896
8/13/79

DR. 2991

DOE/IA-0002/02

MASTER

Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment

Volume 2 of 5 Vols.
Annex 1

April 1979

U.S. Department of Energy

Assistant Secretary for
International Affairs

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Available from:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price: Printed copy: \$9.25
Microfiche: \$3.00

Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment

Volume 2 of 5 Vols.
Annex 1

April 1979

PREPARED BY THE UNITED STATES GEOLOGICAL SURVEY ON BEHALF
OF THE GOVERNMENT OF EGYPT AND THE UNITED STATES DEPARTMENT
OF ENERGY. REPRODUCED BY THE UNITED STATES DEPARTMENT OF
ENERGY WITH THE ASSISTANCE OF THE UNITED STATES DEPARTMENT
OF STATE.

U.S. Department of Energy

Assistant Secretary for
International Affairs
Washington, D.C. 20585

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

eb
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

VOLUME II

ANNEX 1

ENERGY RESOURCES OF EGYPT

TABLE OF CONTENTS

	<u>Page</u>
TABLE OF CONTENTS	i
SUMMARY OF THE ENERGY RESOURCES OF EGYPT	S1
1.0 INTRODUCTION	S1
2.0 OIL AND GAS	S1
2.1 Summary	S1
2.2 Recommendations	S3
3.0 COAL AND OIL SHALE	S6
3.1 Summary and Conclusions	S6
3.2 Recommendations	S7
4.0 URANIUM AND THORIUM	S7
4.1 Summary and Conclusions	S7
4.2 Recommendations	S8
5.0 GEOTHERMAL ENERGY	S9
5.1 Summary and Conclusions	S9
5.2 Recommendations	S10
5.2.1 Exploration Methods	S10
5.2.2 Personnel and Equipment	S10
5.2.3 Training	S11
6.0 WATER RESOURCES	S11
6.1 Summary and Conclusions	S11
6.2 Recommendations	S13
7.0 ENERGY-RELATED MINERAL/COMMODITIES	S13
 A. <u>THE PETROLEUM POTENTIAL OF EGYPT</u>	
1.0 EXECUTIVE SUMMARY	1
2.0 INTRODUCTION	2
2.1 Area and Purpose of Report	2
2.2 Sources and Reliability of Data	4
2.3 Acknowledgements	5

TABLE OF CONTENTS

	<u>Page</u>
3.0 PETROLEUM EXPLORATION AND DEVELOPMENT	5
3.1 History of Petroleum	5
3.2 Petroleum Contracts	6
3.3 Production and Reserves	7
4.0 TECTONIC SETTING	13
4.1 Plate Tectonics	13
4.2 Overview of Regional Tectonic History	15
4.2.1 Precambrian Stage	15
4.2.2 Paleozoic Stage	17
4.2.3 Mesozoic Stage	17
4.2.4 Cenozoic Stage	19
4.3 Tectonic Features	19
4.4 Tectonic Provinces	20
4.4.1 The Arabo-Nubian Massif	20
4.4.2 The Gulf of Suez Basin	20
4.4.3 The Western Red Sea Shelf	20
4.4.4 The Unstable Shelf	20
4.4.5 The Stable Shelf	22
5.0 STRATIGRAPHY	22
5.1 Depositional History	22
5.2 Stratigraphic Sequence	23
5.2.1 Rocks of Paleozoic Age	25
5.2.2 Rocks of Mesozoic Age	30
5.2.2.1 Triassic Rocks	30
5.2.2.2 Jurassic Rocks	30
5.2.2.3 Cretaceous Rocks	32
5.2.3 Rocks of Cenozoic Age	34
5.2.3.1 Paleocene-Eocene Rocks	34
5.2.3.2 Oligocene Rocks	35
5.2.3.3 Miocene Rocks	35
5.2.3.4 Pliocene Rocks	36
5.2.4 Rocks of Quaternary Age	36
6.0 PETROLEUM POTENTIAL	37
6.1 Gulf of Suez Petroleum	37
6.2 Red Sea Petroleum Province	39
6.3 Western Desert Petroleum Province	40
6.4 Northern Sinai Petroleum Province	42
6.5 Nile Basin Petroleum Province	44
6.6 Delta Basin Petroleum Province	44
6.7 Nile Cone-Levantine Platform	45
6.8 Summary of Petroleum Possibilities in Near Future	47

TABLE OF CONTENTS

	<u>Page</u>
7.0 BASIC PETROLEUM EXPLORATION NEEDS IN EGYPT	47
7.1 Nomenclature and Correlation of Stratigraphic Units	48
7.2 Stratigraphic Analysis of Sedimentary Basins	48
7.3 Basement Tectonic Map	49
7.4 Seismic Refraction Survey	49
7.5 Seismic Stratigraphy	50
7.6 Seismic Modeling	50
7.7 Source-Rock Evaluation and Crude-Oil Correlation	50
7.8 Continuing Education of Geoscientists	51
8.0 REFERENCES	52

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Petroleum Production and Reserves of Fields in Egypt	8
2 Well Data for Oil and Gas Wells in Egypt	10

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1 Location of Oil, Gas Fields and Pipelines in Relation to Geographic Provinces of Egypt	3
2 Plate Tectonic Setting of Egypt	14
3 Plate Tectonics of the Northern Red Sea	16
4 Major Tectonic Segments of Egypt	18
5 Major Tectonic Elements and Basins in Egypt	21
6 Generalized Geologic Map of Egypt	24
7 Depth to Top of Basement in Northern Egypt	24
8 Regional Geological Cross Sections EF Eastward and GH Northward Across Egypt	26
9 Stratigraphic Units in Egypt	27
10 Depth to Top of Paleozoic Rocks in Northern Egypt	29
11 Thickness of Paleozoic Rock in Northern Egypt	29
12 Thickness of Jurassic Rocks in Northern Egypt	31
13 Thickness of Early Cretaceous Rocks in Northern Egypt	31
14 Thickness of Late Cretaceous Rocks in Northern Egypt	33
15 Thickness of Paleocene-Eocene Rocks in Northern Egypt	33
16 Geologic Cross Section of the Ras Gharib Field, a Typical Oil Field in the Gulf of Suez Basin	38
17 Geothermal Gradient Map of Northern Western Desert and Nile Delta	43
18 Location of Nile Cone-Levantine Platform in the Mediterranean North of Egypt	46

B. COAL AND OIL SHALE

	<u>Page</u>
1.0 SUMMARY AND CONCLUSIONS	54
2.0 RECOMMENDATIONS	54
3.0 PRESENT KNOWLEDGE OF COAL AND OIL SHALE OCCURRENCE IN EGYPT	61
3.1 Coal	61
3.2 Oil Shale	66
4.0 REFERENCES	68

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Analyses of Coal From Safa Mine, Sinai Peninsula, Egypt	56
2 Chemical Analysis (Proximate) of Samples of Maghara Coal	59
3 Chemical Analysis (Ultimate) of Some Samples of Maghara Coal	59
4 Petrographic Composition of Maghara Coal as Determined by Analysis of Thin Sections by Transmitted Light Microscopy in Terms of Macer>1 Components	60
5 Laboratory Analysis of Oil Shale From Budaa, Quseir, and Galala El Qibliya and Galala El Bahariya, Egypt	67

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1 Location of Coal and Oil Shale Deposits in Egypt	55

C. ASSESSMENT OF URANIUM AND THORIUM RESOURCES IN EGYPT

	<u>Page</u>
1.0 SUMMARY AND CONCLUSIONS	70
2.0 RECOMMENDATIONS	72
3.0 INTRODUCTION	73
4.0 URANIUM DEPOSITS	74
4.1 Gebel El Missikat-El Erediya Area	75
4.2 El Atshan Area	77
4.3 Qatrani Area	77
5.0 PHOSPHATE DEPOSITS	79
6.0 BLACK SANDS	81
7.0 SUGGESTIONS FOR PROSPECTING	83
7.1 Oil Wells	83
7.2 Igneous Rocks	84
7.2.1 Apogranites	84
7.2.2 Ring Dike Complexes	85
7.3 Wadi Sodmein, Fawakhir, and Wadi Um Gheig Areas	85
8.0 PRECAMBRIAN	87
9.0 PALEOZOIC	88
10.0 MESOZOIC	89
11.0 REFERENCES	91

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Phosphate Reserves of Egypt	80

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1 Areas Covered by Airborne Radiometric Surveys, Egypt	71
2 Geologic Map, El Atshan District, Wadi Kareim-Wadi El Dabbah Area, Eastern Desert, Egypt	78

D. POSSIBILITIES FOR DEVELOPMENT OF GEOTHERMAL ENERGY IN EGYPT

	<u>Page</u>
1.0 SUMMARY AND CONCLUSIONS	96
2.0 RECOMMENDATIONS	96
2.1 Exploration Methods	96
2.2 Personnel and Equipment	97
2.3 Training	97
3.0 PRESENT KNOWLEDGE OF GEOTHERMAL CONDITIONS IN EGYPT	97
4.0 EGYPTIAN ORGANIZATIONS CONCERNED WITH GEOTHERMAL CONDITIONS	100
5.0 REFERENCES	102

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Volumes of Flow and Temperatures of Hot Springs of Egypt	103
 <u>E. THE WATER RESOURCES OF EGYPT AND THEIR RELATION TO ENERGY DEVELOPMENT</u>	
	<u>Page</u>
1.0 EXECUTIVE SUMMARY	103
2.0 INTRODUCTION	104
3.0 WATER AND WATER USE IN THE NILE SYSTEMS	106
3.1 Surface-water Resources	106
3.2 Surface-water Use	108
3.3 Groundwater in the Nile System	113
3.4 Extending the Nile Supply	114
3.5 Water Quality	117
4.0 WATER AND WATER USE IN THE WESTERN DESERT	118
4.1 The Resource	118
4.2 Agriculture Use of Western Desert Water	124
4.3 Non-agriculture Uses of Western Desert Water	128
4.4 Water-quality Factors, Western Desert	128
5.0 WATER AND WATER USE IN OTHER ARID REGIONS	129
5.1 Kurayim and Lake Nasser Basins (South Kharga)	129
5.2 Faiyum Depression	129
5.3 Wadi Natrun	130
5.4 Other Areas West of the Nile	130
5.5 Western Coastal Zone	131
5.6 Delta to Suez Area	131
5.7 Eastern Delta	131
5.8 The Sinai	132

	<u>Page</u>
6.0 WATER IN THE CONTEXT OF ENERGY RESOURCES AND SYSTEMS	132
6.1 Hydroelectric Power	132
6.2 Thermal Electric Energy	139
6.3 Nuclear Thermal	143
6.4 Water in Coal Development	143
6.5 Water in Petroleum Development	145
6.6 Geothermal Resources	145
7.0 SUMMARY AND CONCLUSIONS	146
8.0 RECOMMENDATIONS	148
9.0 REFERENCES AND OTHER SOURCES OF INFORMATION	149
10.0 ATTACHMENT	151
10.1 Aswan Segment	151
10.2 Assiut Segment	151
10.3 Cairo Segment	151
10.4 Mansoura Segment	153
10.5 Kafr El Zayat Segment	154

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Areal Water Withdrawals for Domestic and Industrial Uses, Ministry of Irrigation	109
2 Estimated Water Requirements for Present and Future Irrigation in the Nile Valley and Delta	112
3 Delta Wells	114
4 Water Quality, Lake Maryut	119
5 River Nile Quality	120
6 Beneficial and Non-beneficial Use of Nubian Recharge, m ³ /day	123
7 Wells Being Pumped, Kharga Oasis	125
8 Estimated Cost of Irrigation Water, New Wells, Kharga Oasis	127
9 Estimated Cost of Irrigation Water, New Flowing Wells, Dakhla	127
10 Candidate Sites, Pump Storage Hydropower	138
11 Fossil-fired Steam-electric Generating Plants	140
12 Projected Energy Pattern, Egypt	141
A-1 Aswan Segment	157
A-2 Nile Monitoring Program: Assiut Segment	163
A-3 Nile Monitoring Program: Mansoura Segment	164

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1 Schematic of Inflow and Losses, Upper Nile Basin, Annual Averages, $m^3 \times 10^6$	107
2 Schematic, River Flow and Withdrawals, Nile Valley, Annual Averages $m^3 \times 10^6$	110
3 Schematic, Water Withdrawals, Nile Delta, Annual Averages $m^3 \times 10^6$	111
4 Sketch Map Showing Location of Proposed Water Conservation Projects, Upper Nile Basin	115
5 Project Water and Land Development, Western Desert, Egypt	121
6 Sketch Map of Egypt, Showing Location of Certain Water Resources, Eastern Desert and Sinai	133
7 Histogram Showing the Discharge From High Dam and the Percent Passed Through the Turbines	135
8 Histogram Showing the Discharge From the Aswan Dam and the Percent Passed Through the Turbines	136
9 Profile, Nile Channel, Aswan Dam to Nile Delta, Showing Existing and Potential Barrage Hydropower Sites	137
10 Projected Energy Pattern, Egypt, Typical January Day, Year 2000	142
A-1 River Ecosystem Studies	152

F. ASSESSMENT OF ENERGY-RELATED MINERALS/COMMODITIES IN EGYPT

	<u>Page</u>
1.0 INTRODUCTION	165
2.0 MINERAL COMMODITIES	165
2.1 Cement	165
2.1.1 Limestone	166
2.1.2 Other Raw Materials	166
2.2 Iron	167
2.2.1 Bahariya Deposits	167
2.2.2 Aswan Deposits	169
2.2.3 Eastern Desert	169
2.2.4 Other Iron Deposits	169
2.3 Manganese	170
2.4 Aluminum	171

	<u>Page</u>
2.4.1 Nepheline Syenite	171
2.4.2 Aluminous Clay	172
2.5 Barite	172
2.6 Bentonite	174
2.7 Copper	174
2.8 Chromium	176
2.9 Nickel	176
2.10 Titanium	176
2.11 Phosphate	179
2.12 Other Minerals/Commodities	179
2.12.1 Molybdenum	179
2.12.2 Niobium-Tantalum	179
2.12.3 Tin-Tungsten	180
2.12.4 Zirconium	180
3.0 CONCLUSIONS AND RECOMMENDATIONS	180
4.0 REFERENCES	183

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1 Deposits of Iron and Manganese	168
2 Deposits of Aluminous Rocks and Clays, Barite and Bentonite	173
3 Deposits of Copper and Molybdenum	175
4 Deposits of Chromium and Nickel	177
5 Deposits of Tin, Tungsten, and Titanium	178
6 Deposit of Niobium/Tantalum	181

SUMMARY OF THE ENERGY RESOURCES OF EGYPT

By: The U.S. Geological Survey

1.0 INTRODUCTION

The following summary sets forth the conclusions and recommendations of the U.S. Geological Survey geologists assigned to survey Egypt's indigenous energy resources on behalf of the Department of Energy. The results of this survey incorporate preliminary information collected early in 1977 from files, reports, and publications existing in the United States, together with data gathered during a one month's tour of duty in Egypt March-April 1978.

The responsibilities for the work were as follows: oil and gas - John C. Maher; geophysical exploration for oil and reservoir analysis - Ahmed A. Fouda; coal and oil shale - Wilds W. Olive; nuclear raw materials - Lincoln R. Page; geothermal resources - Adel R. Zohdy; water resources - Frank E. Clarke; and energy-related minerals - Gene E. Tolbert.

2.0 OIL AND GAS

2.1 Summary

Exploration in Egypt since the beginning of the century has led to the discovery of 39 oil and gas fields, but significant production was not attained until 1969. Published estimates of proven recoverable oil reserves in Egypt range between 1.67 and 5.1 billion barrels. Proven recoverable oil reserves of Egypt were estimated by World Oil (1977) to be 1,429,000,000 barrels in 1975 and 1,559,000,000 barrels in 1976, a 9.1 percent increase. The same source gives natural gas reserves of 2.19 trillion cubic feet in 1975 and 2.18 trillion cubic feet in 1976, a 3.2 percent decrease. For 1977, the Egyptian General Petroleum Corporation (EGPC) reports crude-oil reserves of 2.1 billion barrels, an annual production of 151,000,000 barrels, and a daily average of 414,787 barrels. It projects production of 675 million cubic feet of gas per day in 1978.

Exploration and production in Egypt have experienced marked oscillations due to internal and external political events (e.g., the loss of the profitable Sinai fields in the 1967 war). Many foreign companies withdrew in the 1960's and exploration virtually ceased. A dramatic change occurred in 1973 when world price increases and the 1972 addition of Indonesian-type of production-sharing contracts attracted foreign companies to enter into new agreements with the Egyptian General Petroleum Corporation (EGPC).

During the period 1973-1977, exploration activities increased year by year, and in 1977 the total area under exploratory agreements reached 591,500 km², an increase of about 15 percent over 1976. However, exploration showed a decrease in the first quarter of 1978. Both Shell Winning N.V. and Conoco relinquished large concessions and drilling declined, as only 15 rigs were in operation compared to 23 in 1977, a 40 percent decrease.

In each year since 1975, the daily oil production has increased by sizeable amounts. In 1976, it increased 42.9 percent over 1975¹, and in 1977 it increased 25 percent over 1976. The rates of increase in production, when compared to an annual increase of less than 10 percent in reserves, indicate that large new discoveries will be needed both to balance withdrawals and to increase total reserves. The Egyptian Government hopes to attain production rates of 500,000 barrels a day in 1978 and 1 million barrels a day in 1982. Because of the present uncertainties in regard to national versus private commercial initiatives in the petroleum industry, the changing investment programs of the oil companies, the recent relinquishment of several huge tracts, and the slackening in drilling activity in early 1978, the chances of reaching the latter figure without decreasing reserves are probably considerably diminished.

The area of promising petroleum prospects in Egypt totals more than 600,000 km², of which only 230,000 km² are reported to have received more than a cursory examination. Prospects appear very favorable for substantial undiscovered reserves in many parts of this large area.

The Gulf of Suez basin holds the most immediate prospects for replacing production and increasing the reserves, but with diminishing results as the larger medium-depth structures are drilled. The development of new seismic techniques that will permit interpretation of structure beneath the masking salt beds in the Gulf of Suez may open new, deep exploration programs in the next few years.

The most promising frontier regions are the relatively unexplored broad expanses of the Western Desert, the Nile Delta basin, the Nile basin, and northern Sinai along with the adjacent offshore tracts. The Red Sea area appears to hold moderate possibilities, perhaps primarily as a gas province. The rate of exploration and development in these areas depends upon economic factors not predictable in this study. A more effective exploration program would require a considerable change in attack. It should include regional subsurface geology and geophysics surveys in all concessions and should emphasize exploration for stratigraphic traps and combination structural - stratigraphic traps by means of basin analysis and the new seismic stratigraphy commonly used now in

¹

This marked increase is believed to be due, in part, to the return of oil fields previously held and developed by the Israelis.

the United States. It is possible that an intensive exploration and drilling program along these lines could greatly increase the present reserves in 10 years.

2.2 Recommendations

An Egyptian national program to improve knowledge of petroleum resources would benefit from a unified program to bring together all knowledge of regional subsurface geology that is now deposited in the files of oil companies, universities and government agencies. The confidentiality imposed on most data by the companies and in part by the government has led to the general unavailability of information, a handicap to national planning. Even regional data and reports not concerned with local prospects have been little used in the few papers that have been published. Scientific discussion and publication of geological and geophysical reports of a regional nature should be encouraged and supported.

To collect, interpret, and utilize presently existing data on petroleum in Egypt, and to attain new critically needed information, several tasks should be undertaken: (1) standardization of stratigraphic nomenclature; (2) an aeromagnetic map; (3) a gravity map; (4) a basement tectonic map; (5) a Paleozoic thickness map; and a map showing sedimentary basins, all on base maps at 1:2,000,000 scale covering all of Egypt. These should be prepared with the collaboration of company, university, and government geoscientists.

The following activities are proposed to fulfill needs for records, maps, and charts, and the technology and methodology required to obtain or prepare them:

1. Nomenclature and Correlation of Stratigraphic Units. Published subsurface type sections with standard nomenclature and age assignments are necessary for geological and geophysical communication. These could be established best by selection of the stratigraphically deepest wells, with complete samples, cores, and electric logs in each basin or province and the preparation of composite sample logs by expert lithologists, aided by paleontologists. These logs would include not only lithology and electrical characteristics, but also fossils and oil, gas, and water information. These standard logs could then be used to extend correlations along cross sections at a vertical scale of 1"=100', designed to outline the regional stratigraphy and facies changes. It might suffice to have one composite standard well section for each province. In addition, it would be well to publish two stratigraphic cross sections at a vertical scale of 1"=200' at right angles across each region.

2. Stratigraphic Analysis of Sedimentary Basins. Regional stratigraphic analysis is an important element of petroleum exploration in frontier areas. It offers a relatively inexpensive means of comparing the petroleum potential of different rocks in different basins so that

priorities can be established for the expenditure of time and money. It requires analysis and synthesis of data and some controlled imagination for interpretation of each basin's petroleum potential. It does not ordinarily provide the detail necessary for selecting a site for an exploratory well, but, from a stratigraphic point of view, aids in selecting the most promising areas for further investigations through the usage of seismic reflection surveys, stratigraphic and structural test holes, and seismic stratigraphy.

Stratigraphic analysis provides information on the occurrence and distribution of potential reservoir rocks, sealing rocks, and source rocks, potential facies and unconformity traps, and on the possibilities for maturation of hydrocarbons and the entrapment of petroleum in each basin. Such studies require reconstruction of the geologic history, including tectonics, environment, mode of deposition of contained rocks, the depth of burial of the rocks at successive stages of basin development, as well as the present structure, thickness, and distribution of the rocks. Paleogeologic maps, particularly those of tectonic units marked by regional unconformities, paleogeographic maps showing environmental interpretations, and thickness maps with lithofacies distribution, are effective tools and should be prepared for the major sedimentary basins in Egypt and published for general use.

3. Basement Tectonic Map. The structural development of Egypt is greatly governed by the basement tectonics. The outline, shape, size, and disposition of the deep sedimentary basins are also partly controlled by the pre-existing topography and structures. Block faulting in the basement commonly accompanies basin subsidence. Many anticlines have resulted from movement of basement blocks. The block fault commonly controls facies, oil-structure development, oil occurrence, and can also control graben basins. It is essential, therefore, to have a reliable tectonic map of the basement. It is recommended that such a map be constructed by employment of: (1) ground and aerial magnetic data, (2) gravity data, (3) refraction seismic data, (4) regional common depth point (CDP) reflection sections, and (5) deep-well data.

4. Seismic Refraction Survey. Previous regional exploratory work in the Western Desert has consisted of widespread gravity and magnetic surveys, scattered structure-drill holes, and some conventional reflection seismic surveys. The results were inconclusive in the evaluation of the Paleozoic basin and the deeper structures, especially the Paleozoic uplift.

Two continuous in-line-reverse refraction profiles are suggested--one along the strike of the general deep trend, the second at right angles. Each profile should be about 100 miles long. Because the immediate object of the survey is to determine major subsurface geologic features with depths anticipated to be about 10 km, the shot points may be offset 30-40 km from the main spread. A cable 20 km long and a shot-point spacing of 4 km is recommended. Dynamite charges of 3,000 pounds will be required for each shot point to produce reliable first arrival data.

This refraction survey should be supplemented by the existing gravity, magnetic, and deep-well data. The object of this survey is to determine (1) the major subsurface geologic features, with special emphasis on the existence and shape of the Paleozoic uplift and Paleozoic basin, (2) the depth and dip of the refraction from the most competent beds, especially the basement, and (3) the effective refraction velocity for identification of gross lithologic units and for correlating reflection seismic records.

5. Seismic Stratigraphy. In Egypt the seismic reflections have been used in the traditional way--only to identify events and study structural deformations with the object of locating structural features which might entrap hydrocarbons. But the seismic data can provide a great deal of information for stratigraphic interpretation by relating seismic data to stratigraphy. Seismic stratigraphy is recommended for all parts of Egypt, but especially for the Nile delta and the Western Desert. It includes (1) seismic-sequence analysis to identify the stratigraphic units, their succession, and the sequence boundaries and lateral extent of strata, (2) seismicfacies analyses to interpret the sedimentary processes and environmental setting and to help predict the lithology of the facies, (3) cycle-sequence analysis to recognize cycles of relative rise-and-fall of sea level---these have a variety of predictable depositional patterns and help in constructing a regional stratigraphic framework necessary for interpreting paleogeography, geologic history, and geologic setting for petroleum-prospect analyses, and (4) true-amplitude analysis ("Bright Spot") will help in detecting petroleum in place, especially gas.

6. Seismic Modeling. Two major interpretive classes of seismic modeling are needed in Egypt--structural and stratigraphic. Structural modeling relates to interpretive problems where structural identification is the primary objective, such as the deep structures or in structurally complicated areas. Stratigraphic modeling concerns interpretive problems where identification of lithologic changes is the primary objective--that is, the trapping mechanism is primarily stratigraphic. Obviously, many problems have elements of both types of models.

7. Source-rock Evaluation and Crude-oil Correlation. To assess the petroleum potential of Egypt, and especially of the Western Desert and Nile delta, and also to select the optimum prospect areas and sites for future wells, a hydrocarbon-source rock evaluation study of well cuttings and samples of outcrops is needed. Such studies include the determination of the hydrocarbon-source quality (richness), source type (gas versus oil) and degree of thermal maturation and identification of specific organic facies that are of interest to exploration.

Source correlations and characterization for crude oil from different oil or gas fields in the Western Desert and Nile delta can readily be made to relate the hydrocarbons to their substance stratigraphic source facies. This knowledge, in conjunction with source-rock data, could focus exploration on prospective stratigraphic units.

8. Continuing Education of Geoscientists. Successful exploration in Egypt might be encouraged not only by economic incentives but also by subsidized educational efforts covering modern concepts and techniques. The basic geologic education of Egyptian earth scientists is very sound, but continuing contact with new theory and new technique is needed. Topics of special importance include stratigraphic interpretation of seismic data and modern sedimentologic analysis of clastic, carbonate, and evaporite depositional systems.

3.0 COAL AND OIL SHALE

3.1 Summary and Conclusions

Both coal and oil shale occur in Egypt. The deposits of oil shale that are known attain thicknesses of only 10 to 15 feet at studied localities, and their hydrocarbon content is low. They may never be economic. The best-known deposits of coal contain total reserves estimated at 95 million to 112 million tons. Of these, the only deposit deemed workable under present conditions of technology and economy is 150 km northeast of Ismailia on the Maghara anticline, Sinai Peninsula. Recoverable reserves are estimated to total 35.6 million tons. A production of 300,000 tons per year was planned for the Safa Mine which was being opened at the time of the 1967 war. The Maghara coal is not good coking coal and would require mixing with 70 percent to 90 percent of imported coking coal to produce a satisfactory coke.

Elsewhere in the Sinai, coal deposits at Wadi Thora, reported to contain 60 million tons, might become economic when a fluidized bed combustion process becomes economic. Deposits known to be present at Ayun Musa are not considered economic because of depth (400-600 m) below the surface, lenticularity of the coal beds, and the presence of formation water under high pressure.

Boreholes at Wadi Araba and Kharga Oasis have intersected coal seams, which are a few centimeters thick. Other seams found in the Western Desert are too deep, too thin, and too remote even for exploitation by subterranean gasification processes.

Although the prospects for developing a coal mining industry in Egypt are not encouraging, the information is not conclusive. Geologic investigation of Middle Jurassic rocks on the Sinai Peninsula might yet discover additional economic reserves to augment those of Maghara.

3.2 Recommendations

1. Determine the distribution of the Middle Jurassic coal-bearing sequence in those areas of the Sinai Peninsula where the sequence is at or near the surface. This will require geologic mapping, paleontologic and stratigraphic investigations, and the preparation of lithofacies maps and diagrams. Drillhole data will be needed in those areas where the sequence is not at the surface. With information thus obtained it should be possible to predict localities in which ancient lagoons may have formed. Such lagoons were likely sites for development of economic coal deposits. Additional drilling would be required to test those localities. Investigations should first be conducted in the Maghara area in order to determine the limits of the deposits known to occur there.

2. Conduct detailed geologic investigations along traverses that transect the exposed coal-bearing sequence. Although the sequence had been mapped in several areas, it was not until the late 1950's that it was recognized that outcropping thin layers of ash represented coal beds that were oxidized at and near the surface. New geologic traverses could result in detection of such layers, and thereby would identify areas for exploration by drilling.

3. Consider pipeline transmission of coal slurry from the Safa Mine to Helwan or to El Arich. Where there are no other commodities to be transported, pipeline transmission provides the cheapest means of transporting coal. Water is probably not present at Maghara in sufficient amounts to permit its wastage at the receiving end of such a line; but this problem might be resolved by providing an additional, smaller line to return the water for reuse; or, a pipeline of sufficient diameter to transport coal and return water during alternate periods could be installed.

4.0 URANIUM AND THORIUM RESOURCES

4.1 Summary and Conclusions

No uranium (U) or thorium (Th) was being produced in 1978 in Egypt. In the past some thorium was recovered with other minerals from the black sands in the Rosetta area of the Nile delta, and small stockpiles of uranium ore have resulted from exploration work at the El Atshan and El Erediya deposits.

Large areas (more than 200,000 km²) of Egypt have been covered by airborne surveys for radioactivity and more than 7,000 anomalies have been identified. However, prospecting or ground radiometric work has been conducted on only 50 of the anomalies. All the main roads and many of the wadi trails have been traversed by car-borne radiometric equipment. The Nuclear Materials Corporation (NMC) and the Remote Sensing Project of the Academy of Science and Technology expect to have a base map of Egypt completed in about 6 months; the anomalies will be compiled on these maps during the next year.

Prospecting, preliminary sampling, and very detailed mapping have been limited to the Qatrani, El Erediya, El Missikat, and El Atshan areas. Except for the black sands at Rosetta, and at places where U and/or Th are associated with niobium and other metals as at Wadi Nugrus, such deposits do not appear important. Limited sampling of phosphate and black sands for uranium has been undertaken.

Geological conditions of sedimentation, structure, and igneous activity in many parts of Egypt appear favorable for finding uranium deposits, but there was no opportunity to match these areas with the known anomalies. The state of prospecting and exploration is about comparable to that in the United States during the early 1950's; thus, with the proper expenditure of funds and effort there is a good chance of finding new and significant deposits. This, however, will take at least 10 years. The presently known deposits may contain several thousand tons of uranium; Dr. El Shazly estimates 1,000 tons at El Missikat. In my opinion, the presently known areas that can be expected to develop into uranium mining and milling districts in the near future are (1) El Missikat-Erediya, (2) El Atshan, and (3) Qatrani.

Recovery of some uranium from phosphate might be possible, provided the wet treatment of phosphate ores is undertaken to produce triple superphosphate. The total uranium resource in phosphate is on the order of 225,000 tons. Present phosphate production is 500,000 tons. If all the proposed production--10,000,000 tons per year--were attained, and all were given wet treatment and uranium was recovered, the production of uranium might be 500-600 tons per year, based on an average grade of 50-60 ppm. At present prices for uranium this might be economically feasible for some fraction of the phosphate ores, particularly those that contain 150 ppm or more.

The black sands on the beaches of the Rosetta and Damietta branches at the mouth of the Nile contain 0.5-1.0 percent of monazite. This amounts to about 0.03 percent U_3O_8 and 5 percent ThO_2 . The monazite in the Abu Khashaba area, Rosetta, is estimated to contain 212 tons of U_3O_8 and 35,350 tons of ThO_2 . There may be equivalent amounts in the Damietta area. Economic production of this uranium probably is dependent upon monazite being extracted as a byproduct of mining of the black sands for titanium and zirconium and then the treatment of monazite for ThO_2 .

4.2 Recommendations

It is the opinion of the writer that Egypt could, by appropriate programs of prospecting, exploration, and development, find and produce the uranium needed for the nuclear plants projected for development by the year 2000.

Some elements of such programs are given below:

1. The search for, evaluation of, and production of uranium will require the involvement of all governmental agencies concerned with minerals, fuels, and groundwater. This could be accomplished by the appropriate transfers by NMC of funds to other agencies for specific investigations, or the transfers of personnel from other agencies to NMC for specific investigations.

2. A training program is needed in the geological, geochemical, geophysical, and hydrologic sciences as they pertain to the search for new deposits of uranium. This should be designed to give present personnel additional experience in foreign countries, and to develop and train new personnel in Egypt. Training might be conducted by Egyptians or foreigners.

3. An expanded geologic, geochemical, and geophysical prospecting program is needed to evaluate known anomalies and environments believed to be favorable for the occurrence of uranium.

4. An exploration program is needed to evaluate the known deposits (particularly those at El Missikat, El Eridiya, El Atshan, and Qatran) by appropriate diamond drilling, underground workings, and systematic sampling. Underground workings should be made in such a fashion that they could serve as preliminary production workings. Financial considerations might make it desirable to do this on a concession basis.

5. Field programs should be supported by additions of modern laboratory and field equipment and by personnel training.

5.0 GEOTHERMAL ENERGY

5.1 Summary and Conclusions

The potential for development of low-level sources of geothermal energy in Egypt is good. However, at present there is no evidence to indicate a high-temperature (greater than 200°C) source or a vapor-dominated system. Discovery of a geothermal source having a temperature of about 150°C is much more likely and, with present day technology, such a source could be used for the generation of electrical energy by employment of a binary fluid system.

Several water wells and natural springs yield water at temperatures that range between 40°C and 60°C. Water at these temperatures can be used locally for heating homes, greenhouses, and hatcheries, and for providing initial heating energy for industries that require water at near boiling temperatures.

To the present (1978), only a few geochemical and regional heat-flow measurements have been made in Egypt. Detailed geophysical exploration of specific geothermal areas has not begun, and consequently test drilling has not been done. Therefore, it is unlikely that electrical energy will be produced from a geothermal plant in Egypt in 1985. In general a basic requirement for development of geothermal power plants is the existence of sites affording vast amounts of hot water (temperature greater than 150°C). To date, such sites have not been identified in Egypt. Alternatively, it should be feasible, by the year 2000, to use solar energy in conjunction with low- or intermediate-temperature geothermal waters such as are known in Egypt to produce a higher energy system. The Supreme Council on New Energies has submitted a proposal to the Ministry of Electricity and Energy to spend approximately 3.15 million Egyptian pounds for geothermal energy over the period 1978-1982.

Most areas of potential geothermal energy are not in the immediate vicinity of Cairo or Alexandria, but are in areas near the Gulf of Suez where new industries or settlements might be founded and which would relieve the population pressures in the larger cities.

5.2 Recommendations

5.2.1 Exploration methods: Continued heat-flow and geo-temperature studies, such as those already conducted and proposed, and including a new cooperative program between the New Mexico State University and the Egyptian Geological Survey, should be continued, expanded and augmented by the following:

1. Deep electrical resistivity surveys including (a) Schlumberger soundings, (b) bipole-dipole total-field surveys, (c) telluric current surveys, (d) self-potential (SP) surveys, (e) audio-magnetotelluric (AMT) soundings, and (f) magnetotelluric (MT) soundings.
2. Seismic refraction, gravity, and aeromagnetic surveys.
3. Drilling of deep test wells.

At present, immediate emphasis should be placed on the field surveys identified in item 1, (a) through (d).

5.2.2 Personnel and equipment: The Egyptian Geological Survey (GSE) and the Desert Institute have personnel who have adequate professional background to conduct deep Schlumberger soundings and SP surveys. Equipment on hand, however, is inadequate except for shallow and intermediate-depth (less than 500 m) soundings. Most of the equipment now in Egypt is at the Geological Survey.

Equipment and technical knowledge necessary to conduct deep electrical survey items 1 (b), (c), (e), and (f) above are totally lacking. In addition, modern resistivity and seismic refraction equipment for deep soundings and programmable pocket calculators and larger programmable desk calculators are needed to support these programs.

5.2.3 Training: Training of Egyptian geophysicists in modern geophysical and geochemical methods of data acquisition, reduction, interpretation, and the use of programmable calculators and computers is highly recommended.

Short courses (3-4 weeks) conducted in Egypt by visiting experts, and visits (3-4 weeks) to the U.S. by Egyptian scientists for training in electrical resistivity, heat flow, and geothermometry methods are recommended to achieve these training objectives. It is recommended, also, that training in the analysis of possible impacts on environments be provided prior to the initiation of drilling or development projects.

6.0 WATER RESOURCES

6.1 Summary and Conclusions

A report by the World Health Organization (1977) estimated the full potential capacity of the Nile System to be at 70×10^9 m³/year, including up-basin conservation, irrigation return flow, and valley and delta groundwater development. If Lee's (1975) figure of 30.4×10^9 m³/year consumptive use for the present 6.3×10^6 feddans and cropland is used, the consumptive requirement for the projected 9×10^9 feddans in the valley and delta ($6.3 + 2.8$) amounts to 43.4×10^9 m³/year. Assuming the 58 to 59 percent irrigation efficiency used in projections by Hoofnagle, et al. (1976), this would require 73 to 74×10^9 m³ of irrigation withdrawal, which exceeds the projected maximum capability of the Nile. Improvement of efficiency to 61.5 percent would approximately balance irrigation demand and projected supply.

Considering the present domestic-industrial withdrawal of 2.68×10^9 m³, the predicted expansion of population (38×10^6 to 67×10^6), and related industrial growth between now and the year 2000, it is reasonable to expect a nonagricultural water requirement of at least 5×10^9 m³; perhaps 7.5×10^9 m³. If this is the case, 70 percent irrigation efficiency would be required to conserve water for municipal and industrial purposes. According to Lee (1975), this is not unreasonable for a closed system like that of the Nile. There also are the alternatives of conserving municipal-industrial water, increasing agricultural productivity on presently irrigated land, and making greater use of desert groundwaters.

The consumptive water requirement of proposed energy development is relatively small by comparison. Even with maximum dependency on fossil fuel, it should not exceed 0.25 percent of the ultimate Nile flow, and thus is a minor element in a massive water balance equation.

In the Western Desert, the water resource of the Nubian aquifer is essentially nonrenewable and dedicated almost entirely to agricultural and related uses. Enough land can be reclaimed to consume whatever freshwater is economically available. Thus, diversion to other uses may result in the loss of productive land.

Some flexibility exists for using the desert's relatively abundant brackish and saline Miocene water in noncritical industrial and energy-related programs (e.g., oil production). In view of the land constraint in Egypt, it seems likely that full use will be made of this brackish resource before resorting to the tradeoff mentioned above.

Water resources of the Eastern Desert and the Sinai are largely unexplored; however, an optimistic view is that sufficient water can be discovered for use in developing their resources, including coal, petroleum, and energy-related minerals. There seems to be no plan for large-scale agriculture in these areas that would compete for the limited supply.

Although present plans for agricultural and industrial expansion together with expected population growth and increased urbanization could totally obligate water resources of the Nile within a decade, this is not likely to happen in view of the opportunities for conservation and development of additional water resources.

A more optimistic, and probably more realistic conclusion, is that Egypt's water resources, in total, will be capable of supporting increasing demands for the remainder of the century provided they are developed and managed effectively. This will require maximum practicable conservation in the upper Nile basin, improvement in irrigation efficiency, and reduction of loss in municipal and industrial uses, particularly through treatment and reuse of waste water. Also, it will require optimum development and utilization of groundwater along the Nile and in the deserts, as well as substitution of saline or brackish water for freshwater when possible. Systematic water-quality monitoring will be required to guard against potential problems related to heavy agricultural and municipal uses.

The Egyptian Government is well aware of the need to expand and conserve water resources, and is taking impressive steps in that direction. The United Nations Water Master Plan Office (Ministry of Irrigation) is engaged in a multi-year project aimed at assessing current water use and improving water-use efficiency through better water management. The same Ministry is conducting groundwater modeling studies of the Nile delta, which are to be followed by similar modeling

in the valley to determine safe groundwater yields. Also, it is cooperating with the United Nations (UNDP) in real-time telemetering of surface-water data. The Desert Institute, along with the Water Master Plan Office, is preparing a proposal for exploring water resources of the Eastern Desert. The Egyptian Academy of Sciences, the U.S. Environmental Protection Agency, the University of Michigan and the Ford Foundation jointly have made much progress in monitoring water quality in Lake Nubia, Lake Nasser, and the Nile River and delta. As recently as March 1978, President Sadat re-emphasized the need to increase exploration and development of Western Desert groundwater.

6.2 Recommendations

Because the Nile must bear the principal burden of increasing water use, it is recommended that maximum practicable support be given to upstream conservation projects. It is recommended also that early effort be made to systematically explore Eastern Desert groundwater resources, particularly in areas where they are likely to be needed in developing strategic minerals. More exploration of the Nubian aquifer beyond the desert depressions and additional groundwater studies at potential desert city sites will help optimize use of desert water and relieve the Nile.

Beyond this, it is recommended that thought be given to establishing an office of water data coordination, like that in the U.S. Geological Survey, to take full advantage of the mass of information now being collected concerning water resources. Such an office could serve as a central library, both conventional and computerized, for the many facts and figures needed for effective water management.

7.0 ENERGY-RELATED MINERAL/COMMODITIES

Conclusions and Recommendations. The main purpose of this report is to assess the availability of energy-related mineral resources in Egypt. In general, most of these minerals are unavailable or found in uneconomic concentrations. However, deposits of materials used in the cement industry and, to a limited extent, iron ore for steel making, are available. Deposits of manganese, clay, and other energy-related minerals may become utilizable to Egypt upon return of the Sinai to Egyptian control. This report does not make detailed recommendations for exploring for, and exploiting energy-related minerals/commodities, although it is certainly appropriate for Egypt to assess the potential of her mineral resources. Any discovery and subsequent development of a mine would help the country's financial situation, whether the metal is consumed internally or exported, and, of course, would provide raw materials needed for increased energy production. In view of increasing

energy demands, it may be advantageous for Egypt to expand exploration efforts for these raw materials in order to offset an eventual increased import quota of energy-related minerals. Any major change in Egypt's energy utilization would require a reexamination of the supply of energy-related minerals.

1. Cement-making materials. These are abundant in those areas which are industrialized, or are likely to be: Nile Valley, Gulf of Suez, Red Sea area, and northern coast.

2. Iron ore. The Bahariya ores, with grades sufficiently high to sustain the transportation costs to the iron and steel complex at Helwan, are limited. Other known deposits are of lower grade; the prospects for finding new deposits of grades equal to or better than Bahariya ores appear to be unfavorable. However, additional geologic exploration is needed to define more precisely the tonnage and grade of known deposits.

3. Manganese. Manganese for the current production of steel is supplied from small deposits in the southeastern corner of Egypt. These deposits can maintain a production of a few thousand tons of manganese per year for several more years.

The Um Bogma ores in Sinai could undoubtedly furnish manganese ore for expanded steel production and could probably produce ore for export. Geological exploration in Sinai should again be initiated, upon return to Egyptian control, in an effort to increase known reserves in the Um Bogma area as well as to explore other favorable areas.

4. Aluminum. Conventional sources of alumina, in the form of bauxite, are unknown in Egypt. Considerable effort has gone into evaluation of nepheline syenite as a source of alumina; undoubtedly, efforts should continue toward utilization of these unconventional sources, particularly as their technologies develop. However, more effort should be focused on finding deposits of high-alumina clays. Although in most instances the technology of extraction of alumina from clay has not proved to be economical (mainly because it is cheaper to use bauxite), the extraction techniques appear to show more promise, from an economic point of view, than extraction from nepheline syenites and related high alumina-low silica hard rocks.

5. Barite. There appear to be several undeveloped deposits of barite in Egypt. These, and particularly the new deposit at Bahariya, should be mapped and evaluated.

6. Bentonite. This material is found at Faiyum Oasis and on the Sinai Peninsula. These areas need to be geologically explored to determine whether sufficient domestic bentonite reserves can be identified to substitute for imported bentonite in drilling mud.

7. Copper. The prospects for developing economic deposits of copper in the Eastern Desert are favorable, but an intensive exploration program will be required. The United Nations has done some work on the more important copper prospects, and although the reserves are small, the geologic environment is favorable for finding additional deposits.

8. Chromium. Chromium deposits identified to date are small and irregular. Although some of the lenses are minable on a small scale, the outlook for discovering large deposits is poor.

9. Nickel. Several nickel prospects are known in the Eastern Desert, all too small to be minable. One prospect needs further evaluation, but on the basis of known geologic information, the chances of identifying economic deposits do not appear to be favorable.

10. Titanium. At least one titanium deposit is known in the Eastern Desert, and although it is in a remote area, it could prove to be minable under the right conditions. Additional geological and geophysical surveys may reveal other deposits.

11. Miscellaneous metals used in steel making. Molybdenum occurrences have been identified in the Eastern Desert, but all are of minor importance and prospects for finding economic concentrations of this metal do not appear to be favorable.

Niobium and tantalum are associated with several granitic complexes in the Eastern Desert but work undertaken so far has not revealed minable deposits.

A. THE PETROLEUM POTENTIAL OF EGYPT

By: John C. Maher, Ahmed A. Fouda,
and Robert E. Garrison

1.0 EXECUTIVE SUMMARY

Oil exploration in Egypt since the beginning of the century has resulted in the discovery of 39 oil and gas fields, but significant production was not attained until 1969. Published estimates of proven recoverable oil reserves in Egypt range between 1.67 and 5.1 billion barrels. The proven recoverable oil reserves in Egypt were estimated by World Oil (1977) to be 1,429,000,000 barrels in 1975 and 1,559,000,000 barrels in 1976, a 9.1 percent increase. The same source gives natural-gas reserves of 2.19 trillion cubic feet (f³) in 1975 and 2.18 trillion f³ in 1976, a 3.2 percent decrease. For 1977, the Egyptian General Petroleum Corporation (EGPC) reports crude-oil reserves of 2.1 billion barrels, an annual production of 151,000,000 barrels, and a daily average of 414,787 barrels. It projects production of 675 million f³ of gas a day in 1978.

Exploration and production in Egypt have experienced marked oscillations due to internal and external political events (e.g., the loss of the profitable Sinai fields in the 1967 war). Exploration virtually ceased in the 1960's and many foreign companies withdrew. A dramatic change occurred in 1973 when world price increases and the 1972 addition of Indonesian-type of production-sharing contracts by Egypt attracted foreign companies to enter into new agreements with EGPC, a state organization.

During the period 1973-1977, exploration activities increased considerably. During 1977, the total area under exploratory agreements reached 591,500 k²m, an increase of about 15 percent over 1976 figures. However, exploration activities showed a decrease in the first quarter of 1978. Both Shell Winning N.V. and Conoco relinquished large concessions, and the drilling activity fell with only 15 rigs in operation as compared to 23 last year, a 40 percent decrease.

Since 1975, the daily oil production has increased by sizeable amounts each year. In 1976, it increased 42.9 percent over 1975¹, and in 1977 it increased 25 percent over 1976. The rate of increase in production compared to an annual increase of less than 10 percent in reserves points out that large new discoveries will be needed both to balance withdrawals and increase total reserves. The Egyptian government hopes to attain a rate of 500,000 barrels a day in 1978 and 1,000,000 barrels a day in 1982. Because of the present uncertainties of petroleum economics, the changing investment programs of the oil companies, the recent relinquishment of several huge tracts, and the slackening in

¹ This marked increase is believed to be due, in part, to the return of oil fields previously held and developed by the Israelis.

drilling activity in early 1978, the chances of reaching the latter figure without lessening reserves are probably considerably diminished.

The area of promising petroleum prospects in Egypt totals more than 600,000 km² of which only 230,000 km² are reported to have received more than a cursory examination. Prospects appear very favorable for substantial undiscovered reserves in many parts of this large area.

The Gulf of Suez Basin holds the most immediate prospects for replacing and increasing the reserves, but with diminishing results as the larger medium-depth structures are drilled. The development of new seismic techniques that will permit interpretation of structure beneath the masking salt beds in the Gulf of Suez may open new deep-exploration programs in the next few years.

The most promising frontier regions are the relatively unexplored broad expanses of the Western Desert, the Nile Delta Basin, Nile Basin, and northern Sinai along with the adjacent offshore tracts. The Red Sea area appears to hold moderate possibilities, perhaps mostly as a gas province. The rate of exploration and development in these areas depends upon economic factors not predictable in this study. It is possible that an intensive exploration and drilling program could double the present reserves in 10 years. A proper exploration program would require a considerable change in attack to include regional subsurface geology and geophysics across all concessions, emphasis upon exploration for stratigraphic traps and combination structure-stratigraphic traps by means of basin analysis, and the new seismic stratigraphy commonly used now in the United States.

2.0 INTRODUCTION

2.1 Area and Purpose of Report

Egypt is situated on the southeastern Mediterranean Coast and forms the northeastern corner of Africa. It is bounded to the north by the Mediterranean Sea, to the east by Israel and the Red Sea, to the south by Sudan, and to the west by Libya. In shape it is almost square -- 1,073 km from north-to-south and 1,226 km from west-to-east. It has an area of 1,002,000 km², about 96 percent of which consists of sand and bare rock. Egypt is readily divided geographically into the following provinces: (1) the Nile Valley and Delta, (2) the Western Desert, (3) the Eastern Desert, and (4) the Sinai Peninsula (figure 1). The Nile River, which rises in the highlands south of Egypt, flows midway south-to-north through the country providing irrigation for the only agricultural land. Ninety-five percent of the 37,500,000 population (1975) lives in the long narrow Nile Valley and about 25 to 30 percent of the population is crowded in the Valley at Cairo. The rainfall is a few centimeters a year except along the Mediterranean Coast.

This summary report on Egypt's petroleum potential was prepared because of Egypt's needs to increase its energy resources to meet the mounting demands of its ever-increasing population, its modernization of

Fig. 1 Location of oil and gas fields and pipelines (1977) in relation to geographic provinces in Egypt

agriculture, and its program of industrialization. Egypt also needs to export surpluses of petroleum to assist with its international balance of trade. The report offers a means of comparing Egypt's petroleum potential with reports of the potential of other energy sources such as coal, uranium, water power, solar radiation, and biomass.

2.2 Sources and Reliability of Data

Considerable basic geological information on Egypt is available as the result of more than a century of scientific investigations by Europeans and Egyptians (Said, 1962, p. 4-7). Much of this is analyzed and synthesized in a comprehensive volume by Said (1962) entitled "The Geology of Egypt." This book provides much information about the structure and stratigraphy of surface rocks. Another useful general paper of that vintage is "Introduction to the Geology of Egypt" (Bar and Klitzsch, 1964). However, both reports preceded the active petroleum exploration activity of the last decade and do not have the more recent subsurface information. Of necessity, this summary report was prepared from many documents from different sources -- the recent literature, the files of the EGPC and oil companies, and discussions with many geoscientists in Egypt. One important recent contribution is "The Geology of the Egyptian Region" by E. M. El Shazly (1977) upon which we have drawn heavily. The interpretations from this report differ considerably in some aspects from unpublished reports by Norton (1970) and Babev (1968) but are used herein because time and data do not permit reconciliation or even firm opinion in a summary report such as this. However, whenever significant to petroleum exploration, these differences are pointed out.

EGPC is the depository of exploratory and production records of all oil companies in Egypt. The reports and records provided for review were multitudinous and much too detailed for our general overview. The few summary and regional reports, primarily from different oil companies, used different nomenclature and ages for the same rocks, and as might be expected, proved to be contradictory in some major interpretations. These were difficult to evaluate as a basis for assessing the petroleum potential of Egypt, even in a qualitative way, without an intensive review of basic data. Accordingly, a quantitative assessment of the petroleum resources of Egypt may be many years away, even if exploration and drilling are intensified.

Little is known even now about the surface rocks in some areas, such as the southern and southwestern parts of Egypt, and subsurface information is still sparse everywhere except in the more closely drilled Gulf of Suez basin. Published geophysical data are much less abundant, particularly in the offshore areas.

2.3 Acknowledgements

During our 5-week mission in Egypt, our principal contacts with EGPC were Moustafa K. E. Ayouty and Abdel Hamid Hedeiwy and, with the General Petroleum Company, D. N. H. Gazeery. Substantial contacts also were made with the Geological Survey of Egypt through Galal Moustafa, Maurice H. Hermina, and Ahmed O. Mansour. Discussions were held with E.M. Shazly of the Nuclear Materials Corporation and with A. M. Abdullah, Cairo University, among the many government and university geologists consulted. The many oil company geologists and geophysicists who were especially helpful include S. E. Ansary and D. J. Shorey of the Western Desert Petroleum Company, Dr. Baha Kamai of the Gulf of Suez Petroleum Company, and Herman C. Burrough of Union Oil Company of Egypt. Numerous contacts were made with the oil companies in Cairo and Alexandria. Special thanks go the Western Desert Petroleum Company for visits to the El Razzak and Abu Al Garadiq fields near the Qattara Depression, to the Gulf of Suez Petroleum Company for a visit to their operations in the Gulf of Suez, and to EGPC for making an office available for our use.

3.0 PETROLEUM EXPLORATION AND DEVELOPMENT

3.1 History of Petroleum Exploration

Discovery of oil in commercial amounts occurred in 1909, but significant production was not attained until 1969 and the first small exports were made in 1975. Until 1966 all oil discoveries in Egypt were in the Gulf of Suez basin, which remains the major source of reserves and production. Since 1966 discoveries have also been made in the Western Desert and in the Nile Delta Basin and the focus of exploration in the Gulf of Suez basin has shifted into offshore areas.

Oil exploration in Egypt since the beginning of the century has located 39 oil and gas fields, as reported by the (EGPC), with total proven recoverable reserves estimated by EGPC to be 2.1 billion barrels of oil and 4.5 trillion f^3 of gas.

Exploration and production in Egypt have experienced marked oscillations due to internal and external political events (e.g., the loss of the profitable Sinai fields in the 1967 war). Exploration virtually ceased in the 1960's and many foreign companies withdrew. A dramatic change occurred in 1973 when world-price increases and the 1972 addition of Indonesian-type of production-sharing contracts by Egypt attracted foreign companies to enter into new agreements with EGPC, a state organization.

During the period 1973-1976, exploration activities increased considerably. For example, during 1976 a total of 369,000 feet of hole was drilled, a 61 percent increase over 1975; as of December 31, 1976, the total area under exploratory agreements with oil companies was

510,927 km² compared to only 184,990 km² a year earlier, a 36 percent increase over 1975. About 28 foreign companies signed agreements with EGPC to explore on more than 30 concessions. In addition, the General Petroleum Corporation (GPC), a wholly owned subsidiary of EGPC that explores primarily in the Gulf of Suez region and the Western Desert, conducted extensive operations.

During 1977, the total area under exploratory agreements reached 591,500 km², an increase of about 15 percent over 1976 figures. About 515,000 km² were on land, 33,600 km² on the shelf, and 43,3000 km² in deep water offshore. Production contracts were awarded in the Sahara, the Western Desert, the western Sinai, and the Mediterranean offshore. Relinquishments were made in the Western Desert, the East Cairo area, the Mediterranean, and the Gulf of Suez.

Geological investigations of surface rocks were conducted in 1977 by 19 organizations in the Western Desert, Eastern Desert, the Gulf of Suez, the Red Sea, and the Mediterranean. Seismic exploration on land decreased; a total of 9,300 linear kilometers was shot.

Exploratory drilling in 1977 was done by 19 organizations. A total of 49,970 meters (m) was drilled onshore, mainly in the Western Desert, but no discoveries were made. Offshore, a total of 172,036 ft (52,450 m) was drilled mainly in the Gulf of Suez, but also in the Red Sea and the Mediterranean Sea. One discovery was made in the Gulf of Suez; it tested 4,685 barrels a day. Extension and development drilling increased sharply in 1977 -- a total of about 118,200 m was drilled.

In 1978, exploration activities showed a decrease in the first quarter. Both Shell Winning N.V. and Conoco relinquished large concessions, and the drilling activity fell with only 15 rigs operating compared to 23 last year, a 40 percent decrease.

3.2 Petroleum Contracts

The Mining Law (No. 66) of 1963 is the basic petroleum law of Egypt. It describes three types of rights: reconnaissance permits, exploration licenses, and exploitation leases. The reconnaissance permit is not exclusive and does not allow drilling. The exploration license is valid for 1 year, renewable three times if minimum work is conducted each year. It remains valid after 4 years as long as one rig is continuously active. Maximum area of one license is 100 km² and the number of licenses any single company can hold depends on its technical and financial capacities. Exploitation leases are granted in principle on only half an exploration license and at least one producing well must have been drilled in the area. Exploitation rights are granted for an initial 30-year period with one 15-year extension possible. Royalty is 15 percent of the marketed value of the petroleum during the original period and 25 percent during the extension period. Only GPC, a nationally owned company, has rights now that follow this basic law as the

other rights are subject to special contracts made according to two different patterns described below:

Participation Agreement. This is known as the Western Desert type contract as it is used in all the area west of the Nile. The Western Desert₂ is divided into 13 areas, each divided into 25 blocks of about 420 km² (12' latitude x 12' longitude). These areas were originally offered for bidding in August 1960. By separate application for each, any company could apply for one or all areas or for any block. The contract is valid for 30 years with only one 15-year extension possible, including a 12-year exploration period. The original area must be reduced by 25 percent after 10 or 12 years. Usually only producing area can be retained; although this retention differs from contract to contract. A large minimum exploration investment is specified in each contract, but no rental fee is charged for the first 10 years. The royalty is 15 percent; the income tax is 50 percent. The royalty may increase to 25 percent as of the 10th year. In case of a commercial discovery, a joint subsidiary with EGPC is formed on a 50/50 basis. After that EGPC contributions from oil are half of the exploration and exploitation expenses. This system is now openly applicable to two contracts.

Production-sharing System. Since late in 1972, all the exploration agreements have been drawn up under this system except for one participation contract. Under this system, the contractor takes all the exploration risk. In case of commercial exploitation, the first 40 percent of the oil produced is set aside to reimburse exploration and development costs. The balance is split in proportions differing from 60/40 and 85/15 in favor of EGPC. Different rates may be applied for offshore concessions, according to the water depth and to the resulting different operating costs. Signature bonuses are generally paid. Production bonuses are to be paid, as agreed, for each contract. The contract includes an exploration period (usually 6 or 8 years, but 12 years in the case of one deep-water area) at the end of which only the producing area can be kept under a development lease usually valid for 30 years. Reductions of 25 percent of original acreage are successively due, usually after a period ranging from one to four years. Exploration commitments are negotiable.

3.3 Production and Reserves

Published estimates of proven recoverable oil reserves in Egypt range between 1.67 and 5.1 billion barrels. The proven recoverable oil reserves in Egypt were estimated by World Oil (1977) to be 1,429,000,000 barrels in 1975 and 1,559,000,000 barrels in 1976, a 9.1 percent increase. The same source gives natural-gas reserves of 2.19 trillion f³ in 1975 and 2.18 trillion f³ in 1976, a 3.2 percent decrease. For 1977, EGPC reports crude oil reserves of 2.1 billion barrels, an annual production of 151,000,000 barrels, and a daily average of 414,787 barrels. Tables 1 and 2 show the petroleum production of the oil and gas fields and the pertinent well data.

TABLE 1

PETROLEUM PRODUCTION AND RESERVES OF FIELDS IN EGYPT

EGYPT FIELD	PROD. AVER	ANNL. PROD.	CUM. PROD.	REMARKS
Abu Garadig	48,724 MCFD (Mar. 1978)	10,544,271 MCF (1977)	12,066,022 BO (1977)	Gas reserves recoverable in 1975: 2.2 MMCFG
	10,593 BPD (Mar. 1978)	4,045,563 BO (1977)		
Abu Madi	16,421 MCFD (Mar. 1978)	5,565,177 MCF (1977)		
Abu-Qir				
Alamein	6,271 BPD (Mar. 1978)	2,612,201 BO (1977)	54,424,201 BO (1977)	Original recoverable (proven)-61,000,000 BO reserves
Amal				Original recoverable reserves-31,450,000 BO
Asl	1,382 BPD (Mar. 1978)	556,581 BO (1977)	37,243,581 BO (1977)	Original recoverable reserves-40,880,000 BO
Belayim Land	32,359 BPD (Mar. 1978)	11,609,960 BO (1977)	252,634,077 BO (1977)	Remaining recoverable reserves in 1975- 247,000,000 BO
			(*incl. Belayim Marine)	
Belayim Marine	50,994 BPD (Mar. 1978)	12,794,117 BO (1977)	252,634,077 BO (1977)	Original recoverable reserves-226,440,000 BO
			(*incl. Belayim Land)	
Ekma			670,700 BO (1962-1967)	
GS 300-1				
GS 382-1	23,080 BPD (Mar. 1978)	198,746 BO (1977)		
GS 391-1				
Hurghada	16 BPD (1968)	6,000 BO (1968)	41,121,000 BO (1968)	Original recoverable reserves-44,000,000 BO
July	143,893 BPD (Mar. 1978)	75,710,419 BO (1977)	18,343,000 BO (1975)	Original recoverable reserves-greater than 500,000,000 BO
		*(incl. Rama- dan field)		
Karim	583 BPD (Mar. 1978)	249,282 BO (1977)	9,494,236 BO (1977)	Original recoverable reserves-12,580,000 BO
Kheir	236 BPD (Mar. 1978)	84,524 BO (1977)	566,438 BO (1977)	Original recoverable reserves-3,800,000 BO
LL 87-1				
LL 87-2				
Matarma	1,132 BPD (1967)	413,114 BO (1967)	1,718,400 BO (1967)	Original recoverable reserves-1,890,000 BO
Meleiha				

EGYPT FIELD	PROD. AVER	ANNL. PROD.	CUM. PROD.	REMARKS
Morgan	69,417 BPD (Mar. 1978)	28,759,400 BO (1977)	530,952,275 BO (1977)	Remaining recoverable reserves 1975 - 1,500,000,000 - 2,000,000,000 BO
Qantara 1				
Ramadan	102,351 BPD (Mar. 1978)	75,710,417 BO (1977) *(incl. July field)	12,800,000 BO (1975)	Original recoverable reserves-greater than 500,000,000 BO
Ras Amer	1,808 BPD (Mar. 1978)	744,066 BO (1977)	6,236,014 BO (1977)	
Ras Bakr	7,017 BPD (Mar. 1978)	2,883,617 BO (1977)	58,142,517 BO (1977)	
Ras Garra	43 BPD (1967)	15,688 BO (1967)	231,850 BO (1967)	Original recoverable reserves-1,269,000 BO
Ras Gharib	7,432 BPD (Mar. 1978)	2,681,369 BO (1977)	258,175,715 BO (1977)	Original recoverable reserves-239,000,000 BO
Ras Sudr	1,169 BPD (Mar. 1978)	636,680 BO (1977)	9,883,862 BO (1977)	Original recoverable reserves-44,000,000 BO
Razzak	6,249 BPD (Mar. 1978)	3,142,659 BO (1977)	28,491,052 BO (1977)	
S. Gharib Mar	6,777 BPD (Mar. 1978)	203,414 BO (1977)		
Sidri Abu	1,600 BPD	585,000 BO	17,095,000 BO	Total reserves 31,450,000 BO
Rudeis	(1967)	(1967)	(1967)	Total remaining recoverable in 1968 - 14,335,000 BO
Shukheir	529 BPD (Mar. 1978)	199,418 BO (1977)	1,223,418 BO (1977)	Original recoverable reserves-3,770,000 BO
Umbarka	1,374 BPD (Mar. 1978)	464,324 BO (1977)	289,764 BO (1977)	
Umm El Yusr	4,374 BPD (Mar. 1978)	1,441,622 BO (1977)	20,400,464 BO (1977)	Original recoverable reserves-31,450,000 BO
Uyun	1,430 BPD (Mar. 1978)	617,586 BO (1977)	3,979,468 BO (1977)	Original recoverable reserves-3,900,000 BO
WD-19	28 BPD (Mar. 1978)	10,265 BO (1977)	179,915 BQ (1977)	
WD-23/2				
WD-33	610 BPD (1976)	223,361 BO (1976)	776,861 BO (1976)	
Yidma	3,314 BPD (Mar. 1978)	1,441,622 BO (1977)	12,325,979 BO (1977)	

TABLE 2

WELL DATA FOR OIL AND GAS FIELDS IN EGYPT

EGYPT	WELLS DRILLED				1975		DEPTHS TO		OIL	GAS/OIL	PRODUCING
FIELD NAME	DISC.	O&G	DRY	TOTAL	WELL STATUS	SHUT-IN	TOP PAY(S)	NET PAY(S)	GRAVITY	RATIO	FORMATION(S)
							(ft.)	(ft.)	(API)	cu.ft./ bbl	AGE(S)
Abu Gara-	1969	17	2	19	6	9	8,800	25	41°		Abu Roash-Upper Cret.
dig							9,340	50			Abu Roash-Upper Cret.
							10,970		36°	1,120	Bahariya-Upper Cret.
Abu Madi	1976										
Abu Qir	1976	9		9							
Alamein	1966	18	2	20			8,300	70-200	33.5°	205	Alamein-Lower Cret.
Amal	1968	1	4	5			6,000	24	30°-33°		Belayim-Middle Miocene
							7,398	18			Kareem-Lower Miocene
							7,630	31			Rudeis-Lower Miocene
Asl	1948			29	9		3,690		22°		Rudeis-Lower Miocene
							3,870		22.5°		-Eocene
Belayim	1955			115	60		5,150	65	20°-24°		Zeit-Middle Miocene
Land							6,230	65			South Gharib-Middle Miocene
							7,050-				
							7,545	260			Belayim-Middle Miocene
							8,230	165			Kareem-Lower Miocene
							8,530	490			Rudeis-Lower Miocene
Belayim	1961			18			6,400		26.5°		Belayim-Middle Miocene
Marine							7,740	65-560	30.5°		Kareem-Lower Miocene
									30.4°	390	Rudeis-Lower Miocene
							9,187		30.2°		

EGYPT FIELD NAME	WELLS DRILLED				1975 WELL STATUS		DEPTHS TO TOP PAY(S)	NET PAY(S)	OIL GRAVITY	GAS/OIL RATIO	PRODUCING FORMATION(S)
	DISC.	O&G	DRY	TOTAL	FLOW	SHUT-IN	(ft.)	(ft.)	(API)	cu.ft./ bbl	AGE(S)
Ekma	1961			2					21°		Nukhul-Lower Miocene
GS 300-1	1976	1		1			6,000	543			Nubian-
GS 382-1	1976	1		1			10,272	748	34.5°		Nubian-
GS 391-1	1976	1	1	2							-Miocene
Hurghada	1913			145	23	122	1,800	65	22°-23°		Nukhul-Lower Miocene
							2,300	130			Nubian Sandstone-Paleozoic
July	1967	18	5	25	5		8,860		34°		Rudeis-Lower Miocene
							9,500		31°		Nubian Sandstone-Upper Cret.
							9,800		31.5°		Nubian Sandstone-Paleozoic
Karim	1958			35			1,970		19°		Kareem-Rudeis-Lower Miocene
							2,460		19°		Nukhul-Lower Miocene
							2,620		17.5°		-Eocene
							2,950		19°		-Upper Cret.
Kheir	1973	2	8	10	2		3,120	40	28°		Kareem-Lower Miocene
LL 87-1	1976						8,200				Kareem-Lower Miocene
							12,500		37.2°		Nubian Sandstone-Upper Cret.
LL 87-2	1976	1		1	1		11,200		29°-34°		Nubian-Upper Cret.
					suspended		12,000				Nubian-Upper Cret.
Matarma	1948			7			2,050		22°	very	Rudeis-Lower Miocene
							3,020		21°	low	-Eocene
Meleiha	1972	3	3	6			5,700		36°		Upper and Lower Cret.
Morgan	1965			89	67		5,080	53	26°		Belayim-Middle Miocene
							5,750	220	33°	600	Kareem-Lower Miocene
Quantara 1	1976	1		1	1		10,200		57°		-Miocene
					suspended						
Ranadan	1974	11	2	16	2		10,170	360	39.9°		Nubian-Upper Cret.
							11,000	1,000	39.9°		Nubian-Paleozoic
Ras Amer	1965	17	3	20			2,790		18°-23°		-Middle Eocene
							2,952				-Upper Cret.
Ras Bakr	1958			91	15	35	2,130	30-100	20°		Nakhul-Lower Miocene
							2,950	100	22°		-Eocene
							3,100	160	23°		-Upper Cret.
							3,800	160	23°		Nubian Sandstone-Paleozoic
Ras Gharib	1938			227		90	2,100	115	24°-26°	196	-Miocene
							2,600	26	27°		Nubian-Upper Cret.
							3,300				Nubian-Paleozoic

EGYPT FIELD NAME	WELLS DRILLED				1975 WELL STATUS		DEPTHS TO TOP PAY(S)	NET PAY(S)	OIL GRAVITY	GAS/OIL RATIO	PRODUCING FORMATION(S)
	DISC.	O&G	DRY	TOTAL	FLOW	SHUT-IN	(ft.)	(ft.)	(API)	cu.ft./ bbl	AGE(S)
Ras Garra	1964		1				7,210	50	30.8°		-Miocene
Ras Sudr	1946			40	16		2,820		23°	very	Rudeis-Lower Miocene
							2,920		20°	low	-Eocene
Razzak	1972	10	6	16	10		5,900	18	40.6°		Abu-Roash-Turonian
								40	39°		Abu-Subeiha-Cenomanian
							7,600	220	37.5°		Alamein-Lower Cret.
							7,875	30	40°		Alamein-Lower Cret.
S. Gharib	1976	1	1	2							
Mar Shuk- heir	1966	9	1	10			2,030	66	30°	very high	Belayim-Middle Miocene
Sidri Abu Rudeis	1957			14			8,530- 8,700	130	20°-23°		Nukhul-Lower Miocene
Umbarka	1969	4	3	7			10,700	35	42°		-Lower Cret.
Umm El Yusr	1968	34	4	38	15	17	2,950		19°-28°	147-316	Rudeis-Lower Miocene
							3,280		19°-28°		Nukhul-Lower Miocene
							3,350		21°		-Eocene
Uyun	1968	11	5	16	11	4	2,950	115	24.6°		Rudeis-Lower Miocene
WD-19	1973	2	1	3			6,700- 8,000		41°		Abu Roash-Turian
WD-23/2	1976	1		1			6,237	26			-Upper Cret.
WD-33	1972	1	2	3	1	1	9,850		32.8°		-Upper Cret.
Yidma	1971	7	1	8		5	8,498	20	43.5°		Alamein-Lower Cret.

Since 1975, the daily oil production has increased by sizable amounts each year. In 1976, Egypt produced an average of 329,773 barrels a day, a 42.9 percent increase over the 1975 average partly due to the return of some wells from Israel. The 1977 average of 414,787 barrels a day represents a 25 percent increase over the 1976 figure. The rates of increase in production compared to the smaller rates in increase of reserves point out that large new discoveries will be needed both to balance withdrawals and to increase total reserves. The Egyptian Government hopes to attain a rate of 500,000 barrels a day in 1978 and 1 million barrels a day in 1982 (Oral communication by Ayouty, 1978).

Because of the present uncertainties of petroleum economics, the changing investment programs of the oil companies, the recent relinquishment of huge tracts by Shell and Conoco, and the slackening in drilling activity in early 1978, the chances of reaching the later figure without lessening reserves are probably considerably diminished.

Most reserves are in the Gulf of Suez basin, where 20 fields produce. Six commercial oil discoveries have been made in the Western Desert. The reserves discovered there are estimated at 220 million barrels of oil and condensate. Six other recent, small discoveries in this region have not been evaluated as commercial yet.

Natural gas production in Egypt began in 1974, and the 1977 production of gas is estimated at 88.3 billion f^3 (70.6 billion f^3 associated with oil, 17.7 billion f^3 nonassociated). Estimates of proved gas reserves range from 2.5 to 4.5 trillion f^3 ; of this, one estimate assigns 1.5 to 2.5 trillion f^3 to the Delta basin, 1 to 1.5 trillion f^3 to the Western Desert, and the remainder, partly used for gas lift of oil and the rest flared, to the El Morgan field in the Gulf of Suez basin. Specifically, the EGPC has estimated 4.5 trillion f^3 of gas reserves at the end of 1977. Projections for 1978 production are 675 million f^3 a day.

4.0 TECTONIC SETTING

4.1 Plate Tectonics

Egypt lies at the northeastern margin of the African plate. Rifting of this plate has occurred since Tertiary times from a spreading center in the Red Sea, and many geoscientists believe subduction of the African plate occurs beneath the European plate to the north (figure 2). Seismically, the surface-wave dispersion curves across the eastern basin of the Mediterranean and the presence of Lg waves along the same path suggest that a continental crustal structure and thick mass, as well as continental upper mantle structure, lie under the eastern Mediterranean, although in some areas it is contaminated by a certain proportion of oceanic crust at the northern edge.

Fig. 2. Plate tectonic setting of Egypt

Some workers also recognize a very small plate to the northeast, the Levantine plate, separated from the African plate by a transform fault through the Gulf of Suez and including the area of the Sinai (figure 2). Geological, geophysical, and seismological evidence indicates that three plates meet at the northern end of the Red Sea. These plates also are known as the Arabian, Nubian, and Sinai (Leventine) plates, and it is the relative motion between them that has brought about the formation of the Gulf of Suez, the Gulf of Aqaba, and the Red Sea (figure 3). There is much geological, geophysical, and seismological evidence to indicate that the Nubian and Arabian plates have separated to form almost the entire Red Sea as a result of sea-floor spreading. The African plate is bounded by source of new area at the ridge, by sinking of area at subduction zone, and by transform faults where area is neither created nor destroyed, i.e., the three main elements of plate tectonics, ridge, subduction zone, and transform faults are observed in this area.

The spreading and the formation of new oceanic crust occurred as a result of the upwelling of the upper mantle, the formation of regional dome, the thinning of the crust, and the formation of graben. The seafloor spreading rate is 1.4 to 0.9 Cm a^{-1} (Phillips and Ross, 1970). It is also suggested that the separation rates are 3.2 to 2.0 Cm a^{-1} (Phillips, 1970). Much has been made recently of suggestions that the sedimentary troughs in the North Sea, which contain significant oil accumulations, are failed arms of triple junctions (Bobbitt and Gallagher, 1978). This situation is clearly the case of the Gulf of Suez, which is the failed spreading arm of the Sinai triple junction.

The study of the dispersion and phase velocities of the fundamental - made Rayleigh waves in the Red Sea and adjacent area (Fouda, 1974) indicates that a localized feature is the substantial amount of ultra-low velocity material in the upper mantle under the sea as well as an upwelling of the upper mantle. This feature is almost confined to the Red Sea shore and does not extend significantly into the stable region. The study also indicates that this Afro-Arabian shield is of the Arabian type -- a young shield, less than 1,100 million years old -- with a well-developed S-wave low-velocity channel in the upper mantle.

4.2 Overview of Regional Tectonic History

The structural development in Egypt has been greatly governed by the Precambrian orogeny which produced the main tectonic trends influencing the later events. The following summarizes the different tectonic stages in the geologic history of Egypt as described by El Shazly (1966a, 1977).

4.2.1 Precambrian Stage: The Precambrian orogeny and crustal and upper mantle structure in Egypt belong to the Arabian type (1,100 to 1,600 million years, Fouda 1974). The major Precambrian orogeny

Fig. 3. Plate tectonics in the Northern Red Sea
(Bobbitt and Gallagher, 1978)

$\pm 1,000$ m.t. corresponds to the Karagme-Ankolean cycle in Africa, and the termination of the Precambrian tectonics in Egypt ± 600 million years ago corresponds roughly to the end of the Precambrian itself (El Shazly, 1977).

Recent structural analyses, especially those using LANDSAT images, have led to a partial understanding of the Precambrian fold pattern within the Egyptian basement (El Shazly, 1977). The earliest folding has axes WNW-ESE to NW-SE, with the major fracture lines being mainly E-W or ESE-WNW. The early folding of metamorphic rock occurred along E-W to ESE-WNW trends; fracturing occurred parallel to the folding. Still greater fractures developed perpendicular to the folds with trends NNW-SSE or N-S, with major fracturing along the NNW-SSE trend. The late folding has an axial trace NNE-SSW and sometimes NE-SW. According to El Shazly (1977), fracturing along NNW-SSE or N-S direction led eventually to the development of five major elongated segments from east-to-west (figure 4). He describes them as follows:

(1) Sinai-Asiatic segment, (2) Red Sea segment, (3) Eastern Desert segment, (4) Western Desert segment, and (5) Gebel El Oweinat segment. Segments 1, 3, and 5 act as high, while segments 2 and 4 act as low. The highs are characterized by a thick crust (40 to 50 km) in the Eastern Desert and Gebel El Oweinat segments, while the lows show a thinner crust, normally 30 to 40 km in the Western Desert and 20 to 40 km in the Red Sea (Phillips and others, 1969). The highs are noted for the occurrence of orogenic granites, while the lows are characterized by the presence of the alkaline, metasomatic granites. Major block faulting was active at the end of the Precambrian.

4.2.2 Paleozoic stage: Through block faulting, Paleozoic basins of various extensions were formed generally trending NNW-SSE. This block faulting is largely controlled by the major faults developed at the late Precambrian-early Paleozoic transition. The Paleozoic sediments are more strongly folded than the overlying Mesozoic sediments from which they are separated by a major unconformity (Permian-Triassic unconformity). Details of the Paleozoic folding are not yet well known but unconformities exist within the Paleozoic succession, which suggest continuing instability.

4.2.3 Mesozoic stage: A Mesozoic basin existed in the area of the present Mediterranean Sea. Subsidiary basins extending into the cratons were controlled initially by major fault lines. In the late Cretaceous, the basins and intervening highs were controlled to a great extent by Laramide diastrophism with folding "Syrian arcs" along an axial trace trending NE-SW to ENE-WSW. The late Cretaceous-early Tertiary diastrophism produced major unconformities between Mesozoic and Tertiary sediments.

Fig. 4. Major Tectonic Segments of Egypt (El Shazly, 1977)

4.2.4 Cenozoic stage: During the Cenozoic, Egypt underwent changes in its relation to the Tethys and the subsequent Mediterranean Sea. The great Paleocene-Eocene transgression was accompanied by southward migration of the axis of deposition of the main sedimentary basin; while northern Egypt became a high, uplift and emergence were conspicuous during the Oligocene though the tendency was already apparent in the late Eocene. Uplift was accompanied by important fracturing through the late Eocene to Early Miocene. Folding and diastrophism during the late Miocene and early Pliocene led to major changes, including the transformation of the Tethys into the Mediterranean Sea. The Quarternary has been a period of regression interrupted by minor transgressions.

Although the Red Sea and other grabens are believed to have originated in late Precambrian-early Paleozoic tectonics, it acquired its characteristics and independence from the Tethys, due to the Cenozoic tectonics, starting with regional doming and development of major fault systems and graben formats followed by spreading. These faults trend NW-SE and show considerable horizontal displacement. A Neogene fault system is well developed in the Red Sea region trending NNW-SSE and some of these faults were still active during Quarternary time. Alpine tectonism, initiated in the late Miocene, is represented in Egypt by open folds trending WNW-ESE and three major fault trends, namely the NW-SE, the NNE-SSW, and the WNW-ESE sets.

4.3 Tectonic Features

The principal features significant in relating the tectonic history of Egypt and its petroleum potential are faulting, especially block faulting, folding, and unconformities. The fault systems are (1) the Mediterranean system which trends E-W, (2) the Erythean system which trends NW-SE, (3) the Aqaba system which trends NE-SW, and (4) the north-south system. Block faulting was prevalent on a large scale during late Precambrian time and occurred again to reshape the basins between Cambrian and Devonian times. It also was associated with the Laramide diastrophism at the end of Cretaceous time. Block faulting created the Red Sea graben and those parallel grabens thought to exist in the Western Desert.

Early folding occurred when Precambrian metamorphic rocks were deformed along E-W and ESE-WNW lines, and somewhat later folding affected the Precambrian granites in a NNE-SSW and NE-SW trend. At the end of Cretaceous time, Laramide folding created the Syrian arcs which trend NE-SW. Finally, Alpine tectonism caused WNW-ESE trending folds in late Miocene time.

Significant modification of the tectonically-created features was made by erosion. These features are now marked by unconformities, several of which were created near the end of Precambrian time. Others were created in the Cambrian-Devonian interval. One major unconformity resulted from the movements at the end of Paleozoic time and another was formed by the late Cretaceous-early Tertiary diastrophism. A conspicuous angular unconformity separates the Pliocene and Quaternary rocks.

4.4 Tectonic Provinces

In terms of its sedimentary history, Egypt has been a persistent cratonic area, at least since the beginning of Paleozoic times. It has been covered intermittently by shallow seas which have spread generally from the north. According to Said (1962), five major tectonic provinces exist (figure 5).

4.4.1 The Arabo-Nubian massif: It is composed of Precambrian crystalline rocks which form the basement of the African and Arabian plates. This is the major element of southeastern Egypt and the southern Sinai, and is not prospective for hydrocarbons.

4.4.2..The Gulf of Suez basin: It has been a region of persistent subsidence and sedimentation since late Paleozoic time and contains over 90 percent of Egypt's proved oil reserves.

4.4.3 The western Red Sea shelf: It includes offshore regions as well as the narrow coastal plain between the Gulf of Suez on the north and the border of Sudan on the south. This region has a relatively thin sedimentary section and high heat flow, and is prospective for petroleum, particularly natural gas.

4.4.4 The unstable shelf: This area of long-continued tectonic instability occupies a belt across northern Egypt from the Libyan border on the west across the northern Sinai on the east. It lies near the leading edge of the northerly moving African plate (figure 2), which probably explains its abundance of tectonic structures and the thick sedimentary succession. It has experienced repeated deformation through Phanerozoic time. Consequently, facies and thickness changes are marked, unconformities are numerous, and several separate basins with intervening swells have developed through time. The most significant deformation resulted from Cenozoic underthrusting of the African plate beneath the Mediterranean ridge (figure 2), producing generally NE-SW trending, asymmetric anticlines which have steep southern flanks, and which are severely faulted and fractured.

The unstable shelf, including offshore areas in the Mediterranean, covers more than 300,000 km² of northern Egypt. This area, with up to 8,000 m of sedimentary rocks, contains numerous anticlines as well as significant facies changes (e.g. the nonmarine Nubia sandstone inter-fingers with marine rocks) and widely scattered indications of oil. Within this belt probably lies the best long-term prospects for substantially

FIGURE 5. MAJOR TECTONIC ELEMENTS AND BASINS IN EGYPT (SAID, 1962)

increased hydrocarbon reserves in Egypt. This region includes four petroleum provinces: (1) the Western Desert, (2) northern Sinai, (3) Nile basin, and (4) Delta Basin.

4.4.5 The stable shelf: This comprises over 350,000 km in southern and southwestern Egypt. It has been little explored and the hydrocarbon potential, as well as much of the basic geology, remains unknown. Large-scale basins and domes are said to be the dominant structures, with anticlines being relatively rare. Over much of the southern part of the region the sedimentary cover is thin and consists of 300 to 400 m of Upper Cretaceous to Eocene strata on Precambrian basement and has thus been considered unpromising. Some as yet unrecognized basins may exist. The northern and southwestern parts of the stable shelf appear more favorable. In the former area, Cenozoic and Mesozoic beds thicken toward the north, and Paleozoic rocks, including marine sediments, appear in the subsurface at about latitude 27°N. Parts of southwestern Egypt lie on the eastern flank of the Kufra basin of Libya. This basin contains in excess of 2,000 m of Paleozoic and Mesozoic strata, in large part nonmarine sandstone.

The stable shelf is a relatively undeformed region. It has been little explored, but is believed to hold at least moderate potential for hydrocarbons. With present levels of knowledge, exploratory efforts for the next few years in this region will focus on acquiring basic information to define individual basins, significant structures, and important facies changes. Because much of the area is capped by nearly flat-lying beds or covered by sand, this information will be obtained mainly from stratigraphic test holes and geophysical methods.

5.0 STRATIGRAPHY

5.1 Depositional History

The basement rocks of Egypt are mostly igneous and metamorphic rocks belonging to the African shield. They include two sedimentary cycles, two volcanic cycles, and four plutonic cycles. The Precambrian-Cambrian boundary is still in doubt, as the youngest plutonic rocks in the basement have isotopic ages that may straddle the boundary. The final Precambrian orogeny determined the tectonic framework of Egypt as a foreland that El Shazly (1977) divides into five major rigid segments which trend NNW-SSE: (1) the Sinai-Asiatic zone, (2) the Red Sea zone, (3) the Eastern Desert zone, (4) the Western Desert zone, and (5) the Gebel El Oweinat zone (figure 4). The Red Sea and Western Desert zones were usually low and received sediments from the other three higher zones.

Paleozoic rocks are widely spread across Egypt in the subsurface particularly from latitude 24°N to the sea, but only exposed in three principal outcrops. All periods are represented and volcanic activity occurred at some time in all. Important movements occurred from Cambrian into Devonian time, but the most important diastrophism accompanied by emergence occurred during late Carboniferous and Permian time.

As El Shazly (1977) has pointed out, the sedimentary basins, the Gulf of Suez basin, the north eastern Western Desert basin, and the northwestern Western Desert basin have a NNW-SSE trend closely paralleling the Red Sea and reflect the influence of the late Precambrian-early Phanerozoic tectonism on subsequent basin formation. All available evidence suggests transgression from a sea, the Tethys, lying to the north. This sea reached its maximum extent during carboniferous time, and withdrew the farthest toward the end of Paleozoic time.

During Mesozoic time, the most obvious tectonic event was the creation of the Syrian arcs which trend NE-SW to ENE-WSW. This occurred during the Laramide orogenic movement. Volcanic rocks are present in all ages of Mesozoic rocks, but are most prevalent in Upper Cretaceous rocks. The seas transgressed several times in Mesozoic time, but the time of the greatest transgression was late Cretaceous.

Depositional conditions during Paleocene-Eocene time were somewhat reversed, as the deep sea was to the south and the shallow water, or even a land mass, was to the north in the Mediterranean. During Oligocene the Tethys became shallow, and the Oligocene period is marked by emergence.

Miocene seas resumed the transgression on Egypt with the maximum in middle Miocene time when the seas reached to the Gulf of Suez and beyond the Egyptian border in the Red Sea region. Although the Red Sea relates to late Precambrian tectonics in origin, it assumed a resemblance to the present Red Sea during the Miocene. At the time of Alpine folding during late Miocene time, uplift and emergence occurred in Egypt. The Mediterranean Sea, as now known, formed in late Miocene time; the Nile Valley, as now known, was shaped by late Miocene and early Pliocene tectonics.

Regression of seas was dominant during Quaternary time. The thick deposits were laid down only in the Nile valley and delta. The Pliocene-Quaternary boundary in the Red Sea region is marked by an angular unconformity as a result of uplift and tectonic movements at that time. Volcanism occurred in the Red Sea trough.

5.2 Stratigraphic Sequence

Precambrian igneous and metamorphic rocks make up most of the basement of Egypt. They represent a northeastward extension of the African shield, which is separated from the Arabian shield by the Red Sea. The oldest rocks are reported to be geosynclinal rocks of Precambrian age, outcropping in the southern part of the Eastern Desert (El Shazly and others, 1973). The basement rocks crop out in about 10 percent of the area of Egypt, mainly in the eastern and southeastern parts (figure 6), but are buried beneath sedimentary and some volcanic rocks to a depth of more than 6 km in much of the northern part (figure 7). The overlying sedimentary and volcanic sequence represents most, if not all, geologic periods of Paleozoic, Mesozoic, and Cenozoic time. Most of the older sedimentary rocks, especially the Paleozoic strata, are concealed in deep basins under the younger Mesozoic and Cenozoic

FIGURE 6. GENERALIZED GEOLOGIC MAP OF EGYPT
(FROM EL SHAZLY, 1977)

FIGURE 7. DEPTH TO TOP OF BASEMENT IN NORTHERN EGYPT (FROM
EL SHAZLY, 1977)

rocks (figure 8). Thickness of the stratigraphic succession increases from south to north, except in southwestern Egypt where a thick Paleozoic sequence lies on the eastern flank of the Kurfa basin (figure 5). The estimated maximum thickness of the sedimentary section along the Mediterranean coast is about 8,000 m. Basically, Egypt has been a cratonic area since Precambrian time.

The sedimentary sequence has been roughly grouped into three lithologic divisions and is related to the tectonic provinces of Egypt, as set up by Said (1962). This relationship, which is modified after Said (1962), is shown on figure 9. It is now incomplete because of lack of subsurface information on older rocks now known from deep wells. The lithologic divisions are shown below with our added comments on their petroleum aspects.

1. Lower clastic division, mainly sandstones of Paleozoic to early Cretaceous age.

Within the Lower clastic division is the Nubia sandstone, a Carboniferous to Cretaceous nonmarine clastic unit which occurs over a large part of central and southern Egypt and which is a reservoir in some fields of the Gulf of Suez basin.

2. Middle calcareous division, consisting of limestones, chalks, shales, and phosphorites of late Cretaceous to late Eocene age.

In many parts of northern Egypt, limestones and shales of late Cretaceous (Cenomanian) age are notably petroliferous in both outcrops and well cores.

3. Upper clastic division, composed of continental and marine sedimentary rocks of Oligocene to Recent age. Calcareous and evaporitic facies of Miocene age are present in parts of the unstable shelf, in the Gulf of Suez basin, and in the Red Sea area. Salt and anhydrite of middle to late Miocene age are prominent along the Red Sea coast and in the Gulf of Suez. In the latter area, they form sealing beds in several oil fields. Seismic records from the Mediterranean north of Egypt show diapiric structures and a prominent widespread reflecting horizon. Both features result from the upper Miocene (Messinian) evaporite sequence, shown by the Deep Sea Drilling Project and marine seismic work to underlie the entire Mediterranean basin as the consequence of a severe regression or complete dessication of this region.

5.2.1 Rocks of Paleozoic age: Paleozoic rocks are exposed in three small areas in southern Sinai on the northwest side of the Gulf of Suez (figure 6). Until deep drilling was done in northern Egypt, it was supposed that Paleozoic rocks were not widespread in Egypt, and that the younger Nubian sandstone commonly rested on the basement. Now it is known that Paleozoic rocks cover the subsurface basement in more than half of Egypt. In the future, even wider distribution may be recognized since sandy facies often make it difficult to distinguish Paleozoic rocks from the younger, more widely spread Nubian sandstone.

Fig. 8. Regional Geological Cross Sections EF Eastward and GH North ward Across Egypt (after M. H. Hermina). See Fig. 9 for index map.

REGIONAL DISTRIBUTION OF STRATIGRAPHIC UNITS IN EGYPT

FIGURE 9. STRATIGRAPHIC UNITS IN EGYPT

The Paleozoic rocks are buried to depths in excess of 4 km along most of the Mediterranean coast and in the Gulf of Suez (figure 10) according to El Gezeery and others (El Shazly, 1977). On much of the Western Desert and in the central part of Sinai, Paleozoic rocks lie from 1 to 3 km in depth. This means that these rocks are within present drillable depths and could be tested if favorable source rocks, reservoirs, and structures were thought to be present.

In figure 11, Gezeery and others (El Shazly, 1977) have shown that Paleozoic basins trend generally NNW-SSE almost parallel to the present Red Sea. This indicates that structural lines in this direction have existed since Precambrian time (El Shazly, 1966a, 1972). This map outlines by lines of thickness three prominent Paleozoic basins -- the Gulf of Suez, the northeastern Western Desert, and the northwestern Western Desert.

In connection with the map of Paleozoic rock thickness in northern Egypt, (figure 11) it must be mentioned that other interpretations of the distribution exist in unpublished records on file at EGPC. Peter Norton's 1970 isopach map of the marine Paleozoic rocks of the Western Desert shows two arches intersecting in the central part. His Matruh-Nile arch trends to the southeast, crossing at his Cairo-Bahrein arch south of the Abu Gharadiq field. Another map that shows conflicting interpretations is the "Paleotectonic and paleogeological map of the United Arab Republic (U.A.R.) by the beginning of Lower Carboniferous time." The map was prepared by A. Bahaev in 1968 and shows basement granites in the area south of Alexandria as well as other anomalies in the Western Desert. These formations are not comparable to those of either Norton or Gezeery. Perhaps new data since 1968 and 1970 accounts for this contradiction in part, but the additional difference in stratigraphic age assignments suggests basic interpretative differences also. We use Gezeery's maps because they are the latest published; however, there is no way to judge the validity of other unpublished maps.

The Gulf of Suez basin has two exposures of Paleozoic rocks that are thought to be mainly Carboniferous and post-Carboniferous in age. The Carboniferous exposures are partly a carbonate facies, but the remainder are mainly clastics. In wells, the top of the Paleozoic rocks is found at depths ranging from 1 to 3 km in the Gulf, and the greater depths northward. The thickness also increases northward from about 0.5 km to an estimated 2 km toward the present Nile delta. The lithology changes from a sandy facies northward into a shaley facies as might be expected. The shape of the Paleozoic basin in the Gulf of Suez is not known due to the lack of deep wells, but the basin may extend toward the Nile delta.

The northeastern Western Desert basin of Gezeery and others (1975) extends from south of Baharia (figure 1) toward the Mediterranean Sea. Paleozoic rocks are only 0.5 km below the surface at Bahariya, but are estimated to be at a depth of 4 km near the Mediterranean Sea. The thin edge of the Paleozoic sequence is south of Bahariya, where it is only 0.5 km thick. But it increases northward to an estimated 2 km near the Mediterranean Sea. The rocks are more sandy around the basin margins and more shaley in the central part.

Fig. 10. Depth to Top of Paleozoic Rocks in Northern Egypt
(from El Shazly, 1977)

Fig. 11. Thickness of Paleozoic rocks in Northern Egypt
(from El Shazly, 1977)

The northwestern Western Desert basin occupies the northwestern part of Egypt and extends into Libya. Paleozoic rocks outcrop near the Egyptian-Libyan-Sudanese borders in the general area marked as basement on Gezeery's map (figure 6), according to El Shazly (1977) and the 1971 edition of the Geological Map of Egypt by the Geological Survey of Egypt (1971). They are sandy near the margins and about half shale and half sandstone near the center. The rocks are 2 to 3 km thick north of the Siwa Oasis and about 2 to 3 km thick south of it.

In the northwestern Western Desert, the Paleozoic sequence is well represented by the succession at Siwa Oasis. Here, the Paleozoic sequence unconformably overlies igneous and metamorphic rocks of the basement and consists of Cambrian and Ordovician rocks undifferentiated, 207 m thick; a basalt layer, 11 m thick; Devonian rocks, 1,032 m thick; and Carboniferous rocks, 1,035 m thick. Above, and separated by a notable unconformity, are Mesozoic and Cenozoic rocks. The Paleozoic sequence is dominantly clastic, with some arkoses; however, a shallow marine environment has been proposed for the Devonian and Carboniferous sediments by El Sweify (1975) in one place, and an offshore marine environment for the Devonian sediments by Andrawis (1972) at another. This suggests that at least part of the sequence is marine. By comparison, the Paleozoic rocks in the southwestern part of the Western Desert are mostly continental in origin with more sandstone and volcanics.

5.2.2 Rocks of Mesozoic age:

5.2.2.1 Triassic rocks: Middle Triassic rocks crop out in a well-studied section (Awad, 1946) that is 200 m thick and located on an anticline in the northeastern Sinai. The sequence, in ascending order, consists of crossbedded sandstones containing fossil plants; sandstones and shale; limestone and marls containing typical ammonites of middle Triassic age; and lithographic limestone. Triassic rocks have been found in the subsurface also. A well at Nekhl, in the Sinai, penetrated 238 m of limestone, and one at Gebel Ataga, in the Gulf of Suez region, penetrated 71 m of sandstone and shale. This suggests transgression of the sea from the north in Triassic time. According to El Shazly (1977), recent evidence suggests that the Triassic seas extended even farther southward into a basin in the Gulf of Suez. A formation of Permian-Triassic age is present on the western side of the Gulf in a maximum thickness of 80 m (Abdallah, Adindani, and Fahmy, 1963). It consists of sandstones, siltstones, and shales, with minor beds of gypsum and salt grading upward into marine limestones and marls. Rocks of Triassic age have not been recognized in other parts of Egypt.

5.2.2.2 Jurassic rocks: Marine Jurassic rocks are exposed in northeastern Egypt, where they crop out in the northern Sinai and on the western side of the Gulf of Suez. Continental Jurassic rocks are present in the southwestern part of the Western Desert. Drilling has shown that Jurassic rocks are widely spread in the subsurface of northern Egypt, as shown in figure 12. The southward extent is in doubt because the continental aspect of both the Jurassic and Cretaceous rocks in the southern Western Desert makes them difficult to recognize or separate.

Fig. 12. Thickness of Jurassic Rocks in Northern Egypt (from El Shazly, 1977)

Fig. 13. Thickness of Early Cretaceous Rocks in Northern Egypt (after El Shazly, 1977)

The thickness of the Jurassic rocks is known to exceed 2.5 km in the northern Sinai and much of the Nile Delta region. In the Western Desert, the thickness is known to range from less than 0.5 km to more than 1 km. The sequence is more marine in character in northeastern Egypt, where it is thickest. Clastics of continental and marine origin predominate in the Jurassic rocks of the Western Desert.

5.2.2.3 Cretaceous rocks: After the regression of Jurassic seas, a marine invasion in early Cretaceous time created a trough along the northern coastline of Egypt. Small basins, or embayments, formed at right angles to this trough, in a northerly direction in the eastern and western Sinai, the eastern and western Nile Delta, and four basins in the Western Desert.

The thickness of early Cretaceous rocks in Egypt is shown in figure 13. It reaches 3 km at Mersa Matruh on the northwest coast, but generally ranges from 0.5 to 2 km over most of the northern part of the Western Desert. The inner epicontinental basins contain from 1.5 to 2 km of early Cretaceous rocks. Early Cretaceous sandstones are found at least as far south at latitude 29°N in most of the Western Desert. The early Cretaceous rocks are composed mainly of clastics, both sandstone and shale. The Nubian sandstone, which is widely distributed throughout Africa and southwestern Asia, is a continental-to shallow-marine facies of the Cretaceous. Early Cretaceous deposits in the northern Western Desert are mostly sandy, but oil drilling has revealed some widespread marine carbonates. These carbonates include a dolomitic sequence termed the El Alamein formation which produces oil in El Alamein and nearby oil fields. This carbonate marks the extreme transgression of the sea at the close of early Cretaceous time.

Late Cretaceous rocks are over 2.5 km thick in the Gulf of Suez and from 1.5 to 2 km thick in much of northern Egypt (figure 14). In general, they decrease in thickness southward, but form several basins of deposits with thickness of from 1.5 to 2 km in areas of the Western Desert. These rocks are predominantly marine carbonates in the centers of the basins. The marine late Cretaceous strata in Egypt form three major facies: a phosphatic offshore facies, a basin facies, and a facies found in structurally high areas between basins (El Shazly, 1977). The phosphatic facies, mostly in the upper part, ranges from continental and offshore-marine sand at the south, to offshore-marine sand and clay, with commercial phosphate deposits, in places to marine carbonates at the north. The facies on interbasinal highs range from carbonaceous sandstone and shale of fluvio-marine origin to dolomitic sandstones and dolomite of an open-marine environment. The basin facies is thicker, more typically marine, and contains more carbonates than the interbasinal high facies. The basin facies is well represented at the Abu Gharadiq oil field in the Western Desert, where Upper Cretaceous limestone and sandstone produce oil and gas.

Fig. 14. Thickness of late Cretaceous rocks in northern Egypt
(from El Shazly, 1977)

Fig. 15. Thickness of Paleocene-Eocene rocks, in northern Egypt
(from El Shazly, 1977)

5.2.3 Rocks of Cenozoic age:

5.2.3.1 Paleocene-Eocene rocks: Paleocene-Eocene strata crop out in fair-sized patches on the Sinai peninsula, but extend continuously as a huge surface blanket from the vicinity of Suez and Cairo (about latitude 30°N) southwestward into the Western Desert, reaching latitude 22°N near the Sudanese border. According to El Gezeery and others in El Shazly (1977), the Paleocene-Eocene interval is predominantly clastic in nature and is less than 0.5 km thick near the coast, whereas to the south, it consists mainly of carbonates and is from 1 to 2 km thick, reaching a maximum in the Nile basin south of Cairo. This facies thickness relationship indicates that the Mediterranean Sea was structurally high and that a shallow sea or positive area may have existed during the deposition of these beds. The distribution (figure 15) also suggests that the Paleocene-Eocene basins may have been controlled by faults trending north to slightly northwest.

The Gulf of Suez basin has only 0.2 to 0.5 km of Paleocene-Eocene rocks; the clastics content increases northward. The Nile basin south of Cairo has as much as 2 km of marine Paleocene-Eocene rocks, mainly carbonates, in its center. The clastic content increases to the north. At Abu Gharadiq in the Western Desert, the maximum thickness is about 1 km, and at Siwa Oasis, only 0.5 km. The clastic content increases to the north as in the other basins.

The Paleocene rocks are typically represented in the Nile Valley by a sequence of a lower interval of conglomeratic shale, grading upward into chalk and then into anhydritic shale. In the southwestern part of the Western Desert, the interval is a succession of chalk and limestone with lesser amounts of marl, shale, and sandstone.

The early Eocene are typically developed in the Nile valley near Luxor, where they consist of lower calcareous shales and upper limestones with chert layers. For the most part, these are regarded as shallow-marine deposits.

The middle Eocene rocks are well developed in central Egypt, the Gulf of Suez, the Sinai, and in the Western Desert south of the latitude of Cairo. Near Helwan, south of Cairo, Eocene formations consist of chalky limestone, dolomitic limestone, and very fossiliferous chalky limestone, in ascending order. A warm, marine environment with neritic and littoral facies is suggested.

The late Eocene rocks were first deposited in deep water and later in shallower marine water. Near Helwan, these rocks are composed of chalky, marly, sandy limestones, marls and sandy marls; and clays and sandy clays. These relate to shallow, neritic seas and shorelines. Deltaic and interdeltic facies are present in the Western Desert in the form of offshore bars, barrier beaches, lagoons, and a prograding delta system. The lithology ranges through carbonate, claystone, siltstone, and sandstone.

5.2.3.2 Oligocene rocks: Continental rocks are characteristic of the Oligocene in Egypt because it was a period of general uplift. Marine rocks are found only in the Western Desert.

The Oligocene rocks are missing in much of the Gulf of Suez and Red Sea regions, as well as in the Cairo-Suez area. Where present, they are continental in nature. On the east side of the Gulf of Suez, Oligocene rocks consist of red sandstone and red shale up to 152 m thick; on the Red Sea coast, they are composed of conglomerate, sandstone, and shale, with thin limestone intercalations in the shale; in the Cairo-Suez area, they are ferruginous sandstones and quartzites.

During Oligocene deposition, continental conditions prevailed around the latitude of Cairo and to the south (Marzouk, 1979). Deltaic rocks were deposited west of the Nile River. In the northern Western Desert, marine rocks consisting of shale and some limestone replace the deltaic sequence. Shallow-water benthonic fossils suggest a shoaling of the Oligocene sea in this area at the end of Oligocene time.

5.2.3.3 Miocene rocks: Many of the features of present-day Egypt originated during the Miocene time. These include the Red Sea, the Mediterranean Sea, and the Nile Basin. Following uplift at the end of the Oligocene time, the early and middle Miocene seas transgressed on Egypt from the north. Then, as a result of the Alpine orogeny, the late Miocene sea regressed northward.

Early Miocene rocks are represented in the Gulf of Suez mainly by open marine to lagoonal shales and marls, with limestones, sandstones, and some anhydrite near the top (El Gezeery and Marzouk, 1974). Toward the basin edges, the section contains equivalent nonmarine and coastal facies of reefal limestone and limy conglomerates. In the Cairo-Suez area, the rocks were deposited in a shallow-marine environment. Reefal limestone is present in the sequence south of Suez (Abdallah and El Hady, 1966). In the eastern Western Desert, continental to estuarine facies predominate, but change to marine or estuarine facies northward along the coast.

Middle Miocene rocks are widespread in Egypt as a result of the maximum extent of the Miocene sea transgression. They overlap onto the basement and, less commonly, the Cretaceous and younger rocks along the Red Sea coast. In places they are as much as 612 m thick (El Shazly, 1966b).

In the Gulf of Suez Basin, the middle Miocene is mainly lagoonal, but partly open marine containing both anhydrite and salt as well as sandstones and shales. In the Suez Canal, the beds are sandstones, clays, and limestones with gypsum; in the Cairo-Suez area the rocks are shallow-marine limestones with intercalated sandstones and clays (Shukri and Ayouty, 1956). The middle Miocene rocks in the Nile Delta are over 900 m thick and consist of shales, with dolomitic limestones grading

southward into sandy shales. In places, a thick anhydrite bed is present at the top. A marine facies seems to pass into fluvial southward and westward (Ouda, 1971). In the northern Western Desert, the rocks are fossiliferous sandy and clayey limestones and shallow-marine limestones. A shallow marine-to-lagoonal environment is indicated.

During late Miocene, the rocks were uplifted and folded along WNW-ESE trends (El Shazly and others, 1975). Most of the rocks are continental. It has been reported by Ross and others (1973) that thick layers of salt and anhydrite of late Miocene age underlie the Red Sea. There, huge, closed lagoons, in which evaporites were deposited and covered by continental deposits, seem to have been present.

5.2.3.4 Pliocene rocks: Uplift begun in late Miocene time, continued into early Pliocene time, with a "Proto-Nile" developing in the Nile River basin. El Shazly (1975) does not believe the "Proto-Nile" was ancestral to the present Nile River, although the Nile may have used parts of the earlier system. On the south, the Pliocene sea followed the established fracture system parallel to the Red Sea as far inland as the border of Sudan. Near Aswan, the succession from oldest to youngest consists of marine - to - estuarine clay containing sandstone lenses, sandstones and gravel interbedded with clay lenses of a regressive phase deposited in a fresh-water basin, and alluvial gravels.

Farther north, along the Nile River, impure limestones, sandstones, and conglomerate of a shoreline facies are reported. Much of the section west of the present Nile Delta consists of sandstones, clays, and limestones with vertebrate fossils. These probably range in origin from fresh water to brackish and even marine waters.

Pliocene rocks are thick under the present Nile delta and for the most part were probably deposited in a shallow-marine environment. However, some estuarine-to-fluvial shales and sandstones are present. Along the Red Sea, the Pliocene rocks, some which are, as much as 150 m thick (El Shazly, 1966b), consist of algal, limy sandstones and clastic limestone of a shallow-marine environment.

In the Gulf of Suez, the wells have encountered about 500 m of Pliocene and younger rocks. The rocks are generally marine to the south and continental sandstone and gravel to the north. Considerable disagreement exists about the separation of Pliocene and Miocene rocks here.

In the Western Desert, pink oolitic limestone has been reported in the Pliocene section (El Shazly, 1975b). This is 60 m thick, lies unconformably on Miocene rocks, and suggests warm shallow-marine conditions.

5.2.4 Rocks of Quaternary age: Quaternary rocks, in the thickness range of 4.4 to 110 m, are characterized by raised beaches and coral reefs along the Mediterranean shore; alluvial deposits in the Nile

Valley and Delta; lacustrine deposits and river mud in the El Fayum depression; alluvial deposits in the wadis and low spots in the deserts and coastal plains; calcareous tufa in some oases; and dunes and wind-derived deposits. In general, the deposits show that the Mediterranean Sea experienced progressive regression after its peak in Pliocene time. The Mediterranean coastal zone is characterized by Pleistocene bars made of detrital limestone.

6.0 PETROLEUM POTENTIAL

The estimated total area of Egypt's promising petroleum regions is more than 600,000 km² of which probably about one-third has received more than a cursory exploration. The principal prospective areas lie within six petroleum provinces: (1) the Gulf of Suez, (2) the Red Sea, (3) the Western Desert, (4) the Northern Sinai, (5) the Nile Basin, and (6) the Delta Basin. The Nile cone-Levantine platform, located in the Mediterranean at depths of from 1,000 to 2,600 m, may add another petroleum province at such time as economics dictate, and technology permits deep-water drilling.

6.1 Gulf of Suez Petroleum Province

The Gulf of Suez is a tectonic element. It is a basin formed mainly by a large graben (EF-figure 8) which covers an area of about 20,000 km². It extends from Suez to Hurghada and contains a thick sequence of sedimentary rocks ranging in age from Carboniferous through Cenozoic. Important geologic events were pre-Miocene faulting and deposition of organic-rich basinal marls and evaporites over the fault blocks in Miocene time. The marls acted as source beds and, in some cases, the evaporites served as sealing beds. Petroleum accumulations are present in Miocene sandstones and reef limestones draped over the fault blocks, as well as in pre-Miocene beds such as Carboniferous and Cretaceous sandstones and Cretaceous and Eocene limestones into which the Miocene age oil migrated (figure 16). However, the principal reservoirs are Miocene sandstones.

The basin has been extensively explored by surface and geophysical mapping. By 1978, more than 40,000 km of seismic lines were shot on land and offshore. During 1922-1968 about 40,000 km² were surveyed by gravity. In addition about 7,000 km of aeromagnetic lines were flown over land and water. Exploratory drilling began in 1886 and more than 300 exploratory wells have been drilled since then. Of these, 80 were offshore. These wells discovered 28 fields with proven recoverable reserves reported by EGPC to be about 3.5 billion barrels of oil, most of which was found in Miocene and pre-Miocene sandstones in Morgan, Belayim, July, Ramadam, and S.G. 300 fields (figure 1). Reserves in Miocene sandstones are present in Sudr, Umm El Yusr, Shukheir, Kareem, Feiran, and Rudeis-Sidri oil fields, and oil in Miocene reef reservoirs are present in Ras Gharib, Bakr, Kareem and Gemso. Pre-Miocene reservoirs ranging from Paleozoic to Eocene in age contain oil in Hurghada, Ras Gharib, Bakr, Amer, Kareem, Sudr, Asl, Ras, Matarma, and Belayim marine fields.

Fig. 16. Geologic cross section of the Ras Gharib field, a typical oil field in the Gulf of Suez basin. (Said, 1962)

The offshore areas of the Gulf of Suez offer the most immediate prospects for substantially increasing Egyptian petroleum reserves. Large tracts remain undrilled and probably contain numerous promising structures and many different reservoirs. Geophysical methods, especially gravity and seismic reflection, have been the keys to locating the complex structural traps here. A substantial part of the open marine areas have not been surveyed by up-to-date seismic techniques that are capable of mapping a reflector beneath the Miocene salt section. The Miocene evaporite section locally produces spurious structures which, combined with the thick post - Miocene sequence, makes seismic interpretations difficult and sometimes unreliable. More extensive and improved marine geophysical surveys are the key to further successful exploration and production in the Gulf of Suez.

6.2 Red Sea Petroleum Province

The Red Sea petroleum province, also a tectonic province, extends from north of Hurghada south to the border of Sudan (figure 5). It has a prospective area, to the 200 m depth, of about 25,000 km². Most of the province is offshore and, except for a few dry wildcat wells, remains largely unexplored. In contrast to the Gulf of Suez basin, pre-Miocene sedimentary rocks are rare in the onshore parts of this area and presumably also in the offshore parts. Except for Upper Cretaceous to Oligocene strata in the Quseir area, Miocene beds directly overlie Precambrian crystalline rocks along the narrow coastal plain; these beds are relatively thin onshore but appear to thicken seaward and may attain thicknesses of several km offshore.

Miocene sedimentary events in the Red Sea region as a whole are similar to those in the Gulf of Suez basin and include deposition of early Miocene organic-rich basinal marls and both middle and late Miocene evaporites. Along the Egyptian coast, these rocks may interdigitate with nonmarine and nearshore marine sands and other clastics derived from the west. This juxtaposition of potential source marls, sealing evaporites and reservoir clastics offers good possibilities for hydrocarbons in the Miocene. If two evaporite layers exist in the offshore region, the upper may act as a seal, as in the Gulf of Suez, while the lower may form prospective diapiric structures.

The high geothermal gradients resulting from rifting of the Red Sea (40-60° C/km) probably insure rapid maturation of organic matter and explain why discoveries in the region to date have been natural gas (e.g., off northern Saudi Arabia and Ethiopia). They also suggest that most future discoveries will also be gas.

In 1965, 500 km of reconnaissance seismic lines were shot, and gravity and magnetic surveys were made on shore. Only a few shallow wells were drilled in this province until the last few years. Union, Esso, Phillips and Hispanoil are carrying out exploration and drilling operations here at this time. No oil discoveries have been made so far

in this province. Most exploration will be offshore, with seismic reflection being the main exploratory tool. Problems to be expected include the effects of the evaporites on seismic records and the probable high degree of lenticularity of the reservoir sands which were formed in alluvial and nearshore marine environments. Effective exploration thus will be a matter of obtaining high-quality marine-seismic records and interpreting them in light of the newly emerging field of seismic stratigraphy.

6.3 Western Desert Petroleum Province

According to the definitions by the EGPC, the prospective area of the Western Desert extends from the Mediterranean coast to the southernmost marine Cretaceous outcrops at latitude 25°N , with its eastern boundary marked by the Kharga-Wadi El Rayan uplift and the Nile Basin. It includes an area of about $650,000\text{ km}^2$ including the continental shelf in the Mediterranean Sea. It is a part of the unstable shelf tectonic province. Among the significant features are the Sollum basin in the northwesternmost part, the Khalda basin in the northwestern part, and the Abu Gharadig basin in the north-central part. The latter may be a continuation of the prolific Sirte basin of Libya.

Active exploration in the Western Desert has been underway since 1946 during which time $100,000\text{ km}$ of seismic lines have been shot, both land and marine. In addition $200,000\text{ km}^2$ have been covered by gravity surveys and $340,000\text{ km}^2$ by aeromagnetic work. About 200 exploratory wells have been drilled in this vast region in which commercial discoveries have been made at Alamein, Yidma, Rassak, Abu Gharadig, Meleiha, and Umbarka (figure 1). Several other discoveries of oil and gas have been reported but have not yet been proven as commercial. EGPC estimates the proven recoverable reserves of these fields are 190 million barrels of oil and condensate. In addition, the Abu Gharadig field has estimated proven reserves of 2.2 billion f^3 of gas.

The six proven commercial fields in the Western Desert appear to be on structures delineated by geophysical methods. All reservoirs are of Cretaceous age. Upper Cretaceous sandstones and limestones contain oil in the Razzak, Meleiha and Abu Gharadig fields (figure 1); in the latter field, Upper Cretaceous (Cenomanian) sandstone is also gas-bearing. Lower Cretaceous dolomites produce oil in the Alamein, Yidma, and Razzak fields, and Lower Cretaceous sandstones are reported to be oil-bearing in the Razzak and Meleiha fields. Significant oil and gas shows in Jurassic and Eocene beds indicate rocks of these ages are also prospective. Complex facies relationships and numerous unconformities within rocks of all these ages are currently being investigated in the subsurface, and initial interpretations suggest the probability of numerous stratigraphic as well as structural traps.

Few wells have penetrated Paleozoic rocks in this area but interdigitating of nonmarine clastic and marine sediments suggest favorable

prospects. More than 3,000 m of Paleozoic strata, including marine shales, occur in the Sollum basin in northwestern Egypt, and oil is reported in a sandstone of presumed Paleozoic age in the Umbarka field in western Egypt.

Future exploration in the Western Desert will continue to emphasize (1) systematic facies mapping based on subsurface well cores and logs, and (2) regional geophysical surveys, especially seismic studies utilizing the principles of seismic stratigraphy. What is needed first, as pointed out in the previous discussions of paleozoic rocks, is a basic understanding of the basement and Paleozoic rocks to provide the foundation for exploration of both Paleozoic and the younger rocks in this region.

Recently some oil companies have relinquished concessions in the Western Desert because of the disappointing drilling results. Disappointing results are generally experienced from time to time in most large petroleum provinces and as a result the exploration activity goes through cycles until enough exploration and drilling has been done to understand the tectonics and sedimentation of the prospective basins. The primary search is always for large untested anticlines, preferably with oil seeps nearby. This phase may be ending in the Western Desert, but enough subsurface data may be at hand to provide leads for the search for combination structure-stratigraphic or stratigraphic traps. This will require a more regional approach covering many concessions owned by different companies.

One of the criteria commonly being used to judge the potential of petroleum provinces and basins is the degree of maturation of organic matter thought to be the source rocks. The following discussion of maturation of petroleum and source rocks in the Western Desert has been abstracted from a company's report on file with the EGPC. It reports that source rocks are present but appear to be irregularly distributed both in time and space. The quality of organic matter in the rocks tends to be on the low side, as 70 percent of the spot samples are "lean" to "average" and only 30 percent are "rich" to "very rich." The type of organic matter is mostly humic or mixed humic-kerogenous, and more rarely, kerogenous. Only a few wells penetrated good and reasonably thick source rocks for oil; these came from early Cretaceous and middle Jurassic sequences.

The geothermal gradient in the Western Desert is lower than average. The present top of the maturation zone (210°F) for oil is mostly between 8,000 and 9,000 ft below the surface. However, the top is shallower at Umbarka and deeper in the Matruh trough zone. Conclusions have been drawn that only those source rocks deposited before the Alamein dolomite sequence (Lower Cretaceous) are likely to have yielded significant quantities of petroleum. The bottom of the maturation zone

(300°F) is thought to lie between 14,000 and 15,000 ft in most areas -- thus it is thought that most known gas-source rocks were never deep enough to permit gas generation. It is concluded that none of the known oil - source rocks were buried below the critical depth (8,000-9,000 ft) much before the beginning of Upper Cretaceous time. Also, some oil-source rocks became mature after Upper Cretaceous depositions only, but most required the added depth and overburden occasioned by Tertiary deposition. Therefore part of the oil generation occurred at almost the same time as the trap formation in late Cretaceous time.

Only small- to moderate-sized accumulations of petroleum have been found so far in the Western Desert and the drilling success ratio has been low. The poor results have been attributed to (1) the very localized presence of good source rocks which generated locally limited quantities of petroleum and (2) the structural and stratigraphic set-up characterized by abundant faults, scarce dip closures, infrequent paleostructures, and a generally unfavorable seal distribution. Improperly sealed traps may have allowed the small volumes of petroleum available to escape.

Figure 17 is a geothermal gradient map of the northern Western Desert and Nile Delta by Khalil and El Demerdash (from El Shazly, 1977). The geothermal gradients on this map are higher toward the basin areas where petroleum might be generated, though data are lacking in many basinal areas. This leaves hope that the wide scattering of the source-rock samples both stratigraphically and geographically is not completely representative of the richness of the many source beds in the Western Desert.

6.4 Northern Sinai Petroleum Province

Northern Sinai, a part of the unstable shelf tectonic province, is defined by EGPC as the area of the Sinai Peninsula north of the latitude of Cairo (about 20°N) to the edge of the continental shelf in the Mediterranean. With these boundaries, it encompasses 100,000 km². This sparsely drilled area has geology and petroleum prospects similar to those of the Western Desert. The sedimentary sequence is about 6,000 m thick. It has the same variety of facies present to the west but differs in two important ways; vastly greater exposures of the different units are present, and no Paleozoic strata are known. Prominent oil shows are reported in Upper Cretaceous rocks. The degree of deformation in the area increases from south to north. Numerous anticlines are present in the northern coastal part.

During 1960-1966, nearly 2,000 km of land and marine seismic lines were shot, and 5,000 km² of gravity surveys and 4,000 km² of magnetic surveys were completed. Six exploratory holes were drilled, but no oil or gas has been discovered as yet. Oil shows were encountered in the Upper Cretaceous beds in three wells in central Sinai.

Fig. 17. Geothermal gradient map of northern Western Desert and Nile Delta, Egypt (Khalil and El Demerdash, 1975)

Because of political problems since 1966, the region has not been open for active exploration. Leasing and exploration recently have been resumed in the westernmost part of the area, but further activity in most of the region awaits resolution of the political problems. Based on the general resemblance of this area to the productive areas of the Western Desert, eventual discoveries are to be expected following appropriate geophysical and regional facies studies both onshore and on the relatively wide continental shelf.

6.5 Nile Basin Petroleum Province

The Nile Basin lies between the stable and unstable shelf tectonic provinces. It extends southward beyond latitude 24°N , westward to the Kharga-Wadi El Rayan uplift, northward to the latitude of Cairo (30°N), and eastward to the Red Sea Hills. It covers an area of about 100,000 km^2 .

The Nile basin has maximum thickness of sedimentary rocks estimated to be about 5,000 m, of which more than 3,000 m are late Cretaceous to Eocene in age, and the remainder early Cretaceous or older. The few wells drilled have made no discoveries to date, but they have encountered oil shows in Eocene limestones and Upper Cretaceous sandstones. Sediment thickness and degree of deformation increase from south to north in the basin, and the best prospects probably lie north of latitude 28°N .

Exploration activity has been limited in this area. In 1969 about 936 km of seismic lines were shot, 12,000 km^2 of gravity surveys were made, and 10,800 km of aeromagnetic surveys were flown. Only 5 exploratory wells have been drilled in this area. Asphalt and residual-oil staining was reported in Eocene limestones in a well about 30 km north of Fayum. Dry asphaltic residue was reported also in this well in Upper Cretaceous sandstone. Other oil indications reported in the Nile Basin include fresh-oil odor in the middle Eocene beds at Wadi El Rayan, inflammable gas in a water well south of Cairo at a depth of about 1,085 ft in middle Eocene beds, and gilsonite at Akhmin that is reported to have been used by the ancient Egyptians.

The Nile Basin has indications of petroleum but its discovery will require more intensive exploration. Regional facies analysis and geophysical surveys will probably be the main exploration tools in this area which may be rated as having moderately high potential for significant production.

6.6 Delta Basin Petroleum Province

The Delta Basin petroleum province covers an area of 50,000 km^2 including its offshore part and extending eastward to the Suez Canal and southward to the latitude of Cairo (30°N). This is predominantly a late Cenozoic basin with an estimated thickness of more than 5,000 m of Miocene and younger sediment in the northern and offshore areas. Most of this is deltaic sediment deposited since the inception of the Nile drainage system in middle or late Miocene time.

During the period 1946-1975, a total of 20,000 km of seismic lines were shot and about 27,000 km² of gravity surveys were completed. About 50 exploratory wells were drilled before the end of 1976.

Four gas discoveries have been made, of which two, Abu Madi and Abu Qir, are commercial (figure 1). The gas occurs in lenticular Miocene sands, but prediction of these sand trends has proved difficult. The Abu Madi and Abu Qir fields were seismic structural-stratigraphic or stratigraphic traps. K. J. Hsu (oral communication) has looked at seismic records from the Delta Basin and notes that the reservoir sandstone bodies are clearly recognizable on them. He believes that the sands are alluvial fills and channels cut into the front of the delta during the pronounced lowering of the late Miocene sea in the Mediterranean region, and that these sands were then sealed beneath delta-front clays during the succeeding Pliocene transgression. Similar interpretations have been offered by WEPCO geologists at Alexandria, and seem to have much merit. This interpretation suggests that the best prospects will be beneath the front of the present delta system and that seismic stratigraphy will be a key exploration tool, especially when interpreted in light of the drastic late Miocene regression which affected the Mediterranean basin.

Although only gas has been found in the northern part of the basin, oil prospects exist in Jurassic, Cretaceous and Eocene rocks beneath the thinner Upper Cenozoic section to the south.

6.7 Nile Cone-Levantine Platform

These two submarine areas cover about 200,000 km² of the Mediterranean and hold potential for petroleum reserves in the distant future (figure 18). The Nile cone is a wedge of Nile-derived sediment extending northwest of the Nile Delta from the base of the continental slope to latitude 33°N. Water depths range from roughly 1,000 m to about 2,600 m. Geophysical records indicate nearly 2 km of post-Miocene sediment; this is underlain by an unknown thickness of Miocene and older deposits, including the late Miocene Mediterranean evaporites which locally form diapiric structures, (Ross and Uchupi, 1977).

East of the Nile cone is the Levantine platform, a large area of rough bottom topography that extends northwestward from the continental slope north of Sinai to water depths of about 2,000 m. Numerous salt diapirs also underlie this area, which is said to resemble the continental margin in the Western Gulf of Mexico, (Ross and Uchupi, 1977).

Some petroleum accumulations may be associated with these deep-water diapiric structures. Most prospective reservoirs probably predate the evaporites or were deposited contemporaneously with them, and the evaporites may act as a seal, as in the Gulf of Suez basin. Deep sea drilling at Site 376 just west of Cyprus encountered a gas show in the upper part of the evaporite sequence. Deep-water turbiditic sands would be the most likely reservoir rocks in this region.

Fig. 18. Location of the Nile cone - Levantine Platform in the Mediterranean North of Egypt. (Ross and Uchupi, 1977)

Exploration for petroleum in these deep offshore areas will depend on technical and political advances over the next few years. Conceivably, such exploration could form the basis for cooperative efforts among nations of the eastern Mediterranean region. At the present time, additional marine geophysical work, particularly continuous seismic profiling, would be the most advisable exploration strategy. French workers, including those from the Institut Francais de Petrole, reportedly have carried out extensive seismic work in the offshore regions near Egypt, but most of this work remains unpublished.

6.8 Summary of Petroleum Possibilities in Near Future

The area of promising petroleum prospects in Egypt totals more than 600,000 km² of which little more than a third has been at least moderately examined. Prospects appear very favorable for substantial undiscovered reserves in many parts of this large area. The Gulf of Suez Basin holds the most immediate prospects for replacing and increasing the reserves, but with diminishing results as the large structures are drilled.

The most promising frontier regions are the relatively unexplored broad expanses of the Western Desert, the Delta Basin, Nile Basin, and northern Sinai along with the adjacent offshore tracts. Special emphasis should be placed on the Western Desert, the Delta Basin, and offshore areas at this time. The Red Sea area appears to hold moderate possibilities, perhaps mostly as a gas province. The rate of exploration and development in these areas depends upon economic factors which are not predictable in this part of the study. It does seem possible that a proper intensive exploration and drilling program could double the present reserves in 10 years. A proper exploration program would require a considerable change in attack to include or even emphasize the possibilities for strategic traps and combination structure-stratigraphic traps now commonly sought in much of the United States.

7.0 BASIC PETROLEUM EXPLORATION NEEDS IN EGYPT

In reviewing the tremendous volume of data and local reports in the files of the EGPC, and noting the differences in interpretations, it becomes readily apparent that little communication and perhaps no discussions of regional subsurface geology takes place between companies, universities, and government agencies. The confidentiality imposed on most data by the companies and in part by the government tends to prevent this. Even regional data and reports not concerned with local prospects have rarely been used in the few published papers. It would be good for the companies and the Egyptian government to encourage scientific discussion and publication of geological and geophysical reports of a regional nature, so that all would benefit from the scientific criticism generated and so that later workers could build upon the earlier reports. Most published geological reports seem to have a half-life of about 10 years but their impact may be tremendous in spurring others to improve on the subject material.

Some of the most obvious needs of this nature are (1) standardization of stratigraphic nomenclature, (2) an aeromagnetic map, (3) a gravity map, (4) a basement tectonic map, (5) a paleozoic thickness map, and (6) a map showing sedimentary basins, all of these maps at 1:2,000,000 scale covering all of Egypt. These should be attempted with the collaboration of company, university, and government geoscientists in a sequence of one or two products each year for publication. The establishment of a local petroleum exploration society affiliated with the American Association of Petroleum Geologists, a world-wide organization of nearly 20,000 members, would be an easy step in the direction of interchange of geological and geophysical information of a theoretical or a regional nature.

The following discussion of needs for petroleum exploration in Egypt pertains to records, maps, and charts needed and the technology and methodology required to obtain or prepare them.

7.1 Nomenclature and Correlation of Stratigraphic Units

Published subsurface type sections with standard nomenclature and age assignments are necessary for geological and geophysical communication. These could be best established by selection of the stratigraphically deepest wells with complete samples, cores, and electric logs in each basin or province, and the preparation of composite sample logs by expert lithogeologists with paleontologic aid. These would include not only lithology and electrical characteristics, but also fossils, oil, gas, and water information. These standard logs could then be used to extend correlations along cross sections with a vertical scale of 1" = 100' designed to outline the regional stratigraphy and facies changes. It might suffice to have one composite standard well section for each province. In addition it would be desirable to publish two stratigraphic cross sections at a vertical scale of 1" = 200' at right angles across each region.

7.2 Stratigraphic Analysis of Sedimentary Basins

Regional stratigraphic analysis is an important method of petroleum exploration in frontier areas. It offers a relatively inexpensive means of comparing the petroleum potential of different rocks in different basins so that priorities can be established for the expenditure of time and money. It requires analysis and synthesis of data and some imagination for interpretation of each basin's petroleum potential. It does not ordinarily provide the detail needed for selecting a site for an exploratory well, however, it aids in selecting the most promising areas, from a stratigraphic point of view, for further investigations by seismic reflection surveys, stratigraphic and structural test holes, and seismic stratigraphy.

Stratigraphic analysis can provide evaluation of potential reservoir rocks, sealing rocks, and source rocks, potential facies and unconformity

traps, and the possibilities for maturation of hydrocarbons and the entrapment of petroleum in each basin. Such studies require reconstruction of the geologic history including tectonics, environment and mode of deposition of rocks, and the depth of burial of rocks at successive stages of basin development as well as the present structure, thickness, and distribution of the rocks. Paleogeologic maps, particularly those of tectonic units marked by regional unconformities, paleographic maps showing environmental interpretations, and thickness maps with lithofacies distribution are effective tools and should be prepared for major sedimentary basins in Egypt and published for general use.

7.3 Basement Tectonic Map

The structural development of Egypt is greatly governed by the basement tectonics. The outline, shape, size and disposition of the deep sedimentary basins are also controlled entirely by the pre-existing topography and structures. Block faulting in the basement seems to be a common accompaniment of basin subsidence. Many anticlines have resulted from movement of basement blocks. The block faulting frequently controls facies, oil-structure development, and oil occurrences. It also controls graben basins. So it is essential to have a reliable basement-tectonic map. It is recommended that such a map be constructed by combined interpretation of the following data to avoid the serious pitfalls of interpretation using just one type of data: (1) ground and aerial magnetic data, (2) gravity data, (3) refraction seismic data, (4) regional CDP reflection sections, and (5) deep-well data.

7.4 Seismic Refraction Survey

Previous regional exploration work in the Western Desert consisted of widespread gravity and magnetic surveys, scattered structure-drill holes, and some conventional reflection-seismic surveys. The results were inconclusive in the evaluation of the Paleozoic basin and the deeper structures, especially the Paleozoic uplift.

Two continuous in-line-reverse refraction profiles are suggested: one along the strike of the general deep trend, the second at right angles. Each profile should be about 100 mi long. Inasmuch as the immediate object of the survey is to determine major subsurface geologic features with depths anticipated to be about 10 km, the shot points may be offset 30 to 40 km from the main spread. A cable 20-km long and a shot-point spacing of 4 km is recommended. Dynamite charges of 3,000 lbs. will be required for each shot point to produce reliable first arrivals.

This refraction survey will be supported by the existing gravity, magnetic, and deep-well data. The object of this survey is to determine (1) the major subsurface geologic features with special emphasis on the existence and shape of the Paleozoic uplift and Paleozoic basin, (2) the depth and dip of the refractions from all competent beds, especially the basement, and (3) the effective refraction velocity for identification of gross lithology and correlating reflection seismic records.

7.5 Seismic Stratigraphy

In Egypt the seismic reflections have been used the traditional way: only to identify events and study structural deformations with the object of locating structural features which might entrap hydrocarbons. But the seismic data can provide a great deal of information for stratigraphic interpretation by relating seismic data to stratigraphy. Seismic stratigraphy is recommended for all parts of Egypt but especially for the Nile Delta and the Western Desert. It includes (1) seismic-sequence analysis to identify the stratigraphic units, their succession, and the sequence boundaries and lateral extent of strata, (2) seismic-facies analyses to interpret the sedimentary processes and environmental setting and help predict the lithology of the facies, (3) cycle-sequence analysis to recognize cycles of relative rise-and-fall of sea level; these have a variety of predictable depositional patterns and help in constructing a regional stratigraphic framework necessary for interpreting paleogeography, geologic history, and geologic setting for petroleum-prospecting analyses, and (4) the true-amplitude analysis ("Bright Spot") which will help in detecting petroleum in place, especially gas.

7.6 Seismic Modeling

The two major interpretive classes of seismic modeling needed in Egypt are structural and stratigraphic. Structural modeling relates to interpretive problems where structural identification is the primary objective such as the deep structures or in structurally complicated areas. Stratigraphic modeling concerns interpretive problems where identification of lithologic changes is the primary objective, that is, the trapping mechanism is primarily stratigraphic. Many such problems exist in the Western Desert and the Nile Delta. Obviously, many problems have elements of both types of modeling.

7.7 Source-Rock Evaluation and Crude-Oil Correlation

To assess the petroleum potential of Egypt, especially in the Western Desert and Nile Delta, and also to select the most optimum prospect areas and sites for future wells, a hydrocarbon-source rock evaluation study of well cuttings and samples of outcrops is needed. Such studies include the determination of the hydrocarbon-source quality (richness), source type (gas versus oil), and degree of thermal maturation and identification of specific organic facies that are of interest to exploration.

Source correlations and characterizations for crude oil from different oil fields in the Western Desert and Nile Delta can readily be made to relate the hydrocarbons to their subsurface stratigraphic source facies. This knowledge, in conjunction with source-rock data, could focus exploration attention of prospective stratigraphic units.

7.8 Continuing Education of Geoscientists

Successive exploration in Egypt might be encouraged not only by economic incentives but also by subsidized educational efforts covering modern concepts and techniques. The basic geologic education of Egyptian earth scientists is very sound but continuing contact with new theory and technique is needed. Topics of special importance include stratigraphic interpretation of seismic data and modern sedimentologic analysis of clastic, carbonate, and evaporite depositional systems.

8.0 REFERENCES CITED

- Abdallah, A. M., and Abd E. Hady, F. M., "Geology of Sadat Area, Gulf of Suez." *Journal Geology U.A.R.*, 1966 v. 10, (1), pp. 1-24.
- Abdallah, A. M., El Adindani, A., and Fahmy, N., Stratigraphy of the Lower Mesozoic Rocks, Western Side of the Gulf of Suez. Egypt: Geol. Sur. Min. Res. Dept., Cairo, Paper no. 27, 1963.
- Andrawis, S. F., New Biostratigraphic Contribution for the Upper Part of the Paleozoic Rocks of Gibb Afia Well no. 2, Western Desert. Egypt: Eighth Arab Petroleum Cong., Algiers, Paper no. 76 (B-3), 1972.
- Awad, G. H., "On the Occurrence of Marine Triassic (Muschelkalk) Deposits in Egypt." *Bulletin-Institute of Egypte*, 1946, v. 27, pp. 397-429.
- Bar and Kiltzsch, "Introduction to the Geology of Egypt," Guidebook to the Geology and Archaeology of Egypt (Petroleum Exploration Soc. Libya, 6th Ann. Field Conf.), 1964, pp. 71-98.
- Bobbitt, J. E., and Gallagher, J. O., The Petroleum Geology of the Gulf of Suez. Offshore Technology Conf. 3091, 1978.
- El Gezeery, M., and Marzouk, I. M., eds., "Miocene Rock-Stratigraphy of Egypt." Stratigraphic Sub-committee of the National Committee of Geological Sciences: *Egyptian Journal of Geology*, 1974, v. 18 (1), pp. 1-59.
- El Shazly, E. M., "Structural Development of Egypt, U.A.R.": Program and Abstracts, Geol Soc. Egypt, Fourth Ann. Meeting, 1966a, pp. 31-38.
- _____, "Lead Deposits in Egypt." *Ann. Mines Geol. Tunisia*, no. 23, 1966b, pp. 245-275.
- _____, On the Development of Segments in the Basement Crust in Northern Africa. Twenty-fourth Int. Geol. Cong., Canada, Abstracts, 1972, p. 27.
- _____, "The Geology of the Egyptian Region." *The Oceans Basins and Margins*, V. 4a -- The Eastern Mediterranean: Plenum Press, New York and London, 1977, pp. 379-444.
- El Shazly, E. M., and others, "Geochronology of Abu Swayel area, South Eastern Desert." *Egyptian Journal of Geology*, v. 17 (1), 1973, pp. 1-18.
- _____, Geologic Interpretation of Landsat Satellite Images for West Nile Delta Area, Egypt. Remote Sensing Research Project, Acad. Sci. Res. Technol., Cairo, 1975.
- El Sweify, A., Subsurface Paleozoic Stratigraphy of Siwa-Faghur area, Western Desert, Egypt. Ninth Arab Petroleum Cong., Dubai, Paper no. 119 (B-3), 1975.

- Fouda, A. A., "The Upper Mantle Structure Under the Stable Regions."
Ph.D. Dissert., UCLA Dissert. Abs. Int., 1974, v. 34, no. 6, p. 2722B.
- Hermina, M.H., 1978, Personal Communication.
- Marzouk, I., Rock-Stratigraphy and Oil Potentialities of the Oligocene and Miocene in the Western Desert, U.A.R. Seventh Arab Petroleum Cong., Kuwait, Paper no. 54 (B-3), 1970.
- Ouda, K., Biostratigraphical Studies of Some Subsurface Miocene Formations from the Western Desert, Egypt. Ph.D. Thesis, Fac. Sci., Univ. of Assiut, Egypt, 1971.
- Phillips, J. D., "Magnetic Anomalies in the Red Sea." Trans. Royal Soc., London, 1971, A 267, pp. 207-217.
- Phillips, J. D., and others, "Magnetic and Gravity Anomalies in the Central Red Sea." Hot Brines and Recent Heavy Metal Deposits in the Red Sea -- Degens, E. T., and Ross, D. A., eds, New York: Springer-Verlag, 1969, p. 98-113.
- Phillips, J. D., and Ross, D. A., "Continuous Seismic Reflection Profiles in the Red Sea." Trans. Royal Soc., London, 1970, A 267, pp. 143-152.
- Ross, D. A., and others, "Red Sea Drillings." Science, 1973, v. 179, pp. 377-380.
- Ross, D.A., and Uchupi, E., "Structure and Sedimentary History of Southeastern Mediterranean-Nile Cone Area." American Association Petroleum Geologists Bulletin, 1977, Vol. 61, p. 872-902.
- Said, R., The Geology of Egypt. Elsevier Publishing Co., Amsterdam-New York, 1962, p. 377.
- Shukri, N. M., and El Ayouti, M. K., "The Geology of Gebel Iweibid-Gebel Gafra Area, Cairo-Suez District." Bull. Soc. Egypte, 1956, v. 29, pp. 67-109.
- World Oil, "World Crude Oil Production by Countries, 1975 and 1976." World Oil, Feb. 15, 1977, p. 132.

B. COAL AND OIL SHALE

By: W. W. Olive

1.0 SUMMARY AND CONCLUSIONS

Both coal and oil shale occur in Egypt (figure 1). The deposits of oil shale that are known attain thicknesses of only 10 to 15 feet at studied localities and their hydrocarbon content is low. They may never be economically attainable. The best-known deposits of coal contain total reserves estimated at 95 million to 112 million tons. Of these, the only deposit deemed workable under present conditions of technology and economy is 150 km northeast of Ismailia on the Maghara anticline, Sinai Peninsula. Recoverable reserves are estimated to total 35.6 million tons. A production of 300,000 tons per year was planned for the Safa Mine which was being opened at the time of the 1967 war. Results of chemical and petrographic analyses of Maghara coal are given in tables 1, 2, 3, and 4. The Maghara coal is not good coking coal and would require mixing with 70 to 90 percent of imported coking coal to produce a satisfactory coke.

Elsewhere in Sinai, coal deposits at Wadi Thora, reported to contain 60 million tonnes, might become economical when a fluidized bed combustion process becomes economical. Deposits known to be present at Ayun Musa are not considered to be economical because of depth (400 to 600 m) below the surface, lenticularity of the coal beds, and the presence of formation water under high pressure.

Boreholes at Wadi Araba and Kharga Oasis have intersected coal seams which are a few centimeters thick. Other seams found in the Western Desert are too deep, too thin, and too remote even for exploitation by subterranean gasification processes.

Although the prospects for developing a coal mining industry in Egypt are not encouraging, the information is not conclusive. Geologic investigation of Middle Jurassic rocks on the Sinai Peninsula might yet discover additional economic reserves to augment those of Maghara. In addition an updated feasibility study on the economics of Maghara coal use might be needed in the light of conditions prevailing when the deposits come under the control of Egypt.

2.0 RECOMMENDATIONS

1. Determine the distribution of the Middle Jurassic coal-bearing sequence in those areas of the Sinai Peninsula where the sequence is at or near the surface.

This will require geologic mapping, paleontologic, and stratigraphic investigations, and the preparation of lithofacies maps and diagrams. Drill-hole data will be needed in those areas where the sequence is not at the surface. With information thus obtained, it should be possible to predict localities in which ancient lagoons may have formed. Such lagoons are likely sites for economic coal deposits.

FIGURE 1. LOCATIONS OF COAL AND OIL SHALE DEPOSITS IN EGYPT

TABLE 1

ANALYSES OF COAL FROM SAFA MINE, SINAI PENINSULA,
EGYPT (POWELL DUFFRYN TECH. SER. LTD., 1963)

UPPER SEAM

Proximate and Ultimate Analyses of Selected Sample

Proximate					Ultimate							Kilocalories per Kilogram
	Moisture	Ash	Volatiles	Fixed Carbon	Moisture	Ash	Carbon	Hydrogen	Nitrogen	Combustible Sulfur	Oxygen (by difference)	
As received	4.9	6.5	50.7	37.9	4.90	6.50	70.66	5.67	1.04	2.97	8.26	Gross 7,215 Net 6,890
Dry		6.8	53.3	39.9		6.84	74.33	5.96	1.09	3.12	8.69	Gross 7,610 Net 7,292
Dry, ash free			57.2	42.8			81.98	6.58	1.21	0.65	9.58	Gross 8,476 Net 8,082

Range in Values Based on Ultimate Analyses of 13 Samples

Moisture	Ash	Carbon	Hydrogen	Nitrogen	Sulfur Combustible	Oxygen (by difference)	Chlorine	Phosphorous	
								in ash	in coal
3.50-5.00	3.61-27.25	52.32-73.96	4.73-6.18	0.70-1.28	1.13-3.89	7.32-9.96	0.032-0.082	0.016-0.049	0.001-0.011

Sulfur, Phosphorous, and Carbon Dioxide in Bulk Sample

Sulfur				Phosphorous		Carbon dioxide
Sulfate	Sulfide	Organic	Total	In ash	In coal	
0.10	2.40	0.56	3.06	0.040	0.003	
						0.08

TABLE 1 (continued)

Minor Elements in Ash of Bulk Sample as Determined From Spectral Analysis*

Germanium	Gallium	Arsenic	Barium	Boron	Beryllium	Bismuth	Cadmium	Cobalt
0.003-0.007	0.004-0.008	<0.003	Not detected	0.02-0.20	0.005-0.010	<0.002	Not detected	0.001-0.004

Chromium	Magnesium	Manganese	Molybdenum	Nickel	Lead	Tin	Vanadium	Yttrium	Zinc
<0.004	<0.01	0.10-0.40	<0.003	0.005-0.10	0.004-0.008	<0.002	0.005-0.010	Not detected	<0.005

* Calcium was beyond the range of sensitivity, not detected.

Gray King Assay at 600°C

Coke, Type "G" kg/Ton	Tar kg/ton	Liquor kg/ton	Ammonia kg/ton	Quantity Nm ³	Gas Calorific Value kcal/Nm ³
561.1	247.3	87.1	0.53	95.1	9,020

TABLE 1 (continued)

MAIN SEAM

Range in Values of Proximate Analyses (as received basis) and Swelling Number for 23 Samples

	Moisture	Ash	Volatile Matter	Fixed Carbon	Total Sulfur	Kilocalories per Kilogram	Swelling number
Range	2.2-11.9	4.0-29.7	44.4-53.3	25.7-38.5	1.96-5.72	5,140-7,480	1-3
Average	5.3	10.9	49.6	31.0	3.35	6,855	

Ranges in Values of Ultimate Analyses (as received basis) for 40 Samples

Moisture	Ash	Carbon	Hydrogen	Nitrogen	Sulfur, Combustible	Oxygen, by difference	Chlorine	Phosphorous	
								in ash	in coal
2.80-11.90	4.40-34.20	46.78-73.34	4.68-6.18	0.62-1.23	1.58-4.28	5.53-10.08	0.021-0.156	0.01-0.082	0-0.014

Ash fusibility of main seam

Deformation °C 1,100-1,245

Hemisphere °C 1,215-1,370

Flow point °C 1,150-1,400

TABLE 2

CHEMICAL ANALYSIS (PROXIMATE) OF SAMPLES OF MAGHARA COAL

	As received %	Coal moisture free %	Coal moisture and ash free %
Moisture	2.8	-	-
Volatile matter	48.1	49.5	57.6
Fixed carbon	35.1	36.4	42.4
Ash	13.7	14.1	-

TABLE 3

CHEMICAL ANALYSIS (ULTIMATE OF SOME SAMPLES OF MAGHARA COAL*)

	As received %	Coal moisture %	Coal moisture and ash free %
Hydrogen	5.6	5.4	6.3
Carbon	63.2	65.0	75.6
Nitrogen	1.2	1.2	1.4
Oxygen	13.4	11.3	13.2
Sulfur	2.9	3.0	3.5
Calorific value (British thermal units)	11,690	12,020	13,990

* Analytical work by Coal Analysis Laboratory, U.S. Bureau of Mines

SULFUR FORMS OF MAGHARA COAL*

	Sulfates	Pyritic	Organic
As received	0.61	1.48	0.84
Moisture free	0.62	1.52	0.87
Moisture and ash free...	0.72	1.77	1.01

* Analytical work by Coal Analysis Laboratory, U.S. Bureau of Mines

TABLE 4

PETROGRAPHIC COMPOSITION OF MAGHARA COAL AS DETERMINED BY ANALYSIS OF THIN SECTIONS BY TRANSMITTED LIGHT MICROSCOPY IN TERMS OF MACER> 1 COMPONENTS. (ABDEL-HALEK, 1973)

Relatively reactive const.				Relatively inert const.	Mineral const.	
Reddish translucent macerals		Yellowish translucent macerals		Semiopaque and opaque macerals		
Sample	Vitrinite	Exinite	Resinite	Semifusinite, fusinite, and micrinite	Pyrite	Clay
4090-2A	78.9	15.1	3.4	0.5	1.7	0.4
4090-2B	74.9	19.2	4.3	0.1	1.1	0.4

Petrographic composition of Maghara coal by analysis of polished granular coal specimens, using reflected light microscopy and in terms of maceral components.

Samples	Vitrinite	Exinite and Resinite	Semifusinite, fusinite, and micrinite	Mineral const.
4090-1A	78.32	16.42	1.62	3.62
4090-1C	77.60	10.60	6.40	5.40

Petrographic composition of Maghara crushed prepared coal from 13 core samples, main seam by means of reflected light microscopy.

Entity composition, Vol. %

	V3	V4	V5	Exinite	Resinite	Semifusinite	Total
Reactives	10.4	36.5	18.2	5.3	2.6	0.6	73.6
	Semifusinite	Micrinite	Fusinite	Pyrite		Clay	Total
Inerts	1.2	3.2	0.6	2.7		18.7	26.4

Additional drilling would be required to test these localities. Investigations should be conducted first in the Maghara area in order to determine the limits of the deposits known to occur there.

2. Conduct detailed geologic investigation along traverses that transect the exposed coal-bearing sequence.

Although the sequence had been mapped in several areas, it was not until the late 1950's that it was recognized that outcropping thin layers of ash represented oxidized coal beds near the surface. New geologic traverses could result in detection of such layers, and thereby identify areas for exploration by drilling.

3. Consider pipeline transmission of coal slurry from the Safa Mine to Helwan or to El Arish.

Where there are no other commodities to be transported, pipeline transmission provides the cheapest means of transporting coal. Water is probably not present at Maghara in sufficient amounts to permit its wastage at the receiving end of such a line. This problem might be resolved by providing an additional, smaller line to return the water for reuse, or, a pipeline of sufficient diameter to transport coal and return water during alternative periods could be installed.

One problem that can be anticipated if the line is laid on the surface is wearing of the pipe where it is in contact with the land surface. Experience in other areas of large diurnal variation in temperature has shown that excessive wear is caused by movement of the pipe due to expansion and contraction.

3.0 PRESENT KNOWLEDGE OF COAL AND OIL SHALE OCCURRENCE IN EGYPT

3.1 Coal

Coal occurs in rocks ranging in age from early Paleozoic to Cenozoic, in northern Egypt and the Sinai Peninsula. In most areas, the coal occurs at depths greater than 500 m, and knowledge of its presence is based largely on well cuttings, electric logs, and a small number of cores from wells drilled in search for oil.

In the Sinai Peninsula and at a few localities west of the Gulf of Suez, the coal-bearing sequences are exposed or are close to the surface. In these areas, the coal measures have been investigated by geologic mapping, drilling, and tunneling, and information on thickness and distribution of coal seams is reliable. Otherwise, data on coal bed thickness as reported from oil tests, except for that based on observation of cores, are unreliable. The thicknesses ascribed to coal beds on the basis of cutting returns may actually represent thicknesses of interstratified thin layers of coal and carbonaceous shale, the shale having separated from the coal before reaching the surface. Also, coal thicknesses based on interpretations of electric logs are subject to error because the log pattern produced by carbonaceous shale is similar to that for coal.

The thickest coal beds, those with possible economic potential, are of early Carboniferous, Middle Jurassic, and Early Cretaceous Ages. Coal also occurs in rocks of middle and late Carboniferous, Permian, Triassic, Early Jurassic, Later Jurassic, and Tertiary Ages; however, it is found in beds only a few centimeters thick, or as fragments of coalified plant material, and is of no economic importance.

From 1958 to 1962, a program of the Egyptian Geological Survey to explore for coal succeeded in defining coal deposits with small, seemingly economic reserves in the areas of the Maghara anticline, Ayun Musa, and Wadi Thora, all on the Sinai Peninsula. Of the three areas, the Maghara deposit was found to have the greatest potential for economic development, and following a period of exploration and development, the Safa Coal Mine was in the process of being installed at the time of the Israeli invasion of 1967.

The Maghara coal deposit is 150 km northeast of Ismailia on the Gulf of Suez and 70 km southwest of El Arish, a port on the Mediterranean. A railway between the two towns passes within 42 km of the Safa Mine, and an asphalt road connecting the towns is 11 km to the south. The area is surrounded by drifting sand which is encroaching from all directions, particularly from the north and west. Elevations in the area range from about 300 to 600 m above sea level.

The deposit is on the northwest flank of the Maghara anticline. The coal-bearing sequence, 90 to 100 m thick, consists of interbedded sandstone, shale, limestone, and coal of Middle Jurassic Age. The sequence contains as many as 10 coal seams; however, only two, designated the Main Seam and the Upper Seam, are of minable thickness (more than 0.65 m thick). Coal beds dip generally 10° or less, except near faults where they dip as much as 70 degrees.

The coal beds have been explored by adits and by drilling on a grid pattern with a spacing of 400 m between holes in the area of the Safa Mine and a spacing of 1,000 m in adjoining areas. As determined from exploration work, the maximum thickness of the Main Seam is 1.90 m and that of the Upper Seam is 0.80 m.

Coal reserves in beds thicker than 0.65 m have been computed for the Upper and Main Seams by methods using standards comparable to those of the U.S. Geological Survey and are reported as follows:

Gross proved	39,900,000 tons
Probable	<u>11,900,000</u> ton
Total	51,800,000 tons

Workable (recoverable) reserves:

Net proved	27,800,000 tons
Probable	<u>7,800,000</u> tons
Total	35,600,000 tons

The coal is described as dark brown to black with vitreous to semi-vitreous luster, and conchoidal fracture. Average specific gravity is 1.26. It is a long-flame coal which, according to the International Classification System, is type 732. It has been equated with typical American western sub-bituminous, C rank coal.

Table 1 presents results of analyses reported by Powell Duffryn Technical Services, Limited, of London, England.

Samples of Maghara coal were submitted to the U.S. Bureau of Mines for analysis; however, the samples when received were partially dried because they had not been kept in airtight containers. Consequently, relative percentages of constituents cannot be considered accurate; and the Bureau of Mines Analysis Laboratory did not classify the coal according to rank. The results of the analyses are presented in table 2.

The coal has a low coking and sintering capacity. The coking characteristics and yields are indicated by the following:

Roga Index	Grey King type	Maximum Expansion (after Audibert Arnu)	Plastometric Indices	
			X	Y
H7-58%	G	30-38%	54-61mm	10-12m

Recovery from dry coal, in percent:

Coke	Resin	Crude benzol	Coking gas	Water	Ammonia
78-80.6	3.3-4.6	0.96-1	10.4-12.8	1.7-4.4	0.2-9.39

Satisfactory coke can be obtained by mixing 10 to 30 percent Maghara coal with imported coking coal. When mixed with good-quality coking coals, such as those of England, Poland, or Russia, the coke yield drops 0.21 or 0.24 percent per each percent of Maghara coal added.

The coal is composed largely of vitrinite and subordinate amounts of exinite and resinite. The petrographic composition of the Maghara coal is indicated by analyses presented in table 4.

The Upper Seam reportedly will yield 59.24 percent coarse class (greater than 13 mm) coal with 4.92 percent ash and 2.66 percent sulfur. The Main Seam will yield 50.93 percent coarse class coal with 7.34 percent ash and 3.51 percent sulfur.

At the time of the Israeli occupation of the Sinai Peninsula in 1967, the Egyptian Geological Survey had opened a shaft and an adit; an incline was extended 360 m downdip, a drift was driven 160 m along strike on the Main Seam, and an incline was driven 325 m downdip along the Upper Seam. Planned production was 300,000 tons per year by the longwall method. Based on 1964 estimates, cost of producing a ton of coal at this production rate would have been L.E. 4.60. The price of coal of similar quality, C.I.F. Port Said, was estimated at L.E. 8.00.

Actual cost of mine installation was not available; however, an estimate provided by Powell Duffryn Services, Ltd. in 1964 indicated that for a 300,000-ton/yr mine, L.E. 4,061,000 foreign currency and L.E. 4,780,000 local currency would be required.

Because of the limited reserves and unfavorable terrain, construction of a rail system for hauling of coal from the mine was not justified, and the road hauling was proposed, using 16-ton, 4-axle, diesel-powered tipper trucks and 10-ton, 2-axle trailers. This would have required an investment of L.E. 945,000 according to 1966 estimates. At this level, the total cost of delivery/ton of coal to Helwan would have been L.E. 2.70, and the total cost would be L.E. 7.30/ton.

Production of run-of-mine coal was anticipated to be 1,300 tons/day which, after cleaning and removing about 20 percent waste, would yield 1,071 tons/day of clean coal.

According to a 1964 proposal, power at the mine was to be provided by four 200kW-diesel generators; additional power was to be provided by three 400 kW, skid-mounted diesel generators until a steam-powered station could be installed. However, the amount of water needed to operate the station may be inadequate.

No difficulties in mining operations are anticipated from inflow of water which, in June 1967, amounted to 60 m³/day, or about 42 liters (1)/minute. Hydrological investigations in the area indicate the presence of fossil water that could be used for mine operations and for domestic purposes. It is estimated that 600 tons/day of water will be needed to produce 300,000 tons of coal/yr, and 1,000 tons/day will be needed to produce 600,000 tons of coal for mine operations. Neither estimate includes water that would be needed for further development work or for operation of a steam plant.

Early plans to operate the mine specified a labor force of 1,742 miners; however, a 1977 report proposes a more highly mechanized operation that would require 416 fewer miners. This would result, most likely, in lowered production costs.

Coal at Ayun Musa, on the east side of the Gulf of Suez and about 14 km southeast of Suez, occurs at depths ranging from about 400 to 600 m. The deposit was discovered in tests drilled for oil in 1958. Twenty-six exploration wells were subsequently drilled in the area.

The coal occurs in lenticular beds within two stratigraphic zones about 40 m apart. The upper zone is 30 to 35 m thick and contains 10 coal beds ranging in thickness from 5 to 120 cm. The lower zone contains one coal bed that ranges from 5 to 120 cm thick. Analysis of core samples gave the following results: moisture 7.2 to 12 percent, ash 8.9 to 30.8 percent, volatiles 35.7 to 45.6 percent, fixed carbon 24.6 to 36.1 percent, and sulfur 1.3 to 4.9 percent. Calorific value of 1 borehole sample was 8,512 cal/gr.

The coal is within an artesian aquifer in which the pressure is 60 atmospheres (850 psi). Owing to the high rates of flow of water, the lenticularity of the coal beds, and their excessive depths, the coal deposit is not considered economic.

Coal at Wadi Thora, also in the western part of the Sinai Peninsula and 25 km east of the harbor of Abu Zenima, occurs in rocks of Carboniferous Age. The coal-bearing sequence is 0.5 to 18 m thick and is 200 to 300 m stratigraphically above basement rocks; it occurs in a single seam which attains a maximum thickness of 80 cm. Geologic investigations, including drilling to depths of 50 m and exploratory drifts, were conducted along and near the outcrop over a distance of 17 km.

Reserves for a coal bed exceeding 0.65 m in thickness, which has been explored by boreholes in an area of 1.5 km², are estimated to be 1.5 million tons. Reserves for the entire area including proved, measured, indicated, and inferred, are estimated at 60 million tons.

Analysis of 10 samples gave the following values: moisture 2 to 4 percent, ash 25 to 59 percent, volatiles 16 to 28 percent, fixed carbon 22 to 44 percent, and sulfur 0.56 to 9.08 percent. The coal, for the most part, is long flame, high ash, and of low quality.

The deposit has little economic value at present, but might eventually become a source of fuel for fluidized bed combustion when this process is developed to the stage that it becomes commercially economical.

Exploration for coal also has been conducted at Wadi Araba along the western side of the northern Gulf of Suez where Carboniferous sediments are near-surface, and at Kharga Oasis where, based on the interpretation of electric logs, thick coal beds were reported to occur at shallow depths in the Nubian Formation. Boreholes drilled at each of these locations failed to find coal in layers more than a few cm thick.

Coal in the Lower Cretaceous and older rocks of the Western Desert is too deep for mining, and is too thin, too deep, and too remote for underground coal gasification by methods now in use or being developed. A process which is currently being developed in Russia is intended to produce gas from beds as deep as 1,000 m, and experiments are being conducted, or are planned, for gasification of coal at a depth of 1,000 m in the Ruhr region of West Germany and the Netherlands. At these depths, the minimum minable thickness would be about 30 ft.

The cost of pressurizing air or oxygen to be injected into the coal seams at depths below 1,000 m in the Western Desert would probably be prohibitive. Additionally, the gas produced would have low calorific value and at present prices could not be transported economically for distances of more than 100 km.

3.2 Oil Shale

Apparently the Egyptian Geological Survey and/or the Egyptian Petroleum Corporation have not undertaken comprehensive investigations of oil shales. Only one report, a master's thesis by Ghaly (1961), was found that pertains to oil shale (referred to as "carbonaceous shale") in Egypt. Analyses of 51 samples collected from four areas -- (1) the Galala El Bahariya area, (2) the Galala El Qibliya, (3) the Budaa area¹, and (4) the Quseir area -- form the basis of the report. These areas are considered to contain the most resources of oil or "carbonaceous" shale in Egypt. Information on the geology of the oil shale beds in these areas is very sketchy, and no attempt has been made to estimate reserves. The oil shale beds range in thickness from a few centimeters to as much as 350 cm at Galala El Qibliya and are interbedded with sand that presumably is not petroliferous. The Quseir deposit was studied in greatest detail, probably because these shales contain the highest concentrations of tars and volatiles. The oil shale in this area is of Late Cretaceous Age, and is exposed in association with sediments that are mined for phosphate.

The oil shale beds are as much as 0.5 to 1.0 m thick. The shale is described as a hard, banded, gray to black rock that has an oil odor. It contains disseminated carbonaceous matter and foraminifera. Carbon/hydrogen values range from 6.9 to 7.9 and the sulfur content is high. Results of analyses of samples from the three localities are presented in table 5.

The report concludes that the Quseir shale is very low grade fuel that " . . . can be industrialized only under severe conditions of lack of fuels." No information was obtained relative to the occurrence of tar sands, possibly because none occur at or near the surface in Egypt.

¹ "Budaa" is also spelled "Buda" in some references.

TABLE 5

LABORATORY ANALYSIS OF OIL SHALE FROM BUDAA, QUSEIR, AND GALALA
EL QIBLIYA AND GALALA EL BAHARIYA, EGYPT (GHALY 1961)

Locality	Moisture	Ash (Analytical Sample)	Loss of Ignition (Analytical Sample)	Ash (Dried Sample)	Loss of Ignition (Dried Sample)
	%	%	%	%	%
Budaa					
Range	0.78-2.65	73.72-90.20	8.01-24.33	75.20-90.26	8.15-24.80
Average	1.82	82.53	15.55	84.16	15.86
Quseir					
Range	1.42-11.72	67.05-90.60	7.40-31.10	70.73-92.72	7.28-48.65
Average	5.76	79.03	15.2	82.11	17.90
Galala El Qibliya and Galala El Bahariya					
Range	0.40-6.90	47.90-86.80	11.70-46.0	51.01-88.12	11.88-48.99
Average	2.27	74.76	18.44	78.03	18.8

4.0 REFERENCES

- Abdel-Khalek, M. L. Geological Aspects, "Characteristics and Utilization Potential of a Jurassic Coal from Sinai Peninsula, Egypt." *Journal of Geology* 17(1). 1973, pps. 71-84.
- Adindini, A. and Shakhov, R. A. "Generalization of Geologic Data on Hard Minerals, Coal." Pt. 1, Sec. B. *Studies on Some Mineral Deposits in Egypt.* Egyptian Geological Survey, 1970, pps. 67-86.
- Al-Far, D. M. "Geology and Coal Deposits of Gabal El-Maghara (Northern Sinai) U.A.R." Egyptian Geological Survey Paper No. 37, 1966, p.59.
- _____. "On the Occurrence of Coal in Bagal Al-Maghara, No. Sinai." Egyptian Geological Survey, Internal Report, 4 pls, (not dated, probably 1964) p. 114.
- Aman, Hassan, et al. "Study on Modernization of Mining Technology in Safa Coal Mine (Maghara Coal Region in Sinai)." Egyptian Geological Survey, Internal Report, 8 tables, 7 drawings, 1977, p. 22.
- Egyptian Geological Survey, Pt. 1. "A Brief History of the Geological Survey, Pt. 2: Concession Agreement." Egyptian Geological Survey, (not dated), p. 32.
- Ghaly, E. L. General Surveying of Egyptian Carbonaceous (oil) Shales. Cairo University, MSc Thesis, Serial No. 6250, 18/10/77, in files of Egyptian Geological Survey, 1961.
- Kamal, Assa; Fawzi, Esmat; Rizk, Keda; Naseef, Antone; Mahmoud, Kamal; and Mahmoud, Khalafella. "Final Report on Kharga Coal Prospecting Borehole No. 1." Egyptian Geological Survey, Internal Report No. 1, 8 appendices, 7 lists, 5 illustrations, 1970, p. 20.
- Kotb, H.; Ghaly, E. L.; and Awad Allah, M. F. "Chemical Studies on Ayun Musa Coal, U.A.R." Egyptian Geological Survey, paper No. 38, 1966, p. 17.
- Moustafa, G. A. and Yaravoi, M. "Wadi Thora and Wadi Buda, West-Central Sinai, Sinai Peninsula." Geological Report on Calculation of the Coal Reserves. Egyptian Geological Survey, Internal Report, 1961, p. 63.
- Petrasccheck, W. E. and Nakhla, F. M. "Contributions to the Study of Um Bogma Coal, West-Central Sinai." *Journal Geology, U.A.R.* (2): 1966, pps. 81-89.
- Powell Duffryn Technical Services, Limited. "Mining Economic Report on the Ayun Musa Coalfield, United Arab Republic, to the General Organization for the Executing of the Industrial Five-Year Plan." Egyptian Geological Survey, Internal Report, 15 tables, Appendices A-6, 10 pls, 1963, p. 69.

- _____. Maghara Coalfield, Report on the Reserves of Block 'A'. Egyptian Geological Survey, Internal Report, 5 tables, 12 pls, 1964, p. 32.
- _____. Maghara Coal Project, Safa Mine, Project Report on the Planning of the Mine Development and Production Phases. Egyptian Geological Survey, Internal Report, v. I, 55 pls, 1964, p. 127.
- _____. Maghara Coal Project Report on Reserves and Relevant Geology to the General Organization for Industrialization. Egyptian Geological Survey, Internal Report, 75 p., 11 tables, 14 pls, 1966, p. 75.
- _____. Maghara Coal Project, Safa Mine, Report on the Transport of Coal Personnel and Materials to the General Organization for Industrialization. Egyptian Geological Survey, Internal Report, Appendices A-G, 7 tables, 14 pls, 1966, p. 64.
- Zavialov, V. D. Recommendations (for) Prospecting in the Northern Part of Sinai. Egyptian Geological Survey, Internal Report, E.R. No. 133, 1960.

C. ASSESSMENT OF URANIUM AND THORIUM RESOURCES IN EGYPT

By: Lincoln R. Page

1.0 SUMMARY AND CONCLUSIONS

No uranium or thorium was being produced in 1978 in Egypt. In the past some thorium was recovered with other minerals from the black sands in the Rosetta area of the Nile delta, and small stockpiles of uranium ore resulted from exploration work at the El Atshan and El Erediya deposits.

Large areas (more than 200,000 km²) of Egypt have been covered by airborne radiometric surveys and more than 7,000 anomalies have been identified. (See figure 1.) Ground radiometric work has established some 50 areas of radioactivity related to uranium or thorium and uranium. Small-scale experimental mining has been carried out at five of these localities and drilling has been done at two. All the main roads and many of the wadi trails have been traversed with car-borne radiometric equipment. The Nuclear Materials Corporation (NMC) and the Remote Sensing Project of the Academy of Science and Technology expect to have a base map of Egypt completed in about 6 months and the anomalies will be compiled on those maps during the next year.

Prospecting, preliminary sampling, and very detailed mapping have been conducted in several areas including Qatrani, El Erediya, El Missikat, and El Atshan areas. Except for the black sands at places along the Mediterranean coast, such as Rosetta, and at places where uranium and/or thorium are associated with niobium and other metals as at Wadi Nugrus, such deposits do not appear important. Extensive sampling and drilling of black sands to a depth of one meter have been done. A small amount of sampling for phosphates in different areas of Egypt indicates that the phosphates between the River Nile and the Red Sea are somewhat higher in uranium content than those in the Western Desert from the River Nile westward to the Kharga-Dakhla Oases and beyond. The phosphate from the first area is more likely to yield worthwhile amounts of by-product uranium than that of the Western Desert.

Geological conditions of sedimentation, structure, and igneous activity in many parts of Egypt appear favorable for finding uranium deposits, but they have not been correlated with the known anomalies. The state of prospecting and exploration is about comparable to that in the United States during the early 1950's; thus, with the proper expenditure of funds and effort, there is a good chance of finding new and significant deposits. This, however, will take at least 10 years. The presently known deposits may contain several thousand tons of uranium; Dr. El Shazly estimates 1,000 tons at El Missikat. In the opinion of the author, the presently known areas that can be expected to develop into uranium mining and milling districts in

Fig. 1. Areas covered by airborne radiometric surveys, Egypt.
(Nuclear Materials Corporation)

the near future are (1) El Missikat - Erediya, (2) El Atshan, and (3) Qatrani, which have been visited by the writer.

Recovery of some uranium from phosphate might be possible, provided the wet treatment of phosphate ores is undertaken to produce triple superphosphate. The total uranium resource in phosphate is on the order of 225,000 tons. Present phosphate production is 500,000 tons. If all the proposed production -- 10,000,000 tons per year -- were attained, and it were all given wet treatment and uranium was recovered, the production of uranium might be 500 to 600 tons per year, based on an average grade of 50 to 60 ppm. At present prices for uranium this might be economically feasible for some fraction of the phosphate ores, particularly those that contain 150 ppm or more.

The black sands on the beaches of the Rosetta and Damietta branches at the mouth of the Nile contain 0.5 to 1.0 percent of monazite. This amounts to about 0.03 percent U_3O_8 and 5 percent ThO_2 . The monazite in the Abu Khashaba area, Rosetta, is estimated to contain 212 tons of U_3O_8 and 35,350 tons of ThO_2 . There may be equivalent amounts in the Damietta area. Economic production of this uranium probably is dependent upon monazite being extracted as a by-product of mining of the black sands for titanium and zirconium and the treatment of monazite for ThO_2 .

2.0 RECOMMENDATIONS

It is the opinion of the writer that Egypt could, by appropriate programs of prospecting, exploration, and development find and produce the uranium needed for the nuclear plants projected for development by the year 2000.

Some elements of such programs are given below:

1. The search for, evaluation of, and production of uranium will require the involvement of all governmental agencies concerned with minerals, fuels, and groundwater. This could be accomplished by the appropriate transfers by NMC of funds to other agencies for specific investigations, or the transfers of personnel from other agencies to NMC for specific investigations.

2. A training program in the geological, geochemical, geophysical, and hydrologic sciences as they pertain to the search for new deposits of uranium. This should be designed to give present personnel additional experience in foreign countries, and to develop and train new personnel in Egypt. Training might be conducted by Egyptians or foreigners.

3. An expanded geologic, geochemical, and geophysical prospecting program to evaluate known anomalies and environments believed to be favorable for the occurrence of uranium.

4. A development exploration program to evaluate the known deposits, particularly those at El Missikat, El Atshan environs, and Qatrani by appropriate diamond drilling, underground workings, and systematic sampling. Underground workings should be made in such a fashion that they could serve as preliminary production workings. Financial matters should be taken into consideration in granting concessions in this area.

5. Addition of modern laboratory and field equipment and training of personnel for employment in support of the field programs.

3.0 INTRODUCTION

Investigations of the uranium and thorium resources of Egypt were the responsibility of the Nuclear Energy Authority until late in 1977 when this part of the nuclear energy program was transferred to the Nuclear Materials Corporation (NMC) with Dr. El Shazly Mohammed El Shazly designated as president. Thus, my visit from March 16 to April 20, 1978 was during a period of reorganization and reorientation of programs. This made it very difficult for the Egyptian counterpart, Dr. El Shazly, to make available much of the information concerning past programs. He did provide access to copies of pertinent published reports (see list of references) and some essential unpublished maps (see list of illustrations) and the limited assay data upon which this report is based. More detailed information on sampling and analytical work undoubtedly exists, as do more detailed maps and reports on the areas discussed below; therefore, this report must be considered incomplete.

The Nuclear Materials Corporation is the agency under the Ministry of Electricity and Energy responsible for finding, exploring, mining, and milling uranium and thorium and other nuclear materials. The Corporation comprises 350 persons including about 70 professionals. The development of the new program is continuing, but details are not available at this time; however, some parts pertinent to the resource picture were discussed in general terms.

One very important part of the revised program involves the production of a geologic base map, using satellite imagery, upon which all known radioactive anomalies and occurrences of radioactive minerals will be plotted. The base map is scheduled for completion within about 6 months, and the plotting of data should be completed in a year under present funding. This map will be used as a basis for planning field projects. Dr. El Shazly also plans as soon as possible to divide the country into four districts, each with a local office responsible for all field operations. At the moment these would be concerned with

geologic and exploration programs and would be under a central office in Cairo. There is much to be done in developing laboratory and other support activities for geologists as well as for prospecting and exploration personnel. Mining and milling capabilities will have to be developed when significant economic reserves are developed as a result of the exploration programs.

Activities. Dr. El Shazly was the primary contact for obtaining information on the uranium and thorium resources of Egypt. Secondary sources of information and work space were provided at the Egyptian Geological Survey and Mining Authority (GSE), and by S.H.A. Bau and Peter Simpson of the United Kingdom Geological Institute, London.

Dr. El Shazly made available during our second meeting the published references on uranium, listed below. In subsequent meetings, he discussed each of the major uranium districts--Qatrani, Gebel El Missikat, El Erediya, and El Atshan. At these meetings his field geologists--Hassan Samir Assaf, Morsy Ahmed Morsy, Dr. Ibrahim A. El Kassas, Mohammed A. El Ghawaby, Fawzy Siha Bakhit, and others explained in detail the geology of areas each has mapped. Dr. El Shazly also arranged field trips to the above areas, guided by the geologists responsible for the field mapping.

The Remote Sensing Project (ASRT), headed by M.A. Abdel Hady at the Academy of Science and Technology, is considered by Dr. El Shazly to be an integral part of his program, and several of his men are detailed to the project. One day was spent visiting these facilities. M. A. El Ghawaby (NMC-ASRT) made available the publications listed later in this report. In addition to contacts within NMC, Dr. El Shazly arranged meetings with members of outside organizations, such as Ramzy El Adl of Transworld Petroleum.

Field trips were made to Helwan, April 1; Qatrani, April 2; and Gebel El Missikat, El Erediya, and El Atshan, April 4-7.

Dr. M. F. El Ramly, of the Egyptian Geological Survey and Mining Authority, furnished a number of reports on the regional geology of the Eastern Desert together with maps of the basement in both the Eastern and Western Deserts. He provided a copy of a draft report on ages of ring structures and discussed at length the uranium and thorium minerals in these bodies. Dr. Hermina (GSE) discussed the phosphate deposits and furnished data from an unpublished manuscript on reserves and phosphate content. He also arranged for the purchase of published reports.

4.0 URANIUM DEPOSITS

Uranium occurs in a number of places in Egypt; it is commonly associated with niobium, thorium, and other metals in refractory minerals from which it is difficult to recover uranium economically. Uranium minerals, such as pitchblende and the secondary silicates,

vandates, and phosphates that may be economic, are known in a few areas. Three of these areas were visited and are believed to be the most favorable possible sources of significant amounts of this metal. Many other areas appear to have geologic characteristics favorable for finding additional deposits, and these are discussed below under "Suggestions for Prospecting."

4.1 Gebel El Missikat-El Erediya Area

The Gebel El Missikat-El Erediya area is within the limits of longitude $33^{\circ}15'$ and $33^{\circ}40'$ E., and latitude $26^{\circ}07'$ and $26^{\circ}40'$ N. Two districts, El Missikat, centered at about longitude $33^{\circ}21'$ E., and latitude $26^{\circ}29'$ N., and El Erediya, centered at about longitude $33^{\circ}28'$ E., and latitude $26^{\circ}20'$ N., appear to be the most favorable parts of the area for further exploration.

Both of these districts are in the same mass of red and pink granite designated as the main member of the "Late Orogenic Plutonites." The granites are cut by younger mafic and trachytic dikes of the "Post-Orogenic Volcanics."

The entire area is intersected by a large northwest-trending fault, and both uranium districts are crossed by smaller faults subparallel to this larger structure as well as by others with more northerly and easterly trends. The younger mafic dikes follow the northwesterly and northerly trends, as do the uraniferous veins at El Erediya. The veins at El Missikat trend northeast to easterly, as do the faults in the anomalous areas of the Gebel Kab Amiri granite east of Erediya. Detailed structural analysis of the entire area is needed to understand which structures are most favorable for finding minable deposits. One thing seems to be clear--granite is the best host rock in this structural environment; granitized metavolcanics of "The Main Geosynclinal Volcanics" appear to be the second best host.

The El Missikat district contains nine northeast trending cherty quartz veins in an area about 2 by 6 km. Secondary uranium minerals are visible in at least three places, associated with the primary minerals fluorite, galena, hematite, and quartz. Numerous sections of the veins show radioactivity greater than 100 milliroentgens per hour (mR/h).

The main vein is on the contact of diorite and pink granite where it trends more easterly; the other veins are in the granite. This main vein is 4 km long and radioactivity anomalies occur along 2.2 km of strike length. At its eastern end two splits continue to trend east, one being 3.5 km long with three anomalies.

Eight other veins are parallel to and southeast of the main vein. Each is as much as 2.5 km long and within 2 km of the main vein. The largest of these veins, 1 km southeast of the main vein, is 2.5 km long and has two uranium-bearing areas. The strike length and extent of each anomaly is summarized on the next page.

Vein	Length of radioactivity anomaly (km)	Total vein length (km)	Comments
Main vein	2.2	4.0	Uranium minerals
1st split	3.5	3.5	
2nd split	1.0	1.0	
1st parallel vein	1.5	2.0	Uranium minerals
2nd parallel, easterly split and extension	1.5	2.5	
3rd parallel	---	1.6	
4th parallel	1.3	2.8	One anomaly
5th parallel	---	1.3	
6th parallel	---	1.5	
7th parallel	0.3	1.3	One anomaly (2 km from main vein)
8th parallel	---	0.9	
	11.3 km	22.4 km	

Therefore, there are more than 11 km of veins with anomalies and approximately 11 additional kilometers that warrant detailed exploration.

The only available data on grade was furnished orally by Fawzy Sika Bakhit, one of the geologists who mapped this area. He stated that the main vein ranges from 0.01 to 0.20 percent uranium over a 4 m thickness. The richer samples were probably from areas containing uranium minerals. Specific thicknesses or average thicknesses are not available; exposures that were seen suggest that 1 to 2 m would be average. Nevertheless, sufficient potential tonnage is indicated by exposures up to 200 m above wadi level to warrant underground exploration of this district. The smaller anomalous area in Wadi Gerra, which was not visited, about 6 km southeast of the main vein, is on a parallel structure. A larger area, 10 km farther southeast, is on a northwest-trending fault which continues into the El Erediya district.

The El Erediya district is about 20 km long and 5 km wide. The main anomalies are parallel to a large northwest-trending fault. They probably are aligned along subsidiary north-trending structures, as is one vein which has been explored. The exploration consisted of a 200 m inclined adit which followed the main vein only for a few tens of meters. Pitch-blende and uranophane have been identified as the ore minerals which are included in siliceous hematitic gangue. The vein is about 1 km long and 2 to 4 m wide, and is not so continuous as the vein at Missikat. About 50 tons of ore with a grade of ± 0.25 percent U_3O_8 is stockpiled. This vein needs more exploratory work to prove tonnage and grade.

Two other areas in the El Erediya district appear more favorable for finding ore. One anomalous zone, 0.5 km wide, extends for 4 km parallel to a northwest-trending fault. This area is southwest of El Erediya; however, a second anomaly, 3 to 5 km north of El Erediya, does not appear to be associated with a fault. This second anomaly merits more detailed study, as do smaller anomalies to the northwest. The Wadi Kab Amiri granite area also appears to warrant more exploration. The combined strike lengths of favorable structures in the El Erediya district are only half as long as those for El Missikat, but El Erediya should be explored in greater detail.

4.2 El Atshan area

The El Atshan area (figure 2) is west of Quseir in the Wadi Kereim-Wadi El Dabbah area, between longitude $33^{\circ}58'$ and $34^{\circ}20'$ E., and latitude $26^{\circ}00'$ and $25^{\circ}40'$ N. Swarms of bostonite dikes of the "Post-Orogenic Volcanics" forming a ring pattern are intruded into metamorphosed shale, sandstone, and conglomerate of "Geosynclinal Sedimentary and Volcanic Rocks" and "Postgeosynclinal Sediments." The ring is about 25 km in diameter and is crossed by northwest- and north-trending faults and fractures. Uranium occurs where these fractures cut the contacts of the bostonite dikes. Anomalous radioactivity is present in zones which extend for about 25 km. To the south, anomalies are also recorded in red and pink granite ("Late Orogenic Granites"), and in the northeast part of the El Atshan area, Cretaceous (phosphatic) sedimentary rocks are exposed in a graben between northwest-trending faults.

The uranium minerals, where exposed in trenches and short adits made during the Yugoslav cooperative program, and sooty pitchblende are yellow secondary minerals. Those observed coat fractures stained with limonite do not show an association with primary minerals. This suggests that the original site of deposition was below the water table and perhaps at some distance. This area should be restudied to see if some of the northwest- and north-trending faults are the sites of primary veins, which could be present where wall rocks are competent to maintain open fractures. The graben of Cretaceous rocks should also be studied to see if uranium has been introduced into sandstones or the phosphate horizons.

There seem to be sufficient shows of uranium in the El Atshan area to warrant considerably more exploration.

4.3 Qatrani Area

The Qatrani is in the Western Desert, about 80 km west and south of Cairo, and northeast of Faiyum. The area known to contain radiometric anomalies is about 10 by 50 km, but similar rocks occur eastward to the Gulf of Suez, according to Dr. El Shazly. The part of the area that has been mapped in detail is between longitude $30^{\circ}35'$ and $30^{\circ}50'$ E., and latitude $29^{\circ}35'$ and $28^{\circ}00'$ N.

FIGURE 2. GEOLOGIC MAP, EL ATSHAN DISTRICT, WADI KAREIM-WADI EL DABBAH AREA, EASTERN DESERT, EGYPT (NUCLEAR MATERIALS CORPORATION)

The uranium found to date is in thin crossbedded sandstone and shale. Many of the radioactive anomalies appear to be associated with silicified fault zones and silicified logs. The highest grade samples are said to contain about 0.05 percent U_3O_8 . In places the gray silicified areas contain hematite that may be of primary origin and related to introduced uranium. Basalt flows (or sills) occur near the uraniferous zone.

Very small shallow trenches have been dug on a few anomalies; but no assay maps were available to check the grade of samples from these pits. It seems quite possible that exploration by drilling would reveal ore bodies. The problem is largely one of finding sandstone beds in the right structural position that are thick enough to form ore bodies. This will require mapping the sandstone units to select targets for drilling. The widespread introduction of small amounts of uranium in these less favorable rocks suggests that larger deposits may be present in other parts of the stratigraphic section.

The country rocks are of Oligocene Age, therefore any ores that may have been introduced will be Oligocene or younger.

5.0 PHOSPHATE DEPOSITS

Uranium is commonly contained in marine phosphate ores, either as a precipitate from sea water during deposition of the phosphate or else introduced by groundwater at a later stage. According to James Cathcart, U.S. Geological Survey (oral communication), most marine phosphates contain 0.005 to 0.01 percent U_3O_8 , unless they have been altered. Phosphate ores are abundant in Egypt; consequently, they are of interest as potential sources of uranium. Table 1 gives the known reserves (after Hermina, 1974, and unpublished data, 1978) as 448,900,000 tons of exploitable reserves containing 20 to 27.5 percent P_2O_5 and probable reserves, based on geologic evidence, of 3,290,000,000 tons of the same grade.

The largest known reserve is Abu Tartur where, according to El Shazly (oral communication), the uranium content is about .005 percent. A few uranium analyses by Wassaf et al. (table 13a, p. 95, 1973) give the grade as 0.012 to 0.014 percent; however, semiquantitative spectral analyses show 0.0001 to 0.0008 percent uranium.

The deposits east of the Nile, according to El Shazly (oral communication), range from .005 to .030 percent and average .010 percent uranium. Estimates of phosphate reserves on both sides of the Nile between Idfu and Qena have been made by Moharram et al. (1970) and Ghanem et al. (1968); Hermina has incorporated these in his tabulation.

TABLE 1

PHOSPHATE RESERVES OF EGYPT¹
(AFTER HERMINA, 1974)

Region	Reserves (millions of tons)		Thickness (in meters)		Grade (percent P_2O_5)	
	Exploitable	Geologic	Range	Average	As mined	Upgraded
Quseir-Safaga ²	71.4	302	0.6-1.2	-	23-27.5	33.5
Kharga-Dakhla:						
Kharga	40.0	-	-	-	21-23	-
Dakhla	-	500	0.2-0.75	-	21	-
Abu Tartur	504 ³	988	1-6	4	25.6 27.0	31.5
Idfu-Qena	237.5	1500	0.5-1.0	-	20-25	29-32
El Mahamid ⁴ production	0.280	-	-	-	27.5	28-30

¹ The total exploitable and geologic reserves of 3,738.9 million tons of phosphate rock at 0.006 percent U_3O_8 (assumed average) would give a U_3O_8 resource of 224,340 tons. Present production is about 500,000 tons of phosphate rock. At 0.006 percent U_3O_8 , this would yield about 30 tons of U_3O_8 per year, provided it was recovered in the wet method production of triple superphosphate.

² Development project at Hemrawein deposits aims to produce 1.2 million tons/yr, averaging 22.6 percent P_2O_5 and 600,000 tons after upgrading.

³ Planned operation of 10 million tons of ore would give 7 million tons/yr, averaging 22.6 percent P_2O_5 and 600,000 tons after upgrading.

⁴ Simple superphosphate, 15 to 16 percent P_2O_5 .

The only map and assay data that were available for study and analysis by the writer depict the East Luxor area. Here the phosphate beds form two belts trending about northwest. The southeast border of the main, or western belt, is a large fault which forms the northeastern boundary of a fault zone as much as 10 km wide. The eastern phosphate belt is within this zone and terminates to the northwest, as does the fault zone. Near the termination a north-trending fault cuts both belts.

Analyses of the phosphate zones in the phosphate middle member, near the intersection of the two faults appear to have eU values higher than 0.02 or higher than normal phosphate rock. Analyses of 0.015 percent or less eU in section nos. 1, 8, 9, 13, 15, all from the northern belt, appear more normal. Analyses of eU from the eastern belt in the fault zone, are like those at the intersections of the faults, > 0.02 eU. The phosphate units below the main phosphate zone are abnormally radioactive; other similar zones are normal. The assays of 0.015 percent eU match radioactivities that are lower than expected, thus suggesting that uranium has been added.

The upper phosphate member samples are mainly in the 0.005 to 0.01 percent eU range, although some are in the 0.01 to 0.015 percent range. The radioactivity of these units is as high as that for many of the higher grade zones in the middle phosphate member, especially in holes 1, 3, 4, 5, 6, 8, and 9. Hole 2 does not cut this unit. The lower phosphate member has high radioactivity only in sections 2 and 4, where the radioactivity appears to match the few eU assays.

In detail there seems to be little relation between P_2O_5 content, eU, and radioactivity. This irregular distribution of eU in respect to radioactivity and P_2O_5 , and its relation to faults suggests that uranium was added to the original uraniferous massive phosphates after faulting. An igneous dike, associated with one of the faults near the north end of the fault zone, indicates the possibility of an igneous source for this younger uranium. If further study should substantiate this suggestion, then the underlying sandstone should be favorable prospecting ground for uranium deposits.

At Abu Tartur in the Western Desert, the contact of the Nubian Sandstone and phosphate-bearing Maestrichtian rocks should be a good target for finding uranium deposits, particularly where it is faulted or folded. Any structure that would trap gas (H_2S) would be especially favorable because the H_2S would precipitate uranium derived from an igneous source or from leaching of phosphate from waters moving through the sandstones.

6.0 BLACK SANDS

Thorium-bearing black sands of the Mediterranean coast were described by Higazy and Naqib (1958) as extending 250 km along the northern beaches of the Nile Delta. They recognize two types of deposits: (1) "concentrated ore" sands, containing 70 to 90 percent heavy minerals, in bands as much as 10 km long, a few meters wide, and about 10 cm (rarely 50 cm) thick; and (2) "diluted ore" sands containing as much as 40 percent heavy minerals, but which average about 15 percent.

The greatest concentrations of heavy minerals are near the mouths of the two principal branches of the Nile, the Rosetta and the Damietta. The Rosetta branch area has received the most attention. Carborne traverses with Geiger-Muller counters were made 250 km along the beaches without finding concentrations of radioactive minerals within the black sands themselves. However, airborne radiometric surveys flown at 50 feet did identify radioactivity associated with the black sands. A concentrate of the black sands contained ilmenite (55 percent), magnetite (15 to 20 percent), zircon (7 to 8 percent), garnet (4 to 6 percent), rutile (1.5 percent), and monazite (0.5 to 1 percent). The monazite contains 0.03 percent U_3O_8 and 5 percent ThO_2 . About 90 percent of the concentrate was less than 100 mesh.

A study was made to see how much of the black sands could be collected each year. It was estimated that 30,000 tons of "concentrated ore" could be recovered annually from each of the two branches of the Nile. The concentrate would contain 300 to 600 tons of monazite.

The "diluted ore" was sampled to a depth of 50 cm with churn water jet drilling at 1 km intervals and was found to contain at least 5 percent heavy minerals. The upper 1 meter was sampled over a distance of 4.9 km and found to contain 1,700,000 tons of heavy minerals with 13,000 tons of monazite. Higazy and Naquib (1958) estimate that the 25 million tons of ore containing 200,000 tons of monazite could probably be mined profitably. This would be equivalent to 600 tons of U_3O_8 and 10,000 tons of ThO_2 , if the average grade is 0.03 and 5 percent, respectively.

The area 5 km north of Rosetta was explored in 1963 by the Egyptian Black Sand Company with 10 scout boreholes in an area of 8 km², and 44 more holes on a 200-m grid around scout hole No. 9 (Kamel, et al. 1973). Borehole No. 9 showed 12.22 percent of economic minerals to a depth of 20 m. The surrounding boreholes were sampled at every meter; careful analyses gave weighted averages of 3.27 percent economic minerals over an area of 20 m, and 3.78 percent over 12 m.

Earlier, the Geological Survey of Egypt had drilled 44 holes in the vicinity of scout hole No. 7 and had gotten an average of 6.62 percent economic minerals to 20 m depth. Assuming uniformity in composition and thickness, the reserves were calculated as 7,500,000 tons of economic minerals for the upper 12 m over 8 km².

In 1973, a study of the eastern part of the East Side Nile section, Abu Khashaba area, at Rosetta was made by Kamel (Kamel, et al. 1973). Using petrographic and chemical analyses of 204 samples from 18 boreholes, he estimated the reserves of total economic minerals in the black sands in the Abu Khashaba area to be 707,000 tons containing 280,000 tons of ilmenite. The upper 5 m of the sampled area contains 65 percent ilmenite and 60 percent of economic minerals. The sand is very fine; 77 percent is minus 100 mesh. Using these latest figures -- 707,000 tons of economic minerals and Higazy's analyses -- yields 212.1 tons of U_3O_8 and 35,350 tons of ThO_2 in this area.

In 1956, C. F. Davidson and S. H. U. Bowie of the United Kingdom Geological Survey estimated the reserves to be "several hundred of tons of U_3O_8 and several thousands of tons of ThO_2 " (oral communication from Bowie, 1978). The new data of Kamel et al. suggests that this figure is too low.

Thorium has been found in association with uranium in several radioactive occurrences in Egypt. The presence of monazite in the black-sand deposits of the Mediterranean Sea coast precludes the exploitation of thorium there except as a by-product of uranium exploitation.

Monazite constitutes about 1 percent of the potentially economic minerals of the black sands of the Mediterranean Sea coast. The programme of the Nuclear Materials Corporation regarding the black sands has achieved the evaluation of the reasonably assured resources of the potentially economic minerals in the top meter of the black sand deposits in the Mediterranean Sea coast and inferred their possible additional resources to the depth of 20 meters. It has also devised a pilot plant for separating the potentially economic minerals and monazite.

The content of potentially economic minerals in the black sands ranges widely. Excluding the low grade sands, the mean content of these minerals is 15 percent. Of these, monazite makes up 1 percent and it is associated with ilmenite, magnetite, garnet, zircon and rutile. For large-scale exploitation of the black sand deposits, it is necessary to separate the potentially economic minerals and utilize them in a large industrial complex. However, small-scale separation of monazite, zircon and rutile from the rich segments of the black sands is considered as a reasonable alternative by the Nuclear Materials Corporation.

Monazite from the black sands contains 5.2 percent thorium and 0.38 percent uranium. The reasonably assured resources of Th and U in the top meter of the black sands are 14,700 tons and 1,070 tons respectively, whereas the estimated additional resources are 280,000 tons and 20,000 tons respectively. These thorium and uranium resources are found in 283 thousand tons of reasonably assured resources of monazite and 5.4 million tons of estimated additional resources (El Shazly, 1965, etc.).

7.0 SUGGESTIONS FOR PROSPECTING

7.1 Oil Wells

The stratigraphic section of the Ras Gharib oil field, Gulf of Suez, (Ramzy El Adl, personal communication, 1978) indicates possible rocks and structures favorable for accumulation of uranium. These features are (a) the clastic base of the Miocene which is draped over Miocene reef limestone, unconformably overlying Cretaceous shales and

Nubian Sandstone that subcrop against the unconformity; (b) porous layers of dipping Nubian Sandstone cut by pre-Miocene gravity faults which probably represent tensional breaks adjacent to the main Gulf of Suez graben faults; the Gulf of Suez faults trend north-northeast and dip northeast. Any uraniferous solution from below could precipitate in the Cretaceous sandstone along the faults, and also where the faults cut the reef limestone and the clastic Miocene. Sulfide in natural gas would be an excellent precipitant, and structural traps would be good targets for exploration.

According to Ramzy El Adl (personal communication), well log data from the Morgan Field well No. 48 (situated offshore in the Gulf) shows abnormally high radioactivity at the tip of the Miocene clastic sequence which is higher than the radioactivity of the normal feldspathic sandstone. The basement rocks were not cut in this well, but in other areas the basement is granite or mafic igneous rocks.

The Gindry Basin at Fiume, near Kirket Qarum, west of Cairo, is a sedimentary basin cut by mafic intrusions, identified by Razy El Adi (personal communication) as basalts similar to those exposed east of Cairo. At Rabata to the southwest, similar mafic rocks were cut by oil wells from sills 60 to 80 feet thick. The basalts may be Oligocene, but some geologists consider them to be pre-Paleocene.

The Abu Garadig oil field, which has a high thermal gradient, lies east of the northwest-trending Gindry Field, and trends east. One well in this field intersected 2 to 3 feet of an abnormally radioactive shale or coaly bed just above the productive oil zone.

In the Umbarka oil field, near the northwest corner of Egypt, Paleozoic rocks are cut by the wells in which some parts of this Paleozoic section show high gamma counts. This area also has a high thermal gradient.

The petroliferous areas, particularly Gindry basin and Abu Garadig, appear to be favorable for finding primary (as well as secondary) uranium minerals. El Shazly mentions occurrences of radioactive minerals to the west of Cairo in this general area.

7.2 Igneous Rocks

Many igneous rocks in Egypt have been identified as being more radioactive than the average igneous rock. Most of these rocks are in apogranites and in the ring dike complexes. Based on experiences in other parts of the world, it is doubtful that any of these will be sufficiently rich in uranium or thorium to be considered as ores. Thorium commonly is more abundant than uranium. Both elements in these rocks are in complex refractory minerals that require special metallurgical treatment for recovering the radioactive elements.

7.2.1 Apogranites: Radioactive apogranites have been described in the Eastern Desert by the Egyptian Geological Survey (1973). They have been

found at Abu Dabbab (Nb, Ta, Sn), Nuweibi, Hums Waggot (2-mica granite), Igla, and Sheikh Salam (2-mica granite). Apogranites of the alkaline order are mostly riebeckite-aegirine pegmatites that contain uranium and thorium in minerals such as pyroclorite (hatchettolite), fergusonite, zircon (malakon and cyrtolite), and thorite (Egyptian Geological Survey, 1973, p. 93).

7.2.2 Ring dike complexes: Ring dike complexes are scattered throughout the Eastern Desert south to the Sudan border. (See El Ramly, et al.) Recent isotopic age determinations (Faul, et al. 1978) indicate that the dikes may range from Cambrian to late Tertiary.

An area of about 20,000 km², south of latitude 25° N., was surveyed by airborne radiometric methods. The most intense anomaly was associated with niobium-tantalum at Wadi Abu Rusheid (Egyptian Geological Survey, 1973, p. 110). Radioactive anomalies were recorded in volcanic rocks at Abu Khruq: 600 milliroentgens per hour (uR/h). At the El Naga area the radioactivity was 3,000 uR/h (equivalent to 510 ppm U) and a ring complex at Nigrub El Fokani containing Nb, Ta, Ni, Be, U, and Y showed 130 ppm U (Egyptian Geological Survey, p. 109).

Anomalies in granite were recorded at Gebel Mueilha (1,000 cps) and at Homrit Mikpid (which contains Sn and Be). A felsite dike at Umm Dowda contains uranium as does Abu Khruq and El Gisera. The El Gisera area revealed 1,000 ppm U on a fault plane associated with a ring dike. The granitic ring dike at Umm Doweilha, which yielded a radioactive anomaly of 800 cps (600 ppm U), is 2 to 10 m thick and several miles long (Egyptian Geological Survey, p. 113). This dike is probably the most favorable target in this region.

The psammitic gneiss at Wadi Rusheid is described by Hashad and Hassan (1959), Hassan (1964, 1972) Hassan et al. (1973), and by El Shazly and Hassan (1959). This radioactive deposit, according to Hassan et al. (1973), is associated with metasomatically affected parts of the psammitic gneiss unit at the contact with schist. The contact is marked by clots of grayish and black mica, criss-crossed actinolite crystals, or talc-carbonate rock. Veins and mica clots contain beryl. Similar relationships characterize the beryl deposits elsewhere in the Eastern Desert. The psammitic unit has been hematized and silicified and contains introduced fluorite, pyrite, arsenopyrite, and chalcopyrite. Zircon, thorite, and columbite, as well as other minerals in the unit are probably primary, not introduced. Secondary uranium minerals occur around metamict thorite in the most altered unit. The metasomatically introduced minerals, plus the distribution of the radioactivity, suggest that uranium might also have been, in part, introduced. If so, the area needs re-examination to look for uraniferous veins associated with favorable structures. The exploration of this deposit was extensive, but it tested only the occurrence of primary minerals in what is probably an intrusive pegmatite.

7.3 Wadi Sodmein, Fawakhir, and Wadi Um Gheig areas

Southwest of Quseir, structural trends in three areas, totalling 5100 km², on the Red Sea designated as Wadi Sodmein, Fawakhir, and

Wadi Um Gheig, have been flown with fixed-wing aircraft equipped with a scintillo-meter PBC-1, recorder, altimeter, and 35-mm camera. The scintillometer has a sensitivity of 190 impulses/second/1 uR/hour. The survey was carried out at a height of 70 m with 1000 m spacing of flight lines. Radioactivity profiles and isorad gamma radioactivity maps were made at 1:1,000,000 scale and matched against geologic maps (El Shazly, et al. p. 40, 1968).

Background values were determined for all the rocks in the area, ranging from Precambrian I (upper Proterozoic) to Quaternary. What appear to be anomalously high values for the rock types recorded in this area suggest that some parts of the formations may have had uranium introduced. Therefore, areas that deserve priority in a prospecting program are:

1. Amphibolites west and east of Gebel Um Naqqat (El Shazly et al. 1968, 42). Three areas, where the range is 563 to 1665 cps, (7.8 to 23 ppm eU) are said to be the result of mixing volcanics with granites. This interpretation may be questionable, as the range for granites normally is 12 to 26.3 ppm eU and the range for volcanics is 121 to 365 cps or 1.6 to 5.1 ppm eU. The 23-ppm area may include introduced uranium.
2. A silicified zone (El Shazly, 1968, p. 44) in "post-geosynclinal sediments" has a count of 1300 cps, and associated sediments (conglomerate, sandstone and mudstone) show as much as 827 cps or 11.5 ppm. This suggests that the silicification may be related to introduced uranium, and the area (not identified) should be checked. Perhaps this is the Wadi El Quash-Wadi Zeidum area and this could be similar to uraniferous areas in Texas.
3. Gebel Um Bisilla area. The total gamma count increases toward the center of the plutons and is anomalous in this respect. Perhaps this area is worth further study as some of the granites record as high as 26.3 ppm eU. These are possibly "two mica granite" deposits, as suggested by the French.
4. "Post-Orogenic volcanics." These are mostly dikes of "intermediate, alkaline, to sub-alkaline, and mafic" of "early Paleozoic Age." The mean of the radioactivity readings ranged from 3800 to 8056 cps. In one area two groups of readings ranged from about 800 to 10,000 cps, and averaged about 5,000 cps; another group ranged from 2,000 to 20,000 cps, and averaged about 8,000 cps. As El Atshan contains introduced uranium in a similar dike and the 0.005 percent to 0.027 percent eU range for some of these dikes is very abnormal for any ordinary igneous rock, it would appear that each dike of more than 1,000 cps, or about 0.002 percent eU might have introduced uranium and should be checked.
5. Gebel Qeif El Igul (Nubian Sandstone) "third detrital sediments." The highest radioactivity recorded is in sandstone with hematitic color and with an abnormal mudstone content. The mean of 490-1012 cps, 6.8 to 14.1 ppm eU, is abnormal for sandstone and the presence of hematite suggests introduction of uranium. This area should be examined.

6. Northern part of Miocene-Pliocene area of detrital calcareous sediments. As in 5 above, an anomaly recording 796 cps (11.1 pm eU) and the presence of hematite suggests an area that should be explored.

8.0 PRECAMBRIAN

Many of the world's uranium deposits occur in (1) Precambrian rocks, commonly below, but associated in space with, the Proterozoic-Archean unconformity; and (2) as concentrations introduced into Proterozoic rocks during an orogenic period at the end of Precambrian time. The oldest Precambrian rocks in Egypt are Proterozoic in age, plus or minus 1195 million years (El Shazly et al. 1973), and hence above the unconformity. Thus, one can assume that the Precambrian rocks of Egypt are most likely to be hosts for uranium that has been introduced near the end of the Precambrian.

The oldest geosynclinal sediment--"First Basement Sediments"--in the southern Eastern Desert (Wadi Abu Swayel Group) include psammatic, pelitic, and calcareous facies interlayed with volcanics and intruded by "First Basement Plutonites." In the central Eastern Desert, following a period of erosion, the youngest parts of the "First Basement Sediments" were deposited as conglomerates containing pebbles of the "First Basement Plutonites."

Therefore, because unconformities and conglomerates are favorable sites for uranium deposits, sedimentary rocks of the Wadi el Muweilik Formation here and at Gebel Atud, 100 km to the southeast, should be prospected. Because leaching of volcanics and granite can produce uranium deposits at the edges of sedimentary basins, this is a favorable environment. The presence of intrusive rocks ranging from ultramafic to felsic within the "First Basement Sediments" suggests that uranium would have been added as a normal igneous component, in the form of vein-type deposits, along early structures similar to those hosting the polymetallic deposit at Umm Samiuki.

The most favorable areas of Precambrian rocks would be those sedimentary, volcanic, or igneous rocks that are cut by late faults and associated dike rocks (as at El Atshan). The "First and Second Basement Plutonites" are considered by the writer to be part of the igneous magma series, but the "Second Basement Volcanics" represent a later magma series that also could have introduced uranium into these Precambrian rocks at about 650 million years. Because these volcanics have alkalic affinities, this magma series would appear to be a more favorable source of uranium. In addition, areas of "Second Basement Sediments" would also be likely hosts for this later generation of uranium mineralization. It is suggested that some of the pink granites of the "Fourth Basement Plutonites", "Third Basement Plutonites" and "Late Orogenic Plutonites" of Precambrian Age precede this group of sediments and therefore are potential source rocks for uranium. Rapakivi structure suggests that other igneous rocks are in a magma series that would also yield uranium solutions. Pink granites are hosts in the El Missikat-El Erediya area.

The structure of the Precambrian basement is the key to the distribution of uranium introduced by younger rocks throughout Egypt. El Shazly divides the Precambrian basement into five segments: three are structural highs--the Sinai-Asiatic, Eastern Desert, and El Oweinat segments--and two act as structural lows--the Red Sea and Western Desert segments. The highs have a 40 to 50 km thick crust; the lows are thinner with 30 to 40 km in the Western Desert and 20 to 24 km in the Red Sea segments. He notes that the highs contain orogenic granite; the lows contain "Fourth Basement Plutonites" or post-orogenic granites. It would appear that the Precambrian basement was either folded or faulted into mountain ranges trending north-northwest in late Precambrian time and then eroded to expose the deeper syntectonic and orogenic rocks in the highs, and to preserve the shallower and younger post-orogenic granites in the lows. All these granites are part of the same magma series and were intruded during the same orogeny. Thus, all these rocks had to have been exposed by erosion in late Precambrian-Eocambrian time to form the surface on which Paleozoic sediments were deposited. The irregular basin areas were filled, and at the end of the Paleozoic a horizontal sediment surface had developed. Thus the uplifts at Siwa Oasis, Bahariya Oasis, and Aswan were later events. The structure in the Precambrian areas today is a product of the cross-folding at the end of the Paleozoic time and subsequent faulting.

El Shazly's folding sequence is as follows: (1) E-W to ESE-WNW trends of folds in metamorphic rocks, (2) WNW-ESE to NW-SE trends preceding but not including basal "Second Basement Sediments," and (3) NNE-SSW trends affecting pink granites--"Fourth Basement Plutonites." Hence, the basins filled by Paleozoic sediments were not folds but were fault-controlled and mark the beginning of NNW faulting in this part of Africa. This faulting had to be early enough in Precambrian time to allow erosion to expose the porphyritic pink granites before deposition of the Cambrian sediments in Sinai. The three sequences of folding also suggest three major divisions of Proterozoic time, separated by orogenies and by erosion intervals prior to the faulting. These old faults could serve as pathways for uranium solutions rising from depth.

9.0 PALEOZOIC

The configuration of the isopachs of Paleozoic sedimentary rocks (El Shazly, 1977), indicates a strong north-northwesterly orientation that reflects the irregular character of the Precambrian basement, because a different east-northeast-trending pattern is shown on the depth map of the top of the Paleozoic (El Shazly, 1977, figure 6) west of the Nile. The north-northwesterly trends are present in the Red Sea and Sinai areas. The east-northeasterly trends in the top of the Paleozoic are also present on the top of basement (El Shazly, 1977, figure 2) and must represent a post-Paleozoic orogeny or folding. The segmentation of these trends on the basement map and the lack of such segmentation on the depth to the Paleozoic map appear to be reflections of the folding of the earlier basins and the Precambrian surface south of Cairo. This folding had little effect on the Paleozoic basins east of the Nile other than to make the basin east of Cairo trend more northerly. The Sinai basins maintained their north-northwesterly trends.

The Paleozoic sedimentary rocks in the southwest corner of the Western Desert are continental, sandy, and contain abundant volcanics. On the Red Sea, the Um Bogma area contains Early Cambrian sedimentary rocks that have unconformities above and below. The overlying Early Carboniferous contains some pinkish sandstone in the upper part where basalt of Jurassic Age separates the Early Carboniferous from Early Cretaceous sedimentary rocks. These pinkish sandstones should be checked for uraniferous deposits.

There are several ages of igneous rocks in the Paleozoic that might be sources of uranium. The volcanism in the Paleozoic produced: (1) andesite dikes of Cambro-Ordovician and Ordovician Ages cutting basement rocks at Um Kroosh, southern Eastern Desert; (2) basalt sheets at the Silurian-Devonian boundary in the subsurface at Siwa Oasis; (3) altered basalt of two ages at the Sharib Well no. 1, Northern Desert that may be Silurian-Devonian or Devonian; (4) late Carboniferous (300 million years) bostonite, olivine basalt, camptonite, trachyte, and nepheline syenite in the Eastern and Western Deserts; and (5) trachyte and bostonite of Permian Age (270 million years and 245 million years). (El Atshan, 273 ± 20 million years.)

Uranium deposits are known to occur in areas of some of these rock types, such as bostonite at El Atshan. Hence, it would seem desirable to check all other similar areas, such as Nash El Qash, Um Shaghir, Gebel Um Kibash, Rabat Well No. 1 in northern Western Desert, Hafafit mine, Wadi Kareen, Um El Khors, and Gebel Mishbeh.

10.0 MESOZOIC

Uranium of Mesozoic age is known at Qatrani and other places, indicating the presence of favorable environments for uranium in the Mesozoic. Some of these are discussed below.

Araif El Naga in the northern Sinai has a Middle Triassic section of crossbedded sandstone. This and the Permo-Triassic section on the east flank of El Galala-El Bahariya Plateau should be checked for sandstone-type deposits. Parts of the Jurassic had continental depositional environments, and like the Triassic should be prospected in areas where the section is cut by younger igneous rocks. The depth map (El Shazly, 1977, figures 4, 9, and 14) for the top of the Masajid Formation (Jurassic) and the Alamein Dolomite (Early Cretaceous) are similar to those of the Paleozoic in terms of trends, but are somewhat more segmented in the northern Western Desert. This suggests reactivation of old faults.

The continental beds of the Cretaceous, particularly the Nubian Sandstone, appear to be favorable host rocks for uranium. The early Cretaceous Malha Formation on the southeastern flanks of El Galala-El Bahariya Plateau and eastward to Sinai contains "violet and pinkish sandstones" in a continental sequence. These colors commonly are associated with uranium mineralization, and these rocks should be studied for that reason. The phosphatic strata of the Late Cretaceous not only appear to contain the normal marine increment of uranium but

also, where subjected to additions introduced by solutions, such deposits as in East Luxor may contain significant amounts of uranium in structurally favorable areas.

The volcanic sources of uraniferous solutions are indicated as (1) alkalic rocks in ring complexes and volcanic plugs of Triassic age (200 to 220 million years) in the Eastern Desert, (2) alkalic olivine basalts as sills, sheets, and dikes at the Triassic-Jurassic boundary (190 to 115 million years), (3) Jurassic and Early Cretaceous rocks in the Sinai, Eastern Desert, and Western Desert, and (4) Late Cretaceous (75-100 million years) volcanics and small intrusions widespread in the Eastern and Western Deserts, such as small granite bodies and veins, alkalic ring complexes, volcanic plugs, alkalic olivine basalt sheets, and lava flows of Wadi Natash type. Such lavas, alkalic basalt, trachyte, and silicic rhyolite are interbedded in the basal Nubian Sandstone in the southern Eastern Desert, but the alkalic ring complexes are outside of the sandstone areas.

Folding at the end of the Cenozoic accentuated the east-northeast-trending folds that started in late Paleozoic time. Minor north-northwest-trending folds seem to be related to faults. By middle Eocene time, most of the northern part of Egypt had a gentle slope to the northeast, and only the Red Sea supported a deep depositional basin of north-northwest trend. Comparison of the Paleocene-Eocene isopach map and the depth map to top of middle Eocene (El Shazly, 1977, figures 18 and 19) show the almost complete filling of all north-and northeast-trending basins.

The continental Oligocene is known to contain uranium at El Qatrani. The area of occurrence is shown on figure 21 of El Shazly (1977), and the stratigraphy is shown in figure 22. The sandstone units of these rocks should be mapped and prospected.

The lagoonal facies of continental deposits, such as in the Miocene of the Western Desert, present another target in areas where igneous rocks are known. In the Western Desert, Shata (1972) reported a pink oolitic (et al. 1975) limestone in the Pliocene lying unconformably on middle Miocene. El Shazly mapped this 5 to 40 km band from west of Wadi El Natrum to the Egyptian-Libyan border. This pink color suggests the possible introduction of uranium. Other possible hosts of uranium are the calcareous tuffas in the Western Desert.

Volcanic activity in the Tertiary started in the Paleocene with intrusion of the nepheline syenite of Gebel Abu Khruq in the south Eastern Desert, and continued with late Eocene and Eocene-Oligocene olivine basalts, and sheets from the south Western Desert. Sheets, flows, and dikes of Oligocene to early Miocene are widely distributed in the Western Desert near the Nile Delta and Valley. Oligocene tholeiitic basalts are known in the Red Sea area.

The Quaternary basalt flows and dikes of St. Johns Island in the Red Sea are comparable to those at the bottom of the Sea ($\pm$ 1.5 million years). Thus, Oligocene and older rocks throughout Egypt, and perhaps younger rocks in the Red Sea area itself, are promising sites for uranium deposits.

11.0 REFERENCES

- Abu Zeid, S. and Abdel Monem, A. A. The Discovery of Uranium-Bearing Quartzitic Veins at Gabel Qatrani Area. Geology and Raw Materials Dept., AEE, Internal Report, Cairo, 1957.
- Annals of the Geologic Survey of Egypt, (III): Cairo, 1973, p. 257.
- Beadwell, H. J. L. The Topography and Geology of Fayum Province, Egyptian Survey Dept., Cairo, 1905.
- Bowen, C. F. and Vondra, C. F. "Paleoenvironmental Interpretations of the Oligocene Gabel El Qatrani Formation, Fayum Depression." Egypt Geological Survey Ann. (4) Cairo, 1974, pps. 115-137.
- El Shazly, E. M. "Classification of Egyptian Mineral Deposits," The U.A.R. Journal Geology, (1) no. 1, 1957, pps. 1-20.
- El Shazly, E. M. Exploration for Mineral Deposits in the U.A.R. U.N. conf. on Application of Science and Technology for the Benefit of the Less Developed Areas, 1962, p. 8.
- El Shazly, E. M. "On the Metallogenic Map of Egypt." International Geology Congress, 22nd, India, 1964, Part V, Proc. Sec. 5, Genetic Problems of Ores, New Delhi, 1968, p. 418-425.
- El Shazly E. M. "Radiometric Methods in Mineral Prospecting: U.A.R. Experience and Wider Application;" Internat. Atomic Energy Agency Conf. on Peaceful Uses of Atomic Energy in Africa, 1970, pps. 170-177.
- El Shazly, E. M.; Abdel Hady, A. M.; El Ghawaky, A. M.; El Kassas, I.A.; Khawasik S. M.; El Shazly, M. M.; and Sanad, S.; Geologic Interpretation of Landsat Satellite Images for West Nile Delta Area, Egypt. Remote Sensing Research Project, Academy of Science Research and Technology, Cairo, 1975.
- El Shazly, E. M.; El Hazik, N. M. T.; Abde Monem, A. A.; Khawasik, S. M.; Zayed, Z. M.; Mustafa, M. E. M.; and Morsi, M. A. Origin of Uranium in Oligocene Qatrani Sediments, Western Desert, Arab Republic of Egypt. Internat. Atomic Energy Agency (Vienna), Peaceful Uses of Atomic Energy in Africa, Formation of Uranium Ore Deposits, 1974, pps. 467-478.
- El Shazly, E. M. and Hassan, M. A. "Geology and Radioactive Mineralization at Wadi Sikait-Wadi Nugrus Area, Eastern Desert." Egypt Jour. Geology, (16) no. 2, 1972.
- El Shazly, E. M.; Hussein, H.A.; Meshref, W.M.; and Assaf, H. S. Exploration for Radioactive Occurrences in Egypt, U.A.R. Internat. Atomic Energy Agency Conf. on Peaceful Uses of Atomic Energy in Africa, 1970, pps. 179-184.

- El Shazly, E. M.; Meshref, W. M.; Fouad, K. M.; Ammar, A. A.; and Meleik, M.L. Aerial Radiometry of El Alamein Oilfield, Egypt, U.A.R. Internat. Atomic Energy Conf. on Peaceful Uses of Atomic Energy in Africa, 1970, pps. 136-143.
- El Shazly, E. M.; Shukri, N. H.; Fouad, K. M.; Ammar, A. A.; and Meleik, M. L. Airborne Radiometry and Regional Geology in the Central Eastern Desert, Egypt, U.A.R. Internat. Geology Cong., 22nd, India, Part V, Proc. Sec. 5, Genetic Problems of Ores, India, 1964, New Delhi, 1968, pps. 37-48.
- Ghanem, M.; Zalata, A.; Razik, T.; Abdel; Said, M.; Mikhailov, I.; Razvaliaev, A.; and Mivtov, 7. Report on the Results of Prospecting and Geological Surveying for Phosphorite in the Area Between the Towns of Idfu and Qena, Nile Valley. Art. 7, Part II, in Moharran et al. 1970.
- Hashad, A. H. and Hassan, M. A. Report on Prospection Work Carried Out in Wadi El Gemal Area, Eastern Desert, Egypt. Internat. Rept. A.E.E., Cairo, U.A.R., 1959.
- Hassan, M. A. Mineralogical and Petrographical Studies of Radioactive Minerals and Rocks in Wadi Sikait-Wadi El Gemal area, Eastern Desert, Egypt. M.Sc. Thesis, Faculty of Science, Cairo Univ., 1964, p. 88.
- Hassan, M.A., "The Occurrence of Columbite Mineralization in Wadi Abu Rusheid, Eastern Desert." Egypt Jour. of Geology, (16): no. 2, 1972.
- Hassan, M.A. "Geology and Geochemistry of Radioactive Columbite-Bearing Psammatic Gneiss of Wadi Abu Rusheid, South-Eastern Desert of Egypt." Egypt Geol. Survey Annals, (III): Internat. Meetings held on the Occasion of the 75th anniversary of the Geological Survey of Egypt. Cairo, Nov. 24-Dec. 1, 1971: 1975, pps 207-226.
- Hermína, M. H. "Preliminary Evaluation of Maghrabi-Liffiya Phosphates, Abu Tartur Area, Western Desert, Egypt." Egypt Geol. Survey Annals, (III): 1973, pps 39-74.
- Higazy, R. A., et al. The Discovery of Uranium Ores in Egypt. U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Proc., Geneva, 1958, pt. 2, 1958, p. 97.
- Higazy, R. A. and Naquib, A. G. A Study of the Egyptian Monazite-Bearing Black Sands. Second U.N. Conf. on Peaceful Uses of Atomic Energy in Africa Proc. Geneva, 1958, pps. 658-662.
- Hussein, H.A.; Faris, M. I.; and Assaf, H. S. "Some Radiometric Investigations at Wadi Kareim-Wadi Dabbah area, Eastern Desert." U.A.R. Jour. Geol. (14): no. 1, 1970, pps. 13-21.
- Hussein, H.A. and Kassas, I. A. "Occurrence of Some Primary Uranium Mineralization at El Atshan Locality, Central Eastern Desert." U.A.R. Jour. Geol. (14): Cairo, 1970, pps. 97-99.

- Kamel, O. A.; Rasmy, A. H.; Khalib, A.; and Bakir, R. "Mineralogic Analysis of Evaluation of Black Sands at Eastern Part of East Side Nile section, Abu Khashaba area, Rosetta, Egypt." Egypt Geo. Survey Annals (III): Cairo, 1973, pps. 227-247.
- Marzouk, I. Rock-Stratigraphy and Oil Potentialities of the Oligocene and Miocene in the Western Desert, U.A.R. Seventh Arab Petrol. Cong. Kuwait, Paper no. 54 (B-3), 1970.
- Moharram, Osman; Gachechiladze, D. Z.; El Ramly, M. F., Ivanov, S.S.; and Amer, A. F. (editors). Studies on Some Mineral Deposits of Egypt. (Summary of the results of work carried out by a team of Egyptian and Soviet geologists under contract no. 1247). Geological Survey, U.A.R. Ministry of Industry, Cairo. 1970.
- Shata, A., "The Pink Pseudo-Oolitic Limestone, a Post-Miocene Rock Unit in Mediterranean Coastal Zone West of the Nile Delta," Egypt Jour. Geol. (16): no. 1, 1972, pps. 1-8.
- Spanderashvilli, G. I. and Mansour, M. "The Egyptian Phosphates." Studies on Some Mineral Deposits of Egypt, p. 11, Sec. C., Art. 6, p. 89-106: U.A.R. Geol. Survey, Ministry of Industry, Cairo, 1970, pps. 89-106.
- Wassaf, A. S.; El Naasan, A.; El Tablawi, A.; Yudin, N. I.; Krylov, D.V.; and Gurov, P. N. On The Results of Geological Exploration at the Abu Tartur Phosphorite Deposit, with calculation of reserve according to Category C. U.S.S.R. Technoexport Contract no. 1988, 1973.

Geological Survey of Egypt:

- E. Ramly, M. F.; Budanov, V. I.; and Hussein, A. A. A. The Alkaline Rocks of Southeastern Egypt. Geological Survey of Egypt, Paper No. 53, 111 p, 1971.
- El Ramly, M. F. Geological Map of the Basement Rocks in the Eastern Desert of Egypt. 1 pt, Cairo, 1972.
- List of Publications, Geological Survey of Egypt, 24 p, 1975.
- Moharram, Osman, et al. Studies on Some Mineral Deposits of Egypt. (Summary of the results of the work carried out by a team of Egyptian and Soviet geologists under contract No. 1247), 1970, p. 260.
- Said, Rushdi; Mikhail, M.F.; Mansour, A. D.; and Elias, A. N. Bibliography of Geology and Related Sciences Concerning Egypt for the Period 1960-1973. The Geological Survey of Egypt and Mining Authority, Cairo, 1975, p. 925.
- Serencsits, C. McC.; El Ramly, M.F.; Faul, Henry; Foland, K. A., and Hussein, A.A. (Unpublished), "Alkaline Ring Complexes in Egypt: Their Ages and Relationship to Tectonic Development of the Red Sea." Geological Survey of Egypt Annals.
- Spanwashvilli, G. I., and Mansour, Mahmoud. "The Egyptian Phosphates." Studies on Some Mineral Deposits of Egypt, Pt. 1, Sec. 6, Art. 6, U.A.R. Geological Survey, Cairo, 1970, pps. 89-106.
- Nuclear Materials Corporation - Remote Sensing Center, ASRT:
- El Shazly, E. M.; Abdel-Hady, M.A.; El Ghawady, M.A.; and El Kassas, I.A., Geologic Interpretation of ERTS-1 Satellite Images for East Aswan Area. Egypt, Proc. Ninth Internat. Symposium on Remote Sensing of Environment. Ann Arbor, Michigan, 1974, pps. 105-119.
- El Shazly, et al. Geological Interpretation of ERTS-1 Satellite Images for West Aswan Area. Egypt, Proc. Ninth Internat. Symposium on Remote Sensing of Environment, 1974, pps. 119-131.
- El Shazly, E. M., et al. (no date), "Geology of Sinai Peninsula from ERTS-1." Satellite Images, Cairo, p. 20.
- El Shazly, et al. Geologic Interpretations of Infrared Thermal Images in East Qatrani Area, Western Desert, Egypt, Cairo, 1974, p. 16.
- El Shazly, et al. Geological and Groundwater Potential Studies of El Ismailia Master Plan Study Area, Cairo, 1975, p. 24.

- El Shazly, et al. "Regional Prospecting for Iron Ores in Bahariya Oasis - El Fayum area, Egypt." Landsat Satellite Images, Cairo, 1976, p. 24.
- El Shazly, et al. "Geology of Kharga-Dakhla Oases Area, Western Desert, Egypt." Landsat-1 Satellite Images, Cairo, 1976, p. 41.
- El Shazly, et al. Geological Investigation of Gebel El Mokattan Area, Cairo, 1976, p. 23.
- El Shazly et al. "Geological Interpretation of Landsat Satellite Images for the Qattara Depression Area, Egypt." NASA Landsat investigation No. GZ 7930 and No. GB 2930, Cairo, 1976, p. 54.
- El Shazly, et al. "Geology and Groundwater Conditions of Tushka Basin Area, Egypt." Landsat Satellite Images, Cairo, 1976, p. 72.

Nuclear Materials Corporation - Geological

- El Shazly, E. M. "Classification of Egyptian Mineral Deposits." The Egyptian Journal of Geology, (I): No. 1, 1975, p. 1-20.
- El Shazly, E. M. Exploration for Mineral Deposits in the U.A.R. U.N. Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas, 1962, p. 8.
- El Shazly, E. M. On the Metallogenic Map of Egypt. Part V, Proc. of Sec. 5, Genetic Problems of Ores, XXII, Internat. Geol. Cong., India, 1964, New Delhi, 1968, pps. 418-425.
- El Shazly, E. M. Radiometric Methods in Mineral Prospecting, U.A.R. Experience and Wider Application, Peaceful Uses of Atomic Energy in Africa, 1970, pps. 170-177.
- El Shazly, E. M. and Hassan, M. A. "Geology and Radioactive Mineralization at Wadi Sikait-Wadi El Gemal Area, Eastern Desert, Egypt." Journal of Geol. (16): No. 2, Cairo, 1972, pps. 201-234.
- El Shazly, E.M.; El Hazik, N. M. T.; et al. Origin of Uranium in Oligocene Qatrani Sediments, Western Desert, Arab Republic of Egypt. International Atomic Energy Agency, Peaceful Uses of Atomic Energy in Africa, formation of uranium ore deposits, Internat. Atomic Energy Comm., Vienna, 1974, pps. 467-478.
- El Shazly, E. M. et al. Exploration for Radioactive Occurrences in Egypt, U.A.R. Peaceful Uses of Atomic Energy in Africa, 1974, pps. 179-184.

D. POSSIBILITIES FOR DEVELOPMENT OF GEOTHERMAL ENERGY IN EGYPT

By: A. R. Zohdy

1.0 SUMMARY AND CONCLUSIONS

The potential is good for development of low-level sources of geothermal energy in Egypt. However, at present there is no evidence to indicate a high temperature (greater than 200°) source of a vapor-dominated system that could generate electrical energy. Discovery of a geothermal source having a temperature of about 150° C is much more likely, and with present-day technology, such a source could be used for the generation of electrical energy by employment of a binary fluid system.

Several water wells and natural springs yield water at temperatures that range between 40° C and 60° C. Water at these temperatures can be used locally for heating homes, greenhouses, and hatcheries, and for providing initial heating energy for industries that require water at near boiling temperatures.

To present (1978), in Egypt, only a few geochemical and regional heat-flow measurements have been made. Detailed geophysical exploration of specific geothermal areas has not begun, and consequently, test drilling has not been done. Therefore, it is unlikely that electrical energy will be produced from a geothermal plant in Egypt in 1985. In general a basic requirement for development of geothermal power plants is the existence of sites affording vast amounts of hot water (temperature greater than 150° C). To date, such sites have not been identified in Egypt. Alternatively, one might hope that it would be feasible, by the year 2000, to use solar energy in conjunction with low- or intermediate-temperature geothermal waters such as are known in Egypt to produce a higher energy system. It is encouraging to know that the Supreme Council on New Energies has submitted a proposal to the Ministry of Electricity and Energy to spend approximately L.E. 3.15 million for geothermal energy over the period 1978-1982.

Most areas of potential geothermal energy are not in the immediate vicinity of Cairo or Alexandria, but are in areas near the Gulf of Suez where new industries or settlements might be founded, thus providing the added benefit of relieving the population pressures in the larger cities.

2.0 RECOMMENDATIONS

2.1 Exploration Methods

It is recommended that continued heat-flow and geotemperature studies such as those already conducted and proposed, including the new cooperative program between the New Mexico State University and the Egyptian Geological Survey, be continued and expanded and that these be augmented by:

1. Deep electrical resistivity surveys including (a) Schlumberger soundings; (b) bipole-dipole total-field surveys; (c) telluric current surveys; (d) self-potential (SP) surveys; (3) audiomagnetotelluric (AMT) soundings; and (f) magnetotelluric (MT) soundings.
2. Seismic refraction, gravity, and aeromagnetic surveys.
3. Drilling of deep test wells.

At present, immediate emphasis should be placed on field surveys of the kinds identified in item 1, (a) through (d).

2.2 Personnel and Equipment

The Egyptian Geological Survey (GSE) and the Desert Institute have personnel who have adequate professional background to conduct deep Schlumberger soundings and SP surveys. Equipment on hand, however, is inadequate except for shallow and intermediate-depth (less than 500 meters) soundings. Most of the equipment now in Egypt is at the Geological Survey.

Equipment and technical knowledge necessary for conducting the deep electrical survey items 1 (b), (c), (e), and (f) above are totally lacking. In addition, modern resistivity and seismic refraction equipment for deep soundings, and programmable pocket calculators and larger programmable desk calculators are needed to support relevant programs.

2.3 Training

Training of Egyptian geophysicists in modern geophysical and geochemical methods of data acquisition, reduction, and interpretation, and in the use of programmable calculators and computers is highly recommended.

To achieve these training objectives, short courses (3-4 weeks) to be conducted in Egypt by visiting experts, and visits (3-4 weeks) to the U.S. by Egyptian scientists for training in electrical resistivity, heat flow, and geothermometry methods are recommended. It is recommended, also, that training in the analysis of possible impacts on environments be provided prior to the initiation of drilling or development projects.

3.0 PRESENT KNOWLEDGE OF GEOTHERMAL CONDITIONS IN EGYPT

Several areas in Egypt present possibilities for the development of geothermal energy uses as evidenced by the presence of warm springs, by moderately high temperatures in deep water wells, and in at least two areas, by evidence of geologically young (Oligocene and Miocene) volcanism. Areas in which these phenomena occur, in order of decreasing importance, are:

1. "Hot" springs on the east and west sides of the Gulf of Suez, and at several oases (see Table 1). The highest temperature reported (El Ramly, 1967) is 75° at Ain Hammam Fara'un;

2. In a belt about 30 km wide along the west coast of the Red Sea, centered Wadi Ghadir ($24^{\circ}49'N.$, $35^{\circ}E.$), heat flows that are four times normal were measured in cooperative studies by the Egyptian Geological Survey and Southern Methodist University;
3. In the Western Desert near Kharga, Dakhla, and Farafra Oases, and near El-Qasr, temperatures near $42^{\circ}C$ were reported in wells that reached depths of about 1,200;
4. In the area east of Cairo (from Cairo to Suez), especially near Gebel El-Ahmar and near El-Angabia, there is evidence of extinct geysers (El Shazly, oral communication);
5. In the Aswan area where the earth's crust is believed to be thin (El Shazly, oral communication);
6. In the Helwan area, where there are mineral springs, but no abnormally warm waters at present, and
7. In the Qatrani area, where there is evidence of extinct hydrothermal activity.

Although no studies aimed directly at exploration for geothermal resources in Egypt have been made, several investigations have provided some knowledge on the potential for their development. El Ramly (1969) presented information on temperatures and volumes of flow from a number of Egypt's hot springs (table 1).

TABLE 1

VOLUMES OF FLOW AND TEMPERATURES OF HOT SPRINGS
OF EGYPT (AFTER EL RAMLY, 1969)

<u>Location</u>	<u>Temperature $^{\circ}C$</u>	<u>Volume m^3 /d</u>	<u>Date</u>
Bahariya Oasis:			
Ain El Bishmu	31.6	380	1961
Dakhla Oasis:			
Ain El Gabal	40	445	1962
El-Qasr	45	?	?
Helwan sulphur spring	31.65	254-810	1964
Ain Al Sukhna	33	15	1962
Kharga Oasis:			
Ain Achor	30	?	1929
Beris and Genah Springs	30-32	?	?

TABLE 1 (continued)

VOLUMES OF FLOW AND TEMPERATURES OF HOT SPRINGS
OF EGYPT (AFTER EL RAMLY, 1969)

<u>Location</u>	<u>Temperature °C</u>	<u>Volume m³/d</u>	<u>Date</u>
Sinai:			
Ain Hammam Fara'un	75	880	1961
Ain Hammam Saidna			
Musa	34	?	?
Umm Khariga	35.8	?	?

Several temperature gradient maps have been prepared on the basis of bottom-hole temperatures obtained from oil wells in the Gulf of Suez area and in the Western Desert. Both the regional and detailed maps of the Gulf of Suez area and the regional map of the Western Desert were compiled originally as tools for oil and gas exploration (F. T. El-Adl, oral communication). The Gulf of Suez maps show that the Ras Gharib field is outlined by a temperature high, whereas the Balaeem field is outlined by a temperature low. The low in the Balaeem area is attributed to the presence of salt deposits of high thermal conductivity. No attempt has been made by the oil and gas investigators to convert these temperature gradient maps (based upon thermal conductivities of rocks) into more useful heat-flow maps, perhaps because temperature gradient determinations derived from bottom-hole temperature measurements and annual mean temperatures at the land surface are crude, and laboratory determinations of thermal conductivity of rocks from the wells have not been made.

As part of a National Science Foundation supported 2-year program (September 1975-March 1978) for the study of "The Egyptian Section of the Afro-Arabian Plate Boundary and Tectonics of Egypt," several investigations were made that were in large measure directed toward an evaluation of the geothermal potential of Egypt. Additional studies would be made in a new program proposed for support by NSF for 1978-79. Heat-flow measurements would be made in twenty new boreholes that would be drilled along three profiles perpendicular to the Red Sea, as a cooperative effort to be carried out by the New Mexico State University and the Egyptian Geological Survey. The principal investigator would be Dr. P. Morgan, who also headed the 1975-1978 cooperative program conducted by Southern Methodist University and GSE.

In the 1975-1978 SMU-GSE study, the following geothermally significant investigations were made:

1. Heat-flow measurements (Morgan and others, 1977a) were made in 120 boreholes drilled for water and mineral exploration and in three boreholes drilled specifically for heat-flow measurement.

In addition, bottom-hole temperature measurements that had been made in 358 holes were obtained from the General Petroleum Corporation (GPC). The highest heat flow, four times normal for Precambrian granitic gneiss, was at Wadi Ghadir, 2 km from the coast of the Red Sea, northeast of Aswan.

2. Both silica (SiO_2) and sodium-potassium-calcium (NA/K/Ca) geothermometry were used to predict water temperatures at depth (Morgan and others, 1977b; Swanberg and others, in press). The highest temperature predicted on the basis of the NA/K/Ca method was 319°C , as calculated from samples obtained at Kharga Oasis in the Western Desert. Swanberg (oral communication) considers this calculation totally unreliable, especially in light of the fact that the temperature determined using the SiO_2 method was only 46.7°C . In fact, all the NA/K/Ca temperature predictions from the Kharga Oasis area seem to average about 250°C , whereas the SiO_2 predictions average about 470°C .
3. Microseismic studies have been made at 10 sites in the Eastern and Western Deserts. High activity was recorded near Abu Dabbab in the Western Desert.

Several areas have been covered by infrared (IR) imagery under the direction of Dr. Abdel Hady and Dr. El Shazly of the Remote Sensing Center, Egypt (see, for example, El Shazly and others, 1974). Although this technique is valuable in mapping apparent earth surface temperatures and may be used to discriminate among outcrops of rocks of markedly different thermal properties; it has practically no probing depth and cannot be used for evaluating temperature at depth.

The Red Sea may be an important source of geothermal energy although little data are available as yet. It is reported that recently an exploratory oil well off the coast of Sudan encountered high geothermal temperatures necessitating its abandonment.

The existence of hot magnetic bodies has been postulated under the Red Sea axial trough. Localization of such hot bodies would be costly but extremely beneficial if found.

4.0 EGYPTIAN ORGANIZATIONS CONCERNED WITH GEOTHERMAL CONDITIONS

Three Egyptian organizations have at least limited capacities to explore for geothermal energy:

1. The Egyptian Geological Survey, under the direction of Dr. Galal Moustafa, employs the largest number of professionals having qualifications necessary for electrical prospecting.

In addition, they have some resistivity equipment, a thermistor for temperature gradient measurements, and a seismograph for microseismic studies.

2. The Desert Institute, under the direction of Dr. Abdu Shata, has a few enthusiastic young scientists who have appropriate background and good experience in electrical prospecting and in hydrogeology.
3. The Egyptian Nuclear Materials corporation, under the direction of Dr. E. M. El Shazly, has a capability in aeromagnetism and aeroradiometry; however, it has no background in heat flow or deep resistivity investigations and has no resistivity equipment at the present time. This organization is under the Ministry of Electricity and Energy, and has proposed a geothermal program.

Proper coordination and cooperation of all personnel and organizations will be almost essential for a successful geothermal exploration program.

Modern resistivity equipment is needed and further education and training of present personnel are highly recommended, especially in the fields of computer applications and modern methods of data interpretation.

Both Dr. F. K. Boulos, of the Egyptian Geological Survey, and Dr. El Shazly, President of the Nuclear Material Corporation, were supplied at the time of our meetings in Egypt with copies of computer programs for (a) the computation of theoretical Schlumberger sounding curves, and (b) the automatic interpretation of Schlumberger sounding curves. The Desert Institute was mailed copies upon return of the U.S. team to the United States.

5.0 REFERENCES

- El Ramly, I. M.. Recent Review of Investigations on Thermal and Mineral Springs in the UAR. Twenty-third International Geological Congress, Vol. 19, 1969, pps. 201-213.
- El Shazley, E. M.; Abdel Hady, M. A.; and Morsy, M. A. Geologic Interpretation of Infrared Thermal Images in East Qatrani Area. The Remote Sensing Research Project. Academy of Scientific Research and Technology, Cairo, Egypt, 1974, p. 15.
- Morgan, P.; Blackwell, D. D.; Farris, J. C.; Boulos, F. K.; and Salib, P. G. (revised version), Preliminary Geothermal Gradient and Heat Flow Values for Northern Egypt and the Gulf of Suez From Oil Well Data. Proceedings of the International Congress on Thermal Waters, Geothermal Energy and Vulcanism of the Mediterranean Area. Athens, Greece, October 1976, Vol, I, Geothermal Energy, 1977a, pps. 424-458.
- Morgan, P.; Boulos, F. K.; and Swanberg, C. A. Geothermal Data From Egypt. Reprint of Paper presented at EAEG meeting in Zagreb, Yugoslavia, May 31-June 3, 1977b, p. 9.
- Swanberg, C. A.; Morgan, P.; Daggett, P.; Henin, S. F.; Melic, Y. S., and El-Sherif, A. A. (in press). Preliminary Report on the Thermal Springs of Egypt.

E. THE WATER RESOURCES OF EGYPT
AND
THEIR RELATION TO ENERGY DEVELOPMENT

By: Frank E. Clarke

1.0 EXECUTIVE SUMMARY

The River Nile is Egypt's principal water resource and its only significant surface-water supply. Since construction of the High Dam just south of Aswan, approximately 56 billion cubic meters (m^3) of water per year have been available for downstream uses. About 52.2 billion of this total currently is withdrawn for valley and delta irrigation of 6.3 million feddans (5.9 million acres), and 2.68 million is used and essentially consumed in municipal and industrial uses. The remainder, plus 5.2 billion m^3 of groundwater and irrigation return, leaves a small surplus of 6.3 billion m^3 for new uses in the future.

Current plans call for increasing Nile irrigated agriculture by 2.8 million feddans (44 percent), and the requirement for municipal and industrial water is expected to reach at least 5 billion m^3 per year by the end of the century. Assuming the present 58 percent irrigation efficiency, these changes would require 73 billion m^3 of water per year, which exceeds the present supply. However, the ultimate yield of the Nile, with conservation above and below the dam, is thought to be about 70 billion m^3 . If irrigation efficiency is increased to 70 percent, which should be possible in a closed system like the Nile Valley, the larger supply would just match demand. Whether or not shortages occur will depend in part on how rapidly conservation can be effected.

The Western Desert has in its Nubian aquifer a very large amount of relatively high-quality nonrenewable groundwater suitable for either irrigated agriculture or industrial purposes. The most recent estimate is that 500,000 feddans of Western Desert lands can be irrigated between now and the end of the century without exceeding practicable pumping cost. Because there is sufficient land to utilize all the water developed, alternative uses would result in the loss of productive land.

The consumptive water requirements for Egypt's proposed energy development, including recovery, processing, and conversion of oil, coal, and uranium, is small when compared to other water needs, approximately 0.25 percent of projected Nile flow, assuming maximum fresh-water use. It is a small fraction in a massive water balance equation, and one which can be reduced still further by utilizing some saline water.

In summary, present plans for agricultural and industrial expansion, together with expected population growth and urbanization, could fully obligate the Nile within a decade. A more optimistic view, and perhaps a more realistic one, is that conservation measures now being planned will enable Egypt's water resources to meet future demands.

2.0 INTRODUCTION

This review of information concerning water resources in the Nile Valley and adjacent coastal and desert areas was completed during the period March 15 to April 7, 1978 as part of an Egypt-U.S.A. cooperative energy options assessment. Its inclusion in the project recognizes the importance of water in energy systems and the possibility that energy development might be constrained by availability of water or competition with other water uses. Companion reports prepared by others involved in the assessment contain additional information on water-related energy options, such as hydropower and geothermal energy.

The generous help of technical personnel made it possible to complete the review in the time allotted and is gratefully acknowledged. Information contained in the references also was very useful in updating water-resource information. The agencies and technical personnel consulted are listed below:

Ministry of Irrigation. Eng. Anwar Hegasy, Undersecretary for Water Distribution; Dr. Mohamed Ali Ezzat, Undersecretary for Desert Irrigation; Eng. Saleh El Nour, Chief, Technical Office Desert Irrigation Department; Dr. K. Hefney, Director, Research Institute for Ground Water; and Eng. Sarwat Fahmy and Mr. Fred Durrant, co-managers, U.N. Project Water Master Plan.

Ministry of Housing and Construction. Mr. Francis Kowal and Mr. John Crane, in-house consultants on water supply and use.

Ministry of Industry. Eng. Kamel Maksoud, Chief, Office of Industrial Planning and Technical Research.

Nuclear Mineral Corporation. Dr. E. M. El Shazly, Chairman.

Geological Survey of Egypt and Mining Authority. Dr. Maurice Hemina.

Desert Institute. Dr. Abdul A. Shata, Director and Head of Water Resources Department.

Egyptian General Petroleum Corporation. Eng. Moustafa K. El Ayouy, Director.

Academy of Scientific Research and Technology. Dr. Moustafa Hafez, Counselor and Head of Environmental Research Council.

General Authority for Rehabilitation and Agricultural Development Projects. Eng. Zaky Mah Aranout, Chairman.

3.0 WATER AND WATER USE IN THE NILE SYSTEM

3.1 Surface-water Resources

Egypt has a very warm and almost rainless climate. Annual precipitation ranges from about 192 millimeters (mm) at Alexandria, through 24 mm at Cairo, to zero at Aswan near the southern border. Corresponding evaporation rates are 0.9, 2.1, and 2.7 meters (m), respectively, so the net atmospheric contribution is negative and Egypt must depend upon drainage from beyond its borders for essentially all its surface water.

The Nile River, which stretches 6,695 kilometers (km) from Uganda to the Mediterranean, fulfills this need. Its principal tributaries, the White and Blue Niles, which originate in the Lake region of Africa and the highlands of Ethiopia, respectively, together with lesser influents, yield an annual flow that varies from 65 to 130 billion m^3 ($10^9 m^3$) and averages 84×10^9 at Aswan in upper Egypt. Within this hydrologic framework, annual daily lows average $50 \times 10^6 m^3$ and highs average $750 \times 10^6 m^3$; however, daily extremes of $42 \times 10^6 m^3$ (1914) and $1,200 \times 10^6 m^3$ (1878) have been recorded. The schematic in figure 1 indicates the source basin gains and losses which contribute to the surface-water supply.

Before the first dam was constructed, there was no means of regulating the highly variable flow of the Nile, except that Faiyum Depression, 90 km southwest of Cairo, was used for offchannel storage of flood water between 2000 and 140 B.C. Construction of Aswan Dam in 1902 provided $2.5 \times 10^9 m^3$ of storage and allowed some cropping beyond the limit of annual flood irrigation. This storage reservoir was expanded to $5 \times 10^9 m^3$ capacity in 1933 by increasing the height of the dam, and another $2.5 \times 10^9 m^3$ of storage was developed in the Sudan at about the same time and made available to Egypt through international agreement. However, total storage still was far too small to facilitate perennial irrigation in the Nile Valley. Completion of the High Dam 7 km south of the Aswan Dam in 1968 finally allowed effective regulation of the river. The $164 \times 10^9 m^3$ of storage provided by its Lake Nasser reservoir is allocated as follows:

Purpose	Max. Surface* elevation above sea level, m	Water in storage $m^3 \times 10^9$
Dead storage (500-year sediment trap)	147	30
Conservation pool (irrigation and other uses)	175	97
Flood control and interim beneficial uses	183	<u>37</u>
Total		164

* River channel elevation at dam, 98 m.

Fig. 1. Schematic of inflow and losses, Upper Nile Basin, annual averages, $M^3 \times 10^9$. Width between arrows is proportional to quantity. (Modified from schematic of U.N. project for Water Master Plan, Ministry of Irrigation).

The $84 \times 10^9 \text{ m}^3$ average annual inflow to Lake Nasser is partitioned by international agreement and provides $10 \times 10^9 \text{ m}^3$ for evaporation and seepage loss, $18.5 \times 10^9 \text{ m}^3$ for the Sudan, and $55.5 \times 10^9 \text{ m}^3$ for Egypt. These quantities are expected to be available during 80 percent of future years, and the quantity available to Egypt during the past several years has been about $56 \times 10^9 \text{ m}^3$.

3.2 Surface-water Use

Of the $56 \times 10^9 \text{ m}^3$ released annually at the High Dam, about $2.68 \times 10^9 \text{ m}^3$ currently are withdrawn for domestic and industrial supply, according to table 1, although the quantity generally reported for such use is $1 \times 10^9 \text{ m}^3$ (e.g., Hoofnagle et al., 1976). The remainder is available for consumptive use in agriculture and nonconsumptive use in navigation and hydroelectric power generation. This supply is extended in the valley through addition of $2.5 \times 10^9 \text{ m}^3$ of irrigation drainage water, $2.3 \times 10^9 \text{ m}^3$ of return flow, and $0.4 \times 10^9 \text{ m}^3$ of groundwater (Hoofnagle et al., 1976), which yields $58.5 \times 10^9 \text{ m}^3$ after adjustment for municipal-industrial withdrawal.

According to Lee (1975), the officially estimated water requirement for irrigating the present 6.3×10^6 feddans of valley and delta land is $52.2 \times 10^9 \text{ m}^3$, which leaves a surplus of $6.3 \times 10^9 \text{ m}^3$ for concurrent competitive uses, such as the development of new lands. Assuming an annual consumption of 112 centimeters (cm), over the area involved (Lee, 1975), these figures represent an irrigation efficiency of 58 percent. The schematics of figures 2 and 3 which detail withdrawals in the valley and delta, show only $4.48 \times 10^9 \text{ m}^3$ actually reaching the Mediterranean via the Rosetta branch, which is only 8 percent of the flow at Aswan. However, an additional $6 \times 10^9 \text{ m}^3$ of brackish water are pumped from the delta directly to the sea (Hoofnagle et al., 1976).

It is evident that use of Nile water will increase. Egypt's population is expected to grow from the present 38×10^6 to 67-70 $\times 10^6$ by the year 2000. Sixty percent of it then will be urban, as compared with the present 42. The per capita water use also may increase from the present 180 to 250 liters (l) per day, and the total requirement for municipal-industrial water is expected to be $5 \times 10^9 \text{ m}^3$ by the end of the century (Maksoud, 1978). An extrapolation of the figures in table 1 suggests that it could be even more, perhaps as much as $7.5 \times 10^9 \text{ m}^3$.

The original plan was to reserve enough water in Lake Nasser for irrigating 1.2×10^6 feddans of new land. Current plans call for development of 2.8×10^6 feddans, much of it in areas east and west of the delta. Table 2 shows one estimate of the water requirement for such land development. The $64.4 \times 10^9 \text{ m}^3$ withdrawal indicated for 8×10^6 feddans, together with the $5 \times 10^9 \text{ m}^3$ estimated for domestic-industrial withdrawal, amounts to $69.4 \times 10^9 \text{ m}^3$, which is well above

TABLE 1

AREAL WATER WITHDRAWALS FOR DOMESTIC AND INDUSTRIAL USES, MINISTRY OF IRRIGATION

Areal	Source	Quantity, million cubic meters ($m^3 \times 10^6$), 1976													Grand Total
		Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	
East Delta	Nile	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	22.8	377.0
	Canals	28.6	28.4	29.0	29.3	28.7	29.4	29.9	30.2	29.7	30.1	29.4	29.5	352.2	
	TOTAL	30.5	30.3	30.9	31.2	30.6	31.3	31.8	32.1	31.6	32.0	31.3	31.4	375.0	
Middle Delta	Nile	20.4	2.7	3.0	2.9	2.8	2.9	2.9	2.9	2.9	3.0	2.7	2.9	520.0	3091.4
	Canals	4.3	19.4	22.7	22.0	22.9	22.3	23.1	23.0	22.2	22.8	22.1	22.6	249.4	
	TOTAL	24.7	22.1	25.7	25.9	25.7	25.2	26.0	25.9	25.1	25.8	24.8	25.5	301.4	
West Delta	Nile	--	--	--	--	--	--	--	--	--	--	--	--	--	1,061.35
	Canals	86.95	79.3	88.4	86.2	90.5	88.5	93.0	93.6	88.1	89.3	87.8	89.7	1,061.35	
	TOTAL	186.95	79.3	88.4	86.2	90.5	88.5	93.0	93.6	88.1	89.3	87.8	89.7	1,061.35	
Middle Egypt	Nile	65.1	61.0	65.2	63.2	65.2	63.2	65.3	65.3	63.2	65.2	63.1	65.1	770.1	815.6
	Canals	2.9	3.2	3.6	3.6	3.9	4.0	4.2	4.2	4.0	4.2	3.9	3.8	45.5	
	TOTAL	68.0	64.2	68.8	66.8	69.1	67.2	69.5	69.5	67.2	69.4	67.0	68.9	815.6	
Upper Egypt	Nile	11.5	11.6	12.5	12.2	11.5	4.7	4.8	4.8	4.7	4.7	4.5	4.7	92.2	125.5
	Canals	4.6	4.8	4.6	4.4	3.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	33.3	
	TOTAL	16.1	16.4	17.1	16.6	15.2	6.3	6.4	6.4	6.3	6.3	6.1	6.3	125.5	
TOTAL		226.25	212.3	230.9	225.7	231.1	218.5	226.7	227.5	218.3	222.8	217.0	221.8	2,678.85

Fig. 2. Schematic river flow and withdrawals, Nile Valley, annual averages, $m^3 \times 10^6$. Width is proportional to quantity. (Modified from schematic of U.N. project for Water Master Plan, Ministry of Irrigation).

Fig. 3 Schematic water withdrawals, Nile Valley, annual averages, $m^3 \times 10^6$. Width is proportional to quantity. (Modified from schematic of U.N. project for Water Master Plan, Ministry of Irrigation).

TABLE 2

ESTIMATED WATER REQUIREMENTS FOR PRESENT
AND FUTURE IRRIGATION IN THE NILE VALLEY AND DELTA
(MODIFIED FROM HOOFNAGLE, ET. AL., 1976)

Month	Water requirement at Aswan, $M^3 \times 10^9$		
	6.3×10^6 feddans (present)	7.1×10^6 feddans	8.0×10^6 feddans
January	2,480	2,480	2,480
February	3,180	3,570	3,980
March	3,200	3,600	4,000
April	3,210	3,610	4,020
May	4,250	4,780	5,320
June	5,040	5,660	6,300
July	6,060	6,800	7,570
August	5,980	6,720	7,470
September	5,830	6,550	7,290
October	5,580	6,270	6,970
November	3,990	4,500	5,010
December	<u>3,380</u>	<u>3,700</u>	<u>4,020</u>
Total	52,180	58,240	64,430

the presently developed Nile resource. On the other hand, it is consistent³ with an estimate that the Nile system eventually can yield $70 \times 10^6 \text{ m}^3$ (World Bank-World Health Organization, 1977). Also, it represents an irrigation efficiency of about 59 percent, which is attainable.

3.3 Groundwater in the Nile System

The Nile Valley extends 1,000 km from Aswan to Cairo and varies in width from 5 to 15 km. Its water-saturated alluvium ranges in depth from 20 m near the Aswan Dam to about 250 m in the vicinity of Assuit, and 50 m near Cairo (Eakin, 1975). Assuming a storage coefficient of 20 percent and an average valley width of 7 km, the upper 15 m of this vast aquifer contains $21 \times 10^9 \text{ m}^3$ of water, about one-third of the present annual yield of the Nile system. The capacity would be proportionally greater if a greater depth of exploitable sediment were assumed.

The Nile Delta, which stretches 200 km from base to apex and 250 km across the base, also serves as a massive ground-water reservoir. Assuming the same 20-percent storage³ coefficient, and 15 m-depth, this 25,000-km area could store $75 \times 10^6 \text{ m}^3$; there is much more water in the sediments which extend to depths of 500 m or more.

The quantity of water which can be withdrawn from the sediment above Cairo is limited by the fact that the Upper Valley is a closed system in which the Nile is the only significant source of recharge, and the surface and groundwater supplies constitute a single interactive resource. In such a system, groundwater can be utilized as a supplemental resource only to the extent that it would otherwise be lost, as by non-beneficial evapotranspiration. The delta, which is semi-open, receiving some rainfall and leaking some water directly to the sea, is more flexible. However, even here excessive pumping might induce saltwater intrusion in certain areas and result in troublesome water-quality problems.

Significant quantities of groundwater already are being used to supplement the Nile's surface supply. Delta wells reported by Eakin (1975) are shown in table 3. If average capacities are assumed, together with 75 percent operation for large pumps and 25 percent for the seasonal pumps, the total annual yield is about $860 \times 10^6 \text{ m}^3$ /year. This may be a conservative figure. According to Hefney (1978), there are 1,000 delta wells of 10 to 100 m^3 /hr. capacity and 100 wells of 1,000-2,000 m^3 /hr. Idris (1976) reported 48 delta wells yielding $3.5 \times 10^6 \text{ m}^3$ /day and said an additional 1,000 wells produce $1.7 \times 10^6 \text{ m}^3$ /day of city water ($620 \times 10^6 \text{ m}^3$ /year), presumably a total for the delta and valley.

A considerable number of 500 m^3 /hr. pumps still are being used to supplement surface-water irrigation in the Upper Valley, despite the High Dam's having decreased this need. Idris (1976) mentioned 350 valley pumps and a total daily discharge of $979 \times 10^6 \text{ m}^3$ /day. This equates to $357 \times 10^6 \text{ m}^3$ /year, which agrees with the generally accepted figure of $350 \times 10^6 \text{ m}^3$ (e.g., Eakin, 1975).

The greatest potential for continuing groundwater development is thought to be in the Upper Valley, where a total of $1 \times 10^9 \text{ m}^3$ might be obtained by proper location of new wells (Eakin, 1975). The Ministry of Irrigation is cooperating with the Massachusetts Institute of Technology (MIT) in a 2-year modeling study aimed at determining the maximum safe groundwater yield of the delta. This will be followed by a similar cooperative study with the Egyptian Academy of Sciences to determine the safe yield of valley sediments.

TABLE 3
DELTA WELLS (EAKIN, 1975)

<u>Number of wells</u>	<u>Capacity, $\text{m}^3/\text{hr.}$</u>	<u>Operating Schedule</u>
45	1,000 - 1,200	18 hr./day
55	1,000	18 hr./day
30	350	Seasonally
115	500 - 700	Seasonally

Whatever the outcome of the investigations, it is likely that the projected land development and urban-industrial expansion will totally obligate the Nile system before the turn of the century, possibly within a decade, unless both the surface supply and the ground water supply are developed to the practicable limits.

3.4 Extending the Nile Supply

Conservation of source water in the basin above Lake Nasser and reduction of losses in irrigation and other uses below the dam are the only means of significantly extending the Nile supply. The projects listed below and located on figure 4 have been proposed for the upstream basin and are thought to be capable of yielding an additional $18 \times 10^9 \text{ m}^3$ of water annually, nine each for Egypt and Sudan. These projects include:

1. A larger reservoir in Lake Victoria at the Owen Falls Dam to form the main reservoir for carry-over storage and to produce hydroelectric power for use in Uganda.
2. A storage reservoir in Lake Albert which would be the regulator controlling the amount of water to be sent to Sudan and Egypt.
3. A regulator or low dam near the outlet of Lake Kyoga for its control in order to facilitate the combined regulation of Lakes Victoria and Albert.

Fig. 4. Sketch map showing location of proposed water conservation projects, Upper Nile Basin. (Names and boundary representation not necessarily authoritative)

4. The Jonglei Canal to divert water away from the Sudd swamps where, at present, 68 percent of it disappears by evapotranspiration by the luxuriant swamp vegetation.
5. Canals for collecting the waters of Bahr El Ghazal tributaries to Bahr El-Jebel and Bahr El-Arab.
6. A diversion canal for bypassing the White Nile waters of the Baro tributary to Sobat River and other tributaries rising in the Ethiopian highlands. These waters are practically lost in Mashar marshes.
7. A dam on the outlet of Lake Tana in Ethiopia to use the Lake for carry-over storage.
8. A dam on the main Nile below Atbara for flood protection and some storage.

To date, positive action has been taken to start only one of the projects, the Jonglei Canal, which bypasses the Sudd swamp, although some water-balance studies which relate to others are underway. It is evident from figure 1 that the magnitude of present loss, $31.4 \times 10^3 \text{ m}^3/\text{year}$ makes the canal a most important conservation effort. The remaining seven projects, some of which involve multinational agreements, will await completion of the Water Master Plan now being prepared cooperatively by the Ministry of Irrigation, the United Nations, and the World Bank in order to weigh costs and benefits against alternative conservation measures below the High Dam.

Current losses in post-dam water use appear to be quite significant in the context of total resources. Drainage water in the usable salt concentration range of 400 to 2,000 mg/l, which is pumped from the delta directly to the sea, amounts to more than 10 percent of the total annual allotment at the dam. About half this amount ($3 \times 10^3 \text{ m}^3$) is lost to irrigation use during a 25-day canal cleaning period in December and January, and according to Hoofnagle et al. (1976), that amount might be saved, at least in part, by lining main canals. The current practice of diverting much of the municipal and industrial waste water away from the system, instead of treating and returning it, probably involves loss of a considerable part of the aforementioned $2.68 \times 10^3 \text{ m}^3/\text{year}$ because Cairo alone diverts a large part of it to Lake Manzala and the sea. This loss will increase as domestic-industrial use expands in the future, unless general reuse is practiced. Even if a reuse system were in effect, the current 40 percent leakage waste, said to occur in the municipal sector, could amount to a sizeable loss.

In addition to these alternatives, Lee (1975), Hoofnagle et al. (1976), and others have discussed the possibility of improving overall irrigation efficiency to 65 or 70 percent, which is considered attainable in closed systems of the Nile Valley type. This probably would require major revision in irrigation practices (length of irrigation runs, cycle of application, etc.).

Any plan for conserving and extending water resources obviously should start with best available knowledge of supply and demand. Assembly and analysis of such data is the objective of the Water Master Plan project. This is expected to be completed and reported by June 1979 and should provide the framework for effective water management.

3.5 Water Quality

Before construction of the High Dam, the quality of Nile River water varied significantly from low flow to flood stage. Although the pH remained relatively constant in the 7.5 to 8 range, the dissolved-solid concentration varied from 220 to 140 mg/l, and the suspended solid from 50 to 4,000 mg/l for low and flood flow, respectively. There also were occasional algae problems during low flow and the E. coli count sometimes reached 200 per milliliter (ml) in July immediately before flooding occurred (Morris, 1959).

Completion of the High Dam brought a number of water-quality changes. Present environmental conditions in Lake Nasser fall between riverine and lacustrine. Stratification occurs in the lake about March and persists until the flood period. Anaerobic conditions develop below the thermocline during the summer and extend up the reservoir for a considerable distance. The annual flood drops most of its estimated 100×10^6 tonnes of sediment upstream of the dam with related quality impacts on both the reservoir and the river.

The effect of High Dam regulation downstream has been to reduce maximum concentrations of solids (both dissolved and suspended) and E. coli and to increase the concentration and variety of algae. Suspended solid concentration generally is below 50 mg/l in the river, and the dissolved solid above Cairo seldom exceeds 200 mg/l, except in local anomalies related to outfalls. According to Sanders (1978), the present maximum E. coli counts are of the order of 10^4 /l, as compared to 10^6 /l before the Dam, because regulated flow minimizes influx of organic waste from the flood plain. On the other hand, he reports general increase in algae, for example, from 2×10^5 /l in December 1966, to 2×10^6 /l in December 1976. The relative proportion of blue-green algae also appears to be increasing.

The sum total of these effects is that the Nile is a relatively clean river from the Dam to Cairo. Raw sewage causes some anaerobic areas near Aswan, and industrial discharges at Asyut depress the oxygen concentration by about 1 mg/l, but these effects disappear a short distance downstream (Sanders, 1978). There also is some waste inflow in the Cairo segment, including traces of oil, heavy metals (such as zinc, cadmium, mercury, copper, cobalt, and iron), as well as phenol, in the range of 0.08 to 0.32 mg/l. Agricultural drainage in the absence of annual flooding appears to have slightly increased the average salt content of the river.

Surface-water quality in the delta is somewhat below that of the upper river, as would be expected in this terminal sector. Although the

water is still generally good, increased nutrients, particularly in the relatively sluggish Damietta Branch, have caused serious hydrophyte problems and related oxygen deficiencies in certain canals. Quality problems also occur in Lake Maryut. This subsea level remnant of ancient freshwater Lake Mareotia, which once discharged to the sea, now is significantly polluted with municipal and industrial waste, as shown in table 4. Mina and Salem (1976) concluded that 37 to 40 percent of the BOD load to the lake consists of settleable solid which can easily be removed, and that the impact would be tolerable if this were done.

Delta canals have been affected to some extent by waste heat, particularly at the Karmouz fossil-fueled generator near Alexandria. The four 16 MW units at this location are limited to 8 MW during summer months to avoid intolerable water temperatures, and cooling towers are being constructed to correct the problem.

Groundwater throughout the valley and delta is generally excellent in quality, below 500 mg/l of contaminants, despite continuing infiltration of irrigation water. Only in the northern part of the delta is brackish water of marginal quality likely to be encountered. The present practice of pumping brackish agricultural drainage directly to the sea is a partial explanation for this favorable condition.

Although overall water quality in the Nile system is excellent at present, effort will be required to avoid its degradation as population and supporting industry expand. Egypt is well aware of this need and has mounted an impressive joint water-quality research program involving the U.S. Environmental Protection Agency, the University of Michigan, the Ford Foundation, the Egyptian Academy of Science, and a number of the country's leading water-quality laboratories. Systematic monitoring is under way in Lake Nasser, Lake Nubia, and the several principal segments of the Nile Valley and Delta. Data are being computerized to facilitate rapid assessment and trend analysis. Table 5 shows data collected in the Cairo segment during 1977. A summary of the program and sample analyses from other river segments are contained in the Attachment to this report. This comprehensive program will be an invaluable aid in assessing and avoiding unfavorable impacts.

4.0 WATER AND WATER USE IN THE WESTERN DESERT

4.1 The Resource

The Western Desert (figure 5), which stretches from Libya to the Nile Valley and from the Qattara Depression near the Mediterranean to the Sudan, covers an area of 685,000 km², and 68.5 percent of Egypt. Within its boundaries, a series of topographic depressions, thought to be primarily the result of water erosion, extend diagonally from Siwa Oasis just north of latitude 29 degrees, through Bahariya, Farafra, Dakhla, and Kharga oases to the Kurayim Basin near the Sudanese border. The northwest margins and the flanks of the depressions are bounded by escarpments which rise to heights of over 300 m above sea level. Their

TABLE 4

WATER QUALITY, LAKE MARYUT (MODIFIED FROM MENA AND SALEM, 1975)

Concentration, mg/l												
Area of lake	Dissolved solid		Chloride, Cl		Sulfate, SO ₄	Hardness (as CaCO ₃)	Dissolved oxygen		BOD		COD	
	Max.	Av.	Max.	Av.			Min.	Av.	Max.	Av.	Max.	Av.
East	4,440	3,168	1,970	1,356	232	638	0	0.5	342	162	445	244
Central	2,904	2,618	1,495	1,101	252	598	2.5	8.5	149	94	149	94
West	2,460	2,739	1,450	1,158	242	641	0.3	10.0	195	98	195	98

TABLE 5

NILE RIVER QUALITY*
(VARIOUS SITES, SEE ATTACHMENT 2)

Nile Monitoring Program--Cairo Segment

Parameters	January 1977									March, 1977									June, 1977								
	H ₁	H ₂	H ₃	C ₁	C ₂	K	K _P	K _N	H ₁	H ₂	H ₃	C ₁	C ₂	K	K _P	K _N	H ₁	H ₂	H ₃	C ₁	C ₂	K	K _P	K _N			
Temperature °C	22	21	21	21	21	20	-	24	18	18.5	18	18.5	19.1	19.6	20	-	6	6	-	-	-	-	-	-	-		
Turbidity	8.7	8.5	8.0	9.0	9.0	14	7.5	7.6	12	12	11.3	8.0	7.9	7.5	6.95	8.1	8	7.85	1.3	2.5	2.5	7.3	4	2.9			
pH	7.7	7.6	7.8	7.4	7.5	7.7	7.7	7.6	8.1	8.15	8.05	8.05	7.9	7.8	7.9	7.8	8.0	7.85	7.96	7.6	7.6	7.96	8.14	8.10			
Alkalinity ph-ph (CaCO ₃)	nil	nil	2	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	0.5	nil	nil	nil	nil			
Total Alkalinity CaCO ₃ (mg/L)	174	136	132	134	134	132	130	134	133.5	134.5	134	132	131.5	132	131	132	114	113.5	114.6	118.5	112.5	110.6	110.6	112.7			
Total Hardness (mg/L)	172	126	138	138	138	144	132	148	118.3	120.3	115	119	121	123.8	121.8	116	108.5	113.5	110	108.5	113	110.6	112	109.3			
Ca Hardness (mg/L)	76	76	66	78	64	60	64	66	66	67.3	67	61.5	61.3	63.5	62.8	61.3	57.5	61.5	58.6	45.5	48.5	54	60.6	59.6			
Mg Hardness (mg/L)	56	56	72	60	74	84	64	82	52.3	47.5	40	57.3	59.8	60.3	58	54.6	54	50.5	51.3	63	64.5	56.6	59.8	54.6			
Chlorides (mg/L)	18	18	20	20	18	22	22	22	17.5	18	19	17.5	17	18	18	17.3	18	18	16	18.5	19.5	18	18	17.3			
Ammonia (mg/L)	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil			
Sulfates (mg/L)	18	18	19.5	19.4	19.4	20.8	20	19.2	17.4	16.5	19.6	19.3	18.8	15.8	15.6	17	14.8	17.5	14	14.3	13.4	13.6	12.9	13.4			
Nitrites (mg/L)	nil	nil	nil	nil	nil	nil	nil	nil	007	.004	.006	.006	.005	nil	nil	nil	nil	.033	.007	.006	.011	.006	.015	.009			
Nitrates (mg/L)	.055	.060	.050	.085	.065	.040	.030	.045	.037	.040	.031	.030	.081	.043	.026	.020	.010	.114	.037	.039	.038	.110	.033	.012			
Total Organic Nitrogen (mg/L)	1.120	1.008	1.008	.784	1.344	.784	1.008	1.008	1.176	1.092	1.148	.812	.840	.868	.784	.597	.560	.812	.598	.588	.784	.672	.747	.747			
Total Phosphates (mg/L)	190	170	180	165	160	180	180	190	283	240	208	295	291	236	285	255	151.3	144.4	195.8	319	376	160	212	168			
Orthophosphates (mg/L)	77.5	77.5	87.5	75	75	65	62.5	65	107	93.6	122	61	82.5	86	67.5	50	130	130	103	135	130	119	131	144			
D. phos. (mg/L)	77.5	52.5	52.5	25	32.5	65	52.5	62.5	83.2	76.3	88.8	74.4	66.9	122.5	125	126.6	98.7	130	103.2	144.4	132.5	132	132	125			
Silica (mg/L)	6.6	5.4	5.6	5.4	6.4	8.2	8.0	8.0	4.7	4.5	6.2	4.4	5.9	5.2	5.6	5.9	6.3	6.5	7.4	6.4	6.6	6.1	7.7	7.3			
Chlorophyll <i>a</i> (mg/L)	14.52	8.94	9.64	13.31	11.06	12.23	12.96	15.85	9.80	14.20	13.92	13.66	11.75	9.85	8.82	10.35	8.91	10.4	11.86	7.25	8.39	6.30	6.41	6.92			
Electrical Conductance (mho/cm)	327	331	338	338	338	334	331	334	308	307	312	317	318	324	327	324	349	370	336	371	355	337	346	334			
T. algal. (org./L)	6x10 ⁶	5.7x10 ⁶	6.5x10 ⁶	4.2x10 ⁶	5.6x10 ⁶	5.3x10 ⁶	6x10 ⁶	5.4x10 ⁶	5.4x10 ⁶	3.9x10 ⁶	4.5x10 ⁶	5.3x10 ⁶	3.8x10 ⁶	2.9x10 ⁶	3.7x10 ⁶	3x10 ⁶	9.6x10 ⁶	7.9x10 ⁶	8.3x10 ⁶	6x10 ⁶	7x10 ⁶	5.8x10 ⁶	5.9x10 ⁶	5.81x10 ⁶			

Water Quality Studies On The River Nile and Lake Nasser
River Monitoring Program
Annual Report - 1977

*Courtesy, U.S. Environmental Protection Agency

Fig. 5. Project Water and Land Development, Western Desert, Egypt. Names and boundary representation are not necessarily authoritative. (Modified from map of Ministry of Irrigation.)

floors slope generally southeastward with subdepressions as low as 1.8 m above the sea. According to Ezzat (1974), temperatures in the area range from extremes of 7 degrees C in winter to 49 degrees C in summer, and average annual rainfall varies from 9.6 mm in Siwa to only 0.3 mm in the southern Kharga Depression, but infrequent storms are known to occur.

The entire Western Desert is underlain by a thick sequence of waterbearing strata (aquifers) consisting of shale, chalk, sand and sandstone. This formation, known as the Nubian reservoir, rests on a basement of granite and gneiss which crops out along the southwestern border. It slopes at a gradient of about 1:2,000 towards the northeast and is capped, except in the depressions, by chalk, limestone, clay, and shale of Upper Cretaceous, Paleocene, and Miocene Age. The sand and sandstone, which make up 30 percent of the aquifer, contain no fossils and thus are undated. However, they are thought to range from Upper Cretaceous at the top of the sequence to Cambrian at the bottom.

Thickness of the Nubian varies with subsurface structural features from 500 m along the Mediterranean coast, through 3,000 m or more south of Bahariya, to a range of 300 to 1,500 m in the Kharga-Dakhla area. Its upper surface in the depressions varies from 50 m to several hundred m below land surface, and artesian heads as great as 157 m above sea level and 50 m above land surface have been reported (Cushman, 1967). Ezzat (1974) concludes that the Nubian sediments were deposited in shallow seas and that freshwater flushing, which established the present fresh water-salt water interface in northern Qattara Depression (figure 5), started during the Paleocene with movement of tropical rainfall northeastward from the Uweinat uplift. Later recharge of the shallower strata during the Oligocene and Miocene is attributed to rivers flowing northward from the Sudan into the area now occupied by the Kharga Depression and southeastward from an anticlinal arch west of the present Nile Valley before the Red Sea graben developed. Continuing recharge to the system is estimated by Ezzat (1974) as follows:

Source	Amount, m ³ /day
Across Libya border	1,820,000
From Uweinat plateau	522,500
From the Sudan	<u>1,016,658</u>
Total	3,359,158

Table 6 shows generally accepted figures for distribution of inflow between beneficial uses and nonbeneficial evaporation in the depression areas. An additional 1.4×10^6 m³/day of brackish water from Miocene formations discharge to Qattara Depression. The total estimated discharge

TABLE 6

BENEFICIAL AND NONBENEFICIAL USE OF NUBIAN RECHARGE, m³/DAY
(ROUNDED FIGURES--PARKINSON AND WORTS, 1976)

Area	Estimated inflow	Beneficial use	Nonbeneficial loss
Siwa Oasis	420,000	120,000	300,000
*Qattara Depression	1,400,000	--	1,400,000
Farafra and Bahariya Oases	520,000	120,000	400,000
Dakhla Oasis	690,000	520,000	170,000
Kharga Oasis	420,000	220,000	200,000
South Kharga (Kurazm and Nasser Basins)	<u>100,000</u>	<u>--</u>	<u>100,000</u>
Total	3,550,000	980,000	2,570,000

* Qattara figure does not include 1,400,000 of brackish Micocene water, which also discharges nonbeneficially.

probably is a conservative figure. Parkinson and Worts (1976) concluded, on the basis of an areal survey, that the water loss in Farafra could be much greater than the $2.5 \times 10^3 \text{ m}^3/\text{day}$ generally assumed, perhaps as much as $300 \text{ to } 500 \times 10^3 \text{ m}^3/\text{day}$. If this is true, the inflow to the Farafra-Bahariya block would be double the figure shown in table 6.

The inflow-outflow values represent only a small part of the total resource available in the massive Nubian aquifer. Parsons (1963), Ezzat (1974), and others estimate the total water in storage to be in the range of $2.3 \text{ to } 3.5 \times 10^{12} \text{ m}^3$. The fact that recharge is a small fraction of this quantity and that 100,000 years may be required for water to reach Qattara from the nearest point of recharge (Hellstrom, 1940), means that effective use must involve resource depletion (i.e., water mining).

4.2 Agricultural Use of Western Desert Water

Inhabitants of the oases have used Nubian water since prehistoric times, much of it in more recent years from ancient native wells. Relatively modern well drilling, which was introduced into the desert in the late 1800's and evolved into systematic government drilling in 1959, has markedly increased groundwater use, particularly in the Dakhla and Kharga oases. Idris (1976) reported a total of 1,686 principal Western Desert wells, 295 of them relatively deep modern installations. These wells, which range in depth from less than 100 to 1,200 m and in yield to $15,000 \text{ m}^3/\text{day}$, are supporting 26,000 feddans of agriculture in Dakhla, 10,000 in Kharga, 6,200 in the Farafra-Bahariya area, and 3,000 in Siwa.

Continuing withdrawal has caused some shallow wells to cease flowing under artesian pressure and some deep wells are being pumped in the north and south of Kharga Depression, as shown in table 7. In Dakhla and Kharga, where groundwater development has been concentrated, shallow-well flow decreased from 218,429 to 218,015 m^3/day from 1960 to 1970, but the shallow plus deep yield increased from 432,683 to 741,878 m^3/day (Ezzat, 1974).

TABLE 7

WELLS BEING PUMPED, KHARGA OASIS (EZZAT, 1976)

Government wells

Sherka 1A	West Kharga	Garmashin 1
Sherka 3	El Sajaha	Garmashin 2
Sherka 34	Hebis	Garmashin 2A
Sherka 2	El Bustan 1C	Garmashin 6
1 Mahariq 2	El Bustan old	Garmashin 16
1 Mahariq 7	Genah 2A	Garmashin 2A replacement
El Kharga 1	Genah 1A	Garmashin 4 replacement
El Kharga 1A	Genah 3A	Baris 1
El Kharga 2	Genah 3B	Baris 12
El Kharga 10		Baris 15
El Kharga 12		Baris 18

Native and Village WellsBaris Area

Baris village
 El Maks
 Doush
 Bajda
 Baris El Qasr
 Om Saeda
 Salm and Fakhara
 El Oeum
 El Gaba
 Badran

Elswhere

Sherka native
 Genah village

Decline in artesian pressure resulting from such withdrawal is not expected to be an insurmountable barrier to further land reclamation. The United Nations Food and Agricultural Organization (FAO) concluded in 1977 that it is economically feasible to increase irrigation in the Dakhla-Kharga area by an average of 2,000 feddans per year between now and the first quarter of the next century, despite the general pumping likely to be required. This program would involve an annual withdrawal of about $500 \times 10^6 \text{ m}^3$ in the terminal year, over 80 percent of it from the Dakhla area, and maximum pumping lifts are expected to range from 30 m in the upper water-bearing strata to 70 m in the lowest one. Although such general pumping is considered economically practical, its energy requirement will be significant. The FAO report states that even continuing extraction at the current rate in Kharga and Dakhla will result in an increased energy requirement of from 2 to 6 gigawatt hours per year by the year 2025. This amounts to an increase from 7 to 22 watt-hours/ m^3 of water delivered at the surface. The extraction required to irrigate the proposed additional land, if increased slowly to minimize drawdown, would require an energy input of 300 watt-hours/ m^3 for a total of 234 gigawatt hours/year by the end of the period. Assuming a pumping schedule of 3,500 hours/year, the report estimates an installed power requirement of 63 megawatts for Kharga and Dakhla.

Deep-well development also involves considerable capital investment, maintenance, and operating cost. Ezzat (1974) has calculated the total costs for new flowing and pumping wells, assuming 6 percent interest on capital, maintenance cost equal to 10 percent of annual amortization, and an annual water requirement of 7.2 to $7.4 \times 10^3 \text{ m}^3$ per feddan. His data in tables 8 and 9 show that unit cost varies with depth of water-bearing formation and type of well screen involved, the latter because of differences in both basic cost and durability. In summary, these figures indicate an average annual cost of 16.9 Egyptian pounds (L.E.) per feddan for new flowing wells in the Dakhla area and L.E. 57.5 and L.E. 42.0, respectively, for flowing and pumping wells in the Kharga area. Data contained in the same report show that annual costs per feddan are in the same range for mild steel, aluminum, and stainless-steel well screens, whereas the cost with bakelite wood screen is consistently lower, from one-third to one-half the cost using metal; the cost with fiberglass ranges from half to equal the cost with metal components, depending upon depth.

Whatever the cost of water mining in the Nubian aquifer, there is active planning for increased production to support expanded agriculture in the Western Desert. Parkinson and Worts (1976) reported that 35,500 feddans in Bahariya, 90,000 in Farafra, and 1,000,000 in southern Kharga might be suitable for farming if water can be supplied. Ezzat (1974) concluded, on the basis of recent mathematical modeling, that the 500×10^3 feddans shown in figure 5 can be converted to agriculture, and that $2,500 \times 10^6 \text{ m}^3$ /year of Nubian water to support it can be made available at acceptable cost.

TABLE 8

ESTIMATED COST OF IRRIGATION WATER, NEW WELLS, KHARGA OASIS

(FROM EZZAT, 1974)

Well type *	Flowing wells		Pumping wells (16 hr/day)	
	Expected discharge (m /day)	Annual cost per feddan (L.E.)	Expected discharge (m /day)	Annual cost per feddan (L.E.)
A	300	101	3,000	32.7
B	3,500	21	7,000	29.2
C	2,500	33	5,000	46.0
D	1,000	75	2,000	60.0
Average:		57.5		42.0

TABLE 9

ESTIMATED COST OF IRRIGATION WATER, NEW FLOWING WELLS, DAKHLA

(FROM EZZAT, 1974)

Well type *	Annual depreciation cost, L.E.	Annual maintenance cost, L.E.	Cost per feddan (7,500 m ² , L.E.)
A	910	91	13.5
B	3,000	300	13.5
C	3,800	380	24.1
Average			16.9

* Based on depth and corresponding screen material

4.3 Nonagricultural Uses of Western Desert Water

All figures for desert irrigation used in this report include an estimated 10 percent for related uses, including domestic supply, and processing farm products, such as dates. In addition, there is the possibility that as much as $80 \times 10^3 \text{ m}^3/\text{day}$ of water eventually may be used for processing phosphate in the Abu Tartur plateau 40 km west of the village of Kharga. Additional nonfarm use may be involved in concentrating iron ore at Bahariya ($50 \times 10^3 \text{ m}^3/\text{day}$) or in processing it more extensively. The latter requirement could be as much as $40 \times 10^6 \text{ m}^3/\text{year}$ and amount to 16 percent of the groundwater available at the site.

It is generally conceded that there is sufficient arable land in the Western Desert to utilize all the groundwater which can be supplied at an acceptable cost. Thus, use for nonagricultural purposes would be at the expense of productive land. Phosphate processing, for example, would involve a loss of about 5,000 feddans of land in the Dakhla sector.

An exception to this constraint is the possibility that the large amount of brackish and saline water presently discharging in the Qattara Depression might be used for certain industrial processes, such as cooling and mud preparation in oil drilling operations. Industrialization of the desert has not yet reached the stage where the value of this resource can be estimated; however, some brackish water has been used in oil exploration.

4.4 Water-quality Factors, Western Desert

Because of recharge and related freshwater flushing in a northeasterly direction, dissolved-solid content of Nubian water increases from south to north and west to east. In Dakhla and Kharga Oases, concentrations range from 200 mg/l in deep aquifers to 600 mg/l in shallow aquifers, presumably because upward percolation and near-surface evaporation have increased the latter. As the fresh water-salt water interface is approached, the pattern reverses and dissolved-solid content increases with depth. In Bahariya, it is 300 mg/l at 700 m depth and increases to 950 mg/l at a depth of 1,760. North of latitude 29, salt concentrations increase more rapidly. In the Ghazalat well of northern Qattara, the dissolved solid is 1,650 mg/l at 980 m depth and 100,00 mg/l at 2,200 meters. In the Mamura well near the seacoast, the concentration increases to 120,000 mg/l at 3,050 m. A zone of relatively fresh water (1,500 mg/l) overlies a saline zone (17,000 mg/l) in the Qattara Depression, perhaps as a result of inflowing Miocene water.

Generally speaking, fresh waters in the Nubian have low-sodium absorption ratios favorable to agriculture. On the other hand, they are characterized by relatively low pH values (acidic), low oxidation-reduction potentials (Eh values), relatively high temperatures (up to 45°C), and high gas contents, particularly nitrogen and carbon dioxide.

Troublesome amounts of ferrous and sulfide ions also are common. Ionic balances, like salt concentrations, show evidence of change in the direction of water movement. Waters from Dakhla Oasis are consistently sulfo-chloride types, whereas some wells in Kharga approach the sulfo-chloride type and others are distinctly alkaline bicarbonate types. The combined effects of low pH, destructive sulfide ion, unfavorable ratio of chloride and sulfate to less aggressive ions, Eh values which hinder protective oxide formation, and elevated temperatures cause Nubian waters to be very corrosive to mild steel. This has been very troublesome in well development and could be a problem in industrial systems. The relatively high iron content also could be troublesome in certain domestic uses, for example food preparation and laundry operations.

5.0 WATER AND WATER USE IN OTHER ARID REGIONS

5.1 Kurayim and Lake Nasser Basins (South Kharga)

This area is said to contain from 1,000,000 to 3,000,000 feddans of land which might be converted to irrigated agriculture if water were available (Parkinson and Worts, 1976). However, Ezzat (1978) has concluded that groundwater from the Nubian can support only 135,000 feddans in South Kharga. It has been suggested that water might be supplied to the area from Lake Nasser. The lake's upper flood-storage level is estimated to be 183 m, and 1,000,000 feddans might be irrigated by gravity flow after a minimum pump lift from the lake over the 185 m divide which separates it from the depression (Parkinson and Worts, 1976). To be effective in perennial irrigation, the system would need to operate economically at the 175 m minimum flood-control level. If present desert irrigation practice is adhered to, the diversion for 1×10^6 feddans would be 5 to 7.5×10^3 m³/year, which equals 7 to 11 percent of the projected Nile resource. It seems unlikely that this would be a viable tradeoff considering the relative productivities of desert and valley lands.

Some thought also has been given to irrigation in Toshka Depression, a natural spillway from Lake Nasser during exceptional floods (e.g., 20-year event). Such periodic flooding would not appear to be a dependable source of irrigation water.

5.2 Faiyum Depression

This desert area, 90 km southwest of Cairo, is actually part of the Nile system. Water for irrigating 270×10^3 feddans is delivered through the Bahr El Yosef Canal, and agricultural drainage terminates either in Lake Karoun, or an alternative depression now being used to reduce the lake's level and to avoid waterlogging and salting of adjacent land. The only groundwater is from percolation of irrigation water and there is no significant groundwater use. The salt concentration in Lake Karoun is higher than that of seawater and thus unfit for agricultural use, although it might be used for certain industrial purposes, such as cooling.

5.3 Wadi Natrun

Wadi Natrun is an elliptical subsea-level depression 70 km northwest of Cairo and adjacent to the delta. It contains several saline lakes in subdepressions; however, a pilot area of 6×10^3 feddans currently is irrigated with local rainfall and groundwater infiltrating from the Nile. Water is supplied by 54 wells which yield a total of $48.6 \times 10^3 \text{ m}^3/\text{day}$ (Idris, 1976). There is no plan to expand agricultural water use in the depression because of drainage and related salinity problems already encountered. It is unlikely that this water supply could be increased significantly for other uses without corresponding extraction from the Nile system. Deep Nubian water in the wadi is saline.

5.4 Other Areas West of the Nile

Modeling studies at the proposed site of Sadat City, east of the Alexandria-Cairo desert road and adjacent to the southern end of Wadi Natrun, indicate that sufficient groundwater can be developed to supply a population of one million. Predicted use in m^3/day for this number of inhabitants is as follows (Ezzat, 1978):

Domestic	140,000
General	35,000
Industrial	100,000
Agricultural	<u>137,500</u>
Total	412,500

This amounts to 140 per capita domestic consumption, less than the present 180-200 in urban areas, and 412 per capita total use, which is considerably less than the 1,000 projected for future desert industrial cities (Maskoud, 1978). Plans for partial reuse in irrigation and ground-water recharge apparently account for the relatively conservative figures. The 300-m thick unconfined aquifer from which this water will be drawn is recharged largely from the Nile. The above pumping rate is expected to result in a 30-m drawdown and an additional extraction of $38 \times 10^3 \text{ m}^3/\text{day}$ ($13.9 \times 10^6 \text{ m}^3/\text{year}$) from the Nile system. Sadat City is planned to start in 1980 and reach maturity in 2000.

In an area of Tahrir province adjacent to the Cairo-Alexandria desert road, 152 wells of 250 to $1,250 \text{ m}^3/\text{hr}$ capacity are being used for supplemental irrigation of 50,000 feddans (Eakin, 1975). Also, in the south Tahrir province, 40 wells averaging $80 \text{ m}^3/\text{hr}$ were constructed to irrigate 3,000 feddans; however, the relatively high lift (70 m) made this project uneconomical. Throughout this area, there appears to be little surplus water which is economically practicable for agricultural needs. Deeper water, either fresh or brackish, might be acceptable for industrial use.

5.5 Western Coastal Zone

Shallow water occurs in relatively thin lenses over brackish and saline water in a narrow west coast belt where precipitation is relatively more abundant (i.e., 90 to 200 mm/year). The shallow aquifer precludes large capacity wells, which would induce salt water intrusion, but there are numerous filtration galleries and low-yield wells, some of which are pumped by windmills in the area. Extension of the Nubarria and Nasser canals as far west as Mersa Matruh will augment the local groundwater supply with canal and irrigation seepage, but related leaching could degrade groundwater quality. It seems unlikely that the freshwater resource will be in excess of agricultural need, even with this supplement.

5.6 Delta to Suez Area

North of the Ismailia Canal, there is limited rainfall and probably corresponding recharge of the groundwater system; however, little quantitative data exist concerning this resource, and information now is being sought in a research project of the Ministry of Irrigation. According to Lee (1975), much of the 450,000-feddan area east of the delta is lacustrine deposit over old river sediment which might be suitable for irrigation with water from the Nile. Some is heavier soil, like that west of the delta, and is likely to involve similar salinity and alkali problems. In any event, water for these lands, like that for any suitable land west of the delta, probably would be primarily a direct or indirect extraction from the Nile.

5.7 Eastern Desert

Little quantitative hydrologic information has been collected in this area to date. The Desert Institute is preparing a working paper, which will, as a principal objective, detail those studies required for better definition of the groundwater resource (Shata, 1978). There is some evidence of usable water from the Nubian in the southern desert. Eakin (1975) mentions a low-yield well from this formation 30 km north of Aswan and 50 km east of Kom Ombo. There is a similar well near La Quita between the Nile and the Red Sea, and another south of Aswan and east of Lake Nasser, which yields a small amount of artesian water. Numerous wadis, such as La Quita which drains to the Nile, and Arabah which drains to the Gulf of Suez, are known to have freshwater springs which might indicate a groundwater resource sufficient for processing energy-related ores in the area. There also is artesian water along the west side of the Gulf of Suez. An oil well at the city of Suez which reached basement clastics, the equivalent of the Nubian at 2,500 m, yielded a relatively large flow of brackish artesian water (Shata, 1978). Farther south Sukhna hot spring emerges with a considerable flow. Non-artesian water occurs in Cretaceous limestone formations 70 km south of Suez and may be upwelling from the Nubian. Although the extent of groundwater is unknown, it is generally agreed that freshwater resources in the Eastern Desert are very limited, as compared with those in the Western Desert (Shata, 1978).

5.8 The Sinai

Groundwater with artesian heads ranging from 5 to 100 m below land surface occurs in sandstone and limestone aquifers in the Maghara area of the Sinai, where Egypt's most promising coal deposit is located (Rudis, 1967). There is a sufficient quantity to allow continuous pumping at modest rates (e.g., 300 to 600 m³/day), but the dissolved-solid content is about 8,000 mg/l and thus is of value only in certain industrial uses.

Relatively hot brackish and saline artesian waters occur on the east side of the Gulf of Suez (Hermina and Wassef, 1969). Near Ayun Musa (Spring of Moses), water in Jurassic deposits at 570 m depth is under 65 atmospheres of pressure and the artesian head is 63 m above sea level. This is saline water with a dissolved-solids content of 9,000 mg/l. Cretaceous water at the same location is under 30 atmospheres of pressure (artesian head 54 m above sea level), and its solids content is about 3,000 mg/l. The odor of hydrogen sulfide can be noted in waters from both formations, and a temperature of 42°C was measured at 440 m depth.

There also are numerous springs in northeastern Sinai, for example, at El Gedirat and Qedeas (Idris, 1976). These, like the hot artesian water discussed above, are thought to be supplied by recharging in Syria.

The Sinai coast has many shallow wells which produce fresh water of 2,000 mg or less from calciferous sandstone. According to Idris (1976), there are 43 wells in the area that yield in the 500 m³/day range, and the total water production is 33,000 m³/day. Here, as in the western coastal belt, there appears to be little fresh water which is surplus to agricultural and related needs. Figure 6 shows some of the principal water resource locations in the Eastern Desert and the Sinai.

6.0 WATER IN THE CONTEXT OF ENERGY RESOURCES AND SYSTEMS

6.1 Hydroelectric Power

Hydroelectric generation is not a consumptive water use, nor is it a significant source of contamination. The principal hydropower installation in Egypt consists of twelve 175-megawatt (MW) turbines on the High Dam, ten operating and two in maintenance. Capacity of the installation cannot be increased for peaking because the reservoir of the Aswan Dam immediately downstream is limited to 3 m variations in level to avoid thermal shock of the masonry structure from the relatively large swings in ambient temperature (air temperatures reach 55°C). Power output also is constrained by transmission line capacity and by regulations governing discharge of irrigation water. Quantities to be released from the High Dam for this purpose are specified daily and must

Fig. 6 Sketch map of Egypt, showing location of certain water resources, Eastern Desert and Sinai (Modified from Desert Institute map)

be adhered to, except that hourly fluctuations within the daily limit are permitted. Daily discharge varies from 80 to $250 \times 10^6 \text{ m}^3/\text{day}$, but usually is held at about $120 \times 10^6 \text{ m}^3$.

Another stage of hydro at Aswan Dam also is constrained by agricultural regulations and has been markedly reduced in capacity by drawdown of the reservoir to provide head for High Dam turbines. The Aswan units originally designed to operate at 23 m head and 345 MW, now operate at 10 m head and 220 MW. Figures 7 and 8 show the percentages of monthly river flow passed through the turbines at the High Dam and Aswan. The constraint on High Dam generation, which results from regulation of irrigation discharge and transmission line limitation, is clearly evident.

Although there is only 70 m fall between Aswan and Cairo, a third stage of hydropower (190 MW) could be provided by low-head turbines operating on three of the four existing barrages, as shown on the river profile of figure 9. No pumped storage is available on the river to generate peaking hydropower. Although there are adjacent high elevations, for example, the scarp near Nag Hammadi and a requirement that water withdrawn from the Nile be returned the same day makes such an installation in this location impracticable.

There is active planning to increase hydropower, including that on the Nile. The most imaginative suggestion is the long-standing proposal to tunnel or channel Mediterranean water 56 km through 230 m of intervening highlands to the Qattara Depression, which is 205 km northwest of Cairo and as much as 134 m below sea level. It is assumed that evaporation would stabilize the receiving lake in 10 years at 60 m below sea level and provide effective fall for both baseload and reservoir or canal-stored peaking water. Although a large surface canal would provide more flow, simplify storage for peaking, and generate more power than a tunnel system, either alternative could make impressive additions to Egypt's power spectrum. The project, currently undergoing a feasibility study, embodies three proposed phases: a filling period when the output would be 315 MW (tunnel) or 670 MW (canal); a second stage, including canal or reservoir peaking, for a total of 1,200 MW; and a third stage, with pump storage increased to provide 2,400 MW or more by the year 2000.

Seven pump-storage sites also have been identified on the Gulf of Suez with the characteristics and capacities shown in table 10. The best of these, near the town of Sukhna, is now undergoing refined feasibility studies.

Recent consideration also has been given to building four new barrages with low-head power turbines at strategic locations on the Nile (figure 9). Implementation of this plan requires approval and support

Fig. 7. Histogram showing the discharge from High Dam and the percent passed through the turbines.
(Courtesy of Master Water Plan Office, Ministry of Irrigation)

Fig. 8. Histogram showing the discharge from the Aswan Dam and the percent passed through the turbines. (Courtesy of Master Water Plan Office, Ministry of Irrigation)

Fig. 9 Profile Nile channel, Aswan Dam to Nile Delta, showing existing and potential barrage hydropower sites.

TABLE 10

CANDIDATE SITES, PUMP STORAGE HYDROPOWER
(MINISTRY OF ENERGY AND ELECTRICITY, 1978)

Design feature	Areal location						
	Calala el Bahariya				Ataya		
	Site				Site		
	1	2	3	4	5	6	7
Level, m							
Maximum	578	545	518	458	478	300	358
Minimum	560	520	460	425	420	240	260
Storage capacity, $m^3 \times 10^6$	8.2	15.9	34.1	14.0	28.4	59.0	72.7
Energy storage GWh	10.87	19.75	38.87	14.33	29.54	36.51	50.89
Maximum installed power, MW	1,000	1,900	3,800	1,400	2,900	3,600	5,000
Distance to sea, m	1,700	1,350	1,900	2,150	3,330	2,650	4,430

from the Ministry of Irrigation. This is not likely to be given unless there is evidence of troublesome channel degradation and meandering resulting from High Dam effects, which might be mitigated by the new structures. There also is a plan for adding more turbines at Aswan Dam.

Although competitive use, particularly in irrigation, is a significant constraint on hydropower development, such development is not likely to affect Egypt's water resources, except in the Qattara project. There, hydraulic head in the new lake probably would yield related head increases in the Nubian aquifer at Siwa and Bahariya and reduce the cost of long-term water recovery.

6.2 Thermal Electric Energy

Fossil-fueled steam-electric generation can consume water through evaporative condenser cooling, boiler blowdown, steam leakage, and stack-gas scrubbing. Water-quality impacts can result from discharge of heated water and boiler waste into receiving bodies with limited dilution capacities. Cooling is by far the greatest consumptive use and also the principal source of water quality problems. Both are proportional to the amount of energy generated by thermal installations; significance of impact depends in part upon the proportion of cooling done with fresh-water resources.

Table 11 shows the fossil-fueled units presently operating and those planned for the near-term, together with information concerning source of cooling water and estimated fresh water consumption. Table 12 and figure 10 show, respectively, a long-term projection of electrical energy development and a suggested pattern of energy generation for a typical January day in the year 2000. The fossil-fueled capabilities shown in the table, including reserves and losses, range from 4.5×10^3 MW in 1985 to 8.3×10^3 MW in the year 2000, depending on the option selected. Generally speaking, option 1 appears to be the most likely (3.4×10^3 MW). Continuous operation at 3.4, 4.5, and 8.3×10^3 MW levels, using conventional cooling-tower systems, would involve annual water consumptions for cooling, makeup, and related housekeeping of 48 to 63, 63 to 83, and 116 to 154×10^6 m³/yr, depending on system efficiency. These figures, which range from 0.07 to 0.22 percent of the 70×10^9 m³ projected annual flow of the Nile, assume all fresh surface-water cooling. It is evident in table 11 that much cooling already is being done with saline water and more use is likely to be made of it in the future to conserve fresh water for more critical uses.

The principal water-quality problem attributed to power generation thus far is thermal pollution of canal water, for example, at the Karmouz Plant in Alexandria. This problem can be expected to increase in both the canals and the Nile, if additional fossil-fueled generators are cooled with once-through systems. However, it can be controlled at the expense of slightly increased water loss by the recycle cooling assumed in the above water consumption figures.

TABLE 11

FOSSIL-FIRED STEAM-ELECTRIC GENERATING PLANTS
(MODIFIED FROM SANDERSON AND PORTER, 1977)

Location	Number of units	Unit size, MW	Total nameplate capacity, MW	Date of installation	Estimated water consumption $m^3 \times 10^6$ per year
Assuit	3	30	90	1967	1.3 - 1.6
Cairo North	2	10	20	1953	--
	1	20	20	1953	--
	2	30	60	1955	1.4 - 1.8
Cairo South ¹	4	60	240	1965	--
	1	7.5	7.5	--	--
Cairo West	3	87	261	1968	--
Cairo West	1	87.5	87.5	1979	4.9 - 6.3
El Tebben	3	15	45	1959	0.6 ⁵ - 0.8
Karmouz	4	16	64	1948-54	0.9 ⁵ - 1.2
Siouf	2	26.5	53	1961	--
Siouf	2	30	60	1968-69	1.6 - 2.0
Damanhour	2	15	30	1960	--
	3	65	195	1968	3.2 - 4.1
Talka	3	12.5	37.5	1956	--
	3	30	90	1967	1.8 - 2.3
Suez ¹	4	25	100	1964	--
Suez ³ ⁴	2	150	300	1982	--
Suez ³ ⁴	2	150	300	1982	--
Suez ³ ⁴	2	150	300	1981	--
Ismailia ³ ⁴	2	110	220	1977	2.8 - 3.6
Kafr El	2	150	300	1981	--
Dawar	2	150	300	1980	--
Abu Kir ³	2	150	300		
Total fresh water consumed					18.5 - 23.7

¹Out of service²Unit load limited to 8 MW in summer because of cooling problem³Sea water cooled⁴Tentative location⁵Assumes full operation

TABLE 12
PROJECTED ENERGY PATTERN, EGYPT

Energy system characteristics	1976	1985	2000			
			Option 1	Option 2	Option 3	Option 4
Capability, MW [*]						
Conventional hydro	1,500	2,130	2,200	2,200	2,200	2,200
Pump storage hydro	0	0	2,900	4,300	2,900	4,300
Fossil-fueled thermal electric	2,289	4,454	3,385	3,985	4,715	8,315
Nuclear-fueled thermal electric	0	0	12,600	10,600	10,600	5,600
Qattara hydro	0	0	0	0	670	670
Total	3,789	6,670	21,085	21,085	21,085	21,085
Demand at generator, MW	1,909	5,045	17,395	17,395	17,395	17,395
Energy generated, KWhr x 10 ⁹						
Load	11.64	30.58	97.79	97.79	97.79	97.79
Pumping energy	0	0	5.50	8.10	5.50	8.10
Total	11.64	30.58	103.29	105.89	103.29	105.89
Energy supply at load, KWhr x 10 ⁹						
Qattara hydro	0	0	0	0	5.7	5.7
Other hydro	8.0	7.4	8.3	8.3	8.3	8.3
Fossil and nuclear thermal	3.6	23.2	95.0	97.6	89.3	91.9
Total (rounded)	11.6	30.6	103.3	105.9	103.3	105.9

Fig. 10. Projected energy pattern, Egypt typical January day, year 2000.

6.3 Nuclear Thermal

Electrical energy generation in a conventional heavy-water reactor involves about 50 percent more consumption of cooling water than a fossil-fired generator of the same capacity. There also are well-known waste problems involving water resources, some of which remain unsolved, even in the most technically advanced societies.

The current plan is to locate all nuclear generators, including the 12,600 MWe baseload of table 12, in coastal areas where saline water can be used for cooling and the impact of heated discharges will be reduced. This plan would essentially eliminate undesirable effects on the Nile system and fresh-water resources in the deserts.

Although commercial quantities of nuclear fuels have not been produced yet in Egypt, there is evidence of related minerals and an estimate that discoveries between now and 2000 might be sufficient to support the country's proposed nuclear energy program. Processing raw material required for 12,600 MWe of nuclear energy generation, including associated fossil-fueled³ electrical generation for enrichment, would consume about 1×10^6 m³ of water (Davis and Wood, 1974).

6.4 Water in Coal Development

Modest amounts of water are required in surface and deep mining of coal. Uses include dust control, fire protection, coal washing, waste disposal and related power generation, and general housekeeping. Kirkpatrick and Davis (1976) estimate the total at 63 l/tonne for underground mining and 17 l/tonne for surface mining, plus an additional 33 l/tonne for waste disposal in each type of operation. They also state about 70/tonne may be required for irrigation to re-establish vegetation in surface-mine land reclamation. It would appear that these figures do not include water for extensive washing of coal. Also, it should be noted that pumping of much larger quantities frequently is required to dewater coal-bearing formations.

Egypt's principal coal resource is located in the Maghara area of the Sinai, 150 km east of Suez, 75 km inland from the sea. It contains an estimated 51.8 million tonnes of measured, proved, and probable coal less than 400 m below the surface, and it is proposed that 35.6 million tonnes be recovered by long-wall deep mining. The aforementioned artesian water in this area would require significant dewatering as part of the mining process, but also would supply water for essential mining operations such as washing. The quantity of water in storage in that part of El Safa and Um Kafa³ Wadis, where most mining would occur, is estimated to be 3.2×10^6 m³ in the sandstone and 0.6×10^6 m³ in the limestone (Rudius, 1967). If pumped at a rate of 300 m³/day, the supply is estimated to be adequate for 35 years, and the cone of depression after 20 years' pumping and 55 m drawdown would have an estimated radius of 350 m (Rudius). The original plan to produce only 300,000 tonnes of coal annually in order to make truck transport practicable would greatly

extend the mining period and might require adjustment of the pumping rate to insure adequate water₃ for mining throughout the period. A recent proposal to pump 600 m³/day also might cause early depletion.

An alternate plan to transport the coal by pipeline would permit faster mining but use more water. At the 300,000 tonnes/year rate, 1×10^3 /day of pipeline water would be needed, assuming one ton of water per ton of coal. This is more than three times the water available at the 300-m³/day pumping and exceeds 600 m³/day by 40 percent. It has been suggested that the coal might be transported by a 20-cm (8-inch) line and the water returned by a 10-cm line to extend the supply. Also, it has been suggested that a single larger line might be used to alternately transport coal and return water. Plans of this kind would facilitate the handling of considerably more coal with the same amount of water. The relatively high sulfur coal involved might produce sulfuric acid when exposed to water and air and cause troublesome corrosion in the transport system, unless preventive treatment is applied.

Mine-mouth conversion of the coal using a steam-electric generator would involve even higher water₃ requirements. Evaporative cooling of a 16-MW unit would consume 600 m³/day, leaving none for other mining operations, and would convert only about 115 tons of coal, assuming 12,000 Btu per heat value.

Although the quantity of water at this site may be ample for mining and associated needs, other than conversion, if reuse is practiced, the overall quality leaves something to be desired. Figures published by Rudius (1967) indicate dissolved-solids concentrations of about 8,000 mg/l, with relatively large amounts of sodium and chloride ions. Such water could be used in mechanical washing, but might discolor the coal and cause sodium absorption problems. On the other hand, the coal may already have absorbed sodium through contact with the water-bearing formation. In any event, it should be practicable to overcome the problem with modern ion-exchange treatment. Water quality would not be a problem in cooling, dust control, waste disposal, or slurry transport, except for the possibility of corrosion mentioned earlier.

Water also is a pertinent consideration at the site of coal deposits near Ayun Musa east of the Gulf of Suez because of high artesian pressures, high temperatures, and high solids mentioned earlier. An exploratory hole at this location yielded 510 m³/day from a depth of 120 m. With the coal located at depths from 418 to 650 m, considerable dewatering probably would be required to recover the coal. Water quality would pose problems similar to those at Maghara, and the relatively high temperature would be an added burden.

Western Desert coal is known to exist in thin veins (e.g., 3 m) at depths ranging from 800 m near Kharga Oasis to 3,000 m near Wadi Natrun. Relatively abundant water in Nubian and Miocene aquifers would make it difficult to recover this coal, even if other problems can be overcome.

6.5 Water in Petroleum Development

Assuming water requirements in Egyptian drilling and refining operations similar to those in the United States, the present 500,000-barrel per day (bbl/day) production would use, and for practical consideration consume, about 2.9×10^6 m³ of water/year; the requirements of the projected one million-bbl capacity would be 5.80×10^6 m³. Water use in refining 81×10^6 bbl/year, the current rate, would amount to 143×10^6 m³, about 11×10^6 m³ of consumptive loss (Davis and Woods, 1974). The corresponding use and consumption figures for 116×10^6 m³ bbl/year in 1985 and 196×10^6 m³ bbl/year in 2000 are 204×10^6 m³ (16×10^6 m³) and 327×10^6 m³ (26×10^6 m³), respectively. Thus, present and projected needs of the petroleum industry are rather nominal, particularly because most production, including all water-flooding operations, are in the Gulf of Suez, and most refining can be located in either the Suez or Alexandria areas where cooling with saline water is practicable.

Drilling operators in Western Desert locations should be able to use water from Miocene formations, and thus conserve the fresh groundwater which is essentially obligated to agriculture. In fact, saline water already is being used for mud preparation in Western Desert petroleum exploration.

6.6 Geothermal Resources

Geothermal energy development involves the use of water resources and relatively high consumptive water loss because of basic inefficiencies in such conversions. This is not a particularly pertinent water resource consideration in Egypt because no geothermal sources of real importance have yet been discovered. Those which are known are located on the Gulf of Suez (figure 6) and in the Eastern and Western Deserts. One well, Umm Khariga, with a temperature of 35.8°C (which is marginally geothermal), occurs in the Eastern Desert, and the groundwater temperatures in the Western Desert are generally 5°C to 7°C above the temperatures expected from ambient conditions. The highest (45°C) was recorded in Qasr hot springs of Dakhla Oasis.

Abnormal temperatures also have been observed in the Nile Delta. An exploratory well, in a north-central location, yielded water at 87°C from an unstated depth, and a bore at Burg-el Arab west of Alexandria showed a near-normal geothermal gradient to 4,000 m depth. However, a geopressured zone was found only in the first location. An Arco exploratory well midway between Alexandria and Libya, at a point just south of Mersa Matruh on the Mediterranean coast, also encountered 145°C water in Jurassic formations at relatively shallow depths.

Other thermal springs reported in the Helwan area actually are mineral springs of normal or only slightly elevated temperature used in artificially-heated health baths.

In the event that geothermal conditions affording temperatures in the 150° to 200°C range are discovered, water volumes of about $1.10 \times 10^6 \text{ m}^3/\text{year}$ would be required to support each generator.

7.0 SUMMARY AND CONCLUSIONS

A report by the World Health Organization (1977) estimated the fully developed capacity of the Nile system at $70 \times 10^9 \text{ m}^3/\text{year}$, including up basin conservation, irrigation return flow, and valley and delta groundwater development. If Lee's (1975) figure of $30.4 \times 10^9 \text{ m}^3/\text{year}$ consumptive use for the present 6.3×10^6 feddans of crop-land is used, the consumptive requirement for the projected 9×10^6 feddans in the valley and delta ($6.3 + 2.8$) amounts to $43.4 \times 10^9 \text{ m}^3/\text{year}$. Assuming the 58 to 59 percent irrigation efficiency used in projections by Hoofnagle, et al. (1976), this would require 73 to $74 \times 10^9 \text{ m}^3$ of irrigation withdrawal which exceeds the projected maximum capability of the Nile. Improvement of efficiency of 61.5 percent would approximately balance irrigation demand and projected supply.

Considering the present domestic-industrial withdrawal of $2.68 \times 10^9 \text{ m}^3$ (table 1), the predicted expansion of population (38×10^6 to 67×10^6), and related industrial growth between now and the year 2000, it is reasonable to expect a nonagricultural water requirement of at least $5 \times 10^9 \text{ m}^3$; perhaps $7.5 \times 10^9 \text{ m}^3$. If this is the case, 70 percent irrigation efficiency would be required to conserve water for municipal and industrial purposes. According to Lee (1975), this is not unreasonable for a closed system like that of the Nile. There also are the alternatives of conserving municipal-industrial water, increasing agricultural productivity on presently irrigated land, and greater utilization of desert groundwaters.

The consumptive water requirement of proposed energy development is relatively small by comparison. Even with maximum dependence on fossil fuel, it should not exceed 0.25 percent of the ultimate Nile flow and thus is a minor element in a massive water balance equation.

In the Western Desert, the water resource of the Nubian aquifer is essentially nonrenewable and dedicated almost entirely to agricultural and related uses. Enough land can be reclaimed to consume whatever fresh water is economically available. Thus, diversion to other uses may result in the loss of productive land.

Some flexibility exists for using the desert's relatively abundant brackish and saline Miocene water in noncritical industrial and energy-related programs (e.g., oil production). In view of the land constraint in Egypt, it seems likely that full use will be made of this brackish resource before resorting to the tradeoff mentioned above.

Water resources of the Eastern Desert and the Sinai are largely unexplored; however, an optimistic view is that sufficient water can be discovered for use in developing their resources, including coal, petroleum, and energy-related minerals. There seems to be no plan for large-scale agriculture in these areas which would compete for the limited supply.

Although present plans for agricultural and industrial expansion, together with expected population growth and increased urbanization, could totally obligate water resources of the Nile as now developed within a decade, this is not likely to happen in view of the opportunities for conservation and development of additional water resources.

A more optimistic, and probably more realistic conclusion, is that Egypt's water resources, in total, will be capable of supporting increasing demands for the remainder of the century, provided they are developed and managed effectively. This will require maximum practicable conservation in the upper Nile basin, improvement in irrigation efficiency, and reduction of loss in municipal and industrial uses, particularly through treatment and reuse of waste water. Also, it will require an optimum development and utilization of groundwater along the Nile and in the deserts, as well as substitution of saline or brackish water for fresh water when they will serve the purpose. Systematic water-quality monitoring will be required to guard against the potential problems related to heavy agricultural and municipal uses.

The Egyptian Government is well aware of the need to expand and conserve water resources and is taking impressive steps in that direction. The United Nations Water Master Plan Office (Ministry of Irrigation) is engaged in a multi-year project aimed at assessing current water use and improving water-use efficiency through better water management. The same Ministry is conducting ground-water modeling studies of the Nile delta, which are to be followed by similar modeling in the valley in order to determine safe groundwater yields. Also, it is cooperating with the United Nations (UNDP) in real-time telemetering of surface water data. The Desert Institute, along with the Water Master Plan Office, is preparing a proposal for exploring water resources of the Eastern Desert. The Egyptian Academy of Sciences, the U.S. Environmental Protection Agency, the University of Michigan and the Ford Foundation, have jointly made much progress in monitoring water quality in Lake Nubia, Lake Nasser, and the Nile River and delta. As recently as March 1978, President Sadat re-emphasized the need to increase exploration and development of Western Desert groundwater.

8.0 RECOMMENDATIONS

Because the Nile must bear the principal burden of increasing water use, it is recommended that maximum practicable support be given to upstream conservation projects. Also, it is recommended that early efforts be made to systematically explore Eastern Desert groundwater resources, particularly in areas where they are likely to be needed in developing strategic minerals. More exploration of the Nubian aquifer beyond the desert depressions and additional groundwater studies at potential desert city sites will help optimize use of desert water and relieve the Nile.

Beyond this, it is recommended that thought be given to establishing an office of water data coordination, like that in the U.S Geological Survey, to take full advantage of the mass of information now being collected concerning water resources. Such an office could serve as a central library, both conventional and computerized, for the many facts and figures needed for effective water management.

9.0 REFERENCES AND OTHER SOURCES OF INFORMATION

- Cushman, Robert E., and Gates, Joseph S., Investigations of Groundwater of El Kharga and El Dakhla Oases, New Valley Project, Western Desert, Egypt. U.S. Geol. Survey Water Supply Paper (in process).
- Davis, G. H., and Wood, L. A., Water Demands for Expanding Energy Development. U.S. Geol. Survey Circ. 703, 1974.
- Hefney, K., Egyptian Ministry of Irrigation, Private Communication, 1978.
- Kirkpatrick, F. A., and Davis, G. H., "Water demands as related to increasing coal utilization in the United States" Wasserwirtschaft and Geurnnung Fossiler Energietrager, Internat. Symposium, Dusseldorf, Deutsches Komite der I.W.R.A. im Deutschen Westband fur Wasserwirtschaft e.v., Paper #14, 1976.
- Eakin, Thomas E., Groundwater in United Arab Republic. Consultant report to U.S./A.I.D., 1975.
- Ezzat, M. A., Exploration of Groundwaters of El Wadi-El Gedid Project Area, New Valley, parts I-IV. Ministry of Agriculture and Land Reclamation, Executive Agency for Desert Irrigation, 1974.
- Ezzat, M. A., Private communication, 1978.
- Hermima, Maurice, and Wassef, Abdalla, Wadi Araba Borehole #1. Egypt Geol. Survey internal report, 1969.
- Hellstrom, B., "The Subterranean Waters in the Libyan Desert," Sattrjek ur Geografiska Annater, v. 34, 1940.
- Hoofnagle, William S., and others, Egypt, Major Constraints to Increasing Agricultural Productivity. Joint U.S.A.-Egypt report for U.S./A.I.D. and Egyptian Ministry of Agriculture, 1976.
- Idris, Hussein, Groundwater Reservoirs in the Arab Republic of Egypt. Egyptian Y.M.C.A. Environmental Symposium Proc., Alexandria, March 1976.
- Lee, J. Karl, Irrigation in Egypt. Consultant report to U.S./A.I.D., 1975.
- Maksoud, K., Egyptian Ministry of Industry, Private Communication, 1978.
- Mina, G. A., and Salem, A. Y., Environmental Protection by Controlled Disposal of Liquid Wastes in Lake Maryut. Egyptian Acad. Sci. Research and Technology Proc. and Y.M.C.A. seminar on environmental action for quality of human life, Alexandria, Egypt, March 25-28, 1976.

Morris, J. Carrell, "Observations on Water Supplies in Egypt," New Zealand Water Works Assoc. Journal. Sept. 1960.

Parkinson, H. L., and Worts, G. F., A Brief Evaluation of Groundwater and Soils Potential for Irrigated Agriculture, Western Desert, Egypt. U.S. Geol. Survey open-file report, 1977.

Parsons, R., Final Report, Siwa Oasis Area, New Valley Project, Western Desert of Egypt. Consultant report to Egyptian General Desert Devel. Organization, 1963.

Rudius Industrial and Mining Assoc. Hydrologic Investigations - Maghara Area - Geol. Survey Yugoslavia, 1967.

Sanders, W. M., U.S. Environmental Protection Agency, Private Communication, 1978.

Sanderson and Porter Power Sector Survey Team, Power Sector Survey, Arab Republic of Egypt: Systems Planning Diagnostic Report sec. 1, 1977.

Shata, A. A., Egyptian Desert Institute, Private Communication, 1978.

United Nations Food and Agricultural Organization, Groundwater Pilot Scheme, New Valley Groundwater Resources, 1977.

World Health Organization-World Bank, Water Supply and Sewage Sector Study, Egypt, v. 1, 1977.

10.0 SAMPLE DATA* ATTACHMENT - SUMMARY, NILE WATER-QUALITY SAMPLING PROGRAM

River segmentation is illustrated in figure A-1. This includes segments at: (1) Aswan at the outlet of Lake Nasser; (2) Assiut, in the middle region between the Lake and the Delta; (3) Cairo, upstream from the Quanter Barrage; (4) Kafr El Zayat-Edfina, on the Rosetta branch; and (e) Mansoura-Faraskour, on the Damietta branch of the Nile. Detailed information on each segment includes: (a) a map which illustrates sampling points, water intakes, industrial effluents and type, municipal discharges, bridges, boat docks, etc., and (b) a narrative description of each segment which includes (i) human settlements (villages and cities, population, and water and sewage facilities) and (ii) human activities (agricultural areas and type, industrial plants and type, direct and indirect use of river for water supply or waste discharge, navigation, and fisheries).

10.1 Aswan Segment

(Mr. Mahmoud Rashid): This segment needs to be further defined by the Aswan Group. The beginning of the segment is the old Aswan Dam. The end of the segment is approximately 20 km downstream from Aswan City.

10.2 Assiut Segment

(Dr. Ahmad A. Swelim): This segment begins at Wasta Island and ends downstream from the Barrage at Sallam Village. The length of this segment is approximately 17 kilometers. A power plant, water treatment plant and a fertilizer plant are located on this segment.

Industrial wastes such as CaF_2 and CaSO_4 are discharged from the fertilizer plant at Mankabad. Ship activity is also observed in this sector, especially at the Barrage (boat dock).

Three sites of measurements were selected. The first site is located at Wasta Island, the second at the water treatment plant and the third at Sallam Village. Samples will be collected at different points in the cross section. The distance from the first site to the third site is approximately 17 km; the distance from the first site to the second site is approximately 1.5 km; the distance from the first site to the Assiut Barrage is approximately 4 km; and the distance from the first site to the fertilizer plant is approximately 13 km.

* Courtesy, U.S. Environmental Protection Agency

WATER QUALITY STUDIES ON THE RIVER NILE
AND LAKE NASSER --ANNUAL REPORT: 1976
PART III: River Ecosystem Studies

Fig. A-1

WATER QUALITY STUDIES ON THE RIVER NILE
AND LAKE NASSER -- ANNUAL REPORT: 1976
PART III: River Ecosystem Studies

10.3 Cairo Segment

The Cairo segment is characterized by the following sites:

- A. Helwan 1 (H1): At about 1 km south to the steel and iron factory. (It represents El-Shobak site.)
- B. Helwan 2 (H2): In front of the iron and steel factory.
- C. Helwan 3 (H3): 1500 m downstream from the iron and steel factory.
- C. Mid-Cairo (C1): In front of the Meredian Hotel.
- E. Mid-Cairo (C2): About 500 m upstream from the Rod El-Farag water works.
- F. El-Kanater (K1): Before river biforkation.
- G. El-Kanater (K2): About 1500 m after the Barrage (start of Damietta branch).
- H. El-Kanater (K3): About 1500 m after the Barrage (start of Rosetta branch).

10.4 Mansoura Segment

The Mansoura segment is divided into two sections and includes the following sites:

- A. Section I: Between El-Mansoura and El-Kheiarria Village and it includes the following three sites:
 - Site 1: In Mansoura City facing the building of the University of Mansoura.
 - Site 2: Facing the output of the factory of fertilizers at Talkha.
 - Site 3: Facing El-Kheiarria Village.
- B. Section II: Between El-Kheiarria and Damietta, and it includes two sites as follows:
 - Site 4: Facing Besat El-Kerim Village.
 - Site 5: In front of Farskur Dam in Damietta City.

10.5 Kafr El Zayat Segment

This segment begins at Kafr El Zayat and ends at Edfina Barrage. Sites have been selected at:

- A. Kafr El Zayat in front of the Ministry of Irrigation Building.
- B. Maahid Bridge.
- C. Three km south of the soap factory.

Additional sites need to be selected to include areas both upstream and downstream from the Edfina Barrage.

Total length of the segment is estimated to be 70 km.

Sampling and Analysis

Sampling: Each site represents a cross-section. Samples should be collected from the following locations within a given cross-section:

- a) one-fourth the distance of the cross-section, and half a meter below the surface
- b) half the distance of the cross-section and half a meter below the surface
- c) half the distance of the cross-section and one meter above the bottom
- d) three-quarters the distance of the cross-section and half a meter below the surface.

If homogeneity of water quality within a cross-section can be established, a final composite sample can be made from the above spot samples.

Each sample should be collected in duplicates, and results reported for each individual analysis.

It is recommended to consult the chapter on sampling in the training manual, and EPA analytical procedures. Both sampling and analysis should follow these procedures.

Bottom sediments should be kept in plastic bags, and refrigerated for transportation. The amount of 200 g of sediment per sample is considered appropriate.

Analysis: A. Parameters to be measured by local segment groups:

1. Field Measurements:

- o Weather conditions
- o Narrative description of segment
- o Time and site identification
- o Flow: Ministry of Irrigation data
 - o Flow meter (optional)
 - o Floating objects (optional)
- o Temperature
- o Electrical Conductance
- o Dissolved Oxygen (Oxygen fixation) followed by titration in the laboratory

2. Laboratory Analyses:

- o Turbidity:
 - o Jackson Candle
 - o Light Scatter (optional)
- o Solids:

o Total Solids	o Volatile Solids
o Dissolved Solids	o Residue after ignition
o Suspended Solids	o Settleable Solids
- o pH
- o Alkalinity: both by methyl red and phenol-phthalein end points
- o BOD: 5-day BOD and rate constant
- o COD: Dichromate oxidation
- o NH₃: Direct Nesslerization or after distillation
- o NO₂: Colorimetric technique, Diazotization
- o NO₃: Colorimetric technique
- o Phosphorus: Ortho and Total
- o Oil and Grease
- o Silica
- o Chlorides: Titration with AgNO₃
- o Hardness: Titration - divalent metal ions

3. Bacteriological Examinations:

- o Bacterial Density: plate counts
- o MPN Index
- o Fecal Streptococci group

The above listed parameters will be measured by local segment groups.

B. Additional Analyses:

Additional analyses will be made by the water pollution laboratories in Cairo at the National Research Center and at Alexandria at the High Institute of Public Health, Alexandria University. These include:

- o Total Organic Carbon
- o Micropollutants
- o Total Kjeldahl Nitrogen
- o Chlorophyll-a
- o Sediment analysis

C. Hydrobiological Examinations:

1. At the Institute of Oceanography and Fishery:

- o Zooplankton
- o Phytoplankton
- o Fishes
- o Benthos
- o Sample collection of sediments and phytoplankton

2. By Dr. Eisha El Ayuti - Cairo University:

- o Algae identification and distribution

3. By Dr. Moustafa Imam:

- o Aquatic plants identification and distribution

WATER QUALITY STUDIES ON THE RIVER NILE
AND LAKE NASSER --ANNUAL REPORT: 1976
PART III: River Ecosystem Studies

TABLE A-1

ASWAN SEGMENT

Station: Aswan Water Treatment Plant

Date : 19/7/1977

Time : 11:40 am

Right Shore				
Depth (m)	Temperature (°C)	Conductance (umho/cm)	D.O. (mg/l)	Flow Rate (m/sec)
Subsurface	21.0	215.0	8.4	0.08
1	21.0	225.0	8.9	
2	20.5	225.0	8.5	
3	20.0	225.0	8.1	0.068
4	20.0	225.0	6.6	
5	20.0	225.0	5.5	0.073
6	20.0	225.0	4.5	
7	20.0	225.0	4.2	0.041

Middle				
Depth (m)	Temperature (°C)	Conductance (umho/cm)	D.O. (mg/l)	Flow Rate (m/sec)
Subsurface	21.0	220.0	8.5	0.118
1	20.5	225.0	8.2	
2	20.0	225.0	8.2	
3	20.0	225.0	8.2	
4	20.0	225.0	7.4	
5	20.0	225.0	6.6	0.07
6	20.0	225.0	6.2	
7	19.5	225.0	5.5	0.043

WATER QUALITY STUDIES ON THE RIVER NILE AND LAKE NASSER
RIVER MONITORING PROGRAM
ANNUAL REPORT - 1977

TABLE A-1 (continued)

ASWAN SEGMENT

Station: El-Sail
 Date : 18/7/1977
 Time : 6:00 pm

Air Temperature: 34° C

Right Shore				
Depth (m)	Temperature (°C)	Conductance (umho/cm)	D.O. (mg/l)	Flow Rate (m/sec)
Subsurface	23.0	310.0	7.6	0.033
1	22.0	290.0	8.0	0.075
2	22.0	240.0	7.8	
3	21.5	230.0	7.5	
4	21.0	225.0	6.9	
5	21.0	225.0	5.5	
Middle				
Depth (m)	Temperature (°C)	Conductance (umho/cm)	D.O. (mg/l)	Flow Rate (m/sec)
Subsurface	20.0	220.0	10.4	0.068
1	20.0	220.0	8.1	
2	20.0	225.0	8.5	
3	20.0	225.0	9.6	
4	20.0	225.0	9.0	
5	20.0	225.0	8.0	0.168
6	20.0	225.0	7.5	
7	20.0	225.0	7.0	
8	20.0	225.0	6.8	
9	20.0	225.0	6.9	0.312

TABLE A-1 (continued)

ASWAN SEGMENT

Station: El-Sail

Air Temperature: 34° C

Date : 18/7/1977

Time : 6:00 pm

(Continued)

Depth (m)	Temperature (°C)	Conductance (umho/cm)	Left Shore	
			D.O. (mg/l)	Flow Rate (m/sec)
Subsurface	21.0	225.0	8.5	0.350
1	20.5	225.0	9.0	
2	20.0	225.0	8.5	
3	20.0	225.0	7.7	
4	20.0	225.0	7.2	0.312

TABLE A-1 (continued)

ASWAN SEGMENT

Station: Oberoy

Air Temperature: 32° C

Date : 19/7/1977

Time : 11:10 am

Depth (m)	Temperature (°C)	Conductance (umho/cm)	Right Shore	
			D.O. (mg/l)	Flow Rate (m/sec)
Subsurface	22.0	220.0	9.0	0.105
1	21.0	220.0	7.8	0.05
2	21.0	220.0	6.2	0.295
3	20.0	220.0	7.5	
4				

TABLE A-1 (continued)

ASWAN SEGMENT

Station: Oberoy
 Date : 19/7/1977
 Time : 11:10 am
 (Continued)

Air Temperature: 32° C

Depth (m)	Temperature (°C)	Conductance (umho/cm)	Middle	
			D.O. (mg/l)	Flow Rate (m/sec)
Subsurface	20.5	220.0	8.4	0.028
1	20.0	220.0	8.6	
2	20.0	225.0	7.4	0.028
3	20.0	225.0	6.7	
4	20.0	225.0	6.5	
5	20.0	225.0	5.4	0.075

Depth (m)	Temperature (°C)	Conductance (umho/cm)	Left shore	
			D.O. (mg/l)	Flow Rate (m/sec)
Subsurface	21.0	225.0	9.0	0.18
1	20.5	225.0	8.6	
2	20.5	230.0	7.5	
3	20.5	230.0	7.0	0.068
4	20.0	230.0	6.9	
5	20.0	230.0	5.5	

WATER QUALITY STUDIES ON THE RIVER NILE AND LAKE NASSER
RIVER MONITORING PROGRAM
ANNUAL REPORT - 1977

TABLE A-1 (continued)

ASWAN SEGMENTS

Station: Aswan Water Treatment Plant

Date : 19/7/1977

Time : 12:15 pm

Depth (m)	Temperature (°C)	Conductance (umho/cm)	Right Shore	
			D.O. (mg/l)	Flow Rate (m/sec)
Subsurface	21.0	225.0	8.5	0.078
1	20.5	225.0	8.4	
2	20.0	225.0	8.0	
3	20.0	225.0	7.4	0.088
4	20.0	225.0	6.5	
5	20.0	225.0	5.9	0.06
6	20.0	230.0	5.2	
7	20.0	230.0	4.9	0.05
8	20.0	230.0	4.5	

TABLE A-1 (continued)

ASWAN SEGMENT

Station	Date	Total Alkalinity (mg/l)	Calcium Hardness (mg/l)	Total Hardness (mg/l)	Chlorides (mg/l)	pH
Al-Sail (Composite)	18/7/1977	106.0	64.0	110.0	25.0	7.5
Al-Sail (Right Side)	18/7/1977	74.0	60.0	100.0	22.0	8.0
Oberoy (Composite)	19/7/1977	64.0	64.0	106.0	11.9	8.6
Aswan Water Treatment Plant (Composite)	19/7/1977	72.0	56.0	140.0	12.9	8.0

TABLE A-1 (continued)

ASWAN SEGMENT

Station	Date	D. Phos. (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)	Sulfates (mg/l)	D. Silica (mg/l)
Al-Sail (Composite)	18/7/1977	0.15	2.5	0.6	10.0	25.0
Al-Sail (Right Side)	18/7/1977	0.32	1.0	4.0	10.0	25.0
Oberoy (Composite)	19/7/1977	0.16	0.08	0.015	10.0	11.8
Aswan Water Treatment Plant (Composite)	19/7/1977	0.14	0.07	0.015	7.0	9.3

WATER QUALITY STUDIES ON THE RIVER NILE AND LAKE NASSER
RIVER MONITORING PROGRAM
ANNUAL REPORT - 1977

TABLE A-2

NILE MONITORING PROGRAM: ASSIUT SEGMENT
RESULTS OF THE PHYSICAL, CHEMICAL AND BACTERIOLOGICAL
PARAMETERS OF ASSUIT SEDIMENT

Parameters	July 1976				October 1976				January 1977				March 1977				July 1977			
	B ₁	B ₂	B ₃	Average	B ₁	B ₂	B ₃	Average	B ₁	B ₂	B ₃	Average	B ₁	B ₂	B ₃	Average	B ₁	B ₂	B ₃	Average
Temperature °C																				
- Air	-	-	-	-	23	23	26	24	17	17	13.5	15.8	18	18	22	19.3	36	36	39	36.3
- Water	27	-	28	27.5	23	23	23	23	15.5	15.5	16	15.6	16	16	18	15.6	26	25	25	25.32
PH	8.1	8.05	8.05	8.06	8.13	8.13	8.05	8.10	8.1	8.1	8.	8.1	8.1	8.05	8.05	8.06	8.1	8.2	8.1	8.13
Specific conductance (u mhos/cm)	265	275	273	270	270	290	290	283.3	235	235	240	235.6	240	258	235	237.6	290	295	293.5	193.3
Total solids at 105°C (mg/l)	207	187	175	189.6	205	198	205	202.6	240	256	234	243.3	209	207	217	211	199	199	193	194
Dissolved solids at 105°C (mg/l)	195	179	169	181	191	192	199	194	201	190	196	195.6	203	201	204	202.6	190	166	85	180.3
Suspended solids " " (mg/l)	12	8	7	9	14	6	6	8.6	39	66	58	54.3	6	6	13	8.3	9	24	8	13.6
Volatile solids at 550°C (mg/l)	32	29	37	32.6	45	48	46	46.3	44	70	64	59.3	69	66	76	70.3	70	53	65	62.6
Alkalinity Ph. Ph. (mg CaO ₂ /l)	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Alkalinity M.C. (mg CaO ₂ /l)	124.85	120.3	122.6	122.58	127.12	129.39	129.39	128.63	131.6	129.36	129.38	130.12	162	134	134	143.3	130	128	127	128.3
Hardness (mg CaO ₂ /l)	53	52	51	52	53	52	54	53	55	59	56	56.6	102	104	104	103.3	104	104	95	102.6
Chlorides (mg/cl/l)	4.004	4.004	4.004	4.004	4.8	4.8	4.8	4.8	12.4	11.12	14.0	13.5	7.39	6.99	7.99	7.45	12.01	11.51	11.51	11.67
Nitrates (mg/No ₂ /l)	0.3	0.4	0.3	0.3	1.4	1.5	1.4	1.43	0.2	0.1	0.2	0.16	1.4	1.0	1.0	1.13	3.1	2.8	3.5	3.13
Nitrates (mg No ₂ /l)	1.35	0.95	0.8	1.03	0.65	0.75	0.7	0.7	0.95	0.90	0.98	0.94	1.8	1.2	1.22	1.40	2.359	2.11	2.32	2.26
Silica (mg SiO ₂ /l)	13.4	15.6	13.6	14.2	15.6	16.8	14.2	15.5	6.4	6.05	6.05	6.16	5.4	5.8	5.9	5.7	9.8	11.2	10.4	10.46
Orthophosphates (mg PO ₄ /l)	0.15	0.05	0.1	0.1	0.1	0.15	0.1	0.11	0.6	0.6	0.6	0.6	1.99	1.67	1.73	1.79	1.4	1.28	1.21	1.28
Total phosphates (mg PO ₄ /l)	1.8	1.2	0.9	1.3	1.7	2.0	1.5	1.7	1.7	1.8	1.7	1.7	2.5	2.9	2.35	2.58	2.42	3.22	3.2	2.94
Ammonia (MG NH ₃ /l)	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
COD (mg O ₂ /l)	17.69	16.684	16.695	16.99	10.18	11.45	13.68	11.77	16	16	16.31	16.10	16.1	16.0	15.0	15.7	15.6	16.0	15.4	15.6
BOD (mg O ₂ /l)	5	4.8	5.5	5.1	2.8	3.2	4.3	3.4	2.66	2.40	2.80	2.62	2.49	2.45	2.9	2.61	2.5	2.5	3.1	2.7
DO (Mg O ₂ /l)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- Location A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- Location B	10.5	10.6	10.3	10.4	12.35	12.0	11.3	11.88	10.35	10.50	10.40	10.40	10.0	9.6	10.4	10.0	12.6	12.4	12	12.2
- Location C	10.5	9.9	10.4	10.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- Location D	-	-	-	-	12.1	11.8	11.0	11.63	10.00	9.80	10.30	10.03	9.8	9.4	10.0	9.7	12.4	12.2	11.8	12.1
Transparency (Cm)	-	-	-	-	-	-	-	-	68	67	65	66.6	77	77	72	75.3	77	75	77	76.3
- Location A	-	-	-	-	-	-	-	-	68	72	65	68.3	-	-	-	-	-	-	-	-
- Location B	-	-	-	-	-	-	-	-	67	70	67	68.0	-	-	-	-	-	-	-	-
- Location C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plate count at 22°C	30x10 ⁶	22x10 ⁶	19x10 ⁶	24x10 ⁶	972x10 ³	2,712x10 ³	184x10 ³	4157x10 ³	161x10 ³	30x10 ³	82x10 ³	181x10 ³	138x10 ⁶	254x10 ⁶	83x10 ⁶	160x10 ⁶	192x10 ⁶	273x10 ⁶	75x10 ⁶	173x10 ⁶
- 37°C	7x10 ⁵	15x10 ⁵	42x10 ⁵	21x10 ⁸	81x10 ³	3x10 ⁶	129x10 ⁷	80x10 ⁵	4x10 ⁶	73x10 ³	215x10 ⁵	109x10 ⁵	10x10 ⁶	1x10 ⁶	26x10 ⁶	124x10 ⁶	16x10 ⁶	7x10 ⁶	48x10 ⁶	27x10 ⁶
MPN. coliforms/ 100ml	5	17	35	19	920	542	1600	1021	11	6	25	14	49	17	70	45	115	60	350	175
Faecal coliforms/100ml	0	0	0	0	2	0	5	2	13	8	49	3	17	23	33	21	5	2	8	5
MPN. Faecal Strept./100ml	0	0	0	0	2	0	5	2	13	8	49	3	17	23	33	21	5	2	8	5
MPN. Faecal Strept./ confirmed	0	0	0	0	2	0	5	2	13	8	49	3	17	23	33	21	5	2	8	5

TABLE A-3

NILE MONITORING PROGRAM: MANSOURA SEGMENT

Parameters	April 1976					July 1976					October 1976					December 1976				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
A. FIELD MEASUREMENTS																				
Depth (cm) - 1/4 cross-section	1.7	2.4	1.0	2.7	6.5	1.75	2.5	1.0	2.75	6.5	1.0	2.0	1.0	2.5	4.5	1.75	2.25	1.75	3.85	4.85
- 1/2 cross section	1.2	3.25	2.3	4.0	7.5	1.5	3.75	3.0	4.0	7.5	1.0	3.25	2.35	4.0	7.5	1.75	3.25	2.75	4.35	7.35
- 3/4 cross section	1.5	2.2	3.2	2.7	4.2	1.5	2.25	3.25	2.75	4.25	1.0	3.0	2.0	2.5	4.5	1.75	2.75	1.25	3.35	4.35
Temperature (°C) - Air	22	23	26	20	21	30	32	31	31	28	29	29	27	26	27.5	19	16	19	15	19
- Water	20	20	21	19	20	29	29	28	29	28.5	25	25	24.5	24	25.5	16	16	16	15	16
Dissolved Oxygen (mg/l)																				
- Surface	4.22	4.86	5.27	4.99	4.43	6.65	5.6	6.56	6.33	6.43	6.1	6.1	6.16	4.93	4.22	9.32	9.16	8.84	8.67	8.62
- Bottom	3.29	3.58	4.0	4.08	6.91	6.17	5.4	6.43	4.99	5.89	5.7	5.7	5.49	4.3	3.03	9.24	8.63	8.62	8.45	7.63
B. LABORATORY ANALYSES																				
pH	7.9	7.25	7.8	8.2	8.8	8.0	8.0	8.1	8.3	8.3	8.35	7.9	8.3	7.7	7.9	8.2	8.2	8.0	7.9	8.0
Specific conductance (umho/cm)	326	326	329	452	552	317	323	326	393	458	382	405	413	493	528	331	331	338	414	478
Solids (mg/l)																				
- Total	316	312	314	382	448	216	250	229	269	294	263	281	335	381	381	309	305	235	350	395
- Filterable	195	188	201	255	316	163	167	158	209	226	215	217	231	305	305	218	228	218	270	309
- Non-filterable	17	14	17	14	17	20	30	28	15	17	21	23	83	41	41	21	26	21	29	38
- Volatile	22	27	22	23	40	34	27	31	24	39	39	43	60	83	83	33	36	18	27	77
Alkalinity (mg/l. CaCO ₃)																				
- Ph.Ph.	2	0	6	4	4	3.0	2	6	6	7	7.0	5	5	7	5	10.0	7	9	5	6
- Total	147	134	146	150	180	120	122	123	126	137	146	143	145	146	148	158	158	157	164	165
Hardness (mg/l)																				
- Total	112	103	111	126	156	106	103	106	114	118	128	130	130	140	145	139	133	137	150	165
- Calcium	65	61	64	72	89	71	66	68	73	68	81	83	80	90	86	86	87	86	92	97
- Magnesium	47	42	47	54	68	35	37	38	41	50	53	47	50	50	59	53	51	51	58	58
Turbidity	2.5	4.5	3.5	2.5	2.0	3	6.5	7.0	6.0	7.5	5.5	6.5	6.5	7.0	6.5	7.5	7.5	6.0	6.5	7.0
Chlorides (mg/l)	14.4	13.8	13.5	27.6	40.8	13.0	15.8	16.8	28.2	38.4	32.4	31.8	36.0	46.8	63.0	28.8	28.8	30.6	31.2	39.0
Nitrites (mg/l)	0.015	0.013	nil	0.056	0.05	0.003	0.004	nil	0.076	0.009	nil	nil	0.01	0.13	0.13	nil	nil	nil	0.13	0.076
Nitrates (mg/l)	0.007	0.006	0.018	0.052	0.033	0.011	0.01	0.014	0.031	0.013	0.038	0.169	0.056	0.22	0.29	0.79	0.068	0.079	0.43	0.61
Silica (mg SiO ₂ /l)	8.6	9.9	7.3	7.99	8.9	10.65	10.65	10.32	4.9	2.66	3.7	4.3	4.5	4.6	6.2	3.0	4.33	3.33	2.33	5.99
Orthophosphates (mg/l)	0.101	0.104	0.133	0.62	0.026	0.293	0.326	0.293	0.293	0.179	0.13	0.16	0.16	0.10	0.13	0.137	0.169	0.169	0.176	0.193
Total phosphates (mg/l)	0.127	0.133	0.140	0.704	0.048	0.329	0.332	0.329	0.326	0.228	0.22	0.32	0.36	0.32	0.29	0.25	0.31	0.313	0.316	0.29
Ammonia (mg NH ₃ /l)	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
C.O.D. (mg/l)	3.2	4.0	3.6	4.5	3.7	3.4	4.7	3.8	6.9	6.5	4.5	5.2	6.0	3.8	4.1	3.6	4.2	4.5	4.7	3.8
B.O.D. (Mg/l)	1.7	1.5	2.0	1.5	2.4	1.6	1.9	1.7	3.6	3.0	3.2	2.8	3.7	3.2	1.8	5.0	4.1	4.4	4.0	2.3
Sodium (mg/l)	31.9	33.4	34.1	34.1	42.2	35.5	24.5	23.5	33.5	42.5	20.8	21.7	21.72	31.2	37.1	35.6	34.1	37.1	46.0	54.9
Potassium (mg/l)	5.2	5.2	5.2	6.4	6.4	5.7	5.7	5.7	5.5	5.5	4.21	4.2	4.2	6.2	5.6	3.4	3.4	3.4	6.6	6.6
Total Organic Nitrogen (mg/l)	2.3	3.2	3.4	4.34	4.25	1.23	1.57	1.68	0.89	1.12	0.962	1.231	0.62	1.56	1.87	0.26	0.46	0.56	1.76	1.68

F. ASSESSMENT OF ENERGY-RELATED

MINERALS/COMMODITIES IN EGYPT

By: Gene E. Tolbert

1.0 INTRODUCTION

Information developed to date indicates severe deficiencies of most of Egypt's energy-related raw materials. Nevertheless, systematic, detailed exploration and evaluation programs may identify additional reserves of manganese, alumina, barite, bentonite, and others. Intense exploration efforts can strengthen current long-term planning; changing political and economic factors may also encourage mining some ores now considered impractical.

Among the principal energy-related minerals or commodities, which include cement, iron, manganese, aluminum, barite, bentonite, and copper, only those raw materials used in making cement or concrete, that is, limestone, clay, sand, and gravel, are abundant in Egypt, and gravel is not abundant everywhere. Most known deposits of energy-related raw materials in Egypt are thought to be too small, too low grade, or too remote to be economically exploited; however, many of those deposits have not been completely evaluated.

2.0 MINERAL COMMODITIES

2.1 Cement

Egypt is currently producing about 4 million tons of cement per year from four plants, located at Cairo, Helwan, Assiut, and Alexandria. Annual imports are approximately 1.5 million tons. Plans are under way to construct several new plants in an effort to meet the rapidly increasing demand for cement. This increase could soon meet twice the current demand.

The raw materials necessary for making portland cement are limestone, shale or clay, sand or silt, and gypsum. By heating these raw materials, which contain calcium carbonate, silica, alumina, iron oxides, and hydrated calcium sulfate, to approximately 1,400° C, a complex aluminosilicate compound is produced, which, when water is added, sets to a rock-like solid. Cement is used as a binder for concrete together with an aggregate composed of sand, gravel, and crushed stone. The amount of concrete used in energy-related industries and for hydropower and nuclear installations is larger than any other energy-related raw material.

2.1.1 Limestone: Known deposits contain billions of tons of limestone that are suitable for the manufacture of cement. Carbonate rocks are widely distributed over Egypt, and have been used, since ancient times, as building stones and to produce lime. More recently, these rocks have found uses in cement, metallurgy, sugar manufacturing, and other chemical industries. A program to assess the limestone resources was undertaken by Egyptian and Soviet geologists during the period 1966-68: this work focused on the Nile Valley between Aswan and Cairo, as well as along the west coast of the Gulf of Suez. Although the main purpose was to identify sources of chemically pure limestone for use in the production of alumina (see section on aluminum), a preliminary assessment was made of all carbonate rocks, especially in the Nile Valley, that could be used as raw materials for various industries.

Upper Cretaceous carbonate rocks in the Nile Valley, between Idfu and Qena, are suitable for cement making; reserves are estimated at several million tons. Paleocene carbonates in the valley, having the proper specifications for cement making, total several tens of millions of tons. The Lower Eocene Thebes and Manfalut Carbonate Formations are present south of Assiut, where reserves are estimated in billions of tons. The principal localities are Wanina, Sidi Saleh, and Hammamia. The middle Eocene section, comprising the Minya, Samalut, and Mokattam Formations, also contain virtually unlimited reserves of carbonate rocks suitable for cement.

In the Gulf of Suez region, billions of tons of carbonate rock, belonging to the middle Eocene, are found south of Suez along the Gulf coast.

Faiyum Oasis is noted for having large reserves of limestone and other raw materials, including clay, gypsum, sand, and gravel suitable for cement.

2.1.2 Other raw materials: As one of the ingredients in cement, gypsum is an energy-related raw material. Gypsum deposits occur at several localities in the northern part of Egypt. Large deposits are found at El Hamman, west of Alexandria and at Ras Malaab, in the Sinai. El Hamman gypsum is mined from a Pleistocene lake bed, and five Miocene deposits are exploited at Ras Malaab. Additional Miocene deposits are present along the Red Sea coast.

Sand is abundant throughout Egypt. Supplies of gravel for concrete are available throughout most of the Nile Valley, although the quality of gravel is not always satisfactory.

The use of all these materials involves high volume combined with low value; therefore, economic constraints impose a definite limitation on the distance they can be transported.

2.2 Iron

Iron and steel are used widely in almost every energy-related activity. Their use involves the use of those subordinate commodities associated with iron and steel production: manganese, chromium, molybdenum, titanium, tin, tungsten, nickel, niobium, tantalum, and vanadium.

The steel complex at Helwan was enlarged in 1974 and 1975 by the addition of two blast furnaces, making a total of four, with a capacity of 1.5 million tons of steel per year.

Iron ore production in Egypt has risen from 35,000 metric tons in 1955, to 1.1 million tons in 1975.

Total iron ore reserves in Egypt are approximately 450 million tons, with Bahariya supplying 250 million of this total. Aswan deposits comprise 120 million tons; the remainder is found in the Eastern Desert. A large proportion of these reserves are low grade (less than 50 percent Fe). (See figure 1.) The main types of deposits (Zitzmann, 1976), in order of importance, are:

1. sedimentary and/or replacement ores in middle Eocene limestone in the Western Desert (Bahariya Oasis);
2. sedimentary oolitic ores in Upper Cretaceous Nubian Sandstone near Aswan;
3. sedimentary-metamorphic banded ores (itabirite) in the Eastern Desert; and
4. beach placers on the coast of the Mediterranean Sea.

2.2.1 Bahariya deposits: The main iron deposits in Egypt are found in four areas in the Bahariya Oasis, 340 kilometers (km) southwest of Cairo: Gebel Ghorabi, El Gedida, El Harra, and Nasser. Their iron deposits extend over an area of 11.7 km² and are mainly composed of hematite and goethite with lenses of ochre and manganese oxides. This sequence of lenticular beds has an average thickness of 12.5 meters (m) and forms the lower part of the middle Eocene limestone (Plateau Group).

The first deposit discovered in the Bahariya Oasis was the Ghorabi deposit, which was first reported by Ball and Neadnell (1903). Open pit mining began after the construction of a 320 km railway. Total reserves of iron ore in the Bahariya district are about 250 million

Fig. 1. Deposits of iron and manganese

tons; the average grade is 50 percent Fe. The production from the Bahariya deposits is approximately one million tons per year. A goal of three million tons of ore is scheduled for 1980.

The El Ghorabi iron deposit is in the northeast part of the Bahariya area. This deposit is lenticular and lies unconformably on the Bahariya Formation, an alternating sequence of sandstone and clay. The grade is approximately 45 percent Fe and the average thickness is 11 m. Total ore reserves for El Ghorabi are 55 million tons, 31 million proved, and 24 probable.

The nearby Nasser deposit is smaller, and contains about 29 million tons of ore of about the same grade as that at El Ghorabi.

The El Gedida iron deposit is the largest and highest grade deposit, having a reserve of 120 million tons of ore averaging 55 percent Fe.

The El Harra deposit contains 54 million tons of ore with a grade of 40 to 50 percent Fe.

A siliceous, unenriched iron deposit which contains 100 million tons of "ore" containing 28 percent Fe and 60 percent SiO_2 is reported at El Heiz, south of Bahariya.

2.2.2 Aswan deposits: In an area of 1000 km^2 northeast of Aswan, 15 occurrences of bedded oolitic hematite are found in two bands ranging in thickness from 20 to 80 centimeters (cm) and 15 to 350 cm. These ores are sedimentary and are interbedded with ferruginous sandstone and clay of the Nubian Formation, which is underlain by Precambrian granite and schist. The ores range from 31 to 62 percent Fe, and average 40 percent Fe. The total reserves in this area are 135 million tons of ore. Approximately 100,000 tons per year are being mined at present.

2.2.3 Eastern Desert: Banded magnetite-hematite ore is found in low grade metamorphic rocks of early Precambrian age in the Eastern Desert. Most of the deposits are thin bands or lenses and are low grade. The ore reserves are estimated to be 80 million tons containing 43 percent Fe. These ores are not being mined because of their low grade, small tonnage, and remote location.

2.2.4 Other iron deposits: Other small deposits of iron minerals are known in Egypt including iron associated with manganese in the Sinai; however, these deposits are too small to be minable. Additional iron occurrences similar in geology and structure to the Bahariya ores are reported at Gebel El Qalamun, south of Fayum, but these occurrences have not been evaluated.

Magnetite is second in abundance to ilmenite in the black sand deposits on the Mediterranean Sea shore. The percentage of magnetite in these sands is about 20 percent of the total potentially economic heavy

minerals. The reasonably assured resources of magnetite in the top meter of the black sand deposits are 5.7 million tons, while the estimated additional resources to the depth of 20 meters are 108 million tons.

2.3 Manganese

Manganese is tied to steel-making, about 15 pounds being required to make one ton of steel. In addition, manganese is important in the manufacture of batteries and chemicals.

Um Bogma Deposit. The principal manganese deposits are found in the Um Bogma area, Sinai Peninsula, about 35 km northeast of Abu Zenima on the Gulf of Suez (see figure 1). Manganese has been mined here since 1913, approximately 4.2 million tons having been produced up to 1967. No ore has been mined since that date. In the year prior to the Israeli occupation, about 200,000 metric tons of ore were exported.² No figures were found for total ore reserves at Um Bogma, and GSE geologists state that the deposits have not been completely evaluated. However, it seems reasonable to assume that the ore reserves will approach three or four times the tonnage that has been mined and the chances for finding additional ore by systematic exploration are good. The production includes various grades of ore, ranging from less than 21.5 percent Mn, which seems to be the average grade of the material, to 50 percent Mn in some places. Much of the mining has been selective. The ore was transported by aerial ropeway 25 km to Abu Zenima, where it was shipped by rail 20 km northwest up the coast to the port of Ras Malab. The average composition of the "run of mine" ore, is 21.5 percent Mn, 37 percent Fe, and 6 percent SiO₂.² Until the recent war, there were plans for fusing this ore to make ferromanganese, utilizing gas from nearby oil fields for power.

The Um Bogma ore is in the lower Carboniferous dolomite series overlying the Nubian Formation. Ore beds are nearly flat lying; the manganese-bearing section is 20 m thick. The minable zone is not a continuous bed but a series of lenses ranging in length from 1 to 400 m, and in thickness from a few centimeters to 8 m. The deposit is classified as sedimentary in origin.

Small deposits of manganese are known in the southeastern part of the Sinai, in the Sharm El Sheikh area, where manganese and iron oxides form the cement in Cretaceous conglomerate. The conglomerate bed is about 4 m thick and the manganese content is 25 percent. Ore reserves are estimated at 30,000 metric tons.

Outcrops of manganese oxides are scattered over a large area in the southeast part of Wadi Araba; however, they are too erratic to represent a minable orebody. Manganese content runs approximately 20 percent and "reserves" are estimated at 4,000 metric tons.

² Oral communication, Egyptian Geological Survey and Mining Authority geologists.

In the Halaib area in southeast Egypt, small lenses of manganese ore occur in Miocene and younger sediments. The reserves in the area are estimated to be 120,000 tons. Several thousand tons of manganese ore from these deposits are consumed each year at the Helwan plant. At present they are mining ore containing 45 percent Mn.

2.4 Aluminum

The production of aluminum not only consumes large amounts of energy but also provides an element that is important in the production, conversion, and transportation of energy. The metal is used in many types of machinery, construction materials, electric generators, and power transmission lines.

It appears that development of an aluminum industry in Egypt must depend on conventional ores from outside Egypt, or on the development of economic methods of beneficiation of alumina-bearing rocks that are not ore grade under present conditions.

Possible sources of aluminous minerals in Egypt are limited to aluminum-bearing clays and alkalic rocks that have subordinate amounts of silica. Bauxite deposits, the common source of alumina, are unknown in Egypt. Because of the scarcity of raw materials for aluminum, attention has focused on high-alumina/ low-silica rocks and clays. Presently these sources are considered to be economically infeasible in most parts of the world, but are the subject of a developing technology to find substitutes for bauxite.

2.4.1 Nepheline syenite: In the Soviet Union a complex method was developed in which nepheline syenite is processed to produce alumina (Al_2O_3), with by-products of cement and alkali carbonates. This method is based on sintering nepheline concentrates with limestone at temperatures of $1,280 - 1,310^\circ \text{C}$. In Egypt, a nepheline syenite intrusion, Gebel Abu Khruq, which makes up part of a ring complex in the Eastern Desert, was identified as a potential source of alumina. This alkaline massif was studied in considerable detail by geologists of the Egyptian Geological Survey and the Soviet Union to determine its potential as a source of aluminum. Results showed that the Abu Khruq syenite differed from similar rocks used by operating plants in the Soviet Union in several ways: 1) the nepheline content of the Egyptian rock was lower, 12 percent compared to 65 to 85 percent in the Soviet Union; 2) feldspar content is as much as 60 percent, whereas the Russian material contains none; 3) the Egyptian rock contains 55 percent SiO_2 and 21 percent Al_2O_3 , and the Russian rocks 40 to 45 percent SiO_2 and 27 to 30 percent Al_2O_3 . Tests on Egyptian material run by laboratories in Russia indicated that, technologically, it was possible to process the Egyptian ore.

The study showed that 26 million tons of rocks of suitable chemistry could be mined at Abu Khruq by open-pit methods. The average chemical composition is 56 percent SiO_2 and 21 percent Al_2O_3 .

Preliminary calculations by Soviet experts indicated that one ton of alumina product from Abu Khruq would yield, as byproducts, 15 to 16 tons of cement, 0.75 ton of soda, and 0.3 to 0.35 ton of potash. To date, this process has not been practical, probably due to its high cost.

2.4.2 Aluminous clay: Deposits of clay are found in west-central Sinai in Carboniferous sedimentary rocks, and in the Nubian Formation in the areas of Aswan, Wadi Araba, and west-central Sinai (see figure 2). Beidellite clays occur in the Dakhla Formation (Upper Cretaceous). Clay beds are also found in the Miocene and middle and upper Eocene, as well as in the Nile flood plain.

Preliminary prospecting and sampling has shown that kaolin deposits at Budra (Wadi Abu Natash) in west-central Sinai, contain small reserves, about 23 million tons, of aluminous clay containing more than 30 percent Al_2O_3 and less than 3 percent Fe. Possibly additional exploration will augment these reserves. Although extraction of alumina from aluminous clays is feasible, in most places it is more economical to import and utilize bauxite as the raw material input. However, when comparing the option of extracting alumina from clays as opposed to using nepheline syenite, it is probable that the use of clays will be more economical. Therefore more attention needs to be given to finding deposits of aluminous clay.

Some of the Nile Valley clays are suitable for refractory use, whereas others, particularly those near Aswan, may be used in the ceramic industry. Present information indicates that high-alumina clay, as well as most ceramic clays, appears to be concentrated in the Sinai.

2.5 Barite

Barite is the principal ingredient in drilling mud. Only a few deposits of barite are known in Egypt (see figure 2). Sixteen veins, intersecting serpentine, contain approximately 250,000 tons of barite ore at Wadi El Gerera in the Elba region, in the southeast corner of Egypt. The main vein extends for 1.5 km on the surface and averages 1.5 m in thickness. However, the deposit does not appear to be worth developing, possibly because of its remote location.

Recently, a new deposit has been found, associated with the iron deposit at Bahariya, but its potential has not yet been determined. The deposit is now being studied by the Geological Survey. Should sufficient reserves be identified they could provide a badly needed substitute for imported barite used in drilling mud.

"East of Aswan and in other localities in the Eastern Desert relatively small barite veins cut granite and other rock units. East Aswan barite deposit has been mined in the past, however, the main problem in the exploitation of the barite is its contamination

Fig. 2. Deposits of aluminous rocks and clays, barite and bentonite

of quartz and other minerals. Ore dressing experiments proved that it is possible to produce high-grade barite from the East Aswan deposit and the beneficiation of the barite is deemed necessary for its marketing."

2.6 Bentonite

Bentonite clay is also a principal component in drilling mud, but it is not being mined in Egypt. Bentonitic clay has been reported from the Sinai Peninsula, but no information concerning these occurrences is available. Clays at the Faiyum Oasis are also reported to be bentonitic, and the Geological Survey of Egypt is currently undertaking a study of the industrial minerals in that area (see figure 2). If substantial reserves of this clay (with suitable characteristics) are found, this might constitute an incentive for oil drilling companies to use indigenous material instead of imported bentonite. Certainly the deposits are favorably located.

Sodium montmorillonite has not been so far discovered in Egypt. At present bentonitic clays are exploited in the range of 5,000 tons annually, from favorably located deposits not far from Cairo. The chemical treatment of these clays is necessary for improving their quality and to widen the range of their utilization. Some deposits have proved to be amenable to treatment.

2.7 Copper

Copper and its alloys are widely used in the electrical, construction, machinery, and transportation industries. To date, a total of only 220,000 tons of cupriferous rocks have been identified in Egypt. Nonetheless, the prospects of finding economical copper deposits in Egypt, particularly in the Eastern Desert, are favorable. It will require an extensive exploration program -- a continuation of the type of work started by the United Nations in the Aswan region several years ago, and now terminated.

Copper-bearing deposits have been identified in the Eastern Desert (see figure 3). None are being exploited at the present time. Um Samiuki and Darhib have mainly copper-zinc (massive sulfide) deposits, containing subordinate amounts of lead. "The latest partial evaluation of reserves at Um Samiuki deposit gives 152,300 tons of massive ore averaging 15.2 percent zinc, 1.15 percent copper, 1.1 percent lead and 50 gram/ton silver (DP/UN/EGY-72-008/2, 1977).

Small deposits of copper-nickel have been identified in the south Eastern Desert and in St. John's Island in the Red Sea. Copper-nickel deposits at Gebel Homr Akarem and El Genena El Gharbia in the Eastern Desert give on partial evaluation reserve figures of 700,000 tons containing 0.95 percent copper and nickel, and 270,000 tons containing 1.18 percent copper and nickel (ibid, 1977)."

Base 500650 2-72

Fig. 3. Deposits of copper and molybdenum

Vein-type copper deposits have also been reported in the Sinai but are too small to be worthwhile. Copper associated with sandstone is found in the western Sinai, on the western coast of the Gulf of Suez, and on the Red Sea coast near Ras Banas. All of these deposits appear to be small, but most have not been fully evaluated.

2.8 Chromium

Chromium is an essential element in energy production, as it is required in nuclear power plants, in oil and gas exploration and development, in refineries, in coal-mine transportation systems, and in fossil-fuel power plants.

Chromium deposits are known in the central and southern part of the Eastern Desert (see figure 4). They consist of small, irregular lenses of chromite in serpentine and talc carbonate rocks. The grade of the deposits is satisfactory, but the reserves constitute only a few thousand tons. The prospects for finding additional reserves are not promising.

2.9 Nickel

Nickel is used chiefly in the manufacture of chemicals and in petroleum refining. It is also used in nuclear-fission power plants, uranium mining and processing, fossil-fuel power plants, and storage batteries.

In Egypt, nickel is found in veins in ultramafic rocks on St. Johns Island in the Red Sea, and in a copper-nickel deposit at Abu Swayel in the southwestern part of the Eastern Desert (see figure 4). The latter deposit is a lenticular, massive sulfide-bearing amphibolite in garnet-bearing, quartz-mica schist near the contact with gneiss. Reserves of both these deposits are not sufficient to be economically recoverable. A deposit of copper-nickel-cobalt is found at Gebel Homr Akarem in the Eastern Desert. Some studies have been undertaken here but economic evaluation is incomplete. Additional work should be done to evaluate this deposit. Other favorable prospects have not been found, and the prospects for discovering economically recoverable reserves of nickel are not encouraging.

2.10 Titanium

The major projected use of titanium in the energy industry is in the construction of heat exchangers for the development of geothermal energy.

"Deposits of titanium ore in Egypt are either found as massive ore disseminated deposits in basic igneous-metamorphic rocks in the Eastern Desert or as black sand deposits on the Mediterranean Sea Coast. (See figure 5).

Fig. 4. Deposits of chromium and nickel

Fig. 5. Deposits of tin, tungsten, and titanium

These former ores include ilmenite and ilmenite-magnetite deposits essentially found in Precambrian metamorphosed gabbros. Other deposits are liable to be found by detailed geological mapping and aeromagnetic surveying. The best known of these deposits is that located at Abu Ghalqa in the Eastern Desert not far from the Red Sea (see figure 5) where the ore reserves have been estimated to be 10 million tons sure ore and 8 million tons probable ore. Trials to exploit the deposit have been carried out in the sixties but full exploitation has not followed.

Ilmenite is the main potentially economic mineral of the black sands deposits on the Mediterranean Sea Coast and it makes up about 65 percent of the total potentially economic minerals while rutile constitutes about 1 percent of the latter. The reasonably assured resources of ilmenite in the top meter of the black sand deposits are 18.4 million tons and the estimated additional resources are 351 million tons, while the reasonably assured resources of rutile are 283 thousand tons and the estimated additional resources are 5.4 million tons.

2.11 Phosphate

Phosphate is not considered an energy-related mineral, but Egypt's phosphate industry is affected by energy development because power is needed to produce superphosphate, and an increase in power availability could benefit the phosphate industry, especially in the Nile Valley. Conversely, if the very large (one billion tons) Abu Tartur phosphate deposit at Kharga Oasis is to be developed and superphosphate produced, large amounts of power will be required.

2.12 Other Minerals/Commodities

2.12.1 Molybdenum: Molybdenum is a refractory metal used as an alloy for steel, and, because of its hardening and strengthening properties, is used in oil and gas pipelines, drilling equipment, abrasive-resistant castings for the mining industry, and in power plant equipment.

Molybdenite is reported in six localities in the northern part of the Eastern Desert. These deposits are associated with small quartz veins in granite and are insignificant in size. Another occurrence is known at Gebel Homr Akarem in the southern part of the Eastern Desert, where quartz veins with molybdenite, cassiterite, and chalcopyrite cut metasediments near a contact with granite body (see figure 3). The deposits found to date do not suggest that large undiscovered concentrations of this metal exist.

2.12.2 Niobium-tantalum: Niobium and tantalum are used as alloys in special steels for construction materials. In the energy field, niobium is used for oil and gas pipelines. "Niobium and tantalum are found in a variety of alkalic igneous-metamorphic rocks in Egypt especially in the Eastern Desert. These rocks include granites, felsites, bostonites, syenites and gneisses. These elements were first recorded in association with the tin deposits of the Eastern Desert by El Shazly and Barakat, and later found in association with uranium and thorium by the Atomic Energy Establishment in several localities including Abu Rusheid, Abu Garadi, Um Safi and West Aswan. At Um Safi the mean

Nb_2O_5 content in the analyzed sample ranges about 0.2 percent. The weight of evidence suggests that Nb and Ta are more likely to be extracted as by-products from uraniferous deposits rather than from other deposits, and that radiometric methods may be the best techniques for finding the discussed elements on a regional scale." (See figure 6.) Soviet and Egyptian geologists have conducted a series of studies of these deposits, but minable reserves of the metals have not yet been found. Small concentrations of oxides of both metals are present at Nuweibi, Abu Rusheid, and Gebel Mueilha, but additional exploration will be required to determine the economic potential of these deposits. These metals are also found in several alkaline ring complexes in southeastern Egypt. These have not been studied in detail, but preliminary evaluations indicate that the metal concentrations are too small. Perhaps more detailed studies will reveal exploitable concentrations in one or more of these complexes.

2.12.3 Tin-tungsten: Tin and tungsten are used in nuclear-fission power plants, in uranium mining and processing, and in coal transportation systems. Tungsten is used in equipment for oil and gas exploration, uranium mining and processing, coal transportation systems, and fossil fuel power plants.

Small tin-tungsten and tungsten deposits are known to occur in the Eastern Desert (see fig. 5). The more important deposits are Igla, Nuweibi, Abu Dabbab, and El Mueilha where veins bearing tin and tungsten cut granite and metamorphic rocks. Reserves of tin and tungsten, mostly in placer deposits, are small and not practical to develop.

2.12.4 Zirconium: Although zircon is found in association with uraniferous mineralizations in the same types of rocks which have been found to be favorable for niobium and tantalum enrichment, the presence of zircon as a detrital mineral in the black sand deposits of the Mediterranean Sea coast render its exploitation more feasible than the latter source.

Zircon makes up about 3 percent of the potentially economic minerals in the black sand deposits of the Mediterranean Sea coast. The reasonably assured resources of zircon in the top meter of the black sand deposits are 849 thousand tons, while the estimated additional resources to the depth of 20 meters are 16.2 million tons.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The main purpose of this report is to assess the availability of energy-related mineral resources in Egypt. In general, most of these minerals are unavailable or found in economically impractical concentrations. However, deposits of materials used in the cement industry and, to a limited extent, iron ore for steel making, are available. Deposits of manganese, clay, and other energy-related minerals may become usable by Egypt upon return to the Sinai to Egyptian control. This report does not make detailed recommendations for exploring for and exploiting energy-related minerals or commodities, although it is certainly appropriate for Egypt to assess the potential of her mineral

resources; any discovery and subsequent development of a mine would help the country's financial situation, whether the metal is consumed internally or exported, and, of course, would provide raw materials needed for increased energy production. This is especially important because the availability of most of these minerals from indigenous sources appears to be limited or nil, and, in view of increasing energy demands, it may be advantageous for Egypt to expand exploration efforts for these raw materials to offset an eventual increased import quota of them. Any major change in Egypt's energy use would require a reexamination of the supply of energy-related minerals.

1. Cement-making materials. These are abundant in those areas that are industrialized, or are likely to be: Nile Valley, Gulf of Suez, Red Sea area, and northern coast.

2. Iron ore. The Bahariya ores, with grades sufficiently high to sustain the transportation costs to the iron and steel complex at Helwan, are limited. Other known deposits are of lower grade, and the prospects for finding new deposits of grades equal to or better than the Bahariya ores appear to be unfavorable although deposits in Gebel El Qalamun have yet to be evaluated. However, additional geologic exploration is needed to define the tonnage and grade of known deposits more precisely.

3. Manganese. Manganese for the current production of steel is supplied from small deposits in the southeastern corner of Egypt. These can maintain a production of a few thousand tons of manganese per year for several more years.

The Um Bogma ores in Sinai could undoubtedly furnish manganese ore for expanded steel production, and could probably produce ore for export. Geological exploration in the Sinai should again be initiated, upon return to Egyptian control, in an effort to increase known reserves in the Um Bogma area, as well as to explore other favorable areas.

4. Aluminum. Conventional sources of alumina, in the form of bauxite, are unknown in Egypt. Considerable effort has gone into evaluation of nepheline syenite as a source of alumina; efforts should continue toward use of these unconventional sources, particularly as their technologies develop. However, more effort should be focused on finding deposits of high-alumina clays. In most instances, the technology of extraction of alumina from clay has not proved feasible, mainly because it is cheaper to use bauxite. The extraction techniques show more promise, from the economic point of view, than extraction from nepheline syenites and related high-alumina, low-silica hard rocks.

5. Barite. There appear to be several undeveloped deposits of barite in Egypt. These, particularly the new deposit at Bahariya, should be mapped and evaluated.

6. Bentonite. This material is found at Faiyum Oasis and on the Sinai Peninsula. These areas need to be geologically explored to determine whether there are sufficient domestic bentonite reserves to substitute for imported bentonite in drilling mud.

7. Copper. The prospects for developing economically worthwhile deposits of copper in the Eastern Desert are good, but require intensive exploration. The United Nations has done some work on the more important copper prospects and, although the reserves are small, the geologic environment is favorable for finding additional deposits.

8. Chromium. Chromium deposits identified to date are small and irregular. Although some of the lenses are minable on a small scale, the outlook for discovering large deposits is poor.

9. Nickel. Several nickel deposits occur in the Eastern Desert, all too small to be minable. One prospect needs further evaluation, but, on the basis of known geologic information, the prospects for identifying economic deposits do not appear to be favorable.

10. Titanium. At least one titanium deposit is known to occur in the Eastern Desert and, although it is in a remote area, it could prove to be minable under the right conditions. Additional geological and geophysical surveys may reveal other deposits.

11. Miscellaneous metals used in steel making. Molybdenum occurrences have been identified in the Eastern Desert, but all are of minor importance and prospects for finding significant concentrations of this metal are not good.

Niobium and tantalum are associated with several granitic complexes in the Eastern Desert but work done to date has not revealed minable deposits.

4.0 REFERENCES

- Adindani, A.; Raljezek, R.; Youssef, H. A.; and Awad, S. M. "Evaluation of El Gharbaniyat Gypsum Deposits." Annals of Geological Survey of Egypt, 5: 1975, pps. 123-137.
- Amer, A. F.; Krintsov, M.I; and Hanna, F.L. "The Egyptian Carbonate Rocks and the Possibilities of Their Utilization." Article II, Studies on Some Mineral Deposits of Egypt, GSE report, 1970.
- Amer A. F.; Krinstov, M.I; and Hanna, F.L. "Assessment of the Egyptian Clay Deposits." Article 12, Studies on Some Mineral Deposits of Egypt, GSE report, 1970.
- Amin, M.S. "The Ilmenite Deposit of Abu Ghalqa, Egypt." Economic Geology 49. 1954, pps. 77-87.
- Bugrov, V.A. and Shalaby, I.M. "First Discovery of Cu-Ni Sulphide Mineralization in Gabbro-Peridotitic Rocks in Eastern Desert of Egypt." Annals of Geological Survey of Egypt 3. 1973, pps. 177-185.
- El-Akkad, S. and Issawi, B.B. Geology and Iron Ore Deposits of Bahariya Oasis. Paper No. 18, Geological Survey of Egypt, 1963, p. 300.

- El Ramly, M.F.; Budanov, V.I.; Hussein, A.A.A.; and Dereniuk, N.E. Ring "Complexes in the Southeastern Desert of Egypt." Article 10, Studies on Some Mineral Deposits of Egypt, GSE report, 1970.
- El Ramly, M.F.; Dereniuk, N.E.; and Armanious, L.K. "Assessment and Technological Testing of the Nepheline Syenites of Gabal Abu Khruq." Article 9, Studies on Some Mineral Deposits of Egypt, GSE report, 1970.
- Geological Survey of Egypt. Mineral Deposits in Egypt (under investigation): Paper no. 61, Geological Survey of Egypt and Mining Authority, 1974, p. 66.
- Goudarzi, G.H.; Rooney, L.F.; and Shaffer, G.L. Supply of Nonfuel Minerals and Materials for the United States Energy Industry, 1975-90. U.S. Geological Professional Paper 1006-B, 1976, p. 37.
- Hassan, M.A. "Geology and Geochemistry of Radioactive Columbite-Bearing Psammitic Gneiss of Wadi Abu Rusheid, Southeastern Desert of Egypt." Annals of Geological Survey of Egypt. 3. 1973, pps. 207-227.
- Hunting Geology and Geophysics, Ltd. Assessment of the Mineral Potential of the Aswan Region. United Arab Republic, Photogeological Survey, UNDP, 1967, p. 138.
- Hussein, A.A.A. and Hassan, M.A. "Further Contribution to Geology and Geochemistry of Some Egyptian Ring Complexes." Annals of the Geological Survey of Egypt 3. 1973, pps. 167-177.
- Kamel, O.A. "The Bahariya Iron Ores, Their Mineralogy and Origin." Annals of Geological Survey of Egypt (7), 1971.
- Moustafa, G.A. and Akaad, M.K. Geology of the Hammash-Sufra District. Geological Survey of Egypt, Paper no. 12, 1962.
- Sabet, A.H. and Tsogoev, V. "Problems of Geological and Economic Evaluation of Tantalum Deposits in Apogranites During States of Prospection and Exploration." Annals of the Geological Survey of Egypt 3. 1973, pps. 87-109.
- Sabet A.H.; Chabanenco, V.; and Tsogoev, V. "Tin-tungsten and Rare-metal Mineralization in Central Eastern Desert of Egypt." Annals of Geological Survey of Egypt 3: 1973, pps. 75-97.
- Said, R. The Geology of Egypt. Elsevier Pub. Co., 1962.
- Zitzmann, A. "The Iron Ore Deposits of the Arab Republic of Egypt." Iron Ore Deposits of Europe, Vol. 1: Hanover, 1976, pps. 129-133.
- Zaatout, M.A. and Abdou, H.F. "A Review of Bahariya Iron Ore Deposits, the Libyan (Western) Desert." Annals of Geological Survey of Egypt, 5. 1975, pps. 71-87.

United States
Department of Energy
Washington, DC 20585

PENALTY FOR PRIVATE
USE TO AVOID PAYMENT
OF POSTAGE, \$300

DOE 350

Official Business
Penalty for Private Use, \$300

THIRD CLASS MAIL