanian Galala and Raha Formations.

The facies of the Lower Cretaceous in the North Sinai changes from sandstone to limestone north of Gebel Maghara and is known as the Risan Aneiza Formation.

Although there are only a few detailed reports on the lithofacies of the Lower Cretaceous, their distribution is known in the central part of the dome structures as shown on the geological maps published by Israel (1980) and Conoco (1989).

During the study, the detailed geological columns were recorded at eleven sites in nine places, including Naqb, and rock samples were also collected for the grain size analysis (Technical Report III).

As described in Technical Report III, the lithological characteristics of the sandstone of the Malha formation are summarized as follows:

1) In most sections, medium to coarse grained porous sandstone predominates,

2) Cross beds are frequently observed,

3) Occasionally, intercalation of shale is recognized. Its thickness is less than 10 m except at Gebel Halal where shale predominates in the central core, especially below 150 m from the top,

4) In the south around Naqb, siltstone or claystone without fissility are observed instead of shale,

5) The Lower Cretaceous formation is common throughout the Sinai Basin and has a porous lithological character.

5-3-3-2 Upper Cretaceous

The Upper Cretaceous in the Sinai Peninsula is divided into the following three stages based on fossil evidence;

1) Cenomanian,
2) Turonian and
3) Senonian.

The Cenomanian formation conformably overlies the Lower Cretaceous and is conformably overlain by the Turonian. However, there is a possibility that the Cenomanian formation unconformably overlies the lower Cretaceous, because the Lower Cretaceous lacks the shale facies at the top of the formation. The Turonian formation is unconformably overlain by the Senonian. Occasionally, a part or the whole of the late Turonian-Coniacian is missing due to erosion.

The Cenomanian consists of limestone, dolomite and calcareous sandstone in the lowermost part grading upward into limestone, dolomitic limestone and dolomite. Dolomite is widely traceable in the Syrian Arc Zone.

The thickness of the Cenomanian varies in a range between 345 m and 575 m in the area. Rather thick Cenomanian rocks are distributed in

Gebel Gebel Minshera, Gebel Magahara, Gebel Hamra, Wadi El-Giddi and Gebel Halal. On the other hand, the thickness of the Cenomanian is rather thin at Gebel Yelleq, Falig, Kherim and Arif El-Naga.

The Turonian distributes on the foot slope of the large anticline and the lithofacies is similar to that of the Cenomanian.

The Turonian consists mostly of foraminiferal limestone but contains some intercalated grey-green shale at Gebel Halal.

The Senonian, in North Sinai, consists of a monotonous sequence represented by chalk in the upper part and marl in the lower part.

The Senonian unconformably overlies the Turonian. A very thick Senonian is observed at Gebel Minshera.

5-4 Cenozoic

5-4-1 Tertiary

5-4-1-1 Paleocene

The formation of the Paleocene in North Sinai is represented by the Esna Formation consisting of shale and marl correlated to the Landenian to Ypresian (Said,1969).

The deep sea was widely spread in Sinai by the transgression after the end of the Upper Cretaceous. The Esna Formation was deposited in the lows among the major structural highs on the Upper Cretaceous in Sinai.

The formation consists of greenish grey to dark grey shale and marl and the alternation of shale and marl at Ain Gudeirat in the east of Quseima.

At Ain Gudeirat, the 20 m thick Esna Formation overlies on the Upper Creaceous marl and is overlain by the alternation of shale and marly limestone of 15 m thick. The Esna Formation is hardly observed in the area north of Halal and Yelleq. In the area around Maghara and Risan Aneiza, the Esna Formation is missing and the upper Cretaceous limestone is overlain by the Eocene limestone.

5-4-1-2 Eocene

The Eocene formations are represented by the Egma Formation which consists of limestone to dolomitic limestone. But the formation may include other Eocene rocks.

The Eocene distributes, similarly to the distribution of the Paleocene in the area from Gebel Halal through Quseima, Arif El-Naga and El-Kuntila to Themed. The Eocene index fossil, Nummulites gizenhensis is abundantly observed in the limestone at Quseima.

The Eocene limestone conformably overlies on the Esna Formation and usually occupies the top of the outcrops.

5-4-1-3 Oligocene

The Oligocene formation is recorded at the off-shore oil exploratory well and it is not reported in the North Sinai so that this formation does not have any affect on the hydrogeology in the study area.

5-4-1-4 Miocene

No Miocene sequence is shown in the geological map published by Conoco (1989). However, the Oligocene-Miocene formation is shown in the south and southeastern sides of the Risan Aneiza on the geological map published by Israel. According to the fossil analysis, these are determined to be Eocene.

Shale predominates in the Miocene sediments observed in the water well with a subordinate amount of marl, limestone and sandstone.

5-4-1-5 Pliocene

The Pliocene is identified only at the off-shore oil exploratory wells. No report mentioned the terrestrial outcrop of the Pliocene.

5-4-2 Quaternary

The Quaternary formation consists of sand, old beach sand and kurkar. The thickness of the formation is about 80 m to 100 m.

The name of kurkar was given to the calcareous sandstone deposited in the shallow sea. Kurkar is distributed along the coastal plain.

The old beach sand mainly consists of fine to coarse sand which is locally diagenetic sandstone and intercalated with gravel and clayey layer. This layer is deposited to a thickness of about 20 m to 60 m, but it is difficult to distinguish the contact with overlying sand dune deposits. This is conformably overlying kurkar in some places which forms unconfined aquifer.

The sand dune is extensively distributed in the coastal plain covering the old beach sand and locally intercalated with clayey and gravel layers. Thickness of sand dune is in a range between 20 m and 30 m.

5-5 Geological structure

5-5-1 General

Geological structure of North Sinai is divided into three major units (Shata, 1956) as shown in Fig. 5-1;

1) Central Sinai Stable Foreland,
2) North Sinai Strongly Folded Belt and
3) North Sinai Foreshore Area.

The Ragabet El-Naam Fault is the boundary between the top two units: 1) and 2). The geological structure has significant implications to the hydrogeology in the study area (Fig. 5-2).

5-5-2 Central Sinai Stable Foreland

This structural unit extends in the area south of the Ragabet El-Naam Fault where a broad syncline is very gently plunging toward the north. Although this is dissected by many faults, geological structure of this area does not suffer from disturbance and indicates gentle structure. The southern end of this unit extends to the south where the Lower Cretaceous crops out.

5-5-3 North Sinai Strongly Folded Belt

This unit occupies a broad area north of the Ragabet El-Naam Fault. Most of the study area is occupied by this structural unit known as Syrian Arc which is characterized by double plunging folds, thrusts and reverse faults.

A typical fold can be observed at Gebel Maghara, Yelleq, Halal. There are also small-scale folds at Gebel Minshera, Arif El-Naga, Kherim and Falig.

Ragabet El-Naam Fault extends from Naqb through Nakhl to the area in the south of Gebel Hamra forming the front of Syrian Arc Zone. The southern side of the fault is relatively uplifted block after the fault activity. Ragabet El-Naam Fault is bounded between the Precambrian rocks and the Lower Cretaceous rocks around the area of Naqb.

5-5-4 North Sinai Foreshore Area

The area neighbours the northern margin of North Sinai Strongly Folded Belt. In the area, the strata, which are older than the Upper Cretaceous, is distributed much deeper from the surface than those of the folded belt. Thick Tertiary deposits cover old rocks in the area and the Quaternary sand dunes cover most of the area.

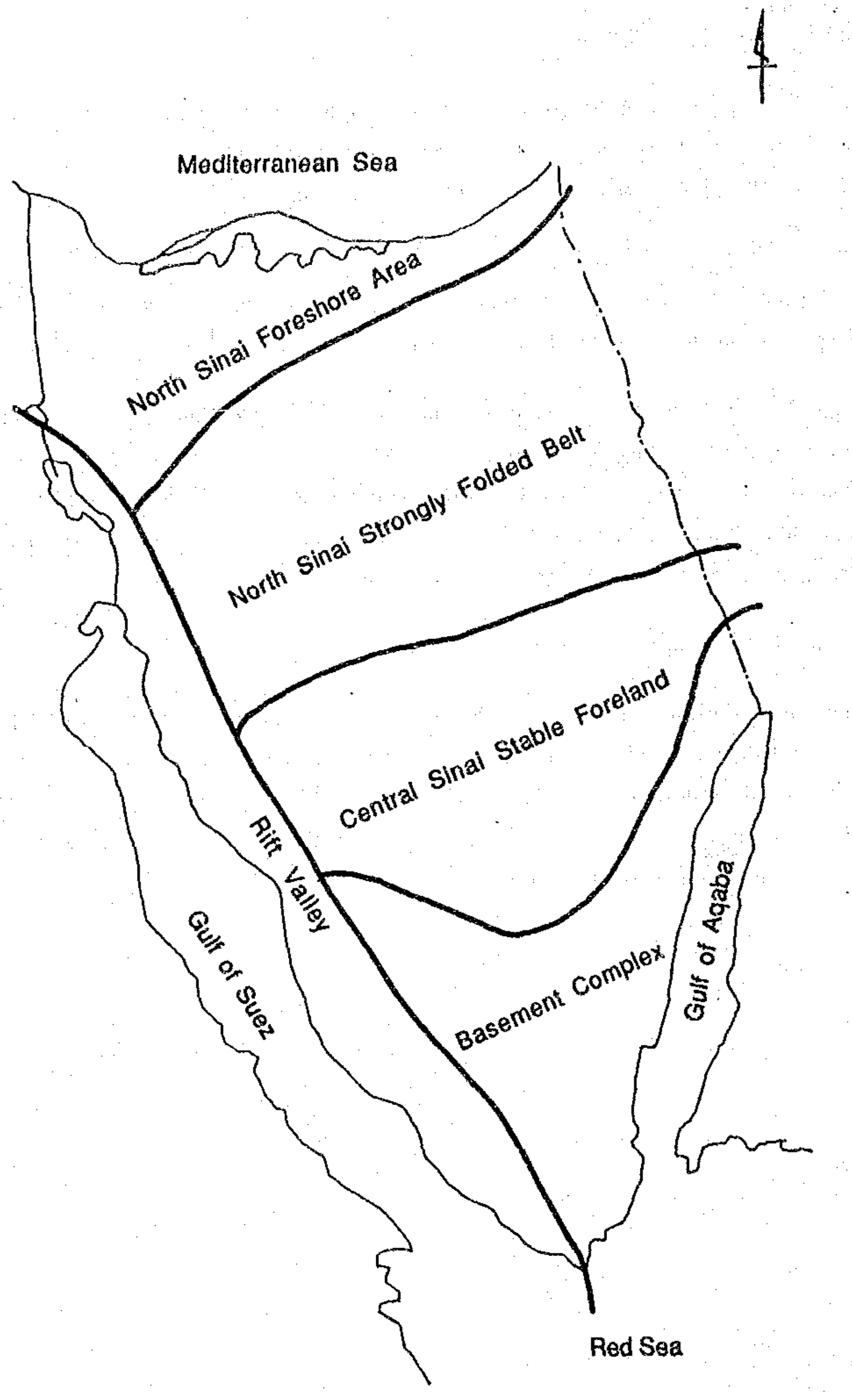

FIG. 5-1 STRUCTURAL ZONES OF THE SINAI PENINSULA

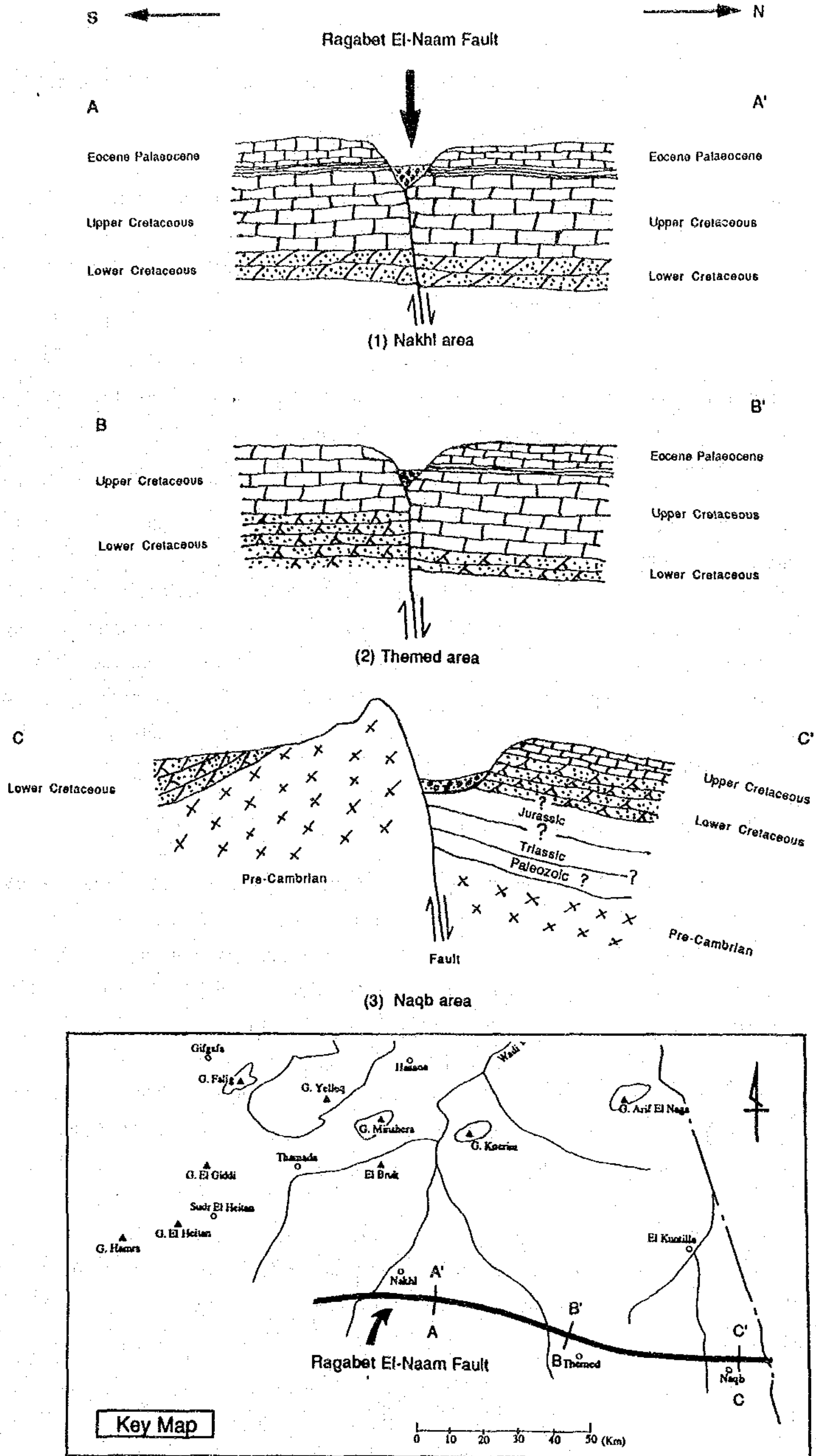

FIG. 5-2 SCHEMATIC CROSS SECTION ALONG THE RAGABET EL-NAAM FAULT

6. DISTRIBUTION OF MAJOR FORMATION OF PROSPECTING AQUIFER

6-1 General

In order to figure out a general feature of the major formations which may contain prospecting aquifers, it is required to interpret distribution and lithology of these formations. For this purpose many geologic columns and cross sections are interpreted.

For the Quaternary formation, a geologic column is available only at some places at Magdaba along the Wadi El-Arish. Therefore, geologic profiles of test wells and the interpretation of the geophysical survey are the major data source.

As for the Pre-Quaternary formations, available geologic columns previously observed are collected at Minshera, Risan Aneiza, Arif El-Naga, Kherim, Wadi Khareiza, Umm Mafuruth, Maghara and Gifgafa. In addition to these geologic columns, field investigations were undertaken to record 12 geologic columns at nine sites. Lithological profiles of existing wells are also reinterpreted to confirm lithology and age referring to these geological columns for determination of the composite columns (Technical Report IV).

6-2 Distribution of Quaternary

The Quaternary formation distributes broadly over the study area mainly in the coastal plain along the Mediterranean and in the alluvial plain along the Wadi El-Arish. Its thickness in the alluvial plain along the Wadi El-Arish in the upper stream is so thin that development of prospecting aquifers is unlikely in this area (Technical Report V).

Distribution of the Quaternary which may include the prospecting aquifer is limited in the coastal plain. However, the Quaternary lithology are hardly obtainable in the western part of the coastal plain due to thick sand dunes covering most of the area.

The Quaternary crops out at some places along the lower stretch of the Wadi El-Arish and the southern most outcrop of the Quaternary is at Magdaba (Fig 6-1~2).

FIG. 6-1 DISTRIBUTION OF TEST WELLS IN COASTAL PLAIN

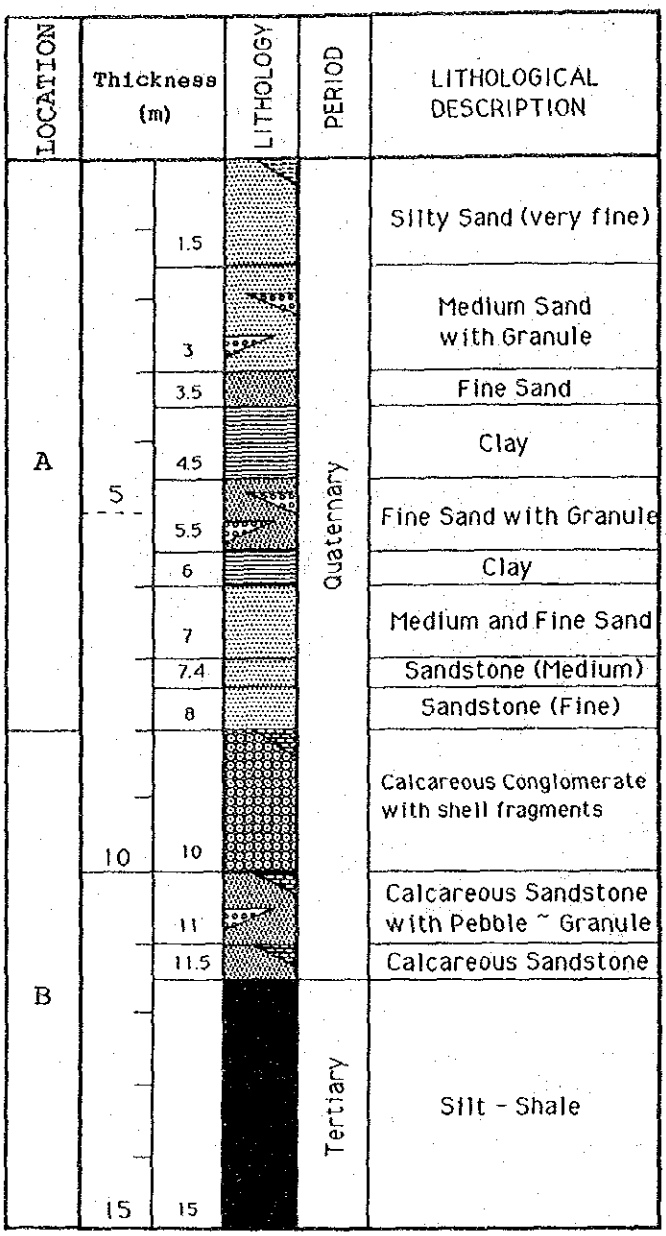

FIG. 6-2 GEOLOGICAL COLUMN OF OUTCROP A , B

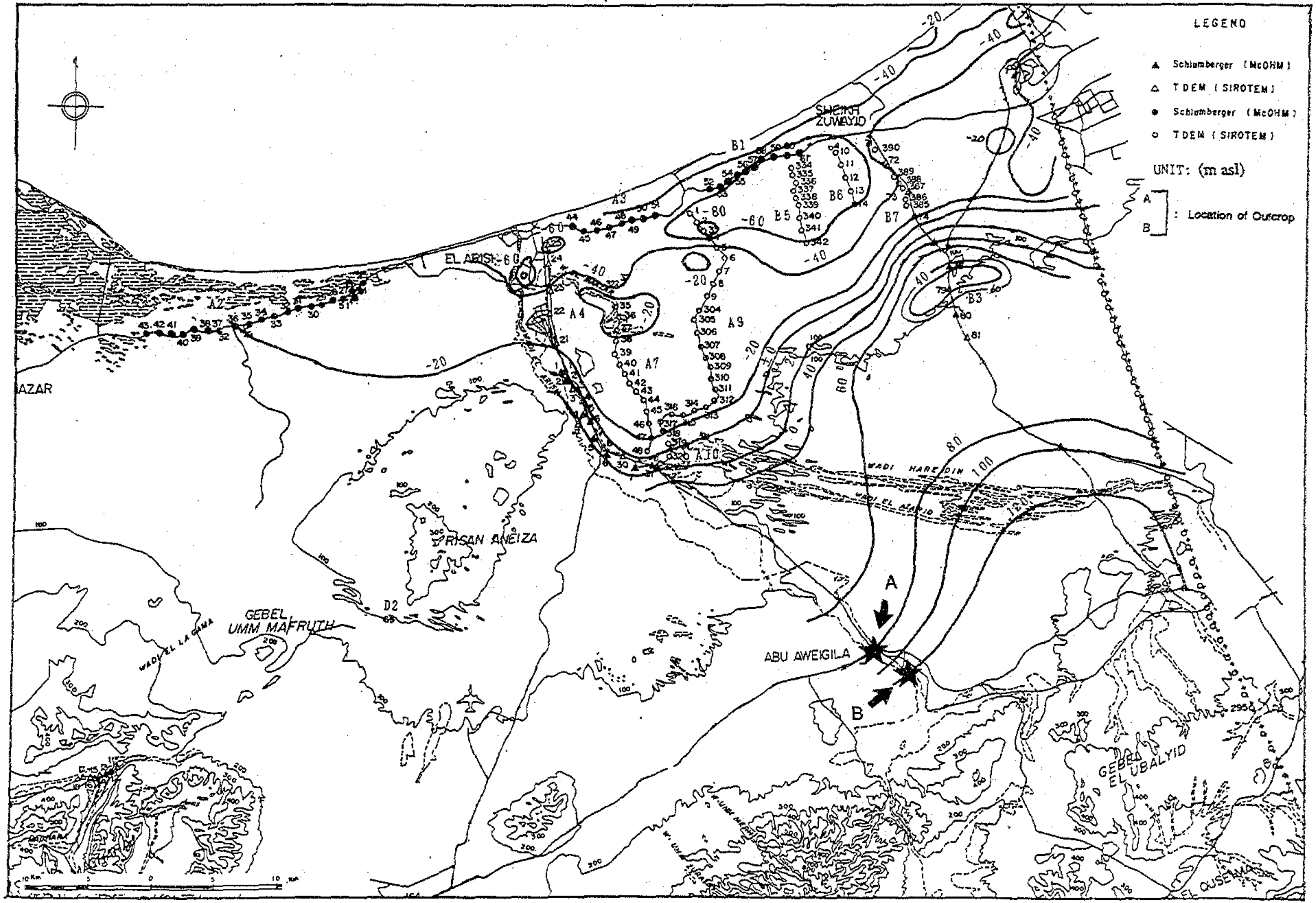

FIG. 6-3 BOTTOM OF QUATERNARY ON THE BASIS OF THE RESULTS OF THE ELECTRICAL RESISTIVITY AND WELL DATA ANALYSIS

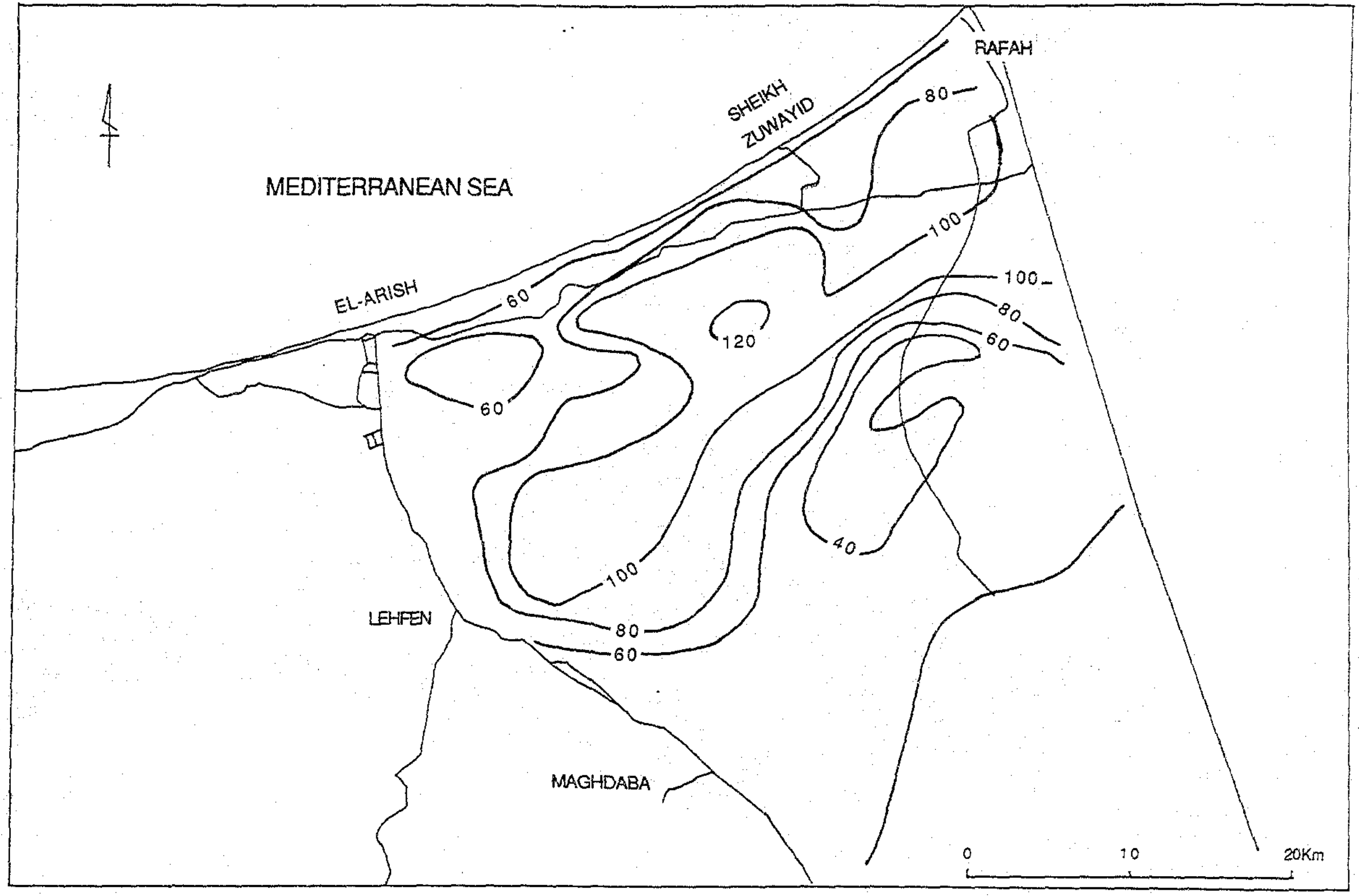

FIG. 6-4 ISOPACH OF QUATERNARY

In the eastern half of the coastal plain, there are many production wells and some test wells (Fig. 6-1).

Based on the geologic sections constructed by these available well data and interpretation of resistivity survey, the base level of the Quaternary is estimated as shown in Fig. 6-3.

There is an abrupt change in the gradient of the base of the Quaternary from Lehfen to the area about 10 km south from Rafah in EW direction. The convergence of contour lines of the base elevation of the Quaternary suggests a fault in the south of Rafah.

It is suggested that the subsidence movement took place in the area after that sedimentary basin occurred along the coast. Elevation of the basal line of the Quaternary deposits is lower than -60 m asl.

An isopach map of the Quaternary is shown in Fig 6-4. There is a thick Quaternary formation extending 20 km from the Wadi El-Arish to the east, toward the international border with Israel. Its coverage is approximately 800 km^2.

6-3 Distribution of Pre-Quaternary

According to the study, it is concluded that prospecting aquifers may develop in the following formations:

1) Tertiary
   - Miocene
   - Eocene
2) Upper Cretaceous
   - Senonian
   - Turonian
   - Cenomanian
3) Lower Cretaceous
4) Jurassic
   - Upper Jurassic
   - Middle to Lower Jurassic

Contour maps are constructed for the Cretaceous formations as a portfolio of the hydrogeological map as listed below:

1) Isobath map
   Lower Cretaceous

2) Top surface
   Upper Cretaceous
   Lower Cretaceous

3) Isopach Map
   Lower Cretaceous

<u>Isobath Map of Lower Cretaceous</u>

The map shows the depth to the top of the sandstone of the Lower Cretaceous from the ground surface. The depth tends to be deep in the central part of the study area. It is 800 - 1,000 m around Hasana, 900 m near Nakhl, 500 - 600 m near Kuntilla and 700 - 800 m near Sudr El Heitan (Portfolio sheet No. 19).

<u>Top Surface of Upper Cretaceous</u>

There are two subsurface valleys on the erosion surface of the Upper Cretaceous. One is observed from Nakhl to Baghdad through Hasana and the other from Gifgafa to Baghdad in ENE-WSW direction. From the confluence of these two subsurface valleys at Baghdad it extends towards the NE direction passing between Gebel Risan Aneisa and Gebel Libni to the east of El-Arish. The elevation of the valley bottom at Nakhl is 400 m and at the east of El-Arish it is -200 m asl with a very gentle slope (Portfolio sheet No. 14).

<u>Top Surface of Lower Cretaceous</u>

Contour lines indicate the relative top elevation of the Lower Cretaceous from the sea water level. On this contour map, similar valley like features as in the Upper Cretaceous formation are observed. It indicates quite a different valley pattern than those on the surface of the Upper Cretaceous. Elevation of the top of the Lower Cretaceous lies at -400 m asl at Nakhl and at -900 m asl in the east of El-Arish with a very gentle gradient. (Portfolio sheet No. 17)

On the contour lines, an influence of faults were observed at some places. A significant influence of the Ragabet El-Naam Fault is recognized-dislocations are observed along the fault at Naqb where the vertical dislocation is estimated to reach a few hundreds meters;.however, it is insignificant at Nakhl. The Lower Cretaceous formation is cut by the fault at these places.

There is an abrupt change in the elevation of the top of the Lower Cretaceous at Gebel Minshera caused by a fault running in the ENE-WSW direction on the northern side of the dome. A similar graben structure is found in the area of Gifgafa which is caused by the faults running in a NW-SE direction. At Talet El-Badan, the Lower Cretaceous thrusts up the Cenomanian northward due to the reverse fault in the NW-SE direction.

Isopach map of Lower Cretaceous

The thickness of the Lower Cretaceous tends to be thick in the central and the northern part of the study area. At Gebel Halal it is confirmed to be 660 m thick. In the southern part of the study area the thickness of the Lower Cretaceous is in a range between 200 m and 300 m (Portfolio sheet No.18).

7. HYDROGEOLOGY

7-1 Hydrogeology of Quaternary

7-1-1 Hydrogeological Structure

A thick Quaternary formation is found extending from the Wadi El-Arish to the international border with Israel to the east covering approximately 800 km^2 along the Mediterranean coast. There is a heavy groundwater extraction at El-Arish and the area from Sheikh Zuwayid to Rafah from aquifers developed in this Quaternary formation.

Through the interpretation of the hydrogeological conditions in the area, the schematic cross-section of the Quaternary extending from El-Arish to Rafah is drawn as shown in Fig 7-1 (Chapter 7, Technical Report I).

Kurkar is the main prospecting aquifer of Quaternary underlain by the Pre-Quaternary mainly consisting of shale, however in some places consisting of sandstone or limestone (Section 7-2, Main Report).

At the test well JNo.9, there is Pre-Quaternary sandstone and gravel bed underlain by shale. These beds form a aquifer which is assumed to contact with the Quaternary aquifer at the boundary between these two formations (Fig. 7-2 and 7-3). The similar circumstances are observed in the sections G-G' and H-H' (Fig. 7-4 and 7-5) where the Pre-Quaternary limestone may contact with the Quaternary aquifer. This may suggest that aquifers in the Pre-Quaternary contact with the aquifers in the Quaternary in some places.

The thickness of kurkar varies from 10 m to 40 m and it thins out in some places: well No.11-11 and 11-20 on the coastal sand dune near Rafah (Section 6-2, Main Report). Kurkar is replaced by the other Quaternary deposit such as gravel, sand and sandstone in the southern end of kurkar.

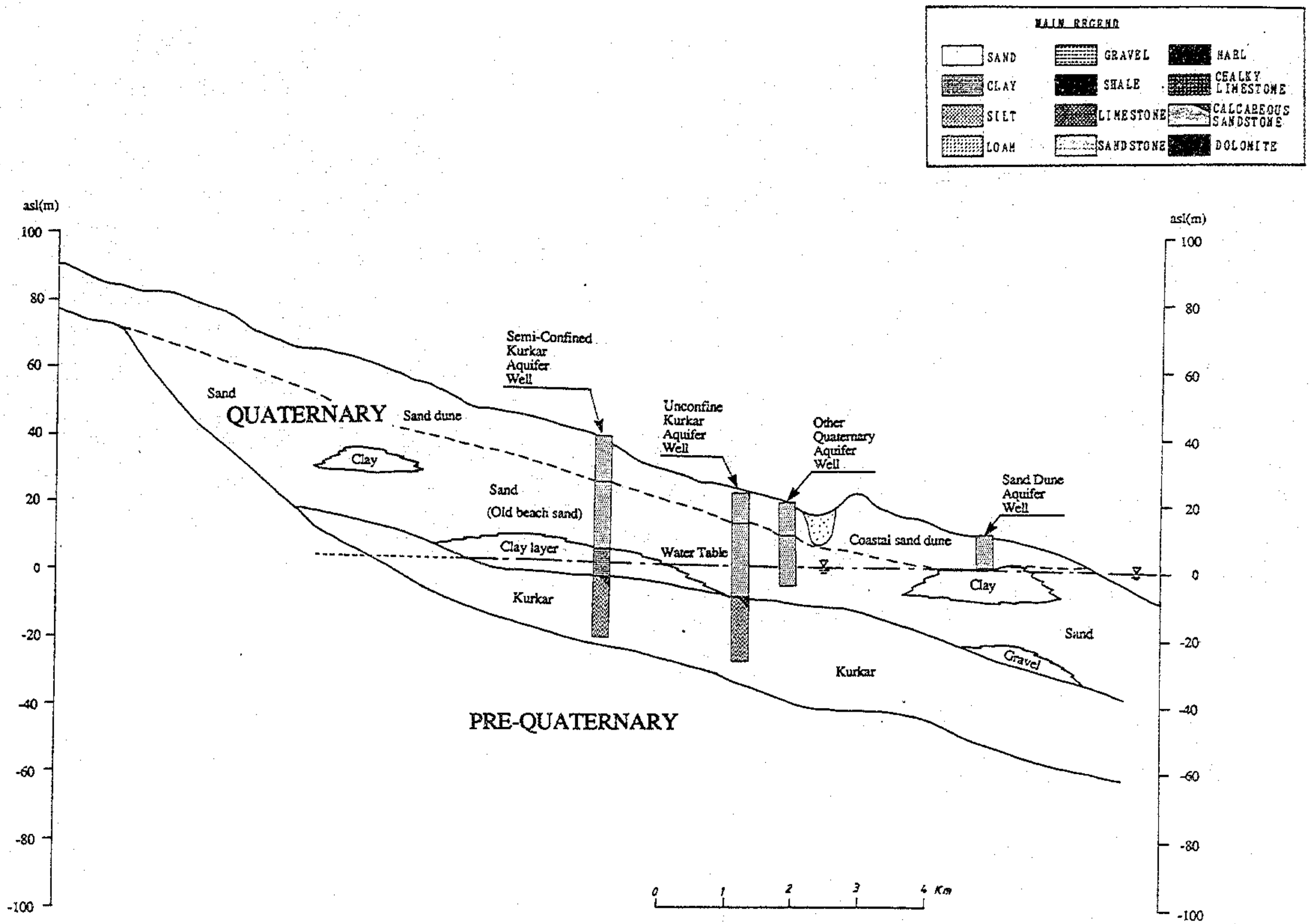

FIG. 7-1 SCHEMATIC GEOLOGICAL SECTION OF QUATERNARY IN THE COASTAL PLAIN

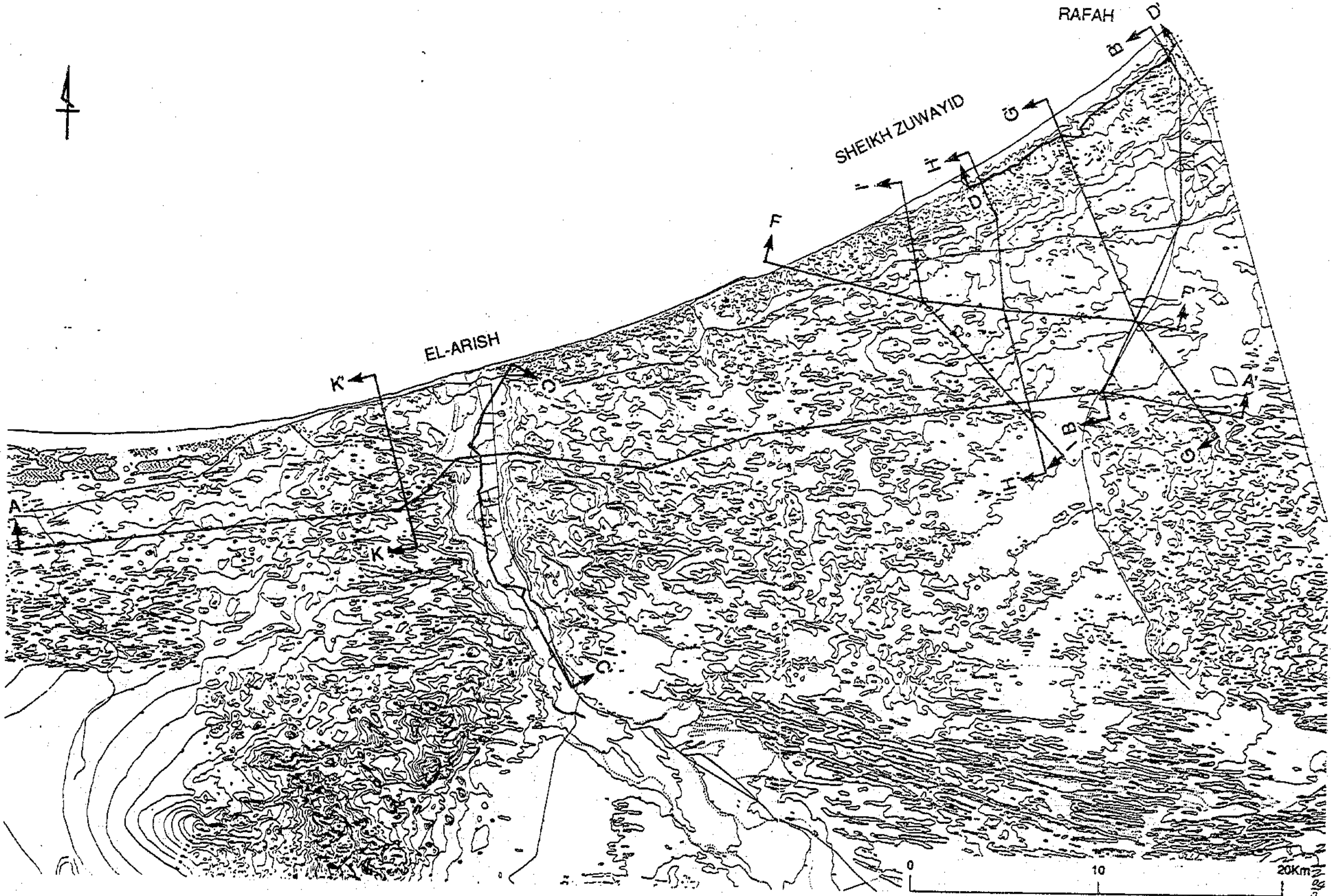

FIG. 7-2 LOCATION OF GEOLOGICAL SECTIONS

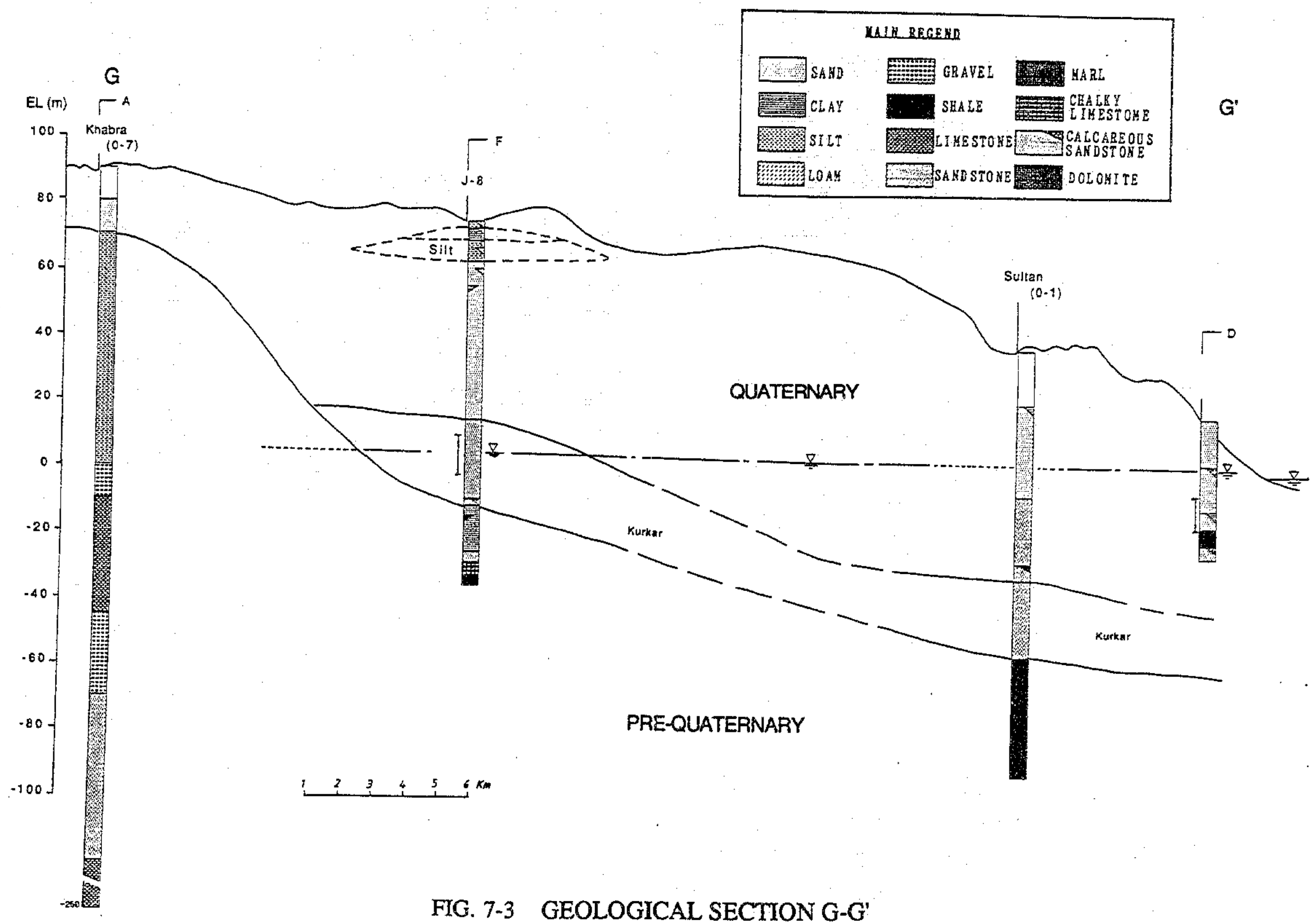

FIG. 7-3 GEOLOGICAL SECTION G-G'

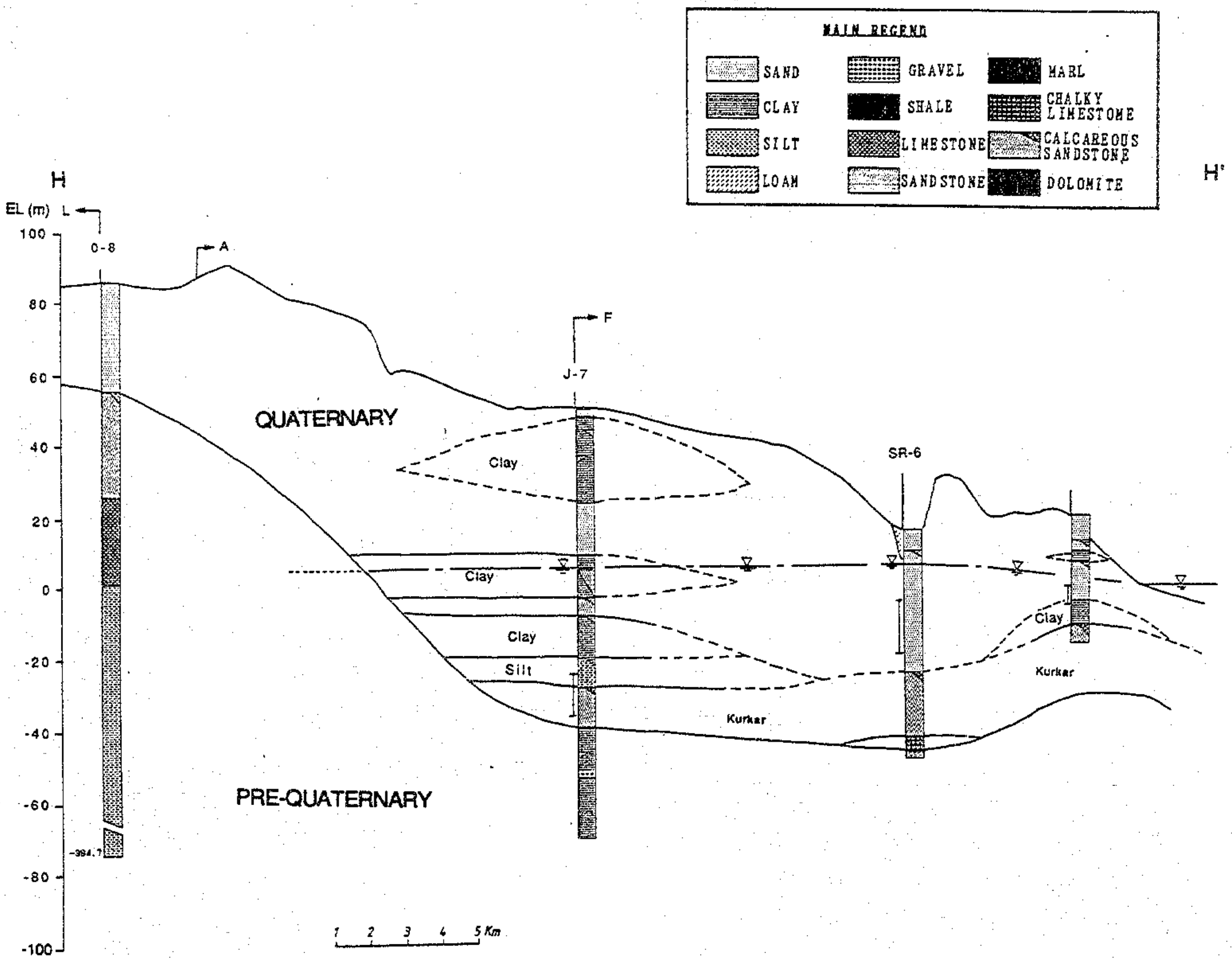

FIG. 7-4 GEOLOGICAL SECTION H-H'

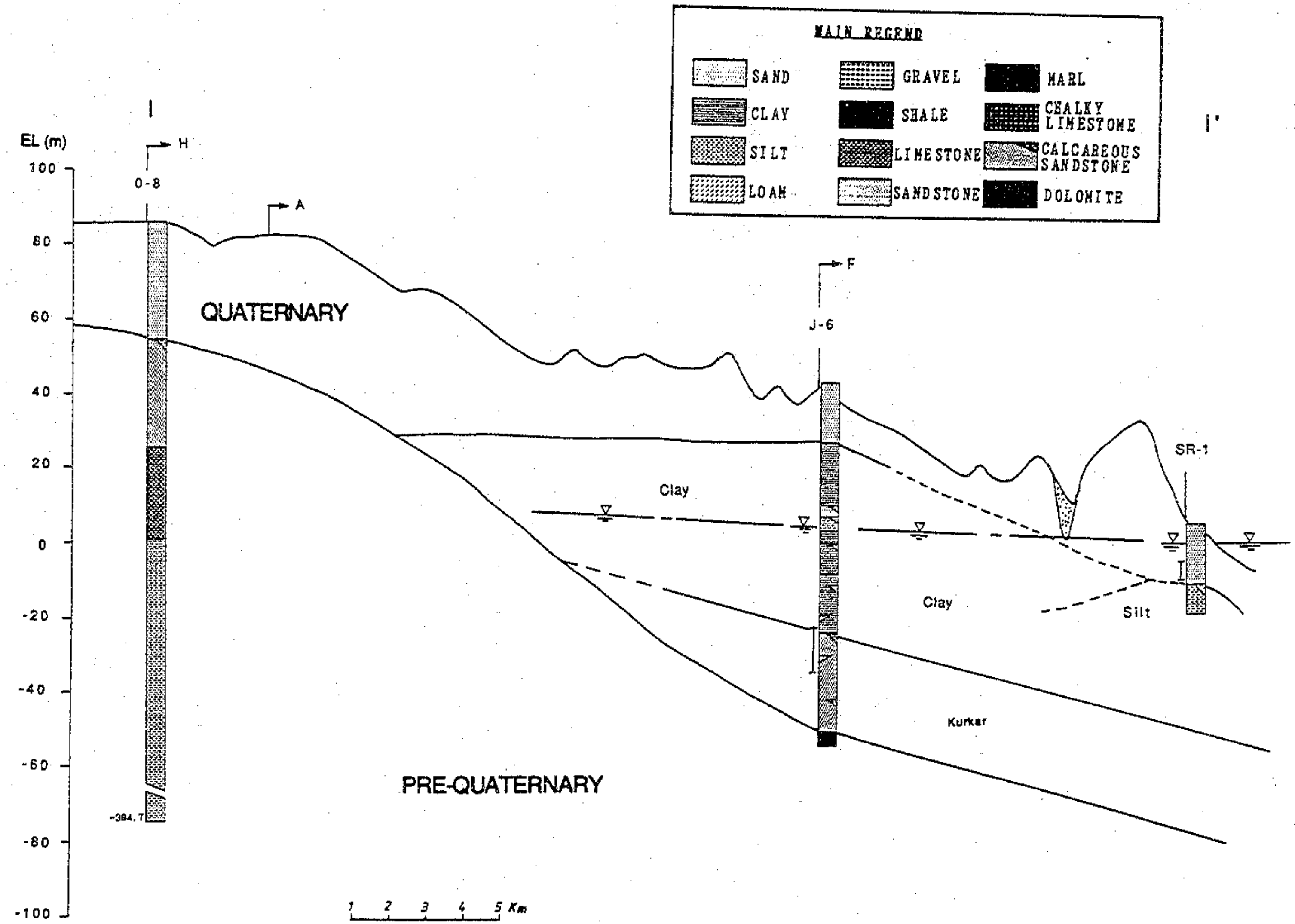

FIG. 7-5 GEOLOGICAL SECTION I-I'

Kurkar is overlain by old beach sand which underlies dune sand. The boundary between old beach sand and dune sand is unknown in many cases. Clayey beds and gravel are interbedded with each other in different thicknesses. Wherever a thick clayey material overlies kurkar, a confined aquifer is formed (Fig 7-3).

The groundwater level along the coast near the Mediterranean coast stays at 1 to 2 m asl and is estimated to be at 4 to 5 m asl at the southern end of kurkar. When the distribution of kurkar and the groundwater level are compared, some part of kurkar is found to be dry in the southern end of kurkar (Fig 7-3).

7-1-2 Water Quality of Quaternary Aquifer

High salinity of the groundwater is a prevailing problem in the study area. There are two possibilities which may affect the salinity of the groundwater: contamination of old saline groundwater or the sea water intrusion since the groundwater in the Pre-Quaternary aquifers has high salinity with various levels of TDS (Section4-3, Technical Report I). At the same time, these well fields in the Quaternary aquifer are facing the Mediterranean.

In order to examine the possibility of the sea water intrusion and compare the chemical characteristics of the groundwater, the ratio of $(Na^{+}+K^{+})/(Ca^{++}+Mg^{++})=R_{equ}$ and Na^{+}/Cl^{-} in equilibrium are calculated. Through interpretation of these data it is assumed that the high salinity of the groundwater in the Quaternary aquifer might be caused by the high salinity of the groundwater in kurkar aquifer or the contamination caused by the high salinity water from the aquifers in the Pre-Quaternary (Section 7-2, Main Report).

It is also found that the age of the groundwater in the Quaternary aquifer ranges from 1,700 to 8,600 years which may suggest the influence of old water occupying a greater part of the groundwater in the Quaternary aquifers (Section 7-2, Main Report).

It appears that there are different aquifers in the area (sand, gravel and kurkar). However, it is difficult to differentiate the characteristics of the water quality by the type of aquifer (Section 7-2, Main Report).

The range of TDS of the groundwater by aquifer is summarized as shown below (Section 7-2, Main Report):

Type of aquifer	Range of TDS (ppm)
Coastal sand dune	300-800
Inland sand	2,500-3,000
Old beach sand	1,300-2,700
Gravel	1,500-5,000
Kurkar : El-Arish	2,500-3,500
Kurkar : Inland	3,600-5,600

The aquifer in the coastal sand dune is the only available groundwater source for potable water. A typical example is the test well SR-1 in Fig. 7-5.

7-1-3 Water Level of Quaternary Aquifer

Since wells are densely distributed in the two well fields (The alluvial plain in the lower stretch of the Wadi El-Arish and the coastal plain from Sheikh Zuwayid to Rafah) a considerable amount of water level data is available. However, the recorded water levels of wells differ so much from each other on a small area so that it is difficult to construct contour lines of the water level in the well field. It might be assumed that the measured water levels had not recovered to their static water level since most of them are production wells. For this reason, a one square kilometer grid was meshed over the well field in order to determine the general feature of the water level of the well field taking an average of all water levels to represent each grid (Section 3-2, Technical Report I).

In 1962, the water level of the well field in El-Arish was in a range between 2 m and 4 m asl, although there were some areas where is distinctively low water level: Grid7-3 , 7-4, 8-5 and 9-2 (Fig 7-6 (A)).

During the 1980s, many wells were constructed and the pumpage rate was significantly increased. Accordingly, the water level in the El-Arish well field was greatly lowered as shown in Fig 7-6 (B).

Water level recession occurred between 1962 and 1988 and was significant especially in the well field on the western side of El-Arish town. In most of the grids in this well field the water level is lowered by 1 to 3 m (Fig 7-7).

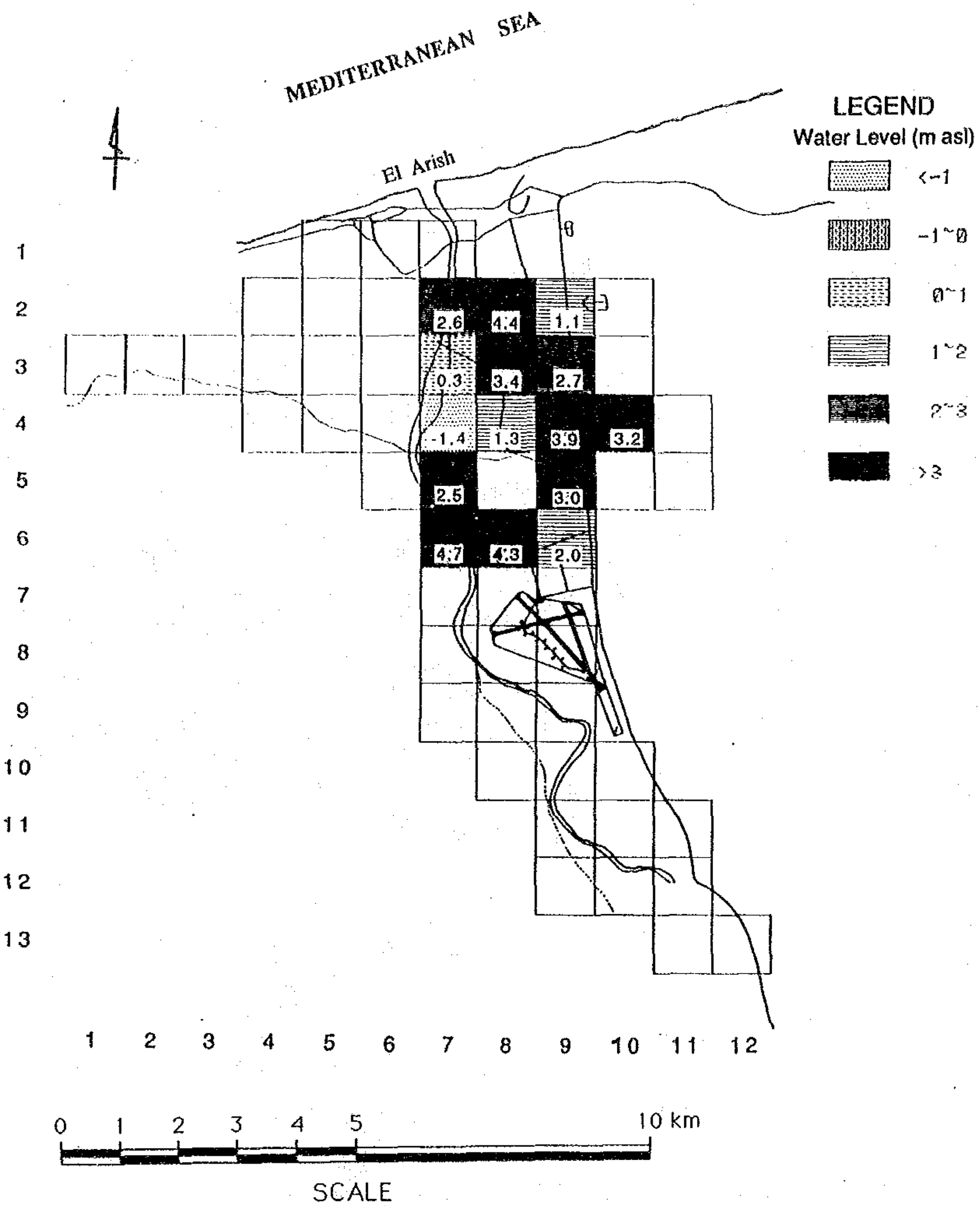

FIG. 7-6(A) AVERAGE WATER LEVEL AT EL - ARISH AREA IN 1962

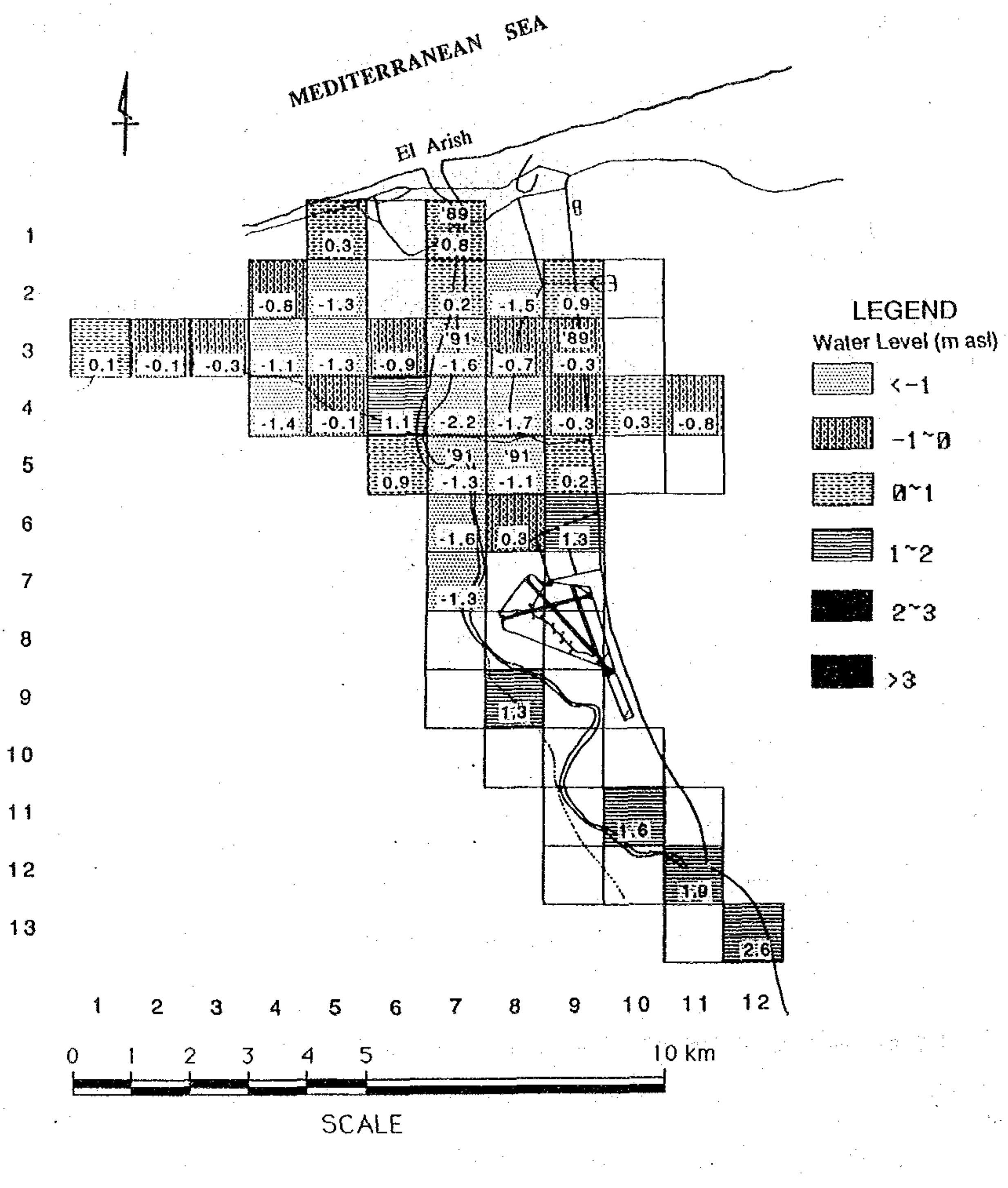

FIG. 7-6(B) AVERAGE WATER LEVEL AT EL - ARISH AREA IN 1988

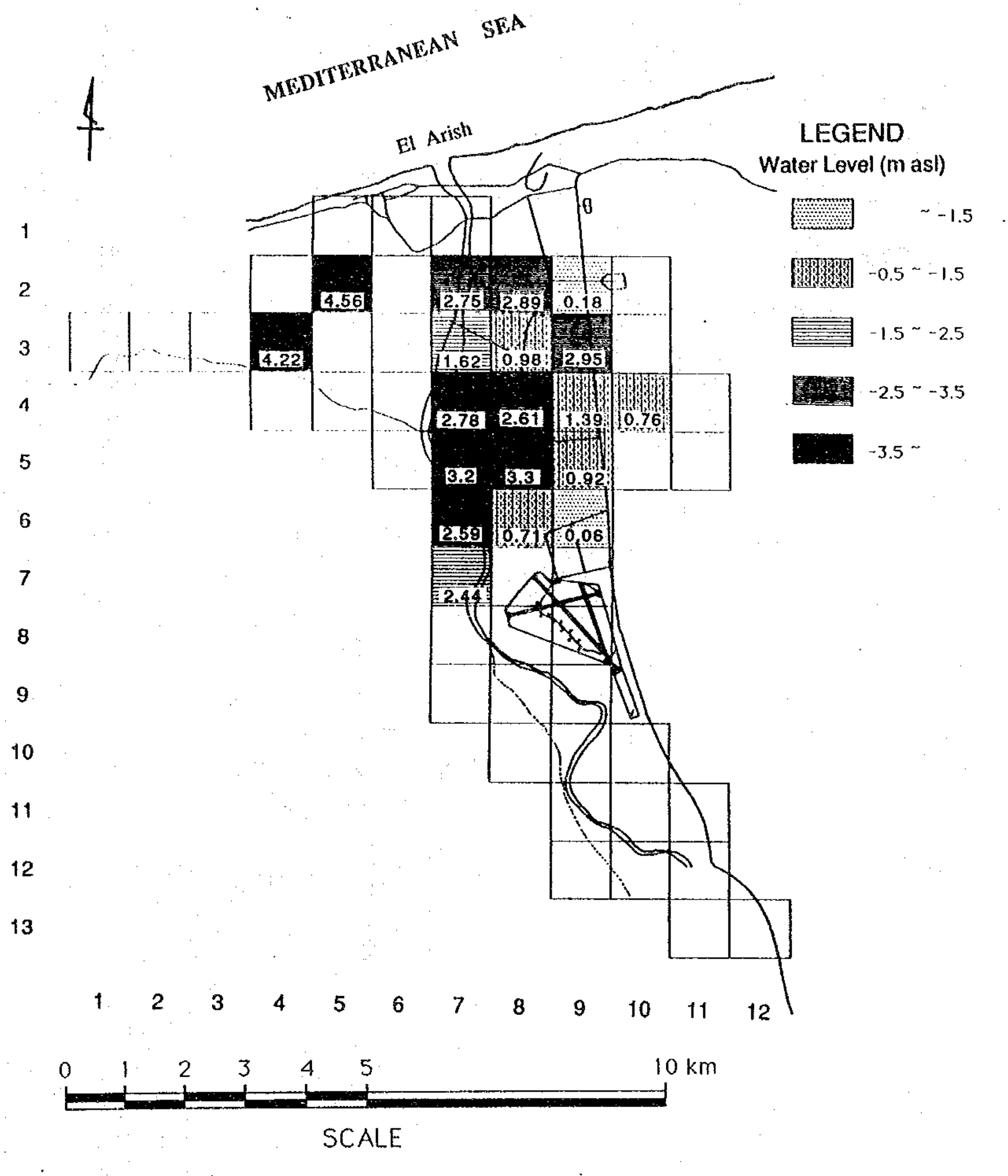

FIG. 7-7 RECESSION OF WATER LEVEL AT EL - ARISH AREA '62→'88

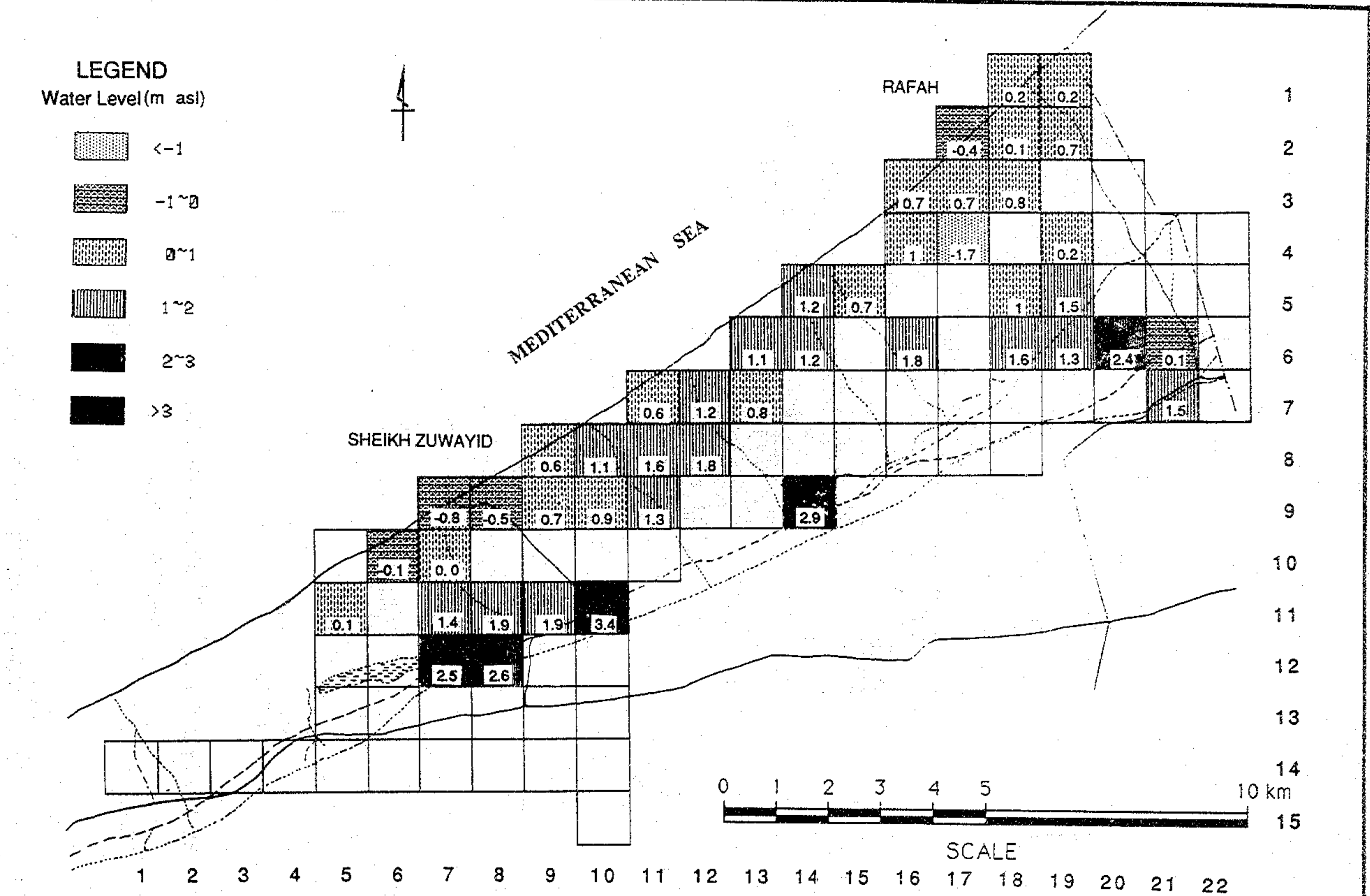

FIG. 7-8 AVERAGE WATER LEVEL AT SHEIKH ZUWAYID - RAFAH AREA IN 1988

Although there is no data to compare the difference of water levels at well fields from Sheikh Zuwayid to Rafah over a certain time span, it is assumed that the water level of the groundwater would be greatly reduced from the original level due to heavy pumpage. In the coastal belt very close to the seashore, the water level is slightly above the sea water level except at some grids where the water level is distinctively low: Grid 7-9 and 17-2 (Fig 7-8).

7-2 Hydrogeology of Tertiary

7-2-1 General

The formations of the Tertiary which have an affect on to the hydrogeology of the study area are the Miocene, Eocene and Paleocene. The formations of the Oligocene and the Paleocene are observed only in the wells along the Mediterranean coast or offshore at the depth of hundreds of meters and are not identified in the study area.

7-2-2 Aquifers in Miocene

As shown in Fig 7-9, the formation assigned to this age is distributed in the coastal foreshore area. The lithology is represented by shale and clay with interbeds of sandstone and limestone. This formation is usually covered by sand dune deposits and are only occasionally found among sand dune deposits as a very small outcrop.

Prospecting aquifers may develop in the limestone and sandstone interbedding the shale or clay. The shale and clay play a role of impermeable barriers to the aquifers in the sandstone or limestone (Technical Report IV).

The sandstone and conglomerate have suitable nature to hold aquifers in the coastal foreshore area.

A relatively moderate TDS is observed at well JNo.9: 3,450 ppm, in the south of Rafah while a rather high TDS is recorded at the well Misri-1 near Magdaba: 10,450 ppm, so that the salinity of the groundwater in the aquifers of the Miocene seems to be rather high.

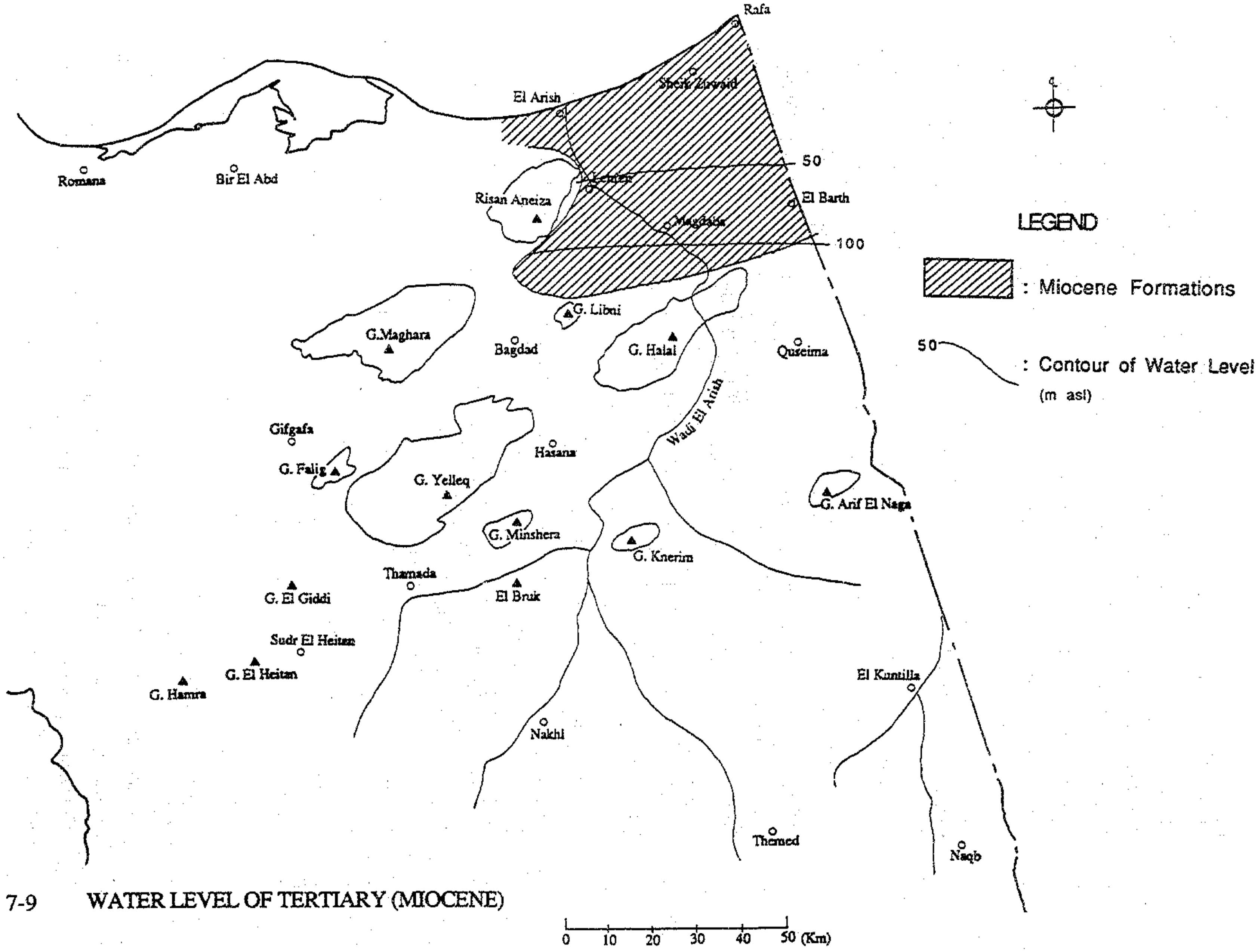

FIG. 7-9 WATER LEVEL OF TERTIARY (MIOCENE)

7-2-3 Aquifers in Eocene

The Eocene is represented by limestone and marl distributed throughout the area south of the line combining Risan Aneiza and Gebel Maghara. Nummulites are the characteristic fossils contained in the limestone.

All existing wells were found in the aquifers developed only in the limestone. A characteristic aspect of the occurrence of the groundwater in such aquifers is that the groundwater is stored at the basal part of the limestone underlain by the Esna Formation, which is observed at the well No.83 El-Mewaleh No.1 and Ain Gudeirat spring. The porosity of the limestone itself is not very high; the water is stored in the fissures developed in the limestone (Fig. 7-10).

Some wells are distributed around Quseima and El-Amro. They are developed in the limestone of the Eocene. Also, there are some springs in the area to the southeast of Quseima with the same hydrogeological set-up. The wells extracting water from the aquifer of the Eocene are also reported at El-Amro.

The Eocene sediments are distributed extensively in the southern part of the study area. In the area, the Eocene limestone is the main component of the huge plateau. The plateau is deeply incised by many wadis. But the Eocene limestone is assumed to be a prospecting aquifer. The thickness of the Eocene limestone reaches 200 m -300 m and is underlain by shale. Some test wells are proposed to be drilled in the area for evaluating the Eocene limestone.

The age of the groundwater at the spring of Ain Gudeirat is determined to be 14,000 years B.P., so that it is assumed that the recharge is not modern but in the Pleistocene. The yield of the spring is estimated to be in the order of 1,500 m^3/day and the TDS is relatively low: 1,440 ppm.

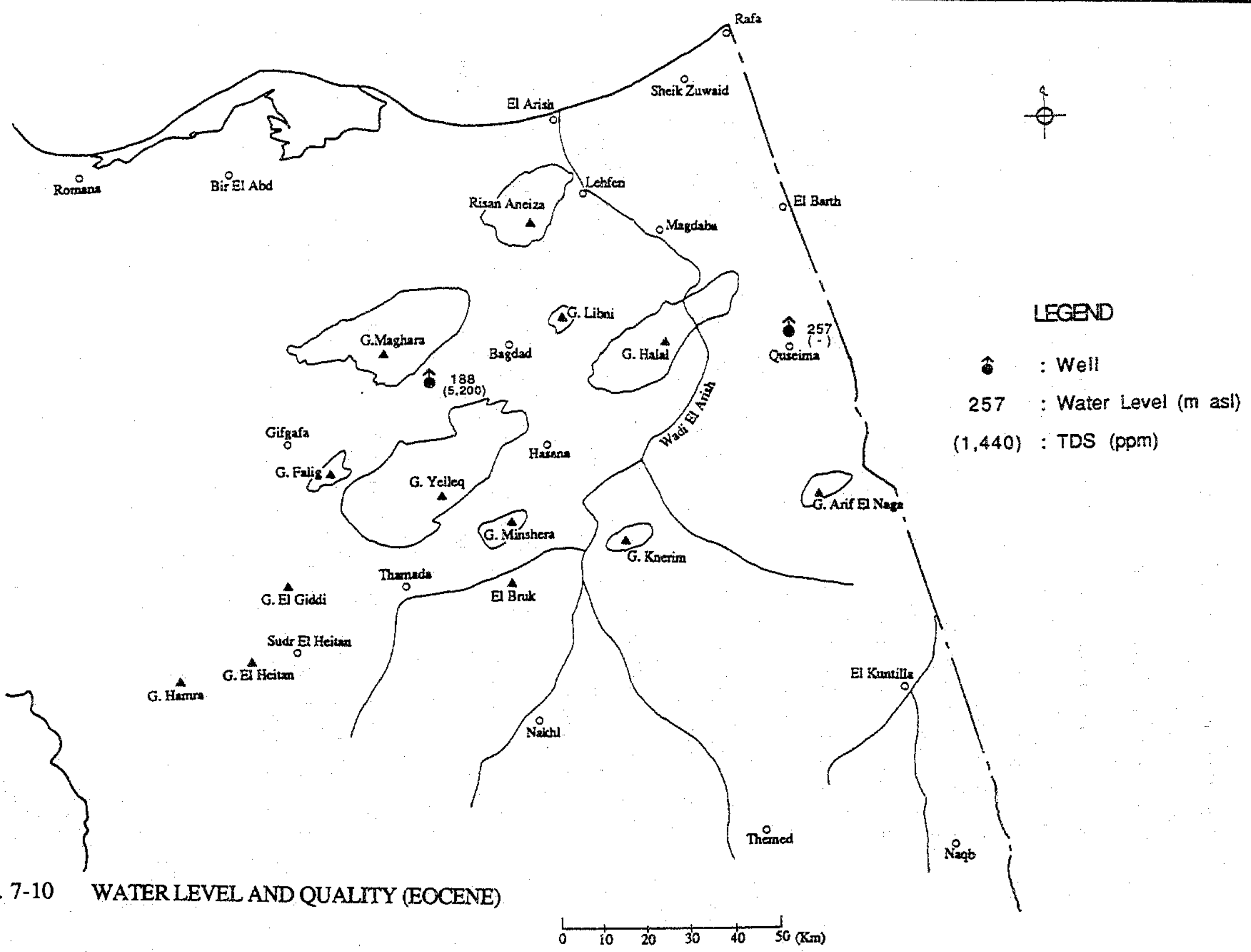

FIG. 7-10 WATER LEVEL AND QUALITY (EOCENE)

7-2-4 Aquifers in Paleocene

It is very unlikely to expect any prospecting aquifers in the Paleocene since the Paleocene in North Sinai is represented by the Esna Formation which consists shale with occasional marl. The thickness of this shale ranges from a few meters to tens of meters. The shale sometimes plays a role of the aquifer bottom of the limestone of the Eocene due to its impermeability.

7-3 Aquifers in Upper Cretaceous

7-3-1 Aquifers in Senonian

There are four wells tapping the water from the aquifer of limestone of the Senonian of which water level are confirmed. These wells are distributed in the area of Hasana, Gebel Libni and Gifgafa (Fig. 7-11).

The water level of the wells sunk into this type of aquifer is 107 m asl at Hasana and 58 m asl at Gebel Libni of which the hydraulic gradient is approximately 2/1,000.

The TDS value variation in a wide range (2,200 ~ 8,480 ppm) is one of the characteristics of the water in the aquifers of the Senonian. It is highly possible that the saline water was originally trapped in the rocks. The salinity might be diluted or saline water is replaced by the less saline water along the movement of the groundwater mass in the aquifer. In the aquifer, where joints and fissures are well developed, the water body can easily move diluting the high original salinity in the aquifer. However, where the transmissivity is low, the amount of water movement might be less than otherwise so that the salinity of the groundwater remains at a high level without becoming diluted.

7-3-2 Aquifers in Turonian

The Turonian is represented by foraminifera rich limestone with shale at the base. The aquifers are found in the limestone. There are three recorded wells tapping water from the aquifers in the limestone of the Turonian: At Hasana, Naqb and Sheira (Fig 7-12). Of these wells, the well at Naqb is located on the northern side of the Ragabet El-Naam Fault and the one at Sheira is on the southern side of the fault.

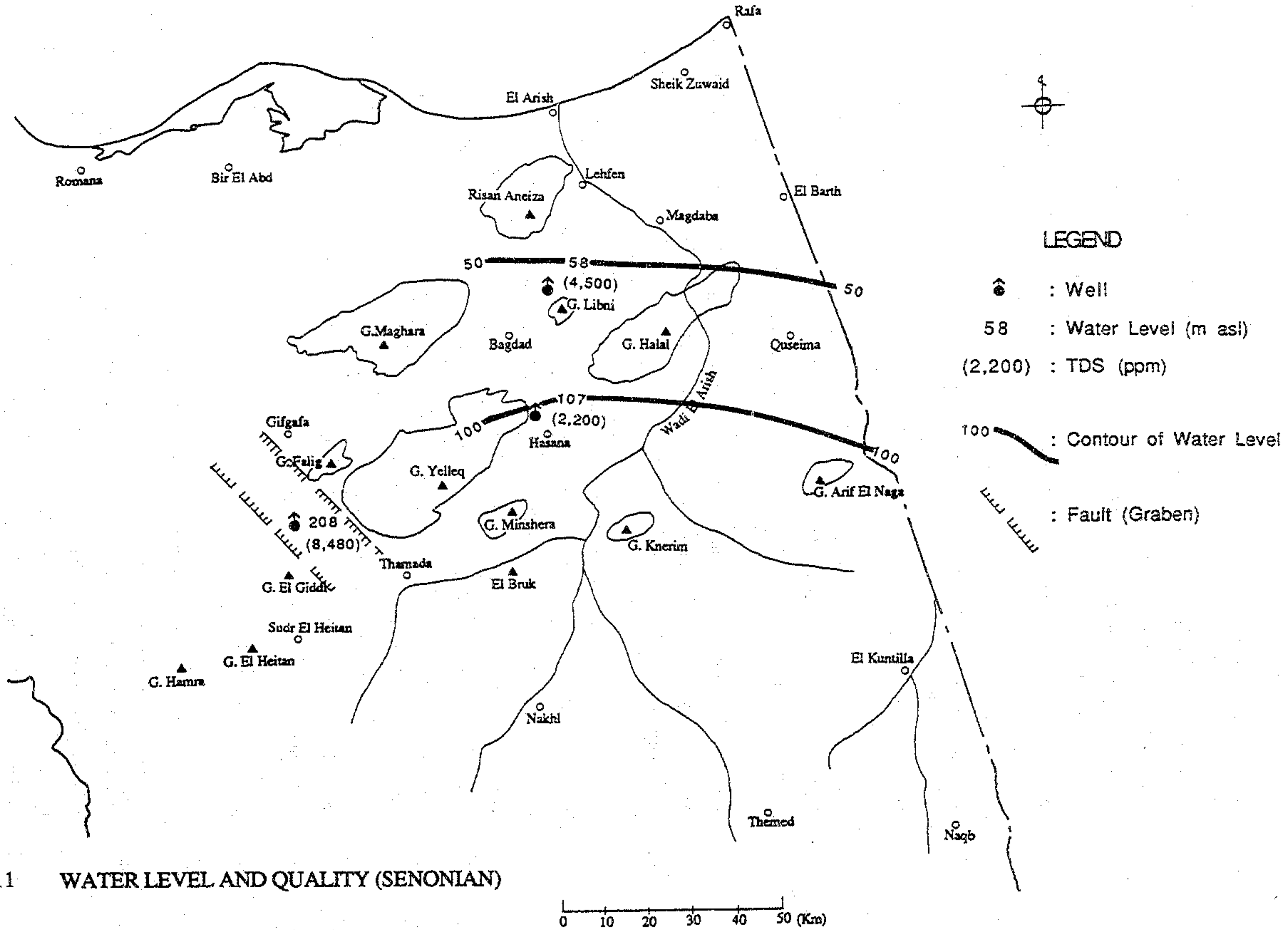

FIG. 7-11 WATER LEVEL AND QUALITY (SENONIAN)

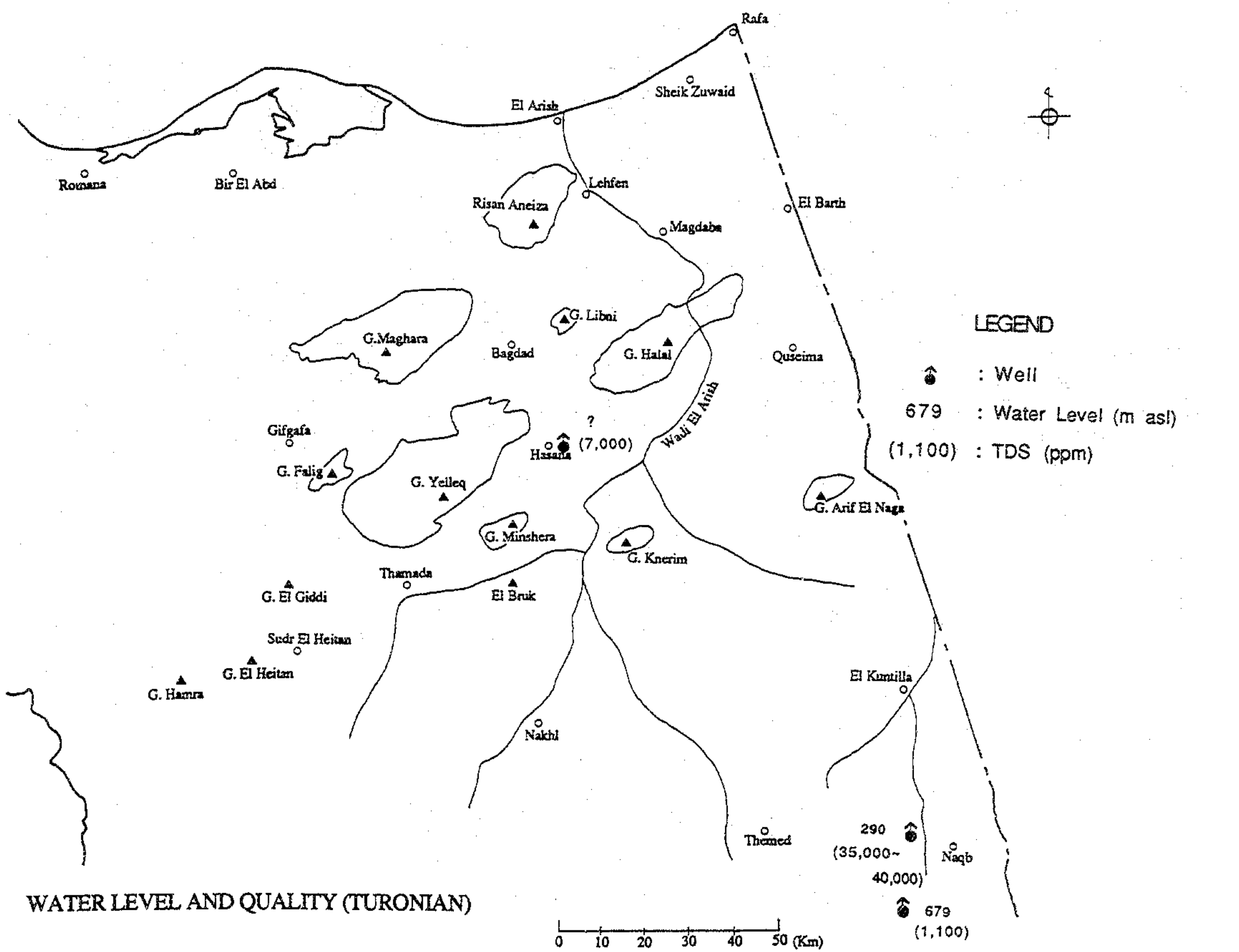

FIG. 7-12 WATER LEVEL AND QUALITY (TURONIAN)

The water level at Naqb is 290 m. At Sheira it is 679 m asl. The difference is assumed to be caused by the fault.

The TDS value at Sheira indicates a rather low value of 1,100 ppm. However, the value at Naqb is much higher (35,000 to 40,000 ppm) which is equivalent to the TDS of sea water.

In the central part of the Sinai peninsula, there is a general tendency for the groundwater to move from south to north, restricted by the geological structure. The Ragabet El-Naam Fault, running in the east-west direction, crosses through Central Sinai and is assumed to play a role as a barrier to the groundwater movement. These hydrogeological setups cause the groundwater to be stored on the southern side of the fault. On the other hand, movement of the groundwater to the northern side of the fault is somehow restricted by the fault.

Under the circumstances, the groundwater at Sheira has more of an opportunity to be diluted of its original salinity by the recharged fresh groundwater, while the groundwater salinity remains at a higher level on the northern side since the groundwater movement from the south is restricted by the fault.

The age of the groundwater at well JNo.17 is estimated to be 22,670 year B.P.

7-3-4 Aquifers in Cenomanian

Lithology of the base of the Cenomanian overlying the Lower Cretaceous is calcareous sandstone. In the upper part of the Cenomaian, lithology is represented by limestone, dolomite and dolomitic limestone. Although it crops out only at domes where the overlying beds are eroded, the Cenomanian is overlain by other beds in a broad area.

The porosity of the limestone is important from a hydrogeologial point of view. As karstic caves and fissures may easily be developed in the given lithology, these limestone bed are recognized to be permeable. Therefore, aquifers developed in this beds are localized types rather than continuous and homogeneous regional types like aquifers in the sandstone of the Lower Cretraceous.

Five wells are sunk into the aquifer of the Cenomanian. The depth to the aquifer from the ground surface is 138 m at well JNo.17. The remaining wells are in a range between 400 m at well P1 Gifgafa, and 818 m at well P16 El-Amro. Well JNo.17 was drilled in a dome at El-Bruk where the overlying bed of the Cenomanian was eroded so that the depth of the aquifer is rather shallow (Fig 7-13).

The water level of these wells are at 223 m asl at El-Bruk, at 169 m asl and 63 m asl at Hasana which suggests the piezometric potential surface of the groundwater in the aquifers is declining from the south to the north.

The salinity of the groundwater of these wells is rather high, ranging between 2,740 and 5,630 ppm. The salinity of well No. 57A is 2,740 ppm. However the salinity of the UNICEF well, 10 km from well No. 57A, is 4,120 ppm. This may indicate that the extent of fissures and joints developed in the limestone are not universal but are localized types.

7-4 Aquifers in Lower Cretaceous

The Lower Cretaceous extends over a greater part of the study area and the lithology of the Lower Cretaecous is represented by the quartzose sandstone with occasional interbeddings of shale. The thickness of the Lower Cretaceous varies from place to place. It is generally in a range between 200 m to 300 m, however a very thick sequence of this bed is observed at Halal reaching 600 m thick (Section 7-5, Main Report).

The whole sequence of the Lower Cretaceous is observed at four sites: Gebel Maghara, Minshera, Arif El-Naga and Naqb (Technical Report III). The whole sequence of the Lower Cretaccouws is also interpreted on 8 lithological profiles of the test wells (Technical Report IV).

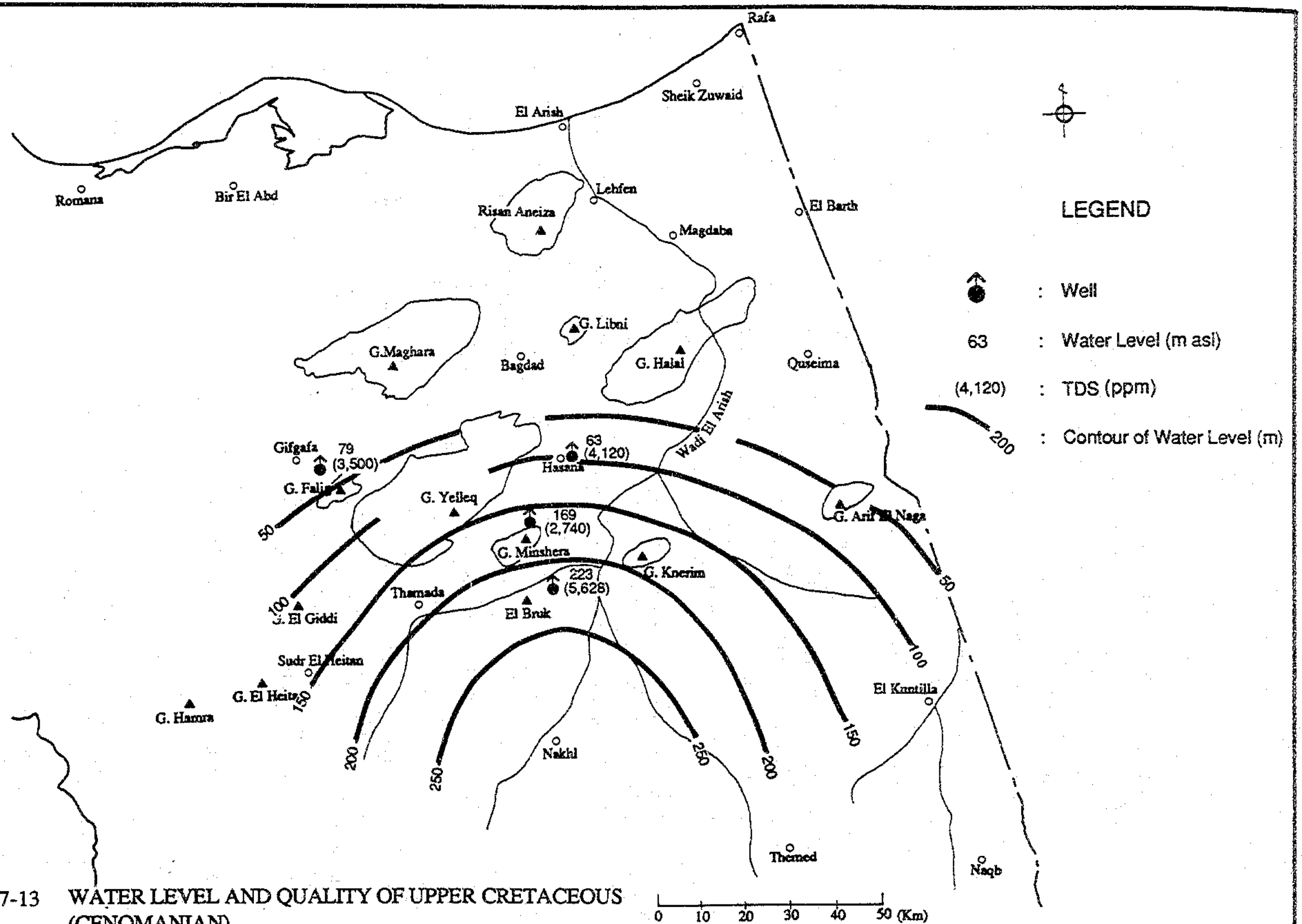

FIG. 7-13 WATER LEVEL AND QUALITY OF UPPER CRETACEOUS (CENOMANIAN)

The interbedded shale is rare in the area of Gebel Alada, Al-Mostadul, Kherim and Minshera, while the shale interbeddings appear frequently in the upper part of the formation at Gebel Maghara and Gebel Mafuruth. On the other hand, a thick shale is observed in the lower part of the formation at Arif El-Naga and Gebel Halal. The interbedded shale is a lenticular type rather than continuous massive type except at the lower part at Arif El-Naga and Gebel Halal (Fig. 7-14).

The lithological facies changes from quartzose sandstone to limestone in the northern part of the study area along the Mediterranean to the north of Gebel Maghara and Gebel Halal. From this area to the south, quartzose sandstone is distributed over 20,000 km^2 with thickness ranging from 200 to 300 m.

Although the information of the hydraulic properties of the sandstone is rather limited, the permeability coefficients and the transmissivities of the aquifers in the sandstone are obtained at six places (Chapter 5 Technical Report I). Permeability coefficients are in the range of from 10^{-4} to 10^{-3} cm/sec and transmissivities are in the range of from 12 to 400 m^2/day.

Since number of the physical constants of the aquifers of the Lower Cretaceous was limited, a grain size analysis was undertaken to interpret the continuity of the sandstone facies and to estimate the permeability of the sandstone aquifer. The permeability of the each sandstone sample is estimated by the passing D_{20} value (Technical Report III). Most of the estimated permeabilities of the sandstone sequence fall into a narrow range between 10^{-3} and 10^{-2} cm/sec (Fig. 7-15).

The permeability of the aquifers in the sandstone of the Lower Cretaceous, obtained by the aquifer test, also falls into a narrow range between 10^{-4} and 10^{-3} cm/sec which may indicate that the aquifers are homogeneous and highly permeable.

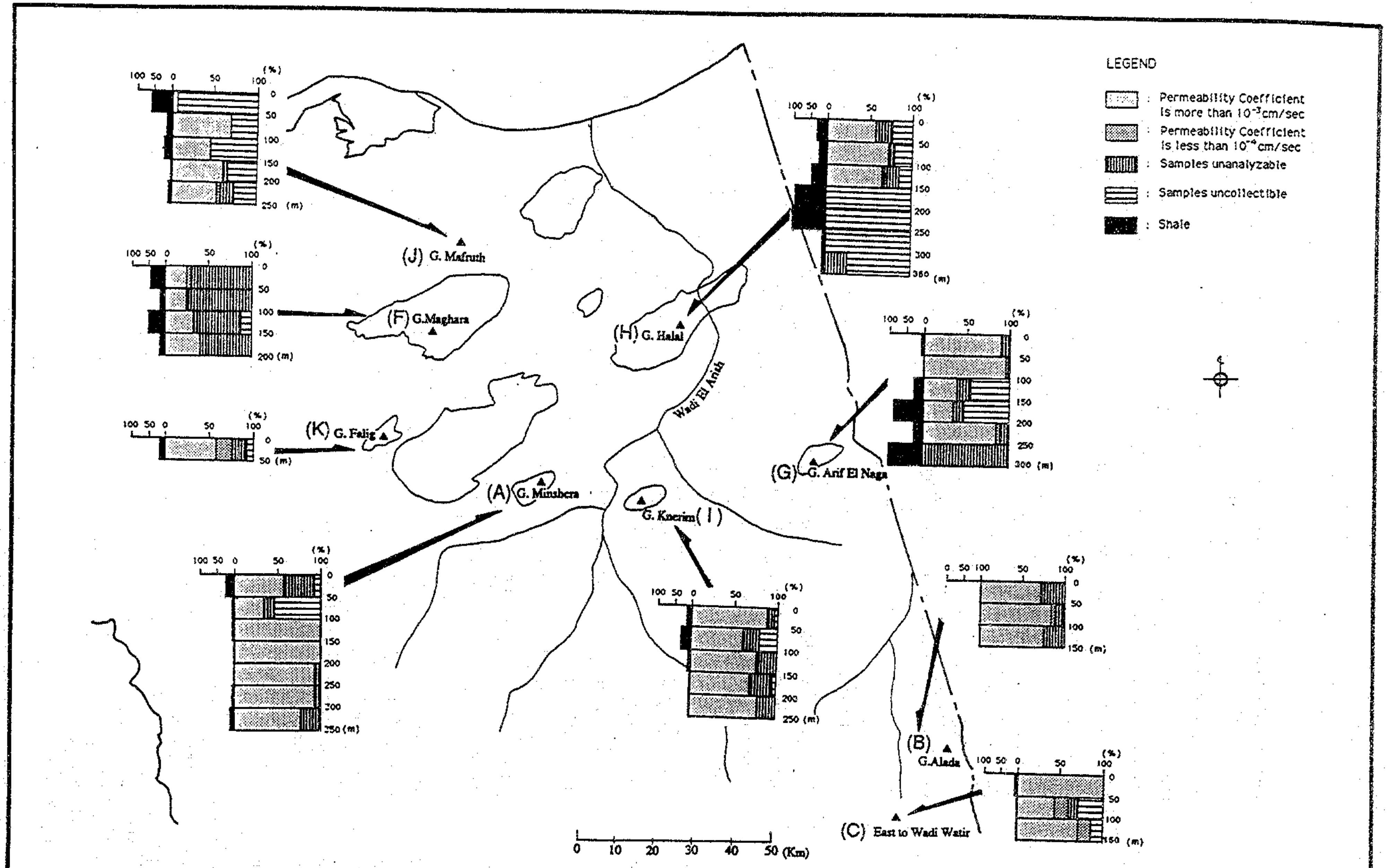

FIG. 7-14 DISTRIBUTION OF PERMEABILITY OF EACH 50m LAYERS

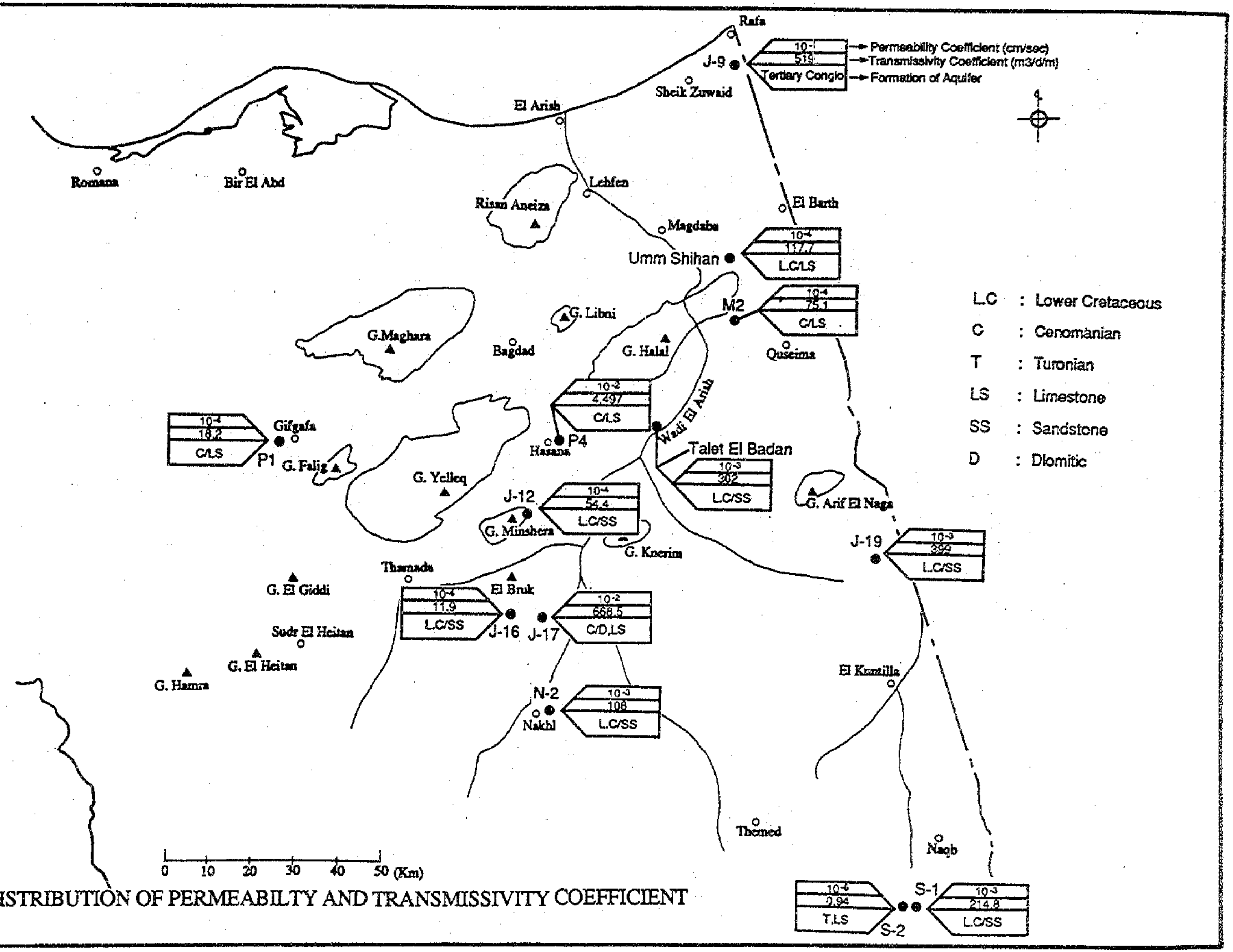

FIG. 7-15 DISTRIBUTION OF PERMEABILTY AND TRANSMISSIVITY COEFFICIENT

The Lower Cretaceous crops out high up on the dome structures except at Naqb. But the depth to the top of this bed from the surface reaches approximately 1,000 m in the northern part of the study area. Distribution of the depth to the top of this bed is in a range of from 500 m to 1,100 m from the ground surface in the study area (Section 7-5, Main Report).

The top surface of the Lower Cretaceous seems like a very gentle and broad underground valley descending gently from the south to the north in a N-S direction. Gebel Minshera, Gebel Kherim and Gebel Halal appear to be "inselberg" in this valley. There are narrow depressions on both sides of Gebel Yelleq and Gebel Halal extending in an ENE-WSW direction (Fig 7-16).

The Lower Cretaceous unconformably overlies the Precambrian in Naqb. However, in the rest of the area the Lower Cretaceous is underlain by the Jurassic. The lithology of the Jurassic varies from place to place and common facies are either limestone, sandstone or shale.

TDS of the groundwater obtained from the aquifers in the sandstone of the Lower Cretaceous is in a range of from 1,200 to 5,400 ppm (Fig 7-17). TDS value of the groundwater of the aquifers in the sandstone of the Lower Cretaceous tends to be lower in the south than in the northern part in the study area. In the vicinity of the dome structure, TDS appears to be high which is assumed to be caused by the structural disturbance allowing the existence of stagnant water. In a broad area where there is no significant structural disturbance, TDS of the groundwater in the sandstone aquifer is in a range of from 1,200 to 1,500 ppm.

14 wells are sunk into the aquifer of the sandstone of the Lower Cretaceous. The highest water level (420 msl) was observed at the well Sheira-1 on the southern side of Ragabet El-Naam Fault. The lowest water level (24 m asl) was measured in the northeastern part of Gebel Halal at the Israel well. According to all the well data, it is suggested that the piezometric potential surface of the groundwater in the aquifer of the sandstone of the Lower Cretaceous gently descends from the south to the north with a gradient of 2/1,000 to 3/1,000 (Fig 7-18).

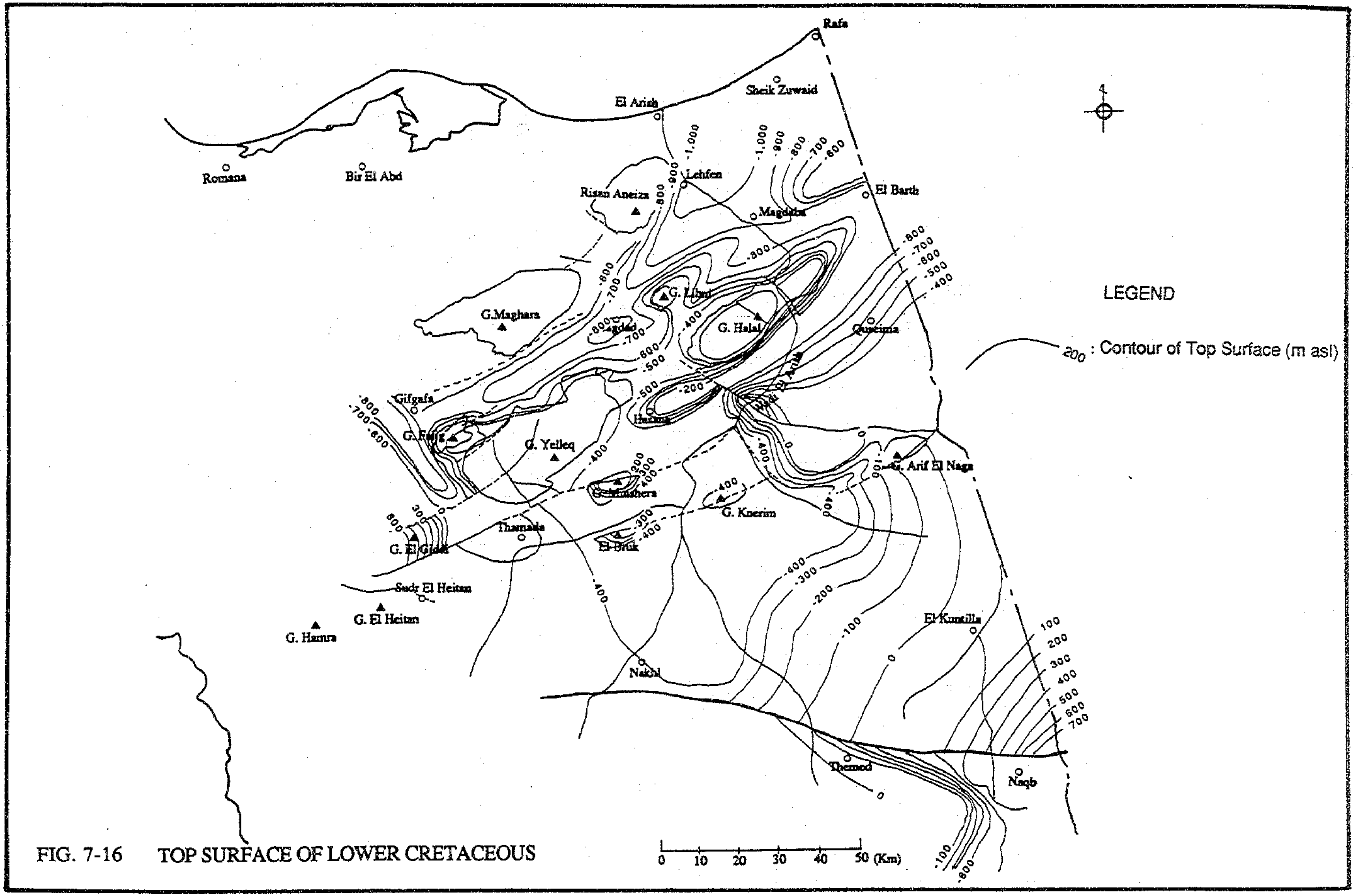

FIG. 7-16 TOP SURFACE OF LOWER CRETACEOUS

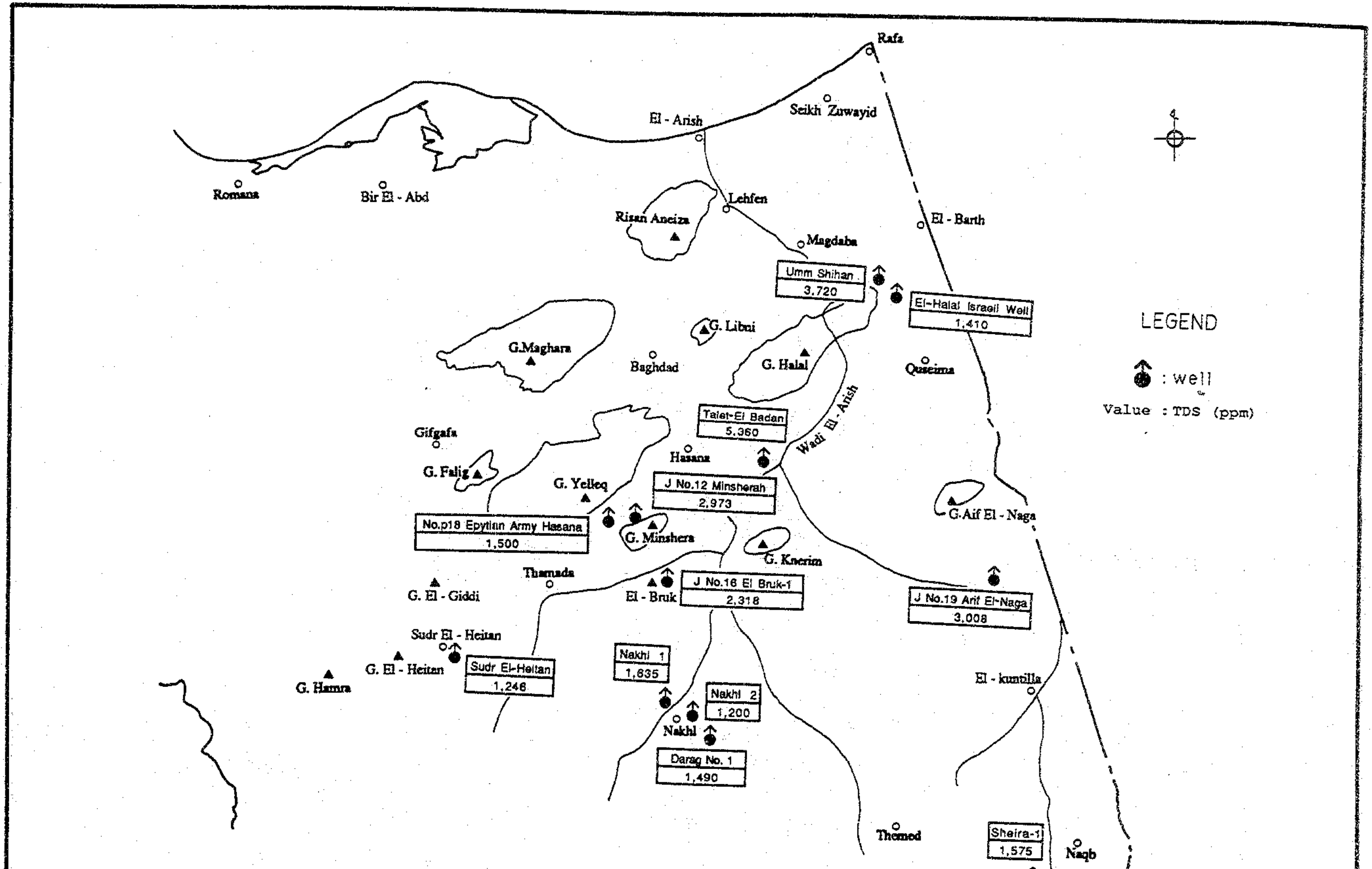

FIG. 7-17 WATER QUALITY (LOWER CRETACEOUS)

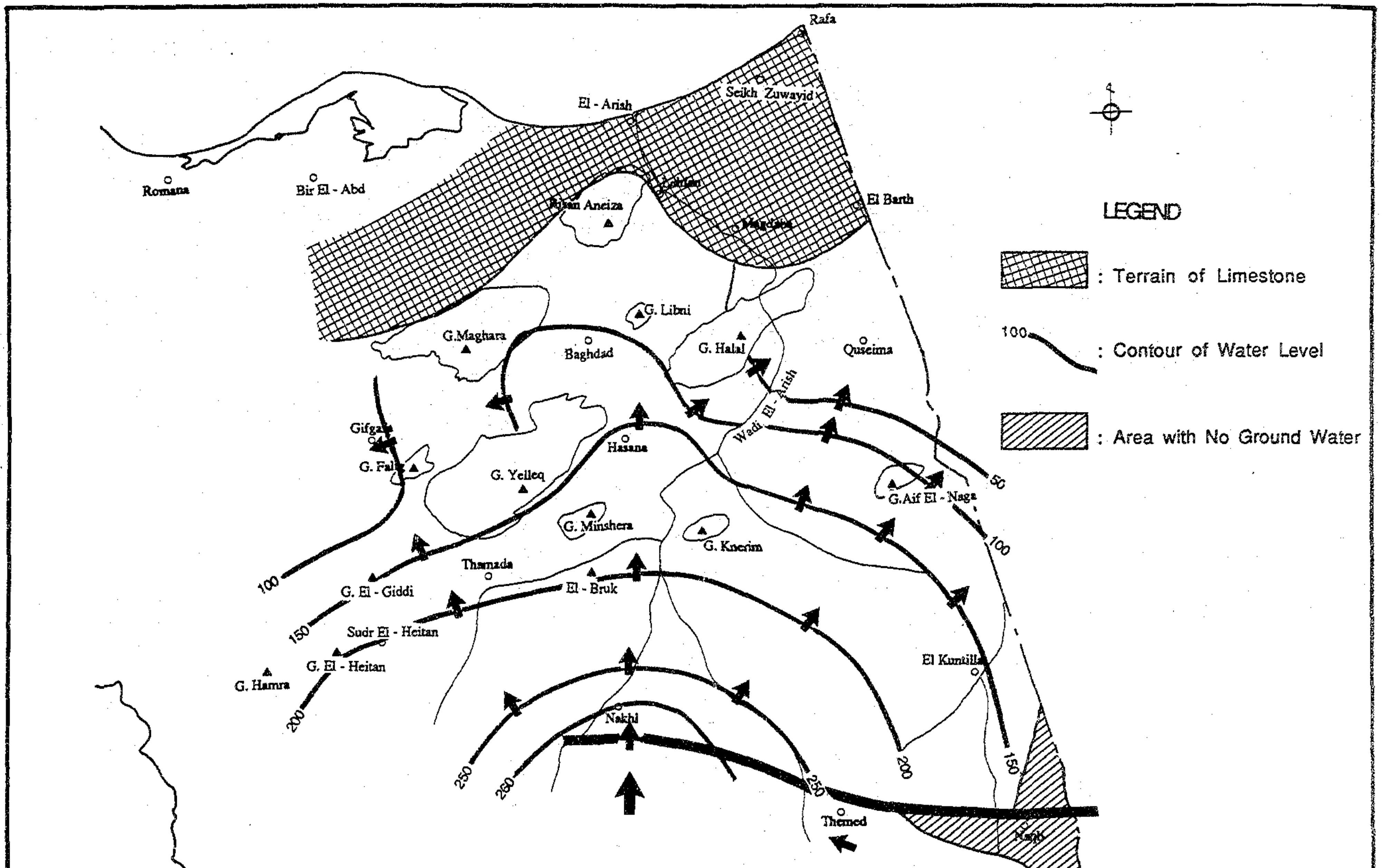

FIG. 7-18 WATER LEVEL OF WELLS IN LOWER CRETACEOUS

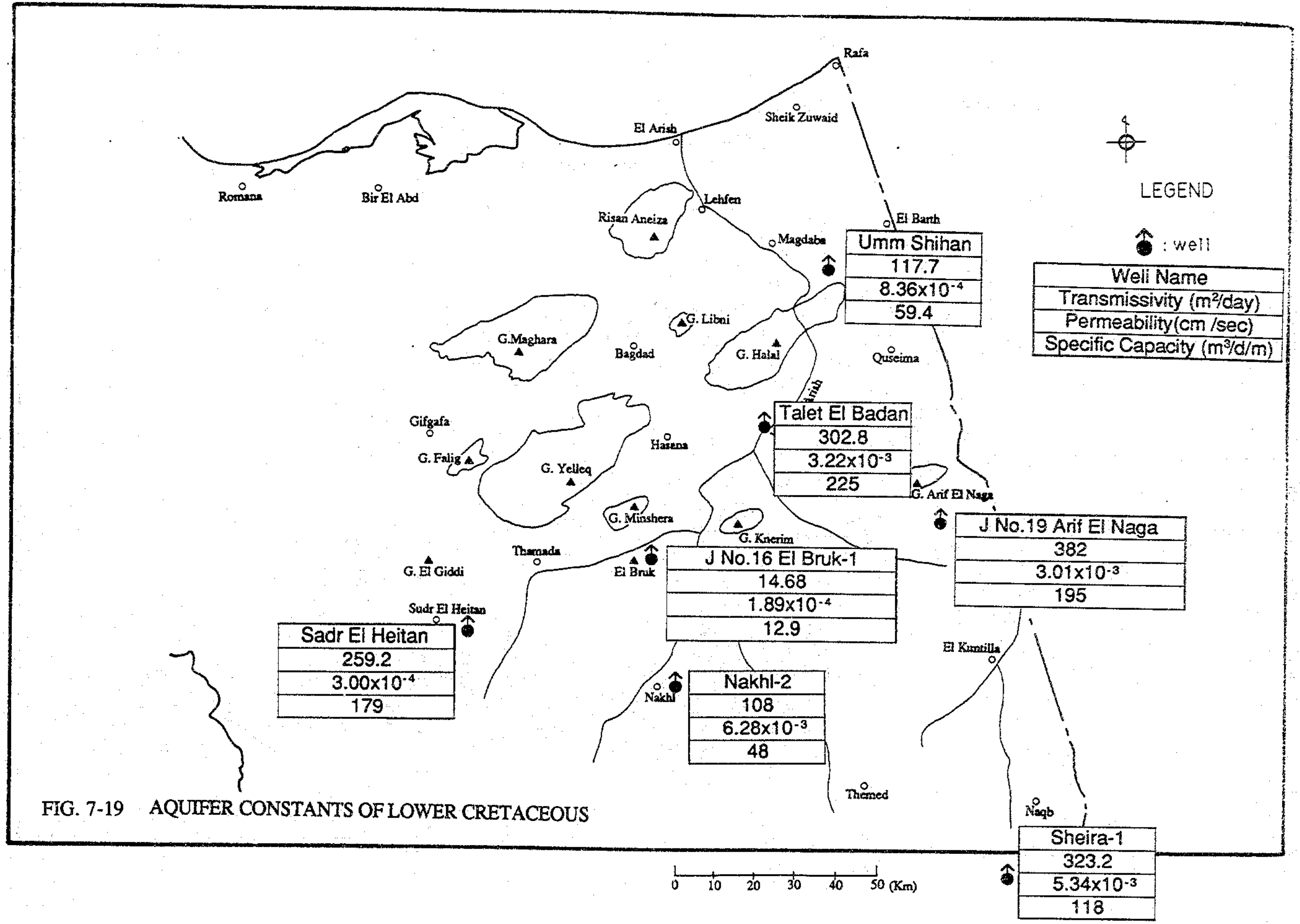

FIG. 7-19 AQUIFER CONSTANTS OF LOWER CRETACEOUS

In addition to the influence of the geological structure of domes on the aquifer, there would be remarkable influence on this aquifer caused by the Ragabet El-Naam Fault which extends from Naqb to the west, crossing the central Sinai. The southern side of the fault is an uplifted block, but the vertical displacement in the central part of the fault at Nakhl seems to be insignificant. However, the vertical displacement of the fault in the western part is significant. At Naqb, the vertical displacement of the fault is estimated to exceed 200 m and the Precambrian rocks are exposed in the southern block. It is suggested that the Lower Cretaceous sandstone, which is demarcated by the fault, is disrupted at the western and eastern terminus of this fault.

Being restricted by the fault, the groundwater in the Lower Cretaceous aquifer moves from the south to the north through the hindrance of dome structures, turning its direction towards a NE direction at the Syrian Arc. The barrier to this flow at the northern end is the limestone of the Lower Cretaceous.

The volume of the sandstone of the Lower Cretaceous excluding interbedded shale and these places structurally disturbed, is estimated to be in an order of $120 \times 10^9 m^3$ and the volume of the groundwater storage in this aquifer is $30 \times 10^9 m^3$ assuming 25 % of the effective porosity.

Results of the aquifer test of the sandstone of the Lower Cretaceous is available at seven wells (Fig 7-18). The productivity of the wells sunk into the aquifers in the sandstone of the Lower Cretaceous is assumed to be high (Chapter 5, Technical Report).

The groundwater is assumed to be old. According to the dating by ^{14}C, the age of the groundwater is in a range between 22,000 and 36,000 Y.B.P. (Chapter 6, Technical Report I).

7-5 Aquifers in Jurassic

7-5-1 General

The Jurassic formations found in North Sinai are the Upper Jurassic and the Middle to Lower Jurassic formations. The Middle to Lower formation is represented by sandstone and shale interbedded by thin coal beds. Rock salt is found in the coal mine. The Upper Jurassic formation is represented by limestone. These formations are found in the dome structures in the study area. The wells sunk into the aquifer in these formations are found only in Gebel Maghara area (Fig 7-20).

7-5-2 Upper Jurassic

There are seven wells sunk into the aquifers in the limestone of the Upper Jurassic formation distributed along the northern fringe of the dome at Maghara. The water levels of these wells in the central part of the northern margin stay in a range between 147 m and 167 m asl. The TDS of the water samples of these wells is in a range between 1,650 and 3,450 ppm. The yield of these wells varies between 5 m^3/hr and 35 m^3/hr hr and the larger yield tends to indicate the lower TDS (Section 7-6, Main Report).

On the other hand, the water levels of the wells distributed on the western and the eastern ends of the northern fringe of the dome indicate higher levels: 210 m - 232 m asl. The TDS of water samples of these wells falls in a range between 3,600 and 3,800 ppm.

7-5-3 Aquifers in Middle to Lower Jurassic

There are three wells sunk into the aquifer of the sandstone of the Middle to Lower Jurassic formations. The water levels stay in a similar level between 301 m and 305 m asl. However the TDS of the water samples varies in a wide range between 4,140 and 7,400 ppm. The yield of these wells are in a range between 3.8 and 5.8 m^3/hr, and the TDS of the groundwater rapidly increases as the pumpage goes on. In addition to the small yield, the draw down is rather high (15 m to 25 m) so that the aquifer of the Middle to Lower Jurassic formation is assumed not to be productive both in qualitative and quantitative aspects.

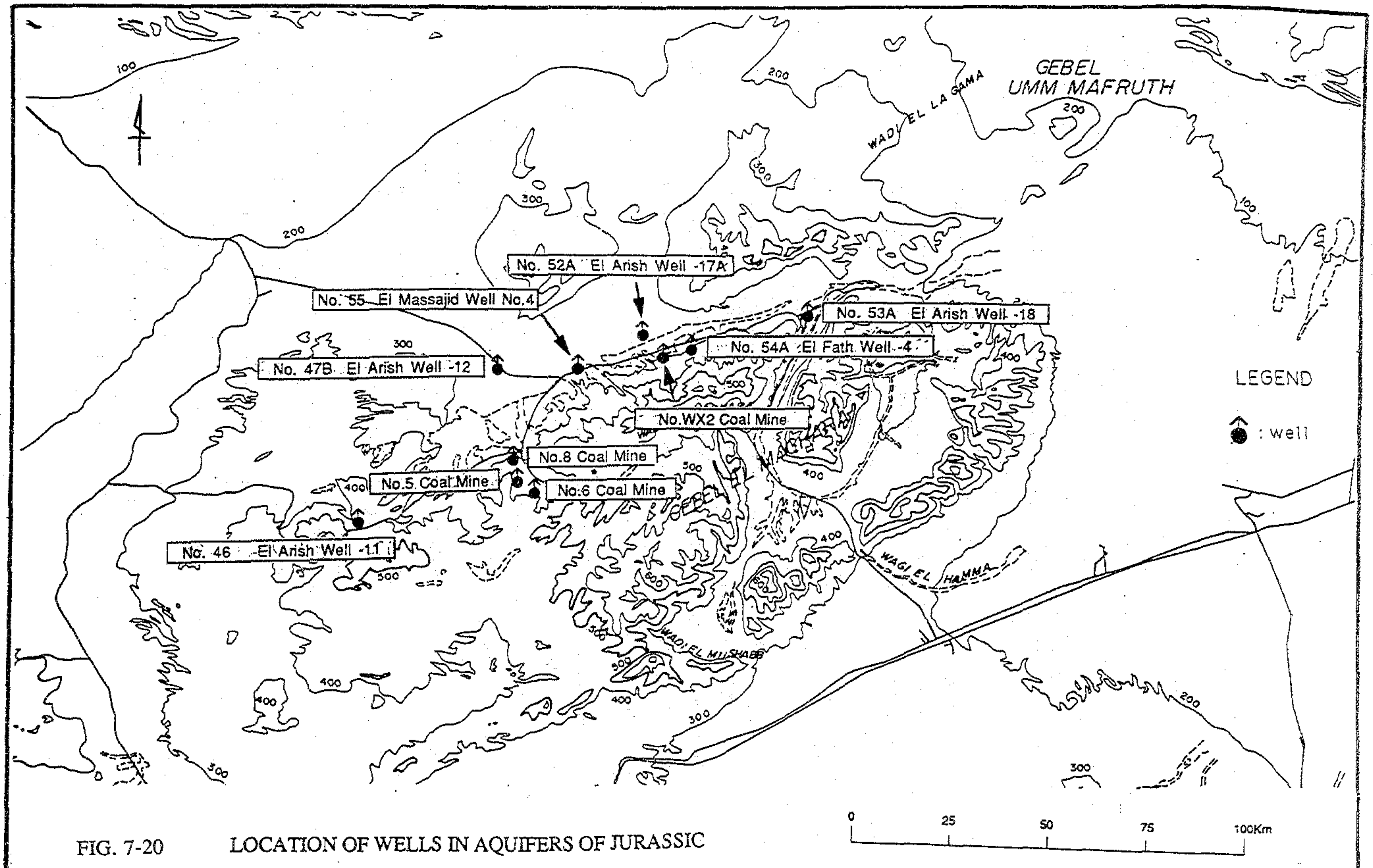

FIG. 7-20 LOCATION OF WELLS IN AQUIFERS OF JURASSIC

8. EVALUATION OF GROUNDWATER RESOURCES

8-1 Quaternary Aquifer

The Quaternary formation with prospecting aquifers extends for 30 km in the coastal plain from El-Arish to Rafah in a width ranging from 10 to 15 km along the seashore. Its thickness is estimated to be 80 to 100 m, and it is 120 m in the thickest part. The base level of the Quaternary in the area is estimated by the interpretation of resistivity survey (Fig. 6-3).

The western limit of this Quaternary formation is still subject to future confirmation. However, according to the test well results on the western side of El-Arish, this formation extends beyond El-Arish town.

A schematic crosssection of the Quaternary in NS direction is shown in Fig. 7-1.

The gravel is assumed to be old wadi deposits, incising the sandy formations; distribution is assumed to be limited. In general, the water levels of the wells having gravel beds in their profiles stay below the gravel bed. Therefore, it is thought that the gravel beds in this Quaternary formation are of no importance from a hydrogeological point of view.

The elevation of the gravel bed in the Wadi El-Arish deposits is low so that the lower half of the gravel is within the piezometric potential surface of the underlying kurkar aquifer. For this reason there are some wells having screens installed at the gravel bed.

Where kurkar is overlain by thick clay, a confined aquifer occurs in kurkar as shown in Fig. 7-5. However, where the extension of the clay bed is limited, the hydraulic continuity is maintained between the aquifers of the kurkar and the overlying Quaternary and the water level is determined by the piezometric potential of kurkar aquifer as shown in Fig. 7-4 and 11. In general, the piezometric potential level is assumed to be determined by the hydraulic head of kurkar aquifer where the aquifer is not isolated from the kurkar.

While the permeability coefficient of kurkar is estimated to be in a range from 10^{-2} cm/sec to 10^{-1} cm/sec, the transmissivity of kurkar is in a wide range from 100 m^2/day to 2,000 m^3/day (Chapter 5, Technical Report I).

The aquifer in the coastal sand dune is thought to be the one isolated from kurkar by clay (Fig. 7-4).

Total extraction of the groundwater from the well field of El-Arish and the coastal plain from Sheikh Zuwayid is estimated to be 51,000 m^3/day and 39,000 m^3/day, respectively (Chapter 8 Technical Report I). Due to the heavy pumpage in these well fields there is an assumed decrease in the water levels. The recession of the water level at some part of the well field in the western side of El-Arish exceeds 4 m since 1962 (Fig. 7-7).

According to the ^{14}C dating, the age of the groundwater at well No. 1-123 and 1-119 are estimated to be 8,620 ±420 and 6,770 ±290Y.BP, respectively. These wells are located on the eastern end of the alluvial plain. While the age of the groundwater at wells No. 1-75 and 1-64, located on the eastern bank of the Wadi El-Arish are estimated to be 1,730 ±140 and 4,390 ±240Y.BP, respectively. These are thought to be very old; as old as the groundwater in the Quaternary aquifers.

Assumptions were made that the recession of the groundwater level was caused by over extraction of the groundwater compared with the inflow of the groundwater into the aquifer where the over extraction was taking place.

The estimated recharge exceeds 800 mm/year at grids No. 8-2 and 9-3, although the estimated annual recharge at grids 7-7, 9-2 and 10-4 is less than 200 mm/year. In the remaining grids, it is in a range between 200 mm/year and 80 mm/year. Considering the magnitude of this recharge, it should be ascribed to the inflow of groundwater from other aquifers into these Quaternary aquifers (Fig. 8-1).

The most broadly extending Quaternary aquifer is developed in kurkar. The TDS of the groundwater in the kurkar aquifer is in a range between 2,500 ppm and 3,800 ppm in the well field at the Wadi El-Arish alluvial plain and between 3,500 ppm and 5,600 ppm at the well field in the Quaternary from Sheik Zuwayid to Rafah.

The difference in these two ranges of TDS may be caused by the influence of flash floods which are assumed to occur once in 10 to 15 years. Although its occurrence is very rare, the highly saline groundwater of the aquifer in the Quaternary deposits may be diluted to a certain extent.

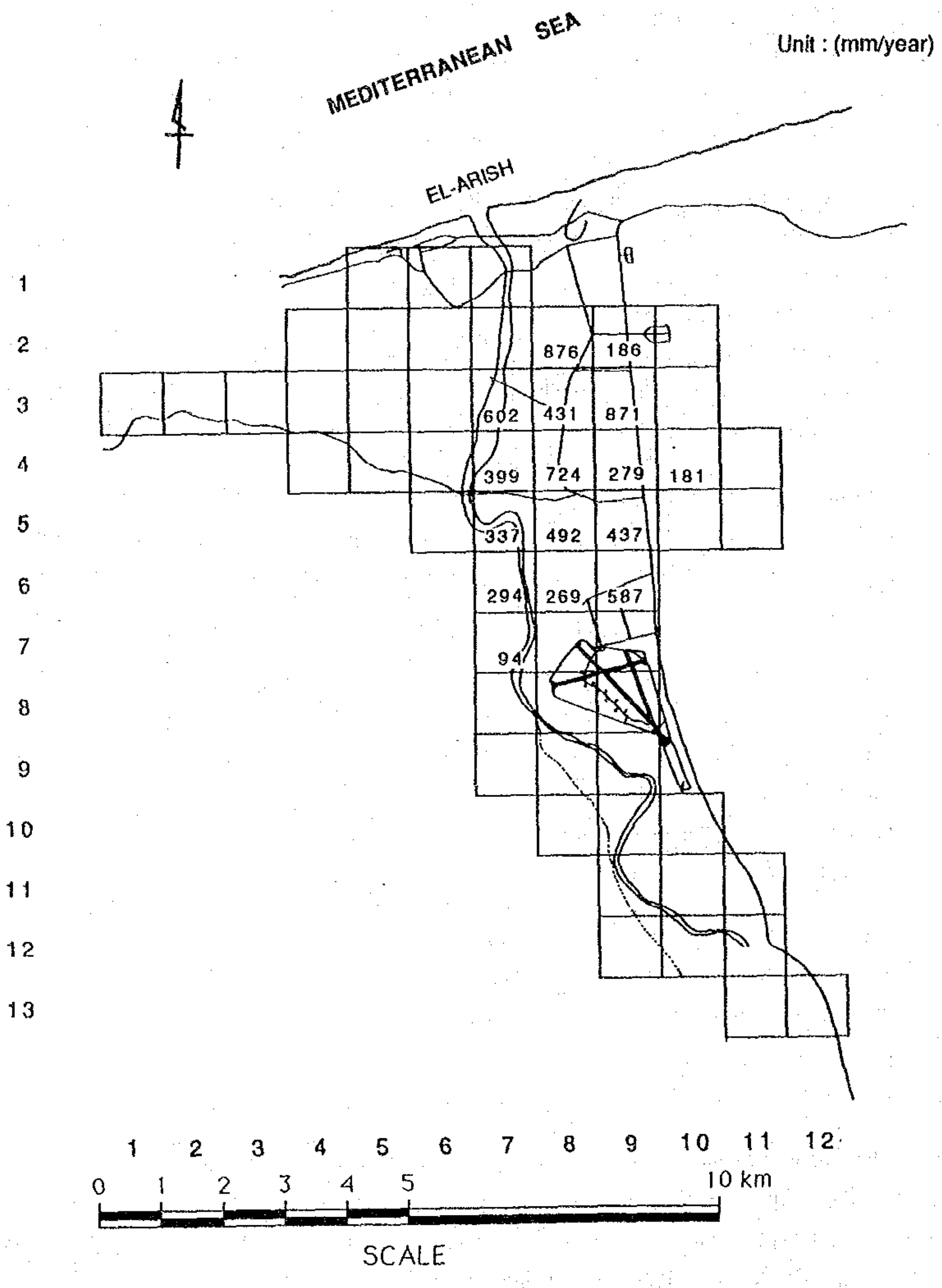

FIG.8-1 ESTIMATED RECHARGE AT EL - ALISH AREA

On the other hand, kurkar in the coastal plain, where these test wells with high salinity were drilled, is overlain broadly by clay, so that the TDS of the groundwater in this aquifer may maintain its original TDS level.

However, the extent to which the groundwater in the aquifer of kurkar in the alluvial plain of the Wadi El-Arish could be diluted, is thought to be limited as shown in the age of the groundwater. This means that the fresh water recharge under the current hydrometorological conditions to the aquifers in the coastal plain is limited only to a certain extent. Accordingly, when over extraction of groundwater takes place, the groundwater with the original low TDS stored in fresh water lenses in the aquifer in the Quaternary deposits, other than kurkar, may be easily exhausted and replenished by the groundwater which had been stored in the kurkar aquifer.

Therefore, to prevent an increase in TDS of the groundwater, the allowable extraction must be within the amount of the recharge of the current climate. However, it would be limited to a very small amount considering the amount of the rainfall. For this reason it is not able to prevent the increase in the TDS to the level of the original TDS of kurkar.

Over extraction may easily cause the recession of the groundwater level. Although there is no proof of the seawater intrusion to these Quaternary aquifers at present, it may occur immediately when the recession of the water level exceeds to a certain level. To prevent further deterioration of the salinity of the Quaternary aquifers to be caused by seawater intrusion, the safe yield for preventing seawater intrusion must be determined.

The safe yield to prevent water level recession could be estimated by referring to the estimated recharge inflow rate (Section 7-2, Main Report).

Comparing the pumpage rate and the recession of the water level, an annual recharge rate is estimated as shown in Fig. 8-1 (Section 8-4, Technical Report I). In the same manner, the safe yield for preventing the groundwater level recession is estimated in the grids where necessary data is available:

Safe Yield for Preventing Water Level Recession

Grid number	Safe yield (m^3/day)	Present extraction (m^3/day)
7-3	1,650	1,870
7-4	1,090	1,330
7-5	920	1,070
7-6	810	1,000
7-7	30	460
8-2	2,400	2,580
8-3	1,180	1,250
8-4	1,980	3,210
8-5	1,350	1,520
9-2	740	800
9-3	510	510
9-4	2,390	2,490
9-5	760	890
9-6	1,610	1,619
10-4	500	570

Major groundwater sources in the Quaternary in the coastal plain from El-Arish to Rafah is aquifers in kurkar. Assuming the distribution of kurkar and an average thickness, the total volume of kurkar is estimated to be 3,000 million m^3. Taking an effective porosity of 0.25, the amount of total storage in kurkar aquifer is approximately of 750 million m^3.

Total extraction of groundwater in these well fields during the 1980s: El-Arish and the coastal plain, is estimated to be 90,000 m^3/day (Chapter 8, Technical report I). When this amount of extraction continued for 8 years, the total extraction would be 262.8 million m^3 which is an enormous amount, considering the total volume of the storage in kurkar aquifer (750 million m^3). This may suggest that there would be groundwater inflow into the Quaternary aquifer from some other older formations since limestone and sandstone of the Pre-Quaternary are in contact with kurkar (Section 7-2, Technical Report I).

8-2 Tertiary Aquifer

8-2-1 Aquifer in Miocene

The formation assigned to this age is distributed in the coastal foreshore area. The lithology is represented by shale and clay with interbedded sandstone and limestone. In these, sandstone and limestone aquifers are contained in the coastal foreshore area. The aquifer, developed in the sandstone, is represented by well J No. 9 El-Massora and the one in the limestone by well Misri-1. There are only two wells of this type of aquifer at present (Section 7-3-2, Main Report).

It is important to collect further information about this aquifer, since this formation is overlain by the Quaternary and the TDS of the groundwater in the aquifer is in a high range. There is an indication which may suggest up-coning of the groundwater of the aquifer in the Miocene into the aquifer in the Quaternary (Section 7-2, Main Report).

8-2-2 Aquifer of Eocene

The Eocene is represented by limestone and chalk distributed in the area south of the line combining Risan Aneiza and Gebel Maghara.

These formations are distributed independently in each area and aquifers develop in the limestone (Section 7-3-2, Main Report).

Hydrogeological data of this type of aquifer are still scarce, however, the depth to the water level and the aquifer is rather shallow in the existing wells, and the groundwater is outcropping at Ain Gudeirat of which yield is estimated at 1,500 m^3/day and TDS is 1,440 ppm.

Two wells are dug in the area 10 km south of Ain Gudeirat. These wells are extracting water at the boundary between the Esna Formation and the overlaying Eocene limestone.

Priority for the future study on this aquifer should be given to the area on the northern side of the line combining Nakhl and Themed, since the geological setup is similar to that in Ain Gudeirat.

8-3 Upper Cretaceous Aquifer

8-3-1 Aquifer in Senonian

The Senonian is distributed over a broad area in the study area. However, it is absent due to heavy erosion around Gebel Maghara and Yelleq and the upper part is eroded in some areas.

The aquifers develop in the limstone of both of the upper and the lower Senonian. These limestones are partly porous, although it is lithologically compact. So the groundwater is mainly stored in the joints or fissures (Section 7-4-2, Main Report).

According to the available data there is a possibility of developing this type of aquifer along the Wadi El-Arish where the TDS of the groundwater is assumed to be low. Otherwise TDS would be too high.

8-3-2 Aquifer of Turonian

The Turonian is represented by the foraminifera rich limestone with shale at the base.

The salinity of the groundwater is high in the aquifer of the Turonian in the North Sinai. The aquifer of the Turonian in the southern part of Ragabet El-Naam Fault is assumed to be productive with a low TDS value. However further data collection will be required since the physical parameters of the aquifer are favourable and the TDS value of the groundwater at the well Sheira-2 is the lowest among all groundwaters from aquifers of the Pre-Quaternary in the study area.

8-3-3 Aquifer in Cenomanian

This formation is distributed over the study area. Lithology of the base of the Cenomanian overlying the Lower Cretaceous is calcreous sandstone. In the upper part of the Cenomanian, lithology is represented by limestone, dolmite and dolomitic limestone.

The aquifer develops in the limestone. There are five wells sunk into the aquifer of the Cenomanian limestone (Section 7-4-5). The depth to the aquifer is in a range between 138 m and 818 m, and the top of the aquifer is shallow in the area near the dome. The depth to the water level is in a range between 35 m and 219 m, and the water level is shallow in the area around El-Amro.

The TDS is distributed in a range between 2,740 ppm and 5,600 ppm, and a relatively low TDS value was observed in the area of Hasana and Gifgafa.

Transmissivity of this type of aquifer is in a wide range between 75 m^2/day and 4,500 m^2/day. A large value of the transmissivity was observed at Hasana and El-Bruk. The lowest value was at Gifgafa. The largest transmissivity was observed at Hasana. It seems that the aquifer in the Cenomanian produces the groundwater with relatively low TDS. Further test will be necessary to confirm the property of the aquifer in the area of Hasana.

8-4 Lower Cretaceous Aquifer

This formation is distributed through out most of the study area. However, the facies changes to limestone in the northern part (Fig 7-18). This formation consists of porous quartzose sandstone with occasional shale. The content of shale is higher in the north and almost absent in the south.

The thickness of the formation varies from place to place; however, in general, it is in a range between 200 m and 300 m. It is very thick at Halal where it reaches 600 m. Excluding the thickness of the interbedded shale, the thickness of the aquifer of the Lower Cretaceous is estimated to be 200 m.

TDS of the groundwater of this aquifer is in a range between 1,200 ppm and 3,000 ppm. The high TDS value was observed at the limestone facies: Umm

Shihan, and in the area near the dome structure where geological structure is significantly disturbed. It is assumed that the movement of the groundwater is restricted where geological structure is significantly disturbed. At Talet El-Badan, an extremely high TDS (5,360 ppm) was observed. It is assumed that the aquifer of the Lower Cretaceous is influenced by the highly saline water in the aquifer of the Upper Cretaceous due to reverse fault in the area. The same situation may occur in Minshera and Arif El-Naga where the reverse fault was observed.

The TDS of the groundwater in the Lower Cretaceous sandstone aquifer is in a range between 1,200 ppm and 1,500 ppm, where there is no significant disturbance of the geological structure. Such groundwater is found in the large triangle area surrounded by Hasana, Nakhl and Kuntilla.

The depth to the aquifer is in a range between 300 m and 1,000 m. It is the deepest in the central part of the study area and most shallow in the area around the dome.

The depth to the water level is in a range between 161 m and 340 m. The shallower water level was observed at the central part of the study area and the deeper water level was observed at Quseima, Kuntilla and Sadr El-Heitan. The water level was also deep at Sheira on the southern side of the Ragabet El-Naam Fault.

Transmissivity of the sandstone of the Lower Cretaceous is in a range between 12 m^2/day and 400 m^2/day. The smaller value of the transmissivity was observed in the area near domes where there is significant structural disturbance. The higher value of transmissivity was observed in the area where no significant structural disturbance was observed. Such an area occupies a broad area in the central part of North Sinai (Chapter 5, Technical Report I).

The Specific capacity at Sheira: Sheira-1, is 118 m^3/day/m and the draw-down is only 4.5 m.

The thickness of the aquifer is an important parameter for the evaluation of the aquifer. The aquifer of the sandstone of the Lower Cretaceous has high transmissivity in the broad area where there is no significant disturbance of the geological structure. In this respect the thickness of the aquifer is of no significant importance since the transmissivity includes the concept of the thickness of the aquifer.

From the viewpoint of water usage, important parameters for evaluating the aquifer of the sandstone in the Lower Cretaceous are the TDS and the depth to the water. The TDS determines the restriction of the water use and the depth to the water determines operation cost of the water source (Chapter 8, Main Report).

For this reason, TDS and the depth to the water are taken as parameters for evaluating the groundwater of the Lower Cretaceous aquifer (Table 8-1 Evaluation of Aquifer in Lower Cretaceous).

Table 8-1 Evaluation of Aquifer in Lower Cretaceous

TDS (ppm) \ Depth to Water (m)		1	2	3	4
		Less than 100	100 ~ 200	200 ~ 300	More than 400
A	Less than 1,500	A1	A2	A3	A4
B	1,500 ~ 2,000	B1	B2	B3	B4
C	2,000 ~ 2,500	C1	C2	C3	C4
D	More than 2,500	D1	D2	D3	D4

The area indicated as A1 shows that there is a high possibility of obtaining the groundwater of TDS less than 1,500 ppm within 100 m from the ground surface. However, exact conditions are subject to further confirmation. The areas indicated by B1, B2, B3, C4 and D3 are also in the same situation since these are narrow areas circumscribed by two contour lines.

It is found that a broad area surrounded by Hasana, Sudr El-Heitan, Nakhl and Arif El-Naga is classified as A2. A2 is categorized as the area where the groundwater of the sandstone aquifer of the Lower Cretaceous is obtainable between 100 m and 200 m from the ground surface, with TDS less than 1,500 ppm, except the area around domes where there is significant disturbance of the structure. The first priority for groundwater development shall be given to this area; its boundary shall be determined by additional data to be obtained through actual development.

Area A3 is arc A2's surrounding area. TDS of the groundwater is expected to be the same magnitude as A1. However, the depth to the water is expected to be deeper, in a range between 200 m and 300 m. The area under this category is found around Sudr El-Heitan, Nakhl and Quseima.

In area A4, the depth to water is more than 300 m although the TDS of the water is expected to be less than 1,500 ppm.

The rest of the area may produce the water with high TDS. It is assumed that the high TDS is caused by structural disturbance which restricts water movement. This is also subject to further confirmation by sufficient information.

8-5 Jurassic Aquifer

The Jurassic formations found in North Siani are the Upper and Middle to Lower formations. The Middle to Lower Jurassic formation is represented by sandstone and shale interbedded by thin coal beds. Rocksalt is found in the coal mine in Maghara. The Upper Jurassic formation is represented by limestone. These formations are found in the dome structures in the study area. The wells sunk into the aquifer in these formations are found only in Gebel Maghara area.

The TDS of the groundwater in this type of aquifer is at a high level, ranging between 4,140 ppm and 7,455 ppm. This is assumed to be one of the characteristics of this groundwater, since rocksalt is occasionally interbedded in this formation.

9. PROPOSED GROUNDWATER DEVELOPMENT

9-1 Introduction

Through the study, many about the hydrogeology in the study area, were found. There are some items, however, that are subject to further confirmation. In the following part of this chapter general technical considerations to that will be useful in the future investigation of the hydrogeology are described. Additionally, required study items are summarized followed by the recommended groundwater development.

9-2 Priority and Proposed Groundwater Development Sites

9-2-1 Quaternary Aquifer

The Quaternary aquifer has been intensively utilized especially in the well field at El-Arish and in the coastal plain from Sheikh-Zuwayid and Rafah. In these areas the Quaternary aquifers are subjected to strict control to prevent further recession of the water level rather than further development. It is of utmost importance to determine the safe yield in each locality of the aquifer to control the extraction amount of groundwater to prevent seawater intrusion.

For this purpose, an establishment of a monitoring network for the Quaternary aquifer is urgently required, utilizing the existing test wells as a part of the monitoring network.

However, since a thick Quaternary formation was identified in a vast area extending in the coastal plain from El-Arish and Sheikh Zuwayid, confirmation of the extension of the aquifer and its hydrogeological properties shall be studied immediately.

In addition, determination of the hydrogeological mechanism and properties of aquifer in the coastal sand dunes is urgent. The same type of aquifer will be available even in the coastal sand dune on the western side of El-Arish.