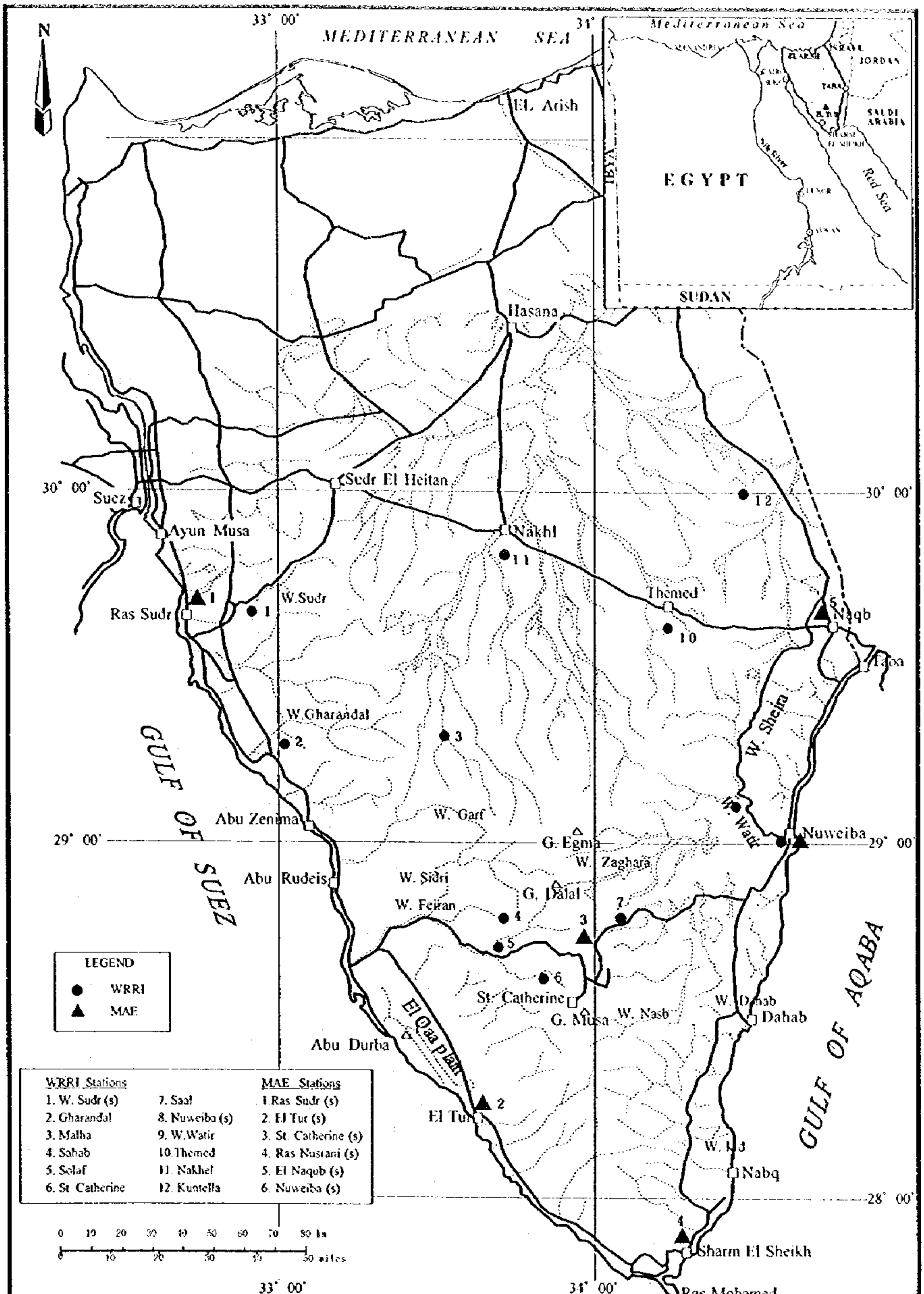

Fig. 3.1.1-1 Hydrometeorological Stations

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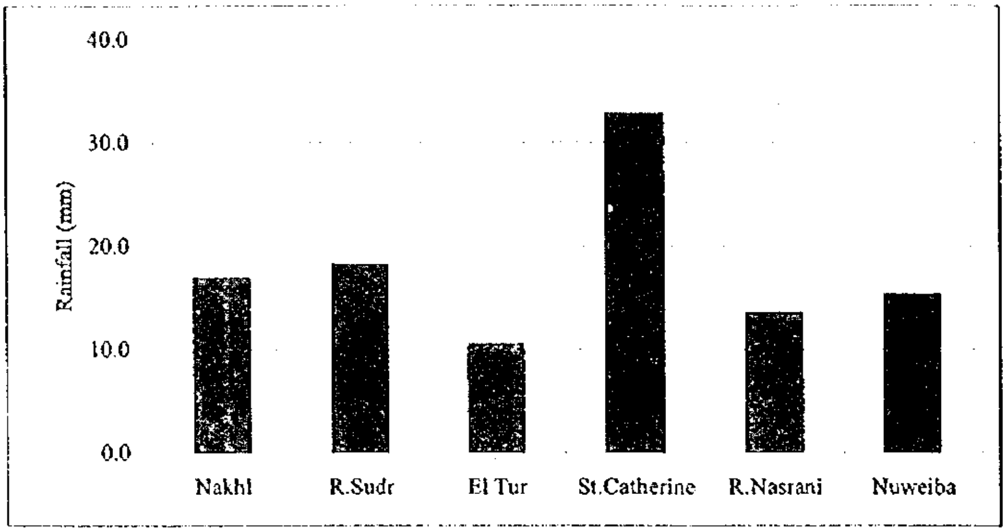


Fig. 3.2.2-1 Annual Average Rainfall in South Sinai

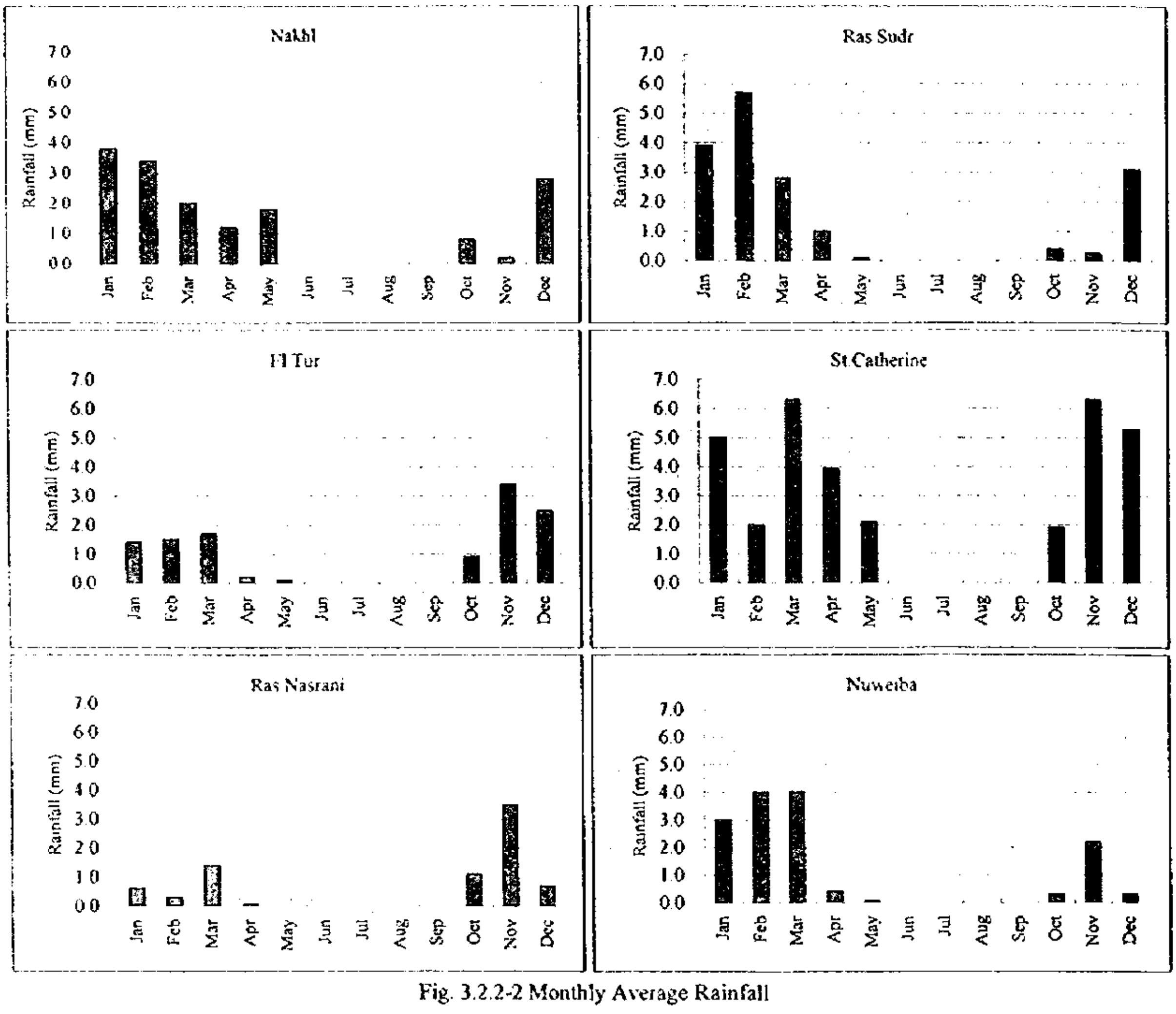


Fig. 3.2.2-2 Monthly Average Rainfall

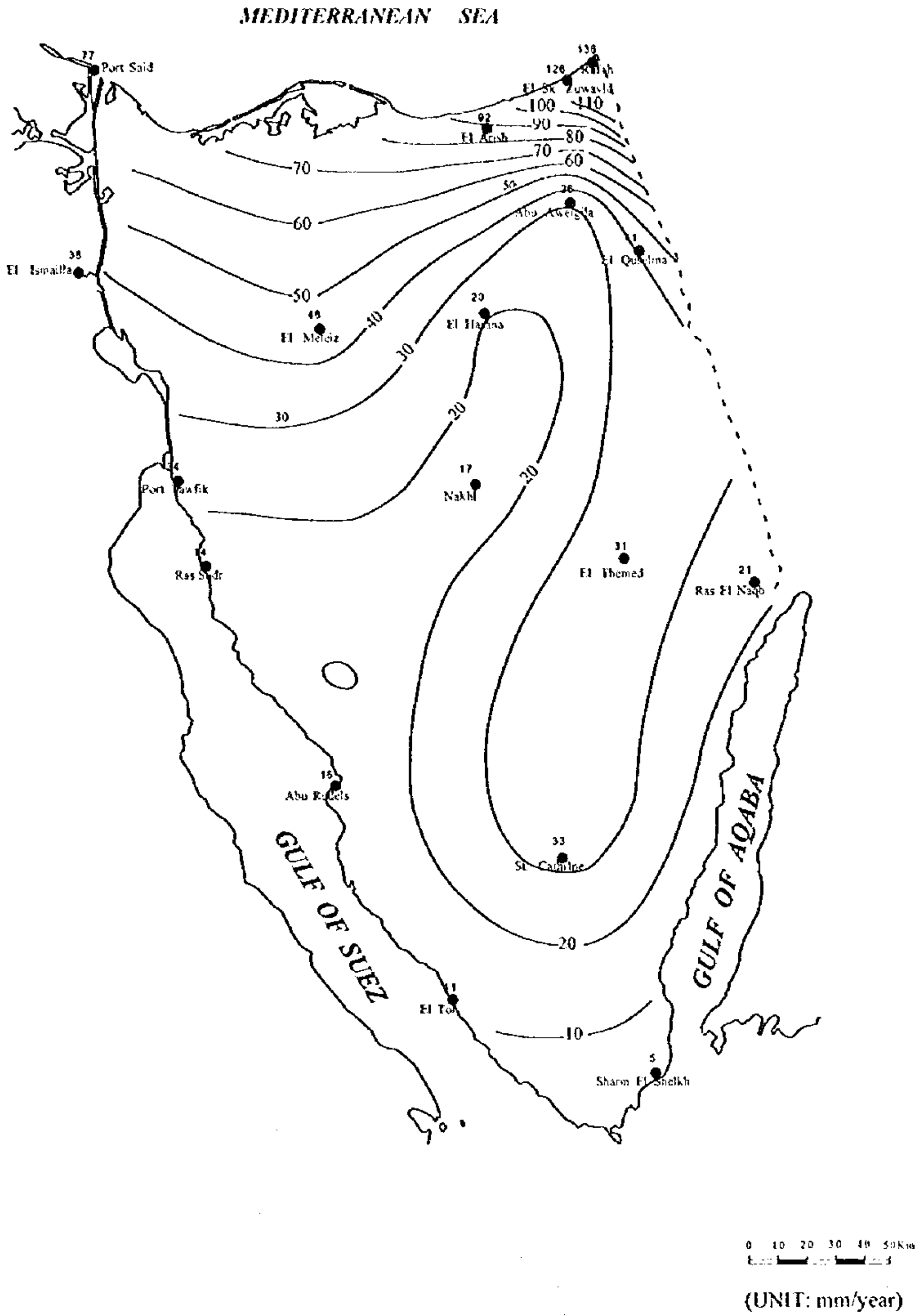
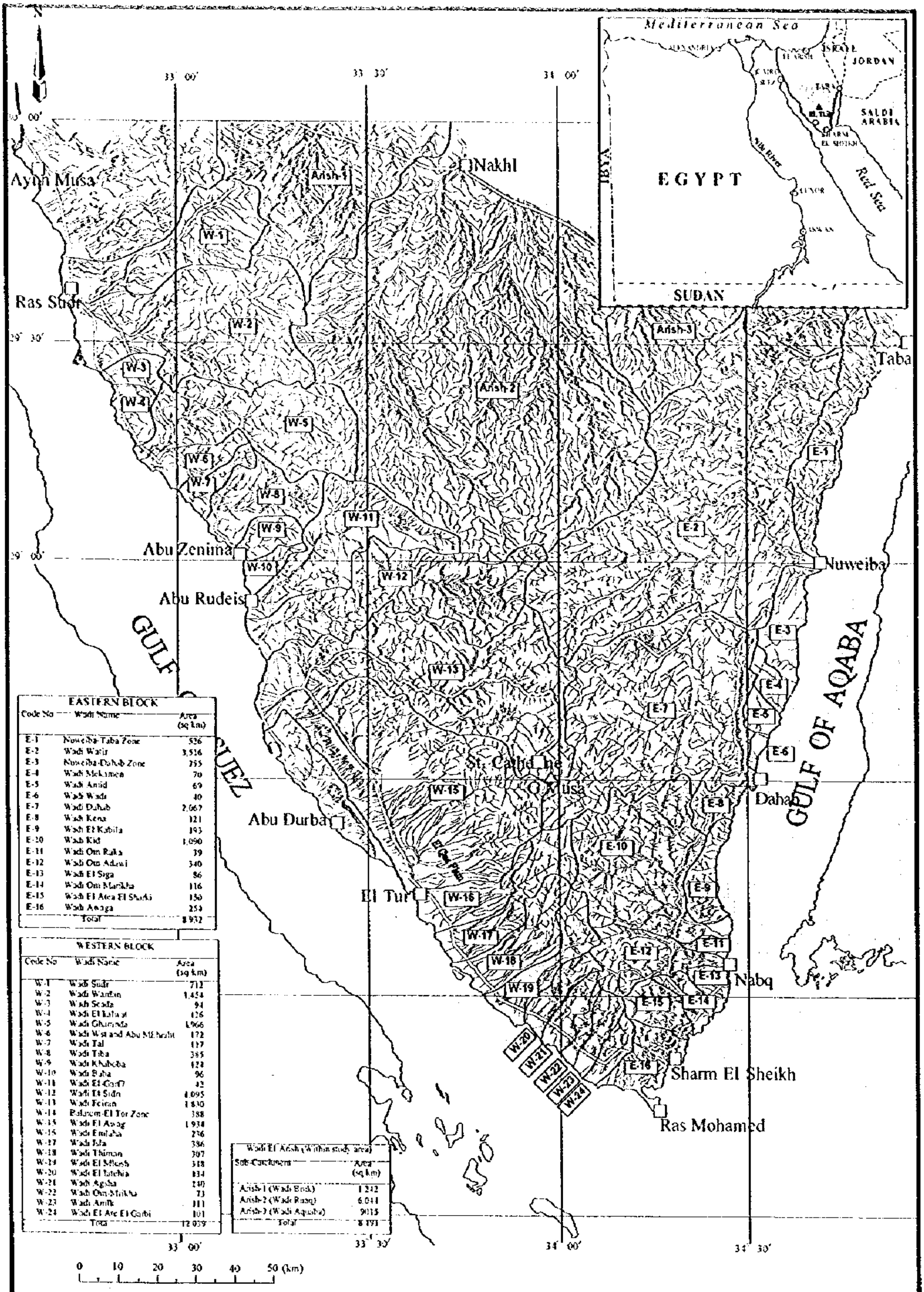


Fig. 3.2.2-3 Annual Average Rainfall Contours



EASTERN BLOCK		
Code No	Wadi Name	Area (sq km)
E-1	Noweiba-Taba Zone	526
E-2	Wadi Watir	3,536
E-3	Noweiba-Dahab Zone	355
E-4	Wadi Mekamen	70
E-5	Wadi Amid	69
E-6	Wadi Wadi	40
E-7	Wadi Dahab	2,067
E-8	Wadi Kena	121
E-9	Wadi El Kabila	193
E-10	Wadi Kid	1,090
E-11	Wadi Om Raka	39
E-12	Wadi Om Adawi	340
E-13	Wadi El Siga	86
E-14	Wadi Om Markha	116
E-15	Wadi El Atea El Sharki	150
E-16	Wadi Awaga	254
Total		8 932

WESTERN BLOCK		
Code No	Wadi Name	Area (sq km)
W-1	Wadi Sudr	712
W-2	Wadi Wardan	1,454
W-3	Wadi Seada	94
W-4	Wadi El Lahata	126
W-5	Wadi Gharanda	1,966
W-6	Wadi Wsi and Abu Mitheiht	172
W-7	Wadi Tal	137
W-8	Wadi Tiba	385
W-9	Wadi Khaboba	128
W-10	Wadi Baba	96
W-11	Wadi El Garf?	42
W-12	Wadi El Sidri	1,095
W-13	Wadi Feiran	1 830
W-14	Balarem-El Tor Zone	388
W-15	Wadi El Awag	1 934
W-16	Wadi Emlaha	256
W-17	Wadi Isla	386
W-18	Wadi Thiman	307
W-19	Wadi El Mikesh	318
W-20	Wadi El Iatchia	134
W-21	Wadi Agsha	140
W-22	Wadi Om-Mrikha	73
W-23	Wadi Amik	111
W-24	Wadi El Ate El Garbi	101
Total		12 039

Wadi El Arish (Within study area)	
Sub-Catchment	Area (sq km)
Arish-1 (Wadi Brok)	1 242
Arish-2 (Wadi Ruaq)	6.044
Arish-3 (Wadi Aqaba)	9015
Total	8 191

Fig. 3.2.3-3 Drainage Catchments

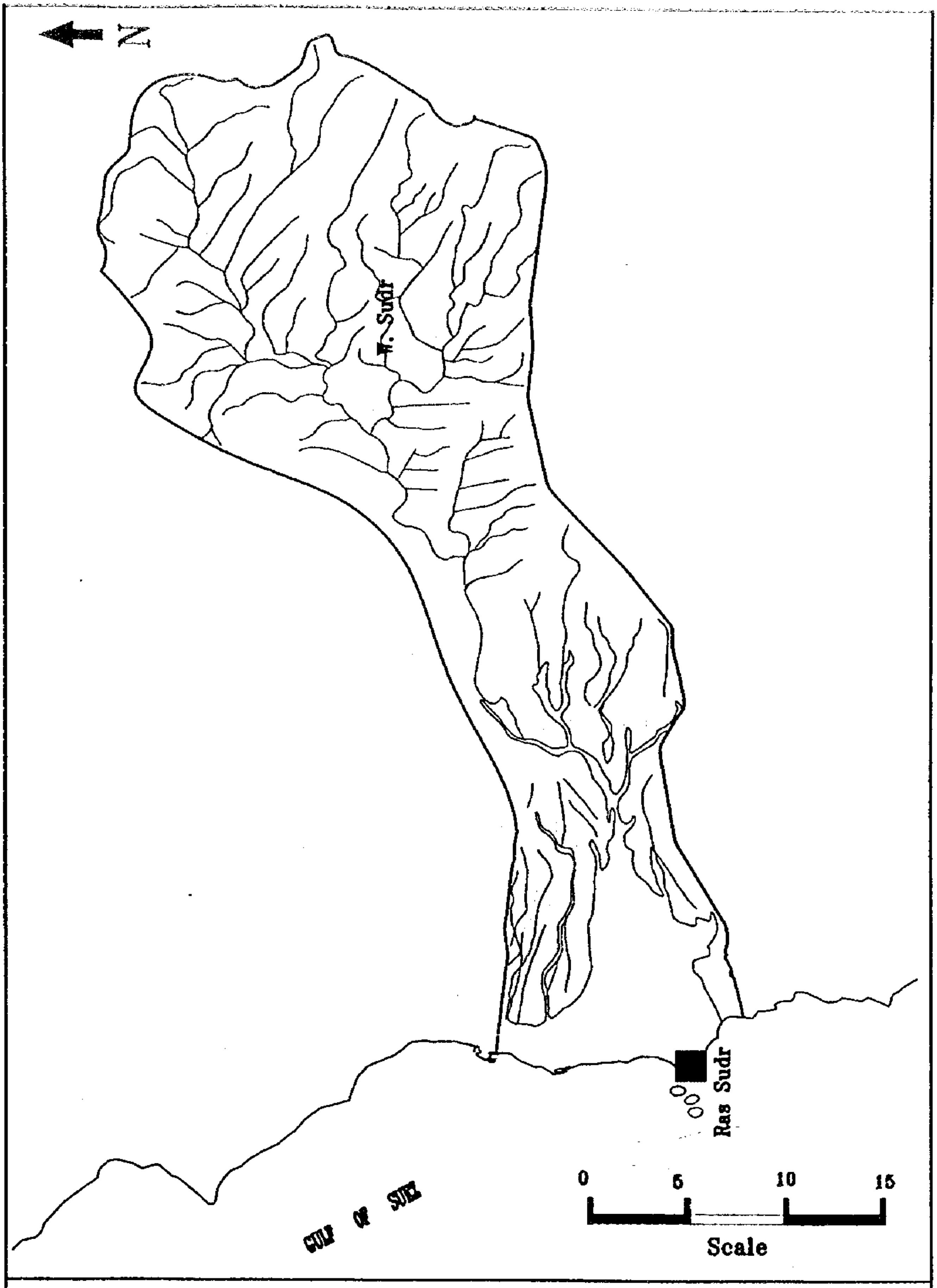


Fig. 3.2.4-1 Wadi Sudr Catchment

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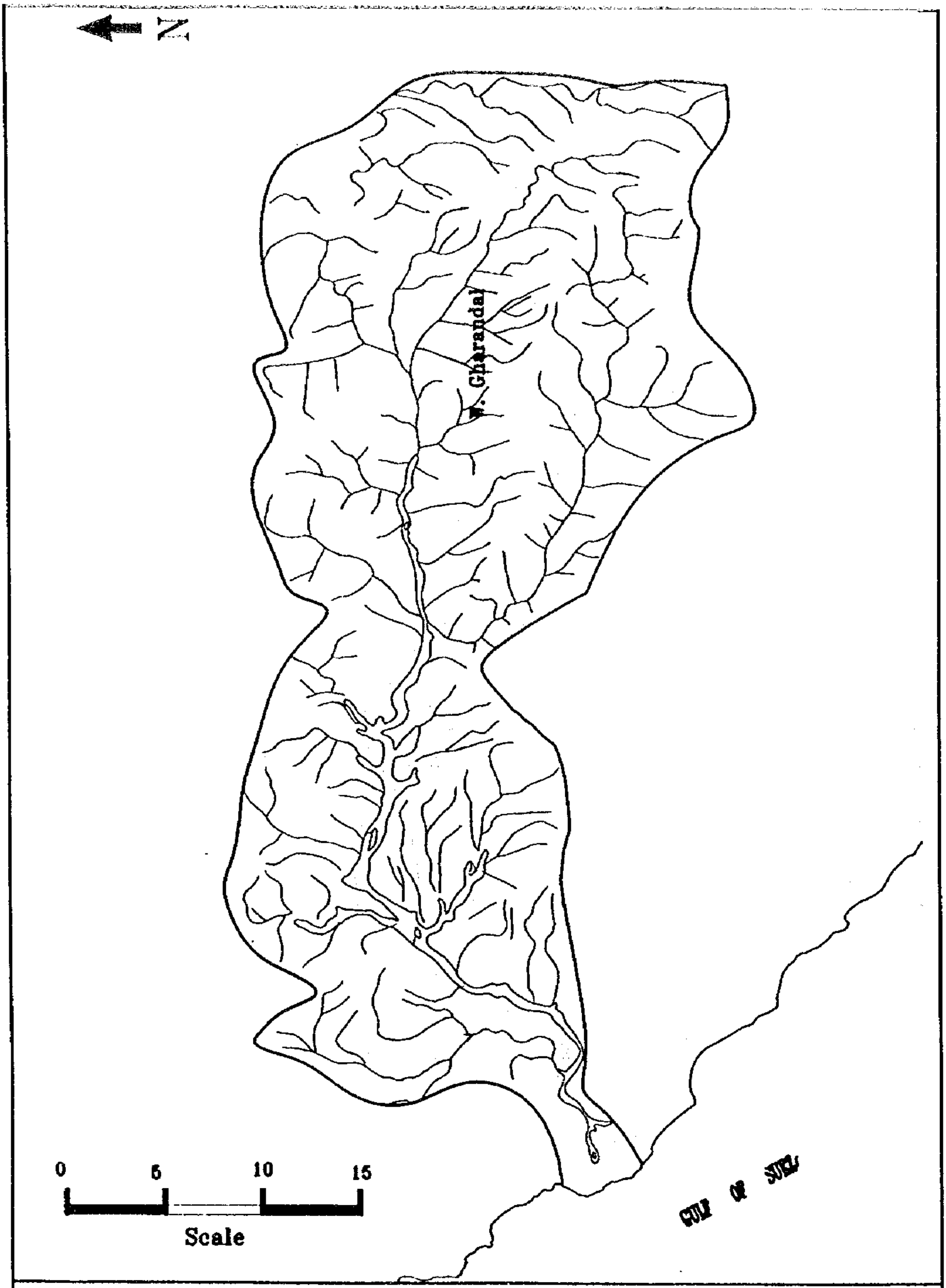

Fig. 3.2.4-2 Wadi Gharandal

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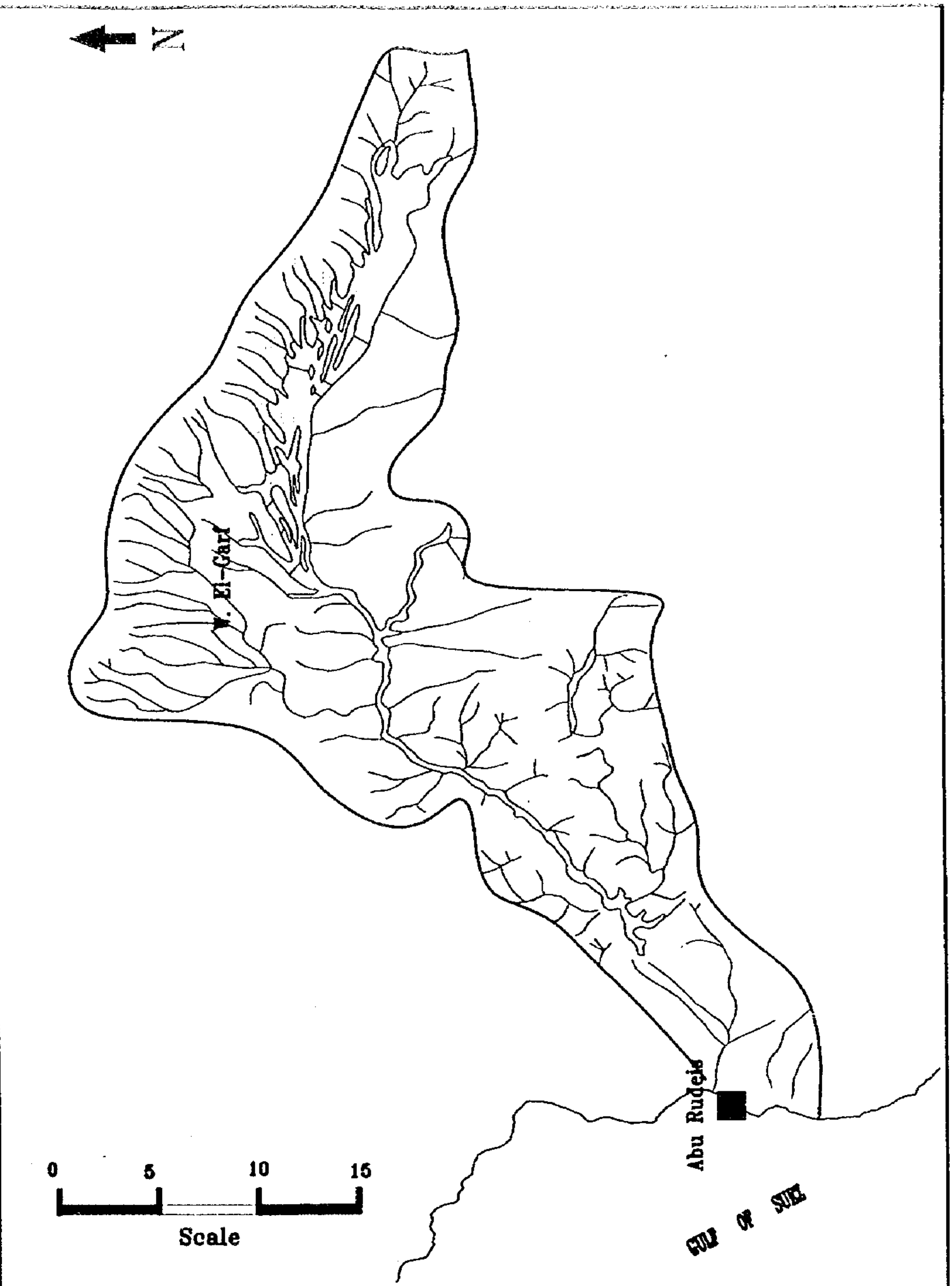

Fig. 3.2.4-3 **Wadi El Garf Catchment**

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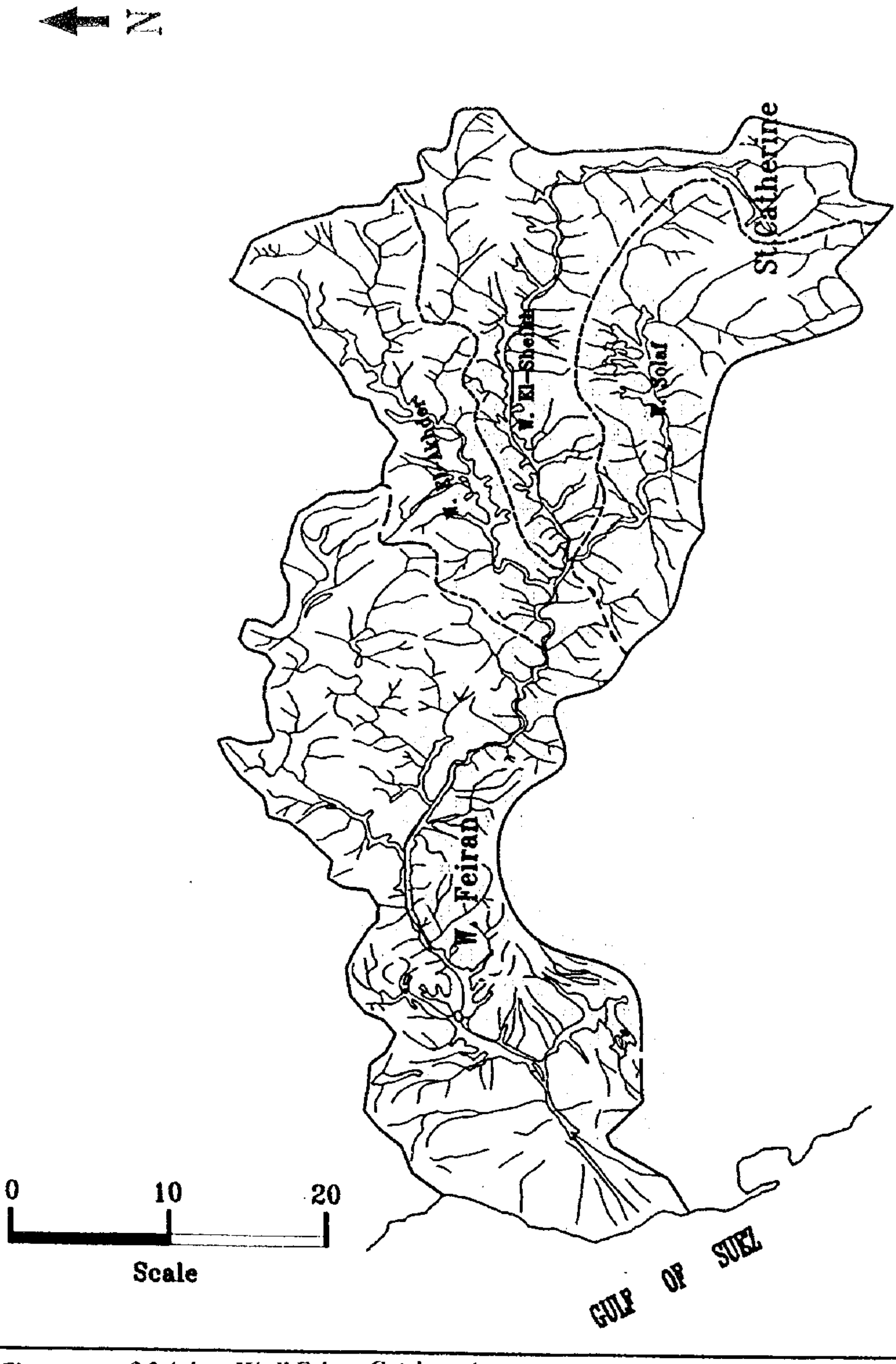

Fig. 3.2.4-4 Wadi Feiran Catchment

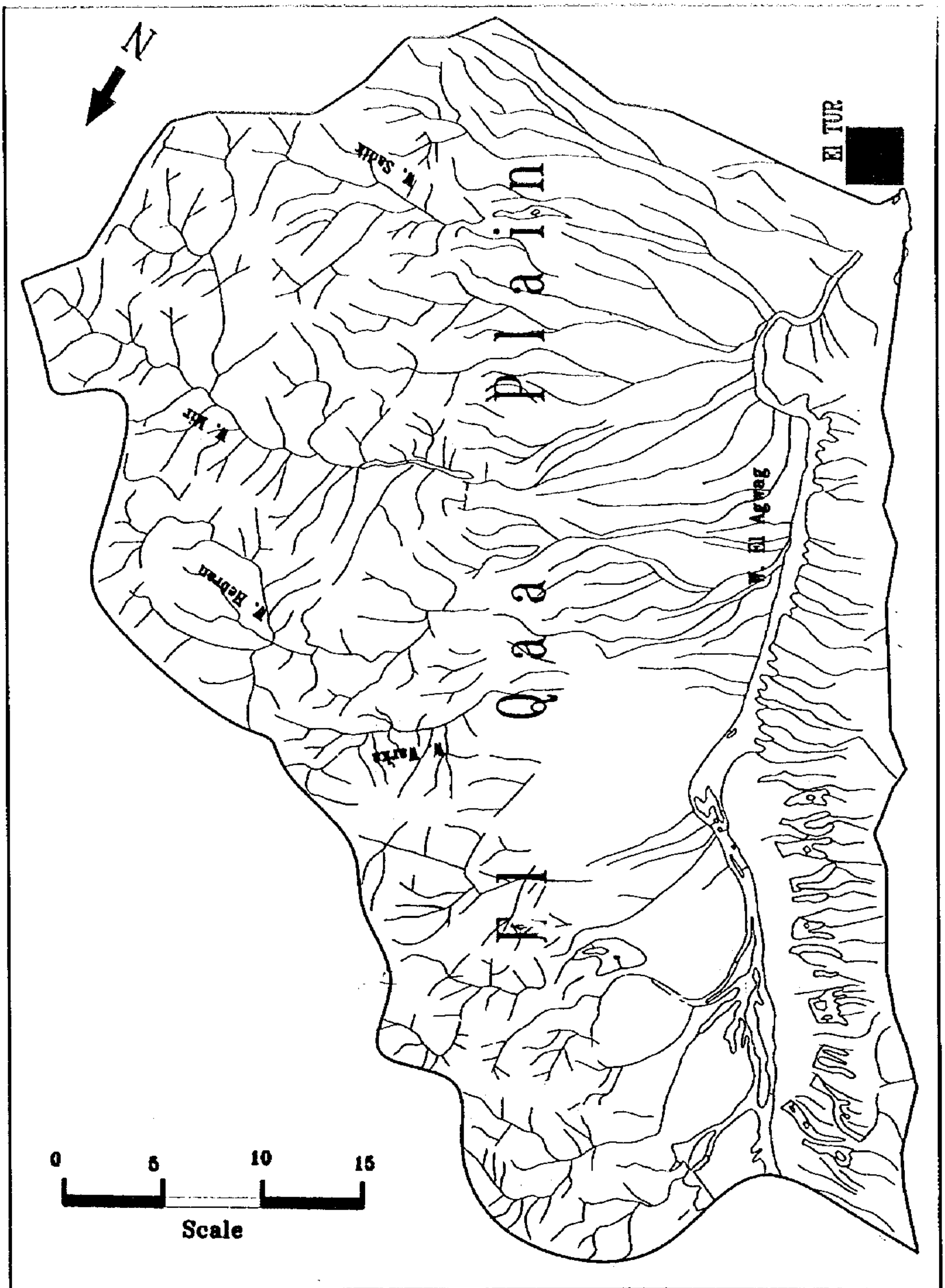

Fig.3.2.4-5 El Qaa Plain Catchment

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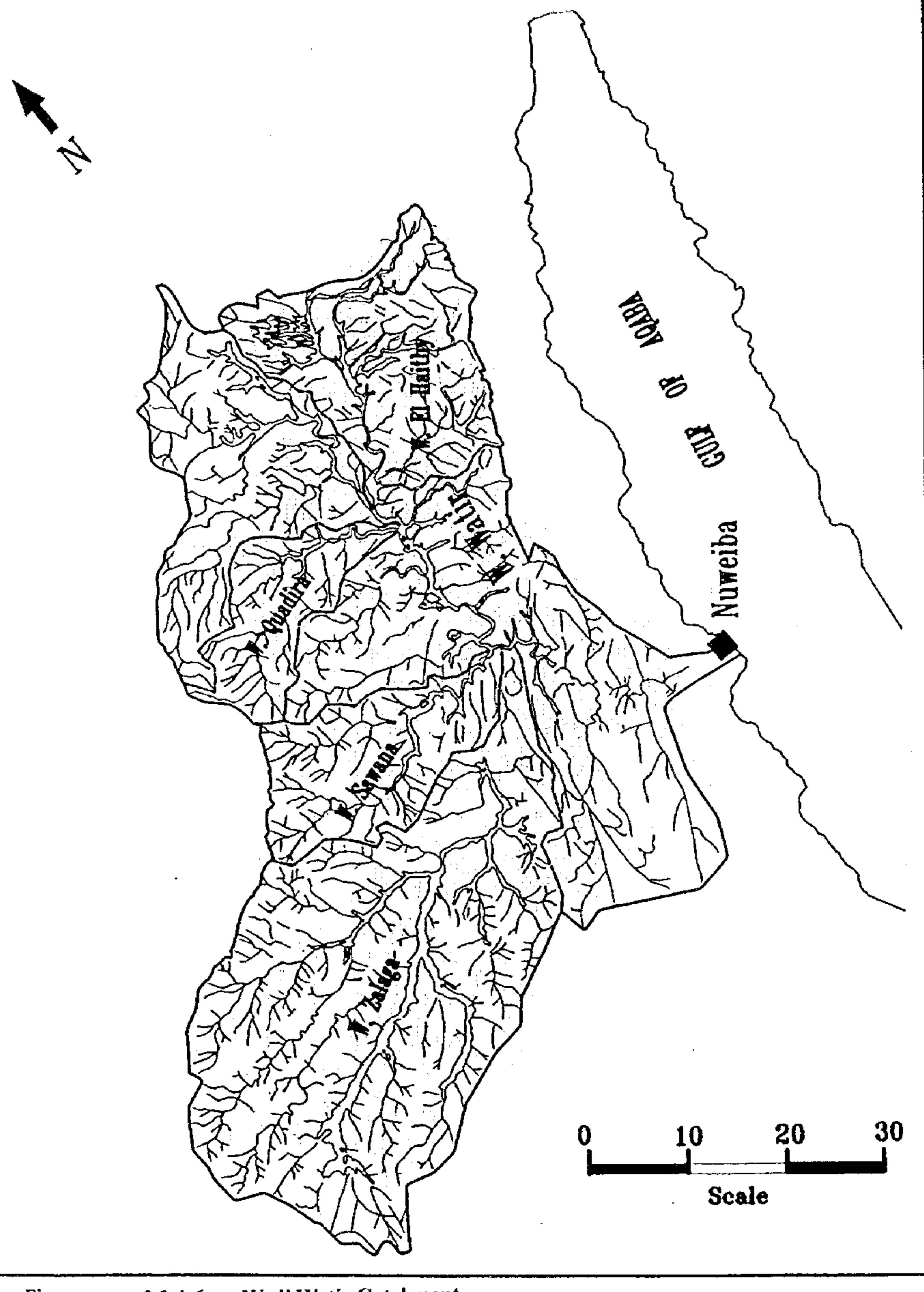

Fig.	3.2.4-6	Wadi Watir Catchment

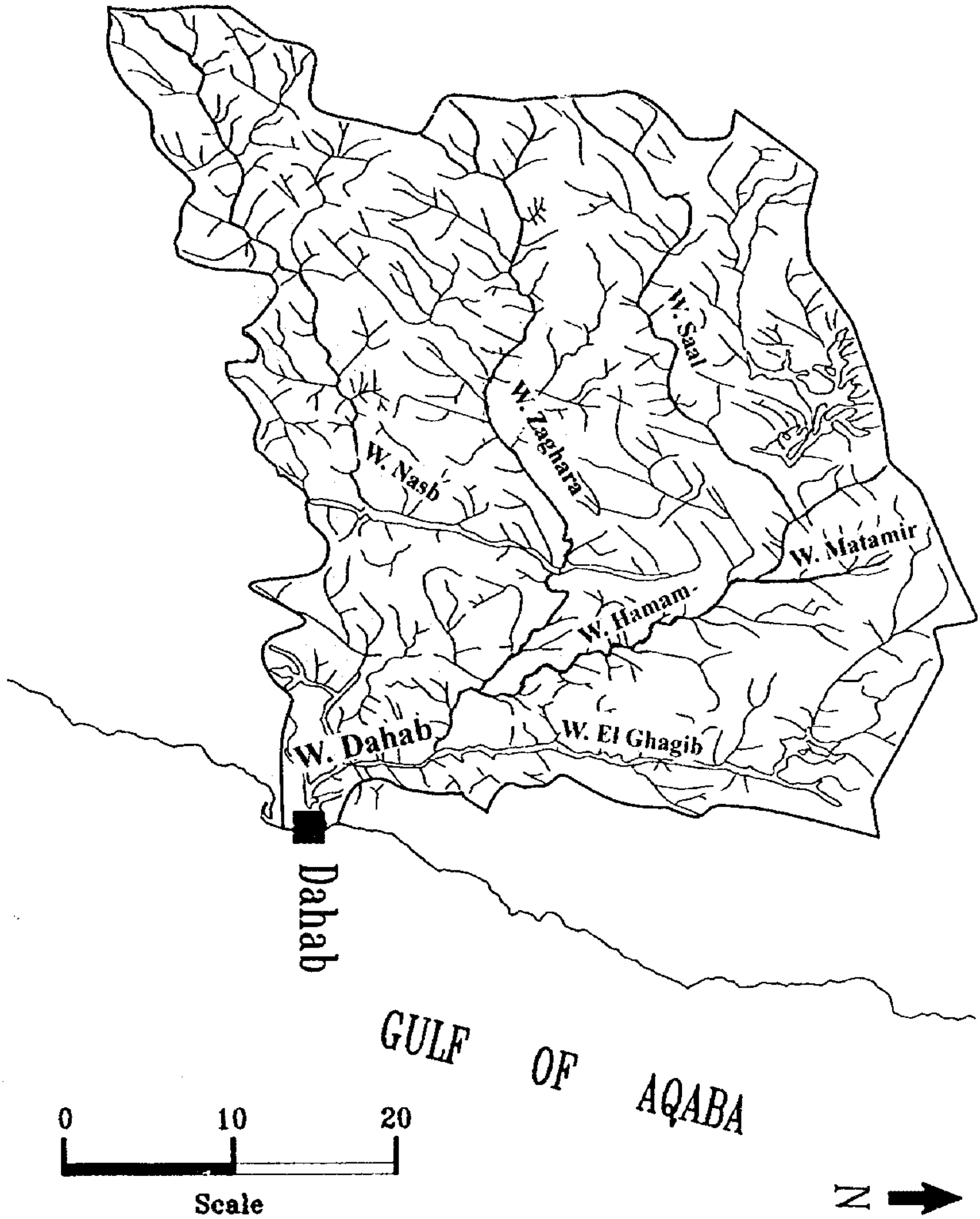

Fig. 3.2.4-7 Wadi Dahab Catchment

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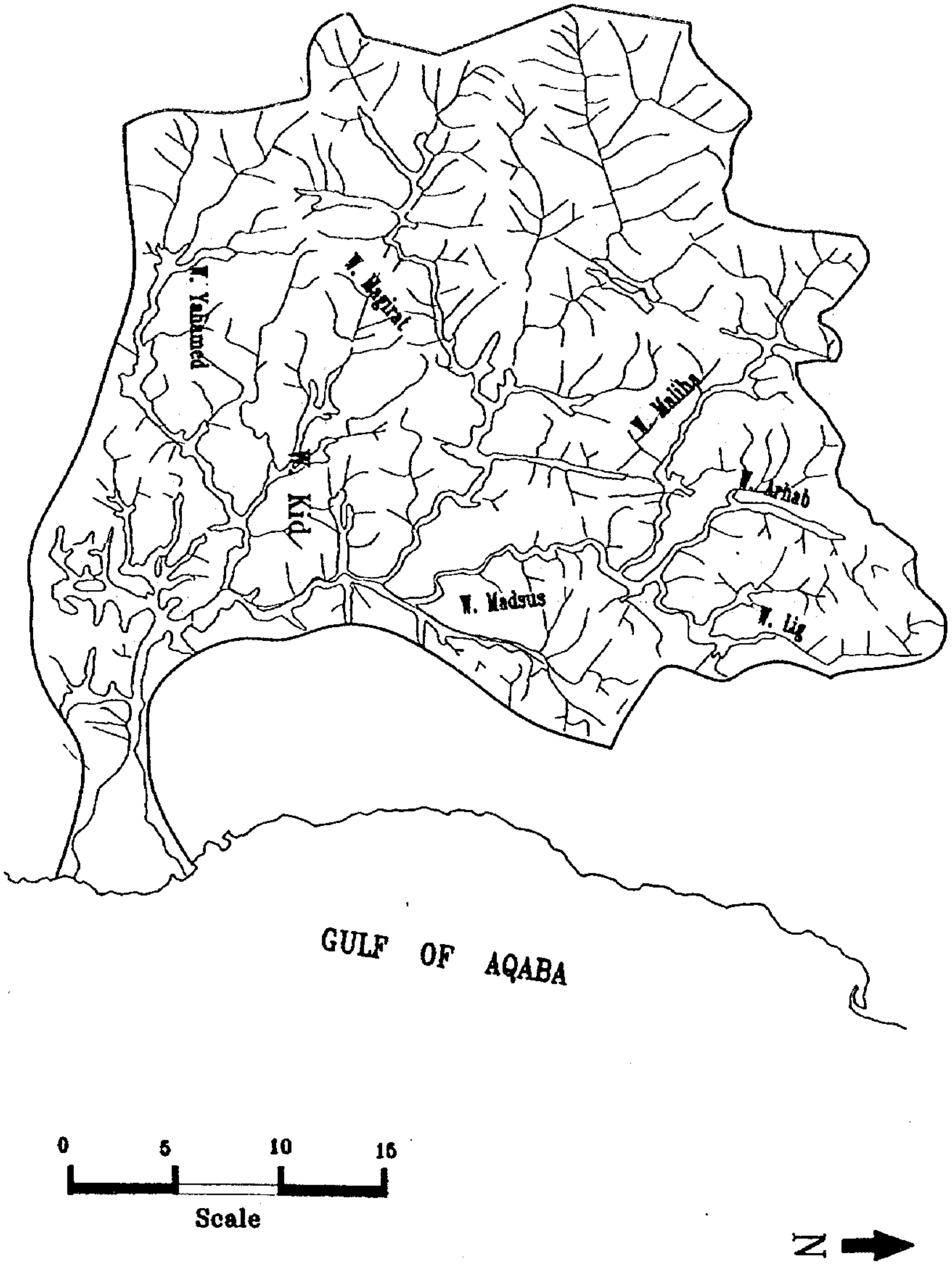

Fig. 3.2.4-8 **Wadi Kid Catchment**

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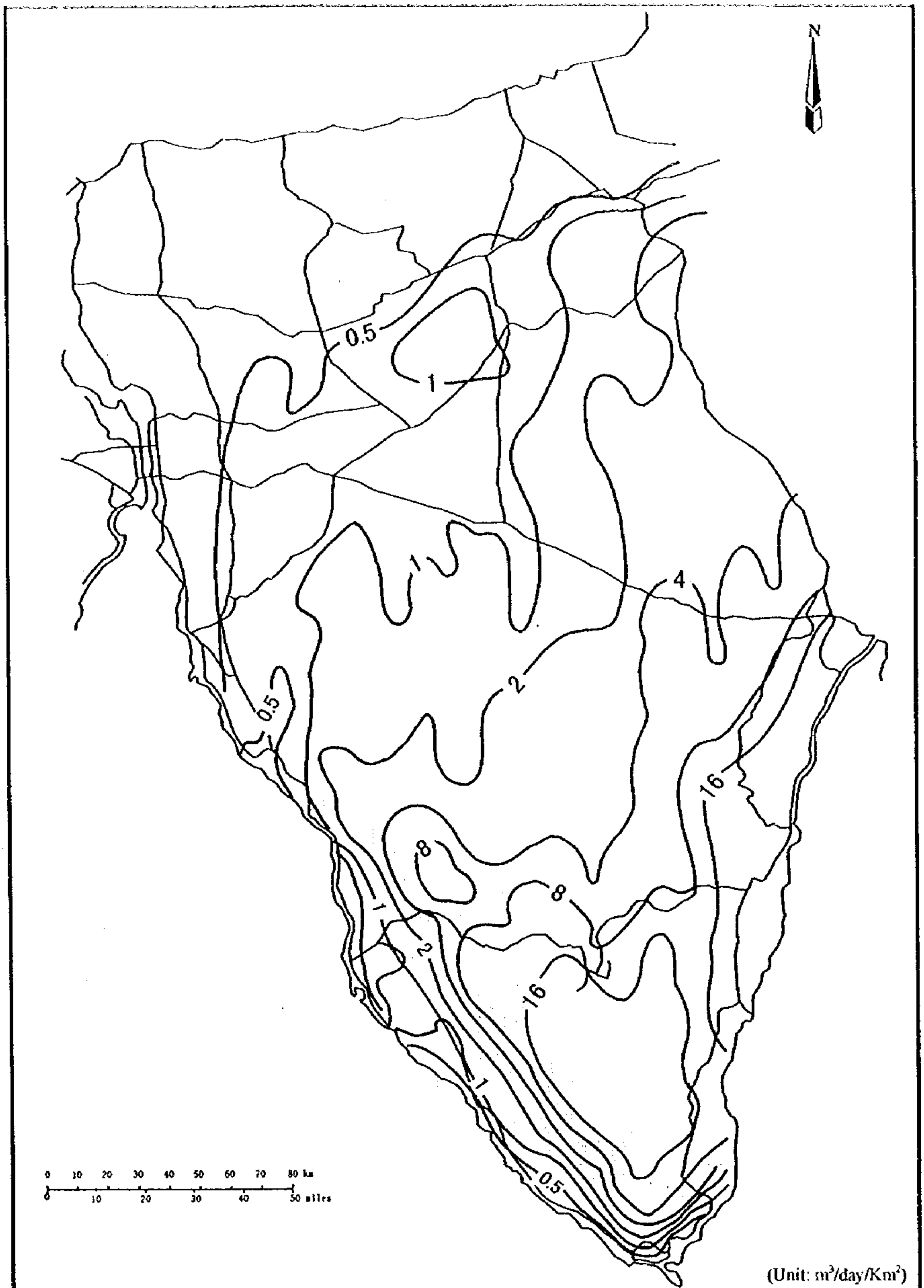

Fig.3.2.5-1 Contour Map For Average Annual Runoff Volume

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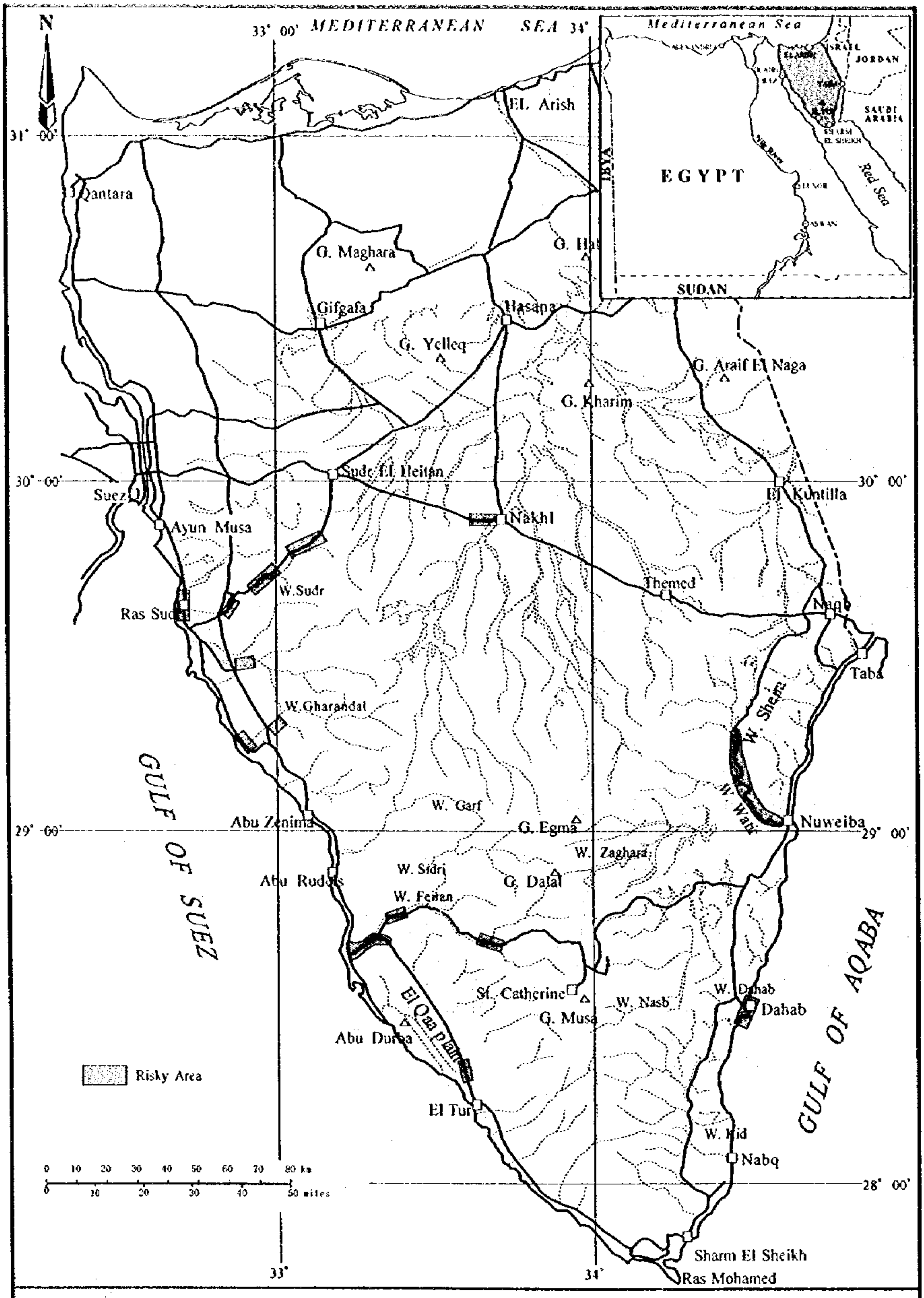

Fig. 3.2.7-1 Risky Areas

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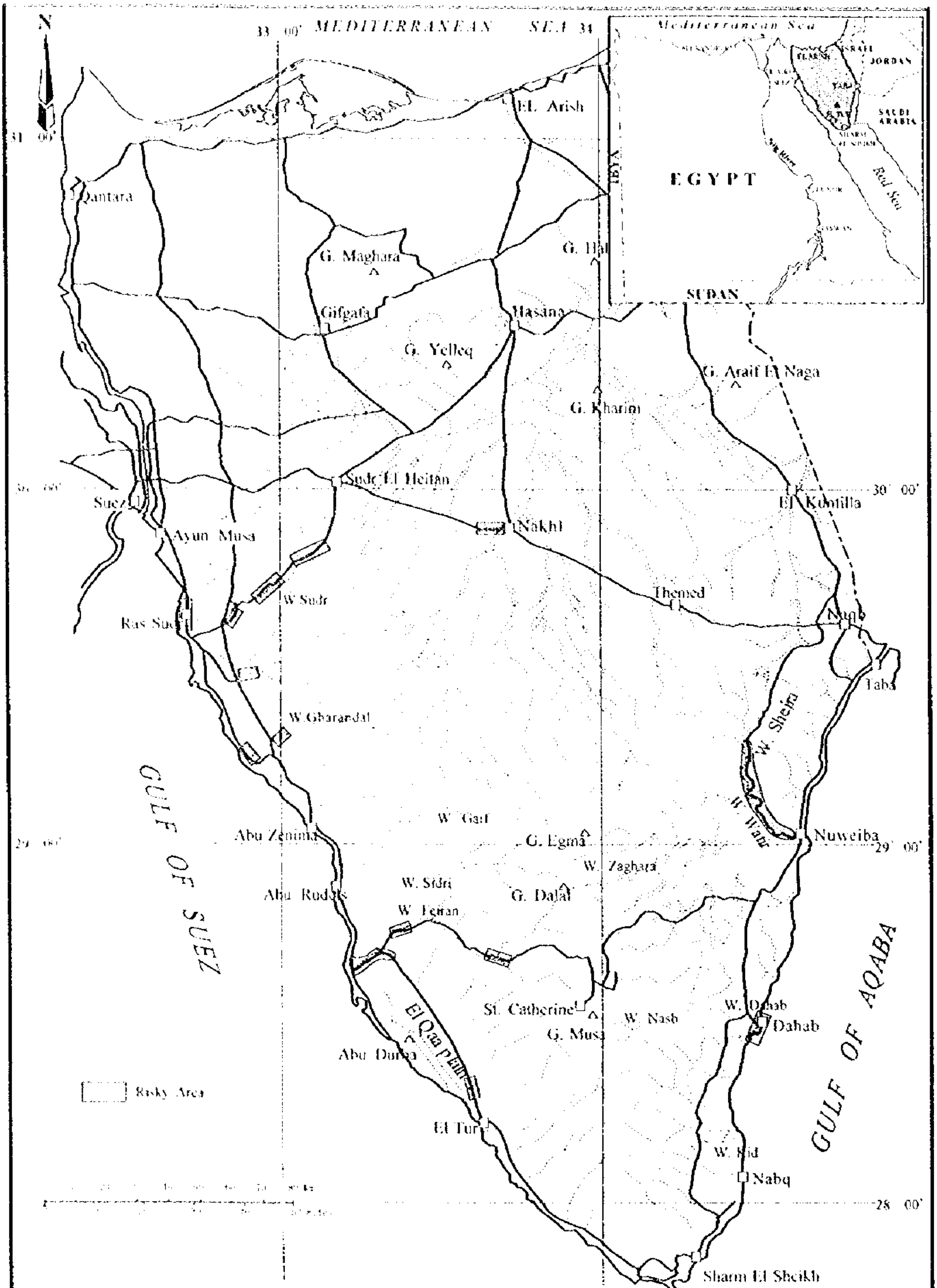

Fig. 3.2.7-1 Risky Areas

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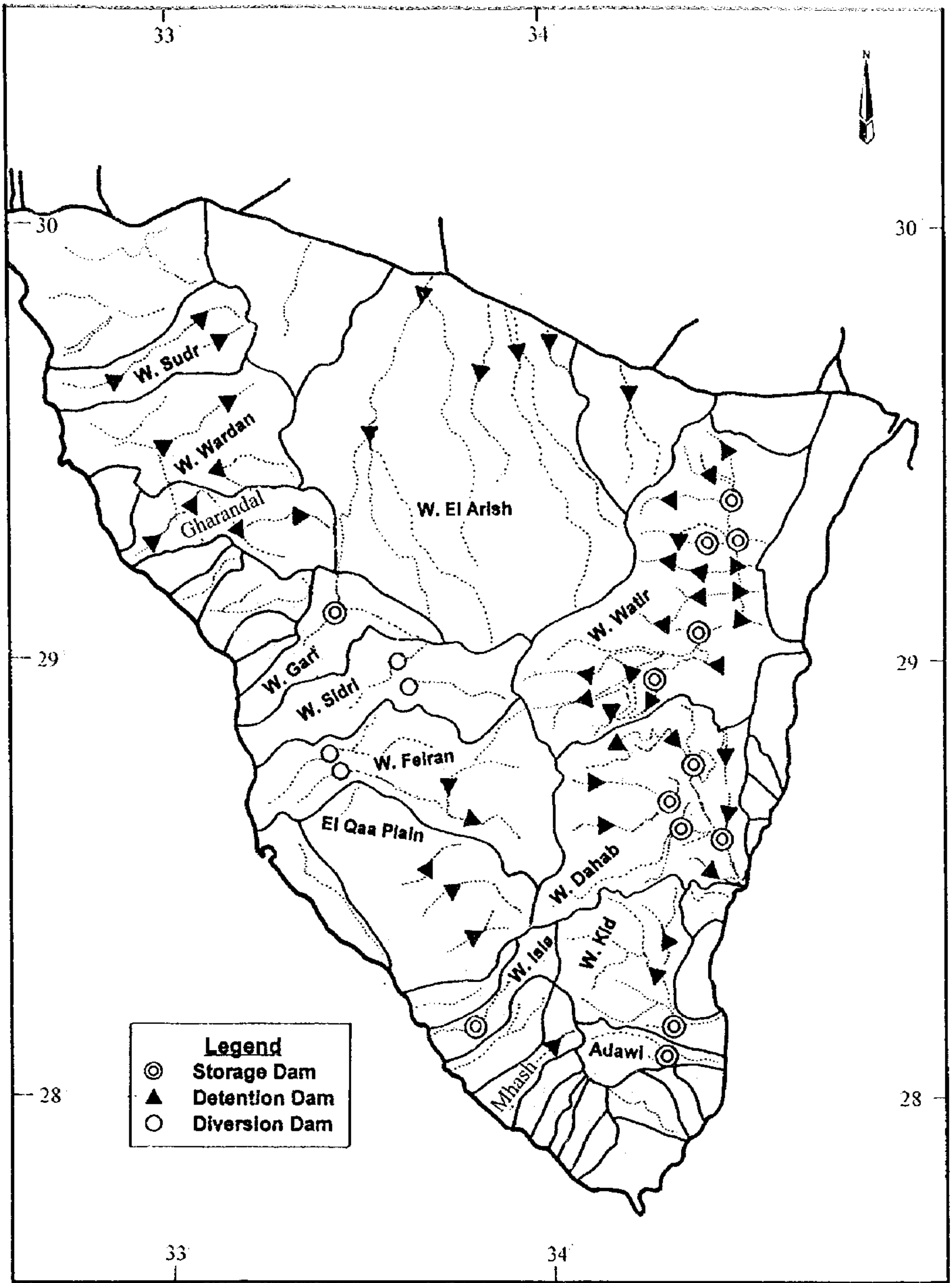

Fig. **3.2.8-1 Location Map of Recharge Facilities**

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CHAPTER IV GEOMORPHOLOGY

4.1 General Geomorphology

The JICA Study team conducted a LANDSAT image analysis, aerial photograph interpretation and field survey in the study area, and constructed Geomorphological Theme Maps.

South Sinai covers an area of approximately 34,000 km^2 and is separated geographically from the Eastern Desert by the Gulf of Suez and from Saudi Arabia by the Gulf of Aqaba. The Peninsula has highly dissected igneous and metamorphic mountains, which rise to a height of 2641 m ASL (Gebel Catherine), form the southern tip of the peninsula.

The central part of the peninsula consists of sub-horizontal Mesozoic and Cenozoic sedimentary rocks, creating the plateau of Gebel El Tih and Gebel Egma, which are drained by the northerly flowing affluent of Wadi El Arish.

4.2 Geomorphological Description

South Sinai is divided into eight (8) characteristic topographical regions as shown in Fig. 4.2-1.

(1) Sinai Plateau (SP)

The Plateau forms the core of the peninsula, situated near its southern end, and consists of an intricate complex of high and very rugged topographic feature. The Plateaux are formed by igneous and metamorphic rocks of Proterozoic age. The highest peak, Gebel Catherine, attains an altitude of 2,641 m ASL. Many other peaks and crests rise above the 2,000 m contour conspicuous among which are Gebel Umm Shomar (2,586 m) and Gebel Sabbagh (2,280 m). The core of the peninsula shows all the signs of youthful physiography. It is dissected by numerous incised wadis that cover everywhere showing signs of downcutting. Drainage in the Horst block of South Sinai is toward the Gulfs of Suez and Aqaba. The main drainage channels are Wadi Feiran and Wadi El Sheikh.

(2) El Tih Plateau (TP)

It forms the tableland of the plateau known as Gebel El Tih. The plateau consists of almost horizontal strata which constitute a distinct geomorphological unit. The plateau is bounded on its east, south and west sides by vertical scarps. The three (3) northern areas of Gebel El Tih, eastern area of Gebel El Gunna and eastern area of Badyat El-Tih are made up mainly of Cretaceous sedimentary rocks.

(3) Egma Plateau (TP)

It forms the tableland of the still higher plateau known as Gebel Egma in the area of Badyat El Tih. The Plateau is formed by Paleocene and lower Eocene sedimentary rocks of Tertiary. The area is part of the Wadi El-Arish water catchment zone.

(4) Sedimentary Hills Area (SH)

It is formed by Mesozoic and Tertiary sedimentary rocks, creating the hills of Gebel Qabeliat, Gebel 'Isa, Gebel Abu 'Alaga, Gebel Kreir and so on, in the western part of South Sinai.

(5) Basement Hills Area (BH)

It is formed by igneous and metamorphic rocks and is distributed around the Sinai Plateaux.

(6) Flat Plain (FP)

The plain is located in Ramlet Himaiyir of eastern part of Abu Zenima along Wadi Garf. It is formed by Quaternary gravel and Wadi sediments.

(7) Alluvial Fan and El Qaa Plain (AF)

i) Alluvial Fans (AF)

The fans are located mainly in Ras Sudr, Ras Sharatib, Ras Abu Rudeis, and Nuweiba. They are formed by alluvial fan deposits from the wide watersheds of Wadi Warden, Wadi Sidri, Wadi Feiran, Wadi Kid, Wadi Dahab, Wadi Watir and so on.

ii) El Qaa Plain (QP)

The plain covers an area of 3,900 km^2 trending NW-SE and is widely expanded in the coastal area, western part of the igneous and metamorphic mountains. The plain is composed of terrace deposits, gravel deposits, alluvial fans and wadi deposits.

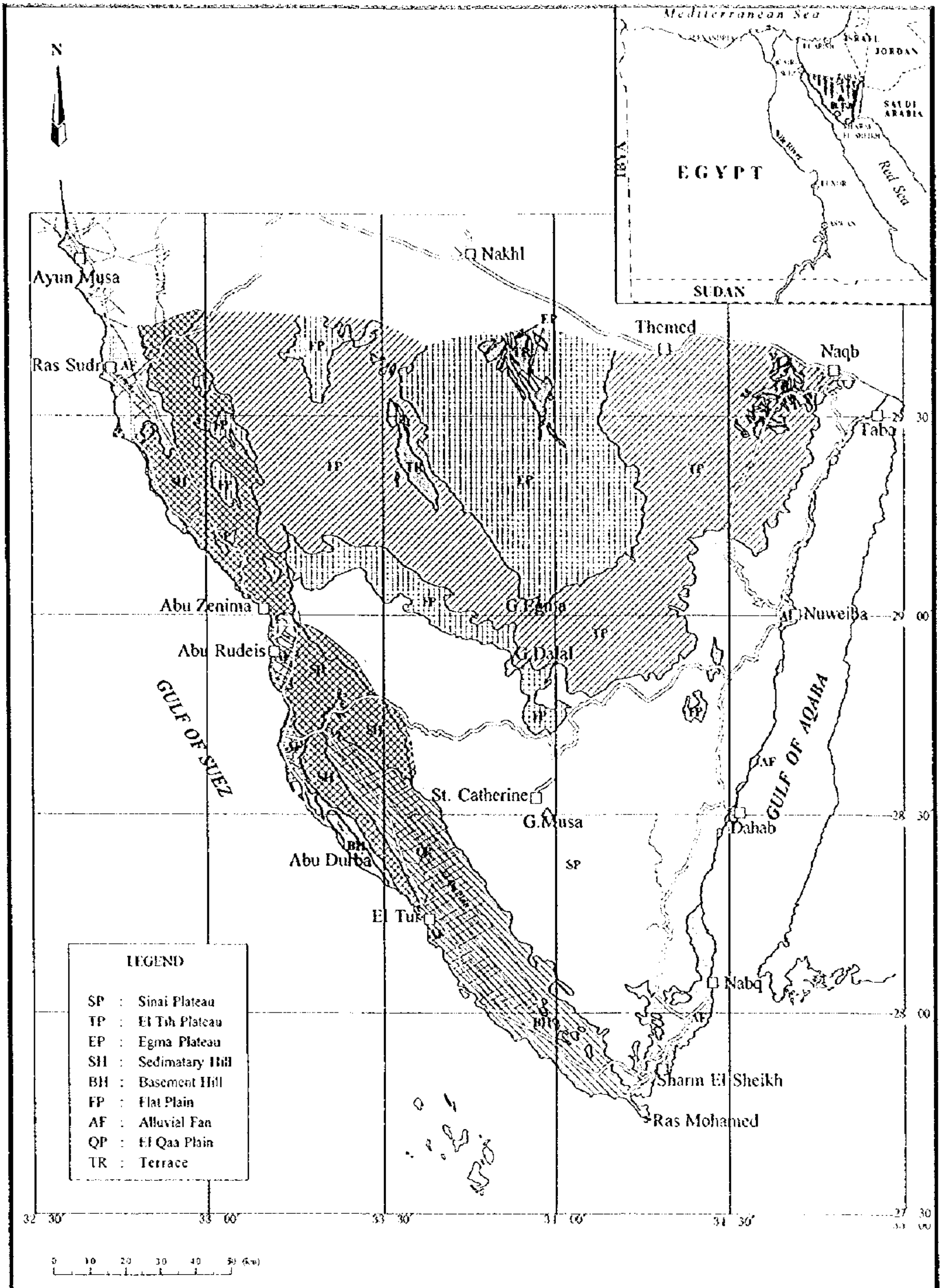

Fig. 4.2-1 Geomorphology

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CHAPTER V GEOLOGY

5.1 Methodology of Geological Study

There are many studies and publication on the geology of the Sinai Peninsula. Distribution, lithology and geological structure of major formations are implicated in the hydrogeological conditions of the Study Area. The geological setting of the area is summarized in this chapter.

Geological analysis was carried out using LANDSAT images, aerial-photos and the field survey in order to clarify the regional geological conditions of the area. Especially, it must be expressed that Geological Map of Sinai (1:250,000) by Geological Survey of Egypt was great help for the study. The results of these interpretations were compiled on Geological Map and Lineament Map, which are illustrated as Fig.5.1-1 and Fig5.5-1.

Analysis of LANDSAT Images

Three (3) scenes of LANDSAT false colour images were used, which were generated using bands of 1, 4 and 5 of Thematic Mapper (TM) data, assigned to blue, green and red, respectively. This band combination has the advantage of emphasizing the color variation of rocks and soil.

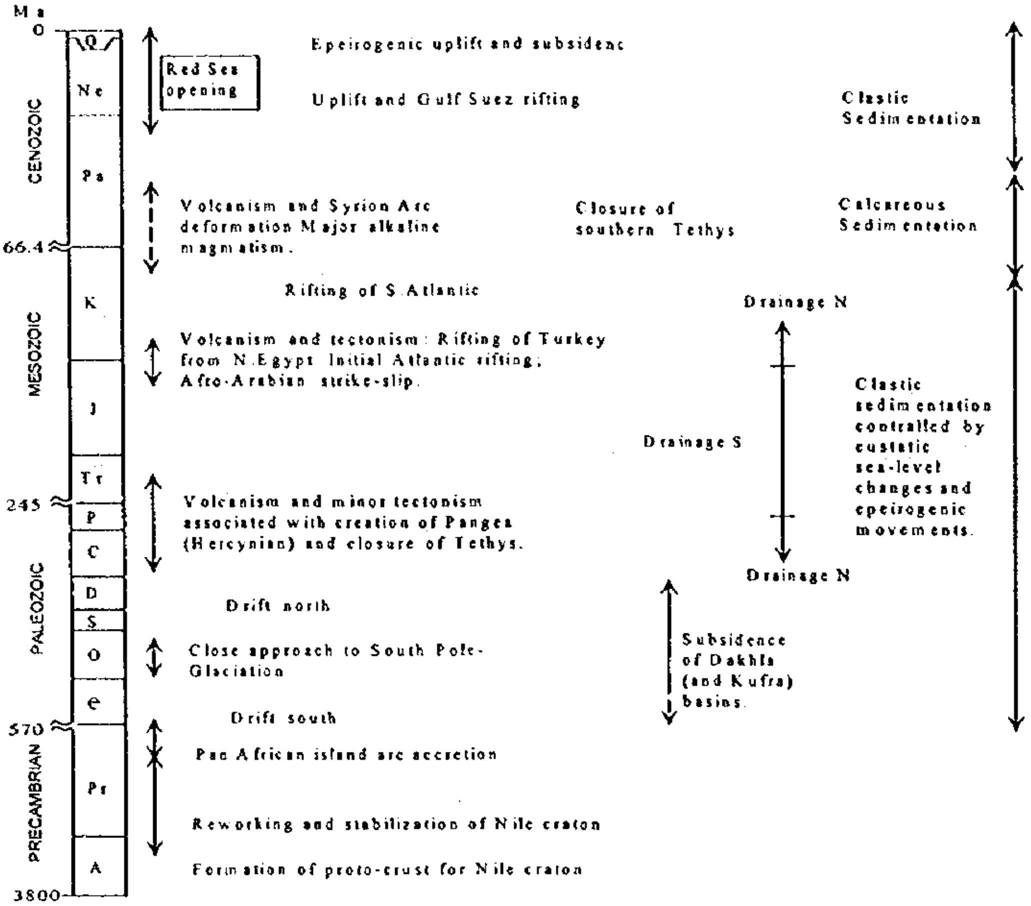
Analysis of these images which were enlarged to 1:250,000 scale was conducted in order to grasp lithological and structural characteristics on the geology and to understand large scaled geological structures and regional distribution of each rock units.

Interpretation of Aerial Photographs

The LANDSAT image analysis was followed by the interpretation of aerial-photos in a scale of 1:20,000. This allowed clarifying the detailed lithological distribution and geological structures.

5.2 General Geology

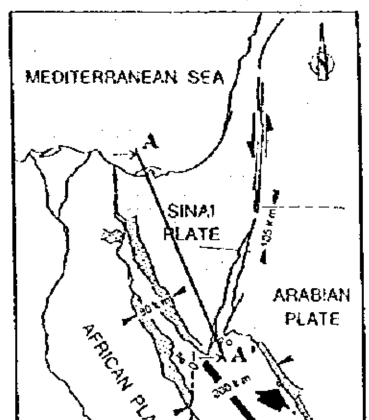
It is very important to grasp a series of tectonic movement in Sinai Peninsular in order to understand its geological and hydrogeological conditions. Major tectonic events in Egypt are shown in following figure. The most important event is "Read Sea Opening" that have formed the Gulf of Suez, Gulf of Aquaba and geological structure of the Sinai Peninsular as a consequence.



Major Tectonic Events in the Geological History of Egypt

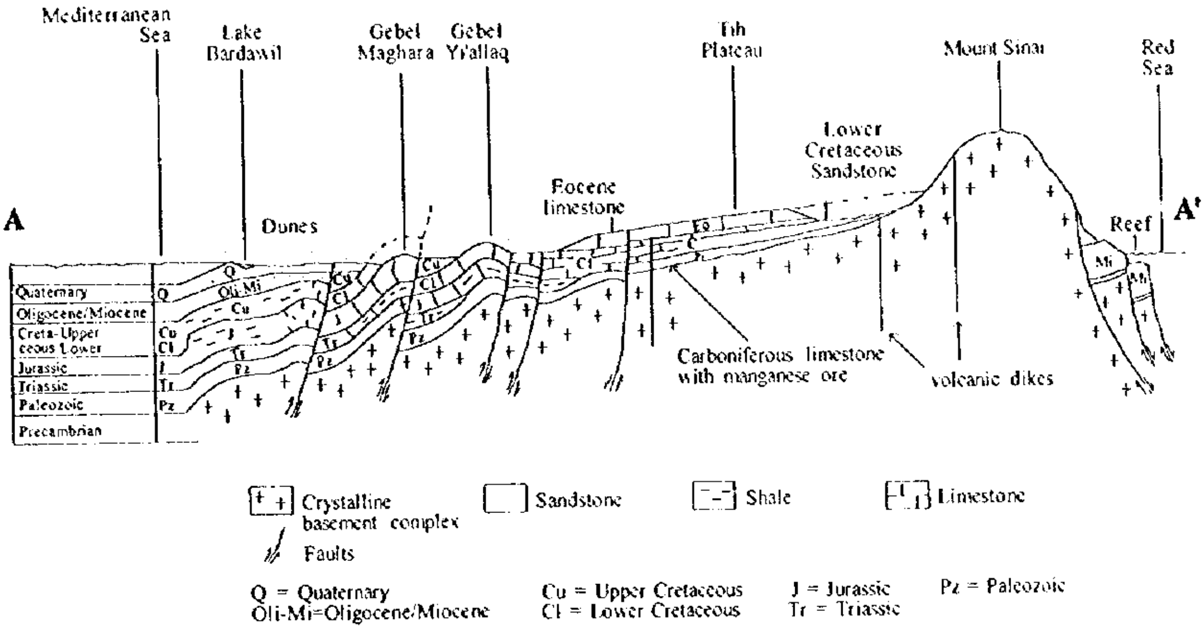
(Paul Morgan (1990):The Geology of Egypt)

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



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

The Geological cross section shows that the Sinai Peninsula was effected by such tectonic movement.



Geological Cross Section of the Sinai Peninsula

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

The Precambrian Rocks develop over a large part of South Sinai and mainly consist of the metamorphic complex of granitic rocks, metamorphic rocks and volcanic rocks. These rocks form a dissected plateau that slopes gently toward the north with the overlying sedimentary rocks ranging from Cambrian to Recent. Overview of stratigraphy in South Sinai is shown in Table 5.2-1.

Tectonic map of Sinai Peninsular is shown in Fig.5.2-1. The most remarkable tectonic structure in South Sinai is the "Ragabet El-Naam Fault" which runs across the central part of the peninsula east to west. There are many dome structures, which are distributed parallel with northeast to southwest direction in the northern side of the fault.

5.3 Geological Description

Geological description was compiled from three (3) sheets of "The geological map of Sinai, Arab Republic of Egypt" (Geological Survey of Egypt, 1994) and "The Geology of Egypt" (Rushdi Said, 1990).

5.3.1 Precambrian

The Precambrian Basement Rocks are distributed mainly in the south of Sinai Peninsula. The rocks are composed of the Middle and Late Precambrian metamorphic rocks and igneous rocks.

The Middle Precambrian Rocks consist of Feiran-Sulaf Gneiss Suite that is composed of hornblende-biotite gneiss and biotite-quartz-silimanite gneiss and calc-silicate gneiss (gno).

The Late Precambrian Rocks are composed of Al Kid-Madsus-Sa'l Metavolcanic Suite, Daha-Attar Melange, Firani Calcalkaline Suite, Rahabah Suite and Catherine Alkaline Suite. The Al Kid-Madsus-Sa'l Metavolcanic Suite (mv) consists of metamorphosed pyroclastic group, metamorphosed volcanic rocks, metamorphosed intermediate volcanic rocks and metamorphosed volcanogenic sedimentary rocks.

The Daha-Attar Melange consists of quartz diorite and hornblende-biotite granodiorite (tsm), leucogabbro and ultramafic rocks (gb), metadiorite (md) and metagabbro (mgb). The Firani Calcalkaline Suite consists of quartz diorite and hornblende-biotite granodiorite (gd) and phyritic rhyodacite and acidic pyroclastic and volcano-clastic deposits (fv). The Rahabah Suite consists of megacrystic and equigranular monzonite (gm), coarse to medium-grained monzonite (gmg) and gabbro (gb).

The Catherine Alkaline Suite consists of granophyre and syenite (cgs), alkaline granite (ckg) and breccia, lapilli tuff and rhyodacite flow deposits (cv).

5.3.2 Paleozoic

The Paleozoic sequence in the study area is divided into the Cambrian and the Carboniferous. The Cambrian is composed of the Arabah Formation (Ca) and the Naqus Formation (Cn). The former consists of varicolored, laminated sandstone with sandy clay and the latter consists of quartzitic sandstone. The Carboniferous is composed of the Abu Thora Formation (Ct) and Abu Durba Formation (Cd). The former consists of sandstone with carbonaceous clay and the latter consists of sandstone with clay beds.

These Paleozoic sedimentary rocks are exposed in the southern central part of the Sinai that includes mainly Umm Bogma area, the eastern part of Abu Zenima and Abu Durba.

5.3.3 Mesozoic

1) Triassic

In central and southern part of Sinai, the fluvial sediments of the Qiseib Formation (Tr) represent the Triassic sequence. The sediments consist of brown, purple and gray fine-coarse grained sandstone, variegated shale and siltstone with channel and overbank deposits, abundant ripple marks, cracks, cross-bedding and silicified tree-trunks, several meters in length.

Volcanic activity of Triassic age is represented by Dorelite sills (Trv).

2) Jurassic

The Jurassic sequence is composed of the Raqabah Formation (Jr) consisting of yellowish white, well bedded sandstone.

During Jurassic time, central Sinai was coastal plain and shallow shelf of low relief, separating the continental Arabo-Nubian shield to the south from the deep marine Tethyan Sea to the north.

The undivided middle-lower Jurassic clastic sediments indicate that continental conditions existed throughout central Sinai during the lower-middle Jurassic time.

These sediments are predominantly ooid and bioclastic lime grainstone and packstone.

3) Cretaceous

(1) Lower Cretaceous

The Lower Cretaceous sequence in Albian to Aptian time is represented by the Malhah Formation (Kl) consisting of sandstone with subordinate interbeds of sandy siltstone and claystone.

The basal fluvial-continental lower Cretaceous sediments unconformably overlie the shallow marine upper Jurassic sediments as a result of a major eustatic fall in sea level.

In central Sinai the pre-Cenomanian section is composed entirely of so-called "Nubian-type" sandstone which attains 780 m thick at Umm Bogma. The basal part

(282m) of this sandstone has been assigned as a Carboniferous age, whilst the upper 498 m is thought to range from Triassic to Lower Cretaceous ages. This sandstone is exposed mainly along the scarp of the Gebel El Tih.

(2) Upper Cretaceous

i) Cenomanian

The Cenomanian sequence is represented by the Galalah Formation (Kg) consisting of greenish yellow marl and claystone with Oyster banks. The top is mainly limestone.

In central Sinai, Cenomanian sediments conformably overlie Lower Cretaceous sandstone along the southern scarp of Gebel El Tih, on the upland plateau of Gebel Gunna and in the core of the Gebel Somar dome.

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

Carbonates become increasingly common to the north and an interbedded carbonate-clastic sequence was penetrated.

ii) Turonian

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

In central Sinai, the Turonian strata are conformable on the Cenomanian beds and range in thickness from 50 m to over 280 m. They consist of uniform, well-bedded, massive limestone and dolomite with minor amounts of marl, shale and chart and attains a thickness of 132 m to 140 m at Gebel Arif El Naga.

The Turonian sediments in central Sinai were deposited in a broad Shallow intertidal-subtidal environment with sabkha type sedimentation being common.

iii) Coniacian

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

In south Sinai, Lewy (1975) states that an oolitic shoal, which can be traced from

Gebel El Heitan eastward to Gebel Abu Kandu, separated the northerly outer shelf from the stable southerly innershelf.

iv) Santonian-Campanian

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

The stable southerly inner-shelf is characterized by medium coarse-grained, glauconitic, bioclastic limestone, tidal flat to marginal basin dolomites and littoral to continental clastics in the extreme south. These clastics, which are known as the Matallah Formation, are exposed at Wadi Matallah and consists of variegated clays, marl, cross-bedded sandstone and oyster beds.

v) Maastrichtian

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

In the southern part of Sinai, an inner shelf to continental environment existed. The clastic ratio of it decreases northward. This sequence in central Sinai consists of thick white soft chalk, which is occasionally bituminous and phosphatic with thin discontinuous beds of brecciated brown-black flint.

Volcanic activity of Cretaceous age is represented by Basaltic dykes (Kv).

5.3.4 Cenozoic

1) Tertiary

(1) Paleocene

The Paleocene sequence is represented by the Esna Formation (Tpe) consisting of green to yellowish green clay with limestone and marly interbeds.

Regional data indicates that the Paleocene was deposited in the lows between the major structural highs in Sinai and its distribution closely follows that of the underlying upper Cretaceous chalk unit.

The Paleocene section, which is known as the Esna shale, has a uniform lithology of greenish gray shale, although in the south a basal chalky facies is present. Thickness of the Esna Shale is approximately 30 to 50m. In central Sinai, it is a thin but clearly mappable dark unit in the Gebel Egma cliffs (35 m thick) and forms extensive plains on the northern flank of Gebel El Mineidra and outcrops in the core of the Nakhl and Darag domes. In the Nakhl and Darag boreholes the Esna shale has a thickness of 59 m and 38 m respectively.

In Central Sinai, field exposures examined by Butter (1981) suggested that the Paleocene is predominantly a chalky limestone facies very similar to the Maastrichtian chalk. Overlying this chalk are the gray-green Esna shale which, according to the dating of the field samples, are diachronous and range from Paleocene to lower Eocene ages. In places, small bodies of the chalk have been observed within the Esna shale in this southern area.

(2) Eocene

The Eocene sediments outcrop in many areas throughout Sinai and have been penetrated in several wells. As a result of poor palaeontological dating, the exact age of the Eocene sequence penetrated in some of the wells is uncertain and in some wells an interval has been assigned to the Eocene solely on lithology.

i) Lower Eocene

The Lower Eocene sequence is represented by the Egma Formation (Tel) consisting of chalky limestone with flint bands and nodules at base and thin successive chert bands at top.

The lower Eocene in Sinai is generally represented by a massive flinty limestone, commonly referred to as the Thebes limestone. However, in southern Sinai, the lower part of the lower Eocene section comprises the Esna shale, which appear to be diachronous in this southern region.

At Gebel Egma in central Sinai, this flinty limestone, known locally as the Egma Limestone, covers the extensive tableland of the Egma Plateau. It varies in thickness from 125 m to 240 m and northward the basal part has a development of yellowish marly limestone (Safra Beds).

ii) Middle-Lower Eocene

The middle to lower Eocene sequence is represented by Darat formation (Ted) consisting of white limestone interbedded with brown marl in lower part and the

Samalut Formation (Tes) consisting of yellowish white limestone interbeds with brown marl, rich in *Nummulites gizehensis zitteli*.

At Wadi Nukhul in central Sinai, the lowermost part of the middle Eocene section is represented by the Darat Formation. These comprise green-brown shale, marls, limestone stringers and gypsiferous shale with thin flint bands. These beds have also been observed in south Sinai but are absent in north Sinai.

iii) Middle Eocene

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

Overlying these predominantly clastic formations is the Mokattam or Plateau limestone.

(3) Miocene.

Lower Miocene sequence is represented by the Sumar Formation (Tms) consisting of conglomerate, marly limestone and sandstone changing in places into calcareous sandstone and the Rudeis Formation (Tmr) consisting of alternate beds of marl and sandstone with fossiliferous carbonate beds in the lower part.

Middle to lower Miocene sequence is represented by the Abu Alaqah Formation (Tma) consisting thick section of conglomerate with interbeds of marl and sandstone and the Qabiliyat Formation (Tmq) consisting of thick section of fossiliferous limestone.

Middle Miocene sequence is represented by the Karim Formation (Tmk) consisting of thick section of gypsum and anhydrite with marly interbeds.

In central and southern Sinai, Miocene sediments are restricted to the eastern bank of the Gulf of Suez.

Detailed palaeobathymetric, nannoplankton biostratigraphy and facies analyses of these exploration boreholes have revealed that from the lower Miocene period through to the beginning of the Messinian, four main facies belts prevailed, namely continental-fluvial, paralic, shelfal and slope with their associated clastic sedimentation (Morathon, 1981). These facies belts migrated southward in response to eustatic sea level changes throughout the Miocene epoch.

During uppermost Miocene Messinian time, the Mediterranean basins were cut off from the global ocean system, resulting in the production of endorheic salt lakes and the Messinian Salinity Crisis. The evaporites were later resettled, as a result of overburden pressure, into halokinetic structure. At this time the onshore north Sinai was a land mass with a northerly-flowing drainage system feeding the salt lakes.

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

(4) Pliocene

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

Volcanic activity in Tertiary age is represented by Basalt dykes (Tv).

2) Quaternary

(1) Pleistocene

Pleistocene formation is represented by Terrace Deposits (Qt) and Gravel Deposits (Qg).

(2) Holocene

Holocene formation is represented by Wadi Deposits (Qw) and Sabkha Deposits (Qsb).

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

5.4 Geological Sequence

In order to estimate the thickness of each formation and to clarify the geological/ hydrogeological conditions, geological maps in a scale of 1/50,000 and geological columns of three areas; Abu Durba, Gebel Dalal and Ras El Gineina areas were prepared. The location of these areas is shown in Fig. 5.4-1. As the result of this survey, Geological Maps (1:50,000) were established for each area.

5.4.1 Abu Durba Area

The Precambrian Igneous Rocks, and Palaeozoic, Mesozoic and Cenozoic Sedimentary Rocks are distributed.

The Geological Map of Abu Durba area is shown in Fig. 5.4-2. The lithological legend and the geologic columnar section are shown in Fig. 5.4-3 and 5.4-4 respectively.

1) Precambrian

The Precambrian Igneous Rocks consist of coarse to medium grained alkaline granite.

2) Paleozoic

(1) Cambrian

The Cambrian sequence is represented by the Arabah Formation and the Naqus Formation.

Arabah Formation: The lithology is alternation of brown and white sandstone, and brown and dark brown colored sandstone containing clay and siltstone. The formation is more than 10 m in thickness.

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

(2) Carboniferous

The Carboniferous sequence is represented by the Abu Durba Formation. It overlies unconformably the Naqus Formation.

Abu Durba Formation: It consists of white coarse grained quartzitic sandstone with intercalated red shale. It is 35 m in thickness.

3) Mesozoic

(1) Lower Cretaceous

The Lower Cretaceous sequence is represented by the Malhah Formation. It overlies unconformably the Abu Durba Formation. The formation is 208 m in thickness.

The lithology is mentioned below:

Thickness	Lithology
0.0 m - 0.6 m	Basal conglomerate consisting of quartz Pebble.
0.6 m - 6.0 m	Pale yellow, coarse to fine grained sandstone, well sorted.
6 m - 8 m	Red to reddish brown, limonite clay bed oxidized, with gypsum vein lets.
8 m - 53 m	Alternated beds of pale brown, fine to medium sandstone and purple to gray, clay beds.
53 m - 76 m	Pale brown, medium to fine sandstone.
76 m - 118 m	Gray to bluish gray, shale intercalating fine sandstone.
118 m - 148 m	White to yellowish white, medium to fine sandstone (Clean bed).
148 m - 208 m	Alternated beds of gray and yellowish brown, fine to medium claystone to shale ,and white to yellowish white coarse to very coarse sandstone.

The Malhah Formation is a main aquifer as shown in Fig. 5.4-2. Two (2) beds from 53 m to 76 m and from 118 m to 148m are aquifers in the Malhah Formation. This sandstone is regionally called as the "Clean Bed" which forms a regional aquifer.

(2) Upper Cretaceous

The upper Cretaceous sequence is represented by the Galalah Formation, the Wata Formation, the Matallah Formation and the Sudr Formation.

Galalah Formation: The lower Galalah Formation consists of bluish gray to gray calcareous shale intercalating with fossiliferous limestone. Its thickness is 40 m. The upper Galalah Formation consists of yellowish gray to yellow fine calcareous sandstone. The thickness is 15 m. The top of the formation consists of pale yellow limestone with sandy fragments. The Galalah Formation is 55 m in total thickness.

The Upper Galalah Formation is an aquifer as shown in Fig. 5.4-2.

Wata Formation: The lower part of the formation consists of alternated beds of red to pale brown shale and light yellow calcareous sandstone intercalated with three (3) beds of fossiliferous limestone beds. The thickness is 23 m. The upper formation consists of white bedded calcareous shale intercalated with two (2) white limestone beds. Its thickness is 19 m. The Wata Formation is 42 m in total thickness.

Matallah Formation: The lower part of the formation consists of alternated beds of white to light gray medium to fine sandstone and gray shale intercalated with fossiliferous limestone. Its thickness is 105 m. The upper formation consists of dark gray calcareous and fossiliferous bedded shale intercalated with fossiliferous sandstone and calcareous sandstone. The thickness is 30 m. The Galalah Formation is 135 m in total thickness.

Sudr Formation: The formation consists mainly of white to white cream massive chalky limestone. A chert bed is observed at 1 m from the boundary with the Matallah Formation. White alternated chalky siltstone beds are observed from 34 m to 42 m. The formation is 122 m in thickness.

4) Cenozoic

(1) Palaeocene

The Palaeocene sequence is represented by the Esna Formation. It consists of pale bluish gray shale, so called as Esna Shale. The formation is 18 m in thickness.

(2) Eocene

The Eocene sequence is represented by the Egma Formation, the Samalut Formation and the Mokattam Formation.

Egma Formation: The lower formation consists of white to creamy white calcareous, massive chalky shale with kaolinite clays. This is called as the Egma Limestone. Its thickness is 40 m. The upper formation consists of light yellowish gray alternated beds of shale and chert (unit: 20 cm to 1 m) with hard chert concretions. The thickness of it is 110 m. The Egma Formation is 150 m in total thickness.

Samalut Formation: The formation consists of light gray flaky shale. The thickness is about 50 m.

Mokattam Formation: The formation consists of yellowish white limestone of which thickness is about 15 m.

(3) Miocene

The Miocene sequence is represented by the Qabiliyat Formation. It unconformably overlies the Mokattam Formation.

The Qabiliyat Formation: It consists of fossiliferous limestone. The formation is more than 30 m in thickness.

(4) Pliocene

The Pliocene sequence is represented by the El Qaa Formation. It consists of alternated beds of calcareous grits and sandstone with gypseous interbeds.

5.4.2 Gebel Dalal and Ras El Gineina areas

Geological Maps of Gebel Dalal and Ras El Gineina areas are shown in Fig. 5.4-5 and 5.4-6. Geologic columnar sections of two areas are compiled in Fig. 5.4-7.

The area is composed of Precambrian igneous rocks, and Palaeozoic, Mesozoic and Cenozoic sedimentary rocks.

1) Precambrian

The Precambrian Igneous Rocks consist of coarse to medium alkaline granite, metamorphic rocks and porphyry dykes.

2) Palaeozoic

(1) Cambrian

The Cambrian sequence is represented by undivided Cambrian Formation.

Undivided Cambrian Formation: The lithology of the formation is brownish white medium to fine sandstone, and alternated beds of sandstone and silty sandstone. The formation is 35 m in thickness.

3) Mesozoic

(1) Jurassic

The Jurassic sequence is represented by the Raqabah Formation. It unconformably overlies the undivided Cambrian formations.

Raqabah Formation: It consists of white calcareous coarse to very coarse sandstone. The formation is laminated and sorted. It is 55 m in thickness.

(2) Lower Cretaceous

The Lower Cretaceous sequence is represented by the Malhah Formation. It unconformably overlies the Abu Durba Formation. The formation is 116 m in thickness. The formation forms a main aquifer due to its high permeability.

Thickness	Lithology
0 - 10 m	White fine to medium sandstone including lenticular sandstone fragments 2 to 3 m length.
10 - 40 m	White coarse to fine sandstone.
40 - 48 m	Light gray silty sandstone and reddish purple to light purple sandy shale to claystone.
48 - 70 m	Reddish brown to pale brown, very coarse to medium sandstone.
70 - 79 m	Alternated beds of white, fine to medium sandstone and reddish white to white, fine sandstone.
79 - 91 m	no outcrops (covered by soil).
91 - 111 m	White to yellowish white, pebble gravel to very coarse sandstone, gravel consisting of quartz, siltstone and chert.
111 - 116 m	Alternated beds of brown to reddish brown chalk and purplish gray medium sandstone

(3) Upper Cretaceous

The Upper Cretaceous sequence is represented by the Galalah Formation, the Wata Formation, the Matallah Formation, the Duwi Formation and the Sudr Formation.

Galalah Formation: The lower part consists of yellowish sandy siltstone with pebble gravel intercalated with fossiliferous limestone. The thickness is 30 m. The upper part consists of yellowish gray, thick limestone, calcareous shale and marl. The thickness is 40 m. The Galalah Formation is totally 70m in thickness.

Wata Formation: The lower formation consists of reddish brown conglomerate with calcareous sinter or clay. The thickness is 18 m. The upper formation consists of light yellowish brown, hard and compact, calcareous shale intercalated with three (3) thin fossiliferous limestone beds. The thickness is 19 m. The Wata Formation is

37 m in total thickness.

Matallah Formation: The lower formation consists of white to light brown, medium to fine calcareous sandstone with fossil fragments. The thickness is 20 m. The upper formation consists of alternated beds of creamy coloured calcareous hard shale and fossiliferous sandstone. The thickness is 30 m. The Matallah Formation is 50 m in total thickness.

Duwi Formation: The lower formation consists of bluish gray calcareous fine sandstone. The thickness is 8 m. The upper formation consists of alternated beds of brown shale and marl, and gray to yellowish gray fine sandstone. The top of the formation includes evaporite deposits. The thickness is 16 m. The Duwi Formation is 24 m in total thickness.

Sudr Formation: The lower formation consists mainly of white to white cream massive chalky limestone. The top of the formation is composed of brownish gray chert, 1 m in thickness. The thickness is 30 m. The upper formation consists of white chalky limestone. The top of it is composed of white chalky shale. The thickness of this formation is 35 m. The Sudr Formation is 65 m in total thickness.

4) Cenozoic

(1) Palaeocene

The Palaeocene sequence is represented by the Esna Formation. It unconformably overlies the Sudr Formation.

Esna Formation: It consists of pale bluish gray shale, so called as Esna Shale. The formation is 20 m in thickness.

(2) Eocene

The Eocene sequence is represented by the Egma Formation.

Egma Formation: The lower formation consists of white calcareous massive chalky shale or limestone with kaolinite clays. It is correlated to the Egma Limestone. The thickness is 25 m. The upper formation consists of light yellowish gray alternated beds of shale and chert (unit: 20 cm to 1 m) with hard shale nodules. The thickness is 30 m. The Egma Formation is more than 50 m in total thickness.

Correlation of the geological columnar sections of the Abu Durba, Gebel Dalal and Ras El Gineina areas are shown in Fig. 5.4-9.

5.5 Geological Structure

5.5.1 General Geological Structure

The Sinai Peninsula is wedged between the African and Arabian plate. The boundary of them are defined by the Gulf of Suez and Gulf of Aqaba-Dead Sea Rift System.

Pre-Cambrian igneous and metamorphic rocks form the Arabo-Nubian shield in the south of Sinai. The field survey and petrographic study indicate that the shield consists of a series of island arcs which were cratonized during the late Precambrian-early Palaeozoic (1,200 to 500 my BP) Pan-African Orogeny (Gass 1981). The peneplained palaeo-surface of the shield inclined gently northward with the overlying sediments, ranging from Cambrian to Recent, thickening northward.

The Central Sinai has been described in detail by Shata (1956) and Said (1962). An east-west trending shear zone of dextral strike-slip faults with displacement up to 2.5 km was recognized by Steinitz et al (1978).

5.5.2 Results of Lineaments Analysis

Lineament analysis was conducted using three (3) scenes of LANDSAT false colour images. The results are described in Fig. 5.5-1.

1) Strike-slip faults in the eastern study area

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

2) Conjugate Fault in the Feiran Oasis

The conjugate faults are well developed in the Feiran Oasis area. The faults are formed in N-S and NE-SW directions. The N-S faults are right-slip faults with the displacement attaining to 1.5 km. The NE-SW faults are left-slip faults with the displacement attaining to 0.5 km. A lot of minor lineaments are intensively developed around the center of conjugate faults. The geological field survey revealed that many open fractures are well developed in the Oasis Feiran area. Many dug wells were constructed in the area.

3) Ring structures

Three (3) ring structures are observed in El-Biarat area, and Qoz Umm Rigum area, northern part of study area and Ain Qaseby area, north of Nuweiba as shown in Fig. 5.5-5. Radial lineaments are well observed in these structures.

The scale of each ring structure is as follows;

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

4) Minor lineaments concentrated areas

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

(1) Ras Umm Maghrab area
(2) Umm Bugma Mine area
(3) Gebel Umm Rig area
(4) Gebel Mileihis area
(5) Wadi Watir area

Many open fractures were observed in the Precambrian Rocks in the following area ;Ras Umm Maghrab area, Gebel Mileihis area, downstream area of the Wadi Dahab.

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

5) Dykes

Dykes are observed in igneous and metamorphic mountains and northwestern area of the study area. Though ages of dykes are Precambrian, Triassic, Cretaceous and Tertiary time, it is difficult to distinguish the age of these dykes on the LANDSAT images.

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

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

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

There are two kinds of dyke; open fractured type and closed fractured type. These characteristics seem to be close relationship with the behavior of groundwater in the Precambrian Rocks.

6) Geological Cross Section

Two geological cross sections were prepared based on the results of geological investigation (LANDSAT Image analysis, aerial photo interpretation, detailed geological field survey and geophysical survey) as shown in Fig. 5.5-3 to 5.5-4. Location of cross sections is shown in Fig. 5.5-2.

Fig. 5.5-3 is a section in E-W direction and includes test well of J-4, 5 and J-6. Fig. 5.5-4 is a section in N-S direction and includes proposed well location J-1, J-3 and J-6.

Tall. 5.2-1 Stratigraphy of South Sinai

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

Tab. 5.2-1 Stratigraphy of South Sinai

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

Table [illegible] Stratigraphy of South Sinai

Epoch	Stage or etc.	Legend	Formation
[illegible]		[illegible]	Sabkha Deposits
		Qw	Wadi Deposits
[illegible]		Qs	Gravel Deposits
		Qt	Terrace Deposits
[illegible]		Tpl	Al Qaa F.
	[illegible]	Tmz	Zeit F.
		Tmq	Qabaliyat F.
		Tmh	Hammam Faraun F.
		Tmb	Belayim F.
[illegible]	Middle	Tmk,Tma	Kareem F. Abu Alaqa F.
		Tmu	Rudeys F. Sumr F.
		Tmr,Tms	Rudeys F. Sumr F.
	[illegible]	Tmn	Nakhl F.
		Tv	Extrusive Basaltic Rock
		Tem	Mokattam F.
		Ted	Darat F.
[illegible]		Tes	Samalut F.
		Tel	Thebes F.
[illegible]		Tpe	Esna F.
	Maastrichtian	Ks	Sudr F.
	[illegible]	Kd	Duwi F.
		Km	Matulla F.
	[illegible]	Kt	Taref Sandstone
	[illegible]	Kw	Wata F.
		Kv	Basaltic Dykes
	[illegible]	Kg	Galala F.
	[illegible]	Kl	Malha F.
		Jr	Raghaba F.
		Tr	Qiseib F.
		Trv	[illegible]
		Cd	Abu Durba F.
		Ct	Abu Thora F.
		Cn	Naqus F.
		Ca	Araba F.
		cgs	Syenite Quartz Syenite
	[illegible]	ckg	[illegible]
		Cv	Rhyodacite Flow Deposits
		gm	Monzonite
	[illegible]	gmg	Monzonite
		[illegible]	Olivine hornblende Gabbro
	[illegible]	gd	Quartz Diorite,Granodiorite
		Fv	[illegible]
		Tsm	Leucogabbro
		Dsm	Dunite Melange
	[illegible]	[illegible]	Metadolite
		mgb	Metagabbro
	Al Kid Metasediments	Mv	Metamorphosed Volcanics
	Feiran Solaf Gneiss Suite	gno	Gneiss,Metabasalt Dykes

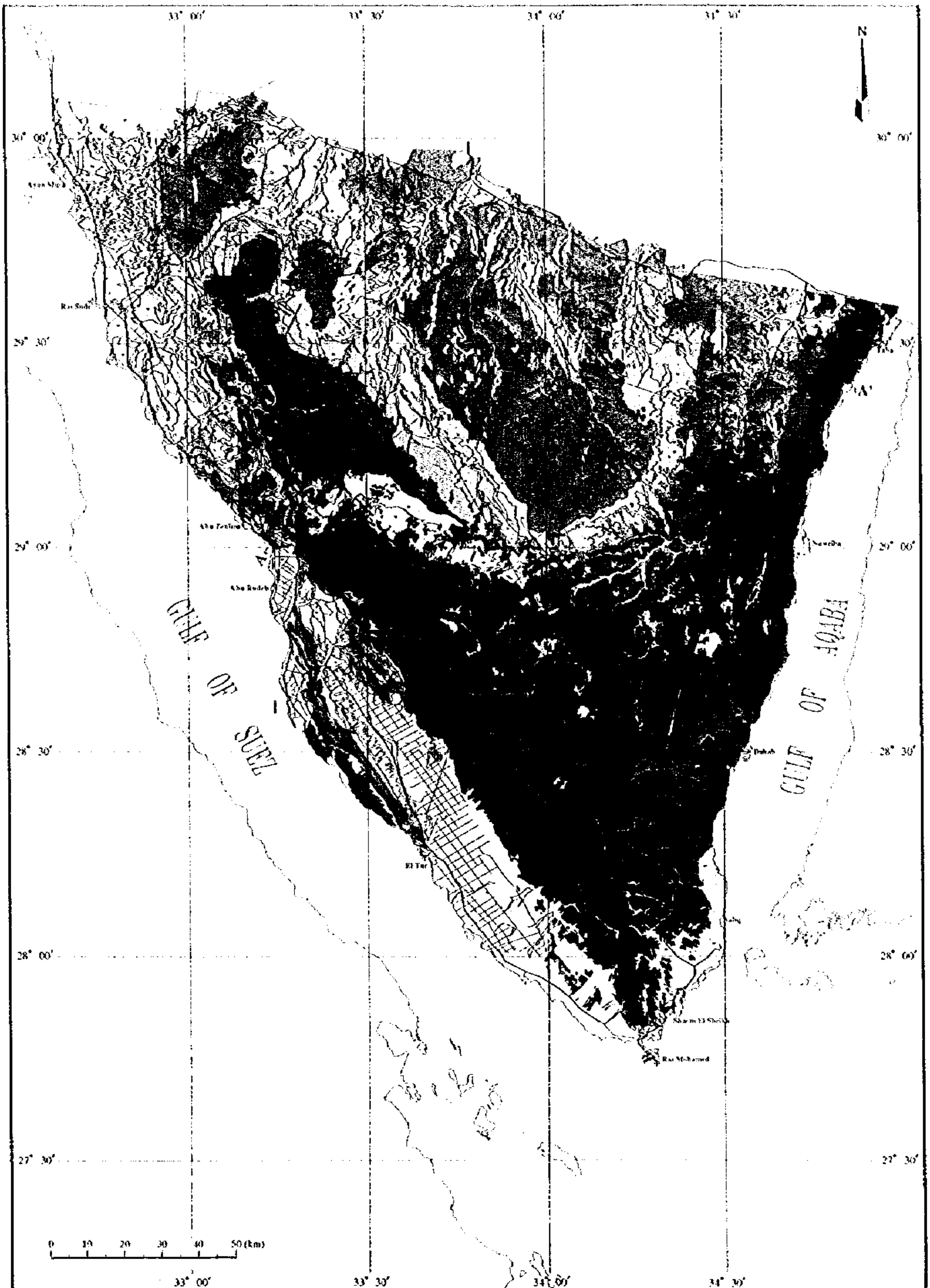


Fig. 5.1-1 Geological Map (South Sinai)

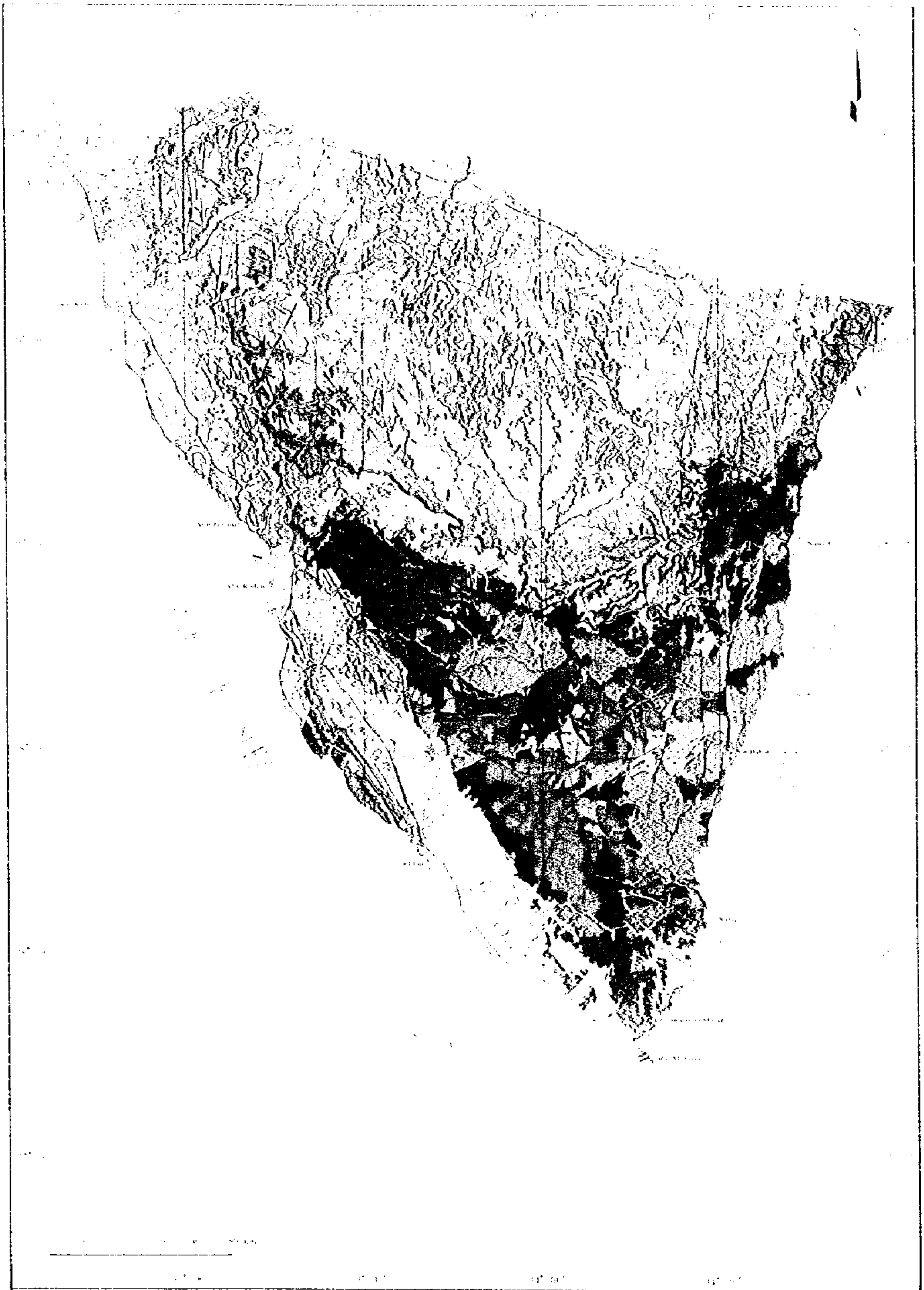


Fig. 5.1-1 Geological Map (South Sinai)

Fig. S.1.1 Geological Map (South Sinai)

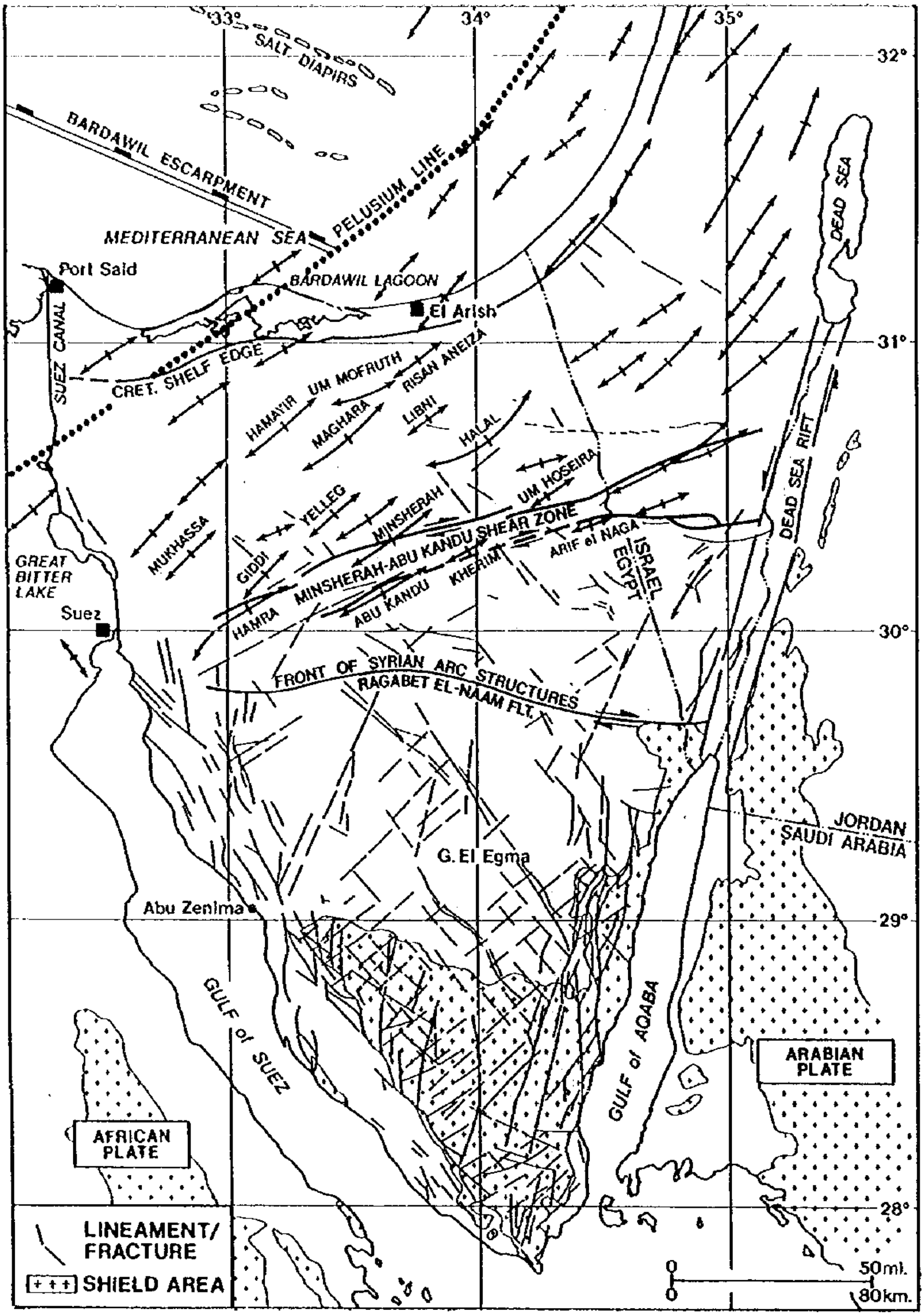


Figure 19.1 Tectonic map of north and central Sinai (after Neev 1975 and Agah 1981).

Fig. 5.2-1 Tectonic Map of North and Sinai (after Neev 1975 and Agah 1981)

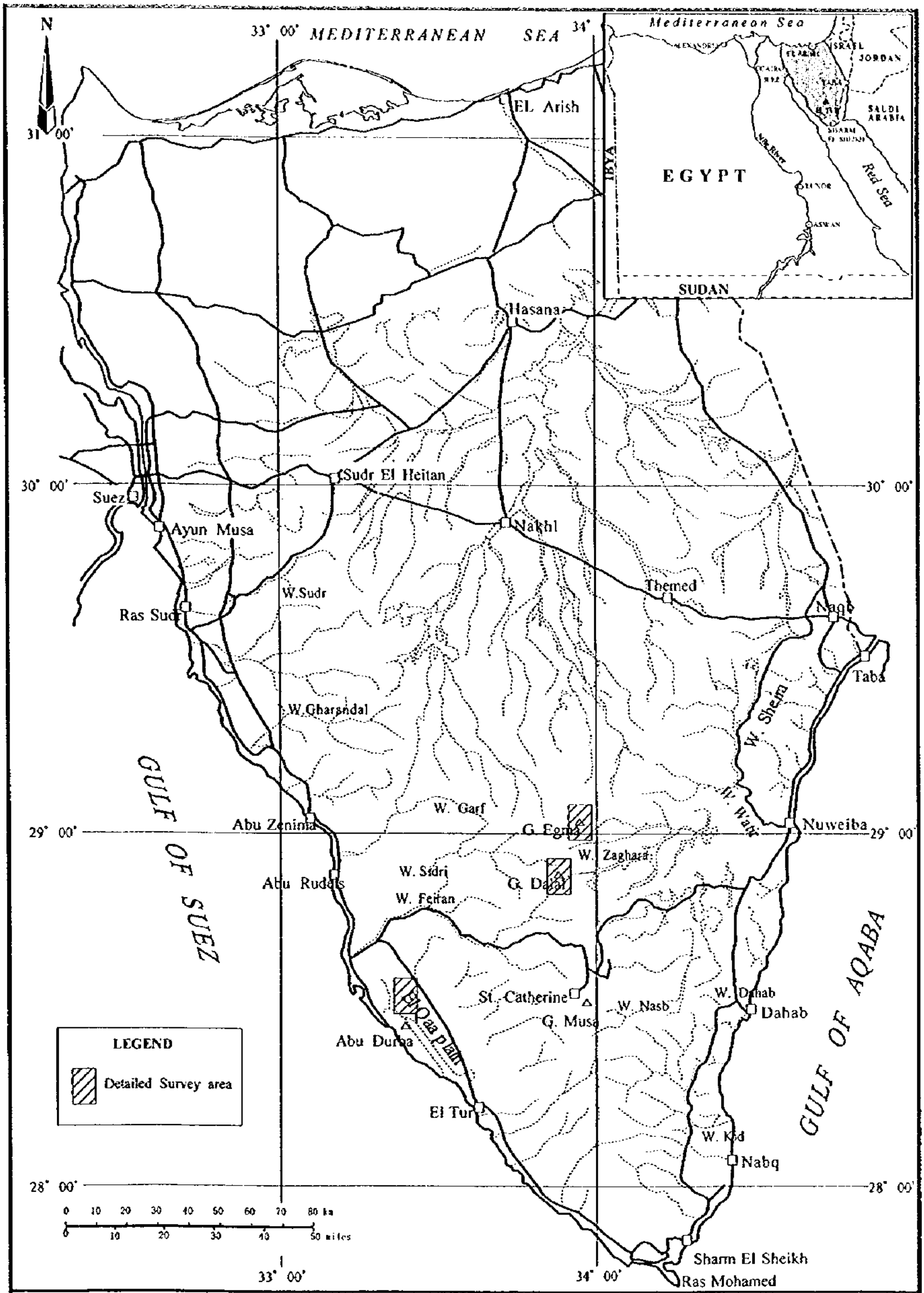


Fig. 5.4-1 Location of Detailed Survey Area

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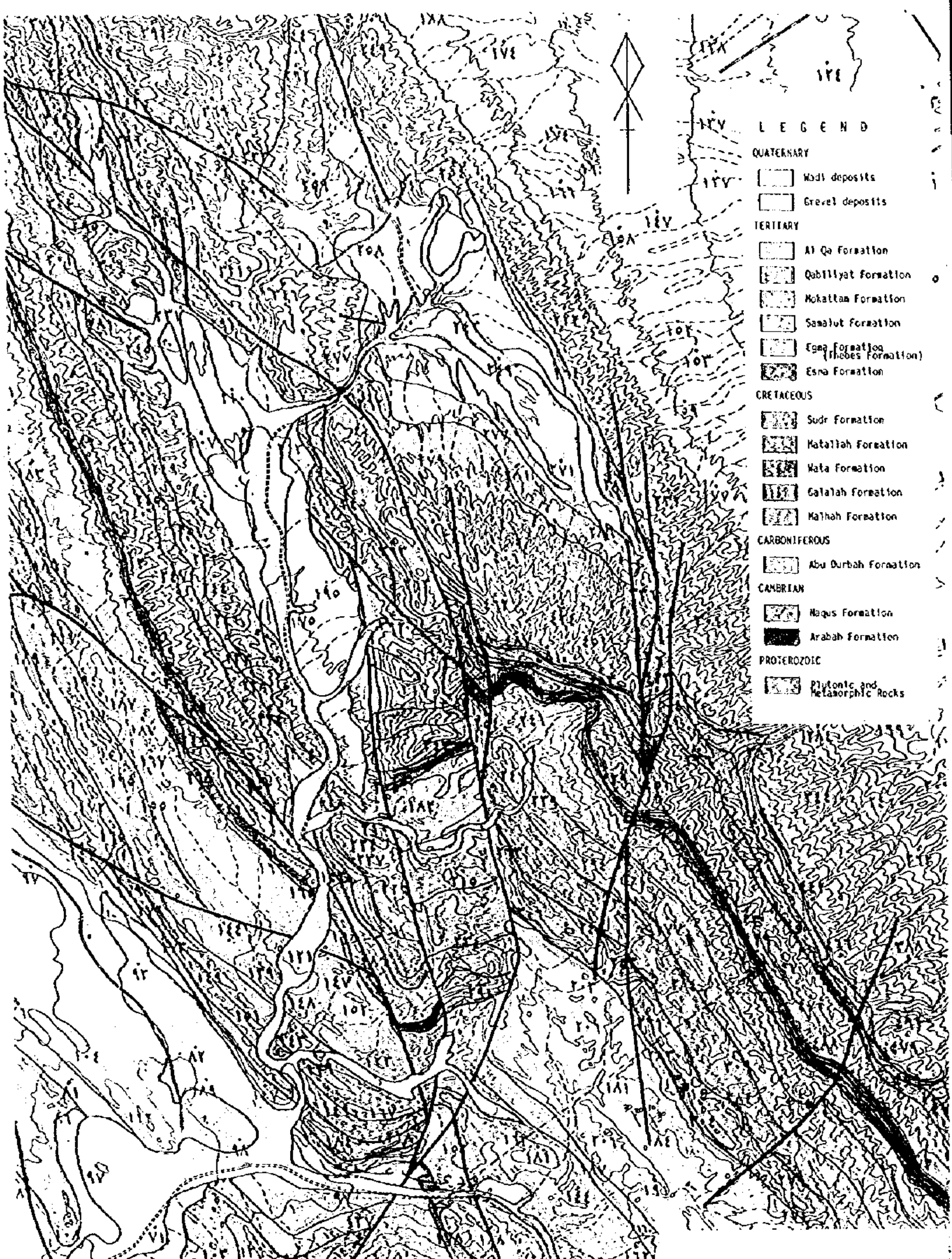

Fig. 5.4-2 Geological Map (Abu Durba Area)

LITHOLOGICAL LEGEND

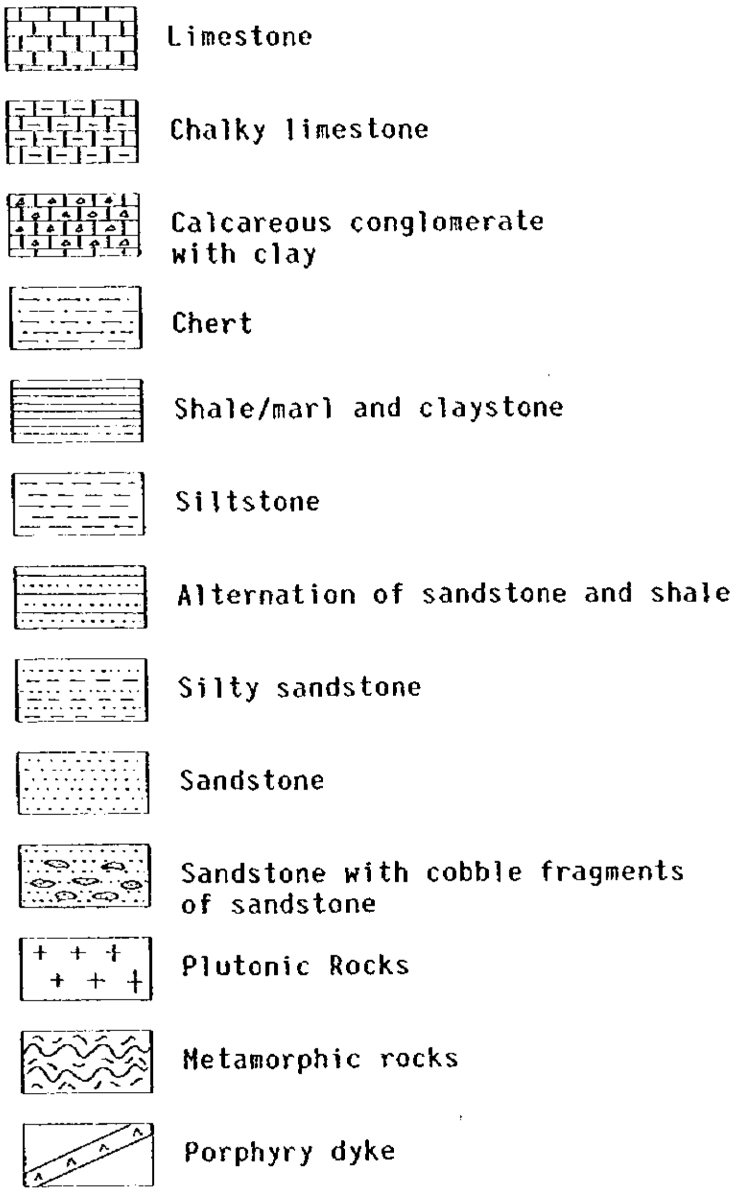

Fig. 5.4-3 Lithological Legend.

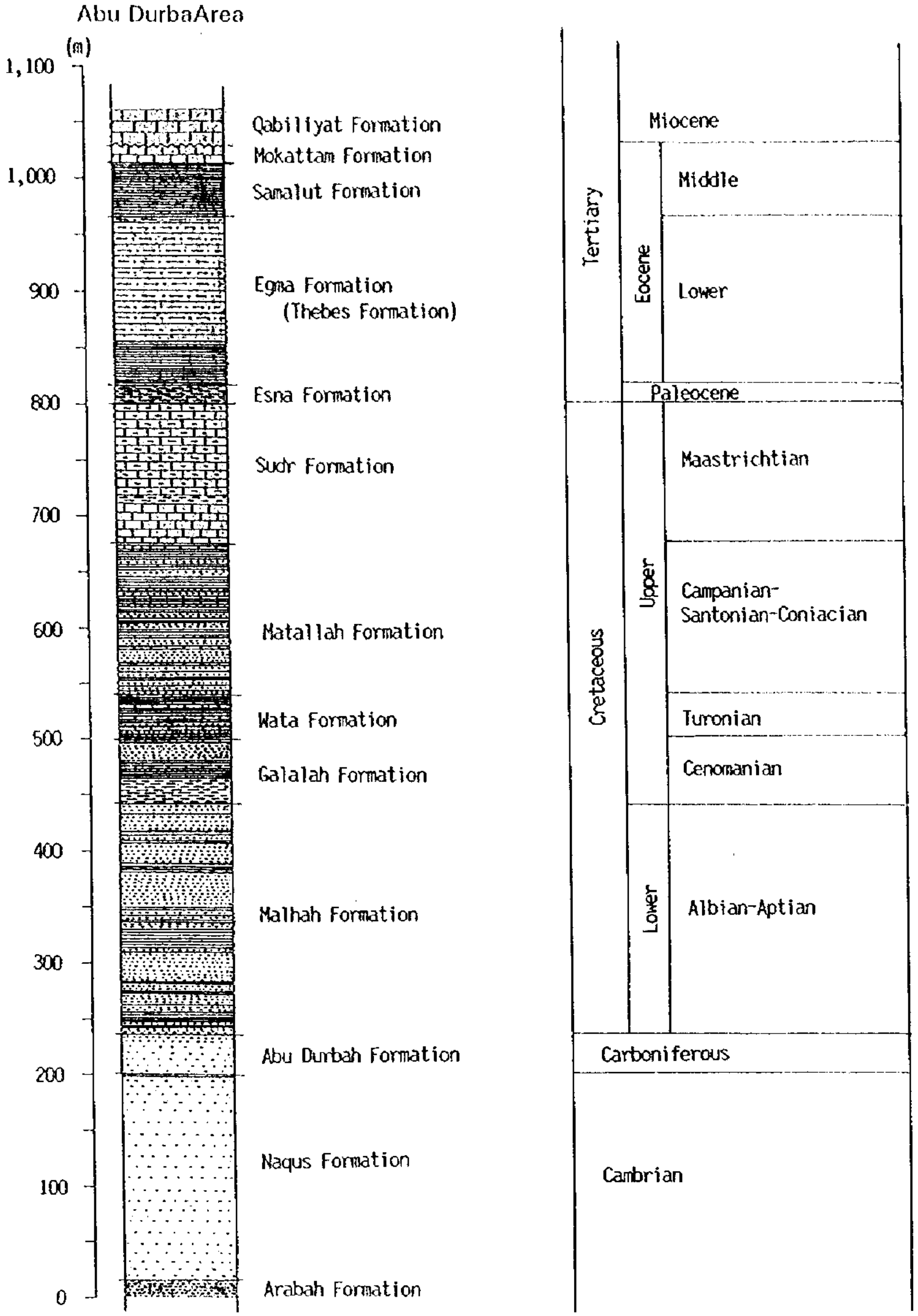

Fig. 5.4-4 Geologic Columnar Section (Abu Durba Area)

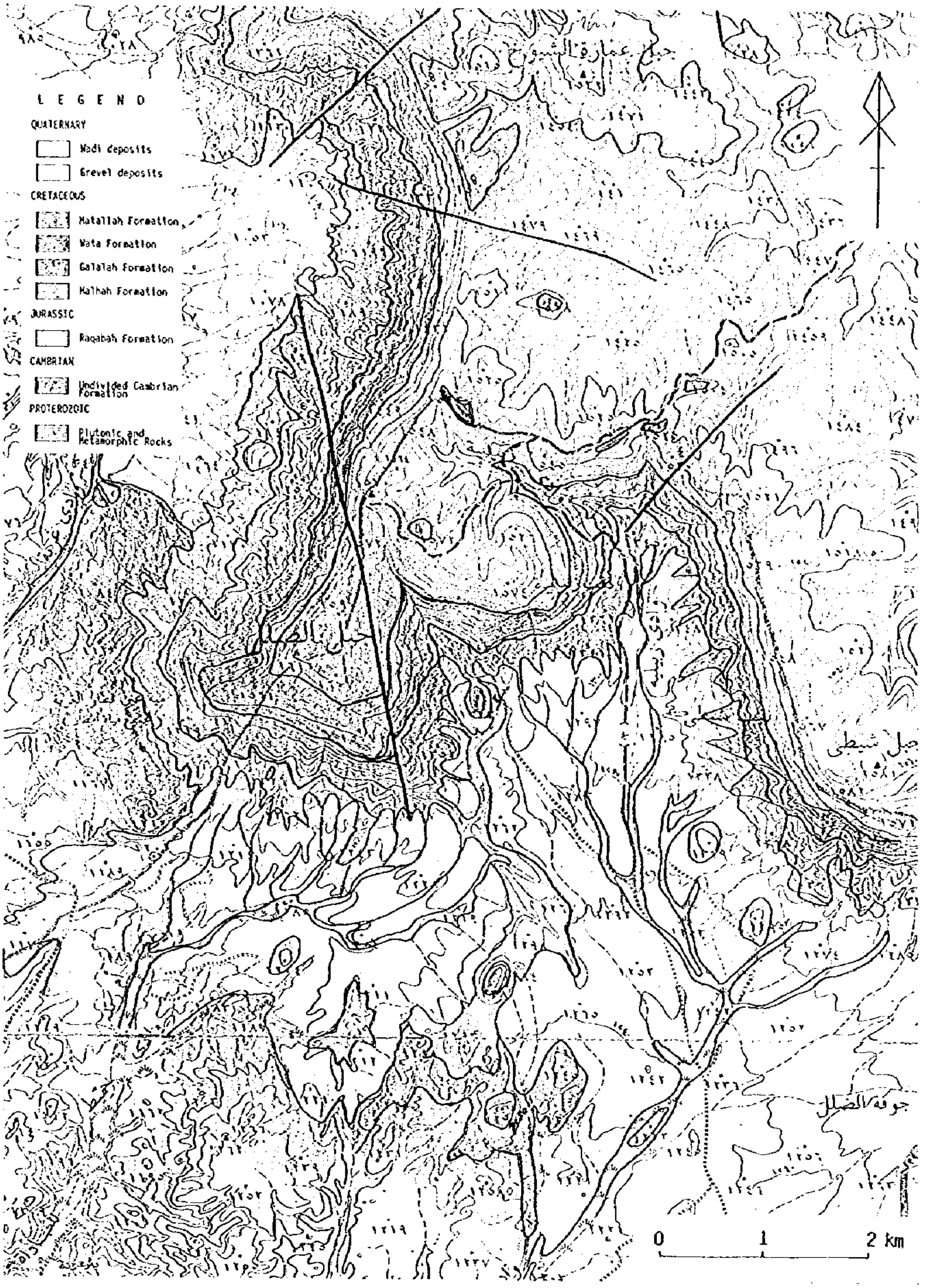

Fig.5.4-5 Geological Map (Gebel Dalal Area)

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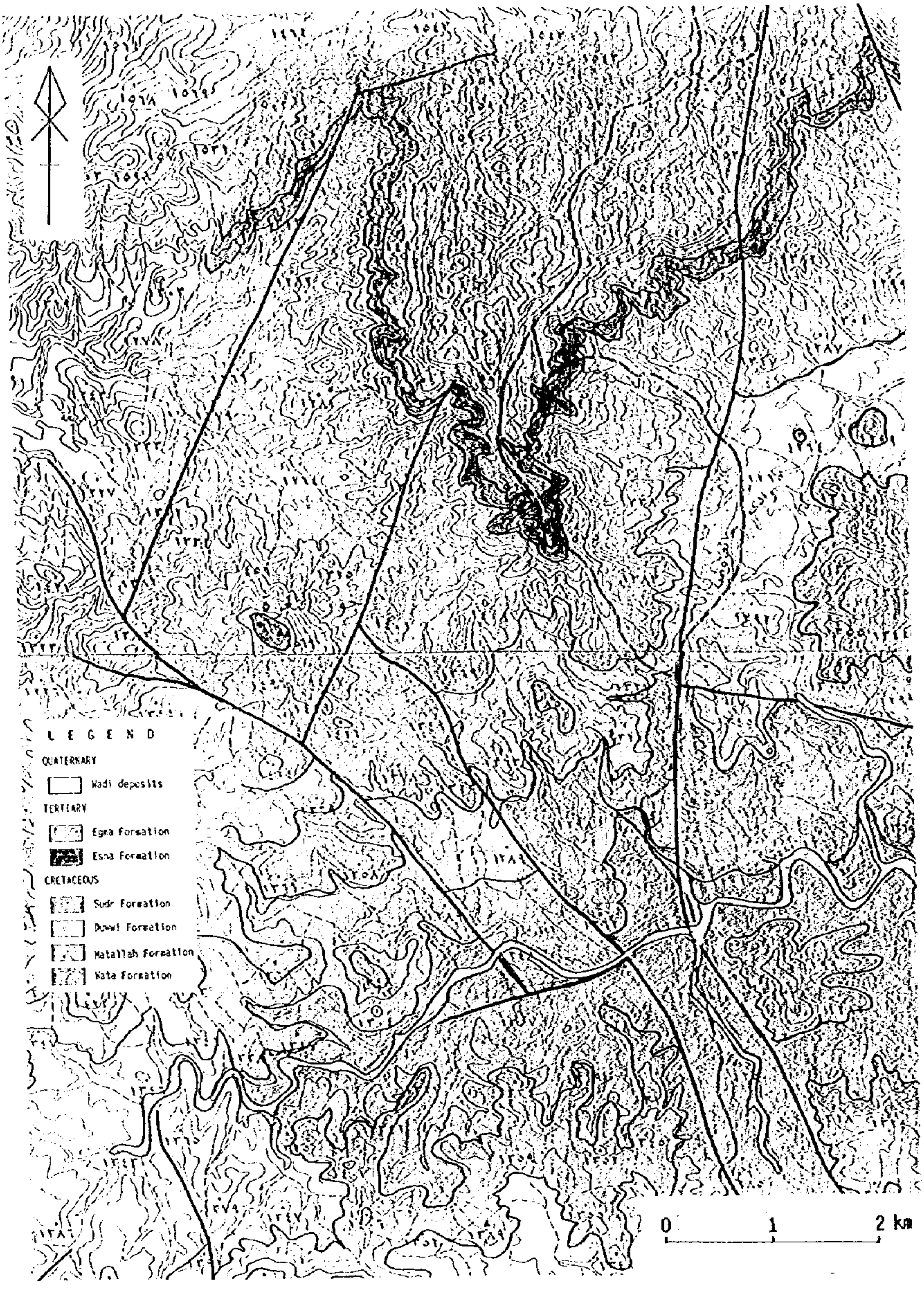

Fig.5.4-6. Geological Map (Ras El Gineina Area)

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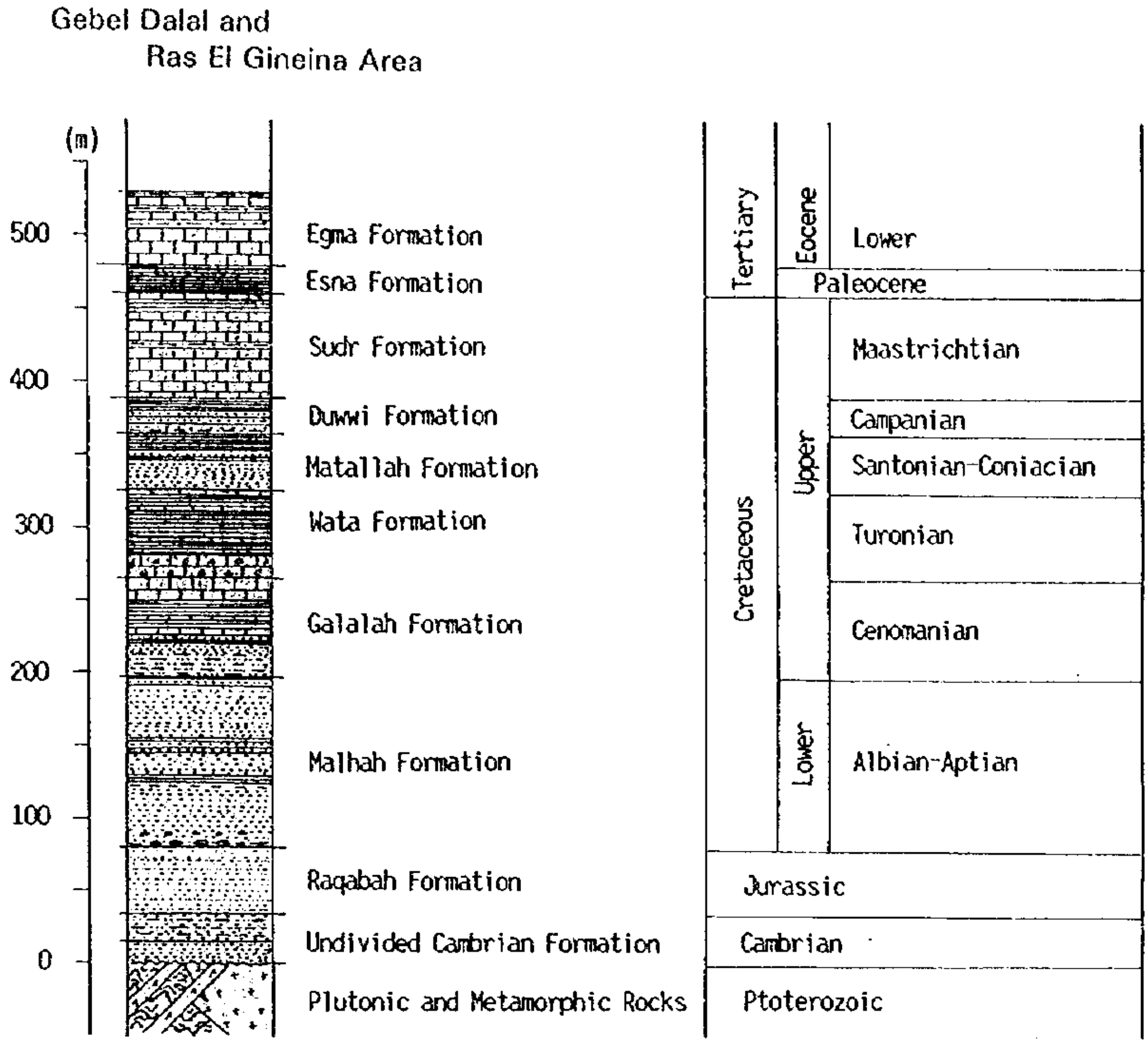

Fig.5.4-7 Geologic Columnar Section (Gebel Dalal and Ras El Gineina Area)

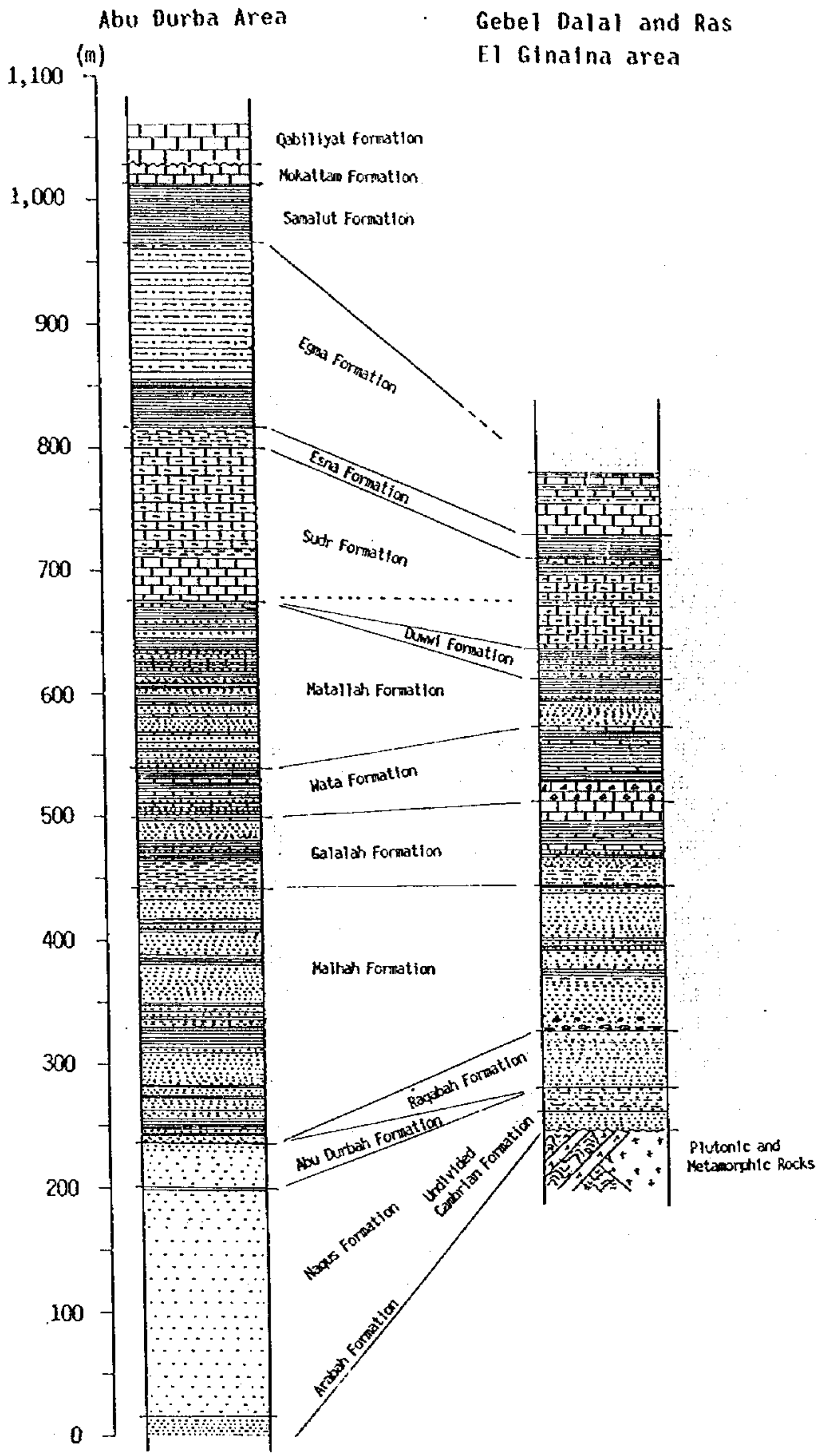

Fig.5.4-8 Correlation of Geologic Columnar Sections

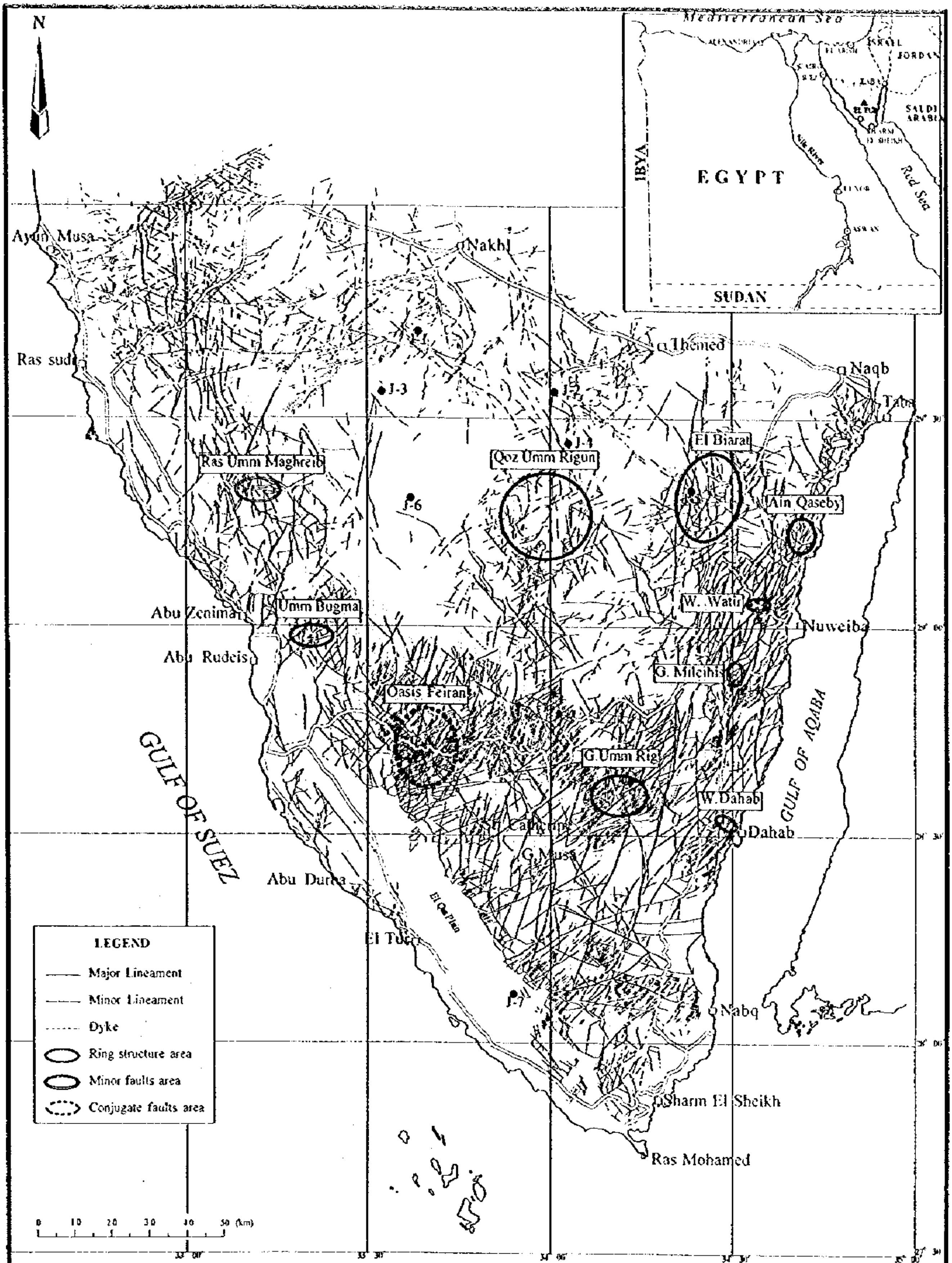

Fig. 5.5-1 Geological Structure

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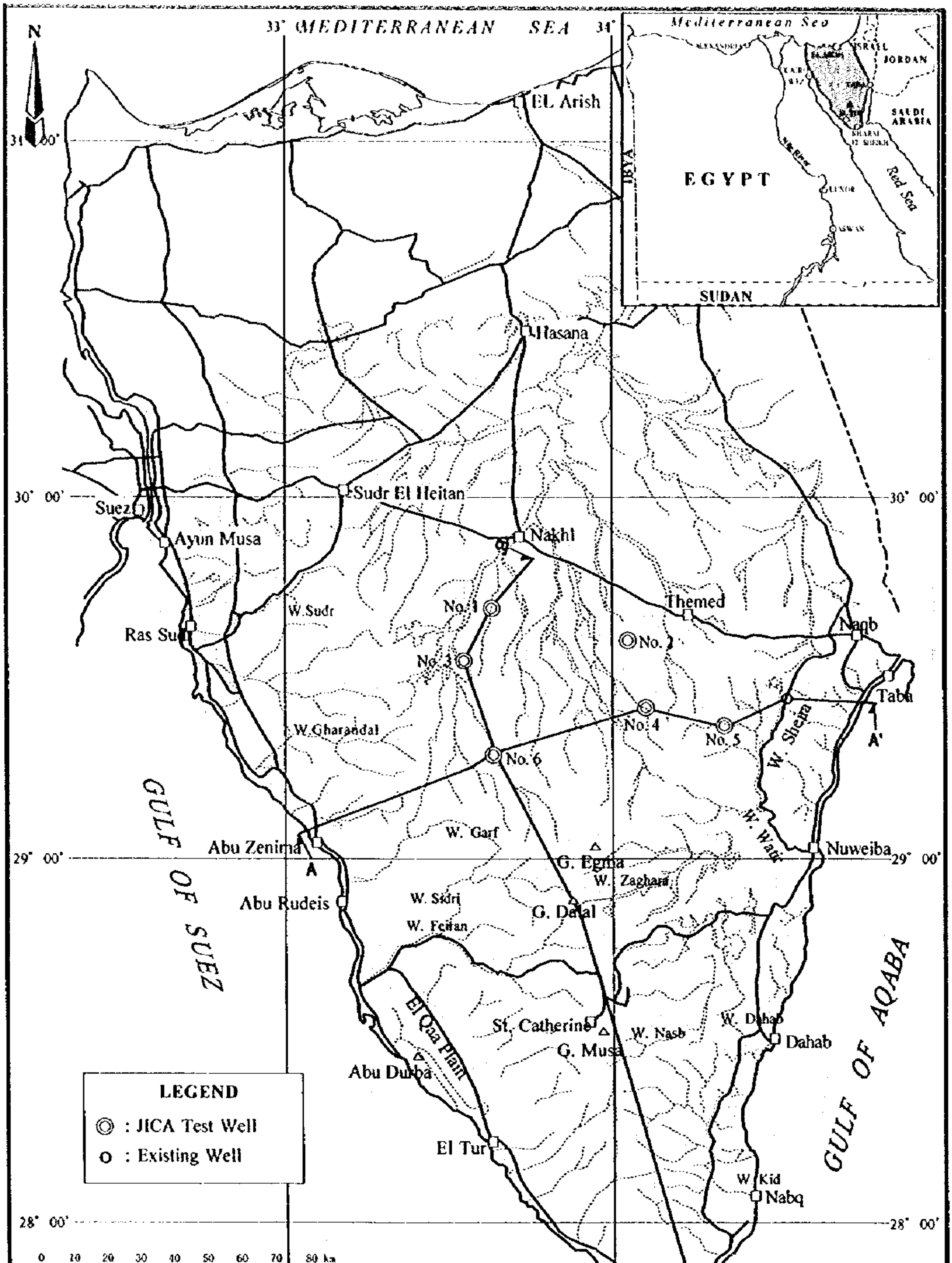

Fig. 5.5-2 Location Map of Geological Cross Section

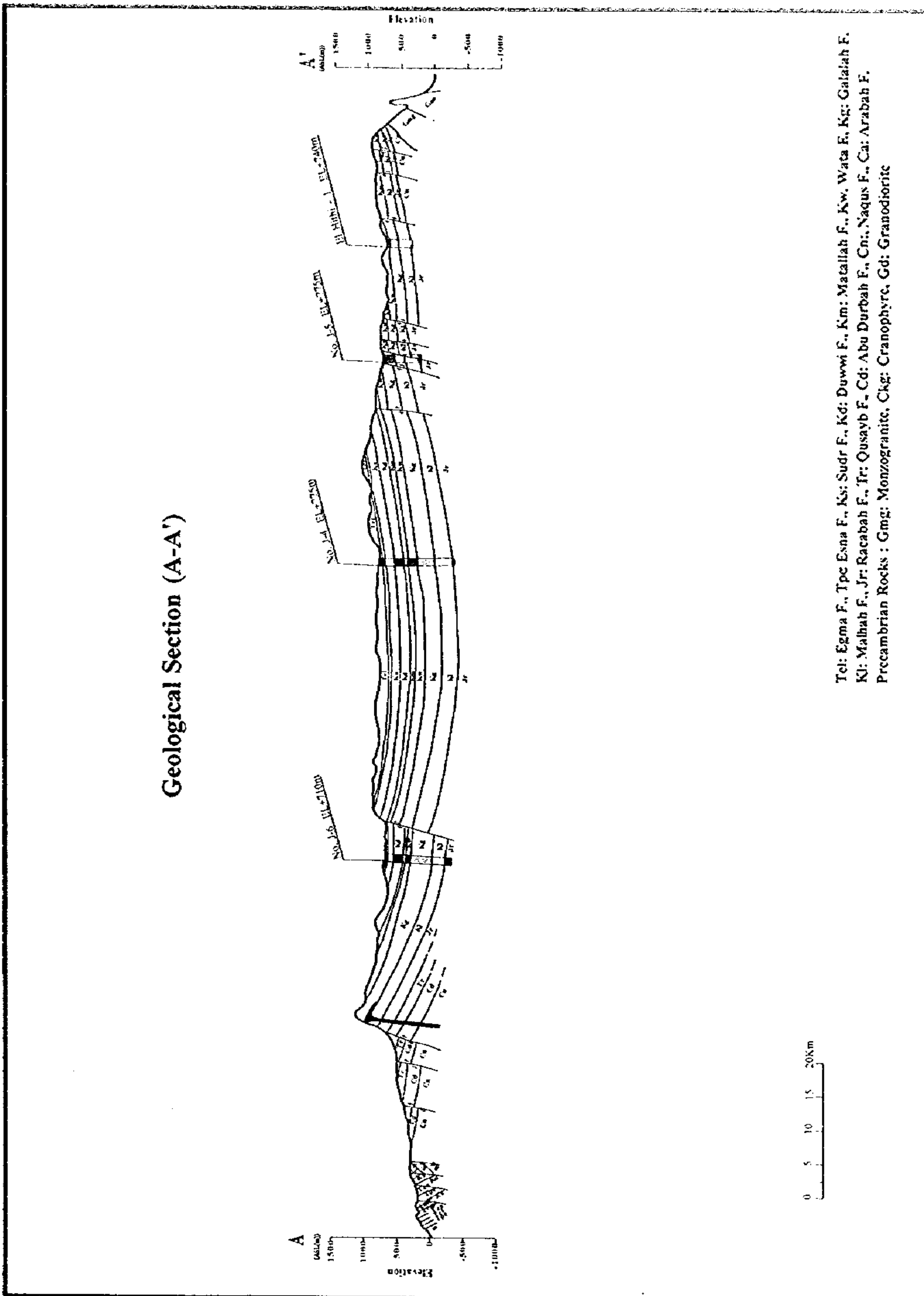

Fig. 5.5-3 Geological Cross Section A-A'

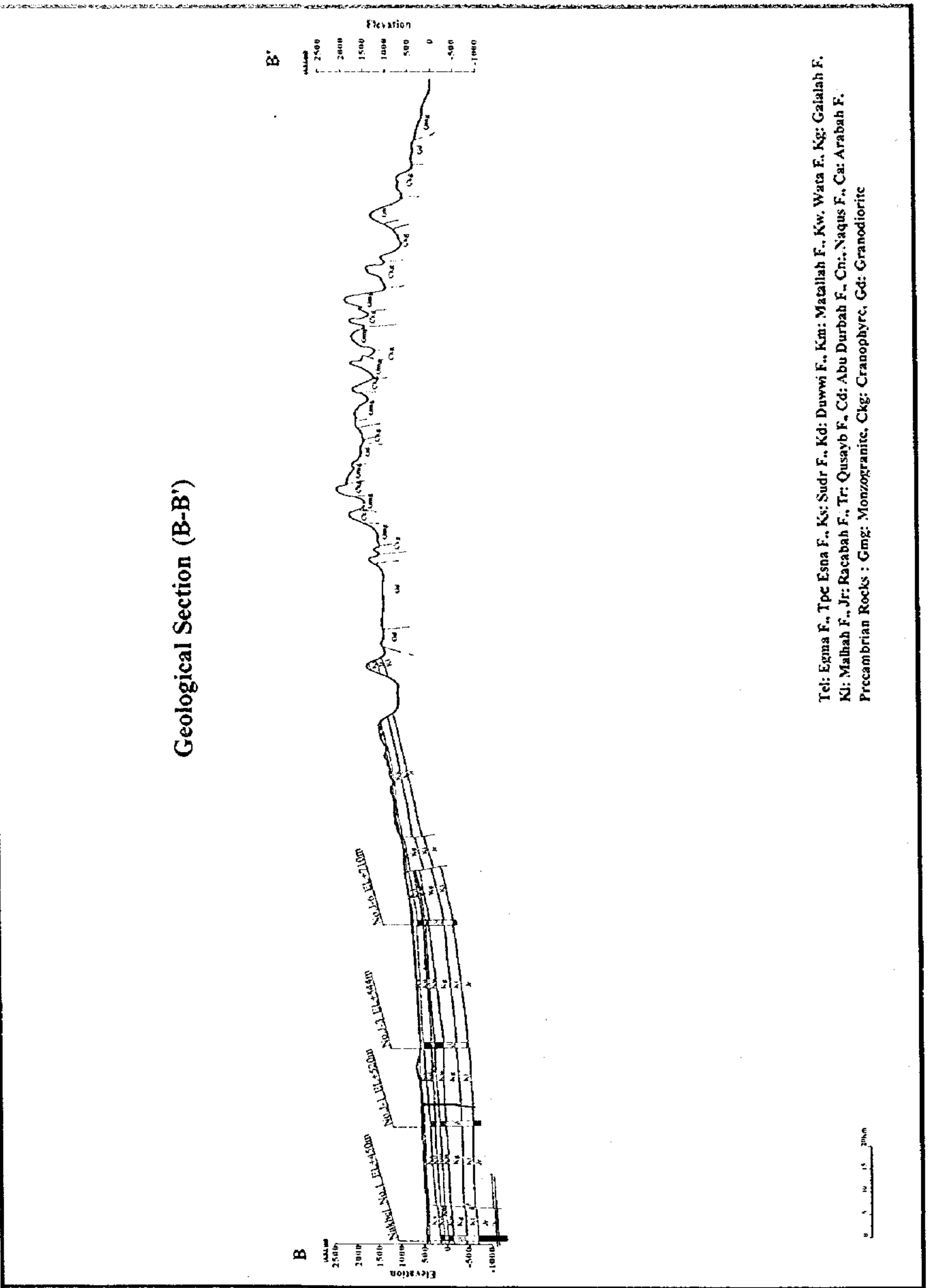

Fig. 5.5-4 Geological cross Section B - B'