OPTIONAL WORKING PAPER NO. 4

SINAI MINERAL RESOURCE EXPLORATION AND DEVELOPMENT PLAN

APRIL 1981

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SINAI DEVELOPMENT STUDY - PHASE I

PERFORMED FOR THE ADVISORY COMMITTEE FOR RECONSTRUCTION
OF THE MINISTRY OF DEVELOPMENT

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EXECUTIVE SUMMARY

This optional working paper on a mineral resource exploration and development plan for Sinai describes the regional geology of the area, discusses mineral deposits of potential economic significance, and presents a dual program of resource evaluations and regional exploration.

More than 20 minerals are categorized according to known occurrences or potentially economic deposits. Overall, the greatest resource potential is for coal, manganese/iron, kaolin, glass sand, gypsum, turquoise, limestone/dolomite, and construction sand and aggregate.

Current exploration and development are assessed at the Maghara coal field, at Umm Bugma and Abu Zenima, at Ras Malaab, and at El Khabouba. We have concluded that activities at the Abu Zenima ferromanganese project, while they may be worthwhile, are diverting both interest and funding from potentially more valuable projects, such as the Wadi Budra kaolinite and El Khabouba glass sand mines.

We recommend resource development of four mineral deposits--Wadi Budra kaolinite, glass sand, turquoise, and cupriferous sandstone. Resource evaluation programs consist of the analysis and preparation of deposits and mines for reactivation--including identification of tonnage and grade of materials, and preliminary estimation of mining and processing costs and market values.

Regional exploration is the broad search for ore deposits of minerals which are known to occur locally, but in subeconomic concentrations. No priorities are assigned for regional exploration, but we have ranked the following resources according to anticipated economic potential--metallic mineral deposits, uranium, potash, and phosphate.

Methods of funding and revisions to existing exploration and exploitation laws are recommended for both resource evaluations and regional exploration.

1.0 INTRODUCTION

This optional working paper on mineral resource exploration and development in Sinai is presented as a complement to our deliverables for Task 4, Exploitable Natural Resources. The information presented herein is also an integral part of the total development study in that the accelerated discovery and development of mineral resources are essential for maximum industrial growth in Sinai.

The paper is divided into five sections:

- 1.0 Introduction
- 2.0 Regional Geology
- 3.0 Economic Geology
- 4.0 Mineral Exploration Program
- 5.0 Conclusions.

A major objective of the Sinai Development Study, Phase I, is to identify early projects and actions that will have a high development impact. While mineral resource exploration and development are generally long-term undertakings, the compelling need to begin industrialization in Sinai as quickly as possible demands acceleration of the process. The purpose of this working paper is to aid rapid mineral resource development by:

- Describing the types of economic mineral deposits that may occur in the region.
- Assessing the status of mineral deposits now being intensively studied or developed for near-future production.
- Outlining a program to rapidly locate, test, and develop undiscovered mineral deposits in Sinai.

This paper is based on:

- Reviews of literature published by the Egyptian Geological Survey and Mining Authority, the Egyptian Department of Mines and Quarries, the Saudi Arabian Ministry of Petroleum and Mineral Resources, and various professional journals.
- Interviews with members of the professional staffs of the Egyptian Geological Survey, the Sinai Manganese Company, Kaiser Engineers and Contractors, the Central Desert Mining Company, the Nuclear Materials Corporation, and the Remote Sensing Center of the Academy of Scientific Research and Technology in Cairo.

- Reconnaissance visits to mineral occurrences, mines, d processing plant sites in Sinai.

Sources of information on Sinai economic geology are listed in the bibliography.

2.0 REGIONAL GEOLOGY

2.1 GEOLOGIC PROVINCES

As shown in Figure 2-1, Sinai can be divided into four geologic provinces:

- Platform Province
- Suez Rift Border Province
- Crystalline Province
- Aqaba Rift Border Province.

The provinces differ in major geologic structural controls, types of geologic units, and varieties of potential mineral deposits. Their differences are mainly the result of Eocene-Oligocene doming of the crystalline Nubian-Arabian shield, which allowed erosion to strip the sedimentary cover from south Sinai; this was followed by normal and wrench faulting, which opened the Suez and Aqaba Gulfs and is related to the Red Sea floor crustal spreading beginning in the Miocene.

The general geology of each province is shown on Figure 2-2 and is described in the following sections. Details regarding lithology, stratigraphy, regional correlation, and mineral associations are presented in Table 2-1.

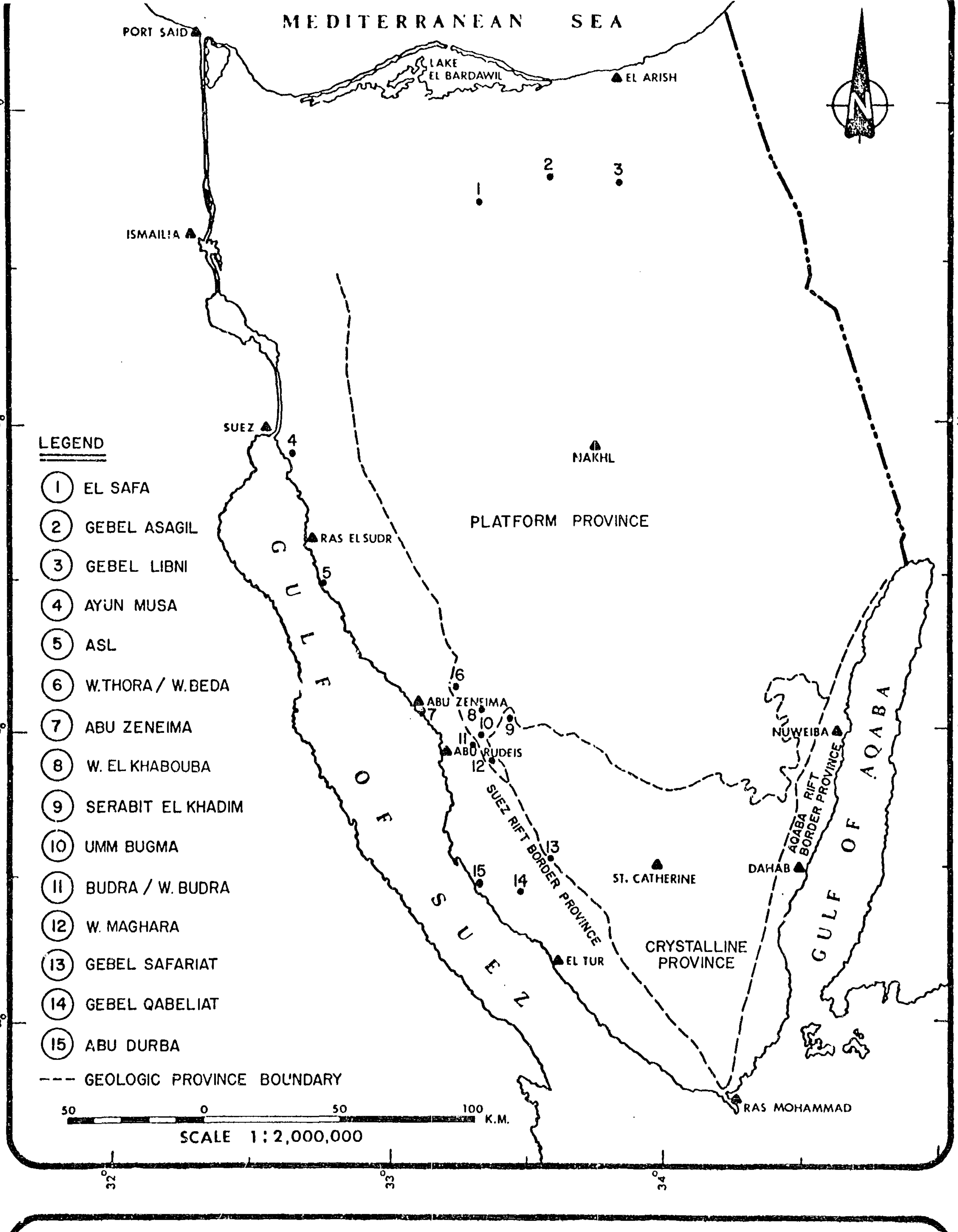
2.2 PLATFORM PROVINCE

The Platform Province is bounded on the south by erosionally exposed Precambrian metamorphic and intrusive rocks and on the north by the Mediterranean Sea. Its eastern and western limits are the Aqaba Rift and the Suez Rift Border Provinces, respectively.

The province is underlain by consolidated sedimentary rocks ranging in age from Cambrian to Pliocene. These bedded rocks are in unconformable, erosional contact with the Precambrian crystalline basement rocks, strike roughly east-west, and dip gently northward. In the northern third of the province, they are largely covered by unconsolidated Pleistocene and recent sand and gravel.

Sedimentary units that have been identified in the Platform Province include:

- Quaternary beach sand and sand dune deposits and wadi alluvium
- Neogene clastic, carbonate, and gypsum beds
- Eocene carbonate rocks
- Paleocene shale
- Cretaceous carbonates and sandstones
- Jurassic marine and fluviomarine beds



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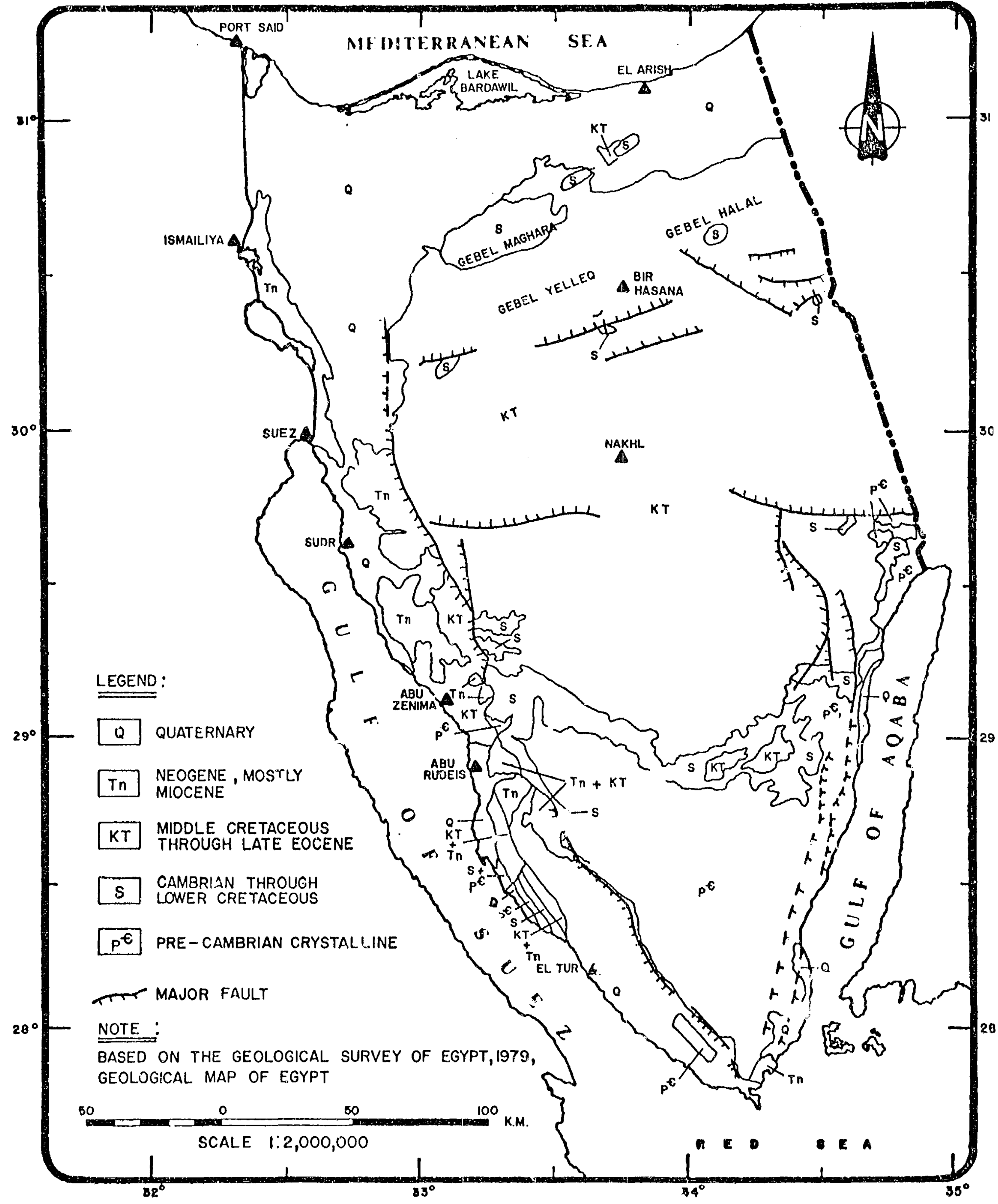
MAP SHOWING PLACE NAMES AND LOCATIONS OF GEOLOGIC PROVINCES

FIG. 2-1



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GEOLOGIC MAP OF SINAI

TABLE 2-1

Correlation of Geology and Ore Deposits in the Red Sea Areas of Egypt and Saudi Arabia

ERA	GEOLOGY: EASTERN EGYPT STRATIGRAPHY	GEOLOGY: LITHOLOGY (EASTERN EGYPT)	GEOLOGY: LITHOLOGY (WESTERN SAUDI ARABIA)	GEOLOGY: WESTERN SAUDI ARABIA STRATIGRAPHY	CORRELATIONS EGYPT/ARABIA	ORE DEPOSITS: EASTERN EGYPT	ORE DEPOSITS: WESTERN SAUDI ARABIA
CENOZOIC	Pleistocene Pliocene	Raised beaches, terraces, gravel, limegrit, marl		RAGHAMAF: Pliocene-Pleistocene			
CENOZOIC	Miocene	Gypsum Limegrit, reef limestone Conglomerate, limegrit		RAGHAMAF: Miocene		Lead-zinc (Umm Gheig)	Lead-zinc (Jabal Dhaylan)
CENOZOIC	UNCONFORMITY		Clay and sandstone	RAGHAMAF: Oligocene		Nepheline syenite (carbonatite)	
CENOZOIC	Eocene	Limestone and chert, shale	Sandstone, clay	RAGHAMAF: Eocene (Shumaysi Fn)			Iron (Wadi Fatimah)
MESOZOIC	Danian	Chalk, Esna shale					
MESOZOIC	Maestrichtian	Phosphate formation, marl, limestone, chert	Clay, limestone, sandstone	Maestrichtian (Usfan Formation)		Phosphate beds (Quseir, Safaga)	
MESOZOIC	Campanian	Quseir variegated shale				Iron (Aswan)	
MESOZOIC	Cenomanian	Nubian sandstone and shale					
MESOZOIC	MAJOR UNCONFORMITY						
	LITHOSTRATIGRAPHY			LITHOSTRATIGRAPHY			
PROTEROZOIC			Conglomerate, cherty limestone, sandstone, shale, andesite, basalt flows	Jibalah Group			Barite, fluorite vein Magnesite
PROTEROZOIC	Younger granite (Gattarian)	Riebeckite granite, micropegmatic granite, albite, muscovite granite	Riebeckite granite	Peralkalic granite (490-530 m.y.)	Younger granite in part (riebeckite granite)		Thorium-bearing zircon and thorite pegmatite
PROTEROZOIC			Rhyolite, Ignimbrite, related pyroclastics, granophyre	Shammar Group	Younger granite in part (micropegmatitic red granite)		Zinc-silver vein
PROTEROZOIC			Biotite granite, muscovite granite	Calc-alkalic granite (570-600 m.y.)	Younger granite in part (albite, muscovite, granite)	Tantalum-tin-tungsten vein and apogranite (Abu Dabbab)	Tungsten-molybdenum vein
PROTEROZOIC	Hammamat Group	Polymictic conglomerate, graywacke, volcanic sandstone, siltstone, marble		Murdama Group			
PROTEROZOIC	UNCONFORMITY		Biotite, hornblende granite, granophyre, diorite	Alkalic granite, granite, diorite			
PROTEROZOIC	Dokhan volcanics	Basalt, andesite, dacite, latite flows, related pyroclastics	Tuffite, conglomerate Marble, chert, tuffite, andesite, quartz keratophyre. Rhyolitic tuff and breccia. Andesite and basalt flows Marble, wacke, conglomerate	Hulayfah Group (Halaban) Nuqrah Formation Afna Formation	Dokhan volcanics + Shadli geosynclinal metavolcanics in part	Ironstone (Wadi Karim) Copper-zinc-lead-silver massive sulfide body (Umm Samiuki) Talc (Atshan)	Gold-silver-copper-zinc vein (Mahd adh Dhahab, Al 'Amar) Ironstone, jaspilite (Sawawin) Copper-zinc-lead-gold-silver massive sulfide deposit (Jabal Sayid, Nuqrah)
PROTEROZOIC	Older granite (Shaitian granite)	Gray biotite, hornblende granite, granodiorite	Biotite, hornblende granite, diorite	Granite, granodiorite, diorite			
PROTEROZOIC	Metagabbro-diorite complex	Gabbro, epidiorite, diabase					
PROTEROZOIC	Barramiya serpentinite	Serpentinite, dolomitic marble	Sericite, chlorite schist, quartzite, conglomerate	URD GROUP: Abt Formation	Wadi Mubarak geosynclinal metasediments in part		Silver-zinc-lead vein
PROTEROZOIC	Wadi Mubarak geosynclinal metasediments	Sericite chlorite schist, phyllite, graywacke	Marble, calcschist, actinolite schist, rhyolitic tuff	URD GROUP: Ar Ridayniyah Formation	Shadli geosynclinal metavolcanics in part		Zinc massive sulfide deposit Copper massive sulfide deposit
PROTEROZOIC	Shadli geosynclinal metavolcanics	Greenstone, pyroclastics	Chert, tuff, greenstone, gabbro, serpentinite	URD GROUP: Ophiolitic Complex	Barramiya serpentinite	Chromite	Chromite, asbestos
PROTEROZOIC			Biotite, hornblende granite	Granite, diorite (1,200-1,000 m.y.)			
PROTEROZOIC			Layered gabbro, anorthosite and peridotite	Rharaba Complex	Layered gabbro	Ilmenite (Abu Ghalqa) Nickel-copper sulfide body (Gabbro Akarem)	Gold-silver-zinc vein Iron-titanium-vanadium lens Nickel-copper-cobalt gossan (Bi'r Nabt)
PROTEROZOIC	Migif Hafafit paragneiss and migmatite	Schist, gneiss, amphibolite, leptynite, quartzite		Hali Group	Wadi Mubarak geosynclinal metasediments in part	Anthophyllite, vermiculite (Hafafit)	
PROTEROZOIC		Granite, orthogneiss		Older basement			

- Triassic carbonate and clastic beds
- Carboniferous dolomites and clastic beds
- Cambrian El Khadim Formation (cupriferous sandstone)
- Proterozoic arkosic sandstone.

The general thickness of the total sedimentary sequence (depth to basement) ranges from zero at the southern boundary of the province to 7000 meters or more along the Mediterranean shore.

Principal geologic structures in the Platform Province are east-northeast trending faults and parallel large folds. Both are restricted to the northern half of the province. The folds are open and plunge moderately to the northeast. The crests of anticlinal folds are responsible for the scattered cretaceous outcrops that form Gebel Maghara, Gebel Yelleq, and Gebel Halal.

2.3 SUEZ RIFT BORDER PROVINCE

The Suez Rift Border Province is separated from the main part of Sinai by a series of well-defined normal faults aligned in a north-northwest, south-southeast direction. The eastern border fault is shown on Figure 2-2. Its northern extent and, thus, the boundaries of the province in north Sinai are unclear because of masking alluvium and sand.

The province, as presently understood, is underlain by a sequence of sedimentary rocks ranging in age from Cambrian to Quaternary. The major units include:

- Quaternary wadi alluvium
- Neogene clastic, carbonate, and evaporite beds
- Eocene carbonate rocks and conglomerates
- Cretaceous carbonates and sandstones
- Jurassic marine and fluviomarine beds.

Because of nondeposition, or the effects of erosion accelerated by faulting, not all of these units are present everywhere in the province.

Structural geology in the Suez Rift Border Province is extremely complex because of the numerous north-northwest, south-southwest trending faults. Many of these evidence significant vertical displacement and are believed to have occurred in late Eocene through Miocene times. Fault blocks tend to be downdropped increasingly westward. This step faulting has downfaulted the central part of the Gulf of Suez, 6000 to 7000 meters relative to the rift shoulders. The trough subsequently filled with Miocene to recent sediments.

Northeasterly oriented transverse faults appear randomly along the province. Some of these exhibit significant vertical and lateral displacement.

Northwest-trending major faults and transverse faults in the province are superimposed on north-south oriented folds. The folds range from large, open structures, such as that at Umm Bugma, to local, tightly folded chevrons, which appear at Wadi Sidri near the gulf. Folding at Umm Bugma is believed to be substantially older than that described near Wadi Sidri and in the northern part of the Platform Province, and may have originated in the late Paleozoic.

2.4 CRYSTALLINE PROVINCE

The Crystalline Province occupies an area of more than 6000 square kilometers of exposed Precambrian formations, including a large number of intrusives, occasional Paleozoic/Mesozoic clastics, and alluvial and lacustrine sediments filling wadi bottoms. The province is structurally bound by the rift faults along the Gulfs of Suez and Aqaba; outcrops of Paleozoic and Mesozoic platform formations mark its northern limits.

Lithogic units in the Crystalline Province include:

- Pleistocene lacustrine and alluvial beds
- Remnants of Paleozoic/Mesozoic clastics
- Post-granite veins and dikes
- Red granites
- Volcanics (andesites, tuffs, and rhyolites)
- Diorite-epidiorite associations
- Metavolcanics
- Metasediments
- Feiran gneisses.

Precambrian

Crystalline rocks in the province are believed to be late Precambrian in age, perhaps about 600 million years old. Metamorphic rocks from four major belts along the margins of the province are characterized by low- to high-grade regionally metamorphosed argillaceous sediments and igneous intrusives, acid and intermediate metavolcanic flows, and metamorphosed acid pyroclastics. Marble and skarn are abundant in the western (Feiran) belt.

Ancient east-west faults exist in the Precambrian basement in the Crystalline Province. Some investigators believe that these structures were rejuvenated during tectonic activity in early Miocene time. In addition, near vertical faults along the Gulf of Aqaba strike north-northeast and dip westward. Evidence of vertical faulting with throws of more than 1000 meters has been reported. In several isolated places in the province, sandstones and limestones of probable Cretaceous age have been found preserved in the resulting grabens.

2.5 AQABA RIFT BORDER PROVINCE

The Aqaba Rift Border Province is separated from the Crystalline Province by a series of faults aligned in a north-northeast, south-southwest direction (Figure 2-2). The eastern boundary of the province consists of a major fault on the western side of the central depression of the Gulf of Aqaba.

Lithology in the province is essentially the same as that in the Crystalline Province. Predominant geologic units are Precambrian metamorphic and igneous intrusive rocks.

Other known geologic units in smaller exposed areas are Quaternary alluvium and Neogene sandstones, which overlie the crystallines in limited areas along the sea, and isolated sedimentary beds of pre-Neogene age which occupy grabens within the crystallines.

Regional structure in the Aqaba Rift Border Province differs from that along the Suez Rift in that major faults exhibit a significant left-lateral component of movement. Faulting in both provinces, however, is related to Miocene spreading and crustal generation in the Red Sea floor.

3.0 ECONOMIC GEOLOGY

3.1 MINERAL OCCURRENCES

Mineral deposits of potential economic significance in Sinai include:

- Construction aggregate and sand
- Limestone and dolomite for cement production
- Coal
- Manganese
- Iron
- Phosphate
- Gypsum
- Kaolin
- High silica sand for glass production
- Copper
- Turquoise
- Lead and zinc carbonate
- Uranium
- Heavy mineral-bearing beach sands (monazite, ilmenite, zircon)
- Sulfur
- Talc and asbestos
- Gold (presence uncertain)
- Tin and tungsten (presence uncertain)
- Potash (presence uncertain)
- Copper-nickel sulfides (presence uncertain)
- Rare metals--niobium, tantalum, cobalt (presence uncertain).

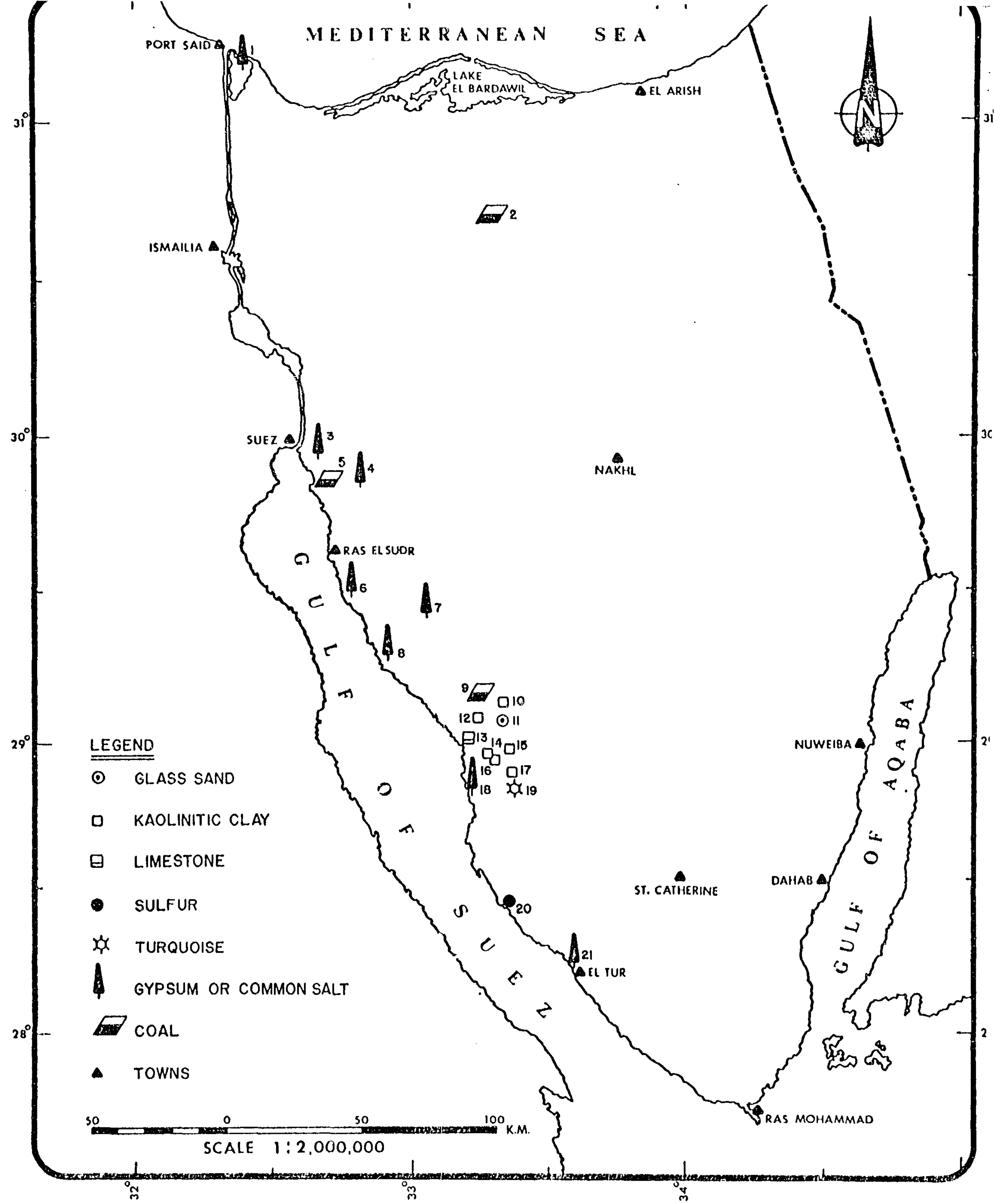
Known occurrences of some of these minerals are briefly described in the following sections. The locations of place names mentioned in the text are shown on Figure 2-1. Nonmetallic mineral occurrences are shown on Figure 3-1, and metallic mineral occurrences are shown on Figure 3-2. A summary of these occurrences is provided in Table 3-1.

3.1.1 Construction Aggregate and Sand

Materials suitable for the production of mortar and cement sand, cement gravel, and base rock occur widely as pediment cover and wadi fill throughout Sinai.

Materials readily available for economic use in the northern third of the region consist of poorly sorted clastic limestone, dolomite, and chert, with a moderate-to-high soluble salt content. Suitable sources of high-grade aggregate have not yet been located. Quarrying of cretaceous limestone exposed in Gebel Libni or Gebel Asagil would yield excellent construction aggregate, but at costs far above that of screened alluvium. Regional exploration and testing may locate presently unknown major sources of quality alluvial construction aggregate.

High quality sources of construction aggregate occur in nearly every wadi throughout south Sinai. In this region, production sites can be conveniently located near each construction project for minimum transport expense.



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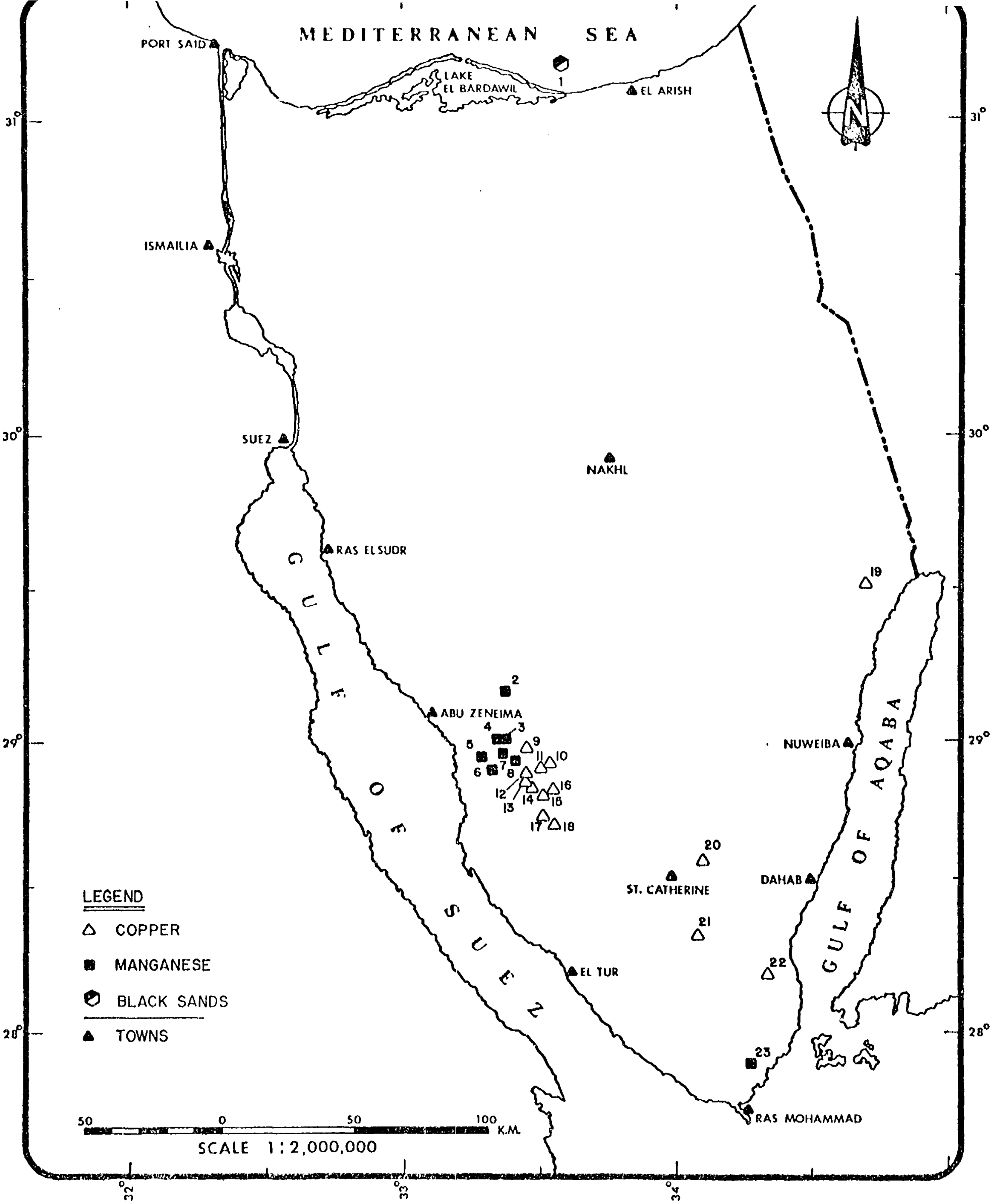
NONMETALLIC MINERAL OCCURRENCE MAP OF SINAI

FIG. 3-1



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METALLIC MINERAL OCCURRENCE MAP OF SINAI

FIG. 3-2

TABLE 3-1

Mineral Occurrence Summary

a. Nonmetallic Occurrences

Location No.*	Name of Locality	Ore Deposit	Comments
1	Port Said	Common salt	Under exploitation, major saline source
2	El Maghara	Coal	37-million-ton estimated reserve
3	El Shatt	Gypsum	Exploited before 1967
4	Wadi Rayana	Gypsum	--
5	Ayun Musa	Coal	Deep-seated seams, 40-million-ton estimated reserve
6	Ras Matarma	Gypsum	--
7	Gharandal	Gypsum	Exploited until 1967
8	Ras Malaab	Gypsum	240-million-ton estimated reserve, exploited until 1967
9	Beda and Thora	Coal	75-million-ton estimated reserve of carbonaceous shales
10	Farsh el Ghozlan	Kaolinitic clay	Exploited until 1967
11	El Khabouba	White sands	Exploited until 1967
12	Musabba Salama	Kaolinitic clay	Exploited until 1967
13	Abu Zenima	Limestone	--
14	Budra	Kaolinitic clay	Exploited until 1967
15	Abu Natash	Kaolinitic clay	Exploited until 1967
16	El Deheissa	Kaolinitic clay	--

*Refer to map in Figure 3-1.

TABLE 3-1 (cont'd)

a. Nonmetallic Occurrences

Location No.*	Name of Locality	Ore Deposit	Comments
17	Gini	Kaolinitic clay	--
18	Wadi Sidri	Gypsum	40-million-ton estimated reserve
19	Sarabit el Khadim	Turquoise	Under exploitation since ancient Egyptian times
20	Abu Durba	Sulfur	--
21	Abu Suweira	Gypsum	--

b. Metallic Occurrences

Location No.*	Name of Locality	Ore Deposit	Comments
1	Wadi el Arish	Black sands	Preliminary field and laboratory studies undertaken
2	Umm Bugma	Manganese	Largest manganese reserves in Egypt, discovered 1898, production began in 1908, production from 1911 to 1967 totalled 5.5 million tons, 4-million-ton reserve
3	Wadi Nassib	Manganese	See comments for location no. 2
4	Wadi el Noaman	Manganese	See comments for location no. 2
5	Wadi Shallal	Manganese	See comments for location no. 2
6	Gebel Abu Qafas	Manganese	See comments for location no. 2
7	Wadi el Husseni	Manganese	See comments for location no. 2
8	Gebel el Adidiya	Manganese	See comments for location no. 2

*Refer to map in Figure 3-1 for nonmetallic mineral occurrences; refer to map in Figure 3-2 for metallic mineral occurrences.

TABLE 3-1 (cont'd)

b. Metallic Occurrences

Location No.*	Name of Locality	Ore Deposit	Comments
9	Sarabit el Khadim	Copper	Ancient workings
10	Abu Suweira	Copper	--
11	Abu Rudeib	Copper	--
12	Rashidia	Copper	--
13	Abu Zagatan	Copper	--
14	Tawilleh	Copper	--
15	Abu el Nimran	Copper	--
16	Tarfa	Copper	--
17	Tarr	Copper	--
18	Feiran	Copper	--
19	East of El Agma	Copper	Ancient mine
20	Regeita	Copper	Ancient mine, 0.21 to 8.85% copper
21	Rahaba	Copper	--
22	Samra	Copper	Ancient mine
23	Sharm el Sheikh	Manganese	Small reserves

*Refer to map in Figure 3-2.

Source: The Geological Survey and Mining Authority of Egypt (1979), Mineral Map of Egypt, Ministry of Industry and Mineral Wealth, 44 p.

3.1.2 Limestone and Dolomite for Cement

Limestone and dolomite suitable for cement manufacturing occur throughout the Platform and Suez Rift Provinces. However, use of this resource in Sinai is more contingent on other siting and resource criteria (i.e., energy availability, infrastructure, transport distances) than on limestone availability.

3.1.3 Coal

Coal deposits have been explored to varying degrees at Gebel Maghara; Ayun Musa, 14 kilometers southeast of Suez; and Wadi Thora, roughly 25 kilometers east of Abu Zenima. Thin coal seams have also been recorded in oil and gas exploration boring logs elsewhere in Sinai, but none suggest sufficient depth and seam thickness to justify further exploration. Of the known coal occurrences, only those at Maghara are presently regarded as having economic potential.

Coal seams appear in middle Jurassic Bathonian sediments on the northwest limb of the Maghara Anticline. The sequence contains up to 10 coal seams, of which two are of commercial thickness. The entire sequence dips northwestward at angles of 5 to 10 degrees. It is divided into numerous blocks by small faults of the same trend.

The principal seams at Maghara--named Upper and Lower--range from a minimum thickness of 20 centimeters to a maximum thickness of 190 centimeters, with few partings, and are separated by 8 to 10 meters of limestone sandstone, clay, and shale. The coal is black, half dull, hard, resinous, and subbituminous A in rank. It is low-ash, high-sulfur, and--based on tests to date--has limited coking potential.

Drill holes at Ayun Musa penetrated up to 11 seams of coal in a 70- to 100-meter sequence of lower Cretaceous rocks, at depths ranging from 400 to 600 meters below surface. Ten coal seams occupied the upper 30 meters of the section, with a maximum seam thickness of 120 centimeters.

The lower part of the sequence contained a single seam, ranging in thickness from 18 to 120 centimeters. The seams are lenticular and nonpersistent, with no apparent workable thickness; because of these characteristics, and great depths and complicated geologic structures, the deposits at Ayun Musa are considered noncommercial. Future exploration potential in the region is also believed to be limited.

Twenty drill holes and several pits and adits have served to test a coal horizon that occurs in Carboniferous sediments at Wadi Beda and Wadi Thora, roughly 14 kilometers apart, east of Abu Zenima. The single seam was found to range between 10 and 80 centimeters in thickness and to be of low quality. It has limited potential beyond local heating use.

3.1.4 Manganese-Iron

Manganese-iron deposits occur as lens-shaped, concordant bodies and fissure fillings in the Carboniferous Umm Bugma Formation east of Abu Zenima and Abu Rudeis. The ore lenses average 2 meters in thickness, but locally achieve a thickness of 4 meters. The host rock consists of red and yellow crystalline dolomite, variegated shale, and sandy clay. An average lens might contain 10,000 tons of ore above a cutoff of 20 percent manganese.

The mineralization consists of manganese oxides mixed with iron oxides; earthy oxides and pyrolusite are associated with goethite-hematite and other minerals such as calcite. Traces of uranium and copper accompany the manganese.

Ore specimens with up to 60 percent manganese occur in the deposits; historically mined, hand-sorted, high-grade material from the Umm Bugma district averages up to 40 percent manganese. Remaining explored deposits of significant tonnage average between 20 and 30 percent manganese.

3.1.5 Iron

Iron associated with manganese east of Abu Zenima has economic significance as a byproduct of manganese extraction, potentially accounting for the difference between profit and loss.

Passing references occur in some reports to ferruginous horizons with oolitic hematite in Cretaceous Nubian sandstones of the Plateau Province. No plotted locations, measured sections, or sample analyses for such occurrences could be found in the available literature, nor were the Egyptian geologists contacted by Dames & Moore able to provide information regarding exposed mineralization. However, the sedimentary horizon that contains oolitic iron ore at Aswan also crosses Sinai and warrants at least reconnaissance exploration.

Micaceous hematite is known to occur in quartz veins in eastern Sinai, in granite at Gebel Abu Mesud. Comparable host granites appear in west Sinai. While known occurrences of iron mineralization of this type in Sinai are not economic, they sustain major mines elsewhere in the world. The potential presence of slightly concealed, higher grade, larger iron-bearing quartz veins in the crystalline rocks of south Sinai warrants reconnaissance investigation.

3.1.6 Phosphate

Phosphatic limestone is interbedded with sandstone, shale, and clay of formations whose outcrops ring the Platform Province of Sinai. Phosphate-bearing sediments have been recorded in this horizon along the eastern Suez coast, in Gebel Qabeliat, Gebel Safariat, and Wadi Sudr, and south of both the El Tih and Igma plateaus. Records for only one measured and sampled section are available--in Gebel Safariat--where an 0.3-meter thick bed of phosphorite was found to contain 24.6 percent P_2O_5.

The single measured and analyzed section of Sinai phosphate does not compare favorably with deposits presently being mined in the eastern and western deserts of Egypt. Along the Nile, commercial phosphate beds range up to 4 meters in thickness and contain as much as 25 percent P_2O_5; the economic minimum thickness is roughly 0.5 meters, averaging 23 percent P_2O_5. However, the phosphate horizon in Sinai has not been systematically explored or even mapped. Thorough exploration, particularly toward east Sinai, may locate exploitable deposits.

3.1.7 Gypsum

Gypsum and anhydrite in Sinai are associated with marl and sandstone in the Miocene Ras Malaab and Ras Gemsa Formations along the Suez Rift Border Province. The best known occurrence, that at Ras Malaab, varies from 5 to 30 meters in thickness. It has been segmented by normal faults, with throws ranging up to 10 meters, and is overlain by 1 to 3 meters of alluvium and leached, weathered caprock. Gypsum and anhydrite appear in thick, interlensing zones surrounded laterally by sandy shale and clay. No other evaporite deposits (bitter salts, sodium chloride) are reported to accompany the known Sinai gypsum occurrences.

3.1.8 Kaolin

Known occurrences of kaolin appear in the Carboniferous Abu Zarab Formation and a clayey and sandy horizon in the Cretaceous Nubian Formation. All reported deposits are located in the Suez Rift Border Province, east of Abu Zenima and Abu Rudeis. The best known of these, where some development and production have occurred, is at Budra, near the Umm Bugma manganese mine.

At the Budra site, four kaolinite beds with an aggregate thickness of 36 meters occur in a 95-meter-thick sequence of Nubian sandstone. The Kaolin horizons are lensoidal-pinching and swelling, with variations in quality. The beds dip to the southwest at angles between 20 and 40 degrees and are offset by faults with throws of up to 100 meters.

The kaolin horizons are pure or slightly silty and sandy, and range in color from light grey through violet to dark grey. The clay is chemically pure or slightly ferruginous, and consists principally of kaolinite with small admixtures of dickite and hydromica. Its quality is suitable for the production of fine ceramics.

Based on available reports, the kaolin deposits at Budra and comparable deposits that may be discovered in the region offer the best quality and most economically available source of clay in Egypt. The kaolin may also be competitive in the export market. Its exploration and development merit serious consideration.

3.1.9 High Silica Sand

Quartzitic sand, which is optimum for the production of clear glass, should be uniformly distributed in size between 200 and 600 micrometers, have an iron content of less than 0.07 percent, and have minimum contaminating sodium, calcium, and potassium. Available reports suggest that the best source of glass sand in Egypt occurs in a quartz sandstone horizon of Carboniferous sedimentary rocks east of Abu Zenima and Abu Rudeis.

The quartz sand horizon at the best known location, near Wadi el Khabouba, northeast of Abu Zenima, is approximately 30 meters thick. Further south near Wadi Budra, where the same horizon was examined during Dames & Moore's field reconnaissance, the quartz sand horizon was approximately 15 meters thick. Sinai Manganese Company engineers reported it to be nearly equal in quality to that at El Khabouba. This physically and chemically persistent horizon represents an unlimited source of high quality silica for glass manufacturing, which may have export potential. Its development for economic production and marketing will require some exploration and testing.

3.1.10 Copper

Precambrian crystalline rocks at a number of locations in south Sinai bear thin quartz veins of short length which contain copper carbonate, probably an oxidation product of sparse chalcopyrite. These types of deposits have no practical exploration potential.

Historically, copper has been produced from copper oxide-bearing sandstones of the Cambrian Serabit el Khadim Formation or from overlying lower Carboniferous strata. Extensive beds of cupriferous sandstone in these units are reported to have been mined in ancient times near Wadi Maghara in west central Sinai. Ores are described as containing up to 18 percent copper in carbonates and silicates. Numerous other locations with cupriferous sandstone outcrops have been described by Egyptian geologists who have worked in the region.

While there has been no thorough evaluation of a copper sandstone deposit in Sinai, comparable deposits elsewhere have supported economic mining operations. The deposits are sometimes associated with sandstone-bearing uranium and silver. Moreover, recent technological developments allow these ores to be treated at very low cost, making them attractive exploration targets. Their potential for economic occurrences and exploitation in Sinai should be pursued.

3.1.11 Turquoise

Turquoise mining is known to have been carried on at Serabit el Khadim, near Umm Bugma, for an extended period. Engineers of the Sinai Manganese Company stated that numerous additional small turquoise mines occur in the region. Hume (1906) also reported turquoise occurrences at Gebel Maghara. No other information regarding turquoise mines and occurrences could be obtained during our investigation.

Turquoise mining is typically a sm ll, labor-intensive industry. Deposits generally occur as thin seams along fractures or small pockets of pebbly stone in a sandstone matrix Owing to this distribution and the fragile nature of the material, mass mining techniques are not applicable and blasting must be minimized. However, despite the labor-intensive nature of turquoise mining, it can be a lucrative enterprise. Top-quality turquoise brings up to LE 200 per kilogram on the European wholesale market. Although limited as a major industrial growth resource, turquoise exploitation potential in south Sinai should be investigated. If sufficiently rich deposits are found, market development, minor financial aid, and technical assistance could launch a cottage industry with long-term income potential for numerous small mines.

3.1.12 Lead and Zinc

Economic deposits of lead and zinc carbonates, the near-surface expression of deeper lead-zinc sulfide ores, occur in Middle Miocene limegrits, brecciated limestones, and calcareous sandstones along the western Red Sea coast. While these deposits appear concentrated in an area substantially south of Sinai and its geologic counterparts on the west side of the Gulf of Suez, their appearance in the basal Miocene marls and conglomerates of the Suez Rift Border Province cannot be excluded from consideration. Lead, associated with barite, was reportedly encountered in an exploration boring in the Asl oil field in the Gulf of Suez off Sinai.

If located in Sinai, lead and zinc deposits would be mineral resources with long-term development potential. Presently proven world reserves are reportedly sufficient to meet world demand for the next 100 years. Nonetheless, domestic resources would be a valuable asset which, under changing political conditions, could contribute to national development in a shorter period of time.

3.1.13 Uranium

Trace amounts of uranium are known to be associated with carbonaceous Jurassic sedimentary rocks in the Maghara area of the Platform Province and with manganese ore deposits east of Abu Zenima and Abu Rudeis. Due to its classified nature, information regarding uranium mineralization elsewhere in Sinai and in Egypt's Eastern and Western Deserts could not be obtained. Consequently, Dames & Moore must rely on its assessment of favorable host environments in Sinai to evaluate the potential for economic uranium occurrences.

Our review of literature for the post-Carboniferous sandstone deposits of north Sinai did not detect the potential presence of pronounced oxidation/reduction fronts. These serve as the concentrating mechanism for roll-front uranium mineralization such as that which occurs in the western United States. Furthermore, extensive sequences of acid extrusive volcanic tuffs or detritus from acid instrusive rocks--indicative of trace amounts of uranium--are not present; therefore, we assess the potential for large uraniferous sandstone deposits in Sinai as limited. This does not preclude the occurrence of small concentrations of uranium in sandstone in close association with igneous intrusive and high-grade metamorphic rocks, particularly in the vicinity of manganese-iron mineralization.

While sedimentary rocks of the Platform Province do not hold promise, the Precambrian crystalline rocks of south Sinai warrant some exploration. We understand that veins up to 2 meters in width and containing pitchblende have been discovered in Precambrian rocks of the Eastern Desert. This general host environment matches that of the Crystalline Province. Comparable geologic environments elsewhere in the world contain highly economic uranium deposits, notably in the Precambrian shield area of Canada. We conclude, therefore, that uranium exploration opportunities in south Sinai warrant further consideration.

3.1.14 Heavy Mineral Bearing Sands

Beach sands with concentrated heavy mineral suites derived from Nile River outwash are known to occur along the Mediterranean coast from the Nile Delta to El Arish. The sands at some locations contain up to 3 percent ilmenite, monazite, zircon, garnet, hematite, rutile, and pyrite. Ilmenite constitutes roughly 60 percent of the heavy mineral suite. These materials were drilled and tested by the Egyptian Black Sand Company at several locations along the north Sinai coast before 1967.

Mediterranean beach sand deposits with the concentrations of heavy minerals identified to date do not appear to be economically promising. The cost of mining, processing, and distributing the potential products of the beach sands far exceeds their estimated market value. Additionally, heavy mineral bearing sands that may occur along the Gulf of Suez are not promising. No further action should be taken to develop these resources at this time.

3.1.15 Sulfur

Elemental sulfur has been reported at Abu Durba, 40 kilometers south of Abu Rudeis along the Gulf of Suez coast, and in the Platform Province near Gebel Bedabaa and the Agama Mound. No details are known regarding these occurrences in the Platform Province.

Near Abu Durba, sulfur is rumored to occur in fractures in shale and sandstone of the Upper Ras Malaab Formation. If true, the sulfur occurrence is comparable to that in Miocene evaporite sediments along the west coast of the Red Sea. At these locations, sulfur is directly and genetically related to gypsum-anhydrite deposits. Comparable deposits have no practical potential as sources of raw elemental sulfur. Economically, the production of sulfur by acid processing of gypsum-anhydrite holds greater opportunities.

Other potential sources of sulfur, such as sulfur cappings over petroleum and gas reservoirs in the Gulf of Suez, were not evaluated during this investigation.

3.1.16 Talc and Asbestos

Occurrences of talc and asbestos are typically associated with Precambrian ultramafic instrusive rocks such as peridotite, serpentinite, gabbro, and norite. Ultramafics of this type host talc and asbestos deposits in the Eastern Desert of Egypt.

Currently available geologic maps of the Crystalline Province of Sinai do not show areas underlain by ultramafic rocks, nor have they been mentioned in most published geologic reports. Nonetheless, an Israeli Geological Survey report prepared in 1976 describes an ultramafic serpentinite mass in the Dahab area of eastern Sinai.

Additional outcrops of ultramafic rocks may occur in the Crystalline Province, but could have been overlooked during previous mapping because of limited areal extent or appearance in weathered exposures. This introduces the possibility of economic talc and asbestos deposits in the province. Economic occurrences of copper-nickel sulfides, also associated with ultramafic intrusives in the Eastern Desert, are additional exploration targets.

3.1.17 Gold

No deposits of gold are known to occur in Sinai. However, an axiom with some merit in the exploration industry is that "gold is where you find it."

Numerous gold deposits are known to exist and have been historically mined in the Eastern Desert of Egypt, where host rock and geologic structural conditions are nearly identical to those in south Sinai. Four types of gold deposits, resulting from four separate cycles of gold mineralization, are found in the Eastern Desert. At least three of the four intrusive and metamorphic events associated with these cycles are also manifested in the Sinai Crystalline Province.

The failure of ancient miners to locate and extract gold in Sinai does not rule out the possible occurrence of economic gold ore deposits. Historic prospecting relied on the appearance of visible gold in surface outcrops to guide the tunneling effort toward valuable buried deposits. Even today at the ancient gold mines of Egypt, gold cannot be found in surface outcrops, but can be located at some depth underground in the old tunnels. Tunnels resulting from such historic prospecting of quartz veins in the Crystalline Province of Sinai are not mentioned in published literature, so tunnel prospecting does not appear to have been undertaken.

New types of gold deposits containing microscopic particles of gold have been found elsewhere in the world, but no exploration for such deposits has yet been attempted in Sinai.

3.1.18 Tin, Tungsten, and Rare Metals

Tin, tungsten, and rare metals such as tantalum and niobium occur in quartz veinlets, stockworks, and the contact zones of silica-rich, small granite instrusives of Gattarian and post-Gattarian age in the Eastern Desert of Egypt. These intrusives are believed to be genetically or spatially related to the pink granites that occur in both the Eastern Desert and south Sinai. One such metal deposit, at Abu Dabbab in the Eastern Desert, is sufficiently rich to warrant immediate development; a number of international companies are competing for the contract to mine the deposit.

Areas of pink Gattarian granite are shown on existing maps to cover large portions of the Crystalline Province of south Sinai. However, ground geologic mapping has not yet been completed in sufficient detail to outline areas of silicic apogranite that might carry tin-tungsten-tantalum-niobium mineralization. Short of extensive detailed mapping, exploration for such deposits can be achieved most rapidly by stream sediment geochemical surveys. This exploration method should find early application in Sinai regional mineral resource development.

3.1.19 Potash

A few geophysical logs from oil and gas exploration borings in the Gulf of Suez, provided to Dames & Moore by the Egyptian Geological Survey, were examined during our investigation. These revealed the presence of geophysical indicators that may represent zones of potash 700 to 1800 meters below the floor of the gulf. Such zones at extreme depths beneath the gulf floor do not, of themselves, bear economic interest, but do serve as exploration guides.

Sedimentary horizons that carry potash beds beneath the gulf may extend eastward beneath the Suez Rift Border Province at shallower depths. Since formation of the rift post-dates the deposition of the potash in evaporite basins, there is no reason to suspect thinning of the valuable potash shoreward. In fact, folding that slightly predated northwest faulting in the province may have served to further concentrate potash deposits. Potash salts become extremely mobile under the forces of folding and faulting. Related tectonic pressures serve to concentrate and thicken potash beds on the crests of anticlinal folds. Broad post-Eocene folds along the central and northern Suez Rift Border Province might prove interesting in this respect and warrant further investigation.

3.1.20 Other Minerals

Other types of mineral deposits known to occur in Sinai include bentonitic clays, sodium sulfate, alunite (aluminum source), marble, coal shale, and feldspar for use in the glass and ceramic industry. The potential of these minerals for exploration and economic development is not discussed in this paper because of a lack of information; nor is the possible production of salt from Lake Bardawil brines described, since this is more of an industrial/chemical undertaking than a mineral resource development opportunity.

3.2 MINERAL PRODUCTION HISTORY

Copper was mined and smelted near Wadi Maghara, east of Abu Zenima, in pharaonic times. Production apparently ceased when supplies of charcoal (made from acacia trees) for smelting were depleted. Turquoise mining is an equally ancient industry east of Abu Zenima, notably at Serabit el Khadim. Production continued on a small scale until the 1967 invasion. Present dormancy is attributed to a lack of dynamite and the failure of younger local residents to continue their fathers' interests in mining.

The production of manganese from nearby Umm Bugma began in 1918 and continued regularly until 1967. Mining for export ranged from 150,000 to 200,000 tons annually, with peaks of 250,000 tons in a few exceptional years. Production in 1966 was approximately 200,000 tons of ore, averaging 23 percent manganese. A 250-ton-per-day smelter to process Umm Bugma ore was nearing completion at Abu Zenima when hostilities began in 1967. The plant was almost totally destroyed by Israeli occupation.

Little is known of kaolin production east of Abu Zenima. Four mines were in operation before 1967. The nature of mining equipment now at these mines and the extent of development suggest a long period of production. When operations ceased in 1967, domestic demand at a rate of 50,000 tons per year was satisfied by the opening of poorer grade mines at Kalabsha, southwest of Aswan.

High quality glass sand was produced at El Khabouba, 20 kilometers northeast of Abu Zenima, at an unknown yearly rate before 1967.

Quality gypsum was mined for export at Ras Malaab, Gharandal, and El Shatt further north along the Suez coast. Ras Malaab was the larger operation; excavations suggest a total pre-1967 yield in excess of several million tons. Further details regarding gypsum production were not available.

Coal resources at Maghara were being explored and developed in 1966. A 50-million-ton total reserve had been identified. Mine development, consisting of a shaft and two inclines, had begun at El Safa in the Maghara field before the 1967 occupation. Planned production capacity was 150,000 tons per year beginning in 1968, escalating to 300,000 tons per year by 1975. The decline portals at El Safa were blasted shut by the Israelis to prevent accidental fires in the gaseous openings; the shaft remains open, but natural deterioration through lack of maintenance has damaged wall supports and hoisting gear.

3.3 CURRENT EXPLORATION AND DEVELOPMENT

Recent exploration and development drilling at Umm Bugma has delineated a manganese ore reserve of 1.2 million tons, containing 22 to 25 percent manganese. Prefeasibility studies by Kaiser Engineers and Constructors, Inc., in association with the Arab Consulting Bureau, suggest marginal economic production. Additional research must be completed to find ways of improving the economics of production and to ensure economic viability. Research funding is under consideration by the Ministry of Development. A successful outcome will lead to construction of a new smelting plant at Abu Zenima and operation by the Sinai Manganese Company.

A prefeasibility study for reactivation of the Ras Malaab Gypsum mine was recently completed for the Sinai Manganese Company by the McKee-Kearney joint venture. Investigation results suggest marginally profitable operating potential if domestic and export markets can be located.

The Sinai Manganese Company is presently opening a pit on a glass sand horizon near Wadi Budra, south of Umm Bugma. Tender offers have reportedly been received from domestic and foreign consumers who will purchase 300,000 tons of glass sand from the pit annually.

The Egyptian Geological Survey and Mining Authority recently solicited tender offers from contractors to conduct feasibility studies, develop a coal mine, and construct a preparation plant at El Safa in the Maghara coal field. The desired level of production is 600,000 tons per year initially, escalating to 1,000,000 tons per year within 3 years. Numerous offers from both domestic and foreign mining companies have been received.

Proven mineable reserves in the El Safa block of the Maghara field are around 36 million tons of subbituminous Type A coal. The Egyptian Geological Survey is currently drill exploring a southwest extension of the Maghara field and has identified an additional 30-million-ton probable reserve of economically recoverable coal.

In addition to the foregoing investigations and development projects, a number of small open pits located 20 to 40 kilometers south of El Arish are providing construction sand and aggregate for that city. Other small gravel pits support road construction at scattered locations in north Sinai and in the Suez Rift Border Province. Minor natural salt harvesting by Bedouins along Lake Bardawil is also reported.

3.4 ASSESSMENT

The exploration and development of coal at Gebel Maghara, as a major resource and national asset, is being ably managed by the Egyptian Geological Survey and Mining Authority. Research directed toward ferromanganese production at Abu Zenima, with its importance to domestic self-sufficiency in the heavy industries, is correctly being administered by the Ministry of Development. However, no comprehensive analyses of the development potential of other known mineral occurrences in Sinai--considering modern technology, costs, and markets--have been completed; nor has thorough exploration for undiscovered mineral deposits, using contemporary, sophisticated methods and concepts, been undertaken.

Achievement of the foregoing tasks will greatly accelerate mineral production and industrialization in Sinai. It will enable the Government to direct funding toward those development opportunities with the greatest possible returns in financial and social benefits; public sector companies will be induced to focus on projects with real economic potential; and foreign capital may be attracted by documented information regarding mineral deposits.

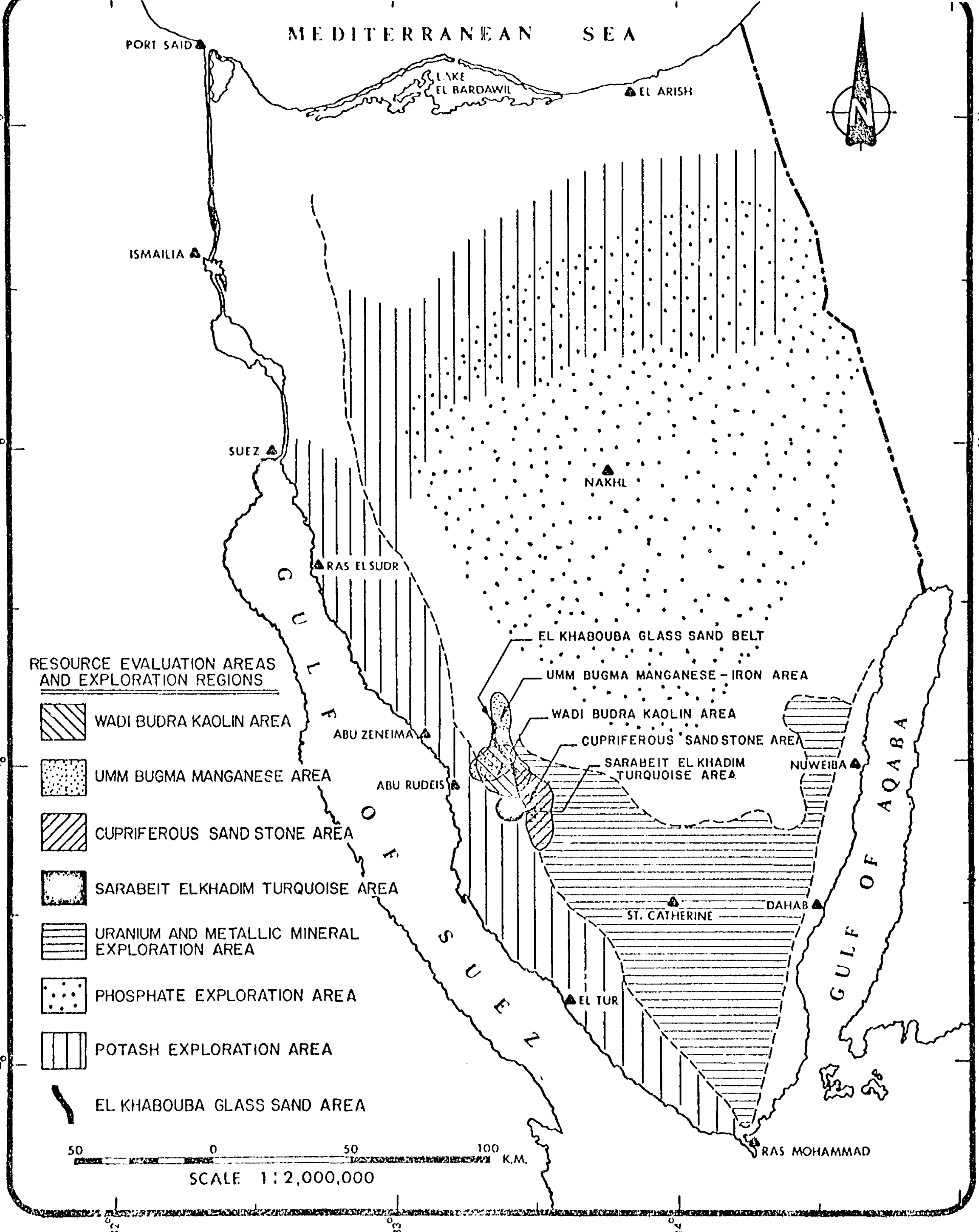
Development planning to achieve the stated goals should include, in order of priority:

- Resource estimations and prefeasibility studies for kaolin, glass sand, and turquoise.

- Local exploration for economic deposits of copper-bearing sandstone.

- Regional exploration for previously undiscovered or unknown ore deposits of iron, phosphate, uranium, potash, talc, asbestos, gold, and other metals such as tin, tungsten, copper-nickel, and niobium-tantalum-cobalt.

The following sections of this paper outline a program for the recommended action. The locations of areas recommended for resource evaluations and regional exploration are shown on Figure 3-3.



Sinai Development Study Phase 1
Ministry of Development

Dames & Moore

MINERAL POTENTIAL MAP OF SINAI

4.0 MINERAL EXPLORATION PROGRAM

4.1 RESOURCE EVALUATIONS

The locations of potentially economic deposits of kaolin, glass sand, turquoise, and cupriferous sandstone are known in Sinai, either by professional geologists or local inhabitants who have worked the deposits. Some of these have obvious exploitation possibilities based on recent historic production; others may have been rendered economic by newly developed technology and changed market conditions.

For most of the known deposits, either no records were made or preserved regarding ore distribution, tonnage, and grade, or prepared records were lost or destroyed during the war. In many cases, unfortunately, knowledgeable operators and workers have also dispersed. Consequently, comprehensive resource evaluation programs must be undertaken to analyze and prepare these deposits and mines for reactivation. The programs will identify the tonnage and grade of material available for mining in each deposit. Preliminary estimates of the mineability, mining and processing costs, and market values will also be included. This information is integral to prefeasibility studies and is a necessary data base for future development planning.

Resource evaluation programs for known deposits of kaolin, glass sand, turquoise, and cupriferous sandstone are discussed in the following sections.

4.1.1 Kaolin

Kaolin was developed in six underground mines and explored in a number of drifts and cross-cuts at Wadi Budra, 10 kilometers south of the Umm Bugma manganese mine.

The initial effort in assessing reactivation potential at Wadi Budra should be a brief market analysis--considering published ore grades, international processing costs, and transport distances--to estimate the competitive position of the deposits in domestic and foreign markets. Optimistic results should be followed by serious attempts to obtain past production records, physical and chemical analyses, and ore reserve maps from prior operators.

Necessary fieldwork will include the mapping of surface outcrops of kaolin, related host rock, and geologic structures at a scale of 1:5000. From these maps, district isopach overlays can be generated to identify the trends of thicker kaolin zones at Wadi Budra.

In conjunction with district mapping, detailed mapping of outcrops adjacent to developed mines and underground mine workings should be mapped at a scale of 1:1000. Available underground maps may only require supplemental surveying.

Using detailed surface and underground maps as a plotting base, exposed kaolin beds at representative locations should then be measured and channel sampled. Samples must reflect true conditions in each developed ore block and zone and must be analyzed for silt and sand content, deleterious chemicals, and processing characteristics.

Preliminary resource estimates involving the delineation of reserve blocks around mapped exposures, bed correlations between exposures, and projections and planimeter measurements of proven, probable, and possible ore reserves can be made at the conclusion of the field program and sample analyses. Concurrently, initial estimates of the tonnage and grade of material required for serious economic consideration must be refined. If proven, probable, and possible reserves meet order-of-magnitude target goals, two courses of action are possible:

- Exploration drilling can begin to enlarge the ore reserves, with a view toward initiating a larger mining and processing operation, or

- Ore reserve development drilling can be started to convert probable and possible ore to proven ore and to acquire geologic data necessary for mine design.

In the latter case, prefeasibility studies can begin concurrently with ore reserve development. These studies would include further marketing research, conceptual mine and process plant design and costing, operating cost estimates, and bench-scale metallurgical tests to develop process flow sheets. Prefeasibility studies mark the end of resource evaluations.

In no event should prefeasibility studies for kaolin production at Wadi Budra begin before the combined totals of the proven ore reserve, plus one-half of the probable ore reserve, satisfy initial order-of-magnitude target goals. Failing in this, additional exploration in the district--employing isopach projections, paleochannel delineation, shallow seismic profiling, and exploration drilling--may be required.

4.1.2 Glass Sand

Quartz sands with chemical and physical characteristics optimum for glass production occur in apparently almost unlimited volumes east of Abu Zenima and Abu Rudeis. Resource evaluation, beginning with a brief market analysis, should focus on:

- Obtaining representative samples of this material for analysis.

- Commissioning analyses that will be regarded as unquestionably reliable by foreign buyers.

- Locating areas along the glass sand sedimentary unit which offer a combination of the following optimum production conditions:

  - Maximum bed thickness of quality sand

  - Favorable overburden conditions to minimize waste stripping

  - Minimum structural disturbance demanding consideration in open-pit mine design

  - Favorable location with respect to access roads and transport facilities (e.g., piers).

The El Khabouba mine, which enjoyed production before 1967, would be a logical starting point in selecting optimum mining sites, but may not itself be the best location. Continuous mapping of glass sand outcrops at a scale of 1:10,000 should be performed, beginning at El Khabouba. From this map, other favorable sites with respect to thickness, access, and transport can be identified and their approximate overburden estimated. Follow-up would include detailed mapping (1:2000 scale), widely spaced reconnaissance drilling, and sampling for analysis.

The results of the foregoing program would provide necessary basic data for prefeasibility studies. For glass sand, these studies must concentrate on market analyses, though conceptual mine designs, capital, and operating cost estimates--particularly transport--will also be important.

4.1.3 Turquoise

Turquoise, unlike most other types of mineral deposits, cannot be inventoried and tested to provide data for conventional prefeasibility studies. Economic development potential can only be estimated by pilot mining operations, which serve to:

- Establish the approximate amount of turquoise recoverable per ton of mined rock at favorable locations.
- Test different mining methods to select those which are most economically productive.
- Generate a nucleus of potential small mine operators, who can subsequently initiate the industry on a small "family mine" scale by training and employing only interested, local inhabitants.
- Provide a bulk sample of turquoise to submit to potential buyers for valuation.

The following program is recommended for Sinai turquoise resource evaluation:

- Interview local residents to identify previous mining sites.
- Complete site visits and reconnaissance mapping of those locations which appear to be promising.
- Select two or three sites for pilot mining.
- Employ and outfit local mining teams.
- Supervise pilot mining and hand sorting of the turquoise.
- Submit the samples for valuation.
- Analyze the material and labor cost of pilot mining, the volume of turquoise recovered, and its market value.

If the results of pilot mining and economic analyses prove favorable, some management and technology organization may be required to launch the industry. For example, a public sector company might be established to:

- Control and lease mining sites under terms which would promote production. Terms might include small royalty payments, minimum production or mine development demands, and actual lessor/operator presence at the site. This would prevent the nonproductive holding of mineral resources by absentee lessors wishing to speculate in future values.

- Provide limited material assistance in the form of drilling and small hauling equipment and blasting supplies.

- Provide technical guidance in small mine development, mining, and recovery methods.

- Purchase turquoise from small mines at equitable prices for domestic or export wholesaling.

4.1.4 Cupriferous Sandstone

An ancient method for extracting copper from certain types of ore, combined with modern techniques for recovering the copper from extracting solutions, has gained wide application in the mining industry. The system is called "heap leaching and cementation recovery." It is particularly suitable for small, remote mining operations in that massive, high-cost processing equipment is not required; only water, sulfuric acid (battery acid), and scrap iron are needed. The technology is simple, and the operating costs are low.

For heap leaching, uncrushed copper ore from a mine is piled on an impermeable pad, either compacted clay or plastic. Water with a small amount of acid is applied to the top of the heap through farm-type sprinklers. The acid water leaches the copper and trickles along the impermeable pad to be collected in ponds. It is then circulated by pumps through concrete troughs containing scrap iron. The copper in the acid solution replaces iron in the scrap and accumulates on the floor of the trough as copper cement. After drying, this is a readily marketable, high unit value commodity (LE 1000 to 1500 per ton).

Heap leaching and cementation recovery are very applicable to sandstone copper ores such as those which occur in Sinai east of Abu Zenima. They are, in fact, some of the most suitable ores for this type of treatment, and their economic potential warrants investigation. For this purpose, we suggest the following program:

- Reconnaissance visits to sandstone copper deposits shown on existing maps, supplemented by information from local residents. Several of the deposits described in technical literature bear ancient mine workings.

- Reconnaissance mapping, outcrop sampling, and sampling in accessible underground workings at apparently favorable sites.

- Preliminary engineering analyses and selection of the best occurrences for further investigation.

- Detailed mapping, test pitting, and exploration tunneling at the most promising locations, followed by channel sampling and assays.

- Preliminary estimates of ore reserve potential and mining and processing costs based on site conditions, ore thickness, and grade.

- Bench-scale heap leach testing of representative materials from favorable deposits.

- Exploration drilling program design and implementation for those deposits that appear to offer economic potential.

Exploration and development beyond this stage would follow the sequence of ore reserve development drilling, prefeasibility studies, bulk testing, and engineering analyses typical for other mineral deposits in Sinai.

4.2 REGIONAL EXPLORATION

4.2.1 Definition

"Regional exploration" is the broad search for ore deposits of minerals which are known to occur locally, but in subeconomic concentrations. It also applies to types of minerals whose presence in any amount is uncertain, but which may logically be expected to occur in the geologic environment being explored. Mineral deposits located during "regional exploration" become the subject of "resource evaluations."

4.2.2 Exploration Targets

Based on available information, those types of minerals worthy of regional exploration in Sinai are:

- Phosphate and iron as bedded ore deposits in Cretaceous sandstone rocks of the Platform Province.

- Potash in evaporite-bearing, Miocene-Eocene sedimentary rocks of the Suez Rift Border Province.

- Uranium as pitchblende in veins in Precambrian rocks of the Crystalline Province.

- Metallic mineral deposits of iron, gold, tin-tungsten, and rare earth metals (niobium, tantalum, cobalt) which may occur as podiform masses in veins, stockworks, or placer (alluvial) deposits in the Crystalline Province.

Each of these minerals is subject to a different type of exploration approach.

4.2.3 Exploration Methods

Regional geologic maps are the basic framework for any exploration program and must, in some cases, be prepared. Maps with a sufficient level of detail for Sinai have already been generated by the Remote Sensing Center in Cairo.

Information shown on regional maps is supplemented by a photointerpretive search for particular structural features relevant to mineral deposits. These might include folds, faults, and shear zones of a particular age and trend, alteration zone discolorations, or ring-dike and domal structures related to particular types of metallic mineral deposits.

Airborne radioactivity and magnetic maps are important supplements to regional geologic and photointerpretive maps. Radioactivity maps define broad areas of apogranites which may host tin-tungsten and rare earth deposits; delineate phosphatic sedimentary rocks which typically carry trace amounts of uranium; and locate strong, linear radioactivity anomalies potentially related to uraniferous pitchblende veins.

Office analyses of these various sources of regional exploration information serve to identify particular locales or areas that should be examined during field reconnaissance.

In all cases, field reconnaissance begins with visits to known mineral occurrences. These are sketch mapped and sampled. Details regarding their nature, mineral content, host rock, structural setting, and related alteration features serve as models and guides for the discovery of larger, potentially concealed mineral deposits.

Next, anomalous or peculiar features detected on regional geologic maps, aerial photographs, and radioactivity and magnetic maps are visited to determine their character. Reconnaissance mapping, ground scintillometer surveys, outcrop sampling, and analyses can be completed in those areas with surface evidence of mineralization.

Reconnaissance examinations are carried on until the nature of each radioactivity or magnetic anomaly, peculiar structural feature, or alteration zone is known.

Outcrop sampling and mapping and stream sediment geochemical surveys can be completed concurrent with regional reconnaissance examinations. At this stage of exploration, samples of alluvial sand from major wadis throughout the area of study are systematically taken and analyzed for heavy metal content--gold, platinum, tin, tungsten, copper, mercury, niobium, tantalum, etc. Plotted on regional maps, anomalous levels of heavy metals in wadi sediments serve to identify broad areas which may contain an enriched source of these valuable metals.

Data from these various regional prospecting programs are next synthesized to identify areas of particular interest. Such areas may show low-level radioactive anomalies which, upon field examination, are found to consist of altered apogranite with numerous small quartz veinlets. Anomalous levels of tin and tungsten could occur in nearby wadi sands. During the next stage of exploration, these and other areas of interest would be subjected to detailed or local mapping, sampling, and geochemical analyses of sands from smaller wadis; ground scintillometer and geophysical surveys; and outcrop sampling, as appropriate.

The foregoing exploration stages serve to locate and progressively focus attention on the most favorable locations for potential ore deposits in the region. In the final stages of regional exploration, a few of the very best sites are selected for more intensive study and are mapped in detail. Rock-chip, soil, and wadi-sand grid geochemical surveys are completed, and one or more of the following may be undertaken--test trenching and representative sampling or reconnaissance drilling, detailed topographic and geophysical surveys, and bulk sampling and bench-scale metallurgical testing.

Mineral deposits that are shown to have economic potential by the final, detailed stages of regional exploration become the subject of subsequent resource evaluations.

The following sections of this paper contain outlines for regional exploration programs which are specifically tailored for the types of mineral occurrences believed to hold economic promise in Sinai.

4.2.4 Phosphate and Iron

Sedimentary host rocks in Egypt are assumed to also appear in Sinai; these areas were determined by remote sensing methods and plotted on regional geologic maps for Sinai. Sedimentary host rocks examined in the field at a few sites were found to contain varying amounts of phosphate. Iron-rich beds have also been reported.

None of the very few locations examined for phosphate and iron in Sinai were found to contain economic thicknesses and grades of mineralization. However, several hundred kilometers of exposed sedimentary host rocks remain to be systematically mapped and examined.

Sedimentary phosphate and iron exploration in Sinai must begin with ground reconnaissance mapping of the entire trace of the host sedimentary horizon. This might be completed at a scale of 1:20,000 or 1:50,000. During ground mapping, outcrops of phosphatic material or ferruginous sandstone at widely spaced intervals should be measured for thickness and the mineral content estimated by field analytical methods.

The regional mapping and analytical program should identify broad areas in which phosphate and sedimentary iron zones appear thicker and richer than average. Subsequent exploration would focus on these areas, beginning with local mapping.

During the next stage of exploration, test trenches in favorable areas should be excavated across phosphate and iron zones at widely spaced intervals. Initial outcrop trenching, sampling, and analyses at 1-kilometer intervals might be appropriate. Low-level airborne radioactivity and magnetic surveys may also be useful.

Combined data from local mapping, sedimentary facies studies, trenching, sample analyses, and airborne surveys may identify a few areas in which phosphate or iron equal or exceed the minimum grade and thickness cut-off criteria for economic consideration. In these areas, more closely spaced trenching and reconnaissance drilling to confirm the presence of some ore grade material should be completed as the final stage of regional exploration.

4.2.5 Uranium

Economic deposits of uranium may occur as pitchblende veins in Precambrian rocks of the Crystalline Province. The first, essential step in uranium exploration in south Sinai will be the completion of airborne radiometric surveys of the entire province. Resulting radioactivity maps will show broad areas of low-level radioactivity and smaller, anomalous areas in different types of host rock and in varying geometric configurations and spatial distributions.

Initial fieldwork in uranium exploration should consist of ground-verifying the various radioactivity zones delineated by aerial surveys. Broad areas of low-level radioactivity are examined to associate activity levels with particular types of metamorphic and igneous rocks. This establishes background levels of radioactivity which are significant in assessing the potential merits of other radioactive anomalies in various host environments.

Next, representative examples of various types of localized, highly anomalous features are selected from the regional radiometric maps for field examination. These are visited and reconnaissance mapped. Ground scintillometer traverses across the anomalies are completed to more accurately define aerial extent and radioactivity levels. Grab samples over wide anomalous areas and channel samples across thin, highly anomalous zones are taken and analyzed to calibrate scintillometer equipment measurements with chemical U_3O_8 content.

Geologic features--such as host rock, faults, alteration zones, and quartz veins--that appear to control the distribution of radioactive minerals should be defined.

The results of the foregoing fieldwork and analyses should be synthesized into a series of models typifying the various kinds of radioactive mineral occurrences found in the Crystalline Province.

Models might be characterized by particular host rock (i.e., pink granite vs. grey granite), a minimum level of radioactivity, geometric configuration (ellipsoidal vs. linear), and association with specific geologic structures (narrow faults vs. broad fracture zones). Based on fieldwork and conditions related to uranium ore deposits elsewhere in the world, attention is then focused on those models with maximum economic potential.

In the next stage of regional exploration, all anomalies on the regional radiometric maps which satisfy the criteria for the most favorable models are identified for field reconnaissance. Reconnaissance will include local mapping, scintillometer surveys, and grab and channel sampling for analyses. At the conclusion of the reconnaissance program, a few of the most attractive areas are selected for detailed mapping, grid geochemical and scintillometer surveys, test pitting, reconnaissance drilling, and sample analyses. Indications of potentially economic ore lead to the resource evaluation stage.

4.2.6 Metallic Mineral Deposits

Only the Crystalline Province is believed to have serious potential for the occurrence of metallic mineral deposits such as gold, tin-tungsten, and rare earth metals.

Airborne surveys recommended for other types of mineral deposits in Sinai are equally appropriate for metallic mineral exploration. Radioactivity maps will delineate broad areas of silicic apogranite which may host tin-tungsten and rare earth metal deposits comparable to those in the Eastern Desert. Aeromagnetic maps may reveal magnetic highs related to massive iron deposits; broad, low-level magnetic anomalies could indicate ultramafic intrusive areas--rock types which, elsewhere in the world, carry copper-nickel, chromite, and platinum ore deposits.

While the foregoing airborne survey data contribute to general exploration planning, the confirmation of the presence of these metallic mineral ores requires extensive fieldwork. The most effective prospecting tools available are stream sediment geochemical surveys. In view of this, we recommend the following exploration approach:

- Stage 1--Airborne survey analyses and ground verification: Airborne radioactivity and magnetic surveys and photointerpretation, followed by ground reconnaissance of localized strong and larger moderate magnetic high areas.

- Stage 2--Reconnaissance geochemical survey: Stream sediment sampling in major wadis and sample geochemical analyses. Sample densities on the order of one per 10 square kilometers are appropriate. One-tenth cubic meter samples are typically excavated from pits at depths below 0.4 meters. These are screened, and material larger than 1 millimeter in diameter is rejected. Sands are pan concentrated into 100- to 200-grab samples which are analyzed for a range of metals.

- Stage 3--Geologic reconnaissance: Areas in which reconnaissance geochemistry detected anomalous levels of heavy metals are subject to more intensive sampling. These areas may be associated with particular aeromagnetic, radioactivity, or photointerpretive features. Smaller wadis in these favorable areas are sampled, and the sands are analyzed for heavy metals. A sampling density on the order of one per 2 square kilometers is appropriate.

- Stage 4--Target delineation: Localized areas in which Stage 3 geochemical surveys detect pronounced stream sediment geochemical anomalies are systematically examined for alteration features, mineralized outcrops, gossans, and veins. Local mapping, outcrop sampling, and reconnaissance geophysical traverses (ground magnetic surveys) may be warranted.

- Stage 5--Evaluation of selected targets: In this final stage of regional exploration, the most favorable locations identified in Stage 4 are subject to detailed geologic mapping, systematic geophysical and geochemical grid surveys, trenching, pitting, and reconnaissance drilling. Beyond this work, they become the subject of resource evaluations.

4.2.7 Potash

Due to the soluble nature of potash, deposits are typically not exposed in surface outcrops. Occurrences in most parts of the world have been detected only by oil and gas drill hole cutting analyses and well geophysical logging. The relationship between potash deposition and subtle changes in regional sedimentary facies, combined with the sparse nature of concrete exploration data from oil and gas drill holes, make potash exploration a highly theoretical and scientific endeavor. Drilling exploration and ore development are extremely costly.

To assess the potential for economic potash occurrences in Sinai, it is necessary to analyze all available oil and gas lithologic and geophysical logs from exploration borings located onshore and flanking the Gulf of Suez. Potash beds can be distinguished on geophysical logs as gamma activity highs combined with resistivity lows.

The sedimentary sequence in which potash occurs is identified from oil and gas exploration lithologic logs. The sedimentary host is correlated between widely spaced borings, and indications of potash are sought in the same stratigraphic interval elsewhere. Subtle lateral changes in the chemical and physical nature of the host stratigraphy give clues regarding probable regions of maximum potash deposition. These may not coincide with areas in which oil and gas exploration has been carried out. For example, while only thin potash horizons occur in producing oil wells in the central Paradox Basin of the western United States, economic deposits of potash occupying the same stratigraphic interval are 100 kilometers away and actively mined.

To identify broad areas of potash deposits, thicknesses of potash measured from oil and gas boring logs are used to generate regional isopach maps. These are supplemented with theoretical projections of maximum evaporite depositional basins using lithostratigraphic facies control concepts.

If these mechanical and theoretical projections indicate potential economic thicknesses or potash below the surface, the next exploration step will be to determine the probable depths of occurrence. This will demand detailed stratigraphic correlations between Miocene-Eocene sedimentary rocks penetrated by drill holes in the Gulf of Suez and outcrops of these formations in the Suez Rift Border Province. Correlations with drill-penetrated Miocene-Eocene strata in the northern Platform Province may also be productive.

If stratigraphic correlations and isopach/lithofacies analyses suggest potential potash occurrences at technically mineable depths in Sinai, a search for structurally suitable environments must be undertaken. The best sites are typically the crests of local anticlinal folds. During regional compressional tectonism which generates folds, potash becomes highly mobile. Potash that has migrated under these conditions has concentrated to form thick ore zones along anticlinal crests in many parts of the world. Potash mines in the United States, Canada, and Russia are extracting such fold-related concentrations.

Finally, locations combining optimum conditions of regional potash depositional thickness, depth of host horizon, and potential fold axis concentration must be drilled on a reconnaissance basis. Drilling concludes the regional exploration stage of resource development.

4.3 EXPLORATION AND DEVELOPMENT SCHEDULE

The approximate minimum times required to complete the resource evaluation projects discussed in this paper--at least to the point where prefeasibility studies should be commissioned and infrastructure development begun, or projects dropped--are listed below. General time frames for the various regional exploration programs are also estimated. These are order-of-magnitude estimates only and assume logical, diligent, and continuous mineral resource development.

4.3.1 Resource Evaluations

- Kaolin, 12 months
- Glass sand, 6 months
- Turquoise, 8 months
- Cupriferous sandstone, 18 months.

4.3.2 Regional Exploration

- Phosphate and iron, 24 months
- Uranium, 36 months
- Metallic minerals, 24 months
- Potash, 48 months.

4.4 FUNDING

The short-term objectives of the resource evaluation and exploration programs discussed in this paper should be to gather, process, and present information on specific mineral occurrences in Sinai, with the goal of attracting foreign and domestic private-sector investment capital. The intermediate-range goal is to promote industrial development in Sinai; the long-term purpose is total national economic health.

Initial work to achieve the described goals should, owing to both local and national importance, be a Government responsibility--either directly or through consultants. Moreover, the need for accelerated development may require governmental stimulation. UNDP, USAID, or World Bank funding should be sought.

Accelerated mineral resource development might also be aided by modifications to existing mineral exploration, exploitation, and export laws affecting Sinai. While current equipment import tax waivers, income tax holidays, and other free-zone considerations applicable to the region hold merit, they may not alone be sufficient to attract foreign capital for mineral exploration and development projects. Current national laws affecting foreign participation in mineral projects are based on comparable regulations evolved for the petroleum industry. Unfortunately, mineral exploration and develop nt bear much greater risk factors than hydrocarbon fuel pro ects profit margins for operating mines are much narrower.

To compensate for these risks, international mining companies and private investors require favorable, well-defined laws regarding taxation, noninterference in management and operations, and minimum product sharing with host governments. As an example, the host government share of products from mines throughout most of the American continent ranges from 5 to 10 percent. Total taxes on net profits, which are reduced according to host government product sharing, amount to approximately 50 percent in most countries. Government involvement in operations is, by law, restricted to auditing, tax collection, and assurances of mine worker health and safety.

Given the above favorable environment for mining enterprise, companies and private investors are often willing to bear the cost of mineral exploration, both regional and local, even where the prospects of success are severely limited. Special laws to create this environment in Sinai could promote a rush of exploration activity, applying the latest technology and the talents of the most skilled professionals and scientists in the world to rapid mineral resource discovery and development in the region.

5.0 CONCLUSIONS

5.1 SUMMARY

5.1.1 Mineral Resource Potential

Dames & Moore concludes that Sinai holds known occurrences or potentially economic deposits of the following minerals:

- Occurrences known (proven or marginally economic deposits)--coal, manganese/iron, kaolin, glass sand, gypsum, turquoise, limestone/dolomite, and construction sand and aggregate.

- Occurrences known (possible economic deposits)--phosphate and copper.

- Occurrences known (improbable economic deposits)--lead and zinc, heavy minerals in beach sands, sulfur, and sedimentary iron ore.

- Occurrences unknown (some exploration potential)--uranium, talc/asbestos, gold, tin-tungsten, copper-nickel, sulfides, rare earth metals, and potash.

5.1.2 Current Exploration and Development

- The Maghara coal field is being both managed for development and further explored in an appropriate manner by the Egyptian Geological Survey and Mining Authority.

- The Umm Bugma/Abu Zenima ferromanganese mine and smelter project is under consideration by the Ministry of Development for further feasibility studies.

- A prefeasibility study has been completed for reactivation of the Ras Malaab gypsum mine.

- The Sinai Manganese Company is developing a glass sand open pit mine south of Umm Bugma.

- The Governorate of South Sinai has received applications for a concession to reactivate the El Khabouba glass sand mine.

Our general assessment of present exploration and development activity is that:

- Maghara coal exploration and development is being well managed.

- While investigations of the Abu Zenima ferromanganese project may be worthy enterprises, they are diverting both interest and funding sources from potentially more valuable projects such as the Wadi Budra kaolinite and El Khabouba glass sand mines.

5.2 RECOMMENDATIONS

5.2.1 Resource Development

Resource development of known mineral deposits should begin in the following order of priority:

- Wadi Budra kaolinite
- Glass sand
- Turquoise
- Cupriferous sandstone.

Development of these resources beyond the prefeasibility stage would be accelerated by allowing competitive public and private sector bidding for their exploitation, rather than granting comprehensive concessions for all mineral deposits in large areas to single public or private sector companies.

5.2.2 Regional Exploration

No priorities are assigned to the regional exploration programs outlined in this paper. However, the following ranking is believed to reflect their real economic potential:

- Metallic mineral deposits
- Uranium
- Potash
- Phosphate.

We recommend that exploration for these materials be initiated as soon as funding is located. Although they each represent long-term exploration and development efforts, their accelerated discovery and development are essential to maximum industrial development in Sinai.

5.2.3 Funding

We suggest that applications be made to the UNDP, USAID, and the World Bank for funding for the mineral resource exploration and development projects recommended herein. We further suggest that modifications to existing exploration and exploitation laws covering mineral resources in Sinai could be effective in attracting foreign investment to the region, thereby accelerating discovery, mine construction, and production.

APPENDIX A

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