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STUDY

THE ARAB REPUBLIC OF EGYPT

NORTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT

FINAL REPORT

MAIN REPORT

October 1992

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

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

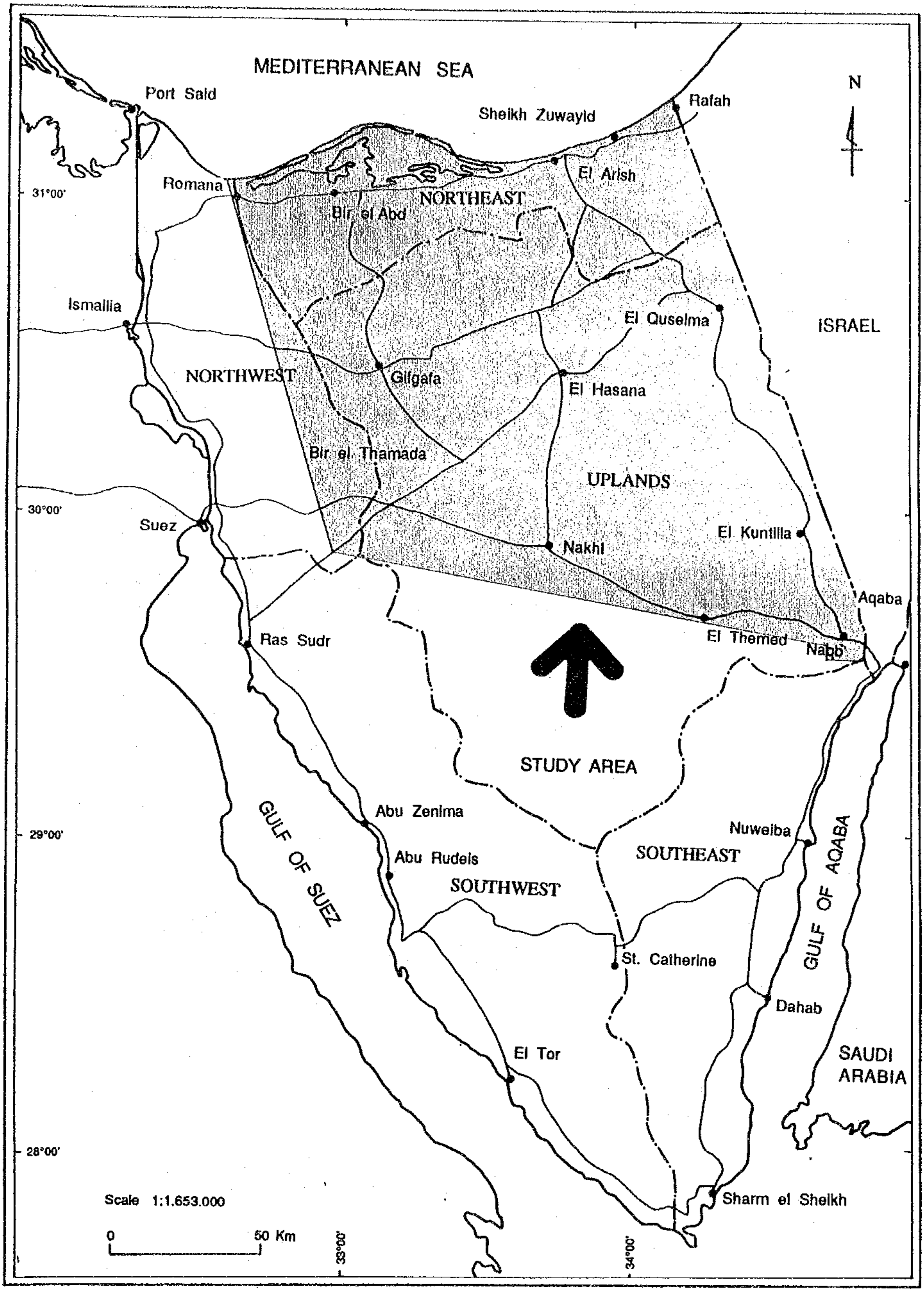
Kensuke Yanagiya
President
Japan International Cooperation Agency

ACKNOWLEDGEMENT

We, members of the JICA Study Team for the North Sinai Groundwater Resources Study, all wish to express our deep sense of gratitude to all the concerned officials of the Government of the Arab Republic of Egypt, the Research Center of Water Resources, the Research Institute for Groundwater Resources, Department of Irrigation and the North Sinai Governorate, for their kind advice and warm-hearted cooperation and hospitality extended to the Study Team. Without their assistance and contribution, the study would never have been accomplished. In particular, we wish to thank his excellency, the Governor of the North Sinai Governorate, General Shash.

Special acknowledgement is also due to those in the Research Institute for Water Resources for the overall arrangement and the close cooperation given to the Team: Dr. Hassan Ibrahim, Director; Mr. A. Awwad Melegy, Project Manager; Mr. Tag El-Din El-Deftar and Dr. Zaghloul, Geologists; Mr. Saleh Nour, Mr. Hassan Bayumi, Branch Office Representative at El-Arish, and the officers at the head office in Cairo and the branch office in El-Arish.

We are also most grateful to Dr. M. El Ghawaby, Professor of the Suez Canal University, who kindly undertook the analyses of rock and water samples.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STUDY AREA

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ABBREVIATION

asl	above the sea level
bgl	below the sea level
EC	EUROPEAN COMMUNITY
Ec	Electric Conductivity
EGSMA	EGYPTIAN GEOLOGICAL SURVEY AND MINING AUTHORITY
equ.	equilibrium
Gak	Gakushuin University, Tokyo, Japan
GMRDP	GEBEL MAGHARA RURAL DEVELOPMENT PLAN
GMS	GROUNDWATER MANAGEMENT STUDY
GRIPS	GROUNDWATER INFORMATION PROCESSING SYSTEM
JICA	JAPAN INTERNATIONAL COOPERATION AGENCY
RIWR	RESEARCH INSTITUTE FOR WATER RESOURCES
SDS	SINAI DEVELOPMENT STUDY
T.U	Toritium Unit
TDS	TOTAL DESSOLVED SOLID
USAID	UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT
WHO	WORLD HEALTH ORGANIZATION
Y.BP	Years Before Present

1 INTRODUCTION

1-1 General

In response to the Government of the Arab Republic of Egypt's request, 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 15th, 1988.

The Japan International Cooperation Agency (JICA), the official agency responsible for the implementation of the 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) was the counterpart agency to the Japanese study mission and also acted as the coordinating body in relation with other relevant organizations 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 and to engage in discussions on the Scope of Work for the study. The attached Scope of Work was agreed upon between the Government of Egypt and the JICA mission on September 1st, 1988.

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

This report consists of the following:

Main Report

Hydrogeological Map

Portfolio of Hydrogeological Map

Technical Report I	Well Survey
Technical Report II	Fossil Analysis
Technical Report III	Grain Size Analysis of Lower Cretaceous Sandstone
Technical Report IV	Composite Column
Technical Report V	Landform Classification

1-2 Background

Egypt is composed mostly of desert. Only 3% of its land is cultivated, coinciding mainly with 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 a high potential for mineral, tourism and agricultural development. For this purpose, various kinds of international cooperation have been inaugurated.

The Sinai Peninsula (area: 61,000 km^2, population: 200,000 in 1988) totally consists of desert land. Except for the northeastern part, the annual rainfall here is estimated at 60~100 mm, which is an extremely low amount.

The development of surface water has been carried out in some districts by the construction of dams. However, the situation is clearly confronting difficulties. In such districts as El-Arish in the northeast and El-Tur in the southwest, groundwater from the 50-100 m levels from the ground surface are being used as drinking water and irrigation water. However, it is alleged that excessive pumping in the recent years has deteriorated the water quality in the aquifers in the alluvium of coastal areas.

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 groundwater. Many researches have already been launched by various international organizations. Among them, the Sinai Development Study (SDS Phase 1), undertaken by USAID, has been executed over a wide area to establish regional development of the Peninsula, including the water resources development since 1980.

Additionally, RIWR has been conducting a water resource study with technical cooperation from the European Community (EC). RIWR also conducted the Groundwater Management Study of El-Arish - Rafah area (GMS) in the northeastern corner of the Peninsula, and compiled all existing hydrogeological data. This has become a valuable data source for the further analysis of the groundwater of the Quaternary aquifers in the area.

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

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.

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

1-4 Objectives

The 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.

2 GENERAL DESCRIPTION OF STUDY AREA

2-1 Geography

The Sinai Peninsula lies between the two arms of the Red sea and the Aqaba. The western side of the Red Sea represents part of the highlands which form the African base known for its extremely old age. It ends eastwardly and westward with two ditch-like regions, namely the Aqaba Gulf and the Gulf. This rocky plateau that slopes down towards the Mediterranean Sea in the northern section represents the sedimentary formation.

Sinai takes on the form of a rectangle with its base extending along the shore of the Mediterranean Sea starting from Port Fouad in the west to Rafah in the east for a distance of 200 km. The apex of the rectangle lies in the extreme south at Ras Mohamed which is 390 km from the coast of the Mediterranean Sea. The western edge extends for about 510 km whereas the eastern edge does not extend more than 240 km. The imaginary line for the political border between Sinai and Palestine, from Rafah in the north to Taba on the Aqaba Gulf, extends for 215 km. Sinai's total area is 61,000 km^2. This is three times larger than the Nile Delta. The study area is the northern half of the peninsula covering 26,000 km^2 of the total 27,574 km^2 area of the North Sinai Governorate.

2-2 Climate

The air temperature in the northern coast of Sinai is generally higher than that in the inland area of the Peninsula. The mean temperature decreases during winter reaching its minimum value in January and increasing to its maximum in August during the summer.

The study area is characterized by cold winters. The average temperature is about 13 degrees centigrade at El-Arish, with a mean minimum value of 7 degrees centigrade in the early morning and rising normally to 11 degrees centigrade by noon with a mean maximum of about 18 degrees centigrade.

In summer, the temperature increases to 26 degrees centigrade as the mean value at El-Arish. The mean maximum temperature varies between 29.9 and 31.1 degrees centigrade. During summer nights, the air temperature drops to its mean minimum temperature of 22 degrees centigrade, while the average maximum temperature exceeds 30 degrees centigrade.

Spring is characterized by moderate temperatures of about 20 degrees centigrade with hot Khamsin periods when the air temperature sometimes rises above 40 degrees centigrade. The mean minimum temperature during this season is about 13 degrees centigrade while the mean maximum temperature is 26 degrees centigrade.

Autumn is characterized by moderate temperatures similar to Spring but slightly lower than in the summer. Temperatures during September normally range between 15 degrees centigrade at midnight and 28 degrees centigrade at midday.

Rainfall has been a serious problem in the study area. The highest annual rainfall of 300 mm is observed in the Rafah area, the northeastern corner of the study area. However, this amount of rain is observed only in a limited area. More than 80% of the study area receives an annual rainfall of less than 60 mm. Most of the study area is under an arid condition.(Fig 2-2-2) Furthermore, the problem of the arid area is that the rainfall is capricious, as shown in Fig 2-2-3. For this reason, the area is always subject to either heavy drought or flooding. In general, the climate is extremely dry and the extent of groundwater recharge is limited.

2-3 Socioeconomic Condition

The total area of North Sinai Governorate is 27,574 km^2 and occupies 2.8 % of Egypt. It consists of the following six administrative Markazs:

Local unit for Markaz and city of El-Arish,

Local unit for Markaz and city of Rafah,

Local unit for Markaz and city of Sheikh Zuwaiyd,

Local unit for Markaz and city of Bir El-Abd, Local unit for Markaz and city of Hasana, and

Local unit for Markaz and city of Nakhl.

In the northern area, agriculture is the main economic activity. In the southern part of the study area, light pasturing is the Beduins' main life support.

Agriculture in Sinai belongs to a scattered poor type. Palm trees, fruit and palma christi are mostly concentrated in the northern part of the study area, especially in the coastal plain from El-Arish to Rafah. Field crops, such as barley, water melon and corn are cultivated in the inland area. However, these crops depend on the capricious rainfall. People of Sinai breed sheep, goats and camels. Most of the animal husbandry is also concentrated in the northern area.

2-4 Existing Development Project.

Since the return of the Peninsula to Egypt,much attention has been drawn to the area. The Jebel Maghara Rural Development Project has commenced and is in its second phase. A pilot farm was constructed and is operating. Additionally, a comprehensive development plan for the eastern border region of Egypt is being undertaken by the Ministry of Development. The first draft of the interim report was released in 1991; the final report is expected to be completed soon.

The availability of a water source is one of the key factors for the future development of the area.

3 PREVIOUS WORK

In the study area, various kinds of studies have been made on hydrogeology since the 1950s although the general geological studies go further back in history.

B. Hellstorm (1953) briefly reported the shallow groundwater in the sand aquifers in the area. L. Farag and A. Shata (1954) recorded a detailed geologic section of the Lower Cretaceous and the Upper Cretaceous over 800 m thick stratum at Minshera. Discussions were made in detail based on the results of fossil analysis. This is one of the most precious data of the geological column in the study area.

A. Shata (1956) described the structural development of the geology in the Sinai Peninsula which is also valuable information of the study since many previous studies were compiled in this paper.

The Well Evaluation Conference (Schlumberger, 1984) summarized many drilling data obtained from oil exploratory wells which is very valuable for interpretation of the lithology and stratigraphy of the deep strata.

The Geology of Egypt (edited by Said, 1962) was revised in 1982 by the same author. The new edition includes much of data obtained by the oil exploratory wells which are useful for interpretation of deep strata.

D.M. Al-Far (1966) made discussions on the Pre-Cretaceous rocks of El-Maghara area which is one of very rare data of the Pre-Cretaceous in the study area.

Joel R. Gat and Arie Issar (1974) made isotope analysis of the groundwater in the Sinai Desert which is the precious data together with the dating undertaken by the study team to interpret the age of the groundwater in the study area.

Collected Reprints, vol.I to III (Geological Survey Israel, 1980) contains 73 papers in various aspects of geology, geochemistry and hydrogeology in the Sinai Peninsula. Of these papers, discussions were made on the Lower Cretaceous sandstone (T. Weissbrod, 1970) and on the Upper Cretaceous (Y. Bartov and G. Steinitz, 1977). Also, history of the Coniacian of the upper part of the Upper Jurassic was described (Z. Lewy, 1975). The age of the fossil water in the Lower Cretaceous is discussed (A. Issar, A. Bein and A. Michael, 1972).

Well Evaluation Conference (Schlumberger, 1984) summarized many drilling data obtained from the oil exploratory wells which are also important data for interpretation of the deep strata since oil exploratory data are rarely published.

Outlines of the Geology of the Northern Negev (Geological Survey of Israel, 1984) includes general geology in the area as well as description of the Quaternary which are useful information of the study.

E. S. Zaghloul (1986) described the geological section of the Wadi El-Rakeib formation and the Lagama formation of the Lower Cretaceous at Gebel Manzour in the Gebel Maghara.

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

The study is compiled mostly of existing peninsula hydrogeological data. The information cards produced with the report were a useful data source.

The report also included an analysis of the water balance. However, it acknowledged that the conclusion could not be emphasized too strongly due to the following facts: most of the estimates of the available groundwater were extremely crude approximations and were computed for the purposes of the very preliminary peninsula-wide planning and derived through the interpretation and analysis of the existing data (p-2-69, Volume V, SDS). However, nobody would dispute that this was a milestone in the study of the water resources in the Peninsula. Many valuable data were cited in the North Sinai Groundwater Resources Study.

In 1988, the final report of the Groundwater Management Study, Phase 1, was completed by RIWR. The objectives of the study were to evaluate available groundwater resources in the area from El-Arish to Rafah and establish a monitoring system for precious groundwater resources.

The Phase 1 study carried out the compilation of existing hydrometeorological and hydrogeological informations for further analysis, and further necessary activities for the attainment of the final target in the Phase 3 were identified.

In the Final Report of the Phase 1 Study, most of the existing work previously done in the area were reviewed and discussed. It could be a remarkable output as most of the existing well data, and valuable information pertaining to the Quaternary aquifers were reviewed and compiled in the appendix of the report. This has become a major data source of the Quaternary hydrogeology of the North Sinai Groundwater Resources Study.

4 CONTENT OF STUDY

4-1 Introduction

Although available data are abundant, the density of existing data is still insufficient, considering the size of the study area: 26,000 km^2. For a hydrogeological study, complete well data accompanied by lithology, stratigraphy and well-logging information, are indispensable. As a matter of fact, 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 the importance of reviewing and reanalyzing the existing well data. Also, efforts were made to construct geological columns in the study area as the references of reanalysis of existing well data. The results were compiled as the composite geological columns (Technical Report IV).

The results of the above work post postulated the necessity for sedimentological analysis of the study area.

After considering the size of the study area, the study period, resources, and target formations were determined. Referring to the high productivity and extension of the sandstone aquifer of the Lower Cretaceous in North Sinai and to the available well data in the study area, the sandstone of the Lower Cretaceous was determined as one of the target formations.

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

Of course, due consideration 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 aquifers.

4-2 Data Base

The Data Base of RIWR is the Groundwater Information Processing System (GRIPS) installed at the head office in Cairo as the central system to serve for the whole Sinai Peninsula. For data compilation and processing of this particular study, dBase III software was provided by the study team.

The existing and additionally obtained hydrogeological data are fed into the dBase III according to the grid of each data location for data compilation and for further reanalysis to evaluate the available data. Although it is not yet compatible with the central system (GRIPS), the print out is presented as a part of the second interim report of July, 1990. The updating and processing to make it compatible with the GRIPS system have been made with the cooperation of RIWR.

In addition to the above mentioned data base, all available well data are compiled on the data sheets for their evaluation and analysis. And the locations of well data are plotted on topographic maps to a scale of one to fifty thousand to visualize information which would be updated whenever additional data are available.

4-3 Landsat Image Analysis

In order to draw all the features of the study area that extends over 26,000 km^2, a satellite image analysis was made. For this purpose the following original data tapes were obtained:

Path 174/Row 39	April 7, 1987	Cloudiness: 0
Path 174/Row 40	April 7, 1987	Cloudiness: 0
Path 175/Row 38	April 14,1987	Cloudiness: 0
Path 175/Row 39	April 14,1987	Cloudiness: 0
Path 175/Row 39	April 5, 1987	Cloudiness: 0

Interpreting the general characteristics of the computer processed colour images, 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

These maps were utilized to draw up the general features of the study area.

4-4 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 at key points. The output of these field surveys is reflected in our revised geological map.

The next task was to analyze the structural geology of the study area. For this purpose, a detailed field survey was executed referring to already established geological columns and aided by aerophoto interpretation.
Some detailed geological profiles were processed for further analysis of the stratigraphy.
The total area covered by this survey is approximately 3,700 km^2 as listed below:

	Survey Site	Approximate Area	No. of Lith. Profile
1	Gebel Risan Aneiza	200 km^2	-
2	Gebel Maghara	700 km^2	3 sites
3	Gebel Halal	700 km^2	2 sites
4	Gebel Yelleq	600 km^2	1 site
5	Sadr El-Heitan	600 km^2	2 sites
6	Gebel Kherim	100 km^2	1 site
7	El-Quseima-Arif El-Naga	500 km^2	2 sites
8	Naqb	300 km^2	2 sites
	Total	3,700 km^2	12 sites

Samples were also collected for micro-fossil analysis wherever necessary. It is hardly possible to determine the stratigraphy through field observation of lithology where similar types of limestones were frequently encountered. The micro-fossil analysis was made on approximately 200 samples by EGSMA through cooperation of RIWR. (Technical Report II)

Results of these analysis were further worked into the three-dimensional distribution of 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 was 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, a grain size analysis was adopted for more than 700 samples collected from eleven sites as shown in Fig. 2-1 of Technical Report III.

4-5 Geophysical Investigation

In order to supplement the geological information, geophysical prospecting was conducted in the study. There are three major objectives for geophysical investigation: the first objective is to identify the strata which may develop an aquifer in the Quaternary; the second objective is to clarify the sandstone distribution of the Lower Cretaceous in the broad open area in the study area, especially in the southern part; the third objective is to prove the general feature of the basement surface in the southeastern part of the study area.

For the first objective, a resistivity meter (McOHM Model 2115) (in the Schlumberger method with AB/2=600 m) and an electromagnetic meter (SIROTEM Model 11 SE) (with the coincident diameters ranging from 50 to 100 meter) were used aiming at prospecting the subsurface strata up to 200-300m at 600 points.

For the second objective, a different type of resistivity meter (Chiba Denshi Model Ch 8708A) in the Schlumberger method with AB/2=800m-3,000m aiming at the subsurface strata up to 1,000m at 50 points was used.

For the third objective, the gravimeter (Model LA Coste type G) was used. In order to maintain the required accuracy, some local representative fresh rock samples were collected for the laboratory determination of the specific gravity. Precise leveling was made at each survey point. A total of 150 points were measured.

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

Prior to the resistivity analysis, available resistivity survey results published by Paver and Jordan, GEOFIZIKA, EGSMA and Gebel Maghara Rural Development Project (GMRDP), were reviewed. Also logging data of bore holes drilled by RIWR and UNICEF were all reviewed to interpret a general tendency of the resistivity value to its corresponding lithology.

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. So, it is inevitable that all available interrelated information of each specific section, as well as verification of the reference point, be integrated.

The results of resistivity survey and electromagnetic survey were interpreted into the resistivity cross section and presented in the second Interim Report in July, 1990 (GEOPHYSICAL PROSPECTING REPORT, Volume 2 of Interim Report 2). In this Final Report the resistivity profiles are further interpreted from a geological point of view to aid in the analysis of the geological cross section (Chapter 6, Main Report).

The results of gravity prospecting are also interpreted to figure out the top of the basement (Chapter 6, Main Report).

4-6 Test Well Drilling and Aquifer Test

There are many wells in the study area. A majority of these wells are production wells distributed in the area from El-Arish to Rafah along the northeastern Mediterranean coast. Since these wells were drilled for domestic and irrigation purpose, their distribution is uneven and technical data are incomplete in many cases. The remaining wells are either oil exploratory wells or test wells.

Considering the size of the study area and the uneven distribution of existing wells, a large number of new test wells are still required for the complete analysis of the entire study area (Technical Report, I).

To obtain the most efficient output aquifers of the study area, the target strata, the Quaternary and the Lower Cretaceous, were determined. Groundwater is intensively utilized from aquifers in the Quaternary. And, groundwater is confirmed at some wells drilled into the Lower Cretaceous aquifer. For this reason, 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,
2) Confirmation of unexploited gravel layers and the extension of gravel beds.

Based on the interpretation of existing data, test well locations were determined and their precise locations were confirmed by the results of resistivity soundings.

General features of the Lower Cretaceous (distribution, thickness and depth to the top) were estimated by the analysis of the geological investigation. The locations of the test wells to the Lower Cretaceous were placed on some dome structures and the terrain where the main underflow moved in the deep-seated sandstone. At the latter, two locations were sited.

The total drilling depth was approximately 4,200 m: 870 m in the Quaternary and 3,300 m in the Lower Cretaceous. Further details are shown in Section 2-1-5 and 2-2-3 (Technical Report I, Well Survey).

4-7 Hydrological Study and Water Quality Analysis

The quantity and quality of the groundwater are the primary interest of the study.

A water balance analysis is one of the useful schemes for estimating the quantity of groundwater where accurate and sufficient hydrometeorological data are available. However, each component of the balance equations include a certain degree of error which, in some cases, especially in the arid zone, exceeds the magnitude of the component of the groundwater recharge.

This method compares each balance component in a single hydrological cycle which usually takes a time span of a full season (a one year period in genial areas). But the time span of a single hydrometeorological cycle in an arid zone extends from 5 to 10 years.

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, threrfore, 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
5) Water quality analysis of selected samples

In addition, there are many shallow wells in the area extending from Bir El-Abd to Romana, but as none of the above-specified data was available a field survey was undertaken to identify their location, height and general features of water quality. The approximate number of the wells surveyed is 400.

5 GEOMORPHOLOGY

5-1 General

The Sinai Peninsula covers an area of some 61,000km^2. It is triangular in shape with its apex formed by the junction of the Gulf of Aqaba and the Gulf of Suez, and its base by the Mediterranean coastline.

The southern part of the Sinai consists of an intricate complex of very rugged mountains formed by Precambrian igneous and metamorphic rocks. Part of the peninsula comprises a massively developed limestone plateau in the south. The prevailing drainage system is formed to the north by the Wadi El Arish with its many affluents. The eastern and western edges are dissected by a deep gorge draining into the Gulf of Aqaba and Gulf of Suez respectively.

In the northern part, the regional dip slope is broken up into many large hills, followed northward by a belt of lowlands, with high sand dunes along the Mediterranean coast.

Various morphologic features are obseved in the investigated area of North Sinai. The major units of geomorphology are the central plateau, the folded mountain and the coastal plain.

A detailed explanation of each geomorphological unit is shown in Technical Report V.

5-2 Central Plateau

Most of the surface of the plateau is covered by the limestone which belongs to the Paleogene. On the other hand, relatively soft sediments, such as chalk and marl of the Upper Cretaceous, are distributed in and around the valley. They are slightly soft and tend to erode easily.

A vast alluvial flat plain is extensively developed in the middle part of the area. The surface of the plain is covered by silt.

5-3 Folded Mountain (Syrian Arc Zone)

The area is characterized by the large mountain blocks which belog to the Syrian Arc Zone.

Gebel Maghara, Halal and Yelleq are sequenced along the major axis from a NE to SW direction. They are made up of double plunging anticlinal structures where the northern face usually has a gentle slope of 10-20 degrees and the southern face is disturbed by the faults and folds.

Most of those mountains are mainly composed of limestone, marl and sandstone which range from the Jurassic to the Upper Cretaceous.

Hills are distributed around these mountainous areas. Many of the hills that consist of Tertiary and Quaternary diluvial deposits are observed in the upperstream of the Wadi El Arish drainage system.

5-4 Coastal Plain

The area is characterized by a vast plain which consists of alluvial fan deposits and sand dunes. Generally, the plain is tilted gently northwards.

A narrow sand bar is observed along the Mediterranean, surrounding lagoons. Lagoonal lowland is distributed along the Mediterranean. Coastal lowland is found along the Sabkhet el Bardawil Lagoon and in other places along the Mediterranean sea.

5-5 Wadi El-Arish

In addition to the four above-mentioned geotectonic units in the peninsula, the drainage system of the Wadi El-Arish is another characteristic unit of morphology in the area. The headwater originates from Gebel Egma in the central plateau passing across the Syrian Arc zone and the northern coastal plain to the Mediterranean. The total length of the wadi is 310 km and the catchment area is approximately 20,000 km^2 which corresponds to one third of the whole peninsula. The wadi incised a sharp Dinqua Gorge crossing Gebel Halal; its tributaries develop small-scale fans and terraces along the river courses.

6 GEOLOGY

6-1 Introduction

There are many studies and publications on the geology of the Sinai Peninsula. The geological structure, distribution of major formations and their stratigraphy and lithology may have direct implications on the hydrogeological conditions in the area.

In order to identify the geological setup, the characteristic aspects of the geology in the study area are summarized in this chapter from a hydrogeological point of view.

6-2 Stratigraphy

6-2-1 Precambrian Rocks

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

The terrain covered by Precambrian rocks forms steep mountains and has vastly different geomorphic features than those of younger rocks. These granite and rhyolite are correlated to the Pan-African rock and are uplifted by the Pan-African orogeny (El Gaby, 1983).

The northern margin of the alkali rhyolite is in contact with the sandstone of the Paleozoic and the Lower Cretaceous cut by the Ragabet El-Naam Fault in an east-west direction.

To the south of the airport, granite and gneiss crop out and form a steep cliff toward Gulf of Aqaba. The rocks are medium to coarse grained biotite granite and gneiss with gneissosity. The rocks develop at the base of the cliff and are unconformably overlain by the sandstone of the Paleozoic and the Lower Cretaceous.

6-2-2 Paleozoic

The Paleozoic rocks crop out at Umm Bogma area in South Sinai and detailed studies were made by, Hassan (1967), Weissbrod (1969) and Said (1980).

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. The columnar section is shown in Fig. 6-2-1.

Sandstone, which consists mainly of pure quarts grain, distributes in the area south from Naqb. Although there is no paleontological evidence for the identification of the geologic age of this sandstone, it is provisionally classified as the sandstone of the Lower Cretaceous (Section 6-2-3-3).

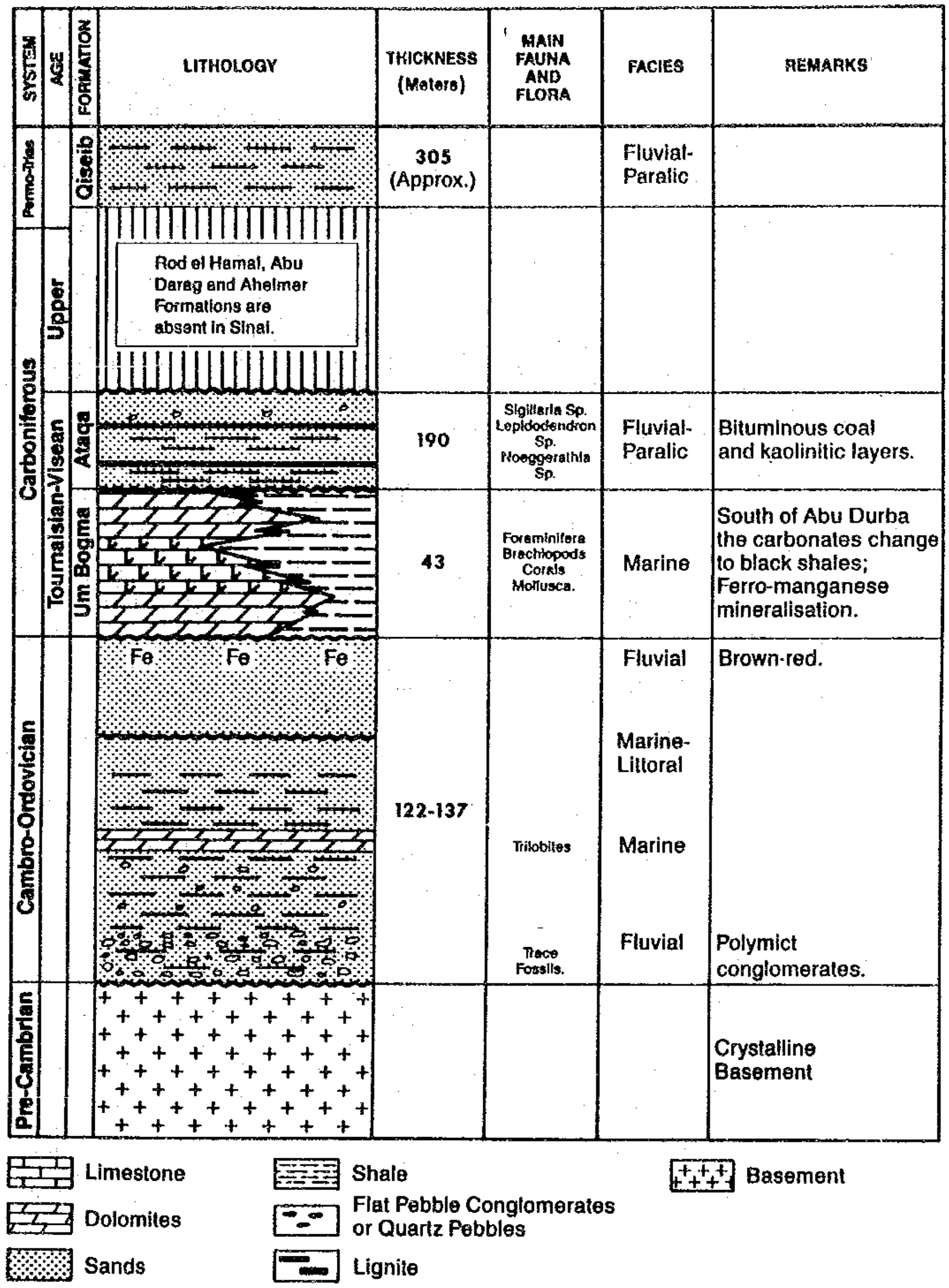


FIG. 6-2-1 LITHOSTRATIGRAPHIC SECTION OF THE PALEOZOIC IN CENTRAL SINAI (D.A.JENKINS,1989)

6-2-3 Mesozoic

6-2-3-1 Triassic

Awad (1946) and Karcz and Zak (1968) pointed out that the Triassic outcrop was found only at the core of the dome structure at Gebel Arif El-Naga. The Triassic sequence of Gebel Arif El-Naga is shown in Fig. 6-2-2.

Druckman (1974) classified the Triassic system into five formations and concluded that these are the marine equivalents of the continental Qiseib Formation;

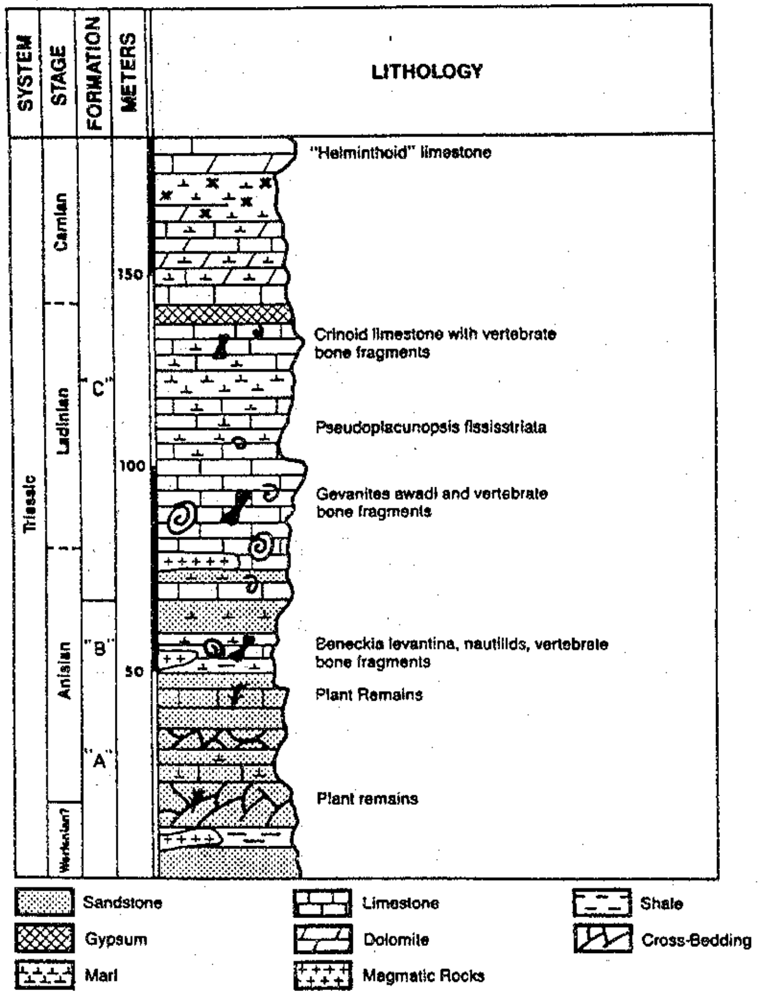
1) The Lowermost Formation
It generally consists of brown to dark grey shale, limestone and sandstone occasionally interbedded with dolomite. This formation is identified at the oil exploratory well, Halal-1, and is observed to be 200 m thick.

2) The Overlying Formation
This formation consists of 50 m thick limestone and overlies the lower most formation at the Halal-1.

3) Gevanim Formation
This formation crops out at Gebel Arif El-Naga. The lower 50 m thick unit of this section consists of multi-coloured, coarse-grained and well cemented sandstone.
Overlying this unit is a 19 m thick unit of argillaceous 'B' beds (Said, 1971)

This formation is observed at Halal-1, Abu Hamth and Arif El-Naga the oil exploratory wells.

4) Sharonim Formation
Sharonim formation represents marine deposits and consists of limestone, dolomite, dolomitic shale and conglomerates.



AFTER KARCZ & ZAK WITH MODIFICATIONS

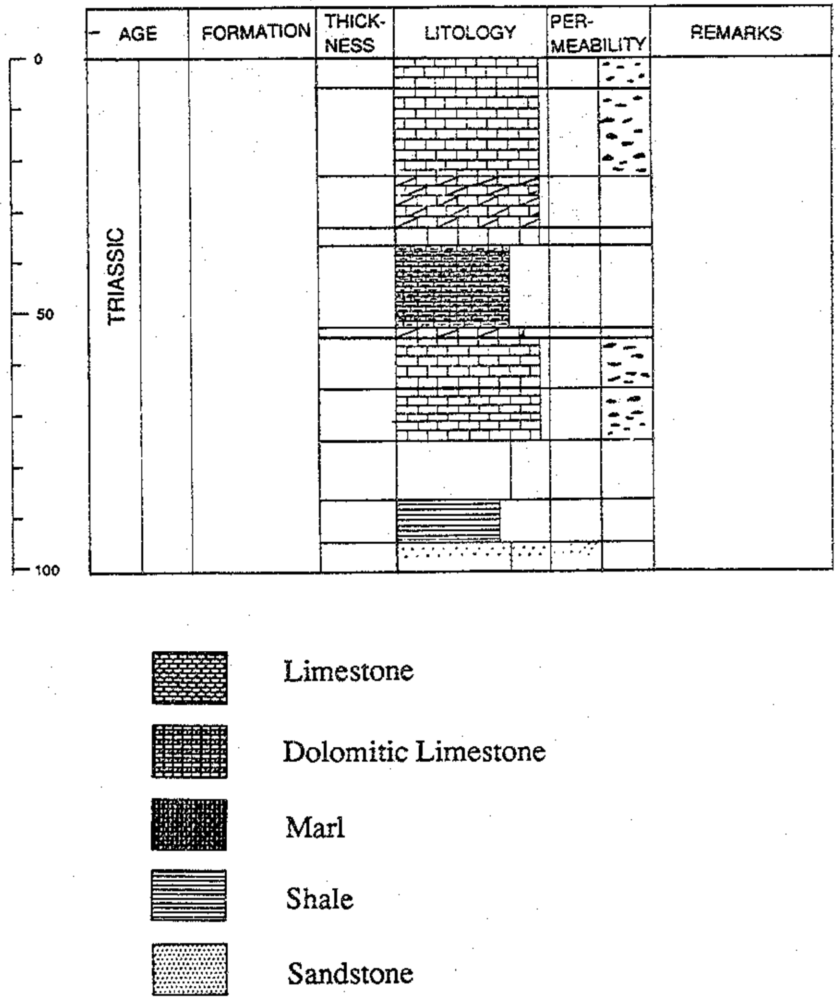


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FIG. 6-2-2 THE TRIASSIC SEQUENCE OF GEBEL ARIF EL NAGA

The formation corresponds to Arif El-Naga 'C' beds and is 116 m thick at Gebel Arif El-Naga, whilst at Halal-1 it is 275 m thick.

5) Mohilla Formation
This formation is identified at Halal-1. The 50 m thick formation consists of dolomite, dolomitic shale, limestone and anhydrite.

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 Tethys Sea.

6-2-3-2 Jurassic

1) General

The Jurassic formation outcrops at the dome structures in the study area;

1) Gebel Maghara
2) Gebel Minshera
3) Gebel Arif El-Naga
4) Gebel El-Giddi

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. The northern flank of the dome is relatively gentle. However, that on the southern flank forms vertical or overtured structure cut by the reverse fault or the thrust fault. Many studies were made on the Jurassic of the Gebel Maghara (Al Far, 1966) and the Jurassic formation was classified into six groups. (Fig. 6-2-3 and Table 6-2-1)

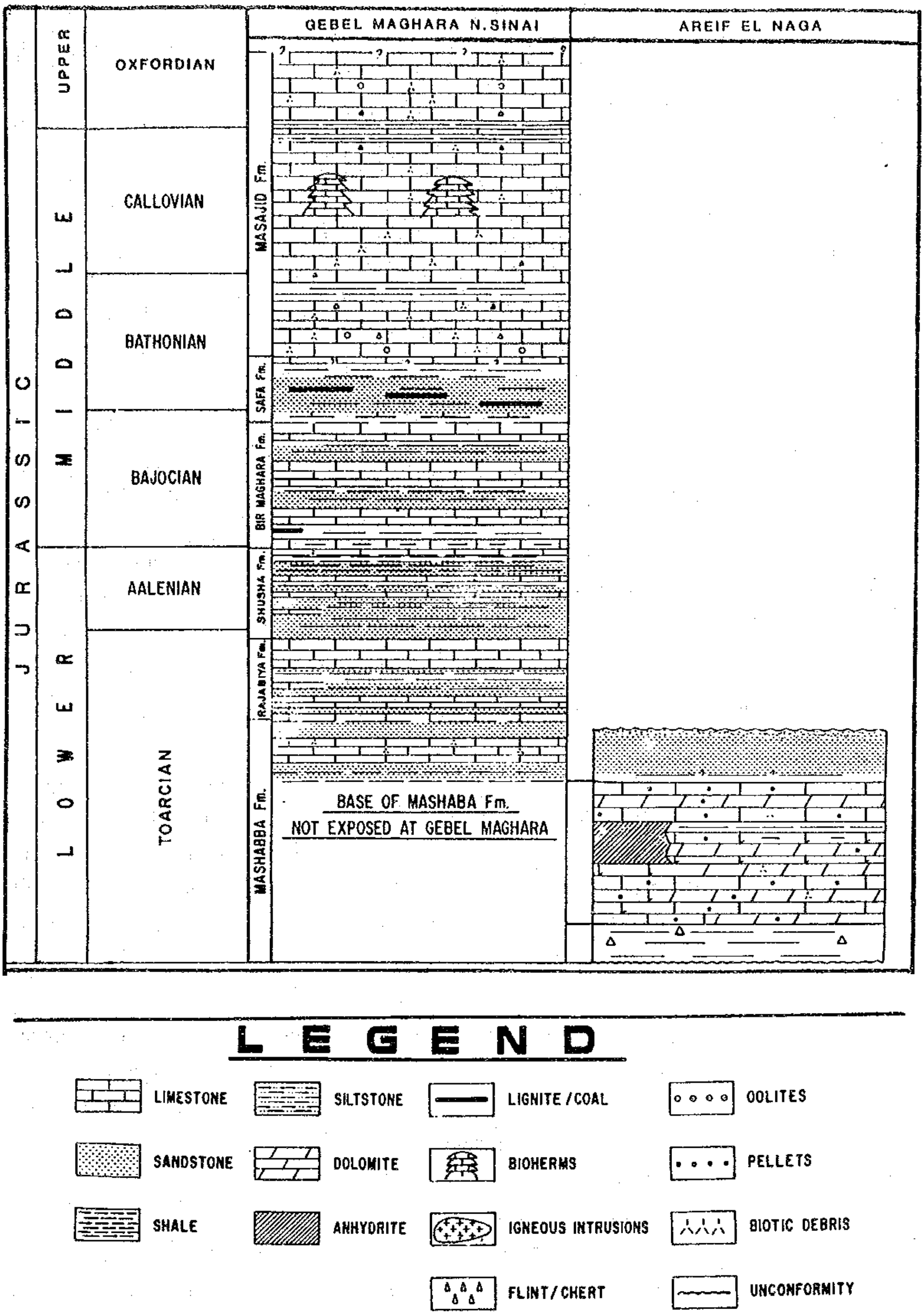


FIG. 6-2-3 COMPOSITE SECTION OF THE JURASSIC SYSTEM IN NORTHERN SINAI

(AFTER M.T.KERDANY & O.H CHERIF,1989)

Table 6-2-1

Thickness and Lithologic Composition of Jurassic Formations, Gebel Maghara.

Formation		Thickness (m)	sd/sh/ls ratio
	Arousiah	443	0-0-100
Masajid	Kehailia	132	2-14-84
Safa		215	34-37-29
	Bir Maghara	216	1-68-31
Bir Maghara	Moweirib	133	2-64-34
	Mahl	93	2-19-79
Shusha		271	52-36-12
Rajabiah		292	2-20-78
Mashabba		100	50-23-27

These formations consist of sandstone, shale and limestone. Detailed lithology of each formation is shown in the Table 6-2-1.

2) Lower Jurassic

The Lowermost Jurassic consists of sandstone with occasional siltstone derived from the Arabo-Nubian massif. The deposition took place during contemporaneous regression of the eustatic sea level and the tectonic uplift in the south. The basal fluvial sandstone includes large wood fragments. (Jenkins, 1989)

The Lowermost Jurassic is overlain by the Rajbiah and Shusha Formation, consisting of shallow marine carbonate and nearshore marine clastics interbedded by occasional well sorted oolitic limestone.

The Lower Jurassic crops out 141 m thick at Gebel Arif El-Naga and consists of variegated sandstone, ferruginous silty shale, limestone, sandy dolomite and marl. These facies are assumed to be deposited in the saline-brackish lagoon of the continental fluvial margin.

The Lower Jurassic is also observed in the oil exploratory wells at Nakhl-1, Abu Hamth, Hamra and El-Khabra.

3) Middle Jurassic

The Middle Jurassic is classified into two groups:

Upper	Safa Formation	clastic facies
Lower	Bir Maghara Formation	clastic ~ carbonate facies

The coal seam at the Gebel Maghara Coal Mine is the sub-bituminous coal of the Safa Formation. The outcrop of the clastic ~ carbonate sequence of the Middle Jurassic is also observed at Gebel Minshera, and in the borehole of Halal-1, Katib El-Makhazin and Giddi.

4) Upper Jurassic

Carbonate rocks are predominant in the Upper Jurassic. They were deposited during the southerly marine transgression at the end of the Bathonian - Callovian times. This is called the Masajid Formation which occurs at Gebel Maghara over 680 m thickness and consists of bioclastic, peloidal packstones and wackestones with isolated biohermal development.

The Masajid Formation is also observed at Halal-1, Hamra and Katib El-Makhazin.

6-2-3-3 Cretaceous

1) Lower Cretaceous

The Lower Cretaceous formation in the study area is represented by the Malha Formation of Abdallah and Adidani (1963).

It overlies unconformably 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 (Said,1971).

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

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

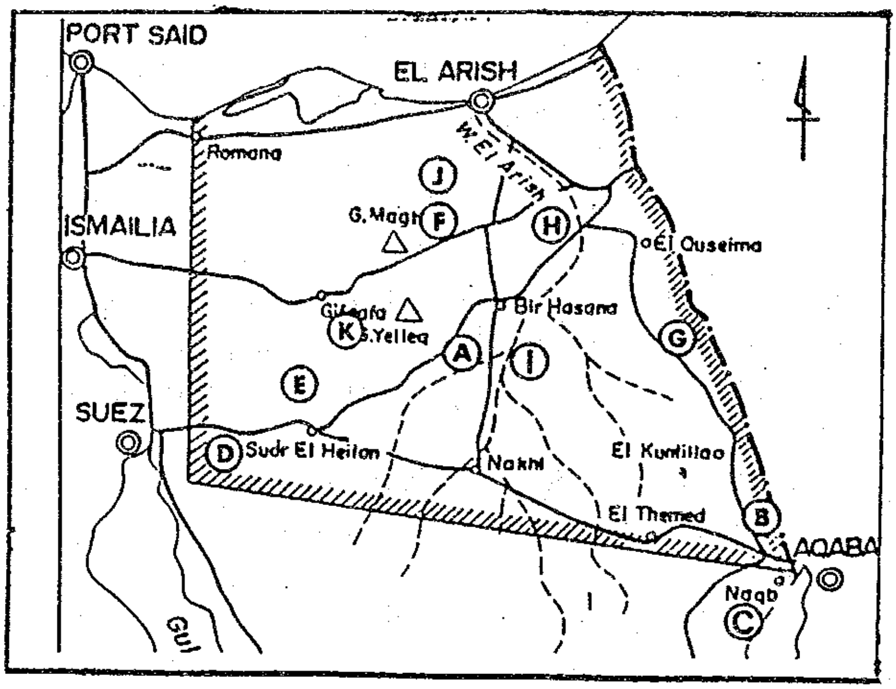
The eleven sites, shown in Fig. 6-2-4, are listed below;

Table 6-2-2

List of Geologic Columns of Lower Cretaceous

Site	Locality	Identification marks
Maghara	Gebel Maghara	F
Maghara	Gebel Mafuruth	J
Halal	Gebel Halal	G
Yelleq	Gebel Falig	K
Minshera	Gebel Minshera	A
Kherim	Gebel Kherim	I
Giddi	Gebel Giddi	E
Raha	Gebel Raha	D
Arif El-Naga	Gebel Arif El-Naga	G
Naqb	Gebel Alad	B
Naqb	East Wadi El-Watir	C

Detailed lithological characteristics of the Malha Formation is described in Technical Report III. Lithological characteristics are summarized as follows:



A : G. Minshera	G : Arif El Naga
B : G. Alada	H : G. Halal
C : East To Wadi Watir	I : G. Kherim
D : G. Raha	J : G. Mafruth
E : G. Giddy	K : G. Falig
F : G. Maghara	

FIG. 6-2-4 SAMPLING SITES

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

(2) Cross beds are frequently observed.

(3) The thickness of this formation is mostly in a range between 200 m and 300 m, although in a geological column more than 600 m is recorded at Gebel Halal.

(4) Occasionally, intercalation of shale is recognized.

(5) Thickness of the shale is less than 10 m except at Gebel Halal where the shale predominates in the central core, especially below 150 m level from the top.

(6) In the south around Naqb, siltstones without fissility are observed instead of shale.

(7) As is shown in Technical Report II, the Lower Cretaceous formation is common throughout Sinai. It is very difficult to correlate the stratigraphical columns because the lithology is similar to each other in the study area.

Generally, sandstone is predominant in the formation and occasionally accompanied by shale. Grain size distribution is a little different in each sandstone.

As previously indicated, the Lower Cretaceous clastic rocks have porous lithologic character.

(8) Grain size tends to become smaller in the Gebel Maghara area where lithofacies change from sandstone to limestone.

It is reported by Jenkins(1989) that the section of the Lower Cretaceous in Gebel Halal is 520 m thick, consisting of 90% sandstone with occasional intercalation of shale. However, it was observed during the study at Gebel Halal that the section of the Lower Cretaceous exceeds 580 m and the proportion of shale is more than 30% (Technical Report III).

Bartov, et al., (1980) reported that "a basal conglomerate (5 to 15 m) is overlain by cross-bedded sandstones (160 to 168 m) which in turn are overlain by a sequence of sandy limestone, shale, siltstone, marl and marly limestone in Gebel Yelleq". It was confirmed during the study that the Lower Cretaceous sandstone is also observed at Gebel Falig in the northwest of the Gebel Yelleq (Technical Report III). The thickness of the sandstone is 30 m as far as observed in the outcrop. But it is estimated that the sandstone extends below the surface.

In the Naqb area there is sandstone overlying unconformably the Precambrian rocks. Above this sandstone another clastic unit of the Lower Cretaceous crops out which is unconformably overlain by the Upper Cretaceous beds. This sandstone is assigned to sediments deposited during the Paleozoic and the Lower Cretaceous.

The most important field evidence is that the sandstone of the Lower Cretaceous is unconformably covered by the Cenomanian strata. Also, the sandstone indicates characteristic lithological facies similar to those of the Lower Cretaceous.

2) Upper Cretaceous

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

Cenomanian
Turonian
Senonian

The Cenomanian formation conformably overlies the Lower Cretaceous and is conformably overlain by the Turonian. 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 and calcareous sandstone in the lowermost part grading upward into limestone, dolomitic limestone and dolomite. Dolomite is widely traceable in the Syrian Arc zone.

Many studies were made on the Turonian in North Sinai by Said (1962), Jenskins et al. (1982) and Shata (1960). According to these studies, the Turonian distributes on the foot slope of the large anticline and the lithofacies are similar to those of the Cenomanian (Said, 1962). The Turonian is absent due to uplift and/or later erosion at Gebel Mahgara (Jenkins et al, 1982). The Turonian consists mostly of foraminiferal limestone but contains some intercalated grey-green shale at Gebel Halal (Shata, 1962).

The Senonian, in North Sinai, consists of a monotonous sequence represented by chalk.

As shown in Fig. 6-2-5, fifteen detailed geologic columns of the Upper Cretaceous were recorded at ten places during the study. At Gebel Minshera a whole sequence of the Upper Cretaceous is observable from the Cenomanian to Senonian.

Thickness of the Cenomanian varies in a range between 345 m and 575 m in the area. Mostly rather thick Cenomanian rocks are distributed in the following sites:

Gebel Minshera	575 m
Gebel Maghara	550 m
Gebel Hamra	550 m

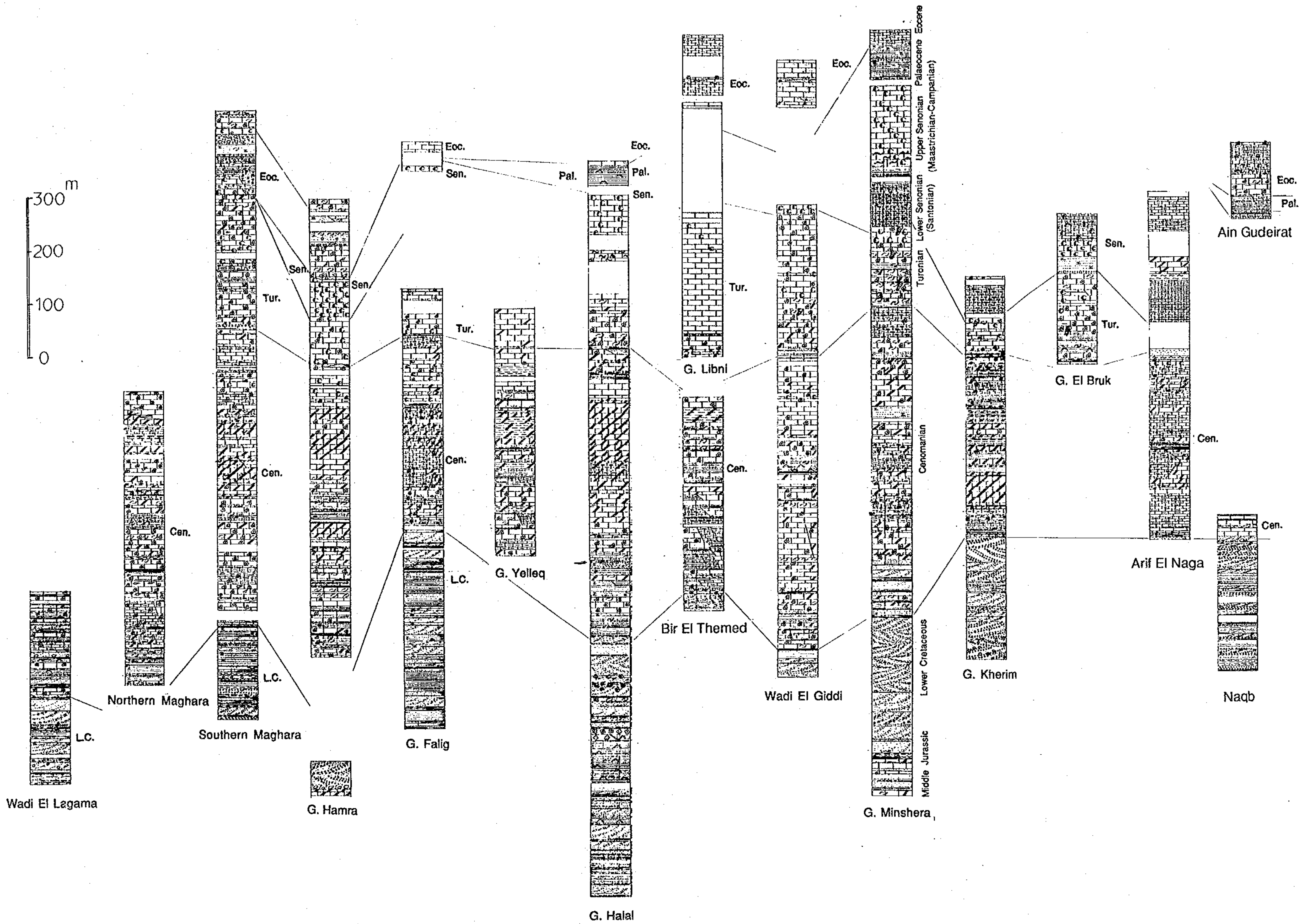


FIG. 6-2-5 GEOLOGICAL COLUMN (JICA STADY TEAM)

Wadi El-Giddy	545 m
Gebel Halal	535 m

On the other hand, the thickness of the Cenomanian is rather thin at Gebel Yelleq, Falig, Kherim and Arif El-Naga.

The Cenomanian is represented by predominating dolomite-dolomitic limestone and a different facies, consisting of calcareous sandstone, shale and limestone, appear at the base of the formation. In the middle part of the Cenomanian shale appears that is 10 to 30 m thick at all columns. The Cenomanian is conformably overlain by the Turonian.

The Turonian consists of limestone, dolomitic limestone and chalky limestone; clastic sediments of sandstone and shale appear at the base of the formation.

The Turonian is either partly or completely eroded in many places. The Turonian is absent at Gebel Maghara, Gebel Arif El-Naga and Naqb. Thick strata of the Turonian are observed in the area of Gebel Halal and Libni Gebel Minshera and El Bruk Gebel Giddi. The thickness of the Turonian in these areas range between 100 m and 270 m; the thickest layer is observed at Gebel Libni and Gebel Giddi. To the west and the southeast of this area the Turonian is heavily eroded. The thickness of the Turonian in the area of Gebel Falig and Yelleq is between 75 m and 85 m, and 70 m thick at Gebel Kherim.

The Senonian unconformably overlie the Turonian. A very thick Senonian is observed at Gebel Minshera (270 m). The lower Senonian is represented by 90 m thick shale at Gebel Minshera. A 20 m thick shale layer appears at the base of the Upper Senonian and is overlain by a 180 m thick formation consisting of chalk and chalky limestone. This type of lithofacies of the Senonian prevails throughout the study area.

6-2-4 Cenozoic

6-2-4-1 Tertiary

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 between the major structural highs in Sinai on the Upper Cretaceous.

Hunter (1981) reported that the Esna Formation is similar to the shale facies of Maastrichtian at the top of the Senonian in South Sinai and determined the age of the Esna Formation as the Paleocene to the Lower Eocene. It is also reported that the thickness of the Eocene formation in North Sinai varies in a range between 30 m and 65 m but the maximum thickness in Gebel Maghara is one meter but often it is absent. (Jenkins, 1989)

The Esna Formation crops out on steep slopes or cliffs in the study area. It is frequently observed in the area west of Halal, Quseima, Arif El-Naga and El-Kuntilla. The Esna Formation is overlain by the Eocene limestone.

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. (Fig. 6-2-6)

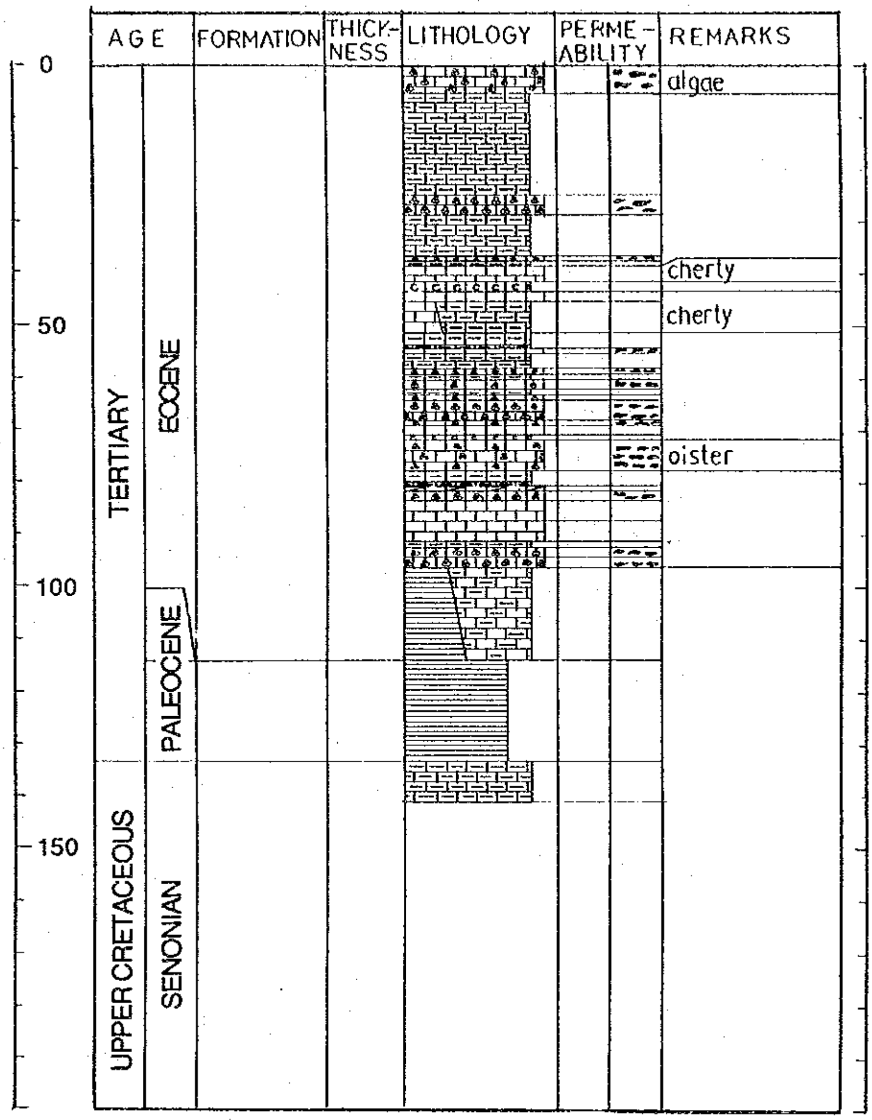


FIG. 6-2-6 LITHOSTRATIGRAPHIC COLUMN

(AIN GUDEIRAT)

(JICA STUDY TEAM)

As shown in Fig. 6-2-6, a 20 m thick Esna Formation overlies on the Upper Cretaceous marl that is overlain by the alternation of shale and marly limestone that is 15 m thick at Ain Gudeirat. 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.

The Esna Formation often contains pyrite so that its features are quite different from other shales.

Although the Esna Formation is dissected by many faults, the strata are generally horizontal and not strongly folded in the area. Therefore, it is supposed that no tectonic movement, such as Syrian Arc movement, occurred after the deposition of the Esna Formation.

2) Eocene

The Eocene formations are represented by The Egma Formation (Bendnell, 1927) which consists of limestone to dolomitic limestone. But the formation may include other Eocene rocks.

Jenkins(1989) classified the Eocene limestone into two groups — the Lower Eocene and the Middle-Upper Eocene — and reported that in north Sinai this lower Eocene limestone occupies the broad synclinal lowlands to the north and east of Gebel Halal, as well as between Gebel Halal and Gebel Yelleq, between Gebel Maghara and Yelleq and between Umm Hoseira and Kherim. It exhibits uniform lithology but has large thickness variations; being very thin to absent in places. The Middle-Upper Eocene sequence in north and central Sinai is characterized by large unconformities; parts of the sequence is missing in certain localities.

The Eocene distributes, similar to the distribution of the Palaeocene, 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 Qusima.

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

3) Oligocine

The Oligocene formation is recorded at the offshore oil exploratory wells and is not reported in the North Sinai so that this formation has no affect on the hydrogeology in the study area.

4) Miocene

Jenkins (1989) reported that the Miocene sequence in the North Sinai is known only from the subsurface where it had been penetrated by exploratory boreholes. No Miocene sequence is shown in the geological map published by Conoco (1988). 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 results of the fossil analysis undertaken by the study team, these limestones are identified as the Eocene limestone (Technical Report II). However, since the Miocene formation was encountered in the water well in the area of El-Arish - Rafah, it is assumed that there might be small-scale outcrops in the sand dune area.

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

5) Pliocene

The Pliocene is identified only at the offshore oil exploratory wells. No report mentions the terrestrial outcrop of the Pliocene.

Outcrops presumably of the Pliocene, are found along the Wadi El-Arish near Magdaba.

6-2-4-2 Quaternary

The Quaternary stratigraphy in the study area is described as a schematic stratigraphy.(Fig. 6-2-7)

Epoch	Column	Name	Description
Holocene		Sand Dune	Loose sand intercalated with clayey layer and gravel
Pleistocene		Old Beach Sand	Loose sand, locally diagenetic sandstone intercaluted with clayey layer and gravel
		Kurkar	Diagenetic calcareous sandstone
Pre - Quaternary			

FIG. 6-2-7 STRATIGRAPHY OF QUATERNARY

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

"Kurkar" is the name given to the calcareous sandstone which is converted into being more or less compact after emplacement. The kurkar is distributed along the coastal plain and their genesis are present in the shallow marine environment.

The old beach sand consists mainly of fine to coarse sand which is locally diagenetic sandstone and intercalated with gravel and clayey layers. This is confromably overlying the kurkar in some places which forms an unconfined aquifer. 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.

Sand dunes are extensively distributed in the coastal plain covering the old beach sand and locally intercalated with clayey and gravel layers. The sand dunes are underlain by impermeable clayey deposits so that the sand dunes hold locally developed aquifers. The thicknesses of the sand dunes range between 20 m and 30 m.

6-3 Geological Structure

6-3-1 General

The geological structure of North Sinai is divided into the following three major units(Shata, 1956) (Fig. 6-3-1).

1) Central Sinai Stable Foreland.
2) North Sinai Strongly Folded Belt
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.

The geological structures are shown in Fig. 6-3-2 and Fig. 6-3-3. Findings obtained through field work are compiled to the attached Geological Map.

6-3-2 Central Sinai Stable Foreland.

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

6-3-3 North Sinai Strongly Folded Belt.

This unit occupies a broad area in the north of the Regabet 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 and Halal. There are also small-scale folds at Gebel Minshera, Arif El-Naga Kherim and Falig.

Elongation of these double plunging folds is in a NE-SW to ENE-WSW direction, distributing in echelon. The dome is dissected by many small faults. The dip of beds in the dome are gentle on the northern slopes and steep on the southern slopes with non-symmetric axis of fold. In some cases the fold overturns towards the south, and reverse faults and thrusts are observed at Gebel Maghara and Arif El-Naga. Most of the faults in the area indicate ENE-WSW or NE-SW directions. Also, there are recognized faults in NW-SE or WNW-ESE directions which are running discordant to the above faults. Most of the concentrated fault area is from Gebel Minshera to Arif El-Naga passing through Kherim which is called the Minshera-Abu Kandu Shear Zone. In the area, right lateral faults and small folds are also observed.

Ragabet El-Naam Fault extends from Naqb through Nakhl to the area in the south of Gebel Hamra through the front of the Syrian Arc zone. The southern side of the fault is a relatively uplifted block that appeared after the fault activity and Precambrian basement rocks are exposed instead of younger sediments.
The Ragabet El-Naam Fault is bounded between Precambrian rocks and Lower Cretaceous rocks around the area of Naqb (Fig. 6-3-5).
Vertical dislocation of the fault is estimated at 200 m at Naqb. The throw decreases toward the west. Its location is hardly observable on the satellite image at Nakhl in the central part of Sinai. The fault is clearly recognized further west beyond the study area. It may suggest that the sandstone of the Lower Cretaceous is cut by the fault on both sides in the west and the east. The throw of the fault is small in the central part so that continuity of the sandstone is assumed to be maintained although there may be disturbance to a certain extent.

The characteristics of this geological structural unit are observed in the lineaments. The predominating directions of the lineaments are ENE-WSW and WNW-ESE which forms a mesh-like network. The direction of lineaments governs the direction of wadi channels and may have an influence on the directions of fissures developed in the formation.

6-3-4 North Sinai Foreshore Area.

The area neighbours the northern margin of the 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 zone. Thick Tertiary deposits covers old rocks in the area and Quaternary sand dunes cover most of the area.

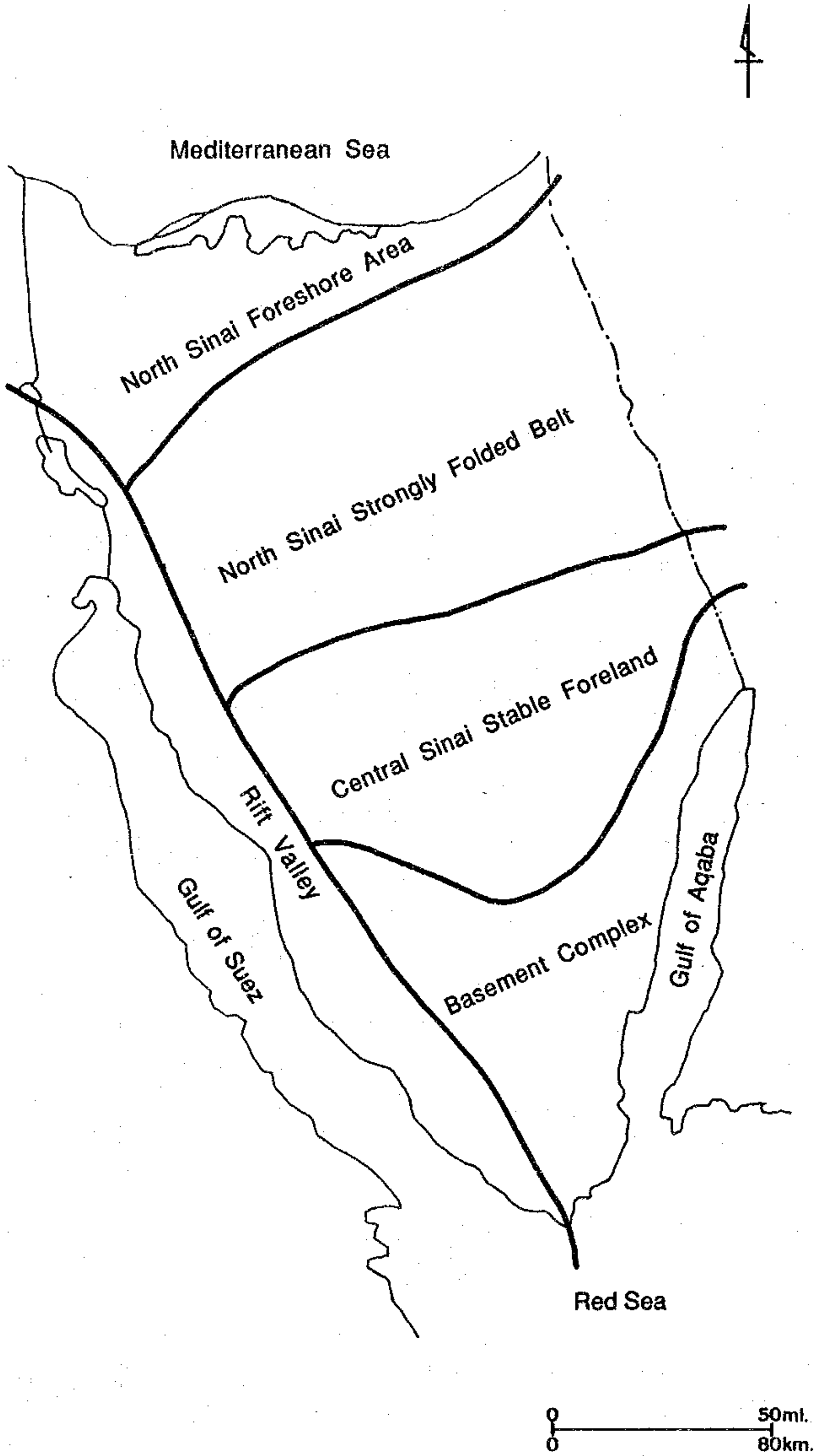


FIG. 6-3-1 STRUCTURAL ZONES OF THE SINAI PENINSULA

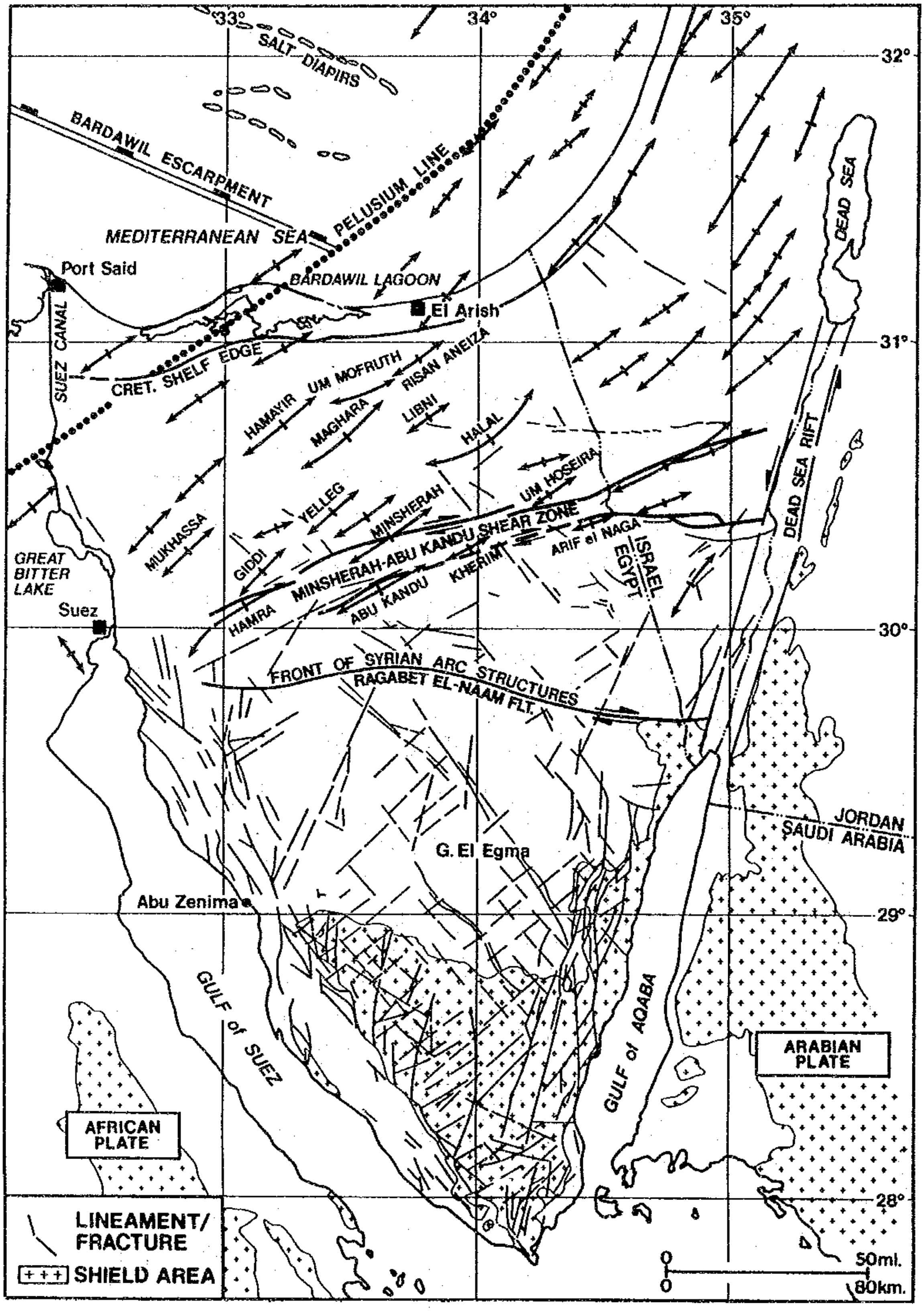


FIG. 6-3-2 TECTONIC MAP OF NORTH AND CENTRAL SINAI (AFTER NEEV 1975 AND AGAH 1981)

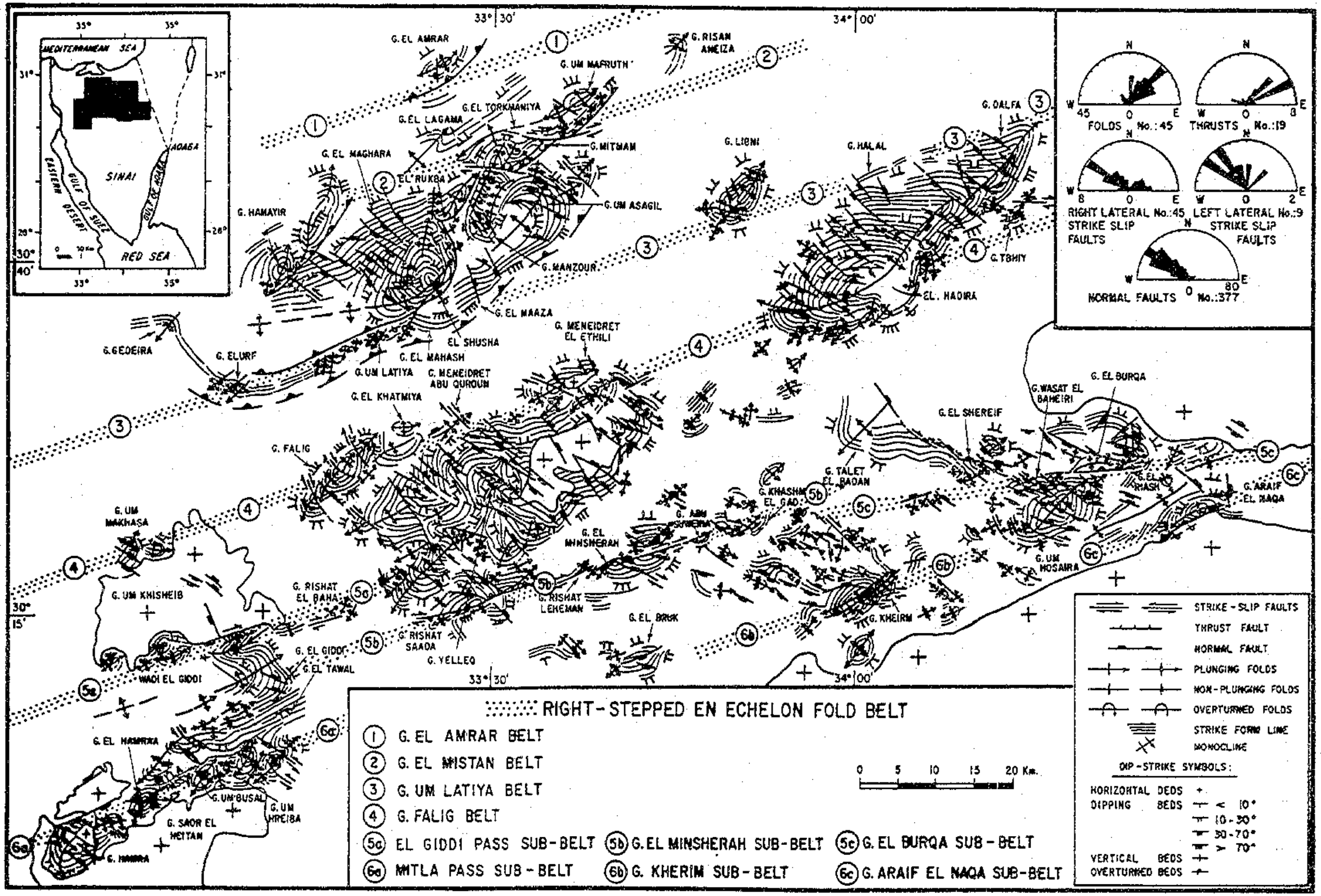


FIG. 6-3-3 STRUCTURAL MAP OF NORTH SINAI SHOWING THE EN-ECHELON FOLD BELTS (ABEL R. MOUSTAFA & MOSBAH H. KHALIL ,1989)

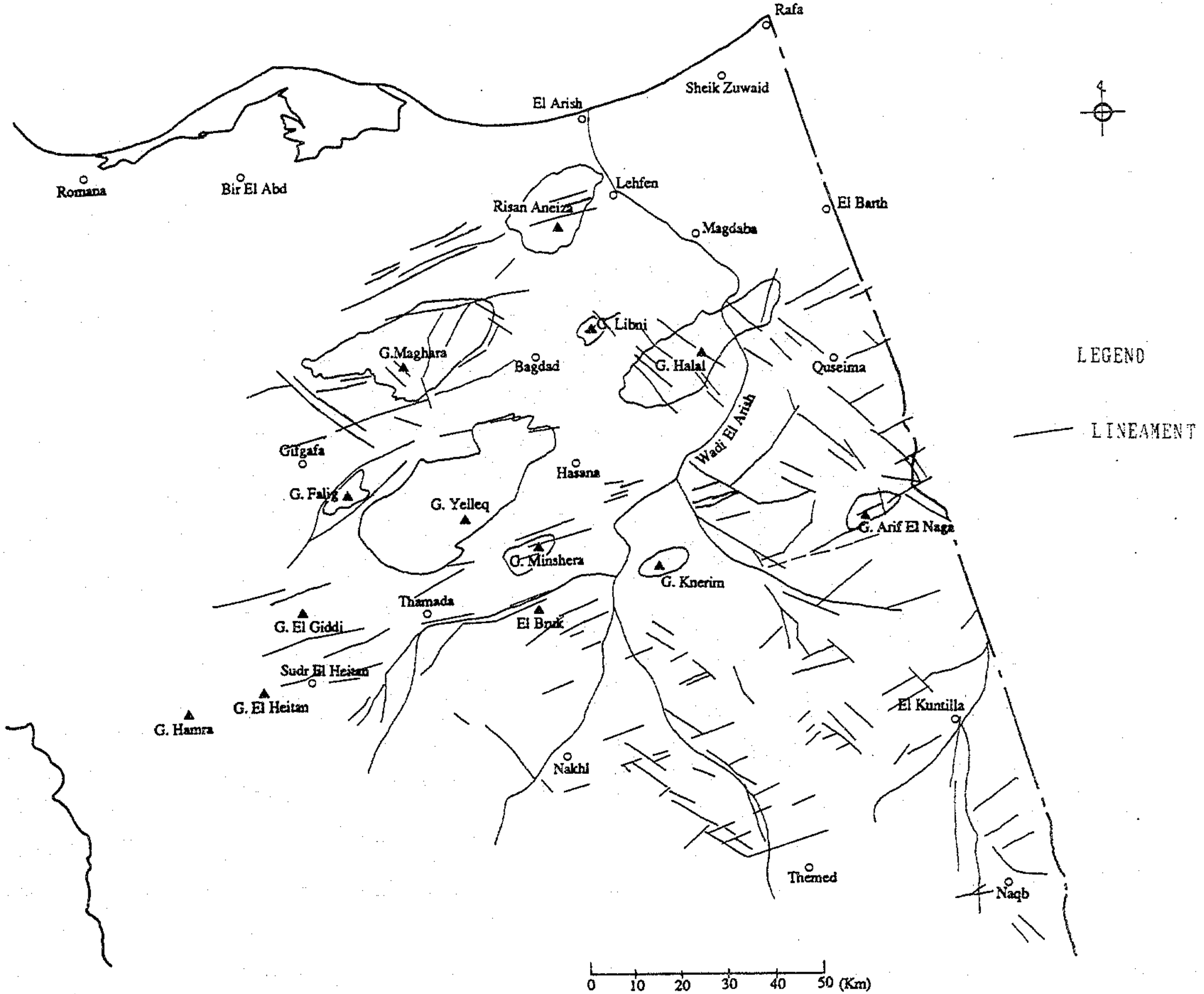


FIG.6-3-4 LINEAMENT IN NORTH SINAI

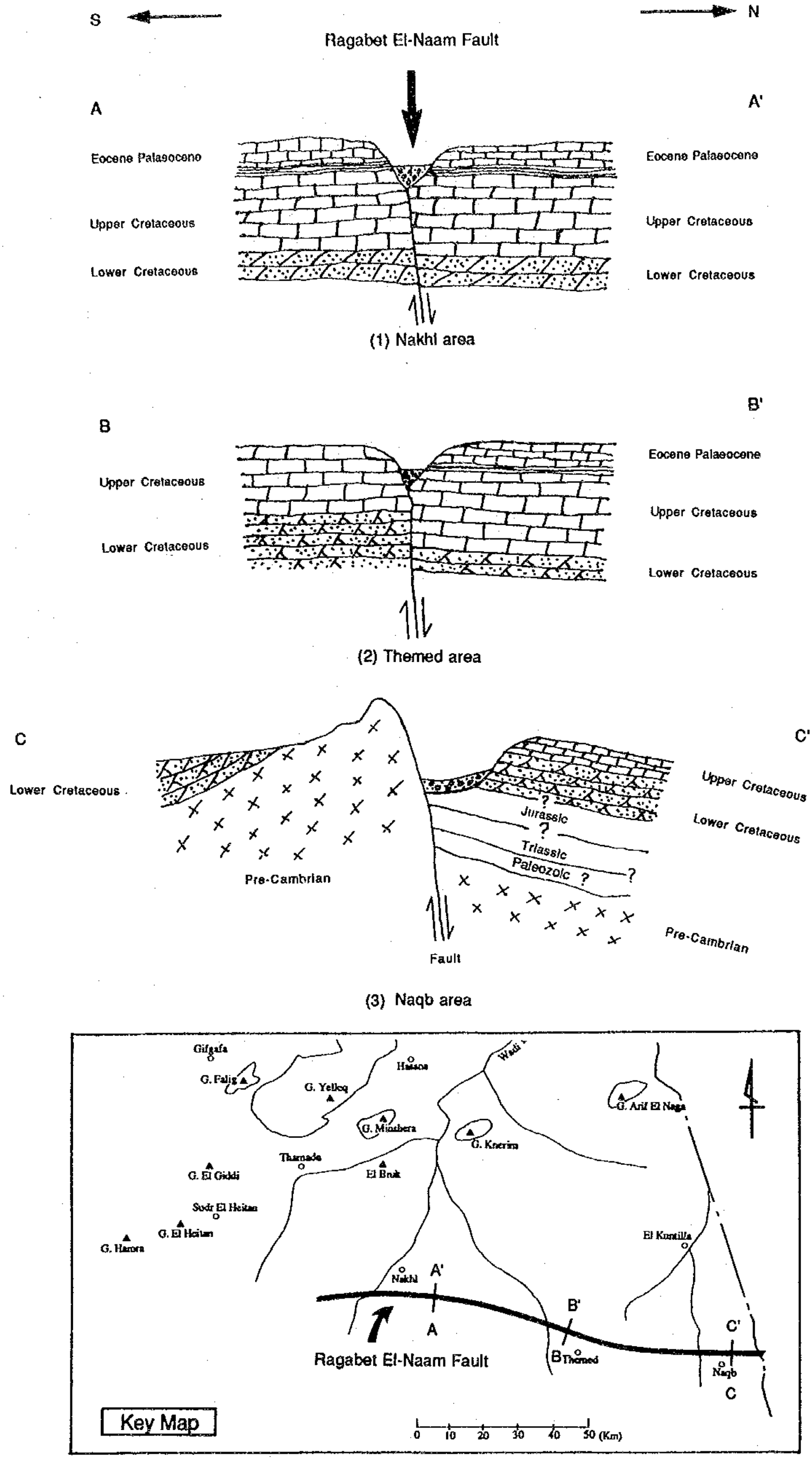


FIG.6-3-5 SCHEMATIC CROSS SECTION ALONG THE RAGABET EL-NAAM FAULT

7 DISTRIBUTION OF MAJOR FORMATION OF PROSPECTING AQUIFER

7-1 Introduction

In order to figure out the general features of the major formations which may contain prospecting aquifers it is required to interpret the distribution of these formations. For this purpose several geologic columns and cross sections are required.

For the Quaternary formation, a geologic column is available only at one place 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 (Technical Report II).

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

7-2 Distribution of Quaternary

7-2-1 Geologic Section 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 the development of prospecting aquifers in this area is unlikely (Technical Report V).

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

In the eastern half of the coastal plain, there are many production wells and some test holes (Fig. 7-2-1). The Quaternary crops out at some places along the lower stretch of the Wadi El-Arish. The southernmost outcrop of the Quaternary is at Magdaba. The upper part of an 8 m thick Quaternary bed is observed at site A. The consecutive lower 7 m part is observed at site B. (Fig. 7-2-2)

The lower part of this bed consists of calcareous sandstone and calcareous conglomerate underlain by the Tertiary shale. The upper part is sand of different grain size.

In order to figure out the general feature of the Quaternary, some test wells were sunk in the coastal plain between El-Arish and Rafah. The objectives of these test holes were to locate the base of the Quaternary and to confirm the extent of the kurkar distribution.

Using all the available lithological profiles, cross sections of the Quaternary in the eastern part of the coastal plain were compiled. Location of the cross sections are shown in the Fig. 7-2-3.

1) A-A' Section

This is the cross section in an EW direction. It is approximately 10 km in-land along the coastline. The thickness of the Quaternary ranges between 80 m and 100 m in the eastern side of the Wadi El-Arish. There is a remarkable decrease in its thickness in the eastern end of the cross section. The thickness of the Quaternary at test well J No. 9 is only 10 m (Fig. 7-2-4).

The kurkar is thins out at 20 km to the east from the Wadi El-Arish and also on the western side of the Wadi El-Arish. The thickest bed of the kurkar is about 60 m. It was observed in the river bed of Wadi El-Arish. The kurkar is approximately 20 m thick in the rest of the section.

A gravel bed is observed in the river bed of the Wadi El-Arish at the confluence of the Wadi El-Arish and the Wadi Mazaar.

The thickness of this gravel bed is 40 m at well No. 1-141. The gravel beds in wells No.1-119 and J No. 2 are assumed to be identical. A thin gravel bed is also observed at well J No. 3 and J No. 5; however, these are probably lenticular types.

2) B-B' Section

This is the cross section in a NS direction through Rafah in the eastern end of the study area. The thickness of the Quaternary in this section is 80 m in the northern part, about 10 km inland from the coast. To the south of well J No. 9 there is remarkable decrease in its thickness. The thickness of the Quaternary within 15 km from this point to the south is from 10 to 20 m and consists of sand. The thickness of the Quaternary increases at test wells J No. 10 and 11 to a range between 30 m and 60 m consisting of thin silt, sand and gravel, overlain by 10 to 20 m thick sand. This sediment is assumed to be wadi deposits and the sandstone in this part of the section is assumed to be the continental kurkar (Fig. 7-2-5).

The sudden change in the thickness of the Quaternary between test wells J No. 8 and 9 suggests a fault in this section.

The lithology of the underlying Pre-Quaternary is different from place to place. It consists of shale, clay, sandstone and dolomite.

The thickness of kurkar is about 40 m and is overlain by thick sand in the northern part of the cross section. However, kurkar is absent in the section south of test well J No. 9.

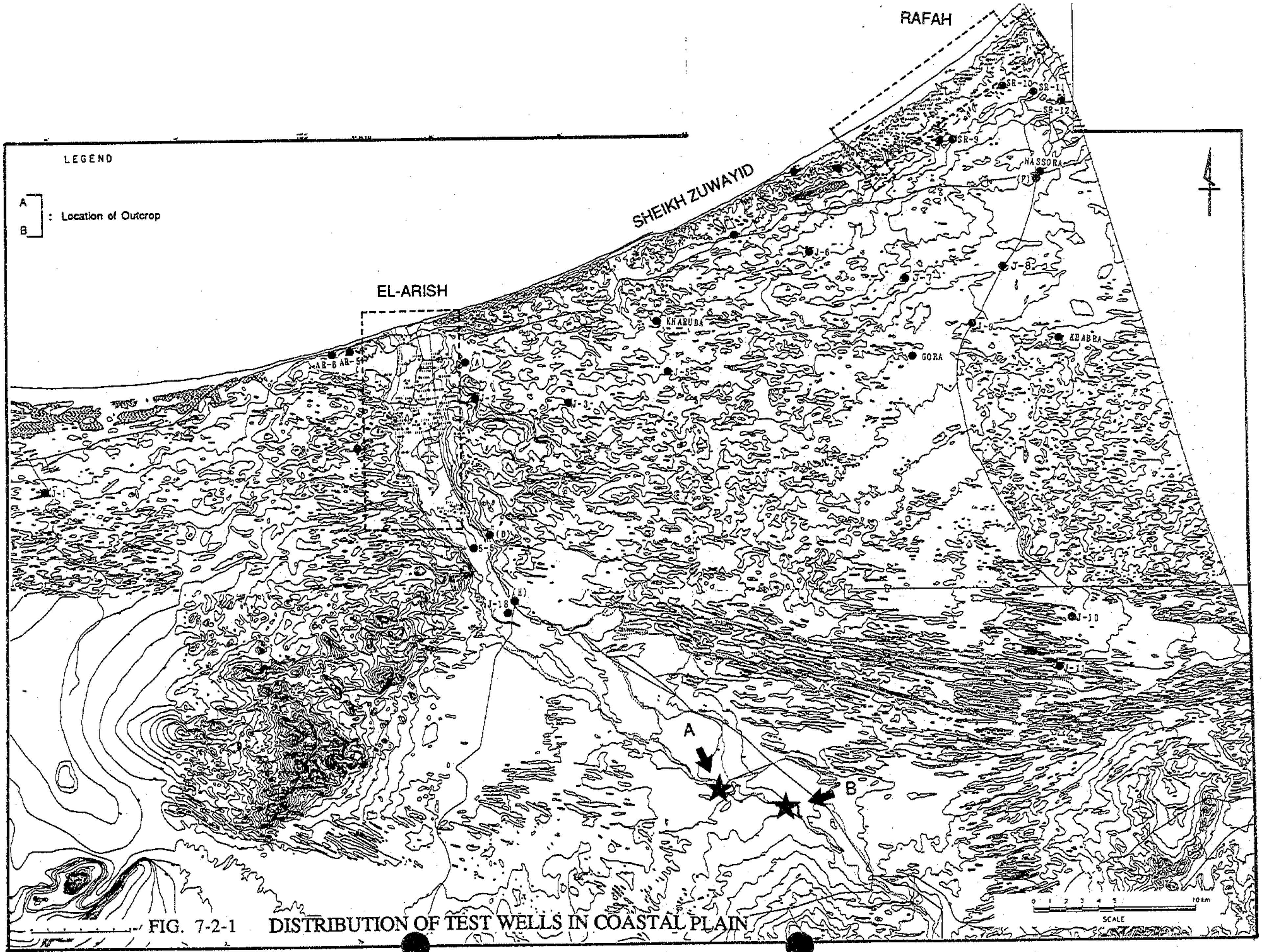


FIG. 7-2-1 DISTRIBUTION OF TEST WELLS IN COASTAL PLAIN

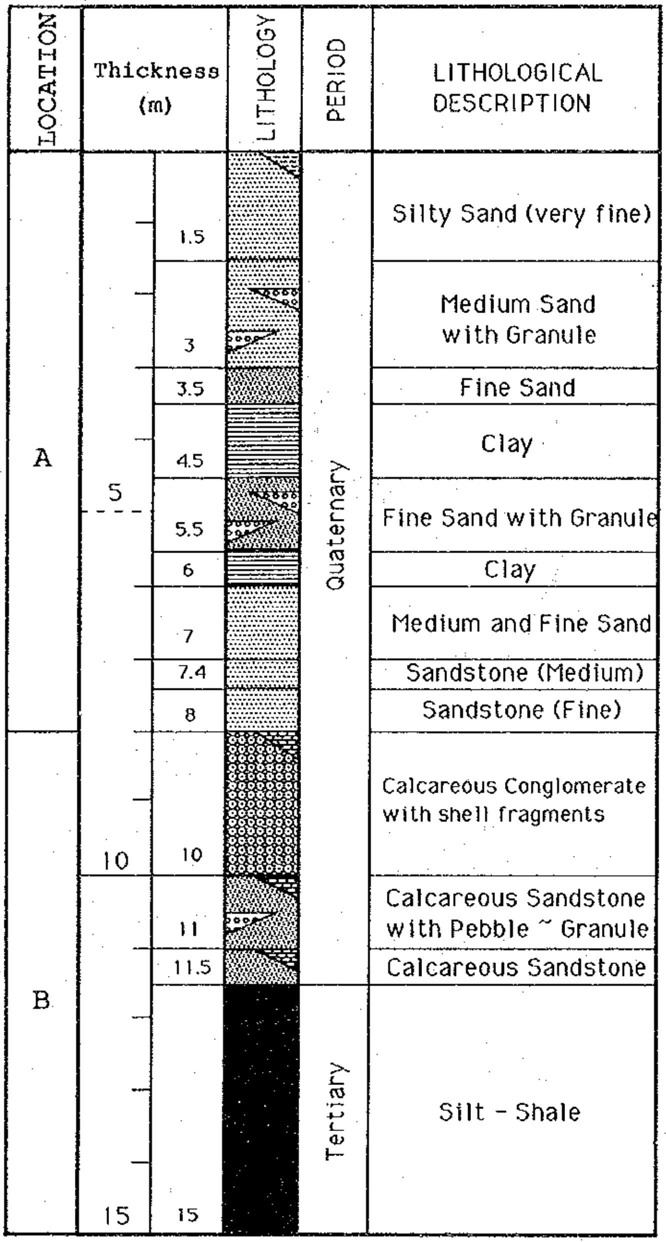


FIG. 7-2-2 GEOLOGICAL COLUMN OF OUTCROP A , B

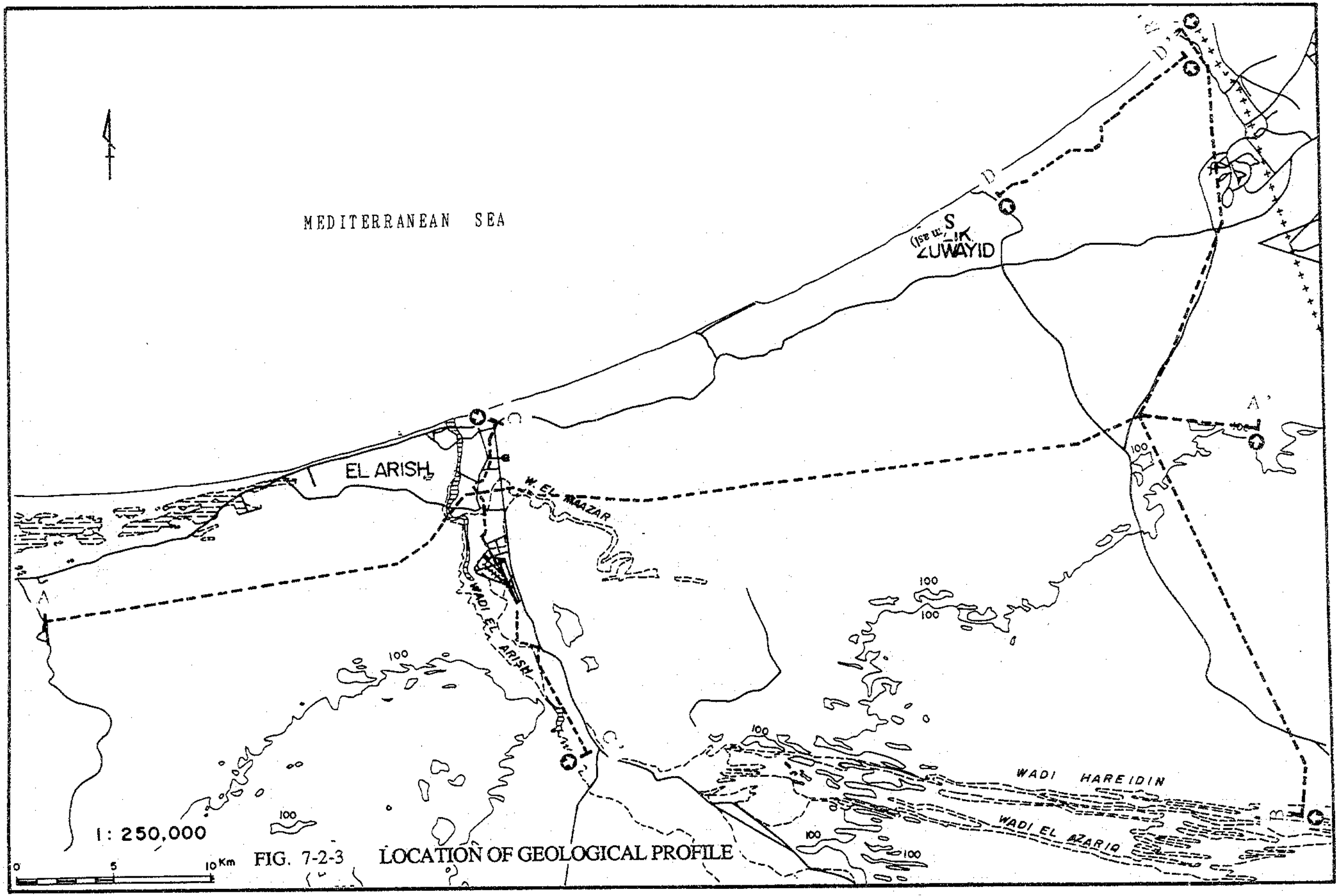


FIG. 7-2-3 LOCATION OF GEOLOGICAL PROFILE

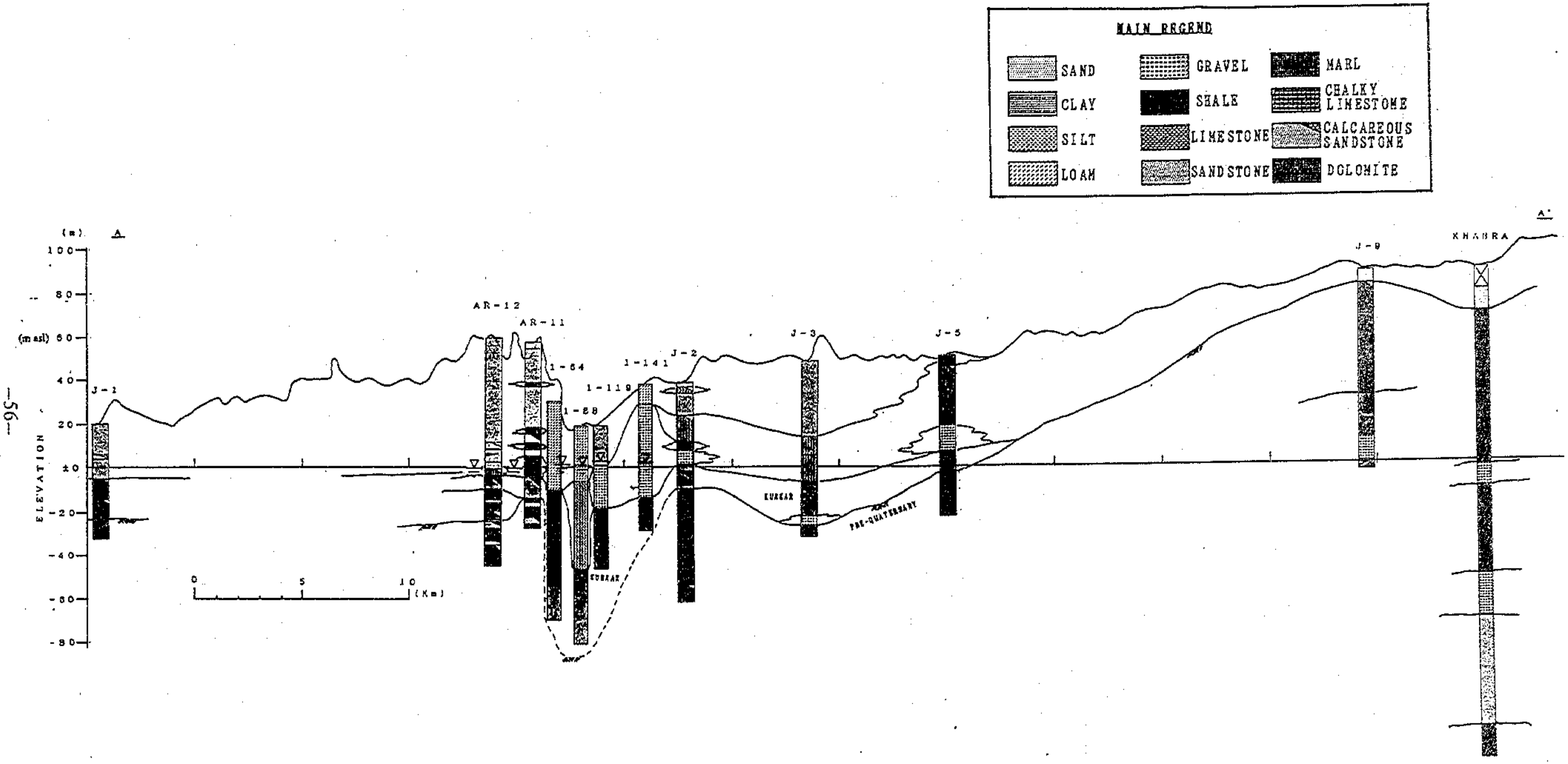


FIG. 7-2-4 GEOLOGICAL SECTION OF NORTHERN PLAIN IN THE SINAI PENINSULA (A-A')

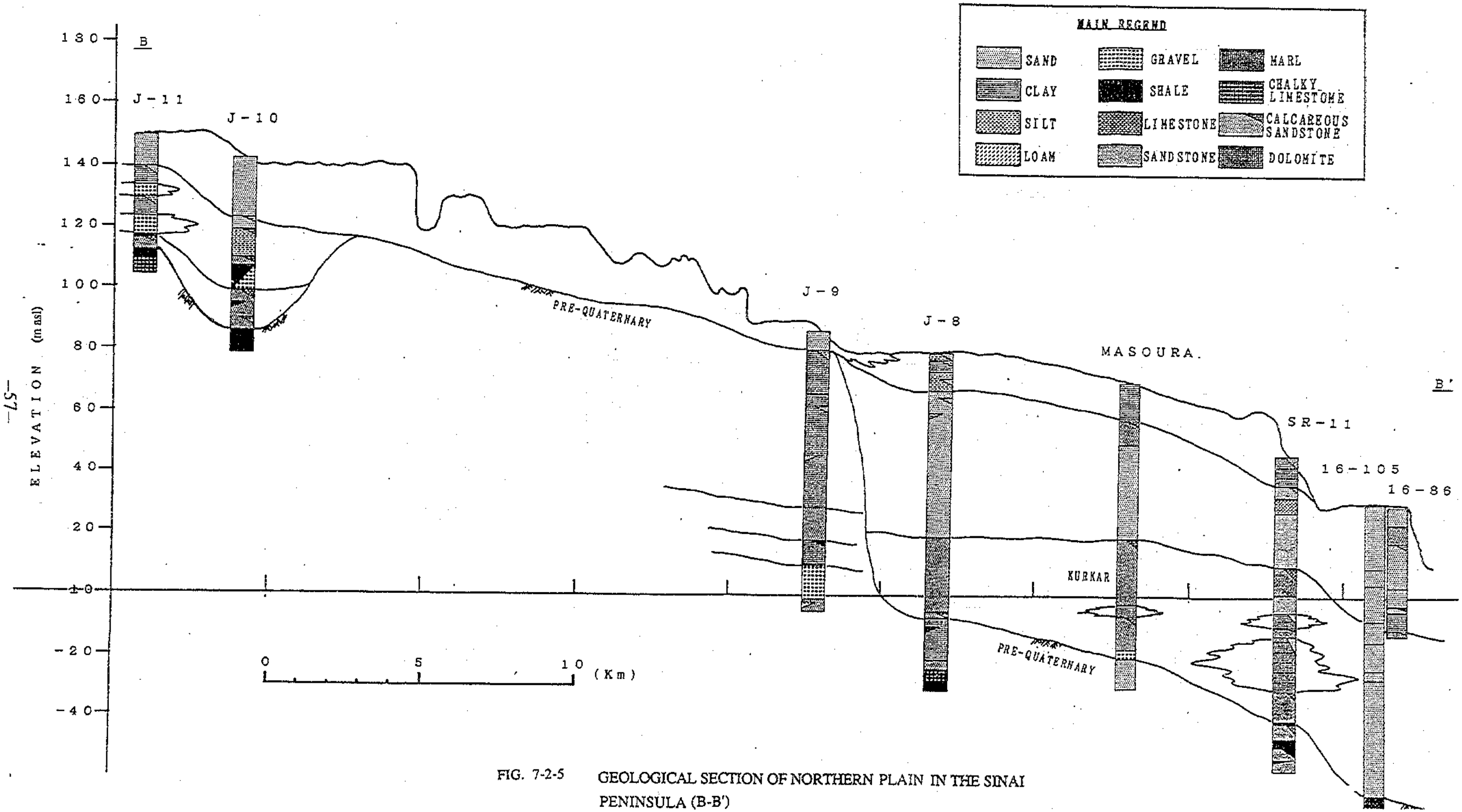


FIG. 7-2-5 GEOLOGICAL SECTION OF NORTHERN PLAIN IN THE SINAI PENINSULA (B-B')

3) C-C' Section

This section runs from north to south, passing near the central part of El-Arish Town (Fig. 7-2-6).
Pre-Quaternary rocks develop at -60 m asl near the sea coast but towards the inland it gradually increases in elevation. At 14 km inland from the coast, the site of well No. 5-1, the pre-Quaternary rocks occur nearly on asl.

This section indicates the characteristic feature of a continuous development of gravel bed and the existence of calcareous sandstone (kurkar) at the lower part. Main aquifers are represented by the gravel bed and the calcareous sandstone (kurkar) in the area.

Lithology of the underlying Pre-Quaternary is mainly clay. However, limestone is observed at the bottom of the Quaternary at wells No.1-113 and 2-26.

The kurkar extends approximately 10 km from the river mouth of the Wadi El-Arish towards the south that is overlain by gravel. The gravel bed extends a little further south from well No.5-5 and is replaced by the Quaternary deposit consisting of silt, sand and gravel in the south at well J No. 18. At this point, there is a gravel bed overlying shale, the age of which is unknown. However, the shale is assumed to be the Pre-Quaternary. The elevation of the kurkar is below the sea level.

4) D-D' Section

This is a cross section of the coastal sand dunes along the coast at the northeastern end of the study area. The thickness of the Quaternary ranges between 40 m to 80 m (Fig. 7-2-7).

The lowest bed of the Quaternary is kurkar although it is absent in the area where wells No.11-18 and 11-20 are located. The thickness of the kurkar ranges between 10 m and 30 m. A thick kurkar bed is observed in the eastern half of the section. In the western half of the section kurkar is relatively thin. The kurkar is underlain by shale in general; chalky limestone where kurkar is absent.

The bottom of the Quaternary is at about -50 m asl in the middle part of the section which extends to the east towards the international border with Israel.

There are gravel beds where wells No. 12-99, 11-23, 16-10, 16-20 and 16-34 locate. However, they are assumed to be local deposits in a limited area on an old wadi bed.

The thickness of the Quaternary sand, including dune sand and old beach sand, ranges between 25 m and 50 m; it exceeds 50 m at some places. Dune sand and old beach sand are not differentiated in the section.

5) Resistivity Profile

These are the sections obtained through interpretation of resistivity profiles along survey lines No. A7, A9 (Fig. 7-2-8 (1)) and lines No. B5, B6, b7 (Fig. 7-2-8 (2)). Location of the resistivity survey lines are shown in Fig. 7-2-9.
There was no geological data for this area. Therefore the resistivity survey was undertaken and the test wells were planned along the survey lines. However, the test wells were transferred to the Pre-Quaternary test wells during the study. Although there are no verification points along the survey lines it is useful as a reference for estimating the elevation of the bottom of the Quaternary.

Since the lithology of the Pre-Quaternary in this area is most probably clay or shale, the boundary between the Quaternary and the Pre-Quaternary is estimated as shown in Fig. 7-2-9.

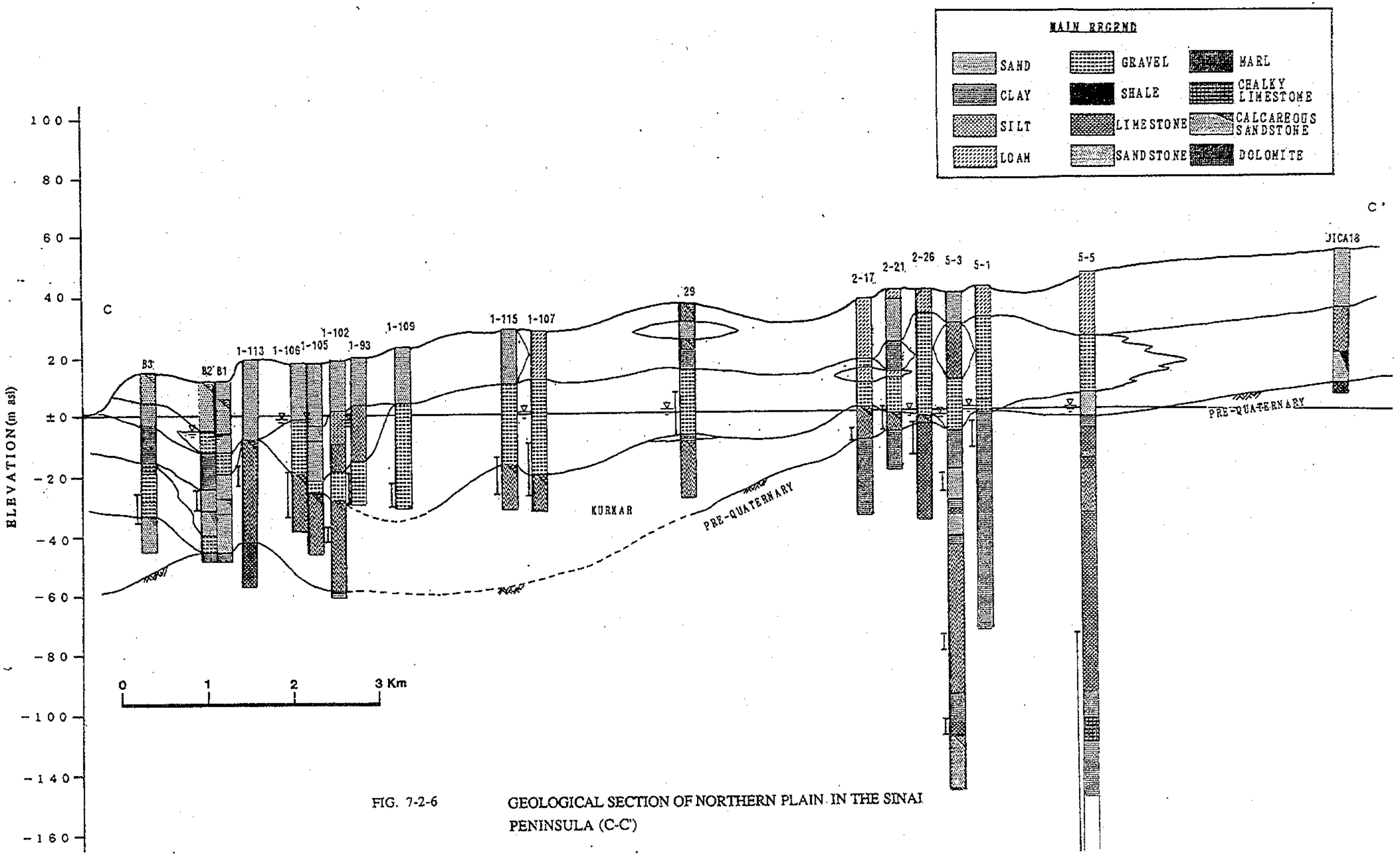


FIG. 7-2-6 GEOLOGICAL SECTION OF NORTHERN PLAIN IN THE SINAI PENINSULA (C-C')

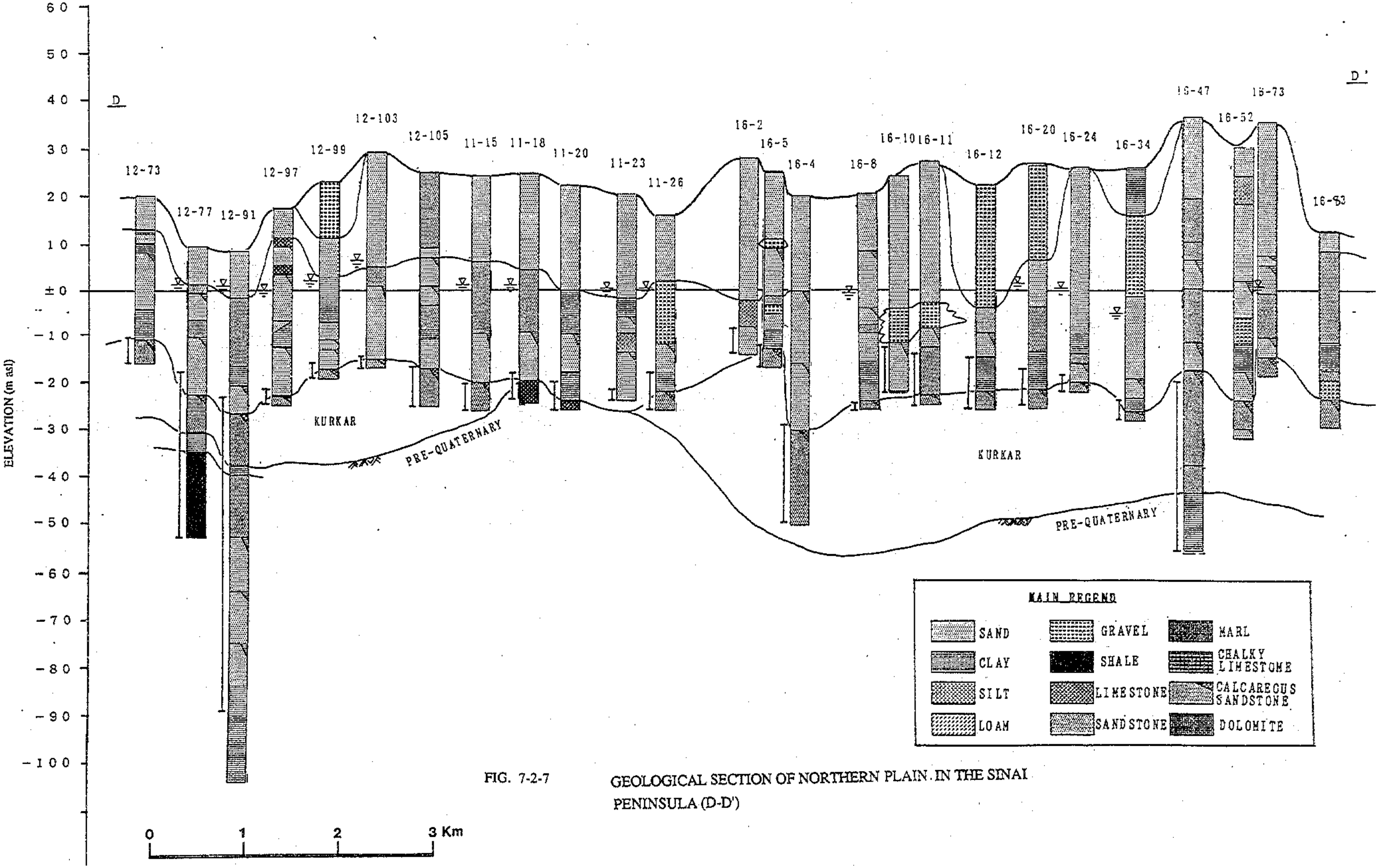


FIG. 7-2-7 GEOLOGICAL SECTION OF NORTHERN PLAIN IN THE SINAI PENINSULA (D-D')

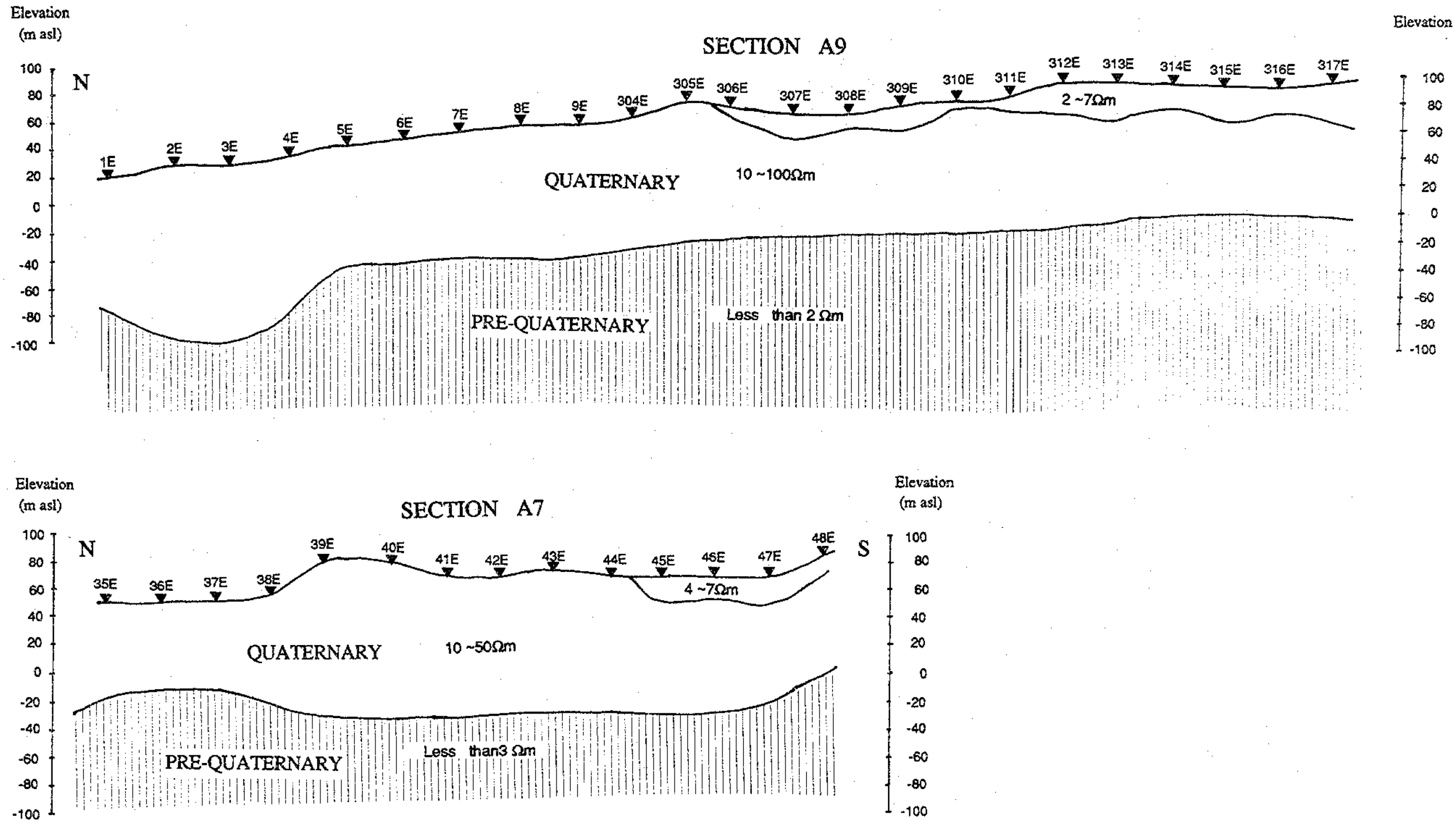


FIG. 7-2-8(1) RESISTIVITY PROFILE OF SECTION A7,A9

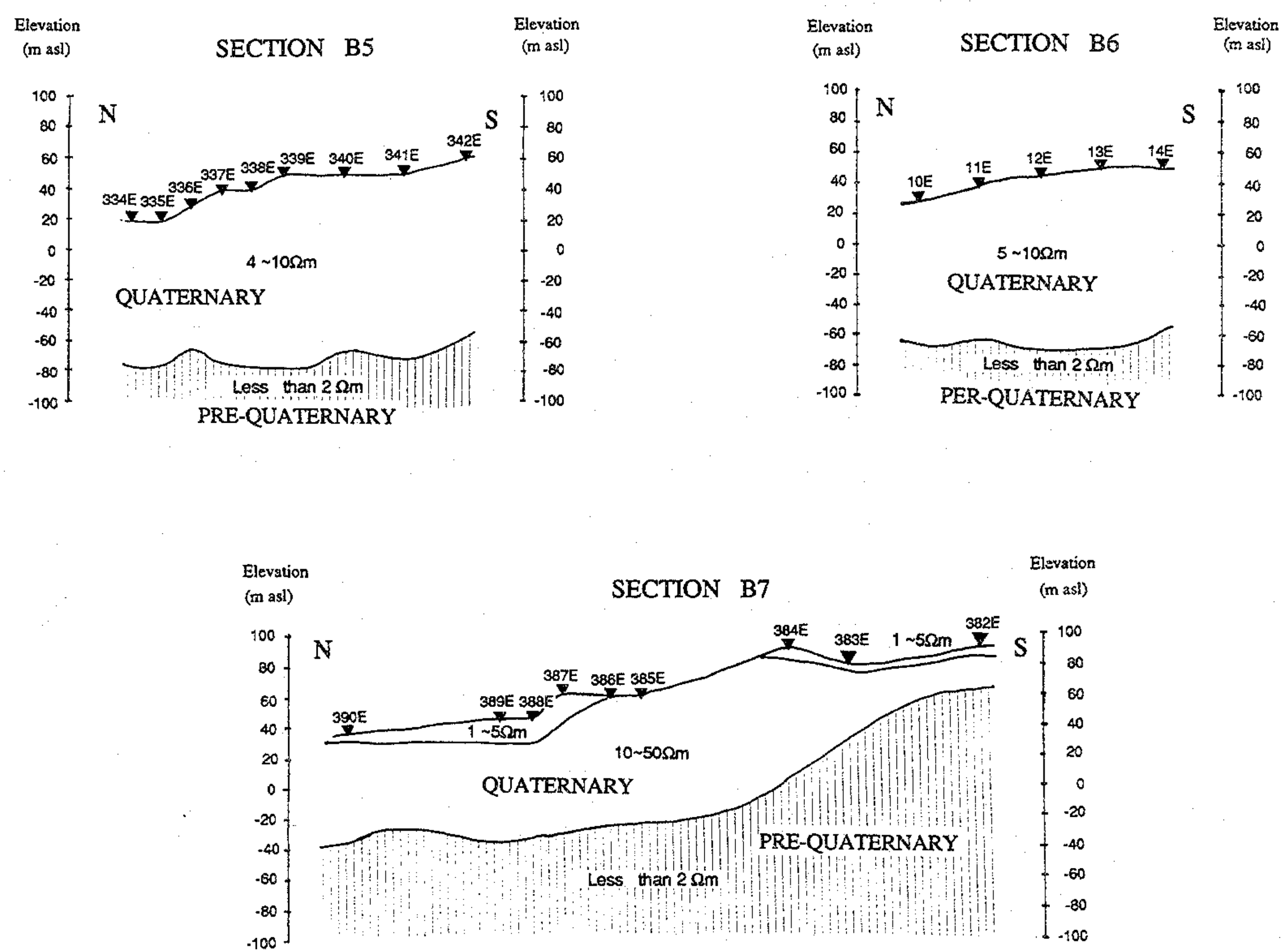


FIG. 7-2-8(2) RESISTIVITY PROFILE OF SECTION B5,B6,B7

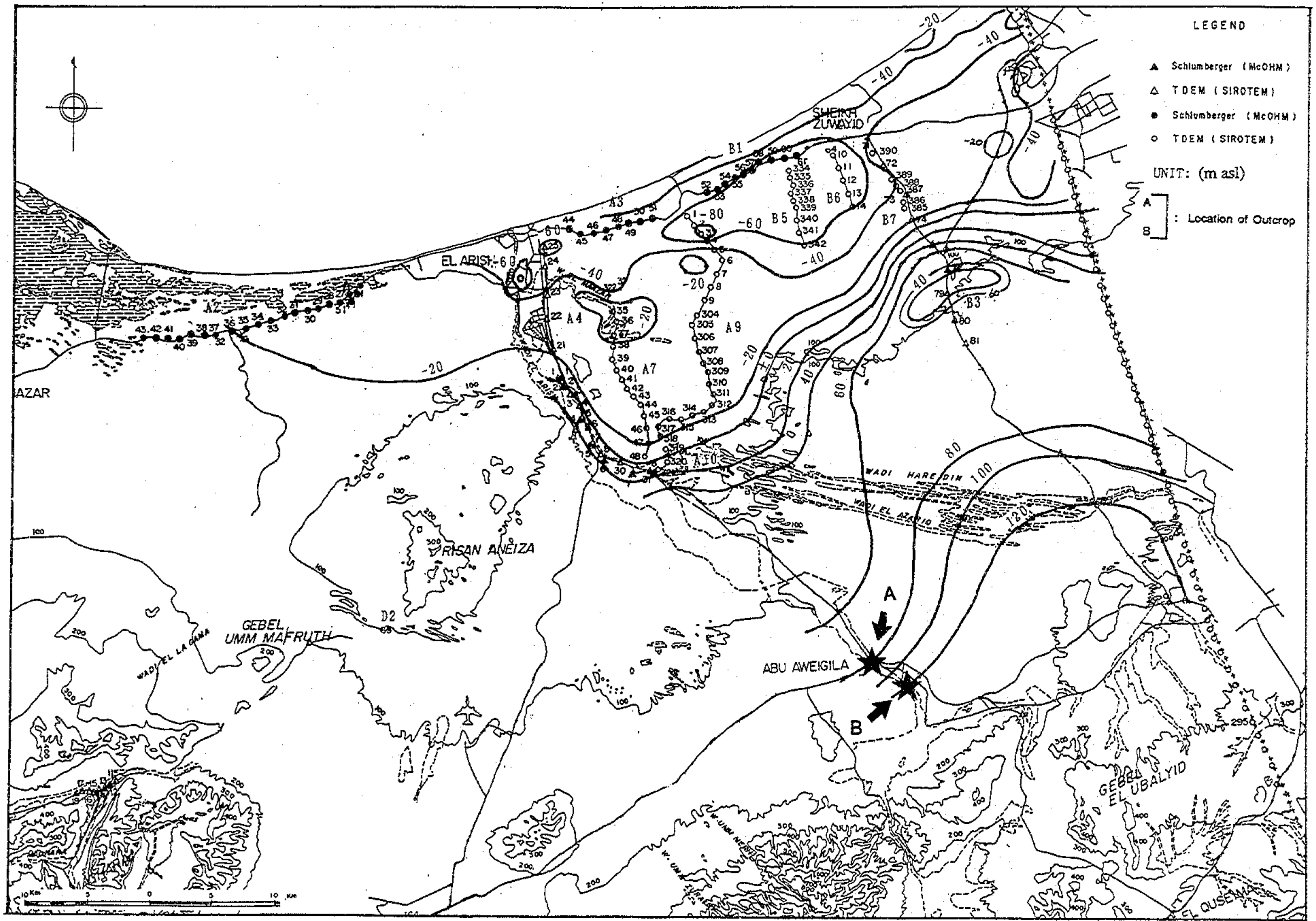


FIG. 7-2-9 BOTTOM OF QUATERNARY ON THE BASIS OF THE RESULTS OF THE ELECTRICAL RESISTIVITY AND WELL DATA ANALYSIS

7-2-2 Thickness of the Quaternary

Based on the above geologic cross sections, the base level of the Quaternary is estimated as shown in Fig. 7-2-9. There is an abrupt change in the gradient of the base of the Quaternary from Lehfen to an area about 10 km south of Rafah in an EW direction. The convergence of contour lines of the base elevation of the Quaternary suggests a fault in the southern part of Rafah.

A 13 to 20 km wide thick deposit of the Quaternary is assumed in the coastal plain from Wadi El-Arish to the international border with Israel. It is suggested that the subsidence movement took place in the area after that sedimentary basin occured along the coast. Elevation of the basal line of the Quaternary deposits is lower than -60 m asl.

At present, there are many wells concentrated at the lower part of the Wadi El-Arish alluvial plain and in the narrow strip of the coastal plain from Sheikh Zuwayid to Rafah although the extent of the Quaternary is far much broader than the present well field.

Comparing the base elevation of the Quaternary sediment and corresponding elevation of the ground surface, an isopach map of the Quaternary was drawn as shown in Fig. 7-2-10.

Since available water level data are limited, the isopach of the Quaternary aquifer is not obtainable. Instead, distribution of the Quaternary formation in the northeastern corner of the study area is shown in Fig. 7-2-10.

There is a thick Quaternary formation extending 20 km from the Wadi El-Arish to the east towards the international border with Israel; its coverage is approximately 800 km^2.

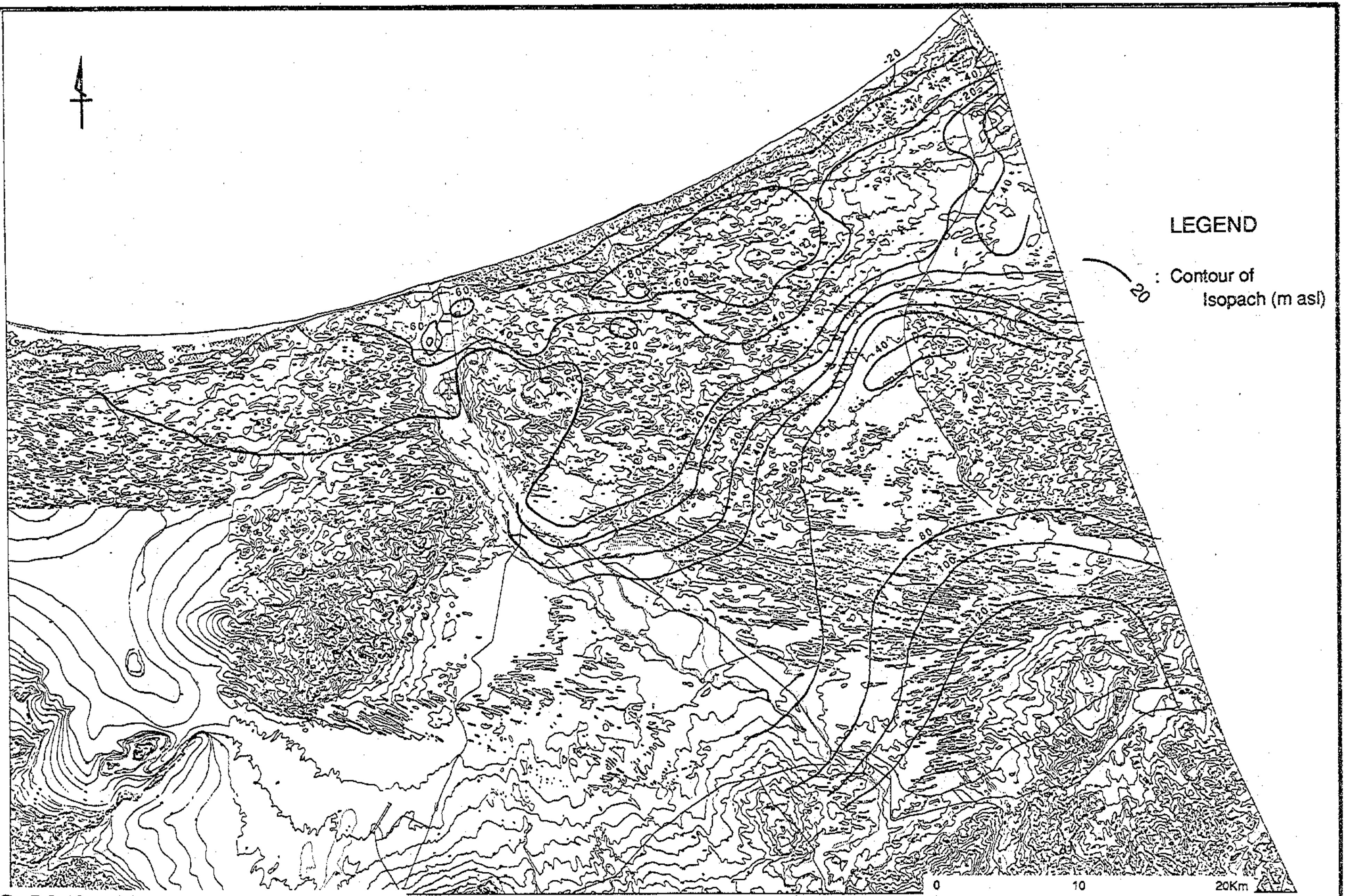


FIG. 7-2-10 ISOPACH OF QUATERNARY

7-2-3 Distribution of kurkar

Kurkar is a productive aquifer in the Quaternary in the study area, therefore, it is important to identify its distribution and thickness. This was one of the objectives of the test wells of this study. For this purpose, locations of the test wells were determined to confirm the extension of kurkar wards south from the coast.

After all, kurkar is detected at test wells J No. 2, 3, 5, 6, 7 and 8, but no kurkar is observed at test wells J No. 18 and 9 (Fig. 7-2-5, Fig. 7-2-6). Interpretation of both lithological profiles of existing wells and the bottom feature of the Quaternary basin lead to an estimated distribution of kurkar (see Fig. 7-2-11).

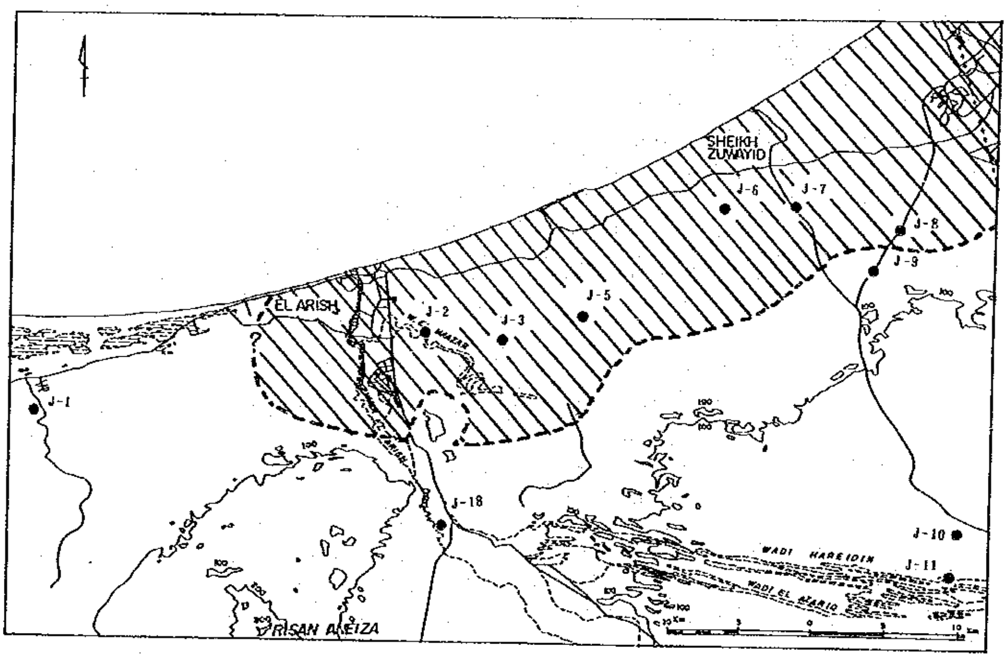


Fig. 7-2-11 DISTRIBUTION OF KURKAR

Kurkar having a width of 15 km is distributed in the coastal plain from El-Arish to the national border with Israel in the east. However, its western end is still subject to further confirmation.

7-3 Distribution of Pre-Quaternary

7-3-1 Geological Column

In order to establish standard geological profiles, detailed observations of geological sections were made at 12 sites in nine places. Through this observation, detailed lithology and stratigraphic sequence of the Lower Cretaceous, Upper Cretaceous and Tertiary were obtained (Chapter 6). These geologic columns are recognized as being standard in their vicinity. Reference was made to these columns for the reanalysis of lithologic profiles of existing wells to determine lithofacies and age. Reference is also made for determination of location of test wells to be sunk into the aquifers of the Pre-Quaternary.

7-3-2 Composite Columns

During the study more than one hundred geological profiles of existing wells were collected. Some of them had no description of lithology and/or age. Others revealed contradictions between geological profiles and logging curves. Since these wells were drilled by different institutions, well data were described differently. For these reasons, all collected well data were reviewed as shown in Technical Report IV.

As the first effort, contradictions between gamma ray logging and lithological description were eliminated. Take resistivity and gamma ray counting for example, shale indicates a relatively low resistivity but relatively high gamma ray counting, while sandstone indicates the opposite.

Results of the above interpretation were further analyzed by referring to samples of slime and the standard geological columns in the vicinity since the difference between shale and marl could not be distinguished by well logging. It should be noted that the Cenomanian is represented by dolomite, dolomitic limestone and limestone, and the Turonian is absent in some places, and the Senonian is represented by marl and chalk.