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No. 2

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

WATER RESOURCES RESEARCH INSTITUTE
NATIONAL WATER RESEARCH CENTER
MINISTRY OF PUBLIC WORKS AND WATER RESOURCES
THE ARAB REPUBLIC OF EGYPT

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT

MAIN REPORT

MARCH 1999

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO

IN ASSOCIATION WITH

SANYU CONSULTANTS INC., TOKYO

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In this report, project costs are estimated based on March 1998 prices with an exchange rate of US$1.00 = Egyptian Pound (LE) 3.39 = Japanese Yen ¥ 128.69

PREFACE

In response to a request from the Government of the Arab Republic of Egypt, the Government of Japan decided to conduct a master plan study on the South Sinai Groundwater Resources Study and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched a study team headed by Mr. Yasumasa YAMASAKI, Pacific Consultants International (PCI) and consist of PCI and Sanyu Consultants Inc., to Egypt five times between March 1996 and March 1999.

The team held discussions with the officials concerned of the Government of Egypt, and conducted field surveys at the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

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

Finally, 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 Study.

March 1999

Kimio FUJITA
President
Japan International Cooperation Agency

SOUTH SINAI GROUNDWATER RESOURCES STUDY
IN
THE ARAB REPUBLIC OF EGYPT

March 1999

Mr. Kimio Fujita
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

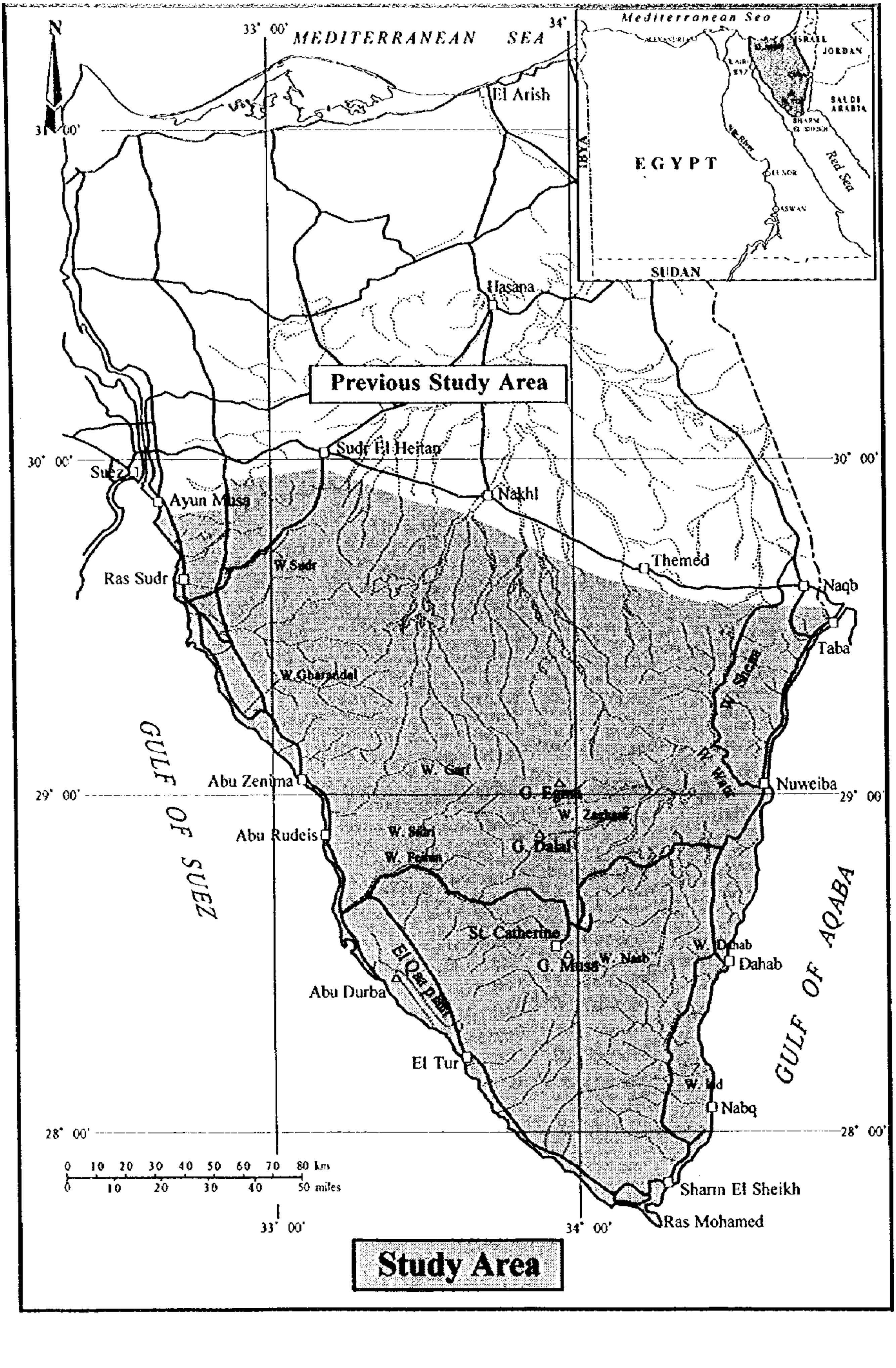
We are pleased to submit the final report entitled "SOUTH SINAI GROUNDWATER RESOURCES STUDY ". The Study Team has prepared this report in accordance with the contract between Japan International Cooperation Agency and Pacific Consultants International in association with Sanyu Consultants Inc.

This report presents the results of the evaluation of the groundwater resources development potential and the groundwater development plan. In addition, a set of hydrogeological map and groundwater resources evaluation map of whole Sinai Peninsula were prepared as "Water Resources Maps" and submitted herewith.

All members of the Study Team wish to express grateful acknowledgments to the personnel of your Agency, Ministry of Foreign Affairs, and Embassy of Japan in Egypt, and also to officials and individuals of the Government of Egypt for their assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the implementation of NPDS (National Plan for Development of Sinai) and other relevant projects.

Yours faithfully,

Yasumasa YAMASAKI
Team Leader
South Sinai Groundwater Resources Study
in The Arab Republic of Egypt



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Themed
Naqb
Taba
Ras Sudr
W. Sadr
W. Gharandal
W. Sheira
W. Watir
Nuweiba
Abu Zenima
W. Garf
G. Egma
W. Zeghara
Abu Rudeis
W. Sidri
W. Feiran
G. Dalal
St. Catherine
G. Musa
W. Nasb
W. Dahab
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Abu Durba
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El Tur
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Sharm El Sheikh
Ras Mohamed
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GULF OF AQABA
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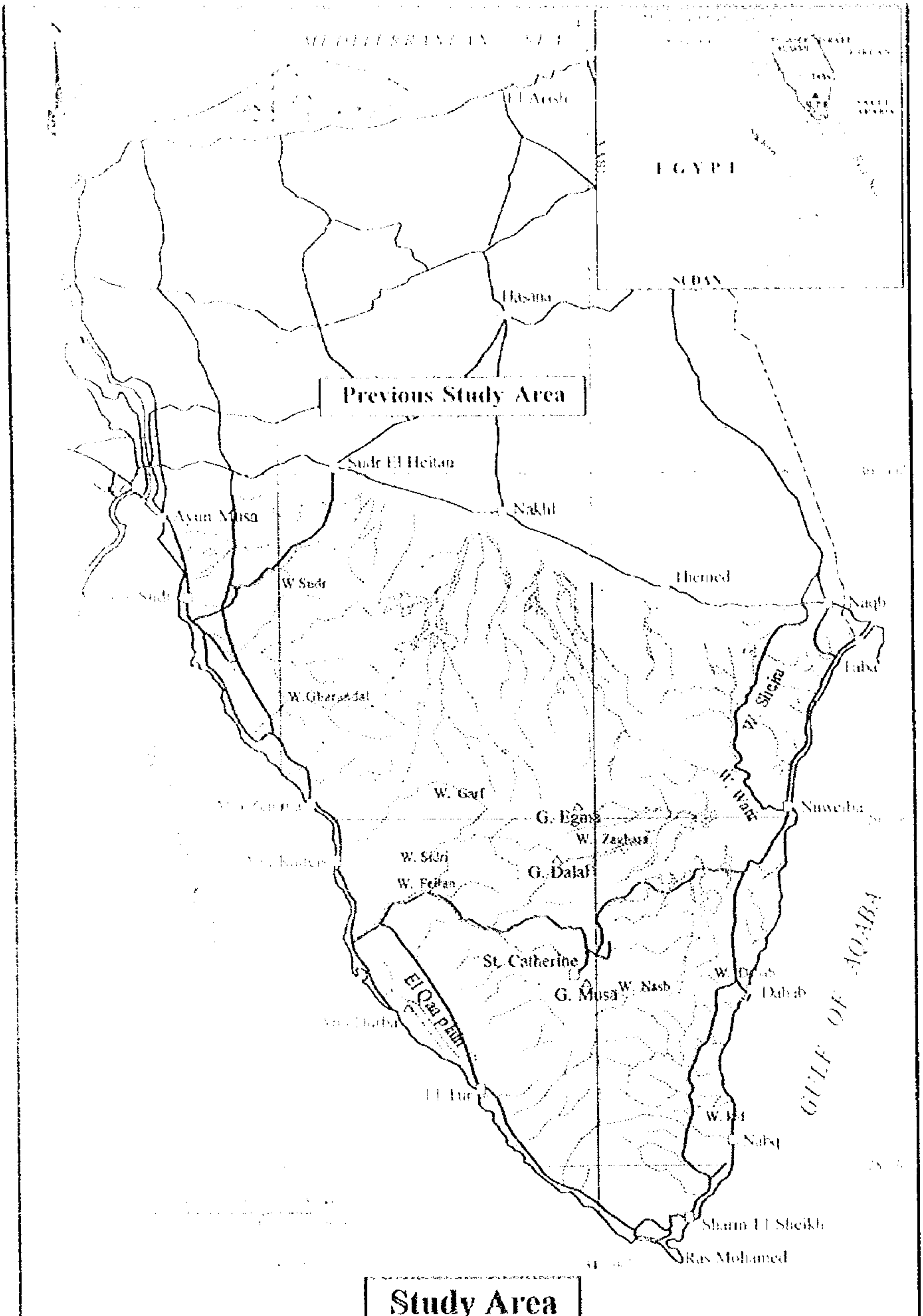
SAUDI ARABIA
EGYPT
LIBYA
SUDAN
Red Sea


EGYPT
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GULF OF AQABA
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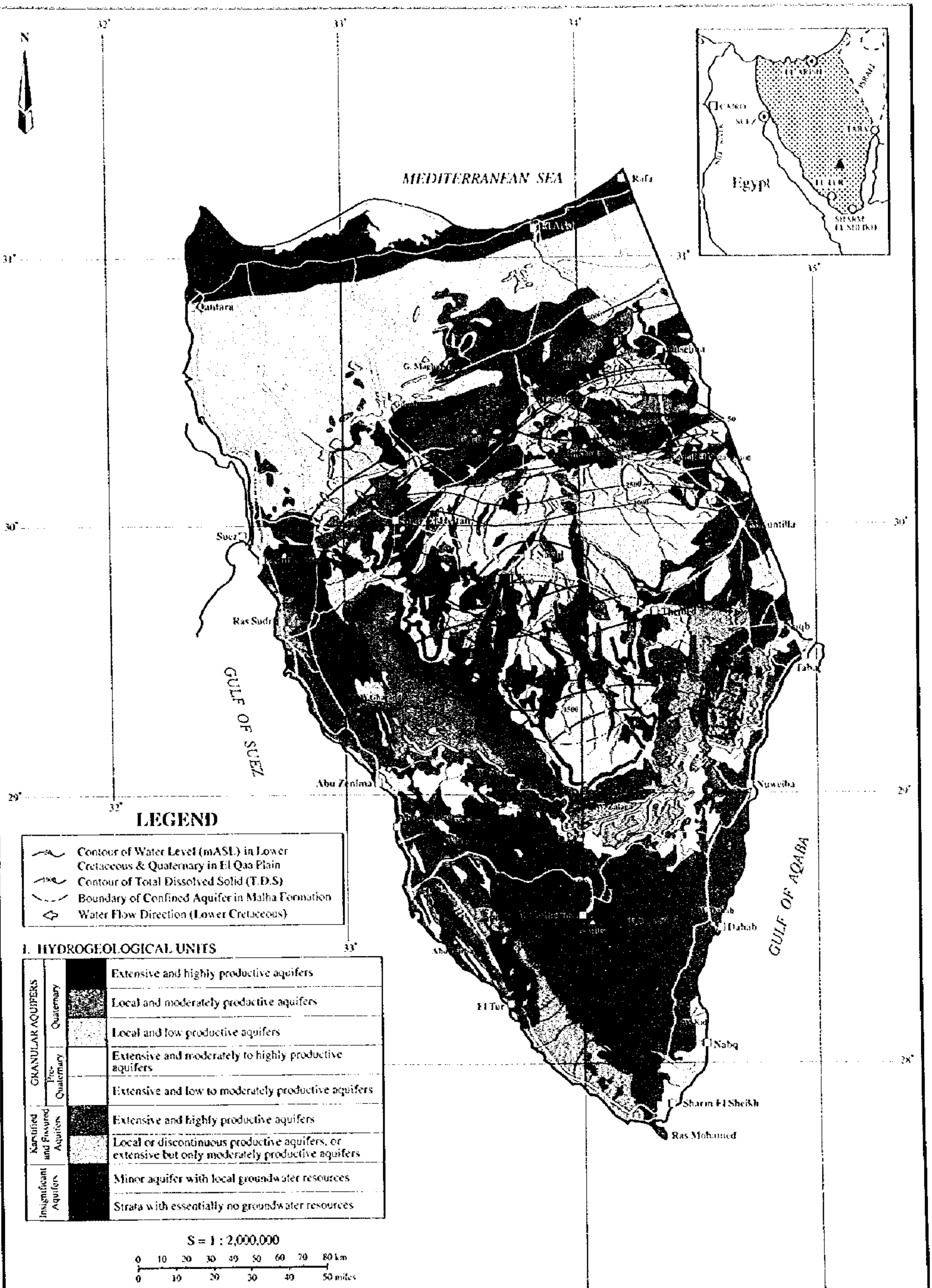
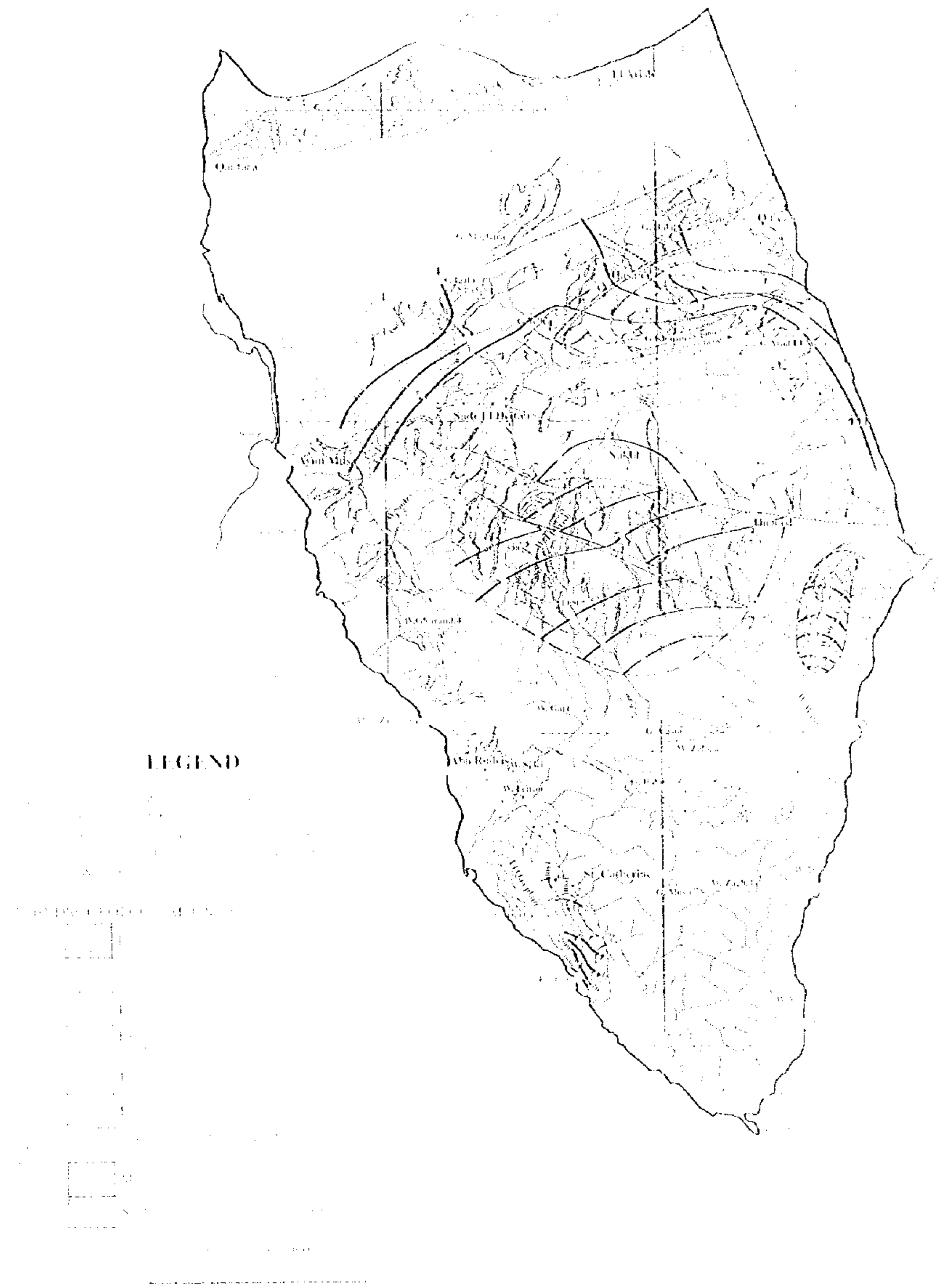
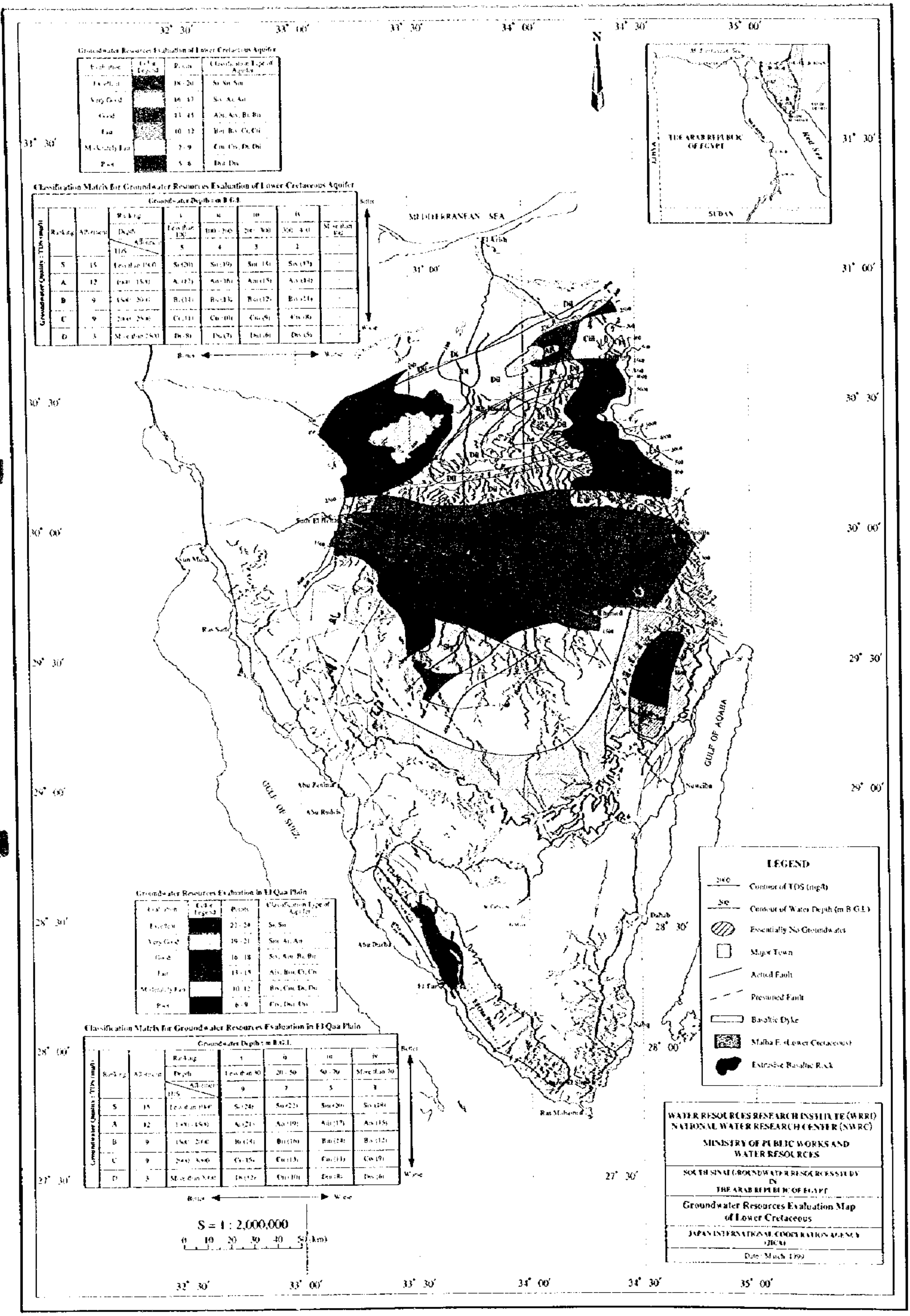
Study Area

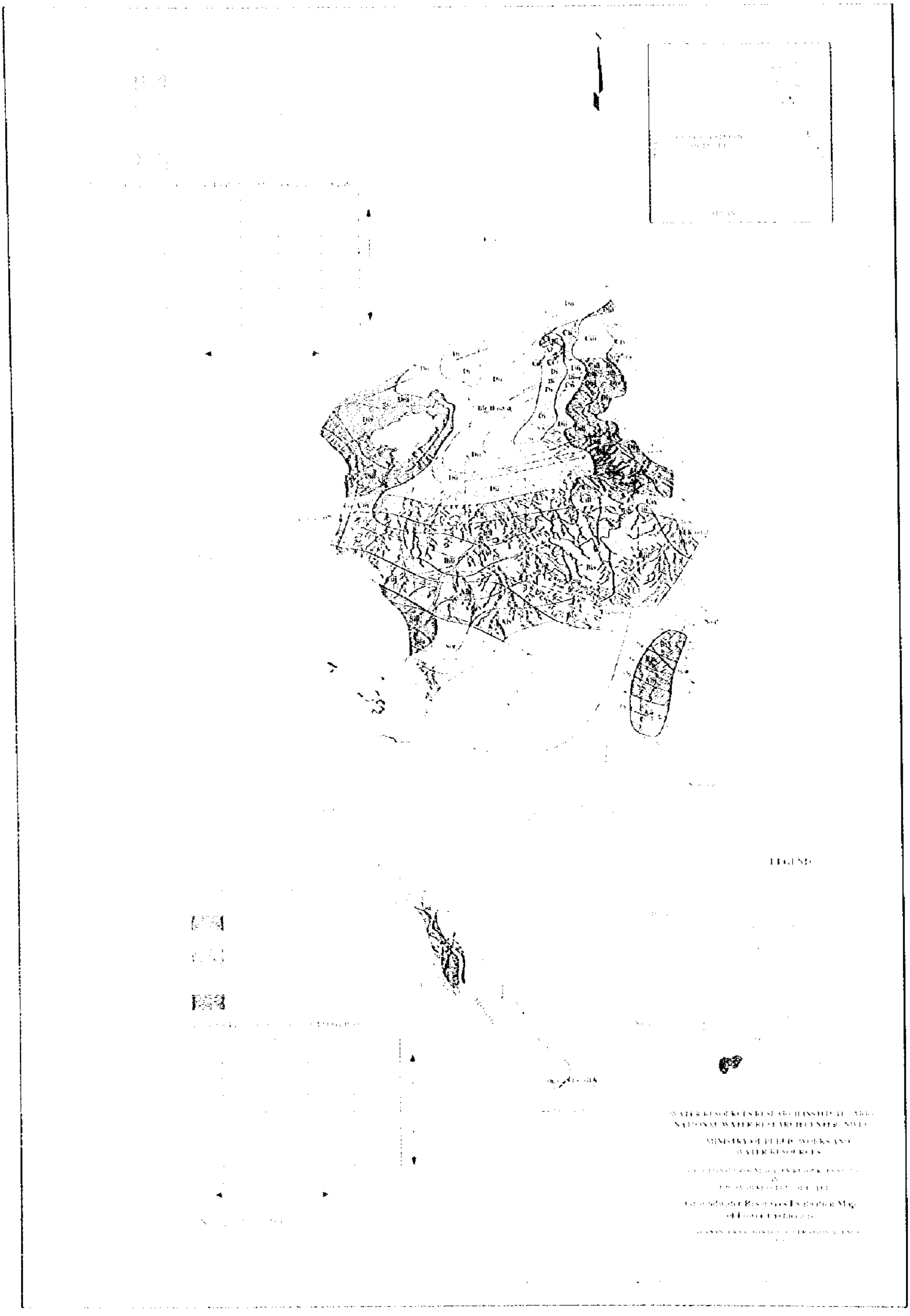


Hydrogeological Map of Sinai Peninsula



Hydrogeological Map of Sinai Peninsula


Groundwater Resources Evaluation of Lower Cretaceous Aquifer
Classification Matrix for Groundwater Resources Evaluation of Lower Cretaceous Aquifer
MEDITERRANEAN SEA
THE ARAB REPUBLIC OF EGYPT
SUDAN
Red Sea
GULF OF SUEZ
GULF OF AQABA
El Arish
Ras Sudr
Abu Zenima
Abu Rudeis
Nuweiba
Dahab
El Tur
Ras Mohamed
Groundwater Resources Evaluation in El Qaa Plain
Classification Matrix for Groundwater Resources Evaluation in El Qaa Plain
LEGEND
Contour of TDS (mg/l)
Contour of Water Depth (m B.G.L)
Essentially No Groundwater
Major Town
Acted Fault
Presumed Fault
Basaltic Dyke
Malha F. (Lower Cretaceous)
Extrusive Basaltic Rock
S = 1 : 2,000,000
0 10 20 30 40 50 (km)
WATER RESOURCES RESEARCH INSTITUTE (WRRI)
NATIONAL WATER RESEARCH CENTER (NWRC)
MINISTRY OF PUBLIC WORKS AND WATER RESOURCES
SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT
Groundwater Resources Evaluation Map of Lower Cretaceous
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
Date: March 1999

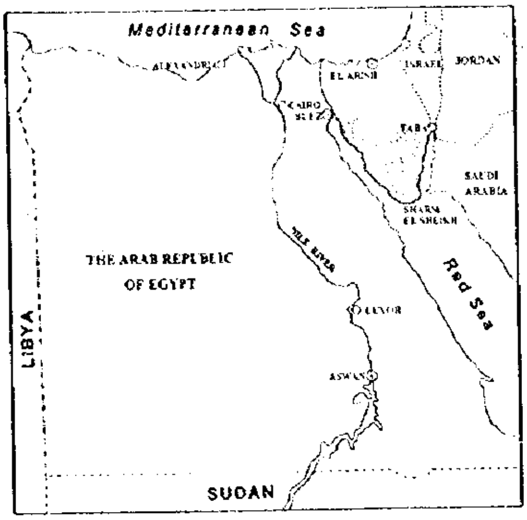

LEGEND

OUTLINE

Background of Study

Egypt is mainly covered by desert and only 4 % of its land is arable, mainly the alluvial plain of the Nile and its delta. In order to cope with the rapid population increase and urbanization, moreover, the controlled international water right of the Nile, the government of Egypt has been pressed into the development of the Sinai Peninsula based on the "National Plan for Development of Sinai" (NPDS) from 1994 to 2017.

There are three alternatives of water sources for Sinai Development, namely, (1) Nile water transmission, (2) Groundwater development and (3) Desalination of seawater. The second one has so much unknown information that it is indispensable to evaluate the potential of groundwater resources for the development of the Sinai Peninsula.



< Location map of Study Area >

The potential of groundwater resources in the Northern part of Sinai was estimated within the "North Sinai Groundwater Resources Study" conducted by Japan International Cooperation Agency (JICA) in the period between 1988 and 1992. However, the potential of groundwater resources in South Sinai has not been evaluated because the available data were limited.

Under these circumstances, the Government of the Arab Republic of Egypt requested the Government of Japan to conduct a water resources development study for South Sinai.

Study Area

The study area covers the South Sinai Governorate (approximately 34,000 km^2) as shown in the opening page (location map of Study Area).

Objectives of Study

The main objectives of the Study are listed as follows;

(1) To prepare a series of water resources maps to evaluate groundwater potential in South Sinai.

(2) To formulate water resources development master plan in South Sinai.

(3) To perform the technology transfer to Egyptian counterpart personnel in the courses of the Study.

(4) To up-date the hydrogeological map of North Sinai basically based on the data prepared by WRRI (Water Resources Research Institute).

. **Conclusion**

(1) Through the Study, Hydrogeological Map and Groundwater Evaluation Map has been prepared covering the both South Sinai and North Sinai. (Refer to frontispieces and printed maps) These investigations included the following:

a) Revision of the Geological map for South Sinai.

b) Preparing a complete inventory for all the existing wells in the study area.

c) Conducting geophysical surveys, which resulted in the preparation of geoelectric, profiles for Egma and El Tih Plateaux, El Qaa Plain and Major wadi areas, and the delineation of the basement of the Lower Cretaceous in the Central Sinai zone.

d) A total of 6351m of test wells were drilled concentrating mainly in the El Tih and Egma plateau where no test wells had been drilled before. The well drilling program included observation of stratigraphy, pumping tests, water quality analysis, age dating analysis, grain size analysis and fossil analysis.

The compilation of the above mentioned two maps is the main and most important output of this Study because they serve as the basis for any future groundwater development and insure efficient use of investment in this field.

(2) The study concluded that the groundwater volume in the Main Block of the Lower Cretaceous aquifer is about 100 billion cubic meters of good quality water (TDS less than 1500 mg/l, drinking water quality). Hydrogeological analysis and age dating analysis revealed that this water is non-renewable fossil water. Estimating that about 14% of this stored water could be tapped for consumption, the available resources could meet the water demand level of the target year of NPDS of about 50×10^6 m^3/year for more than 280 years.

(3) Due to the importance of the aquifer in the El Qaa Plain because it is the main water resource for the South Sinai Capital of El Tur City, detail investigation of that aquifer

was made including computer simulation. The results of the study revealed that due to the limited recharge of that aquifer, it could meet the water demand level of El Tur City in 2007 without serious saline water intrusion. Water demand beyond that level should be met through as water resources such as Nile water or desalination of seawater.

(4) A water development scheme based on the water demand of the NPDS is proposed. Preliminary investigation of the feasibility of the proposed projects has been conducted. Although the results of the feasibility show that the EIRRs for the proposed projects are relatively low, this does not mean that the proposed projects should be discarded. In arid zones such as Sinai, the availability of groundwater resources could be one of the most important factors for the execution of the projects. Since the Study concluded that groundwater development potential of the Quaternary aquifer in El Qaa Plain and the Lower Cretaceous aquifer could meet the water demand of NPDS, the proposed projects are worth to execute as basic infrastructure for NPDS.

(5) An Initial Environmental Examination was conducted for the proposed projects which revealed that the implementation of the proposed projects will not seriously affect the environment and thus an Environment Impact Assessment is not required.

(6) Existence of a new groundwater aquifer has been confirmed at the southern reaches of El Qaa Plain.

Recommendations

(1) New groundwater aquifer was confirmed in the south El Qaa Plain. However, its distribution and hydrogeological features shall be studied in detail.

(2) Detailed feasibility study including the assessment of the water supply impact on the NPDS should be started as soon as possible. Such study should cover both groundwater and surface as well. The study should include the establishment of groundwater monitoring system to avoid excessive extraction. The study for wastewater treatment and disposal should be also included in the schemes.

(3) The availability of good quality groundwater at Central Sinai should encourage the settlement of Bedouin in that area. This in return will have a very positive impact on the living standards of these people. More comprehensive plans should be prepared for the Bedouin settlement in central Sinai.

(4) Number of production well is increasing in both South and North Sinai. They are tapping groundwater in the Lower Cretaceous Aquifer. Groundwater in the Lower Cretaceous Aquifer is essentially of fossil water although a little recharge is expected

from the surface water. Groundwater development of the Lower Cretaceous Aquifer will lead recession of groundwater level. Considering this situation, groundwater development in Sinai shall be carried out under proper control system. Especially, careful attention shall be paid to the change of groundwater level in the development. From this point of view, groundwater level monitoring shall be properly continued using automatic water gauges installed in the Test Wells.

TABLE OF CONTENTS

List of Tables

List of Figures

ABBREVIATION

ASL	: above the sea level
BGL	: below the ground level
BRGM	: Bureau de Recherches Geologiques et Minieres
CAPMAS	: Central Agency for Public Mobilization and Statistics
CBE	: Central Bank of Egypt
EC	: Electric Conductivity
EGSMA	: Egyptian Geological Survey and Mining Authority
ERSAP	: Economic Reform and Structural Adjustment Program
G.	: Gebel (Mountain)
GDP	: Gross Domestic Product
GPS	: Global Positioning System
GVA	: Gross Value Added
IMF	: International Monetary Fund
JICA	: Japan Intentional Cooperation Agency
LGU	: Local Government Unit
MAE	: Meteorological Authority of Egypt
NPDS	: National Plan for Development of Sinai
NSGRS	: North Sinai Groundwater Resources Study
RBA	: Roads and Bridge Authorities
RIWR	: Research Institute for Water Resources (Ex-WRRI)
SDS	: Sinai Development Study
SSGRS	: South Sinai Groundwater Resources Study
T	: Temperature
TDS	: Total Dissolved Solid
TEM	: Transient Electro Magnetic
USAID	: United States Agency for International Development
USGS	: United States Geological Survey
W.	: Wadi (Arid River)
WRRI	: Water Resources Research Institute
WRS	: Water Resources Study

CHAPTER I INTRODUCTION

1.1 Background of Study

Egypt is mainly covered by desert and only 4 % of its land is arable, mainly the alluvial plain of the Nile and its delta. In order to cope with the increasing population, the government of Egypt has been pressed into the development of the Sinai Peninsula which have high potentials in mineral resources, tourism, and agricultural development. Under these circumstances, various kinds of international cooperation have been undertaken in the Sinai Peninsula.

The government of Egypt decided to implement the "National Plan for Development of Sinai" (NPDS) starting from 1994. The plan aims at achieving comprehensive development of Sinai over the period from 1994 to 2017.

The Sinai Peninsula is located in the east of Egypt and is totally composed of desert except for the northeastern area. Because of its extremely low rainfall, no surface water is available. Only small amount of spring and groundwater are extracted for drinking and irrigation use.

Water transmission from the Nile, development of groundwater resources and desalination of sea water are considered to be the future water resources in the Sinai Peninsula. Out of the three, water transmission from the Nile is now under implementation.

It is indispensable to evaluate the potential of groundwater resources for the development of the Sinai Peninsula. The potential of groundwater resources in the Northern part of Sinai was estimated within the "North Sinai Groundwater Resources Study (NSGRS)" conducted by Japan International Cooperation Agency (JICA) in the period between 1988 and 1992. However, the potential of groundwater resources in South Sinai was not evaluated because the available data were limited.

Under these circumstances, the Government of the Arab Republic of Egypt requested the Government of Japan to conduct a water resources development study to evaluate the water resources potential in South Sinai in order to cope with the increasing future water demand of the area.

1.2 Study Area

The study area was determined in the Scope of Work agreed upon between the both government on 10 October 1995. It will cover the South Sinai Governorate (approximately 34,000 km^2) as shown in the opening page (location map of Study Area).

1.3 Objective of Study

The objective of the Study are defined in the above mentioned Scope of Work as follows;

(1) to prepare a series of water resources maps to evaluate groundwater potential in South Sinai.

(2) to formulate a water resources development master plan in South Sinai.

(3) to perform technology transfer to Egyptian counterpart personnel in the courses of the Study.

(4) to up-date the hydrogeological maps for North Sinai depending on the data prepared by WRRI.

1.4 Previous Studies

Many groundwater resources development studies were undertaken in the Sinai Peninsula by various agencies. The major studies are Sinai Development Study (SDS) by USAID and Sinai Water Resources Study (SWRS) by RIWR in cooperation with EC. In addition to these, WRRI has been executed active groundwater resources studies in major wadis represented by South Sinai Water Resources Development Project (SSWRDP) in South Sinai.

SDS completed in 1984 and prepared a comprehensive development study concerning Sinai Peninsula proposing the development schemes for the migration to Sinai from 1983 to 2000. SDS classified the type of aquifers and recommended further detailed studies to evaluate the potential of water sources in Sinai. The study evaluated a certain degree of surface water and groundwater was available, however, the study recommended to transmit water from the Nile River.

SWRS was implemented by RIWR in cooperation with EEC to assess the groundwater resources in Sinai Peninsula. The study summarized the hydrogeological characteristics of aquifers and detailed study was concentrated on the Quaternary Aquifers in El Qaa Plain. A lot of boreholes were drilled mainly in the Maghara area and the coastal plain of North Sinai area. In SWRS, groundwater simulation were carried out on the aquifers in El Qaa Plain, El Arish area and Romana-Bir El Abd area. A numerical modeling of the Lower Cretaceous aquifer was tried but it was not completed due to lack of exact data and information.

Prior to the current Study, North Sinai Groundwater Resources Study (NSGRS) was executed by JICA during the period from 1988 to 1992. A total number of 19 test wells were drilled in North Sinai. Seven (7) wells out of these were drilled into the Lower Cretaceous sandstone.

The study estimated the groundwater storage in the Lower Cretaceous and concluded that it was recharged in the South Sinai area approximately 20,000 years ago using C-14 dating of groundwater.

As the results, the study prepared a series of hydrogeological maps for North Sinai and recommended to expand the study to South Sinai to evaluate the groundwater resources for the whole Sinai.

SSWRDP was conducted by WRRI under the finance by the Italian Government and concluded in 1996 directing the main emphasis to the Wadi Watir area. The study is composed of geological studies, geophysical investigation, hydrological studies, groundwater development strategy, geochemical investigations, environmental and economical aspects, design of proposed dams and tender documents for proposed projects.

Finally three (3) major projects were proposed to utilize the water resources in the Wadi Watir area: To construct five (5) storage dams and 17 detention dams to prevent flood disasters, To construct seven (7) deep wells to develop Lower Cretaceous aquifer and To develop and utilize Ain Furtaga spring.

WRRI has been conducting groundwater resources studies in South Sinai by geological and geophysical surveys. Based on the results of these studies, a number of production wells and piezometers were drilled penetrating into both Quaternary Aquifers and Pre-Quaternary Aquifers revealing hydrogeological characteristics of aquifers. Furthermore, active groundwater development is going on in El Qaa Plain and other areas by WRRI or under the supervision of WRRI collecting many hydrogeological data.

1.5 Implementation of Study

The Water Resources Research Institute (WRRI[1]) of the National Water Research Center (NWRC) was assigned as the counterpart organization from the Government of Egypt, while the Japan International Cooperation Agency (JICA) was assigned as the official agency responsible for the implementation of the technical cooperation program

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1 : Research Institute for Water Resources (RIWR) was the counterpart agency in the former JICA Study. The name was changed to WRRI in 1994.

of the Government of Japan.

The Study has been conducted by the Japanese study team dispatched by JICA together with the Egyptian counterpart staff. The Study was commenced in March 1996 and completed in March 1999. Total schedule of the Study is shown in Table 1.5-1. Contents and flow chart of the Study are shown in Fig. 1.5-1.

The Study consists of hydrological study, hydrogeological study, evaluation of groundwater development potential, water use, formulation of groundwater development plan, socio-economic evaluation and environmental aspects. Following items of tests and analyses were included as a part of the field survey.

Item	Quantity	
Test well drilling	Seven (7) wells	6,351 m
Pumping test		
- by air lifting	Seven (7) wells	-
- by submersible pump	Six (6) wells	-
Installation of water level gauge	Six (6) wells	Six (6) gauges
Grain size analysis	Six (6) wells	134 samples
Microfossil analysis	Six (6) wells	273 samples
Isotope analysis	Six (6) wells	12 samples
Water quality analysis	Six (6) wells	42 samples

The members involved in the Study are listed below.

Name	Assignment
<JICA Study Team>	
Mr. Yasumasa YAMASAKI	Team Leader /Groundwater Development Planner
Mr. Norifumi YAMAMOTO	Hydrogeologist (A)
Mr. Yusuke OSHIKA	Hydrogeologist (B)
Mr. Motomu GOTO	Remote Sensing Expert
Dr. Mahbub A. K. M. REZA	Hydrologist/Water Balance Analyst
Mr. Yuichi HATA	Water Quality Expert
Mr. Masaru FUJITA	Geophysicist (A)
Mr. Kunio KIMURA	Geophysicist (B)
Mr. Mamoru NAKAMURA	Drilling Expert (A)
Mr. Satoshi ARAYA	Drilling Expert (B)
Mr. Katsuhiro FUJISAKI	Groundwater Simulation Expert
Mr. Hiroaki MIYAKOSHI	Water Supply Planning Expert
Mr. Jiro YABE	Implementation Planner/ Cost Estimator
Mr. Tatsuo TASHINO	Financial/Economic Analyst
Mr. Takashi KITAGUCHI	Environmental/ Ecological Expert
Mr. Takuya OMURA	Coordinator (Mar. 1996-May 1996)
Mr. Kyoichi SUGIMOTO	Coordinator (May 1996-Sep.1998)
<WRRI Staff>	<Title>
Prof. Dr. Mohamed Samir Mahmoud Farid	Director of WRRI
Mr. Medhat El Bihery	Hydrogeologist
Ms. Hoda Sharaf	Hydrogeologist
Dr. Ahmed Hassan Fahmi	Hydrologist
Dr. Abdel Hafez Hassan	Hydrogeologist
Dr. Hatem Abdel Rahman	Groundwater Hydrologist
Mr. Abd El Haq	Hydrogeologist
Mr. Shawky Sami Hassan	Hydrogeologist
Mr. Abdo Gasser	Geologist
Mr. Mostafa Mohamed El Kharakany	Survey Engineer
Ms. Sanaa Ibrahim Israel	Database
Mr. Ahmed Maher Nassif	Geologist
Mr. Abd El Aziz	Environmentalist
Ms. Amal Moustafa Azab	Hydrologist
<Egyptian Consultant>	<Title>
Mr. Mohamed Tag El-Din El-Deftar	Senior Geologist

1.6 Composition of Report

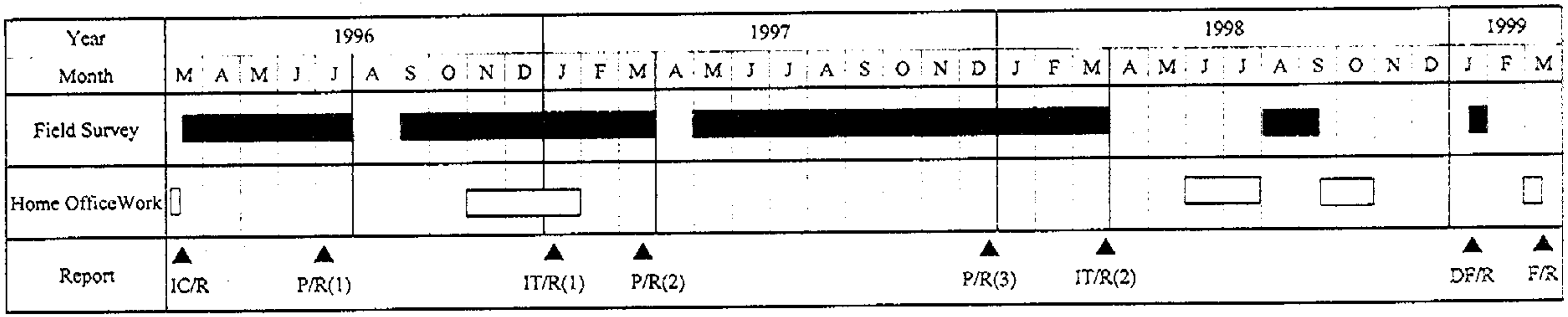
This report consists of four (4) volumes: Executive Summary Report, Main Report, Supporting Report and Data Book.

The Main Report presents the summarized results of all the studies. In Chapter II, the basic information for the Study is described. Hydrogeology and groundwater development potential are presented in Chapter III and IV. Water demand and groundwater development plans are described in Chapter V and VI. In Chapter VII, proposed development plans are evaluated. Chapter VIII deals with the conclusion and recommendations.

Detailed study results are described in the Supporting Reports and Data Book. The contents of the Supporting Report are as follows;

In Chapter II through VIII, the basic information for the Study is described. Water supply, demand and groundwater development potential are described in Chapter IX to XII. Groundwater development plans are described in Chapter XIII. Environmental aspect and Socio-Economy are described in Chapter XIV and XV, respectively. Chapter XVI deals with the Project Evaluation.

Table 1.5-1 Total Schedule of the Study



IC/R	: Inception Report
P/R	: Progress Report
IT/R	: Interim Report
DF/R	: Draft Final Report
F/R	: Final Report

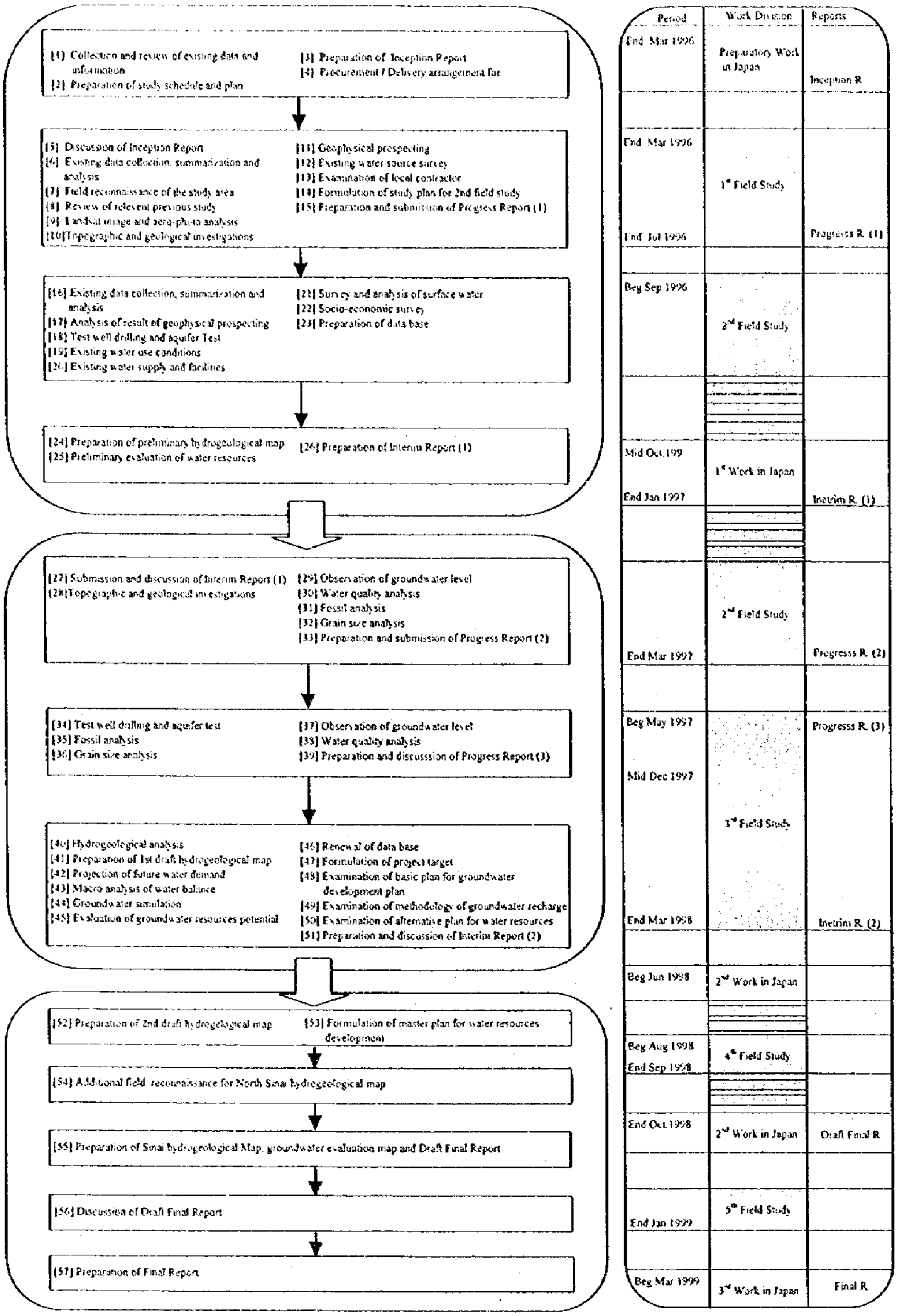


Fig. 1.5-1 Flow Chart of the Study

CHAPTER II GENERAL DESCRIPTION OF STUDY AREA

2.1 Geomorphology

2.1.1 General Geomorphology

The Sinai Peninsula covers an area of 61,000 km^2 in a shape of triangle of which apex is at the southern end of the peninsula and its base is facing to the Mediterranean Sea in the north. The peninsula is geographically isolated from the main land of Egypt by the Suez Canal and the Gulf of Suez in the west. The Gulf of Aqaba and the international border with Israel limit the eastern end of the peninsula.

Four (4) major geomorphological units are identified in the area from the south to the north;

- South Mountain
- Central Plateau
- Syrian Arc Zone
- Northern Coastal Plain

Among them, South Mountain and Central Plateau are recognized in South Sinai (the Study area).

The South Mountain is a mountainous unit consisting of highly dissected basement rocks with steep slopes and intricate landforms. The highest peak rises on the Gebel Catherine at an altitude of 2,641 m. There are some high peaks exceeding 2,000 mASL in the area. Therefore, many wadis develop deeply incising mountain slopes and flow into either the Gulf of Suez or the Gulf of Aqaba. Representative wadis are the Wadi Watir and Wadi Feiran.

The Central Plateau is located in the north of the South Mountain. There are two plateaus: The El Tih Plateau forms a tableland and is overlain by the Egma Plateau. Those plateaus gently inclined to the north.

In addition, there is the El Qaa Plain in the southwestern side of the peninsula. It was formed in a area between the South Mountain and the mountain range of the Abu Durba.

Furthermore, topography of South Sinai is subdivided into following eight (8) categories by LANDSAT image analysis, aerial photograph interpretation and field survey. Geomorphological Map is presented in Fig. 2.1-1.

(1) Sinai Plateau (SP)
(2) El Tih Plateau (TP)
(3) Egma Plateau (TP)
(4) Sedimentary Hills (SH)
(5) Basement Hills (BH)
(6) Flat Plain (FP)
(7) Alluvial Fan and El Qaa Plain (AF)
(8) Terrace (TR)

2.1.2 Geomorphological Description

1) Sinai Plateau (SP)

The Plateau forms the core of the peninsula, situated near its southern end, and consists of an intricate complex of high and very rugged topographic feature. The Plateaux are formed by igneous and metamorphic rocks of Proterozoic age. The highest peak, Gebel Catherine, attains an altitude of 2,641 m ASL. Many other peaks and crests rise above 2,000 m. Numerous incised wadis dissect this plateau.

2) El Tih Plateau (TP)

The plateau forms a tableland known as Gebel El Tih and consists of almost horizontal strata that constitute a distinct geomorphological unit. The plateau is bounded on its east, south and west sides by vertical scarps.

3) Egma Plateau (EP)

The Plateau forms the tableland of the still higher plateau known as Gebel Egma in the area of the El Tih Plateau. It is formed by Paleocene and lower Eocene sedimentary rocks. The Wadi El-Arish, the largest wadi in whole Sinai, originates from this plateau.

4) Sedimentary Hills (SH)

There are ranges of hills along the west side of scarps of the El Tih Plateau. They are formed by Mesozoic and Tertiary sedimentary rocks.

5) Basement Hills (BH)

Isolated hills are distributed in the Abu Durba area and the south of El Qaa Plain. They are composed of Precambrian Basement rocks.

6) Flat Plain (FP)

The area in the middle to upstream of the Wadi Garf is characterized by flat topographic feature. Same features are recognized in the area between Ras Sudr and Abu Zenima. They are formed by Quaternary gravel and Wadi sediments.

7) Alluvial Fan and El Qaa Plain (AF)

(1) Alluvial Fans (AF)

Alluvial Fans are formed at the mouths of wadis and are formed by alluvial fan deposits. They are mainly distributed in Ras Sudr, Abu Rudeis, and Nuweiba area, and mouths the Wadi Wadi Sidri, Wadi Feiran, Wadi Kid, Wadi Dahab, Wadi Watir, etc.

(2) El Qaa Plain (QP)

The plain covers an area of 3,900 km^2 trending NW-SE and is widely expanded in the coastal area, southwestern part of the Sinai Plateau. The plain is composed of terrace deposits, gravel deposits, alluvial fans and wadi deposits. Northern area of El Qaa plain is located between the igneous and metamorphic mountains and the hill of the Abu Durba area. On the one hand, southern area of the plain is directly facing to the Gulf of Suez.

8) Terrace (TR)

River terrace is mainly formed along the Wadi El Arish.

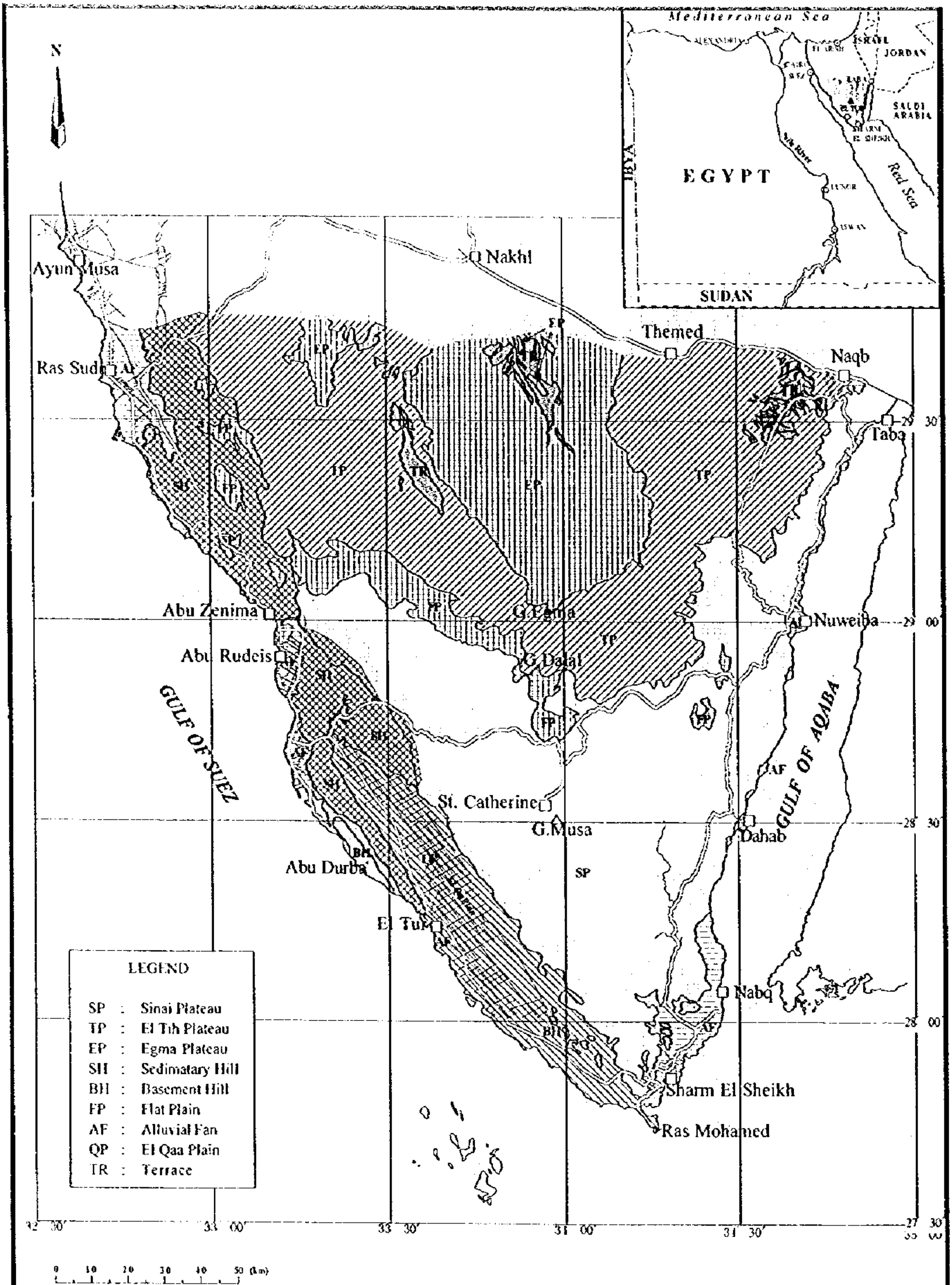


Fig. 2.1-1 Geomorphology

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT | JICA

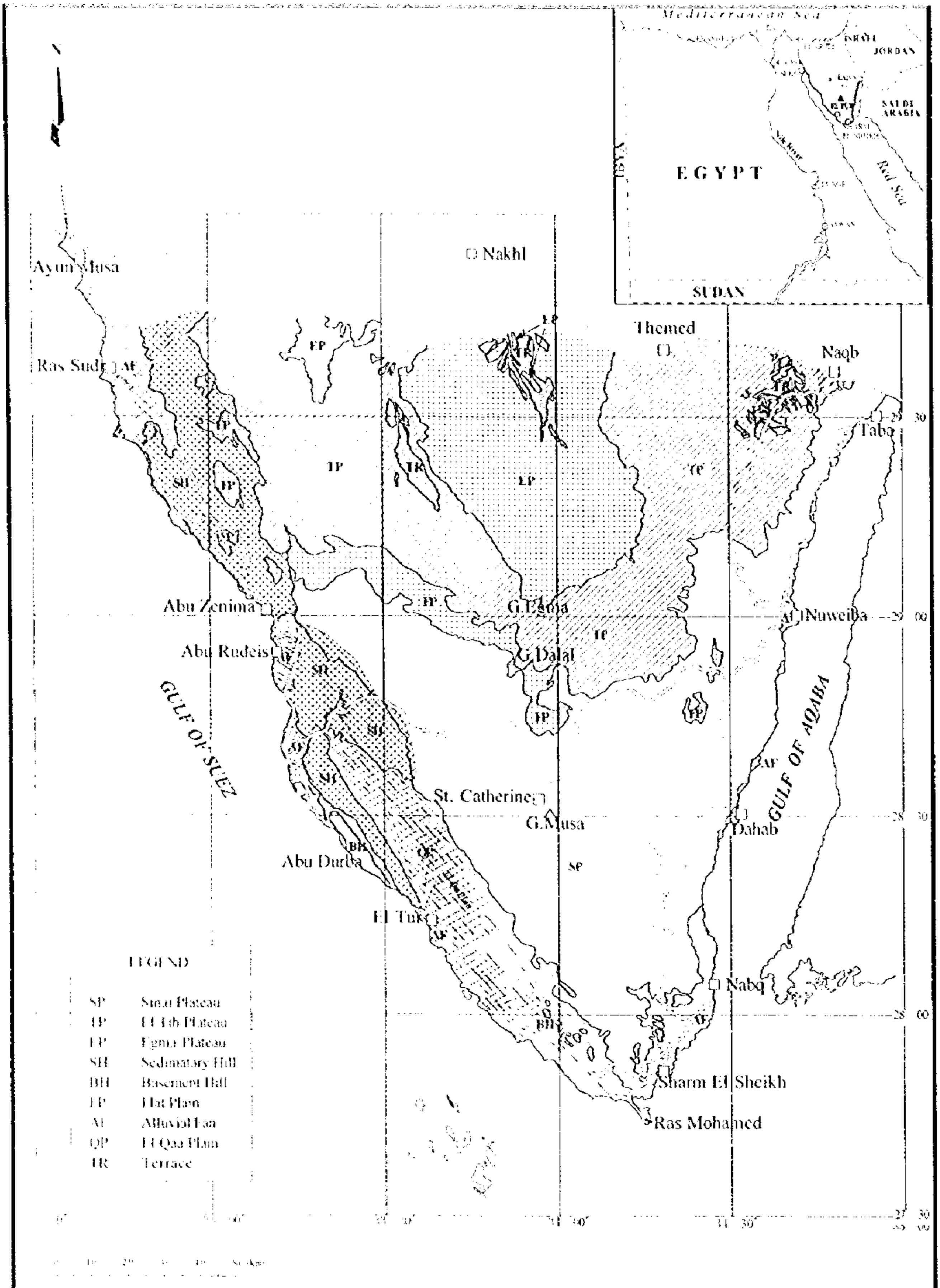


Fig. 2.1-1 Geomorphology

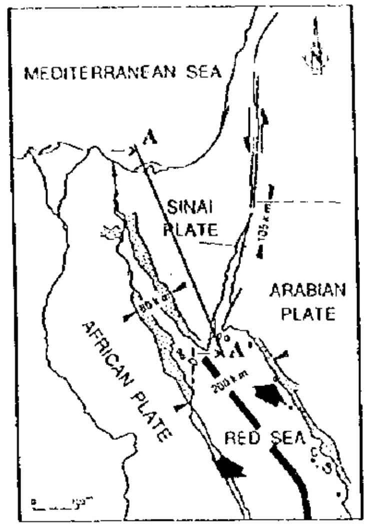
SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT | JICA

2.2 Geology

2.2.1 General Geology

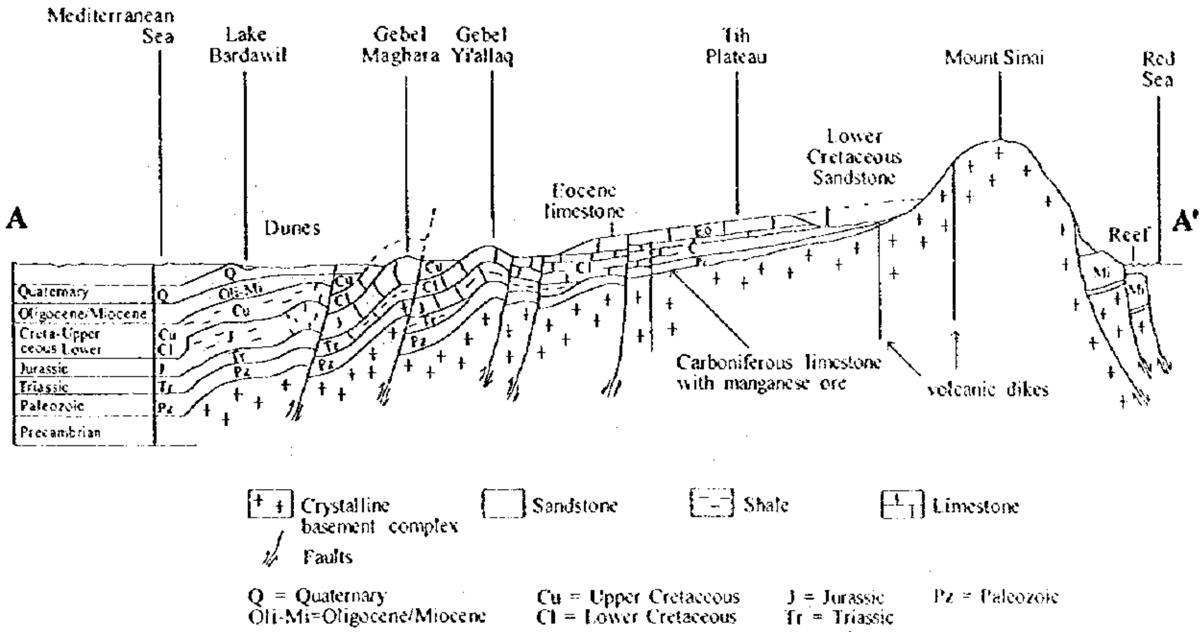
Major tectonic events in Egypt are shown in following figure. The most important event is "Red Sea Opening" that has formed the Gulf of Suez, Gulf of Aquaba and geological structure of the Sinai Peninsular as a consequence.

The Arabian, Sinai and African (Nubian) Plate meet each other around the southernmost of Gulf of Suez or Sinai Peninsula as shown in the figure right. It is assumed that the three plates have been formed by the separation between African Plate and Arabian Plate caused by Seafloor Spreading, and the relative movement among Sinai Plate and them. The rifting of Red Sea and Gulf of Suez began in Oligocene time and developed in the Miocene from the stratigraphic and structural point of view.



Tectonic Framework of Gulf of Suez
– Red Sea Rift System (Garfeenhel, 1981)

The Sinai Peninsula was effected by such tectonic movement as shown in the geological cross section below.



<Geological Cross section of the Sinai Peninsula>

(Rosel und Wolfgang Jahn (1997):Sinai and Red Sea)

The Precambrian Rocks develop over a large part of South Sinai and mainly consist of the metamorphic complex of granitic rocks, metamorphic rocks and volcanic rocks. These rocks form a dissected plateau that slopes gently toward the north with the overlying sedimentary rocks from Cambrian to Recent. Overview of stratigraphy in South Sinai is shown in Table 2.2-1.

Tectonic map of Sinai Peninsula is shown in Fig.2.2-2. The most remarkable tectonic structure in South Sinai is the "Ragabet El-Naam Fault" which runs across the central part of the peninsula east to west. There are many dome structures, which are distributed parallel with northeast to southwest direction in the northern side of the fault.

Geological structure of the Sinai Peninsula is divided into four (4) units from south to north. They are represented by different formations.

(1) Basement Complex: Precambrian Igneous, Metamorphic and Intrusive Rocks

(2) Central Sinai Stable Foreland: Gently Inclined Sedimentary Rocks from Paleozoic to Eocene.

(3) North Sinai Strongly Folded Belt: Strongly folded Triassic to Cretaceous Formations, and Not-folded Paleocene and Eocene formations.

(4) North Sinai Foreshore Area: Quaternary Deposits, especially Sand Dune Deposits.

The area of the Basement Complex is corresponding to the area of the South Mountains of geomorphological units. It is composed of Precambrian igneous, sedimentary, metamorphic and intrusive rocks.

The Central Sinai Stable Foreland is characterized gently inclined sedimentary rocks from Paleozoic to Cenozoic (Eocene) that are underlain by the Precambrian Basement Rocks. This unit covers the Egma and El Tih Plateaux.

The North Sinai Strongly Folded Belt occupies the most of North Sinai. It is characterized by double plunging fold (dome structure), thrust and reverse faults. Typical fold is observed at many mountains such as Gebels Maghara, Yelleq, Halal Minshera, Kherim and Arif El Naga. The Ragabet El Naam Fault separates this belt from the Central Sinai Stable Foreland. Formations older than Tertiary are strongly folded and their sequence is often observed in the core of these structure due to erosion.

The North Sinai Foreshore Area is neighbouring northern margin of the North Sinai Strongly Folded Zone. Sand Dune covers the most part of the area.

The Basement Complex and the Central Sinai Stable Foreland occupy the South Sinai.

2.2.2 Geological Description

The stratigraphy in the area is shown in Table 2.2-1. Geological Map (Fig. 2.2-1) and Structure Map (Fig. 2.2-2) were prepared through the Study referring "The Geological Map of Sinai, Arab Republic of Egypt (Geological Survey of Egypt, 1994)". Geological Cross Section is presented in Fig. 2.2-3.

Detailed description of geology is presented in Chapter V of the Supporting Report.

1) Precambrian Basement Rocks

Precambrian Basement Rocks occupy the southern half of South Sinai forming Basement Complex. The rocks are composed of the Middle and Late Precambrian metamorphic rocks and igneous rocks.

The former is represented by the Feiran Suite mainly composed of gneiss. It covers an area along the Wadi Feiran forming relatively gentle topographic features, while the latter forms rugged steep topographic features.

The latter is composed of Kid-Madsus Suite, Dha-Attar Melange, Firani Suite, Rahabah Suite and Catherine Suite. They consist of metamorphosed pyroclastic rocks, volcanic rocks and sedimentary rocks. Among them, the Catherine Suite occupies the center area of South Sinai around St. Catherine town and adjacent area. It rise to a height of 2641 m ASL (Gebel Catherine), form the southern tip of the peninsula. The area shows youthful physiography. It is dissected by numerous incised wadis that cover everywhere showing signs of downcutting.

The Middle Precambrian is also distributes in the western half of the Abu Durba Mountain.

The Precambrian Basement rocks are overlain by Paleozoic Formation in the northern half of South Sinai and Abu Durba area.

2) Paleozoic

The Paleozoic Formations are exposed widely in the catchment area of the Wadi Garf and Sidri, and the upstream area of the Wadi Zaghara. They are overlain by Mesozoic Formations and never crop out in the El Tih Plateau.

The Paleozoic Sequence is divided into Cambrian and Carboniferous. Their lithofacies are as follows;

Age	Formation	Lithofacies
Carboniferous	Abu Durba Formation	sandstone with clay beds
	Abu Thrah Formation	sandstone with carbanaceous clay
Cambrian	Naqus Formation	quartzitic sandstone
	Arabah Formation	varicolored laminated sandstone with sandy clay

Geological columns of those formations are presented in Fig. 2.2-4.

The total thickness of Paleozoic Formations is more than 200 m in Abu Durba area and it becomes less than 100 m at the Gebel Dalal and Gebel Ginaina in the south of the El Tih Plateau.

(1) Cambrian

The Cambrian Formation is divided into Arabah Formation and Naqus Formation in Abu Durba area, while it is undivided in the Gebel Dalal and Gebel Gineina.

The Arabah Formation is more than 10 m in thickness. It is characterized by alternation of brown and white sandstone, and brown sandstone containing clay and siltstone. .

The Naqus Formation overlies conformably the Arabah Formation. The formation is 236 m in thickness. The lithology is dark brown siltstone, and alternated bed of medium to coarse sandstone and quartzitic sandstone. It frequently contains quartz cobble in white and yellow colours. The top of the formation is composed of purplish red shale (two beds, 90 cm and 120 cm).

In Gebel Dalal and Gebel Gineina area, the Undivided Cambrian Formation is composed of brownish white medium to fine sandstone, and alternated beds of sandstone and silty sandstone. The formation is 35 m in thickness.

The Paleozoic Formations are uncomformably overlain by the Mesozoic Formation.

(2) Carboniferous

The Carboniferous formation is divided into Abu Thrah Formation and Abu Durba Formation. The former consists of sandstone with carbonaceous clay and the latter consists of sandstone with clay beds.

3) Mesozoic

The Mesozoic Sequence is divided into Triassic, Jurassic and Cretaceous Formations. Cretaceous Formations are divided into the Lower Cretaceous of sandstone facies and the Upper Cretaceous of limestone facies.

(1) Triassic

The Triassic occupies in a small area near Abu Zenima and Abu Rudeis. It is represented by the Qiseib Formation composed of varicolored (mainly red) sandstone and mudstone. The Triassic Formation is lack in the El Tih Plateau area as shown in Fig. 2.2-4.

(2) Jurassic

The Jurassic sequence is composed of Raqabah Formation (Jr) consisting of yellowish white, well-bedded sandstone. The Raqabah Formation crops out along the fringe of the El Tih Plateau and is overlain by the Lower Cretaceous Malha Formation. Distribution of the Raqabah Formation in the El Tih Plateau area is confirmed by Test Wells, J-1, J-4 and J-6 at depth of 1110m, 1106m and 800m, respectively.

(3) Lower Cretaceous

The Lower Cretaceous sequence of Albian to Aptian age is represented by Malhah Formation (Kl) consisting of sandstone with subordinate interbeds of sandy siltstone and claystone. The Lower Cretaceous Formation unconformably overlies the Upper Jurassic Formations.

In central Sinai the pre-Cenomanian section is composed entirely of so-called "Nubian-type" sandstone which attains 780 m thick at Umm Bogma. The basal part (282m) of this sandstone has been assigned as a Carboniferous age, whilst the upper 498 m is thought to range from Triassic to Lower Cretaceous ages. This sandstone is exposed mainly along the scarp of the Gebel El Tih.

Six (6) Test Wells were drilled in the Study area by the Study Team in order to confirm the Lower Cretaceous Formation as mentioned below (for locations, see Fig. 2.2-5.

Well No.	Depth (m)	Coordination	Altitude (mASL)	Top (mBGL)	Bottom (mBGL)	Thickness (m)
J-1 South Nakhl	1,254	29°42'31"N 33°39'08"E	520	865	1,110	245
J-2 South Themed	1,260	29°34'35"N 34°01'43"E	657	1,050	1,260+	210+
J-3 North Malha	1,000	29°33'53"N 33°32'15"E	544	771	1,000+	229+
J-4 South Themed	1,130	29°26'21"N 34°02'56"E	775	845	1,106	261
J-5 Wadi Khareiza	557	29°20'18"N 34°22'41"E	740	310	500	190
J-6 South Malha	900	29°19'40"N 33°36'48"E	710	610	795	185

Note: Numbers with the symbol (+) mean that the drilled well did not reached the bottom of the Lower Cretaceous formation.

The drilling results indicate that the Lower Cretaceous continuously distributes under the El Tih Plateau and tend to increase its thickness toward the north.

The Lower Cretaceous is uncomformably overlain by the Upper Cretaceous.

(4) Upper Cretaceous

The Upper Cretaceous in South Sinai is divided into five (5) stages and six (6) formations as shown below:

Stage	Formation	Lithofacies
Maastrichtian	Sudr Formation	White to pale gray chalk, thick chert band
Santonian - Campanian	Duwwi Formation	Alternation of clastics and carbonates with phosphates
	Matallah Formation	Thick alternation of clay and marl
Coniacian	Tarif Sandstone	Crossbeded sandstone with clay
Turonian	Wata Formation	Light yellow to brown limestone, partly dolomitic
Cenomanian	Galalah Formation	Greenish yellow marl and clay. Marly limestone at the top

The Upper Cretaceous Formations were also confirmed at the Test Wells except the Well J-5 where the sequence from the Coniacian to Maastrichtian were eroded

i) Cenomanian.

The Cenomanian sequence is represented by Galalah Formation (Kg) consisting of greenish yellow marl and claystone with Oyster banks. The top is mainly limestone. In Central Sinai, Galalah Formation crops out along the southern scarp of the El Tih Plateau overlying the Lower Cretaceous Malhah Formation.

The sequence is predominantly marl and shale. The sediments are generally thin at the southeast, but thicken to the west and north, attaining a thickness of 190m at the northwest scarp of Gebel El Tih.

ii) Turonian

The Turonian sequence is represented by Wata Formation (Kw) consisting of light yellow to brown, thick-bedded, partly dolomitic limestone with clastic beds in the middle part.

In Central Sinai, the Turonian strata are conformable on the Cenomanian beds and range in thickness from 50 m to over 280 m. They consist of uniform, well-bedded, massive limestone and dolomite with minor amounts of marl, shale and chert.

The Wata Formation crops out widely along the Wadi Khareiza where the Test Well J-5 is located.

iii) Coniacian

The Coniacian sequence is represented by Tarif Sandstone (Kt) consisting of yellowish brown, crossbedded sandstone with minor clay interbeds.

iv) Santonian-Campanian

The Santonian to Campanian sequence is represented by Matallah Formation (Km) consisting of thick sequence of alternate beds of yellowish green clays and marl and Duwwi Formation (Kd) consisting of alternate beds of clastics and carbonates with phosphatic intercalation.

v) Maastrichtian

The Maastrichtian sequence is represented by Sudr Formation (Ks) consisting of white to pale gray chalk and chalky limestone alternate in the lower part, with yellowish green marly beds. The upper part is rich in *Pecten farafrensis*, and the lower part is rich in *Exogyra vescularis*.

The Sudr Formation is commonly observed at so-called "Table Mountains" distributed on the El Tih Plateau.

(5) Volcanic Activity

Volcanic activities of basaltic dykes (Kv) were occurred in the Cretaceous. This activity sometimes affected the Lower Cretaceous sandstone making it hardened.

4) Cenozoic

The Cenozoic sequence in South Sinai is divided into Tertiary and Quaternary.

(1) Tertiary

Tertiary sequence is distributed on the El Tih Plateau and the western side of South Sinai. The Paleocene and Eocene formations are observed on the El Tih Plateau forming so-called "Table Mountains". On the one hand, the Miocene and Pliocene formations occupy the areas along the Gulf of Suez.

i) Paleocene

The Paleocene sequence in South Sinai is the Esna formation mainly consists of uniform lithology of green to greenish grey shale (Esna Shale) with interbeded limestone and marl. It is overlain by the Eocene Egma Formation and is underlain by the Upper Cretaceous Sudr Formation. Thickness of the Esna Formation is approximately 30 to 50 m.

ii) Eocene

The Eocene sequence in South Sinai is represented by the Egma Formation (Lower Eocene) followed by the Darat Formation (Lower to Middle Eocene) and the Mokattam Formation (Middle Eocene).

The Egma Formation is composed of chalky limestone with flint band, and successive thin chert bands at the top. The Egma Formation forms the top table of "Table Mountains" on the El Tih Plateau.

The Darat Formation appears at the Wadi Nakhl, Central Sinai. It comprises green-brown shale, marls, limestone stringers and gypsiferous shale with thin flint bands and is characterized by *Nummulites gizehensis zitteli*.

The middle Eocene sequence is composed of Mokattam Formation (Tem) consisting of yellowish white limestone with banks of *Nummulites gizehensis Forskal* and *Nummulites lyelli*. It overlies the Darat Formation.

iii) Miocene

The Miocene sequence is divided into three (3) sequences, the Lower Miocene (the Sumar Formation and Rudeis Formation), the Lower to Middle Miocene (the Abu Alaqah Formation and Qabiliyat Formation) and the Middle Miocene (the Karim Formation). Distribution of those Miocene Formations are restricted to the eastern bank of the Gulf of Suez. Aparting from this sequence, marly sediments are observed in the Wadi Feiran. It is called as the "Feiran Bed".

The Sumar Formation consists of conglomerate, marly limestone and sandstone changing in places into calcareous sandstone and the Rudeis Formation is composed of alternate beds of marl and sandstone with fossiliferous carbonate beds in the lower part.

The Abu Alaqah Formation consists of thick conglomerate with interbeds of marl and sandstone and Qabiliyat Formation (Tmq) consists of thick fossiliferous limestone.

The Karim Formation (Tmk) consists of thick section of gypsum and anhydrite with marly interbeds. This formation is clearly identified on the LANDSAT images as bluish color.

In the Wadi Feiran, marly sediments appear from place to place between Oasis Feiran and Tarfa Village. They are called as Feiran Bed consisting of yellowish silts and clays interbedded with minor sands and gravels. The Bed deposited during early Neogene in dammed lakes by porphyry dykes in the wadi. Then, the deposits were itermittently disrupted by floods (Issar & Eckstein, 1969).

iv) Pliocene

Pliocene sequence is represented by El Qaa Formation (Tpl) consisting of alternate beds of calcareous grits and sandstone with gypseous interbeds, in places, rich in Ostreas.

Volcanic activity of Basalt dykes is known in Tertiary age.

(2) Quaternary

The Quaternary sequence in South Sinai is divided into the Pleistocene and Holocene sequences.

i) Pleistocene

Pleistocene formation distributes as Terrace Deposits and Gravel Deposits along the major wadis such as the Wadi Watir, the Wadi Feiran.

ii) Holocene

Holocene formation is represented by Wadi Deposits and Sabkha Deposits.

The Plio-Pleistocene and Holocene sequence is represented on shore by thin continental to littoral sediments which are approximately 300 m thick.

2.2.3 Geological Structure

The Sinai Peninsula is wedged between the African and Arabian plates. The boundaries of those are defined by the Gulf of Suez and Gulf of Aqaba-Dead Sea Rift Systems. In the south, the Precambrian Basement Rocks exposed forming the Arabo-Nubian Shield. The Shield were cratonized during the late Precambrian-early Palaeozoic (1,200 to 500 my BP) Pan-African Orogeny (Gass 1981). The peneplained palaeo-surface of the shield inclined gently northward with the overlying sediments, ranging from Cambrian to Recent, thickening northward. In the Central Sinai, an east-west trending shear zone of dextral strike-slip faults with up to 2.5 km of displacement was recognized.

Geological structure in the Study Area is presented in Fig. 2.2-6.

Five (5) characteristic structures are recognized in the Study area;

(1) Strike-slip faults (eastern study area)

(2) Conjugate Faults (Oasis Feiran area)

(3) Ring Structures (El Biarat, Qoz Umm Rigum and Ain Qaseby)

(4) Minor Lineaments concentrated

(5) Dykes

Characters of each structure are described below.

1) Strike-slip faults (eastern study area)

The major lineaments are distributed in the eastern area of South Sinai. Main directions of major lineaments are N-S and NE-SW. These lineaments seem to be faults systems developed in the Precambrian Basement Rocks. Along the western side of the Gulf of Aqaba, a 30 km^2 wide of shear belt of sub-paralleled faults is developed trending in N-S to NE-SW directions. Sinistral movements on these faults have been recognized based on offsets of magmatic bodies and lithological contacts in Precambrian Rock. The cumulative displacement, measured independently at several localities across the belt, attains to a total of 24 km.

2) Conjugate Fault in the Feiran Oasis

The conjugate faults are well developed in the Feiran Oasis area where the Precambrian Feiran Calc-Alkali Suite is mainly distributed. The faults are formed in N-S and NE-SW directions. The N-S faults are right-slip faults with the displacement attaining to 1.5 km. The NE-SW faults are left-slip faults with the displacement attaining to 0.5 km. A lot of minor lineaments are intensively developed around the center of conjugate faults. Well-developed open fractures are observed in the Oasis Feiran area. Many dug wells were constructed in the area.

3) Ring structures

The ring structures are observed in the three(3) areas which are El-Biarat area (northeastern part of study area), Qoz Umm Rigum area (northern part of study area) and Ain Qaseby area (north of Nuweiba). Radial lineaments are well observed in these structures.

The scale of each ring structure is as follows;

Area	Diameter (km)
El-Biarat area	25
Qoz Umm Rigum area	25 (not clear)
Ain Qaseby area	15

4) Area of minor lineaments concentrated

There are several areas where minor lineaments are intensively concentrated. Those are distributed in the following areas.

i) Ras Umm Maghrab area
ii) Umm Bugma Mine area
iii) Gebel Umm Rig area
iv) Gebel Mileihis area
v) Gebel Mikeimin area

Many open fractures were observed in the Precambrian Rocks in the following areas;

i) Ras Umm Maghrab area

ii) Gebel Mileihis area

iii) The downstream of the Wadi Dahab

Most of dug wells are constructed in the Quaternary Deposits near these open fractures.

5) Dykes

The dykes are observed in the Precambrian Basement Rocks, and the Cretaceous sedimentary rocks in the northwestern area. Ages of dykes are Precambrian, Triassic, Cretaceous and Tertiary. It is difficult to distinguish the age of each dyke.

Around St. Catherine area, the dykes are intensively distributed as the dike swarms in the Precambrian Rocks. The direction of dykes shows mainly N-S direction, and rarely NW-SE and E-W directions.

The dykes extend more than 30 km parallel to the major lineaments. These dykes were formed accompanied to the main structures.

In the western area, Tertiary dykes intruded to the Cretaceous and Tertiary sedimentary rocks trending in directions of WNW-ESE and NNE-SSW.

There are two (2) kinds of dykes, open fractured type and closed fractured type. These characteristics seem to have a close relationship with the behavior of groundwater in the Precambrian Rocks.

Tall. 2.2-1 Stratigraphy of South Sinai

Era and Sub-era		Period	Epoch	Stage or etc.	Legend	Formation
Cenozoic	Quaternary		Holocene		Qsb	Sabkah Deposits
					QW	Wadi Deposits
			Pleistocene		Qg	Gravel Deposits
					Qt	Terrace Deposits
	Tertiary	Neogene	Pliocene		Tpl	Al Qa F.
			Miocene	Upper	Tmz	Zayt F.
					Tmq	Quabiliyat F.
					Tmh	Hammam,Firawn F.
				Middle	Tmb	Balaim F.
					Tmk/Tma	Karim F. / Abu Alagah F.
					Tmu	Rudays F. / Sumar F.
					Tmr/Tms	Rudays F. / Sumar F.
				Lower	Tmu	Nakhl F.
					Tv	Extrusive Basaltic Rocks
		Paleogene	Eocene		Tem	Mokattm F.
					Ted	Darat F.
						Smalut F.
					Tei	Egma F.
			Paleocene		Tce	Esna F.
Mesozoic		Cretaceous	(Upper Cretaceous)	Maastrichtian	Ks	Sudr F.
				Santonian-Campanian	Kd	Duwwi F.
					Km	Matallah F.
				Coniacian	Kt	Tarif Sandstone
				Turonian		Wata F.
						Basaltic Dykes
				Cenomanian		Galalah F.
			(Lower Cretaceous)	Albian-Aptian		Malhah F.
		Jurassic				Raqabah F.
		Triassic				Qusayb F.
						Dolerite Sills
Paleozoic		Carboniferous			Cd	Abu Durbah F.
						Abu Thrah F.
		Cambrian				Naqus F.
						Arabah F.
Proterozoic		Precambrian		Cathrine Alkaline Suite		Senite,Quartz Senite
						Granophyer,Synite Alkaline Granite
						Rhyodacite Flow Deposits
				Rahaboh Suite		Monzonite
						Monzonite
						Olivine-hornblend Gabbro
				Frani Calcalkaline Suite		Quartz Diorite,Granodyolite
						Rnyodacite,Volcanoclastic Deposits
				Daha-Attar Melange		Leucogabbro
						Dunite Melange
						Metadiolite
						Metagabbro
				Al Kids-Madsus		Metamorphosed Volcanics
				Firan-Sulaf Gneiss Suite		Gneiss,Metabasite Dykes

Table 2.2-1 Stratigraphy of South Sinai

Era and Sub-era		Period	Epoch	Stage or etc.	Legend	Formation
Cenozoic	Quaternary		Holocene		Qsb	Sabkah Deposits
					QW	Wadi Deposits
			Pleistocene		Qg	Gravel Deposits
					Qt	Terrace Deposits
	Tertiary	Neogene	Pliocene		Tpl	Al Qa F.
			Miocene	Upper	Tmz	Zayt F.
					Tmq	Quabiliyat F.
					Tmh	Hammam Firawn F.
				Middle	Tmb	Balaim F.
					Tmk/Tma	Karim F. / Abu Alaqah F.
					Tmu	Rudays F. / Sumar F.
					Tmr/Tms	Rudays F. / Sumar F.
				Lower	Tmu	Nakhl F.
					Tv	Extrusive Basaltic Rocks
		Paleogene	Eocene		Tem	Mokattm F.
					Ted	Darat F.
					Tes	Smalut F.
					Tel	Egma F.
			Paleocene		Tpe	Esna F.
Mesozoic		Cretaceous	(Upper Cretaceous)	Maastrichtian	Ks	Sudr F.
				Santonian-Campanian	Kd	Duwwi F.
					Km	Matallah F.
				Coniacian	Kt	Tarif Sandstone
				Turonian	Kw	Wata F.
					Kv	Basaltic Dykes
				Cenomanian	Kg	Galalah F.
			(Lower Cretaceous)	Albian-Aptian	Kl	Malhah F.
		Jurassic			Jr	Raqabah F.
		Triassic			Tr	Qusayb F.
					Trv	Dolerite Sills
Paleozoic		Carboniferous			Cd	Abu Durbah F.
					Ct	Abu Thrah F.
		Cambrian			Cn	Naqus F.
					[illegible]	Arabah F.
Proterozoic		Precambrian		Cathrine Alkaline Suite	cgs	Senite, Quartz Senite
					cdg	Granophyer, Syenite Alkaline Granite
					Cv	Rhyodacite Flow Deposits
					gm	Monzonite
				Rahaboh Suite	gmg	Monzonite
					[illegible]	Olivine-hornblend Gabbro
				Firan Calcalkaline Suite	gd	Quartz Diorite, Granodyolite
					Fv	Rhyodacite, Volcanoclastic Deposits
					Tsm	Leucogabbro
				Daha-Attar Melange	[illegible]	Dunite Melange
					[illegible]	Metadiolite
					mgb	Metagabbro
				Al Kids-Madsus	Mv	Metamorphosed Volcanics
				Firan-Sulaf Gneiss Suite	gno	Gneiss, Metabasite Dykes

Stratigraphic unit	Symbol	Description
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	Tv	[illegible]
[illegible]	Tem	[illegible]
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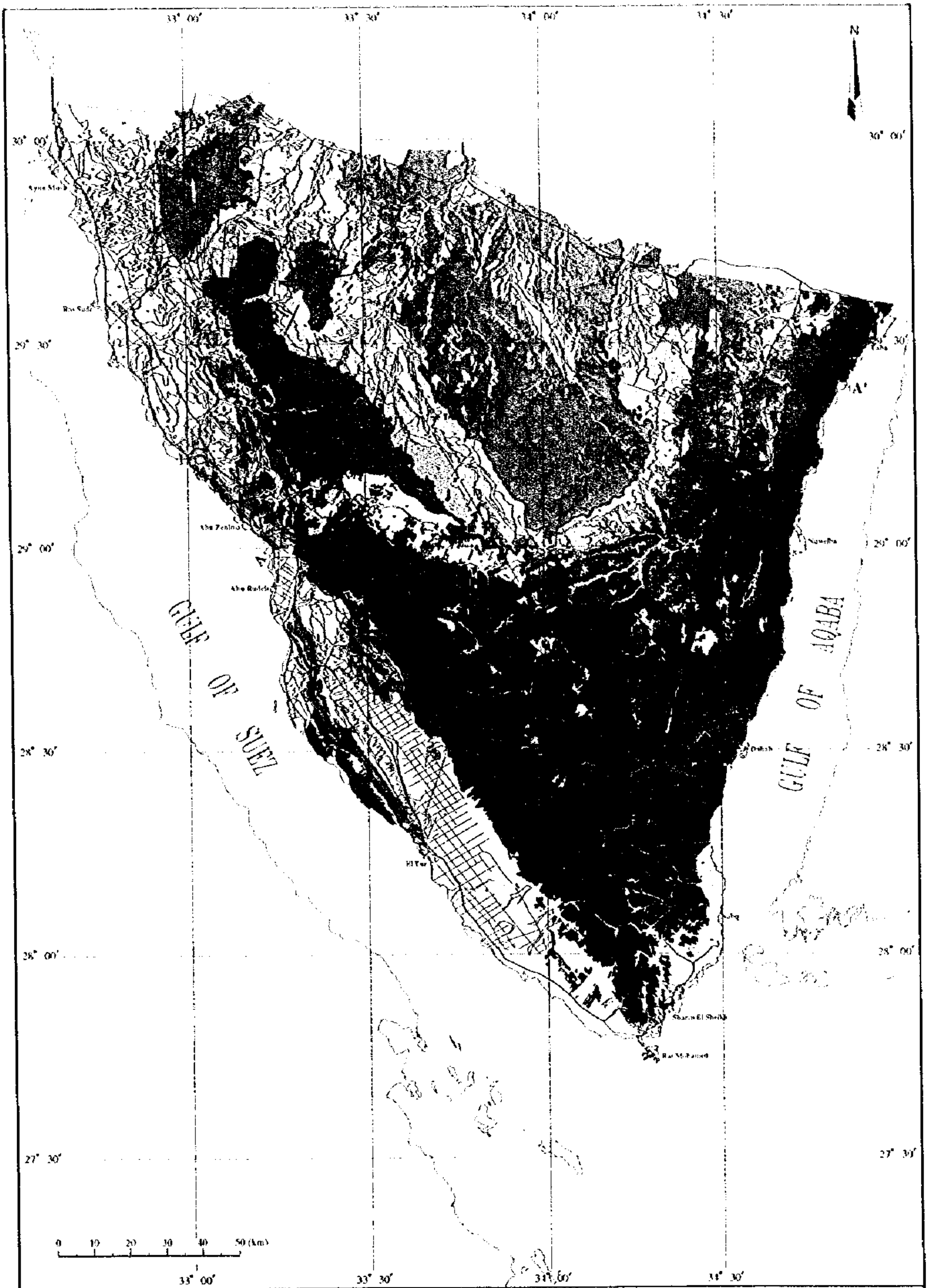

Fig. 2.2-1 Geological Map (South Sinai)

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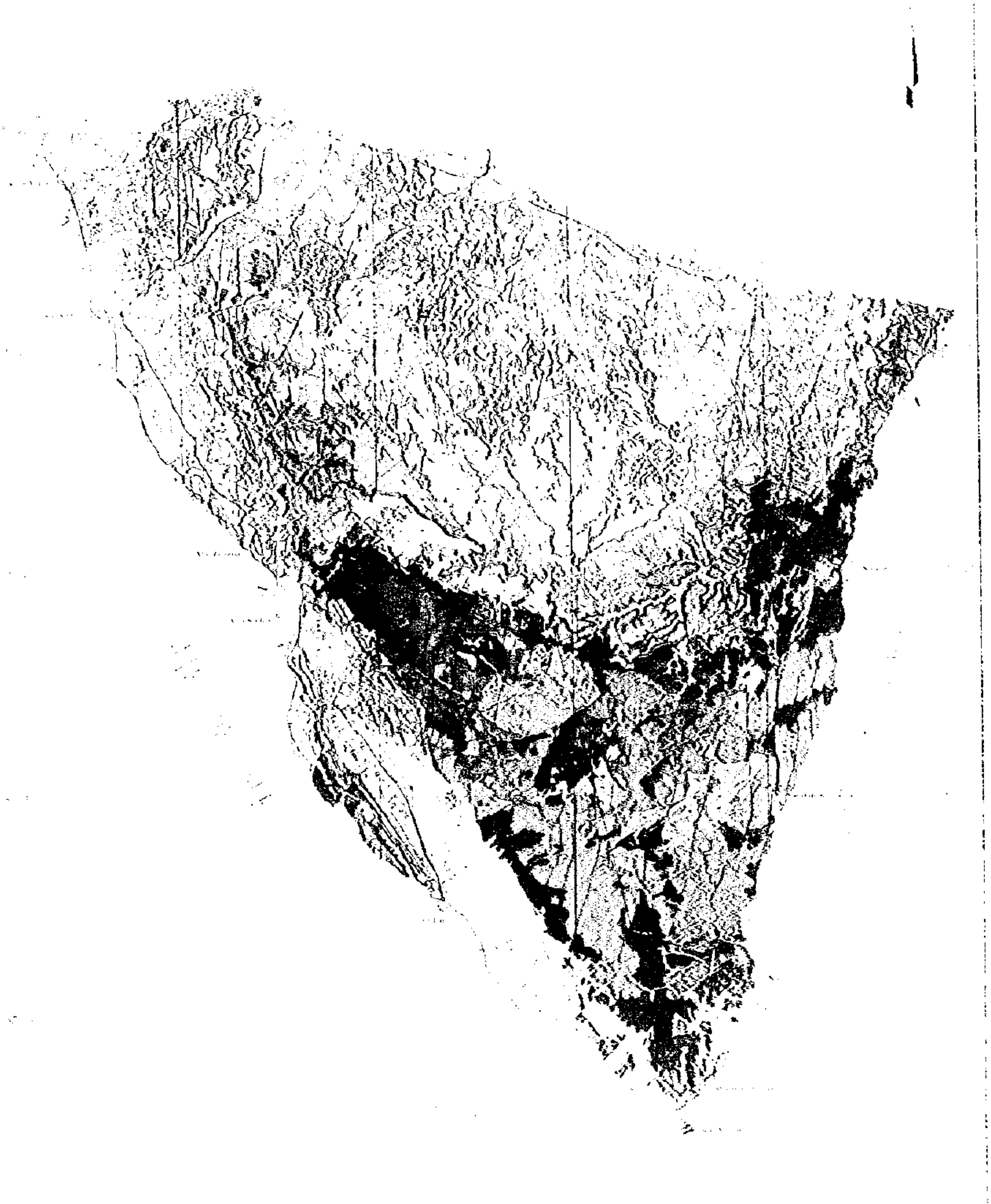

Fig. 2.2-1 Geological Map (South Sinai)

Fig. [illegible] Geological Map (South Sinai)

[illegible] GROUNDWATER [illegible] | JICA

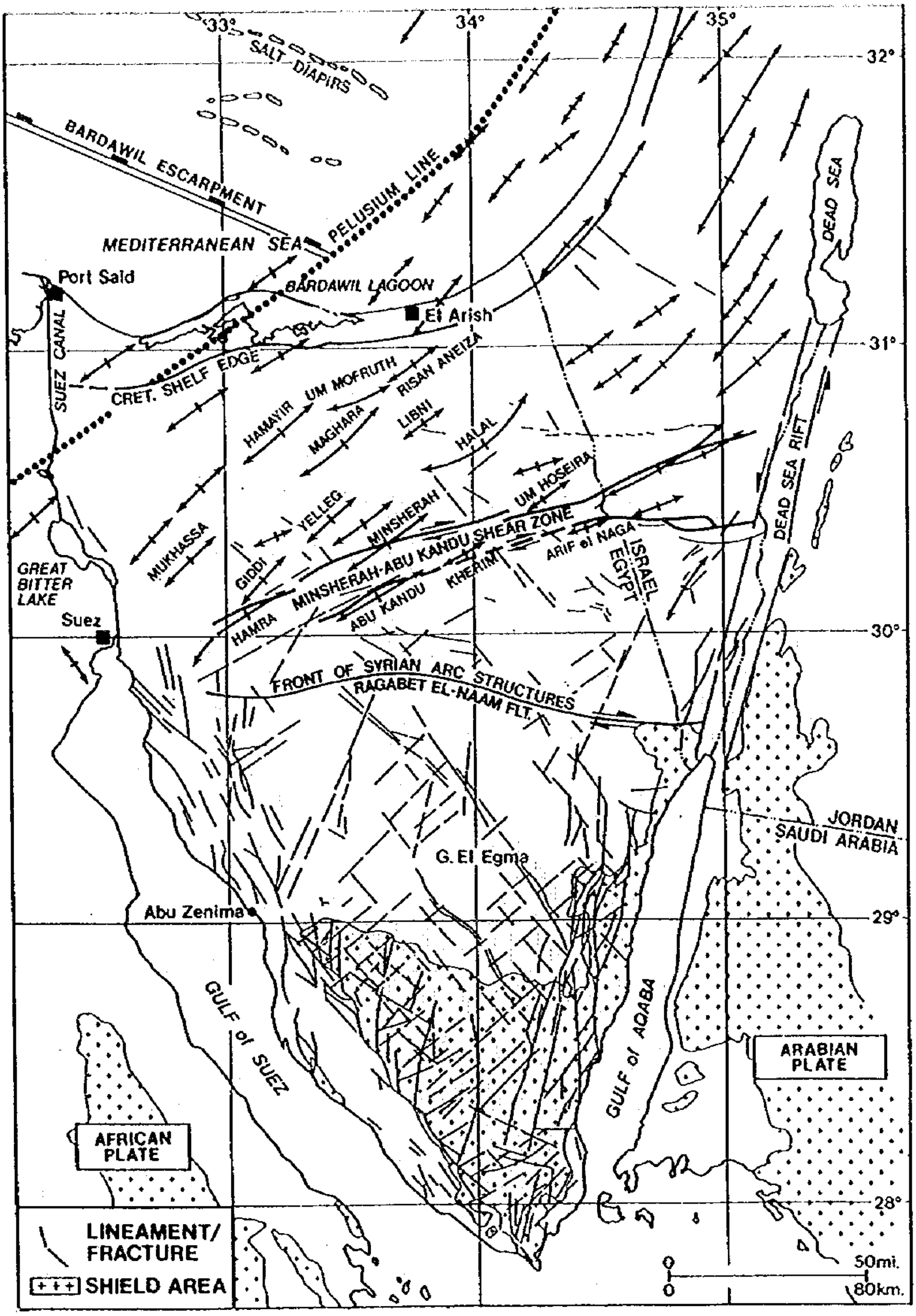

Fig. 2.2-2 Geological Structure of Sinai (after Neev 1975 and Agah 1981)

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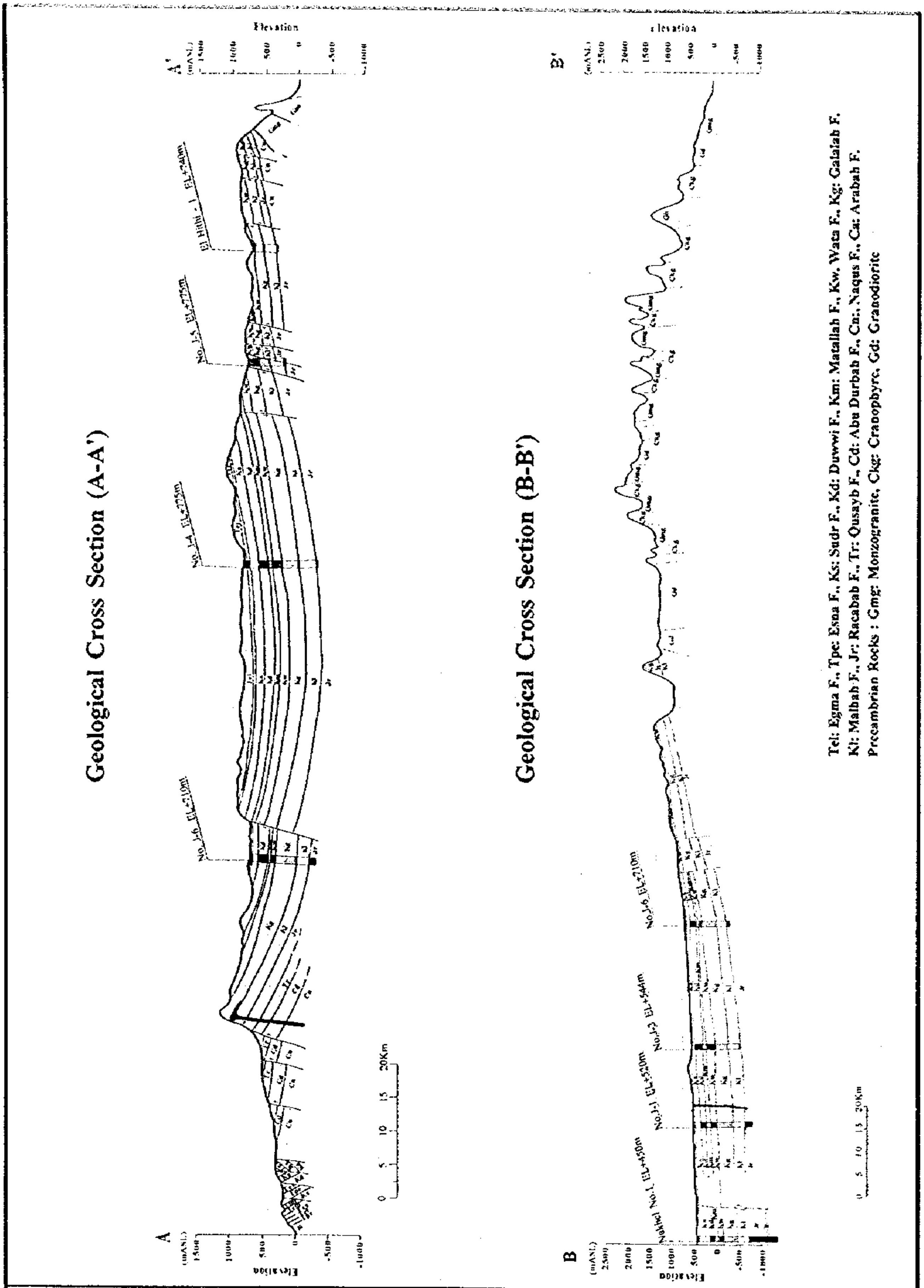

Fig. 2.2-3 Geological Cross Section (A-A', B-B')

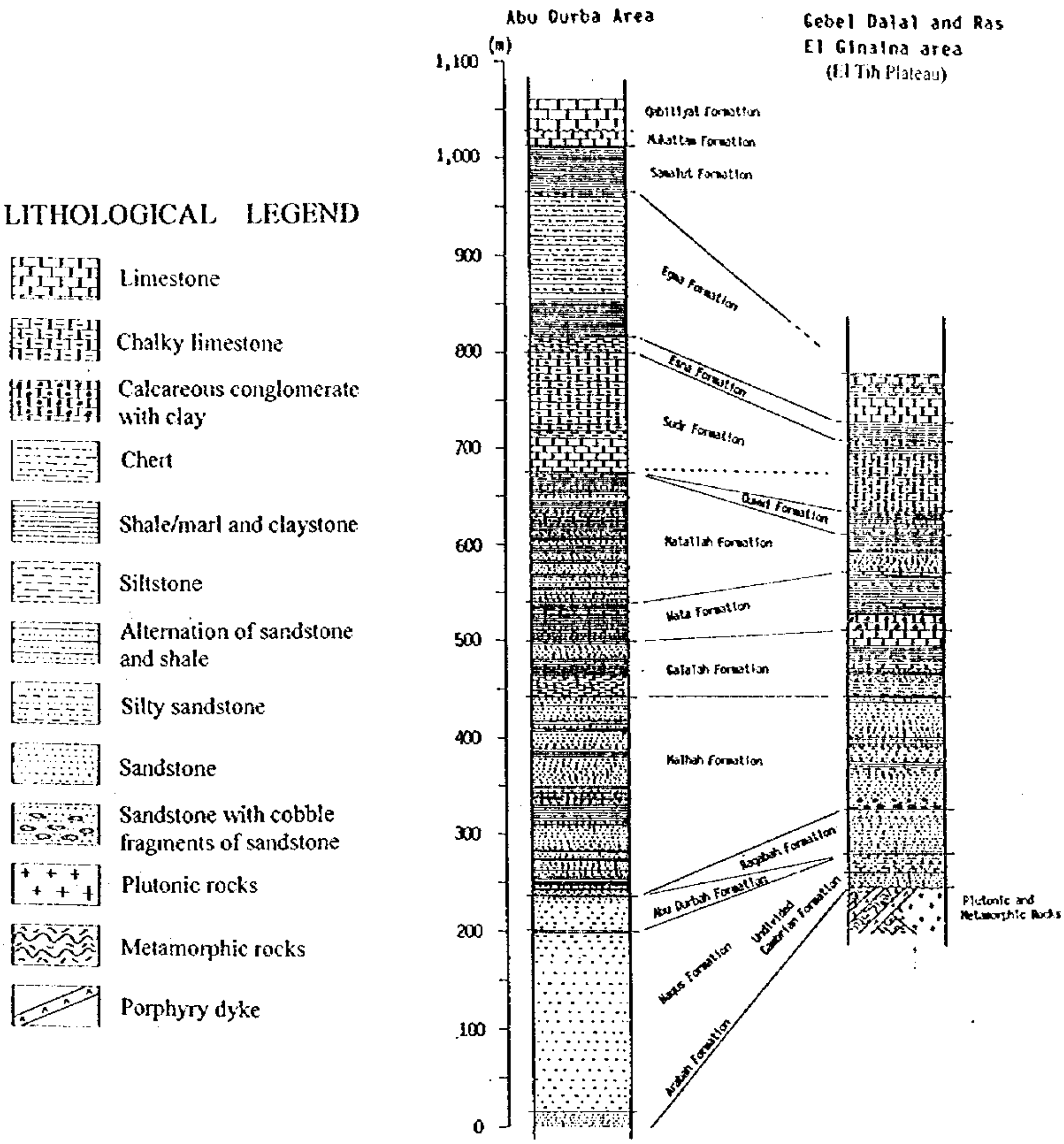

Fig. 2.2-4 Geological Column (Abu Durba and Southern Fringe of El Tih Plateau)

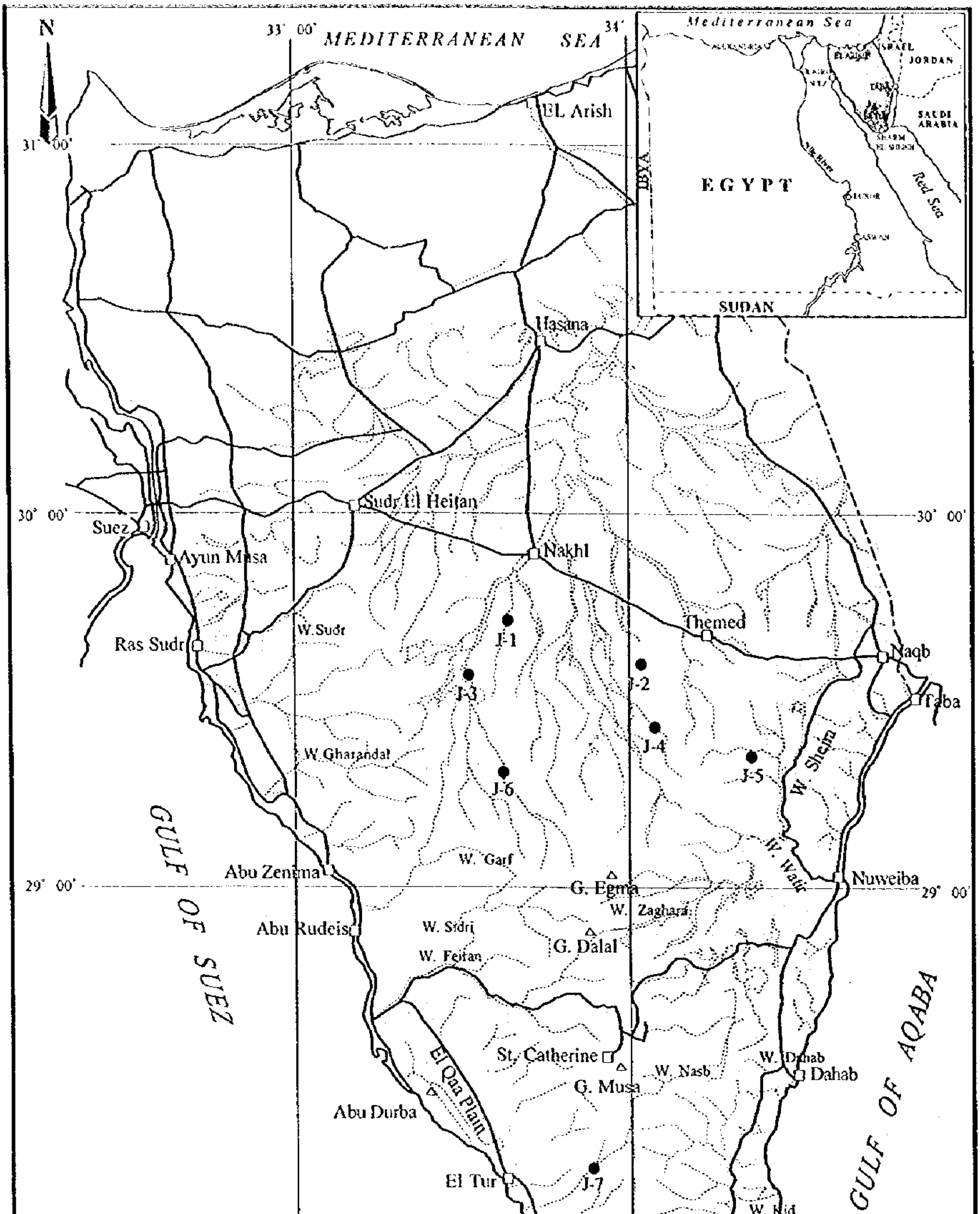

Fig. 2.2-5 Drilling Location of JICA Test Well

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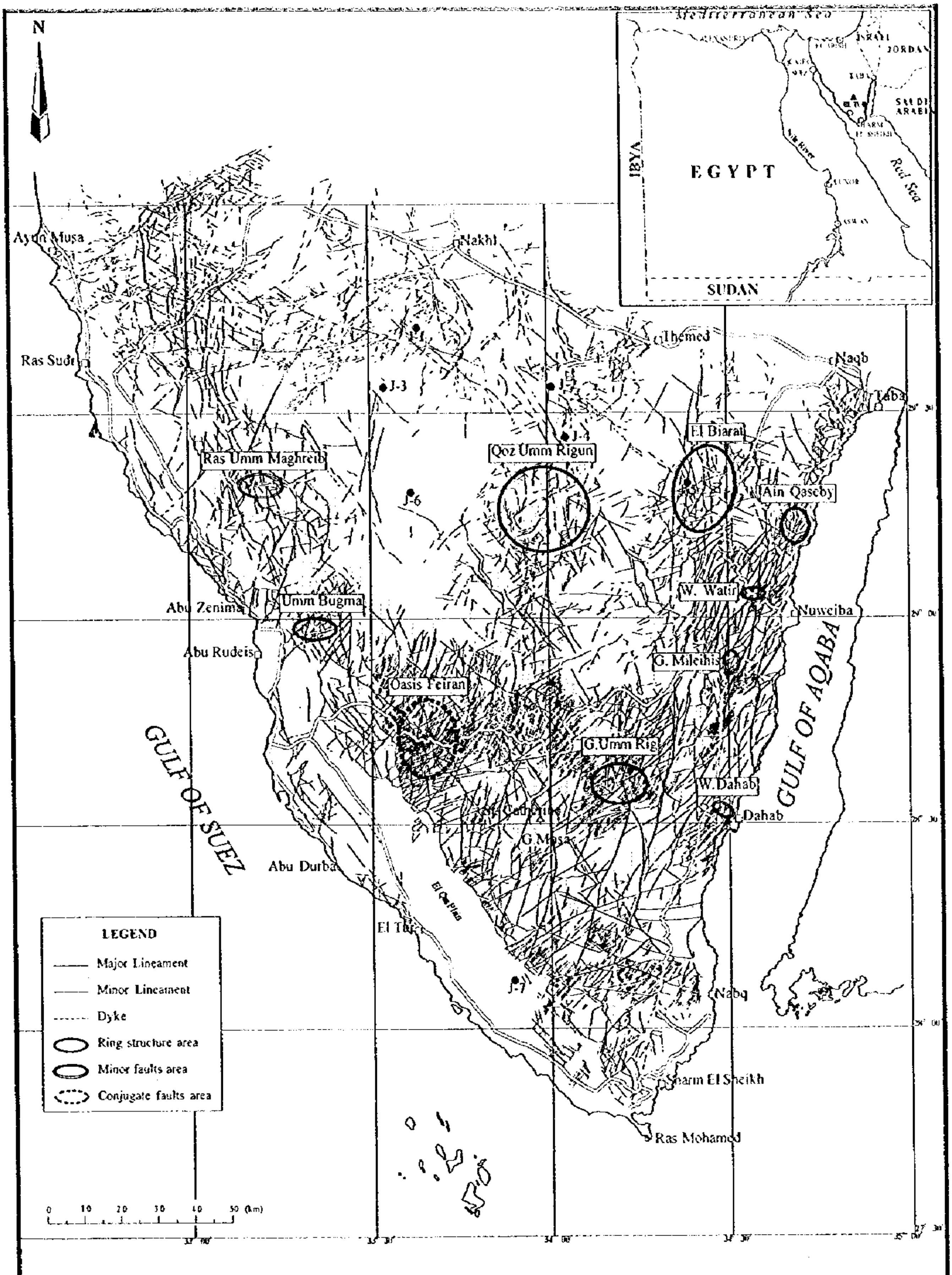

Fig. 2.2-6 Structure Map (South Sinai)

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