3.5 Lower Cretaceous Aquifer

3.5.1 General Features

1) General Features

The Lower Cretaceous Malhah Formation overlies the Jurassic Formation and is overlain by the Upper Cretaceous Formations. The Lower Cretaceous is represented by quartzose sandstone and shale. The sandstone forms aquifer and it is the most prospective aquifer in the Study Area. Thickness of the Lower Cretaceous is about from 200 m to 300 m although it changes from place to place. The most significant aquifer occurs in the quartzose sandstone and its thickness is generally more than 100 m.

The Lower Cretaceous Sandstone has been considered as the most prospective aquifer in Sinai, however, actual study and development have been continued mainly in the marginal area of the Sandstone such as Wadi Gharandal, Wadi Feiran and Wadi Watir (including W. Sheira). Therefore, the area on the Egma and El Tih Plateaux (hereinafter referred to as "Main Block" in this report) was the vast virgin area in terms of hydrogeological information.

The Lower Cretaceous Aquifer is divided into following three (3) blocks considering the hydrogeological situation as shown in Fig. 3.5-1.

(1) Main Block: Aquifer distributed in the El Tih and Egma Plateau except Wadi Sheira area.

(2) Sheira Block: Aquifer distributed in the Wadi Sheira and the upstream of the Wadi Watir hydrogeologically isolating from the Main Block.

(3) Feiran Block: Aquifer distributed in the downstream area of the Wadi Feiran without any hydrogeological connection with other blocks.

In addition, (4) Gharandal Sub Block was identified in the Wadi Gharandal area with hydrogeological connection with the Main Block.

3.5.2 Well Inventory for Lower Cretaceous Aquifer

Wells reached the Lower Cretaceous are shown in Table 3.5-1. In addition, oil exploratory wells were drilled in South Sinai as illustrated in Fig. 3.5-2. Among them, eight (8) wells penetrated to the bottom of the Lower Cretaceous as shown below.

Well Name	Coordination		Well Name	Coordination	
	Lat.	Long.		Lat.	Long.
No.J-1*	29° 42'31"	33° 39'08"	Gharandal-3	29° 20'03"	33° 11'31"
No.J-4*	29° 26'21"	34° 02'56"	Ayun Musa-1	29° 53'09"	32° 38'58"
No.J-5*	29° 20'18"	34° 22'41"	Ayun Musa-2	29° 53'08"	32° 40'20"
No.J-6*	29° 19'40"	33° 36'48"	Abu Hamth No.1	29° 57'57"	33° 38'47"
Sheira-1	29° 29'04"	34° 35'38"	El Hamra No.1	29° 58'18"	32° 54'02"
Feiran-1	28° 47'12"	33° 25'52"	Ayun Musa No.14	29° 51'30"	32° 42'30"
Feiran-2	28° 46'45"	33° 24'35"	Wa"di Baba Well	29° 00'??"	33° 13'30"
Feiran-5	28° 47'18"	33° 24'24"	Nakhel-1	29° 55'45"	33° 42'41"

* : JICA Wells

3.5.3 Supplementary Geological Survey

Geophysical survey by Schlumberger method was executed in the Main Block. Furthermore, six (6) test wells were drilled by the Study Team to grasp the hydrogeological characteristics of the Lower Cretaceous Aquifer. Details of the surveys are presented in Chapter V and Chapter VI respectively in the Supporting Report.

The geology of the Study Area is classified into seven (7) layers in terms of apparent resistivity as shown below.

Layer	Resistivity Rang (ohm-m)	Estimated Lithology	Geological Interpretation
1	5 - 71	sand and gravel, limestone	Quaternary Deposits (Q) Egma Formation (Te)
2	13	shale	Esna Formation (Tp)
3	27 - 37	chalk, marl	Sudr Formation (Ks)
4	4 - 92	limestone	Matallah Formation (Km)
5	4 - 19 (rarely 98)	limestone, shale, sandstone	Wata Formation (Kw) Galala Formation (Kg)
6	36 - 90	sandstone, shale	Malhah Formation (Kml)
7	180 - 4100<	sandstone, basement rocks	Pre-Cretaceous

Drilling log of Test Wells are shown in Fig. 3.5-3 (1) to 3.5-3 (6). Drilling results are summarized as follows.

	J-1	J-2	J-3	J-4	J-5	J-6
Elevation (mASL)	520	657	544	745	740	710
Drilling Depth (m)	1,250	1,200	1,150	1,130	555	900
Top of L.C. (mBGL)	890	1,050	771	810	310	610
Bottom of L.C. (mBGL)	1,110	1,200+	1,000+	1,108	500	790
Thickness (m)	220	150+	229+	261	190	180

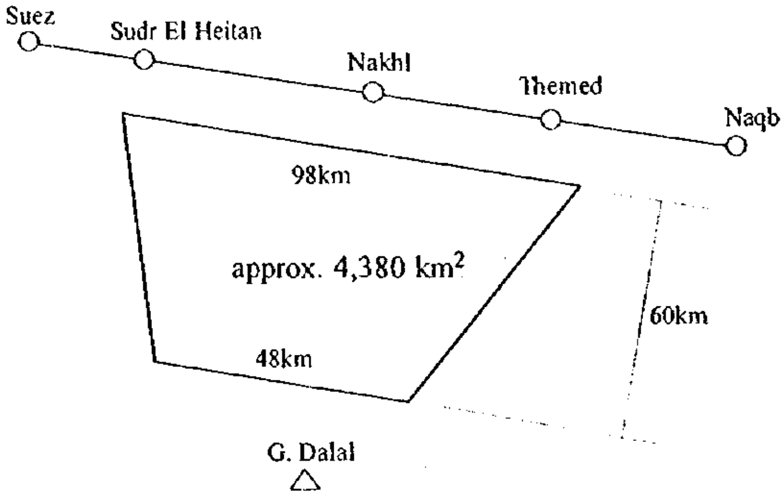
Pumping Test by submersible pump was carried out to evaluate hydrogeological characteristics of the aquifer. Results are shown below.

Well Name	S.W.L (mBGL)	D.W.L (mBGL)	Discharge Rate (m^3/h)	Specific Capacity (l/s/m)	Transmissivity (m^2/day)	TDS (mg/l)
JICA 1	312.8	317.9	39.6	2.2	950.4	1,206
JICA 2	424.0	443.4	23.0	0.3	109.2	1,182
JICA 3	284.4	290.38	35.6	1.6	470.3	470
JICA 4	501.0	501.2	10.6	2.5	19.9	1,047
JICA 6	438.5	439.3	9.6	3.7	114.8	1,520

3.5.4 Configuration of Aquifer

1) Main Block

The north side of the Study Area is almost bounded by the National Highway (Suez-Naqb Road). Shape of the Main Block is trapezoidal, of which longer side is about 100 km long and shorter side is about 50 km long and distance of both side is 60 km long as shown below.



< Schematic Area of Main Block >

The area of the Main Block is roughly estimated as 4,380 km^2.

The Lower Cretaceous Aquifer was figured out as follows;

- Top of Lower Cretaceous (Fig. 3.5-4)
- Bottom of Lower Cretaceous (Fig. 3.5-5)
- Isopach of Lower Cretaceous Aquifer (Fig. 3.5-6)

The Lower Cretaceous in the Main Block generally increases its thickness toward the north: It is 180 m thick at Well No. J-6 and more than 261 m at Well No. J-3.

2) Sheira Block

The Wadi Sheira area, in the southeast of Naqb, is also underlain by the Lower Cretaceous Formation. The formation is cut by faults in both eastern and western sides, therefore, the area forms a "graben". Therefore, the Sheira Block is hydrogeologically independent from other blocks. It is approximately 36 km long and 17 km width. The area of the Sheira Block is about 600 km^2.

3) Feiran Block

The Lower Cretaceous Aquifer is distributed in the down stream of the Wadi Feiran, covering about 160 km^2 of area. Thickness is in a range between 203 to 286 m.

The Feiran Block is hydrogeologically separated from other blocks as well as the Sheira Block.

3.5.5 Groundwater Level

In the Main Block of the Lower Cretaceous Aquifer, static water level (piezometric head) was confirmed by five (5) JICA Wells for the first time in the Main Block; they were. J-1, J-2, J-3, J-4 and J-6.

Groundwater level was shown in Fig. 3.5-7 (1) and 3.5-7 (2). Groundwater gently flows down from south to north (from the fringe of Egma Plateau to Nakhl). Confirmed water level is 272 mASL at J-6 and 244 mASL at J-4, that are located in most southern locations. In northern part of the Study area, it is 203 mASL at J-1 and 233 mASL at J-2. At Nakhl area it ranges from 190 mASL to 208 mASL.

Gradient of water level is calculated as below.

Well	SWL (mASL)	Distance (km)	gradient
No. J-6	272	0	-
No. J-3	260	27.5	0.4/1000
No. J-1	203	20.0	2.9/1000
Nakhl-5	190	31.0	0.4/1000

Groundwater gradient from the south to the north is generally less than 1/1000. Significant change of gradient appears between J-3 and J-1. Groundwater gradient is 2.9/1000 in this section. This is rather large compared with other sections. Geological map indicates that there is a series of basaltic dykes between J-3 and J-1 running E-W direction. These dykes act as a kind of dam because they are generally massive so that groundwater flow is prevent to across them.

This phenomena was also confirmed in the section between J-6 and Gharandal-1 where another series of basaltic dykes intrude in NW-SE direction.

Well	SWL	distance	gradient
No. J-6	272.0	0	-
Gharandal-1	191.8	45	1.8/1000

Gradient is 1.8/1000 in this section, while it is 0.4/1000 in the Main Block.

The Wadi Gharandal area is in the western marginal area of the Main Block. Static water level here is 78 mBGL and 192 mASL. Drawdown is small, 9.6 m.

The Wadi Sheira and the Wadi Watir (Sheira Block) is isolated from the Main Block from geological and hydrological point of view (Fig. 3.5-1). The Sheira Block is tectonically subsided by two (2) faults running in the N-S direction. On the other hand, the Basement Rocks are uplifted between the Main Block and the Sheira Block. Water level in the Sheira Block is more than 400 mASL. In contrary to this, water level in the eastern side of Main Block is less than 270 mASL. There is a significant gap of water level between both areas.

In the Sheira Block, groundwater level is 467 mASL at Sheira 2 and 421 mASL at Sheira 3. Groundwater flows gently toward the south with 1.5/1000 of gradient.

The Wadi Feiran area is isolated from other blocks of the Lower Cretaceous. Water level is from 38 m to 67 mBGL and 203 m to 286 mASL. Drawdown during extraction is generally small, in a range between 5.9 m to 16.5 m.

It was the first attempt to conduct test well drilling for the Lower Cretaceous Aquifer on El Tih Plateau and to install Automatic Groundwater Level Monitoring Equipment for long term monitoring. Groundwater level is measured every an hour. This monitoring result has very important and interesting aspect because El Tih Plateau is virgin area for the aquifer study from the hydrogeological point of view. Furthermore, there is no withdrawal from the aquifer not like Nakhl area. This means that it is possible to monitor the natural condition of groundwater movement in the aquifer.

Fig. 3.5-8 shows fluctuation of the groundwater table at J-1 and J-3. J-3 can be representative of monitoring results because of its whole yearlong duration. About 20cm of natural drawdown was clearly recorded in the period between November 1997 to November 1998. On the other hand, no change of groundwater fluctuation was observed at J-1 during two-month and half. It may be affected by hydrogeological structures such as intrusion of dykes and faults.

<Correction of water level at Nakhl area in North Sinai: Previous Project>

Groundwater level at Nakhl area in the previous Project were corrected on the basis of data analysis and field survey. During this survey, the Study Team got accurate elevation and coordination of reliable wells around Nakhl from hydrological point of view. As groundwater is developed at Nakhl area after the completion of the previous Project, reliable data were accumulated at present by WRRI. According to the results, static water level is in a range from 190 mASL to 208 mASL. There is about 60 m of difference in the data between the oil exploratory wells and newly constructed production wells.

In the construction of North Sinai Hydrogeological Maps in 1992, groundwater level data at Nakhl area were derived from oil exploratory wells because no other data were available at that time. They were as follows:

Well Name	SWL (mASL)
Darag-1	263
Nakhl-1	269
Nakhl-2	260

Previous data were carefully reviewed in the Study to solve this problem. As the result, it was concluded that data from oil exploratory wells were less reliable compared with the wells supervised by WRRI, although oil exploratory reached the Lower Cretaceous Formation.

Furthermore reliable data is available at present, those data from oil exploratory wells were omitted in the construction of Hydrogeological Maps.

3.5.6 Groundwater Quality

TDS of the Lower Cretaceous Aquifer is presented in Fig. 3.5-9. TDS of each block is summarized as follows.

Location	Measured TDS Value (mg/lit.)			Remarks (Well Name)
	Lowest	Highest	Average	
Main Block (El Tih Plateau)	470	1,520	997	JICA-1 to 6
Gharandal Sub-Block	-	-	1,822	Gharandal-1
Nakhl and Themed area	1,536	1,768	1,667	Nakhl-1 to 8
Sheira Block	1,080	1,562	1,173	Sheira-1, 3, 4
Feiran Block	784	840	812	Feiran-1, 2

TDS values satisfy the Drinking Water Quality Standard in the Main Block, the Sheira Block and the Feiran block. Although TDS do not satisfy the standard in other blocks, it is suitable for agricultural use.

The data of chemical analysis are plotted in a piper diagram as shown in Fig. 3.5-10. Most data are plotted in the field of Noncarbonate hardness type.

Water type and TDS are summarized as the table below and are shown in Fig. 3.5-11.

Sr. No.	Area	Code No.	Well Name	Water Type	TDS (mg/l)
41	El Tih	45BB-001	JICA-1	$CaSO_4$	1,206
42	El Tih	55CA-001	JICA-2	$NaCl$	1,182
43	El Tih	45CA-001	JICA-3	Na_2SO_4	470
44	El Tih	55EA-001	JICA-4	Na_2SO_4	1,047
46	El Tih	46AB-001	JICA-6	$NaCl$	1,520
27	Nakhl	44ED-001	Nakhl-1	$NaCl$	1,690
28	Nakhl	44DC-001	Nakhl-2	$CaSO_4$	1,630
30	Nakhl	44DD-001	Nakhl-4	Na_2SO_4	1,536
31	Nakhl	44DD-002	Nakhl-5	$NaCl$	1,614
32	Nakhl	44DD-003	Nakhl-6	$NaCl$	1,634
33	Nakhl	44EC-001	Nakhl-7	$NaCl$	1,732
34	Nakhl	55BD-002	Nakhl-8	$NaCl$	1,728
35	Themed	55BD-002	Themed-1	$NaCl$	1,728
3	Sheira	65DA-001	Sheira-1	$CaSO_4$	1,562
9	W. Watir	56BE-001	Sheira-3	$CaSO_4$	1,080
10	W. Watir	56BE-002	Sheira-4	Na_2SO_4	1,068
14	W. Feiran	37BE-001	Feiran-1	$NaCl$	784
15	W. Feiran	37BE-002	Feiran-2	$NaCl$	840
25	Ayun Musa	24EC-011	Ayun Musa-1	$MgSO_4$	2,599

The most predominant water type is $NaCl$ type. It is distributed in the Nakhl and Themed area and in the Wadi Feiran. Following to $NaCl$ type, Na_2SO_4 and $CaSO_4$ types are distributed in the El Tih Plateau.

3.5.7 Groundwater Age

In order to analyze the recharging mechanism, stable isotope and radio-isotope were analyzed existing wells and JICA wells, eight (8) wells in table. C-14 ages are shown in Fig. 3.5-12. C-14 ages including North Sinai are summarized in the following table.

Well No.	C-14 Age (y.BP)	Remarks
J No.16 El Bruk	29,690 ± 1,190	Gak*-15769
J No.19 Arif El Naga	34,780 <	Gak*-16033
Sheira-1	22,350 ± 2,160	Gak*-16032
Ayun Musa	30,900 <	Issar 1981
Nakhl-5	27,000 ± 2,000	AEA**, Egypt
Sudr El Heitan	26,000 ± 2,000	AEA**, Egypt
Sheira-1(Km83)	22,000 ± 2,000	AEA**, Egypt
J-1	20,000 ± 2,000	AEA**, Egypt
J-2	23,200 ± 2,000	AEA**, Egypt
J-3	21,500 ± 2,000	AEA**, Egypt
J-4	18,000 ± 2,000	AEA**, Egypt
J-6	14,000 ± 2,000	AEA**, Egypt

* Gakusyuin University, Japan

** Atomic Energy Authority, National Center for Nuclear Safety and Radiation Control, Egypt

In South Sinai (including adjacent area), C-14 age of groundwater ranges from 21,500 y.BP at J-3 to 27,000 y.BP at Nakhl-5. The oldest age appears at Ayun Musa spring of which age is more than 30,900 y.BP. In North Sinai, the age becomes more older: it is 29,690 y.BP at J-15 (El Bruk-1) and more than 34,780 y.BP at J-19 (Araif El Naga).

These data indicate that groundwater in the Lower Cretaceous Sandstone was recharged more than 20,000 years ago when the area had received more rainfall than present.

Based on the above data, velocity of groundwater flow in the Lower Cretaceous Aquifer is estimated as shown in the tables below.

Location	C-14 Age (y.BP)	Distance (km)	Accumulated Distance (km)	Velocity (m/year)	Velocity (cm/day)
Outcrop		0.0	0.0		
- J-3	21,500	42.5	42.5	1.98	0.54
- Nakhl-5	27,000	50.0	92.5	9.09	2.49
- J No.16 El Bruk	29,690	20.0	112.5	7.43	2.04

Location	C-14 Age (y.BP)	Distance (km)	Accumulated Distance (km)	Velocity (m/year)	Velocity (cm/day)
Outcrop		0.0	0.0		
- J-2	23,200	75.0	42.5	3.23	0.89
- J No.19 Arif El Naga	34,780	85.0	127.5	7.34	2.01

It is the most striking feature of above assumption that the velocity of groundwater shows much difference between in South Sinai and in North Sinai. In the western part of the Main Block, the velocity of groundwater is 0.5 cm/day between outcrop (recharge area in the past) and Well J-3, while its 2.5 cm/day between J-3 and Nakhl 1-5.

After Nakhl-5, it is 2 cm/day. In the eastern part of it, the velocity is 0.9 cm/day between outcrop and J-2. However, it becomes fast, 2 cm/day in the section from J-2 to J No. 19 Araif El Naga in North Sinai.

3.5.8 Hydrogeological Characteristics of Aquifer

The Lower Cretaceous is generally composed of quartzose sandstone facies, shaly facies, and intercalation of sandstone and shale. The Jurassic Formation also consists of sandstone and shale. In most case, both formations are separated by shaly facies. Its thickness ranges from 15 m to 40 m in the Test Wells.

1) Main Block

The Lower Cretaceous Formation and underlying formations crop out in the southern fringe of the Egma Plateau along as the Wadis Zalaga and the Wadi Garf as shown in Fig. 3.5-13. Eroded surface of both wadis reached the horizon of the Jurassic/Paleozoic. Therefore, elevation of the Lower Cretaceous is higher than that of the Wadi Deposits. The Wadis Zalaga is one of the active wadis, therefore, the Wadi Zaghara area is supposed to be main recharge area to Pre-Quaternary aquifers as well as the Wadi Garf area. As shown in fig 3.5-13, the Quaternary Wadi Deposits directly overlies the Jurassic Formation in most places in the Wadi Zaghara and its tributaries. The Lower Cretaceous Sandstone crops out along the wadi, mainly at the lower part of the cliff. The channel of the wadi is filled by soft silty sediments of the Quaternary and it is underlain mainly by the Jurassic Formation. The Lower Cretaceous Sandstone has a few chances to contact with the Quaternary Wadi Deposits.

The hydrogeological features described above suggest that the Lower Cretaceous Sandstone cannot be recharged by the flood water, while the Jurassic Formation is directly recharged by the flood water occurred in the wadi area.

As results of discussion above, although the Lower Cretaceous cannot receive a direct recharge from flood water, there is a possibility that the Lower Cretaceous has a chance to be recharged from other sandstone in the southern area of its distribution after other sandstone is saturated by groundwater.

Contrary to this situation, no groundwater leakage can be recognized between the Lower Cretaceous Sandstone and other sandstone except faulted areas. This is supported by the water quality data. TDS value is generally less than 1,500 mg/l in the Lower Cretaceous Sandstone, while that of the Jurassic and the Cambrian Formations are more than 5,000 mg/l. Furthermore, logging data of Test wells indicate that TDS is much higher in the Jurassic Aquifer compared with the Lower Cretaceous Aquifer.

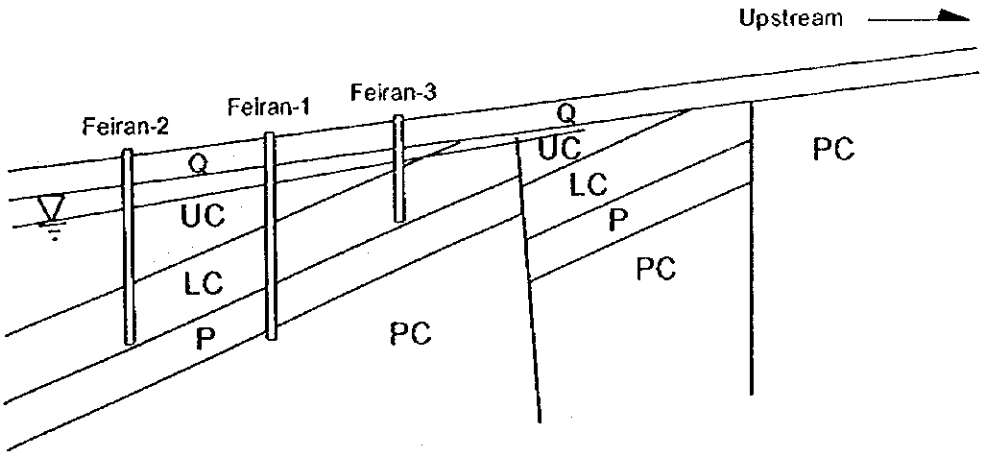
2) Sheira Block

The Sheira Block is basically formed by faults and it is hydrogeologically independent from the other blocks. A geological profile of the Sheira Black is shown in Fig. 3.5-14. The Lower Cretaceous Formation is completely overlain by younger formations. Groundwater age by C-14 is 22,360 y.BP and 22,000 y.BP. It suggests that groundwater was recharged in ancient age. Extremely low content of Tritium (0.1 T.U) means that no or scarce groundwater is recharged to the aquifer.

Contrary to the Main Block, groundwater table of this Block inclines to the south with 1.2/1000 of gradient. The south of the Block contacts with the Precambrian Basement Rocks in which Ain Furtaga Spring occurs about 17 km south from the southern end of the Block. Although, it rains less than only 20mm/year in the area, Ain Furtaga spring yields groundwater continuously. Considering the above situation, groundwater in the Sheira Block may supplies groundwater to Ain Furtaga in some extent through fissures and faults developed in the Basement Rocks in addition to in the area, although Ain Furtaga will receive recharge from the Basement Rocks..

3) Feiran Block

The Feiran Block is distributed in a narrow area in the downstream of the Wadi Feiran. The Block contacts with the Precambrian Basement Rocks in the east and cut by faults in the west. It seems that groundwater in the Feiran Block is stored in a small area. It size is estimated as about 90 km^2 (= 6 km x 15 km). In some part, the Block is directly overlain by the Quaternary Wadi Deposits. A schematic section is presented below;



(Schematic Section of Wadi Feiran)

The Precambrian Rocks were densely intruded by dolerite dykes elongated in mainly NNE-SSW direction. Therefore, the Precambrian Rocks can act as conduit of groundwater which is infiltrated to the fissures and joints developed in the rocks. Hydrogeological situation above will make the Lower Cretaceous Formation easy to be recharged through both the Precambrian Rocks and the Quaternary Wadi Deposits.

4) Differentiation of Groundwater Zone

On the basis of analysis on groundwater level and gradient of the aquifer, three (3) groundwater zone were differentiated as shown in Fig. 3.5-15. Schematic sections of groundwater are presented as Fig. 3.5-16.

Based on the figures above, three (3) aquifer zone in the Main Block were differentiated as follows;

(1) Dry Zone: Till about 16 to 24 km north from the outcrop at the fringe of El Tih Plateau (hereinafter boundary with unconfined zone is referred to as "groundwater front").

(2) Unconfined Zone: Till 6 to 12 km north from the groundwater front (hereinafter boundary with unconfined zone is referred to as "confined front")

(3) Confined Zone: All the area of Main Block except dry zone and unconfined zone. It distributes in the north of confined front.

5) Difference of Groundwater Quality between the Lower Cretaceous and other Aquifers

TDS value of the Lower Cretaceous Aquifer is from 470 to 1200 mg/l while that of other aquifers are generally more high.

This phenomenon could be explained by difference of recharge amount to each aquifer. Sandstone of the Lower Cretaceous and older formation were deposited in the continental margin, therefore, no saline water was generally stored in them. In the age of Upper Cretaceous, transgression caused the deposition of limestone. So far as limestone is a kind of marine deposits, it can be stated that the area was under sea water during the Upper Cretaceous age. It means that groundwater in sandstone was contaminated by saline water from the sea.

After the Egma Formation deposited in Eocene, the area was uplifted and rivers cut deep valleys eroding limestone of the Eocene and Upper Cretaceous ages. When eroded surface reached the top of the Lower Cretaceous Sandstone, it was the start of recharge to the Sandstone by flood water which was fresh water, and it ended after erosion surface reached the bottom of the Sandstone.

C-14 ages of groundwater in the Lower Cretaceous is between 14,000 y.BP and 25,000 y.BP in South Sinai. It is just around the acme of the W"urm Glacial Stage and is said that this period was rainier than the present, so called "Pluvial Stage". During this period, the Lower Cretaceous Sandstone received enough fresh water from the surface water and water quality in the Sandstone accordingly became fresh.

The Jurassic to Paleozoic Sandstone had no chance to encounter surface water until the Lower Cretaceous Formation had been completely eroded in the Wadi Zalaga and Garf areas. Thus, finish of recharge to the Lower Cretaceous aquifer means start of recharge to the older aquifers.

The Jurassic to Paleozoic sandstone was covered by the Wadi Deposits which consist of sand, gravel and silt. In the recharge area, silty material is dominant in the deposits so that recharge to the sandstone is prevented in a certain degree.

Thus it can be said that the Jurassic to Paleozoic sandstone has not received enough recharge of fresh water by surface water.

Process mentioned above caused the difference of water quality between the Lower Cretaceous and the Jurassic to the Paleozoic Formations.

3.5.9 Estimation of Groundwater Storage

Groundwater storage of the Main Block of the Lower Cretaceous is estimated based on the isopach map and profiles assuming the aquifer thickness as 60% of the total thickness of the Lower Cretaceous Formation and effective porosity as 0.15. The results are as follows.

Area	Storage (x 10^9 m^3)
Main Block	98
Sheira Block	13
Feiran Block	1.6

3.5.10 Groundwater Extraction

Groundwater in the Lower Cretaceous is used for domestic and/or irrigation water supply. Extraction rate in each area is summarized as follows.

Area	Number of Production Well	Extraction (m^3/year)	Irrigation Area (feddan)
<Main area>			
Wadi Gharandal	3	240,000	150
Sudr El Heitan	1	40,000	10
Nakhl	6	480,000	300
Themed	3	240,000	150
Sub-Total	13	1,000,000	600
Wadi Feiran	6	720,000	300
Wadi Sheira	4	360,000	150
Total	23	2,080,000	1,050

Extraction of groundwater from the Main Block is estimated as,

$$Q_{\text{Total Extraction}} = 1{,}000{,}000 \text{ m}^3\text{/year}$$

3.5.11 Groundwater Potential Area

A groundwater resources evaluation map was constructed based on the results of the Study as shown in Fig. 3.5-17. Selected evaluation criteria are groundwater quality and depth of groundwater table from the ground surface (mBGL) due to following reasons.

(1) Groundwater quality is the most important criteria for both drinking and irrigation use.

(2) Groundwater level (mBGL) controls availability of submersible pump and operation cost of extraction.

(3) Depth of aquifer from ground surface will affect construction cost of wells. However so far as the Lower Cretaceous is concerned, necessary drilling depth is around 1000 m. Even if there is a difference of depth, it is within 100 m. Therefore, this factor is not selected to evaluate the sandstone of the Lower Cretaceous.

(4) Thickness of aquifer is not selected. Although it is generally important factor in selection of well locations, it has less importance to evaluate the Lower Cretaceous Aquifer. Because the aquifer is generally more than 100 m thick in the entire area. It is enough to install screen in the well. In this case, difference of aquifer thickness will affect less to yield of wells.

(5) Aquifer constants such as permeability and transmissivity are also important factors that control yield of wells. In the sandstone of the Lower Cretaceous, cross bedding and lamination are well recognized. Therefore, grain size distribution

frequently changes in the section. On the other hand, yield of wells during pumping test was more than 30 m^3/hour. Large difference among wells are not recognized. In general, facies of the sandstone changes so frequently because it is of the continental margin deposit. It will not allow to make zoning of aquifer constants. Heterogeneity of aquifer is reflected in water quality. Therefore, it is possible to take this factor into consideration as water quality. Thus this factor is not selected.

Evaluation table is shown below;

TDS (mg/l)	Groundwater Depth (mBGL)	i	ii	iii	iv	-
		Less than 100	100-200	200-300	300-400	More than 400
S	Less than 1000	Si	Sii	Siii	Siv	-
A	1000-1500	Ai	Aii	Aiii	Aiv	-
B	1500-2000	Bi	Bii	Biii	Biv	-
C	2000-2500	Ci	Cii	Ciii	Civ	-
D	More than 2500	Di	Dii	Diii	Div	-

Better

Worse

Better Worse

Based on the criteria above, groundwater potential areas are estimated. At present the maximum capacity of submersible pump is of 400 m head.

(1) Condition 1; TDS: less than 1500 mg/l. Groundwater level: less than 350 mBGL. This area is suitable for drinking water supply.

Prospective area is a triangular area wide spread in the southward from Nakhl of which area is about 1,050 km^2 as shown in Fig. 3.5-18.

(2) Condition 2; TDS: less than 3000 mg/l, Groundwater level: less than 350 mBGL. This area is suitable for irrigation water supply.

Prospective area is a triangular area wide spread in the south of Nakhl of which area is about 2,500 km^2 as shown in Fig. 3.5-19.

Table 3.5-1 Hydrogeological Data (Lower Cretaceous)

Sr. No.	Well Identification		Elev. (mASL)	S.W.L. (mBGL)	S.W.L. (mASL)	D.W.L. (mBGL)	D.W.L. (mASL)	TDS (mg/l)	Discharge Rate (m^3/h)	Specific Capacity (l/s/m)	Trans -missivity (m^2/day)
	WRRI Code No.	Well Name									
	Pre- Quaternary Cased Well										
3	65DA-001	Sheira 1	820	353.00	467.00			1562	22		
4	65DA-002	Sheira 2	825	85.00	740.00			1100	5		
5	65CA-001	Sheira 1(K83)	835	349.45	485.55	353.32	481.68	1200	29.5	2.12	539.9
6	65CA-002	Sheira 2 (K82)	810	347.00	463.00			1080	1200		
8	65CA-004	El Hithi 2 (K70.5)	720	93.00	627.00			1050	72		
9	56BE-001	Sheira No.3 (K52)	562	141.10	420.90	147.58	414.42	1080	50	2.14	156.8
10	56BE-002	Sheira No.4 (K53)	579	149.30	429.70	159.75	419.25	1068	46.1	1.23	168.7
14	37BE-001	Feiran 1	280	37.74	242.26	54.20	225.80	784	50.41	0.85	113.5
15	37BE-002	Feiran 2	280	57.30	222.70	63.18	216.82	840	60.4	2.85	312
16	37BE-003	Feiran 3	325	39.39	285.61	49.70	275.30	850	74.9	2.02	281.16
17	37BE-004	Feiran 4	270	66.87	203.13	74.51	195.49	1152	56.6	2.06	414.72
18	37BE-005	Feiran 5	280	37.39	242.61	48.85	231.15	972	66	1.60	293.76
19	37BE-006	Feiran 6	285	40.05	244.95	46.75	238.25	832	72	2.99	50.11
22	36CC-001	Wadi Gharandal 1	270	78.20	191.80	87.76	182.24	1822	50	1.45	194
25	24EC-001	Ayun Musa 1	4	11.00	-7.00			2599	20	1.9m^3/h/m	
26	24CE-002	Ayun Musa 2	26	14.00	12.00			3860	70	3.2m^3/h/m	
27	44ED-001	Nakhl 1	435	254.47	180.53	258.87	176.13	1690	41.9	1.73	460
28	44DC-001	Nakhl 2	420	236.23	183.77	237.45	182.55	1630	40.9	3.37	665.3
30	44DD-001	Nakhl 4	380	200.58	179.42	201.41	178.59	1536	40.9	3.18	561.35
31	44DD-002	Nakhl 5	380	198.47	181.53	202.53	177.47	1614	35.68	2.44	1164.5
33	44EC-001	Nakhl 7	425	227.50	197.50	232.72	192.28	1732	44.77	2.38	468.2
34	55BD-001	Nakhl 8 (Themed 2)	600	376.84	223.16	387.06	212.94	1728	40.45	1.10	592.2
35	55BD-002	El Themed 1	615	382.35	232.65	383.17	231.83	1768	18.9	6.40	1016.6
36	34CD-001	Sudr El Hitan	443	270.00	173.00	300.00	143.00	1656	20	0.19	
41	45BB-001	JICA 1	520	312.77	207.23	317.87	202.13	1206	39.6	2.15	950.4
42	55CA-001	JICA 2	657	423.96	233.04	443.37	213.63	1182	22.95	0.33	109.21
43	45CA-001	JICA 3	544	284.35	259.65	6.03	537.97	470	35.55	1.64	470.3
44	55EA-001	JICA 4	775	501.00	274.00	501.18	273.82	1047	10.56	2.48	19.9
45	56AB-001	JICA 5	740								
46	46AB-001	JICA 6	710	438.53	271.47	439.26	270.74	1520	9.62	3.66	114.79
	Pre-Quaternary Spring										
1	24EC-011	Ayun Musa	10					2559			

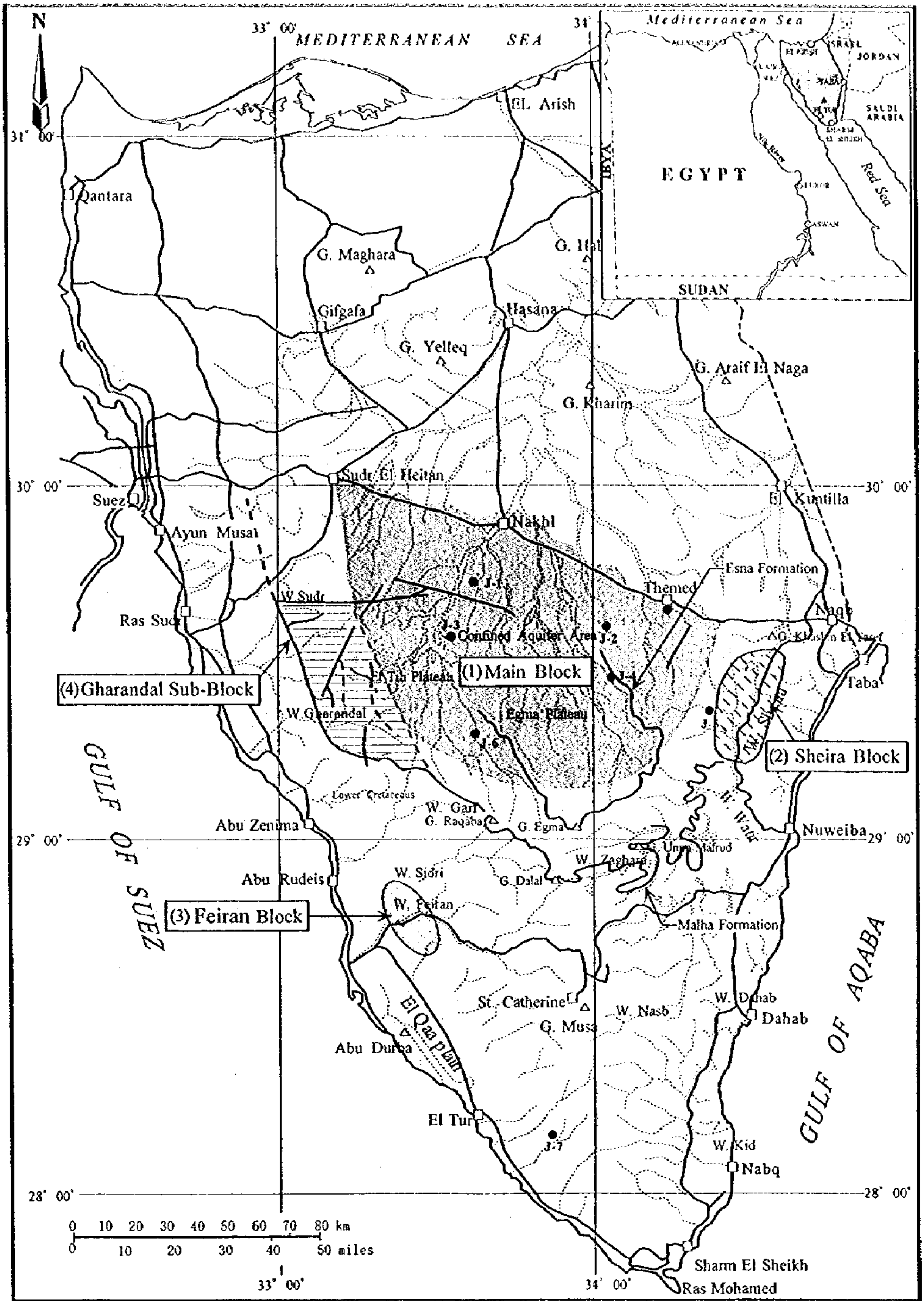


Fig. 3.5-1 Distribution of Lower Cretaceous Aquifer

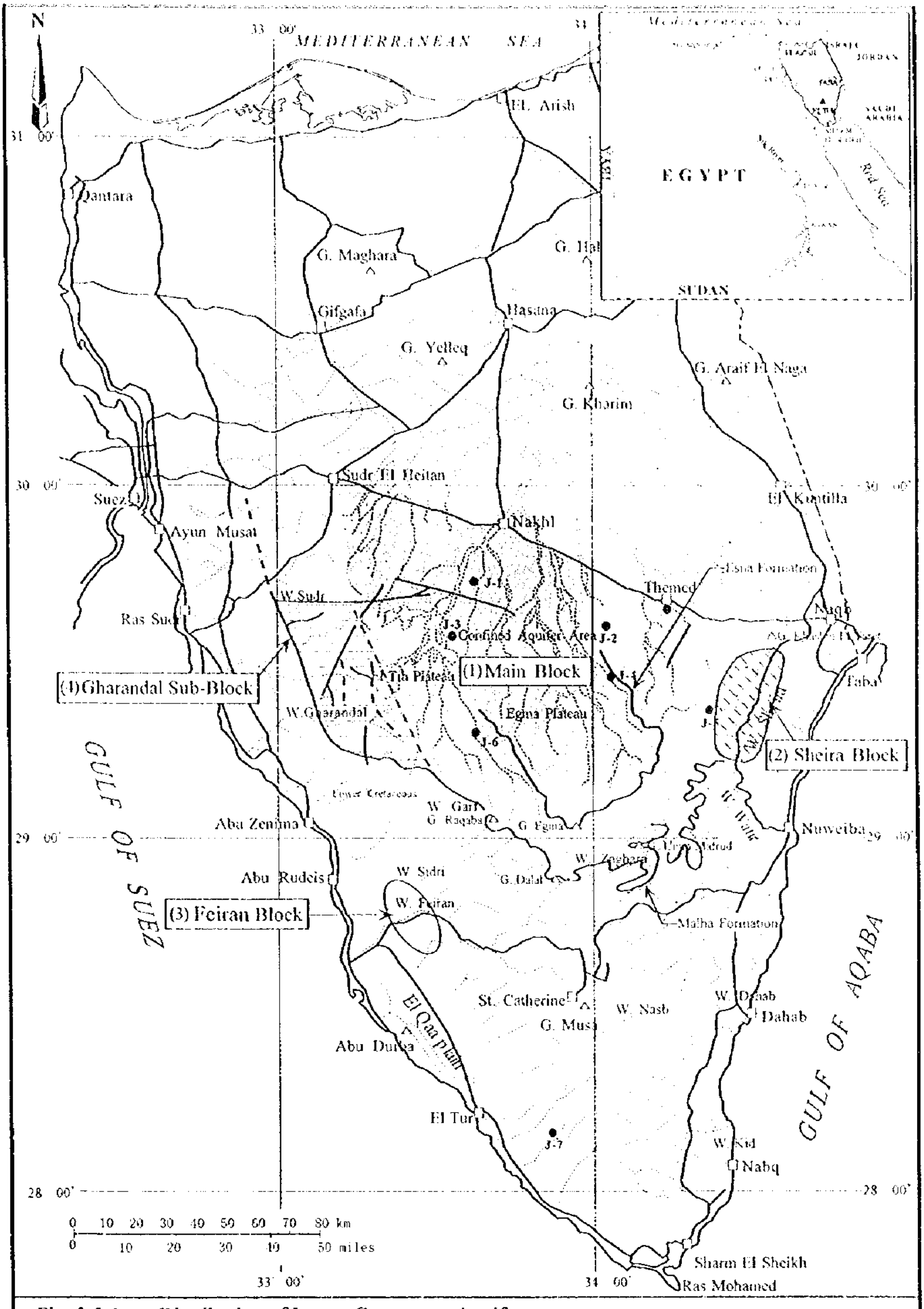


Fig. 3.5-1 Distribution of Lower Cretaceous Aquifer

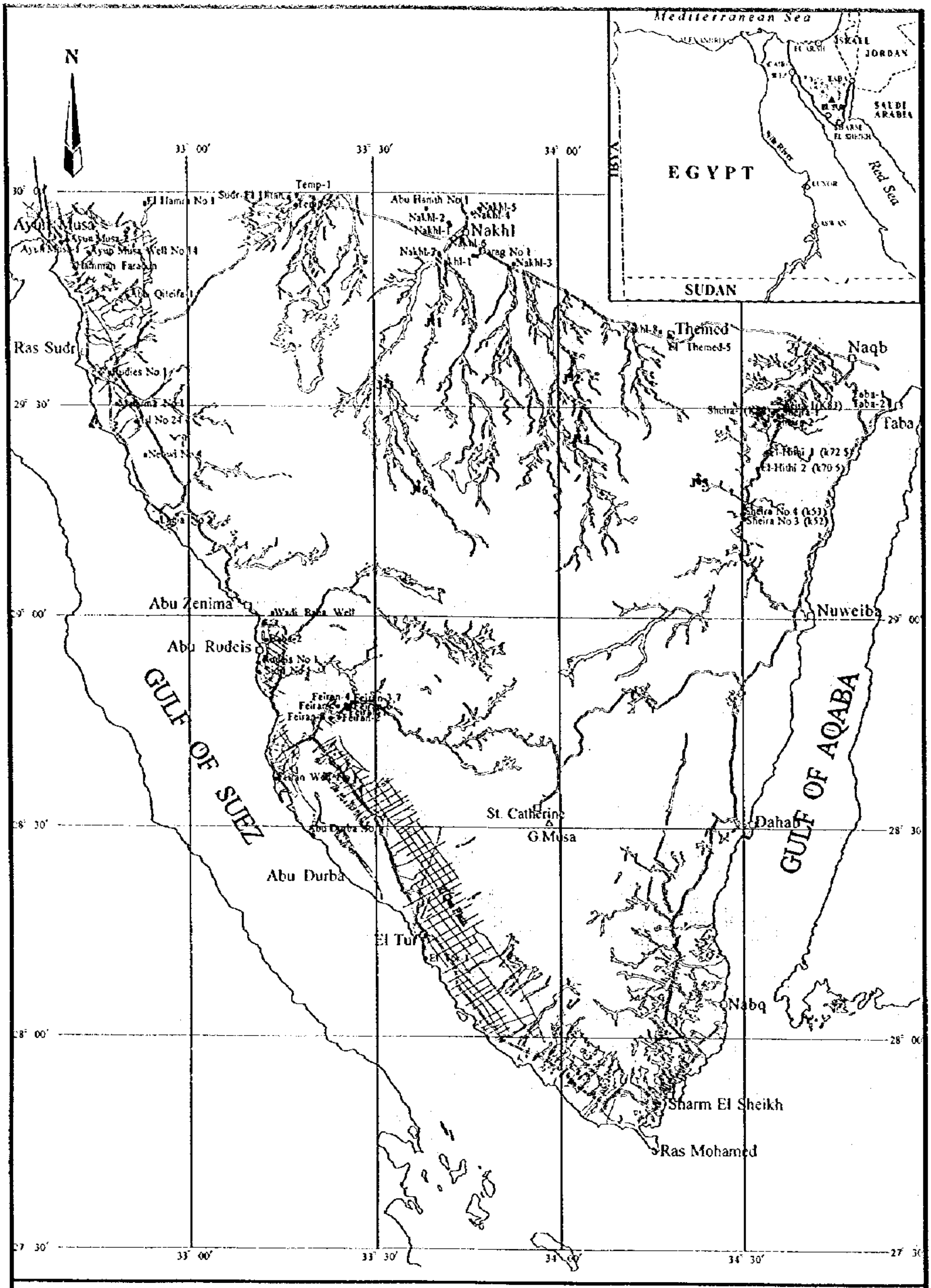


Fig. 3.5-2 Well Location of Lower Cretaceous

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

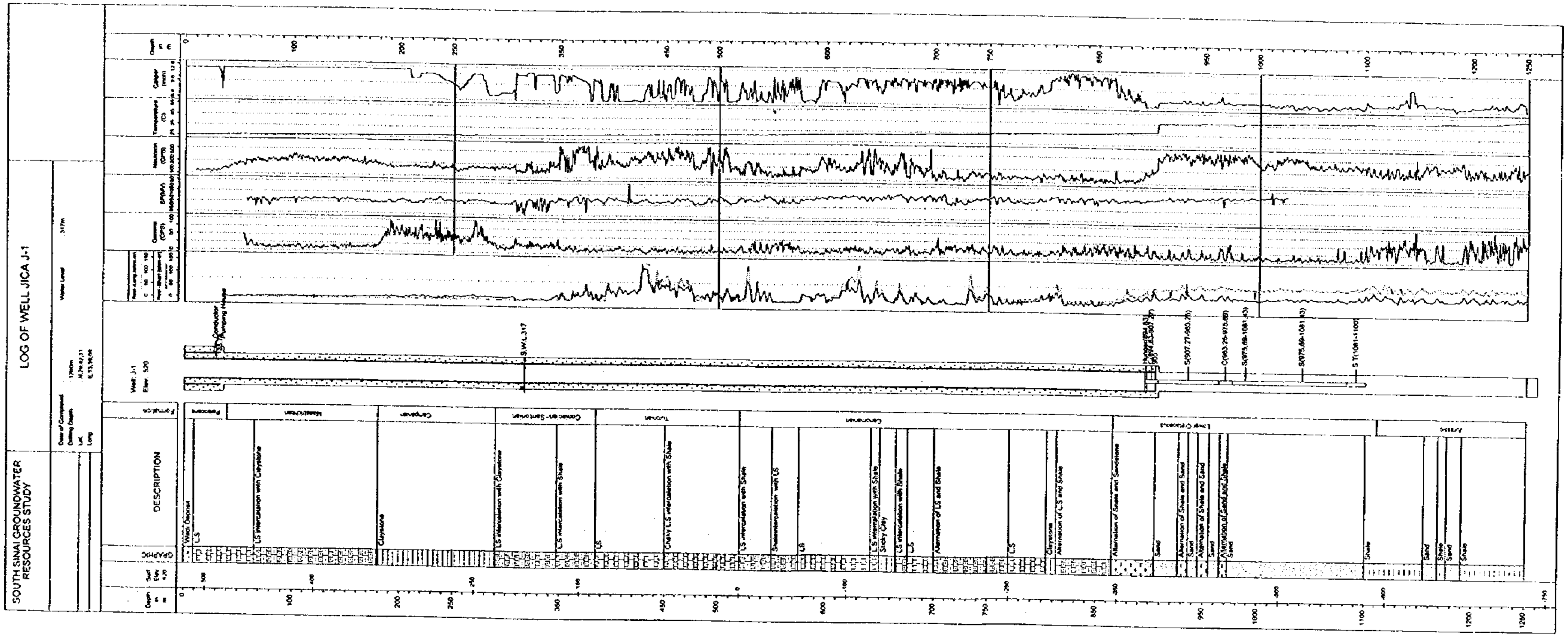


Fig. 3.5-3 (1) Drilling Log (JICA Test Well J-1)

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT

JICA

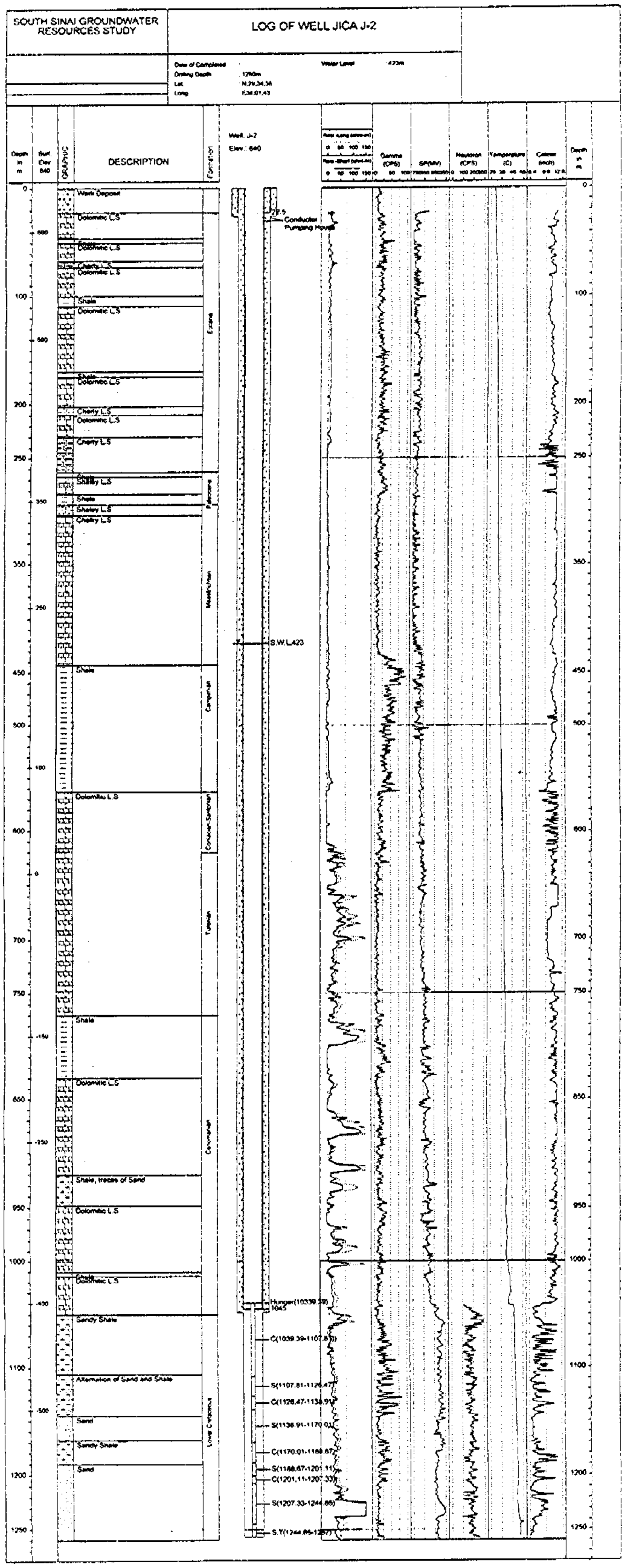


Fig. 3.5-3 (2) Drilling Log (JICA Test Well J-2)

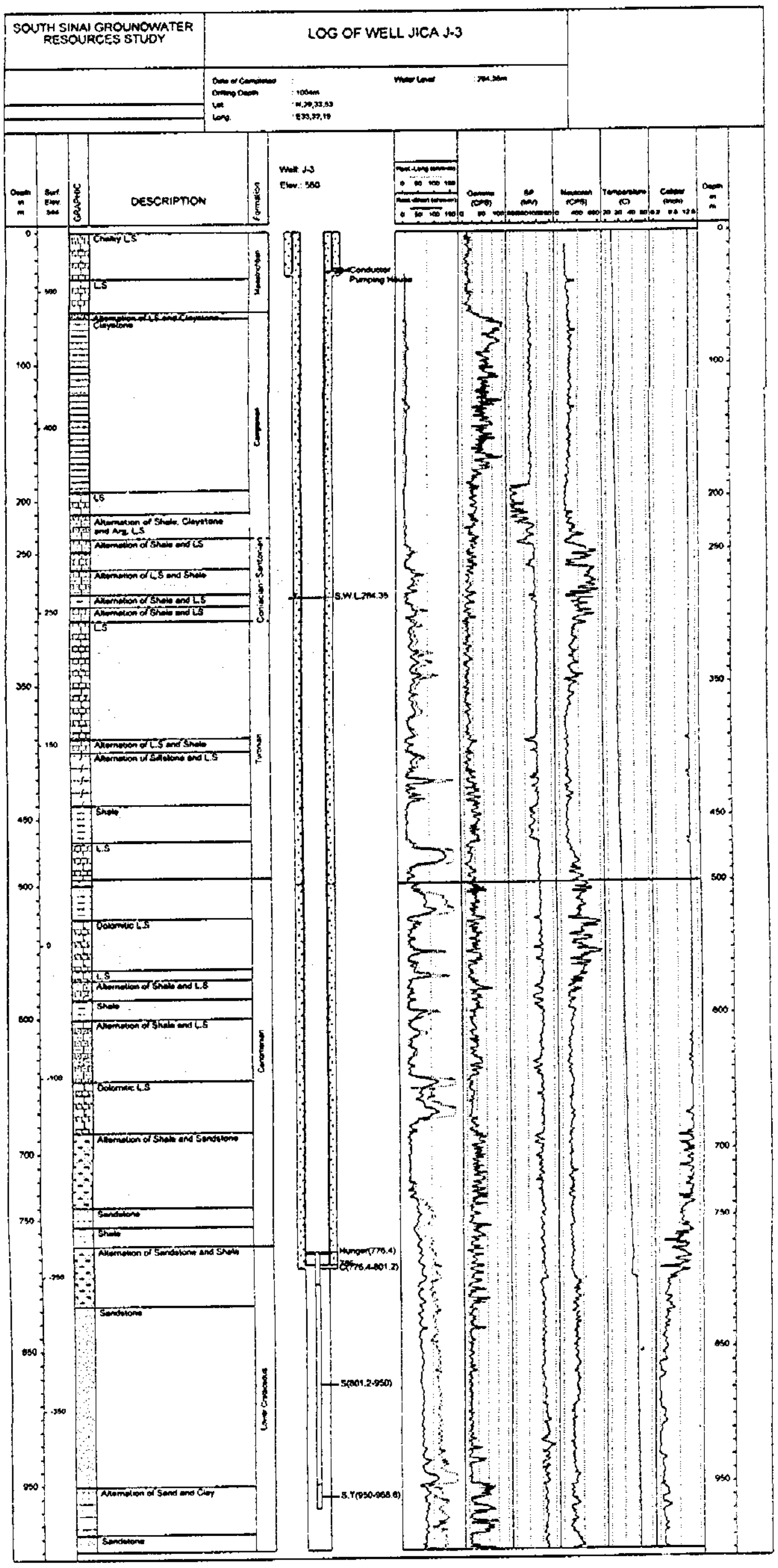


Fig. 3.5-3 (3) Drilling Log (JICA Test Well J-3)

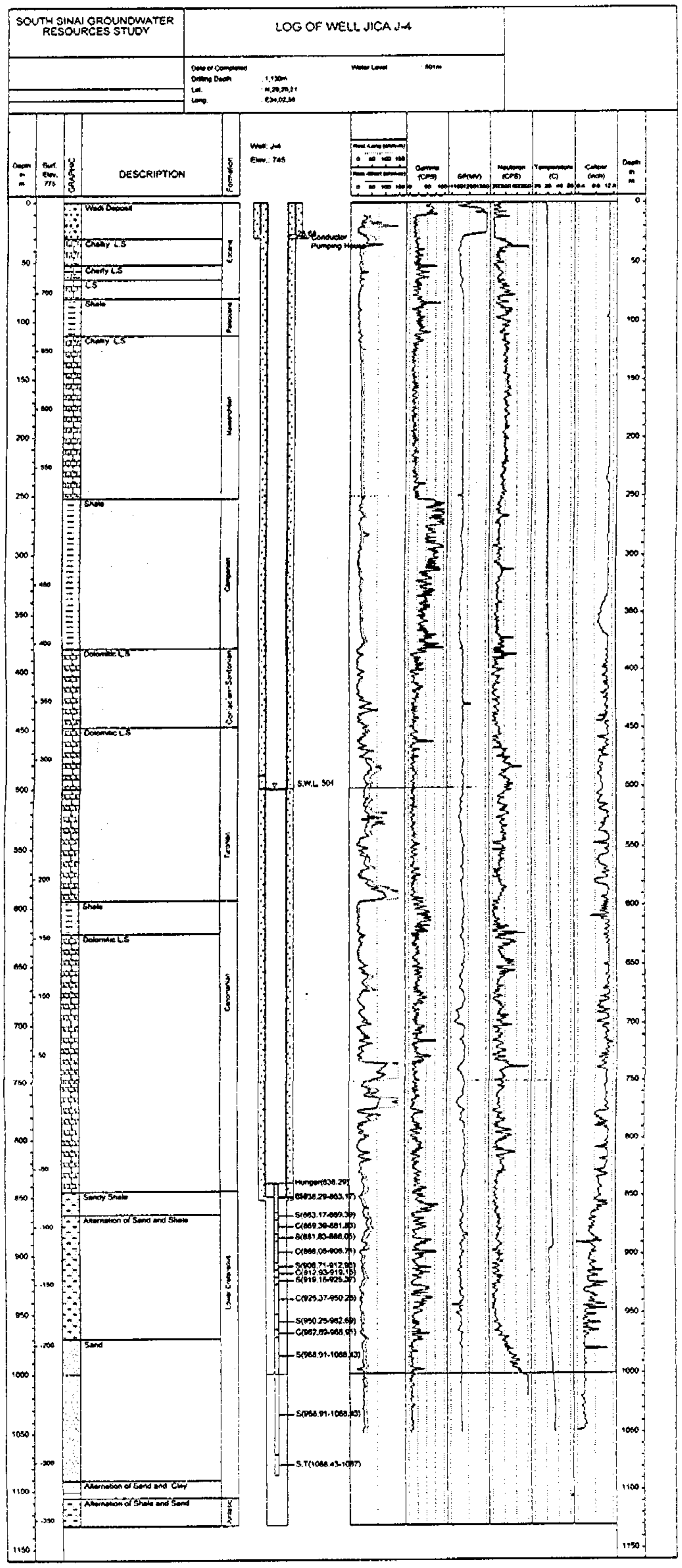


Fig. 3.5-3 (4)　Drilling Log (JICA Test Well J-4)

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT

JICA

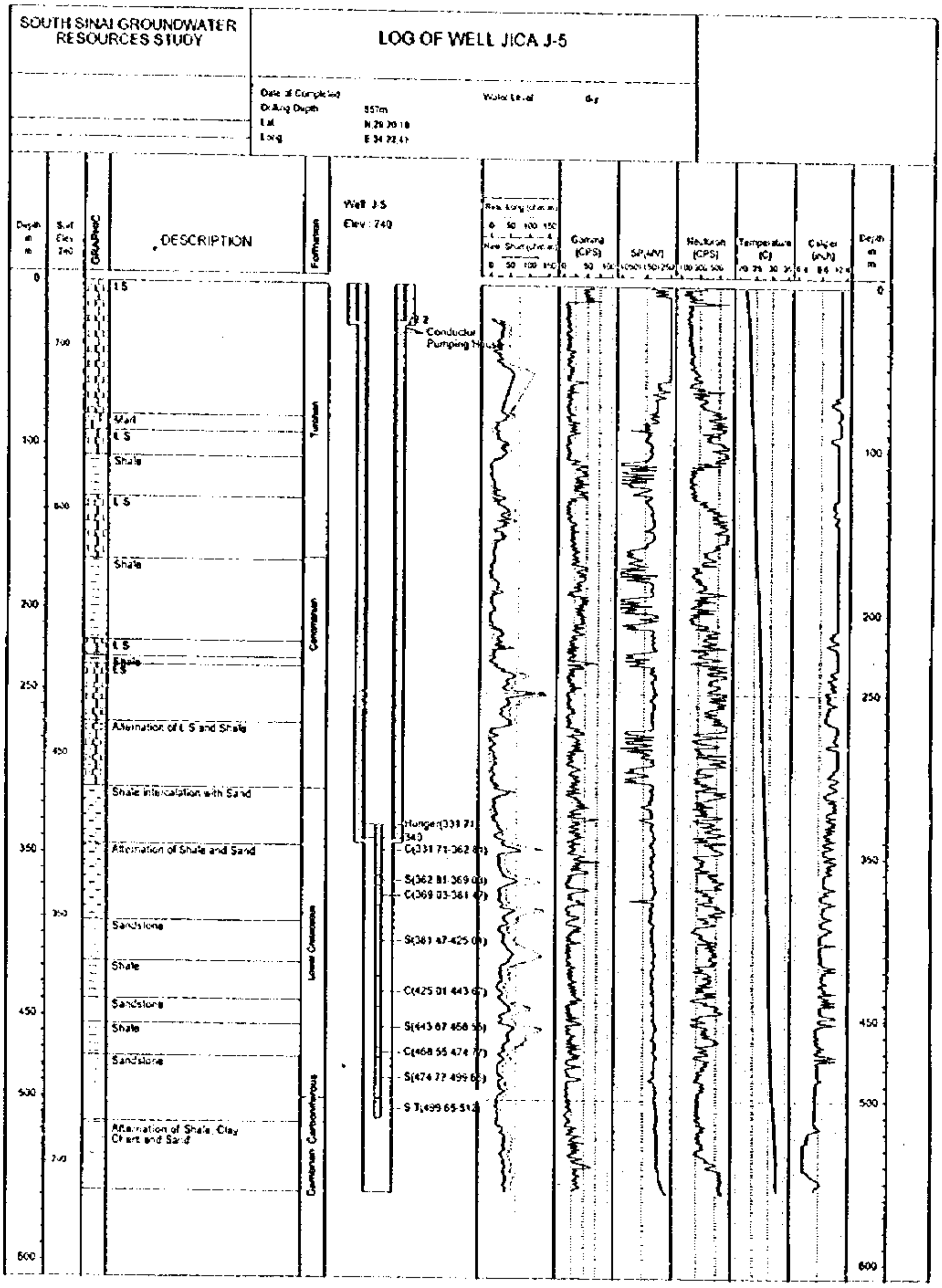


Fig. 3.5-3 (5) Drilling Log (JICA Test Well J-5)

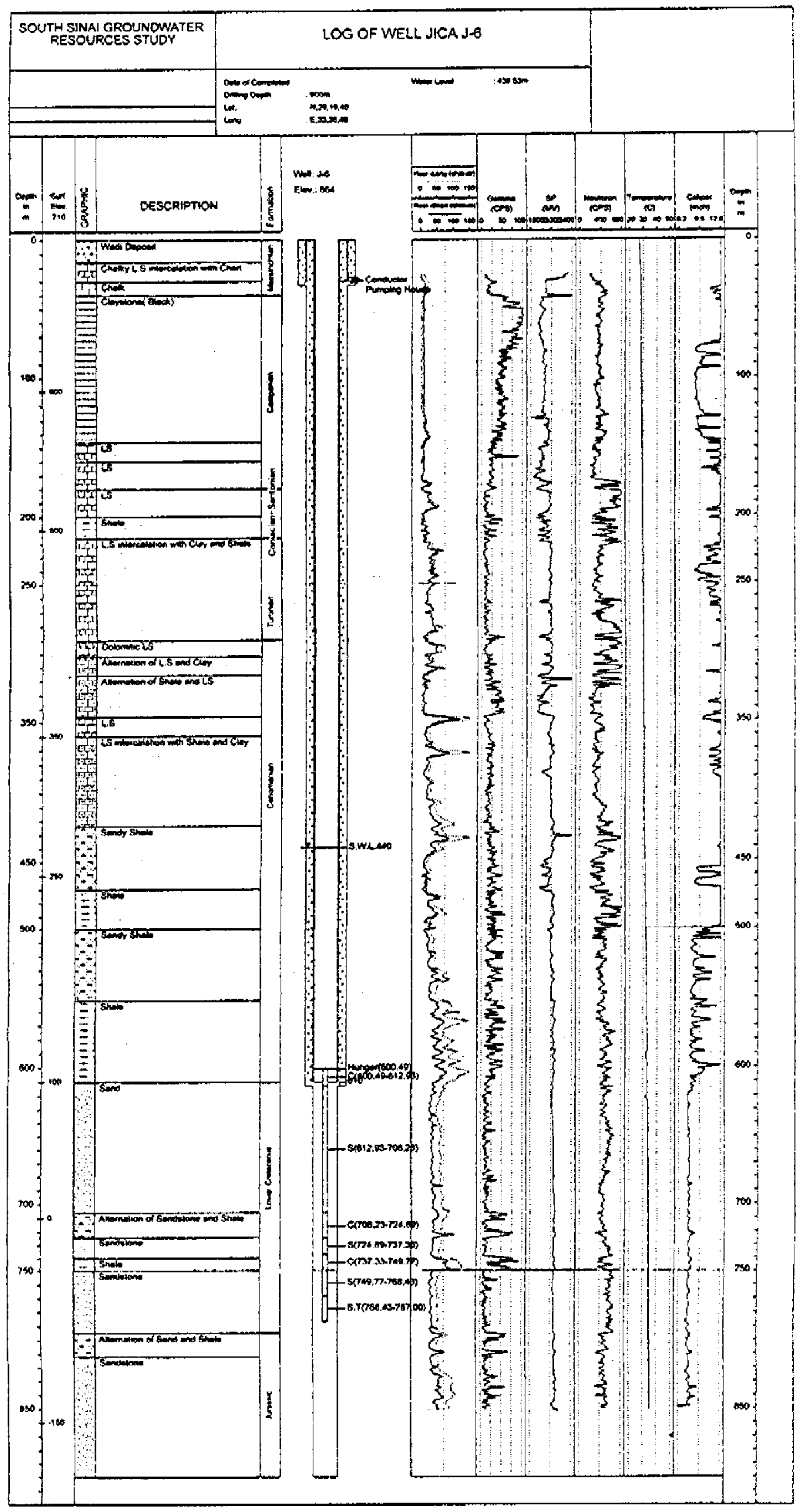


Fig. 3.5-3 (6)   Drilling Log (JICA Test Well J-6)

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT

JICA

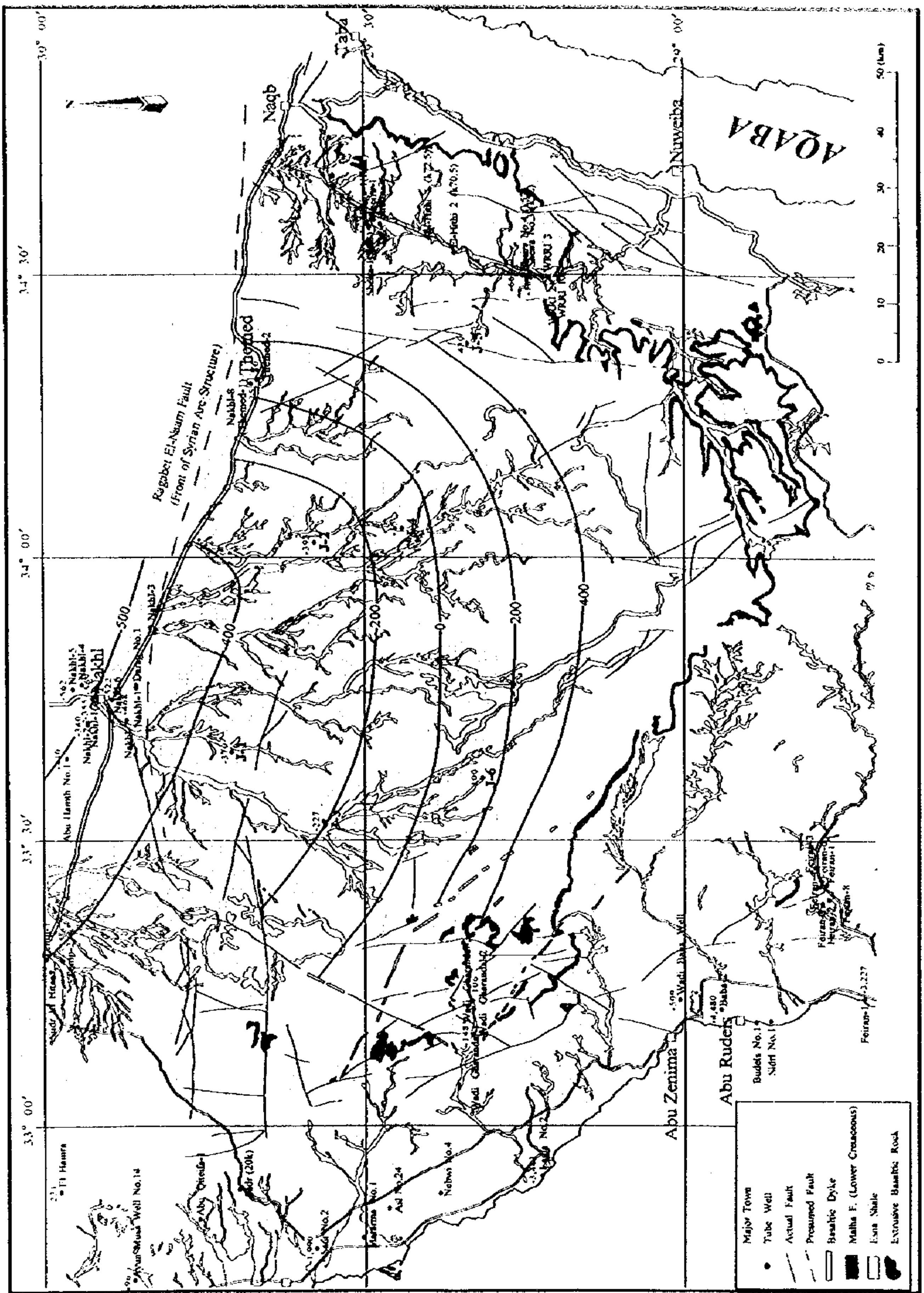


Fig. 3.5-4 Top of Lower Cretaceous

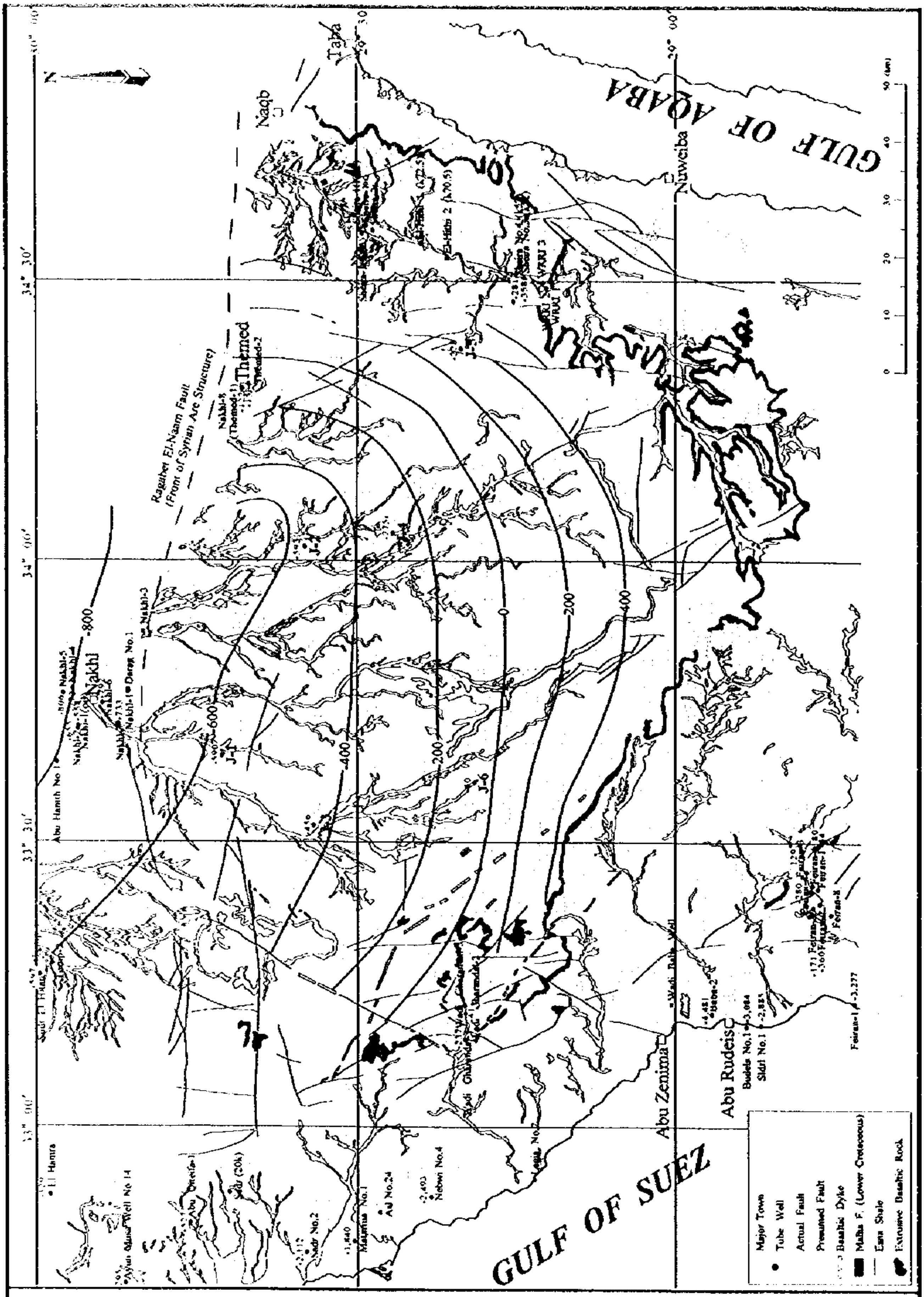


Fig. 3.5-5 Bottom of Lower Cretaceous

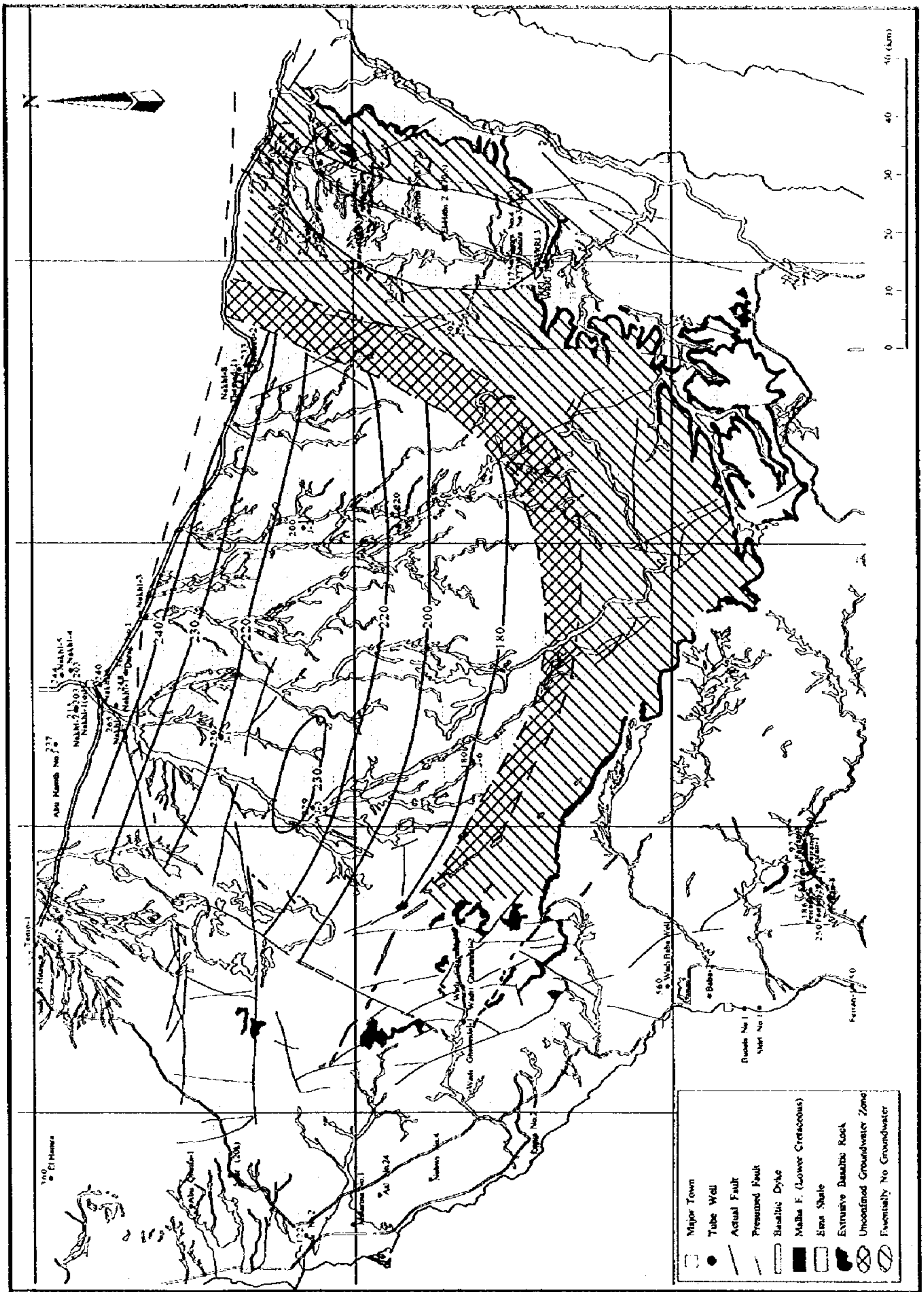


Fig. 3.5-6 Isopach of Lower Cretaceous

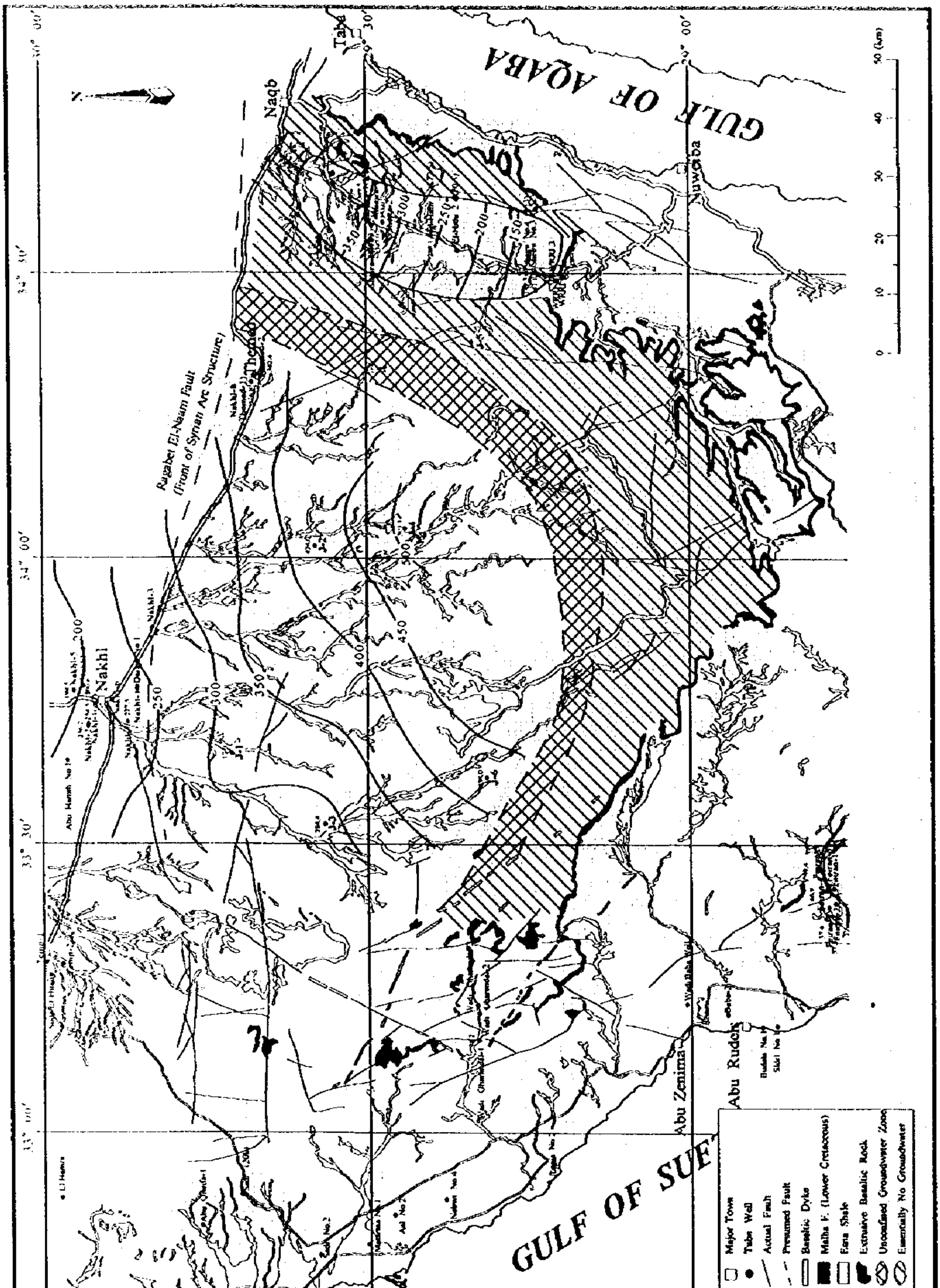


Fig. 3.5-7 (1)   Groundwater Level of Lower Cretaceous (in mBGL)

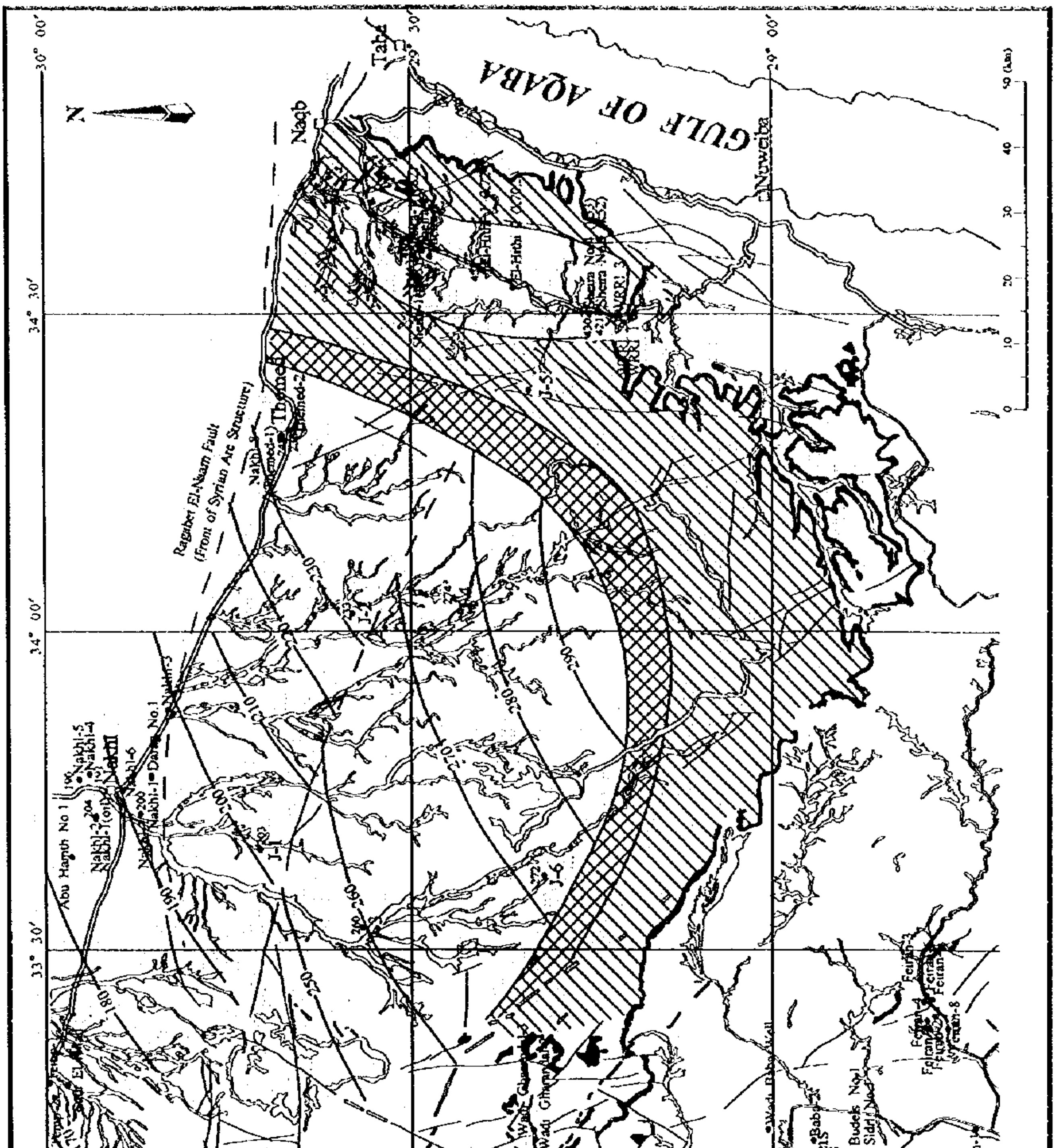


Fig. 3.5-7 (2) Groundwater Level of Lower Cretaceous (in mASL)

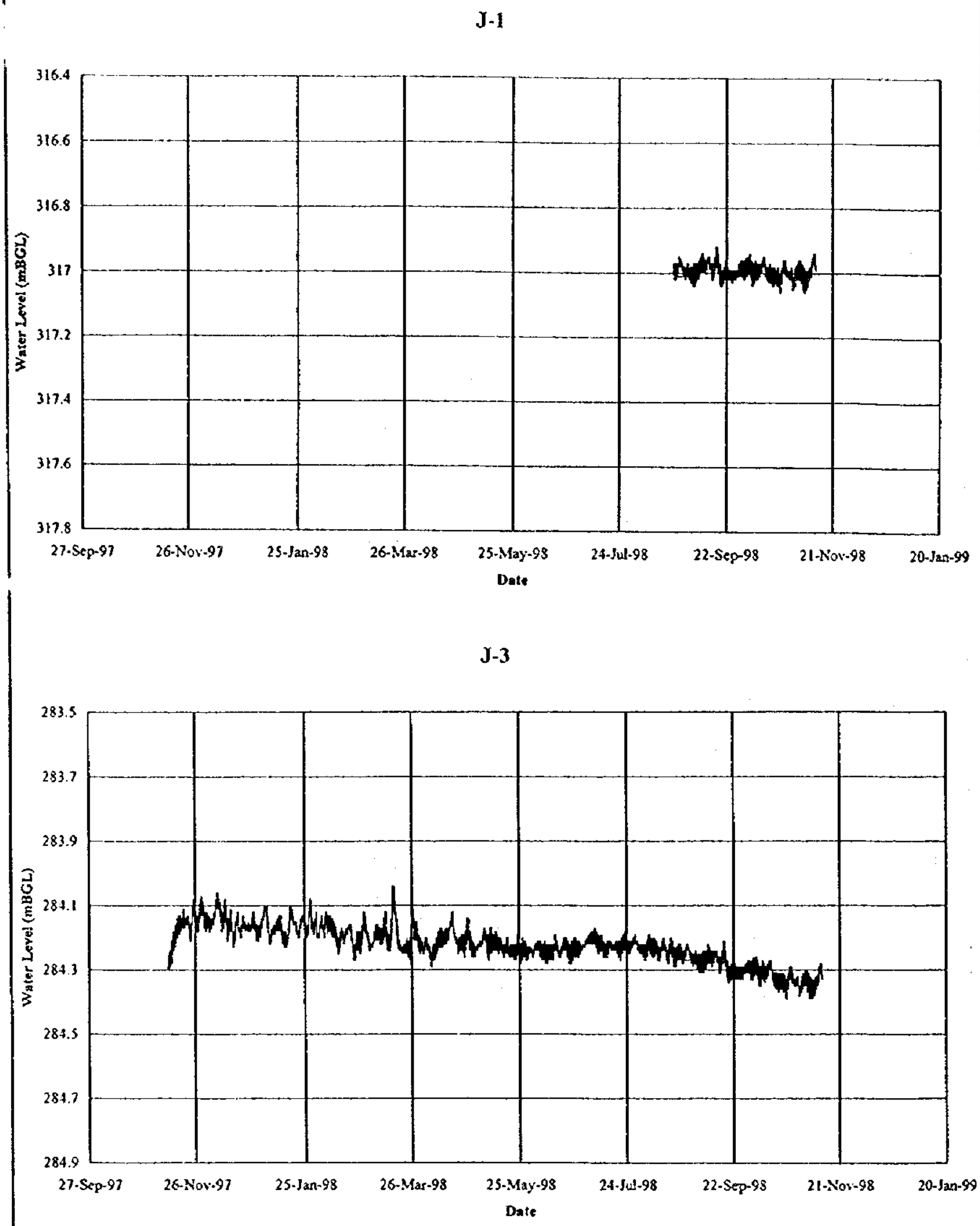


Fig. 3.5-8 Fluctuation of Groundwater Level at J-1 and J-3 (Lower Cretaceous)

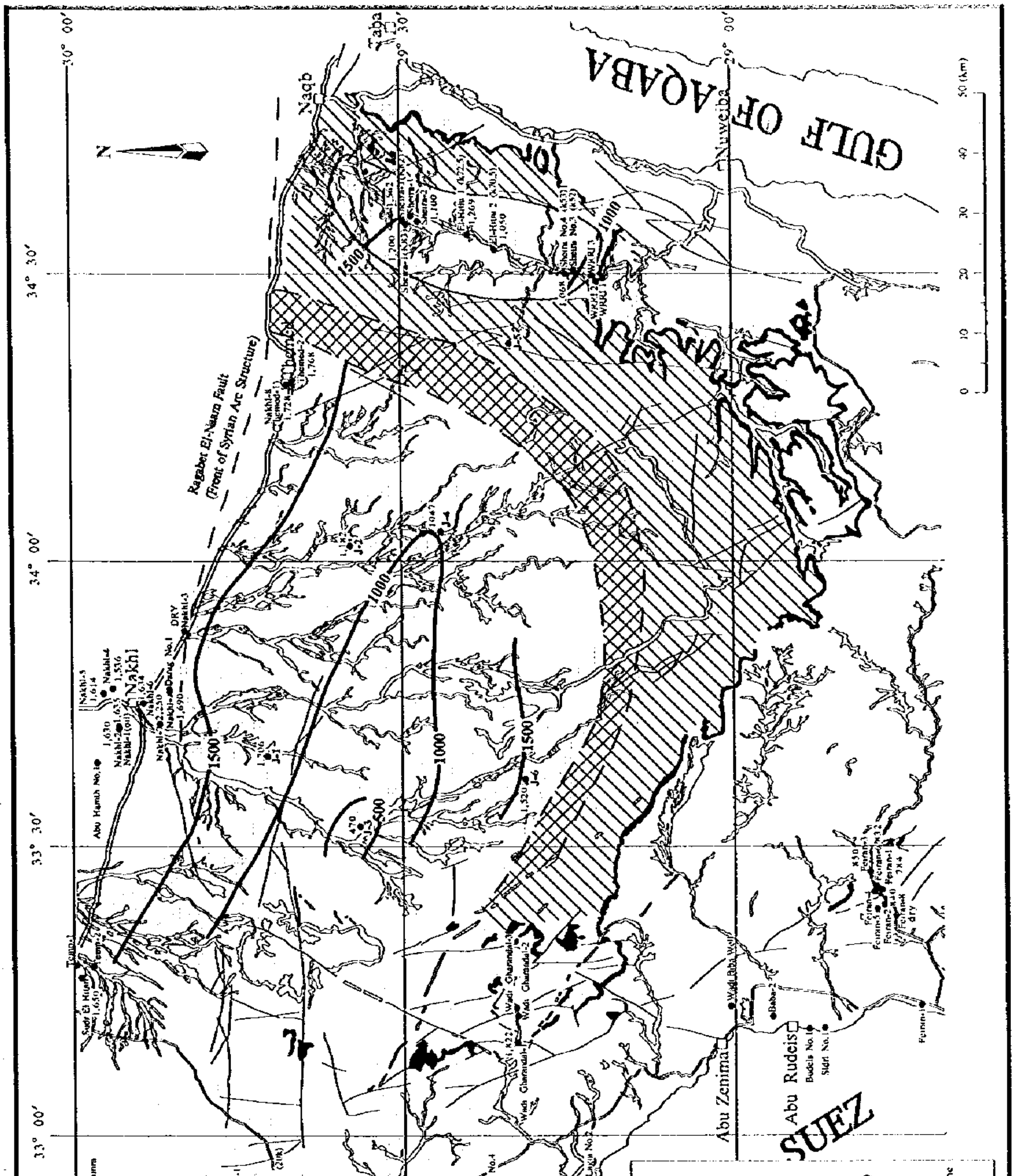
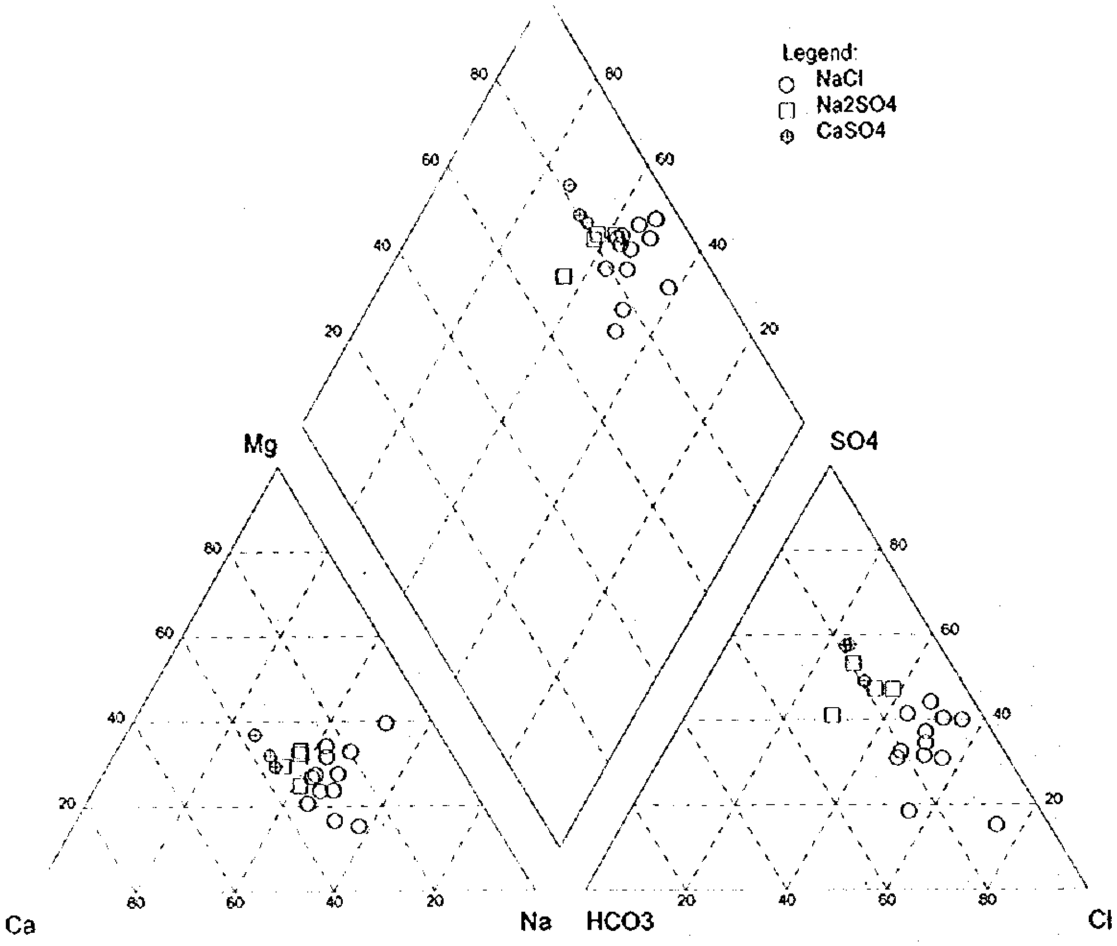


Fig. 3.5-9 Groundwater Quality of Lower Cretaceous



Area		Number of Sample
Main Block	Existing Well	8
	JICA Test Well	5
Gharandal Sub-Block		1
Sheira Block		3
Feiran Block		2
Total		19

Fig.3.5-10 Piper Diagram

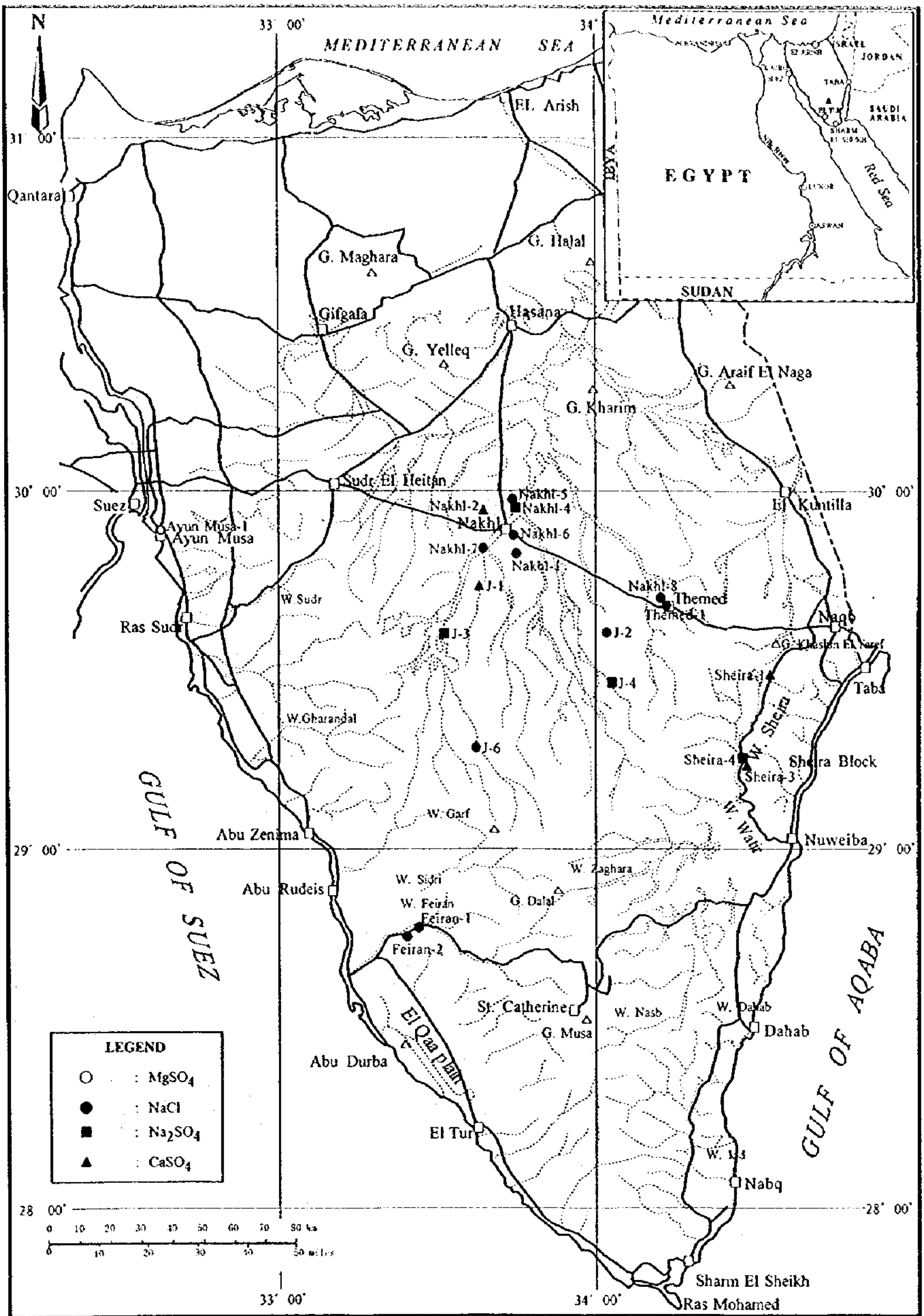


Fig. 3.5-11 Water Type of Lower Cretaceous Aquifer

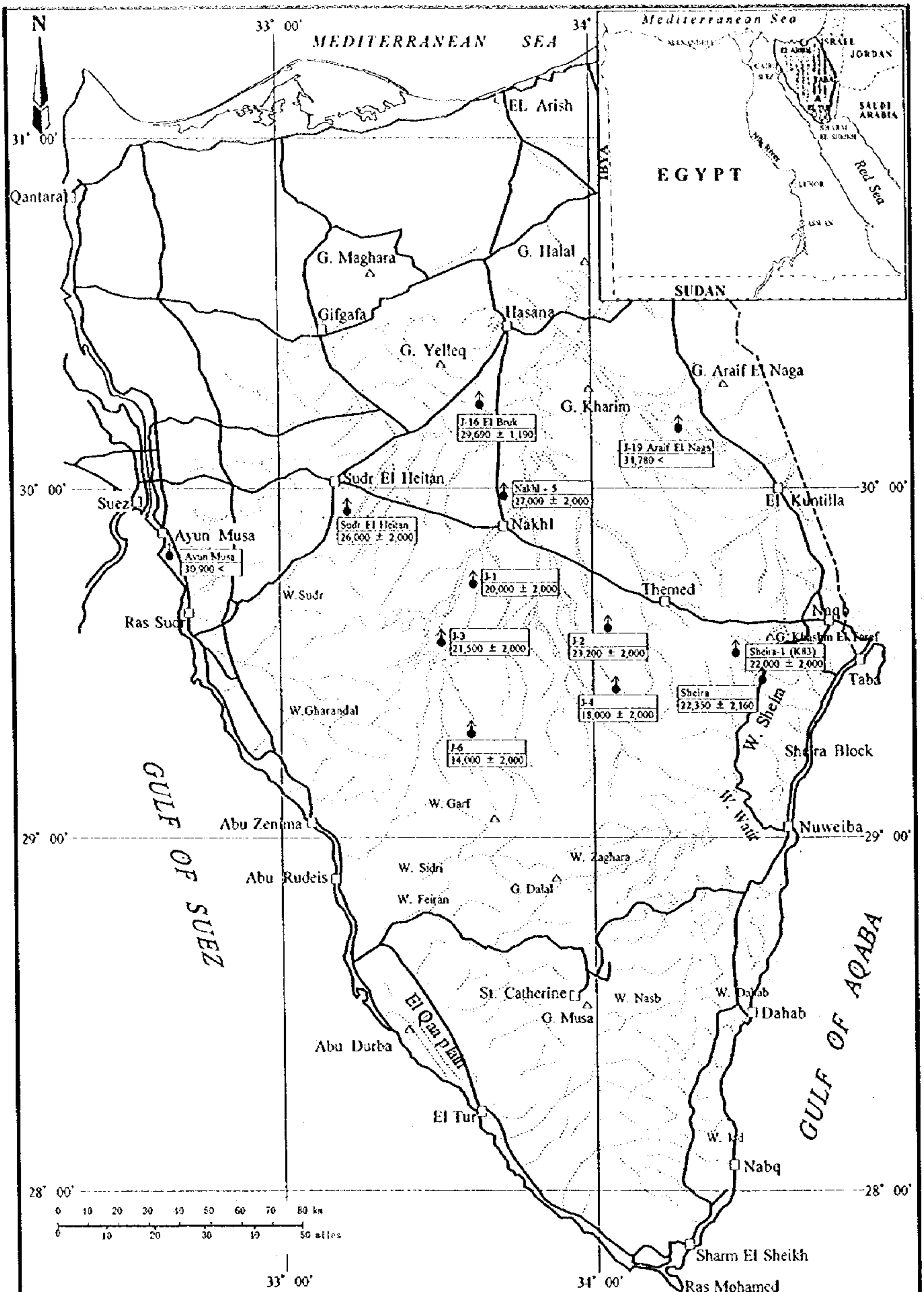


Fig. 3.5-12 Groundwater Age of Lower Cretaceous

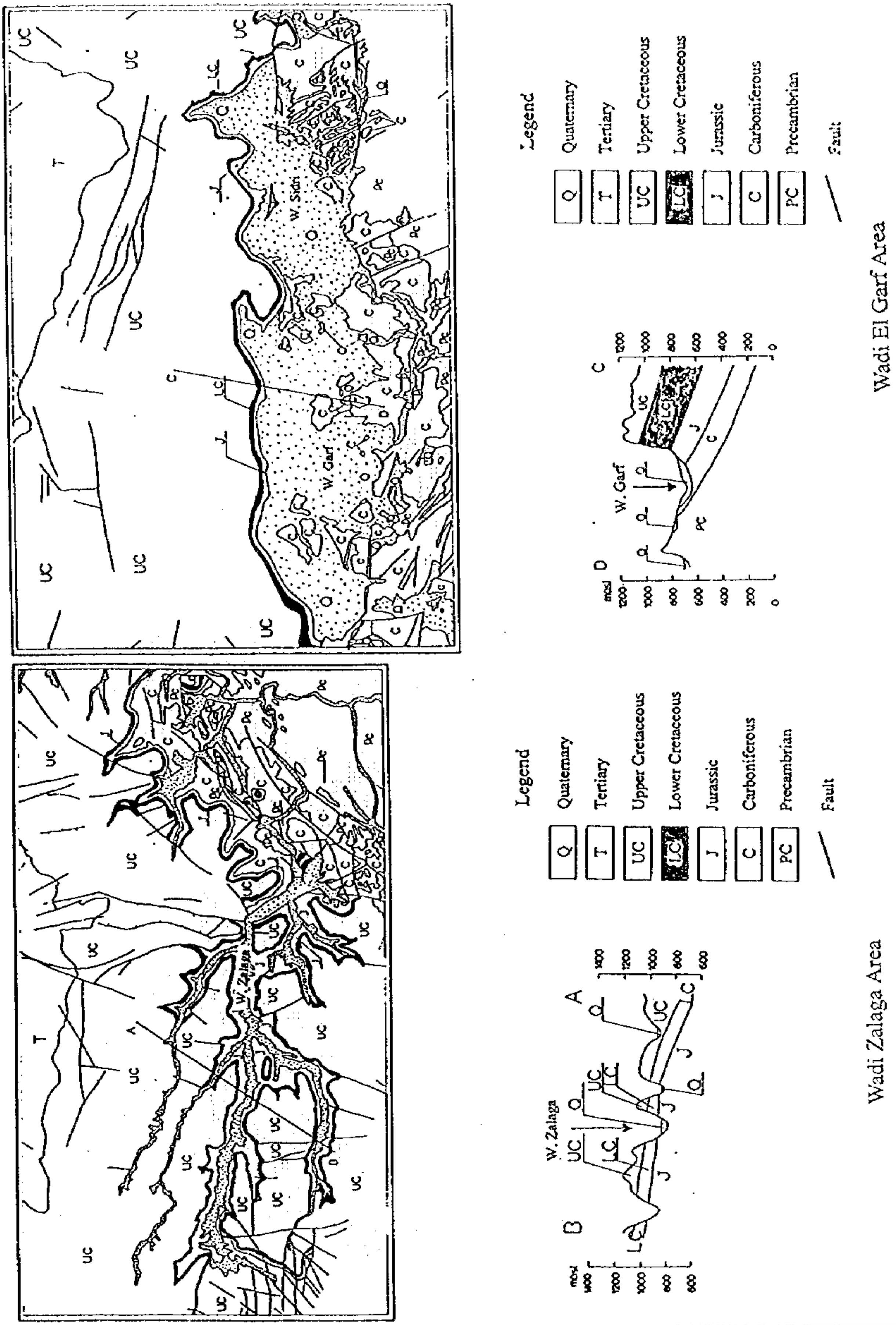


Fig. 3.5-13 Geological Map and Section (Wadi Zalaga and Garf)

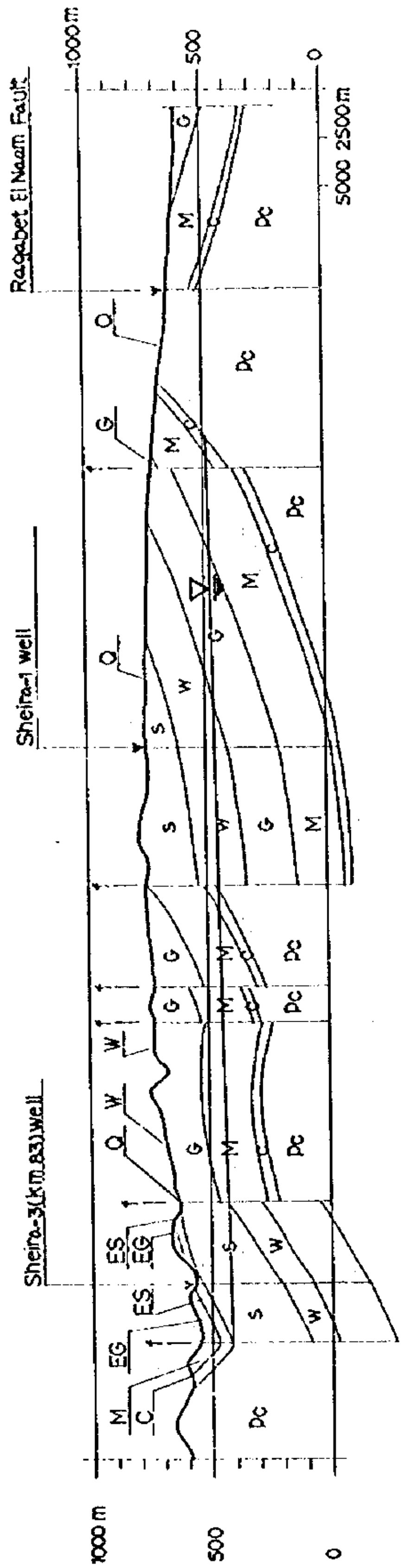


Fig. 3.5-14 Geological Profile (Sheira Block)

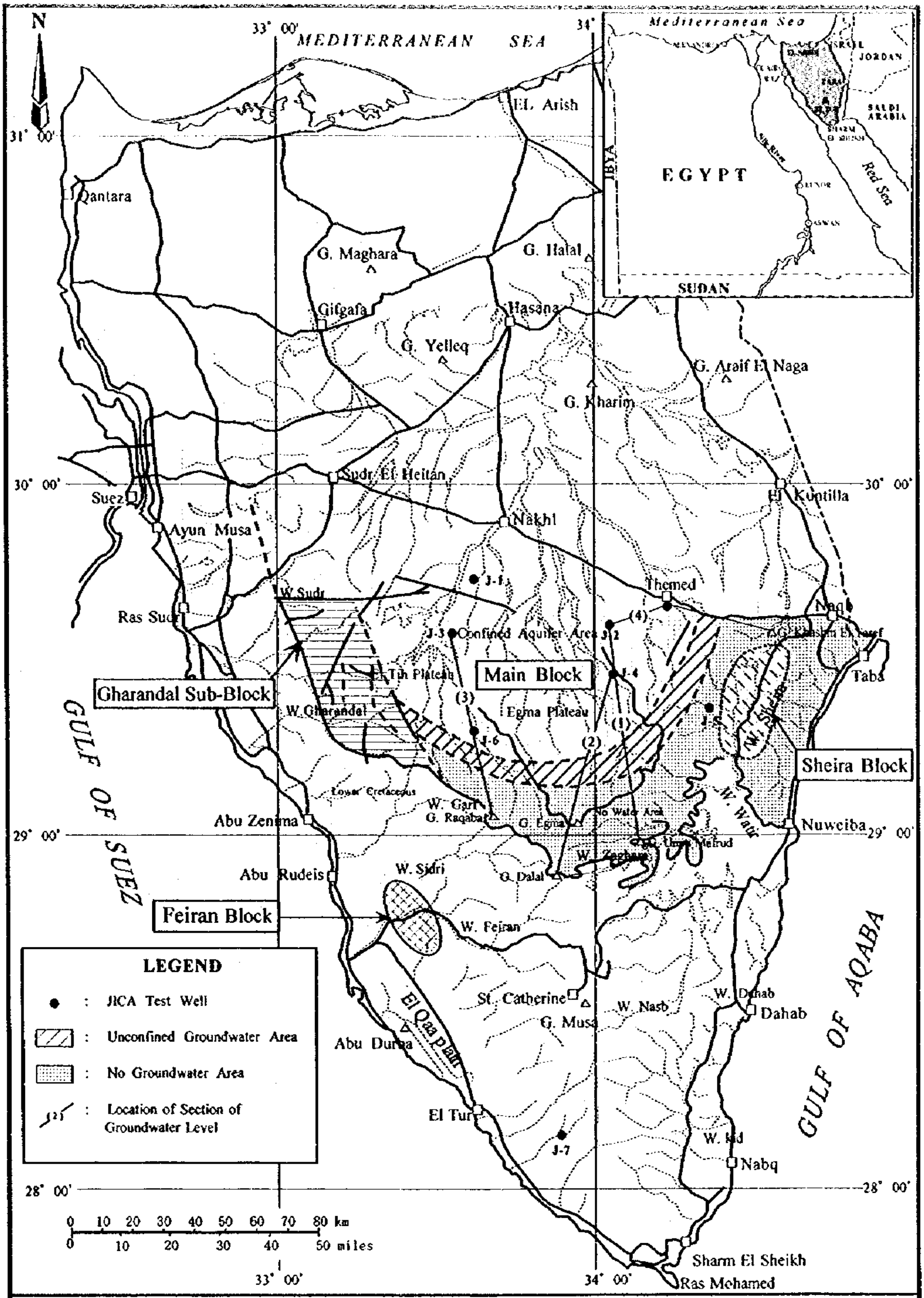


Fig. 3.5-15 Differentiated Groundwater Zone in Main Block (Lower Cretaceous)

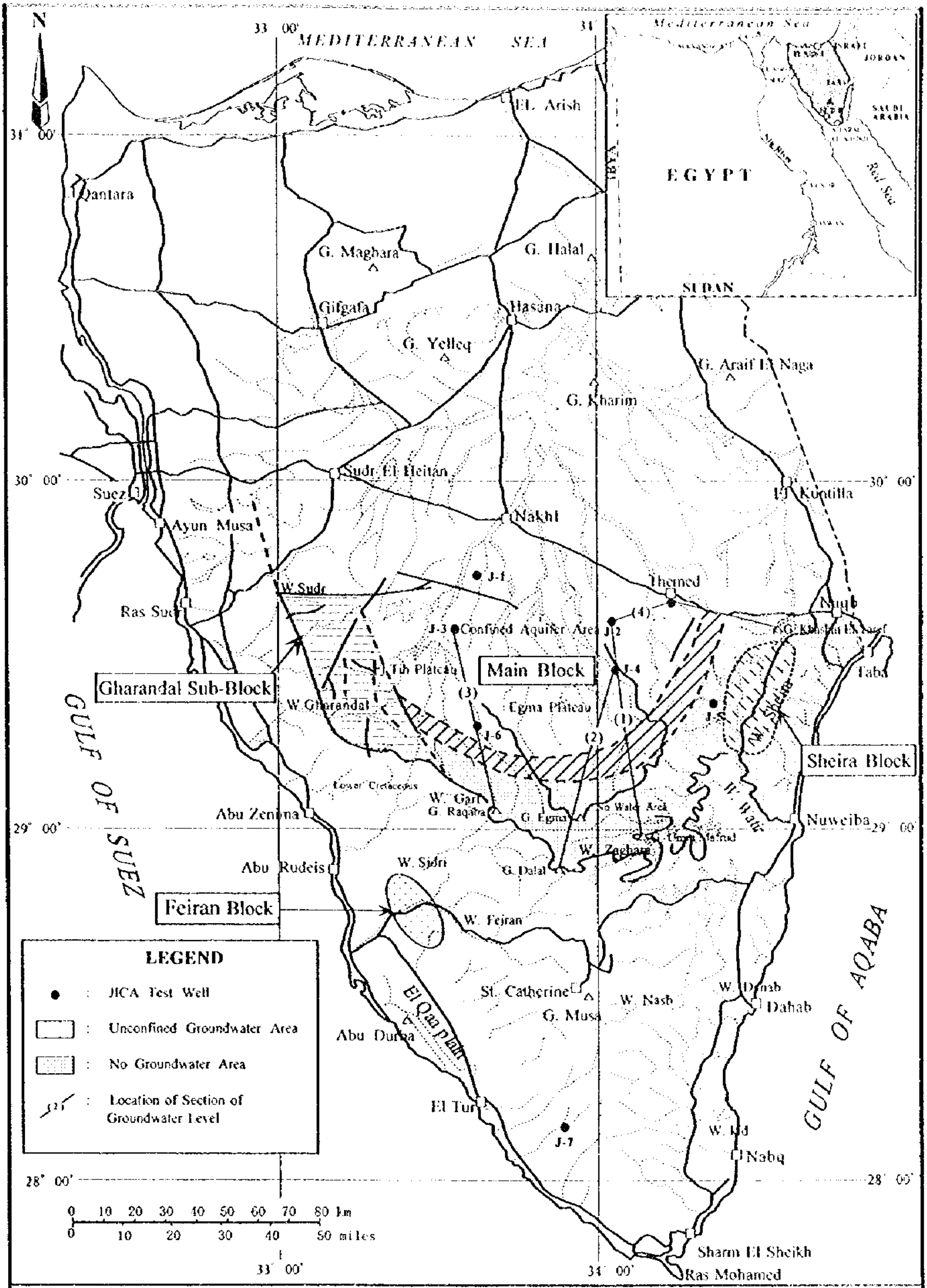


Fig. 3.5-15 Differentiated Groundwater Zone in Main Block (Lower Cretaceous)

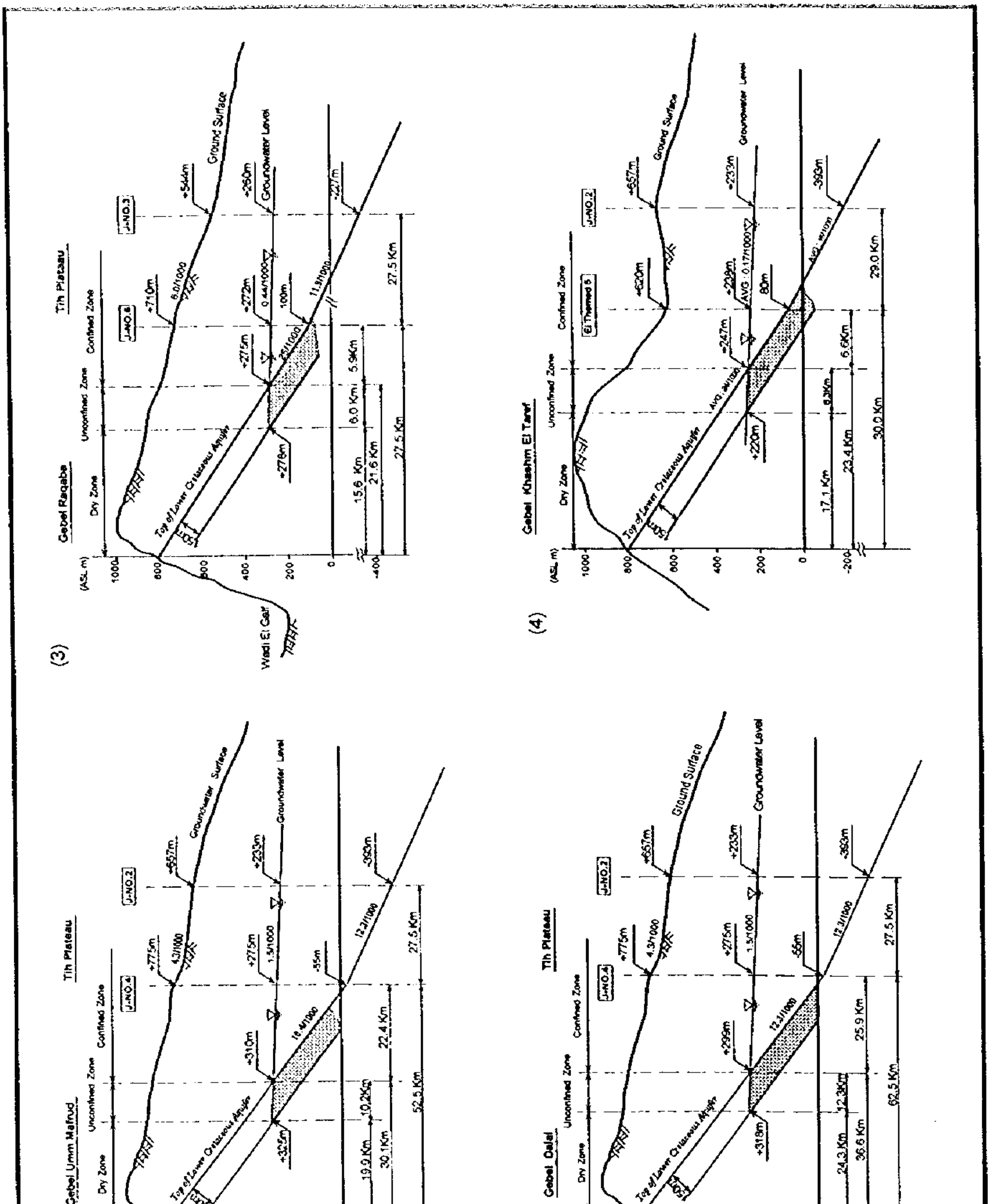
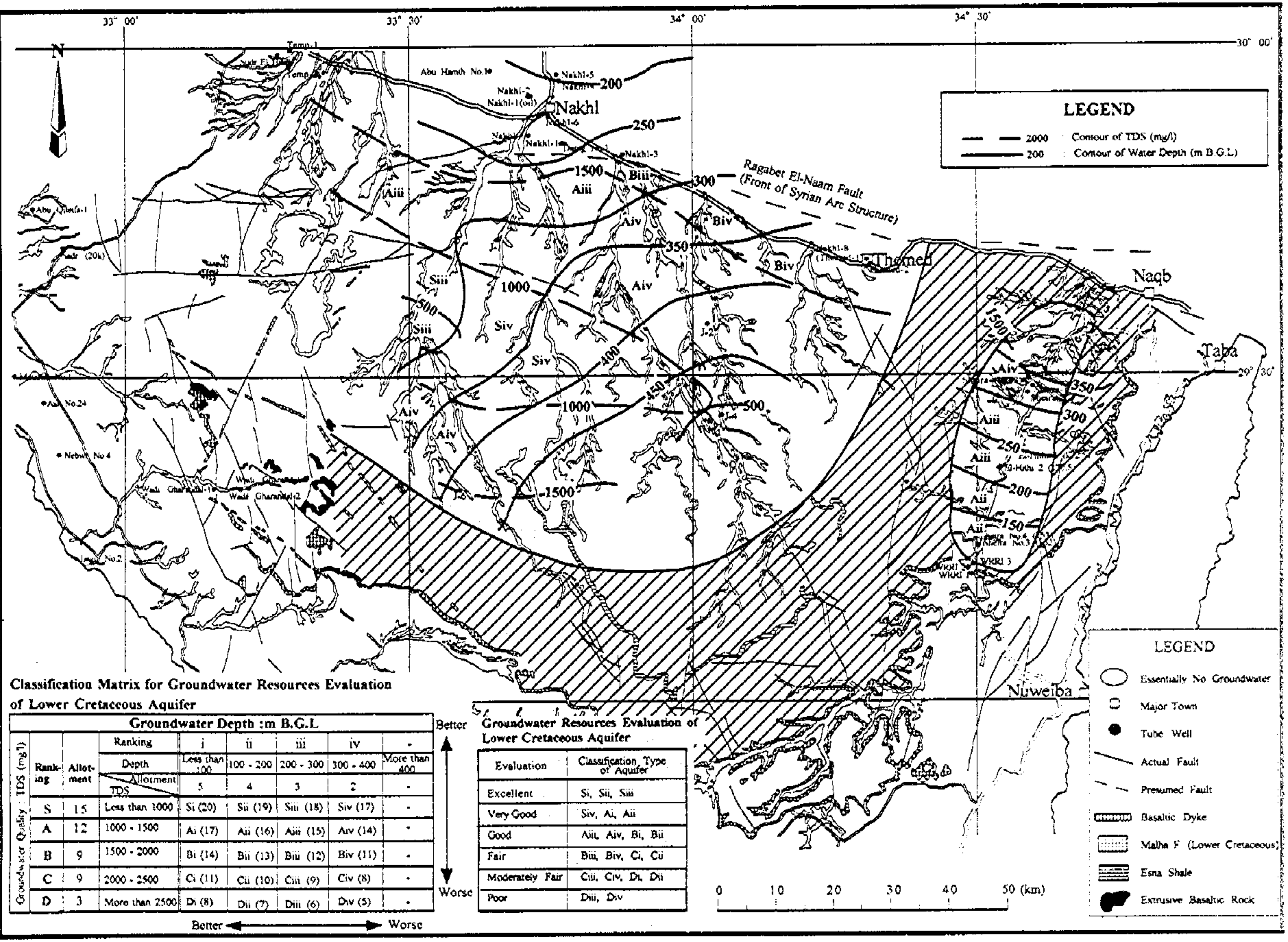


Fig. 3.5-16 Section of Groundwaer Table (Lower Cretaceous)



Classification Matrix for Groundwater Resources Evaluation of Lower Cretaceous Aquifer

Groundwater Quality : TDS (mg/l)			Groundwater Depth :m B.G.L					
	Ranking	Allotment	Ranking	i	ii	iii	iv	-
			Depth	Less than 100	100 - 200	200 - 300	300 - 400	More than 400
			Allotment / TDS	5	4	3	2	-
	S	15	Less than 1000	Si (20)	Sii (19)	Siii (18)	Siv (17)	-
	A	12	1000 - 1500	Ai (17)	Aii (16)	Aiii (15)	Aiv (14)	-
	B	9	1500 - 2000	Bi (14)	Bii (13)	Biii (12)	Biv (11)	-
	C	9	2000 - 2500	Ci (11)	Cii (10)	Ciii (9)	Civ (8)	-
	D	3	More than 2500	Di (8)	Dii (7)	Diii (6)	Div (5)	-

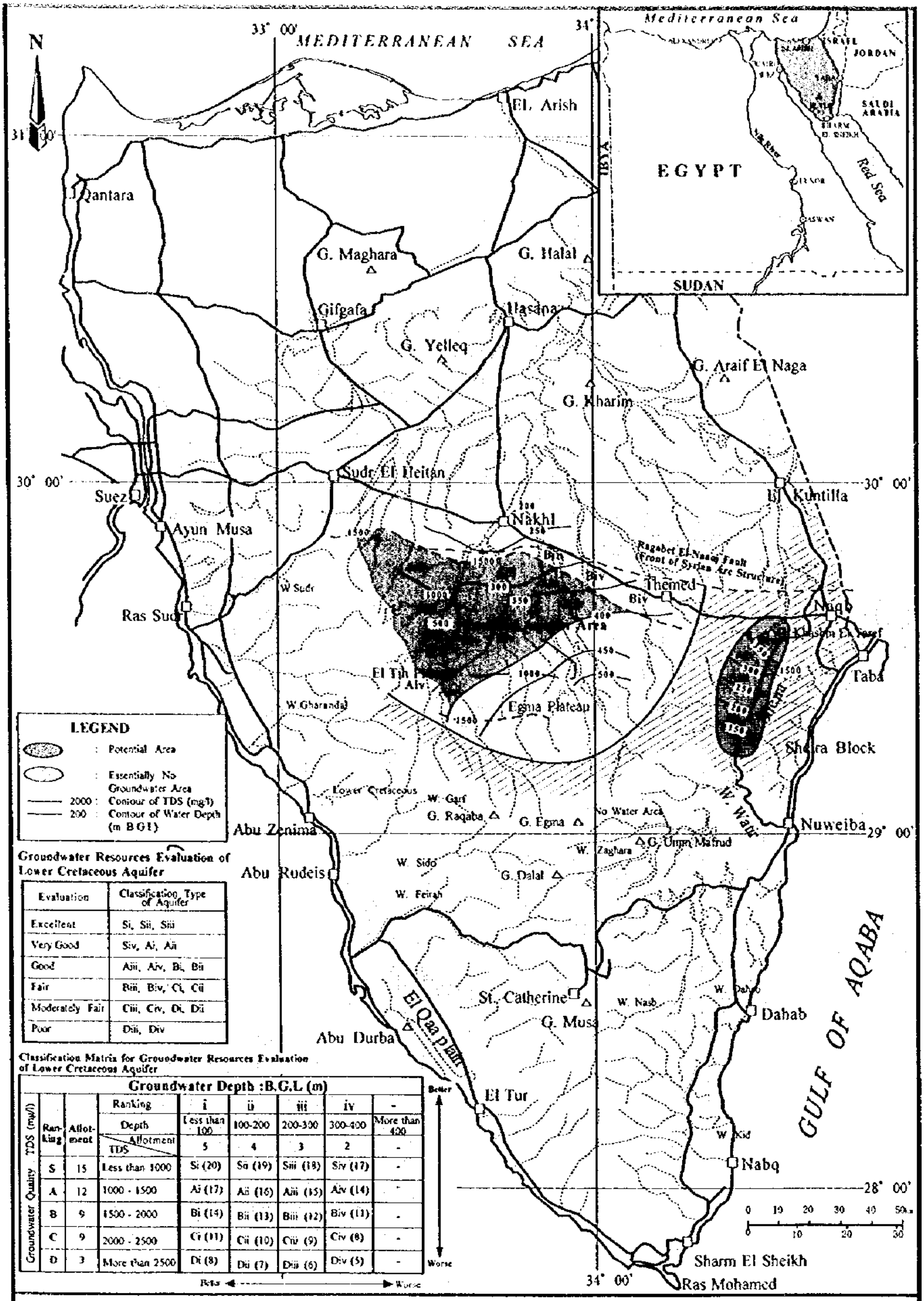
Better ↔ Worse

Better ↕ Worse

Groundwater Resources Evaluation of Lower Cretaceous Aquifer

Evaluation	Classification Type of Aquifer
Excellent	Si, Sii, Siii
Very Good	Siv, Ai, Aii
Good	Aiii, Aiv, Bi, Bii
Fair	Biii, Biv, Ci, Cii
Moderately Fair	Ciii, Civ, Di, Dii
Poor	Diii, Div

Fig. 3.5-17 Groundwater Evaluation Map (Lower Cretaceous)



LEGEND

- ▨ : Potential Area
- ○ : Essentially No Groundwater Area
- —— 2000 : Contour of TDS (mg/l)
- —— 200 : Contour of Water Depth (m BGI)

Groundwater Resources Evaluation of Lower Cretaceous Aquifer

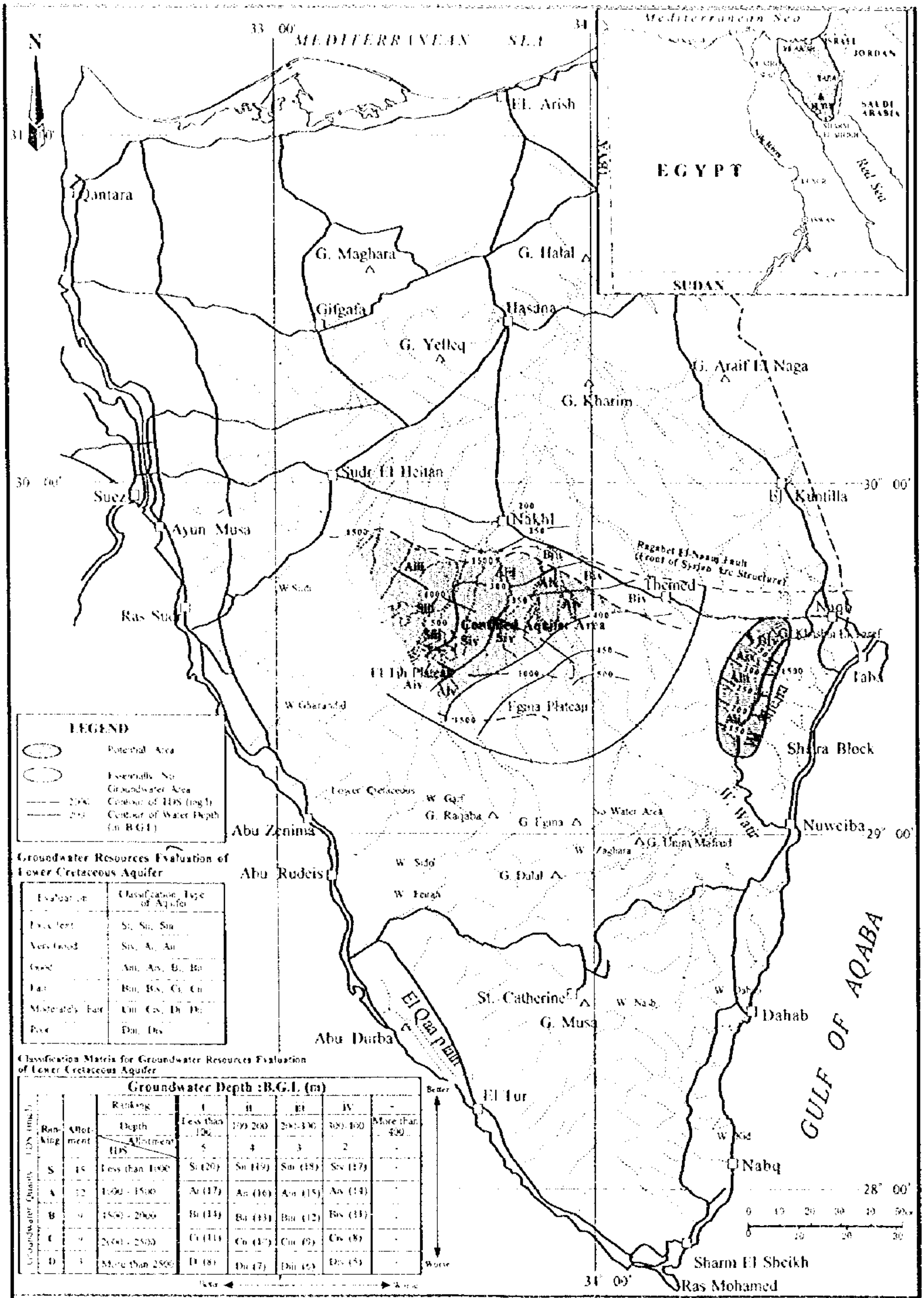
Evaluation	Classification Type of Aquifer
Excellent	Si, Sii, Siii
Very Good	Siv, Ai, Aii
Good	Aiii, Aiv, Bi, Bii
Fair	Biii, Biv, Ci, Cii
Moderately Fair	Ciii, Civ, Di, Dii
Poor	Diii, Div

Classification Matrix for Groundwater Resources Evaluation of Lower Cretaceous Aquifer

			Groundwater Depth :B.G.L (m)					
Groundwater Quality TDS (mg/l)	Ranking	Allotment	Ranking	i	ii	iii	iv	-
			Depth	Less than 100	100-200	200-300	300-400	More than 400
			Allotment / TDS	5	4	3	2	-
	S	15	Less than 1000	Si (20)	Sii (19)	Siii (18)	Siv (17)	-
	A	12	1000 - 1500	Ai (17)	Aii (16)	Aiii (15)	Aiv (14)	-
	B	9	1500 - 2000	Bi (14)	Bii (13)	Biii (12)	Biv (11)	-
	C	9	2000 - 2500	Ci (11)	Cii (10)	Ciii (9)	Civ (8)	-
	D	3	More than 2500	Di (8)	Dii (7)	Diii (6)	Div (5)	-

Better ◀ ---- ▶ Worse

Fig. 3.5-18 Groundwater Evaluation for Drinking (Lower Cretaceous)



LEGEND

- Potential Area
- Essentially No Groundwater Area
- 2000 Contour of TDS (mg/l)
- 200 Contour of Water Depth (m B.G.L.)

Groundwater Resources Evaluation of Lower Cretaceous Aquifer

Evaluation	Classification Type of Aquifer
Excellent	Si, Sii, Siii
Very Good	Siv, Ai, Aii
Good	Aiii, Aiv, Bi, Bii
Fair	Biii, Biv, Ci, Cii
Moderately Fair	Ciii, Civ, Di, Dii
Poor	Diii, Div

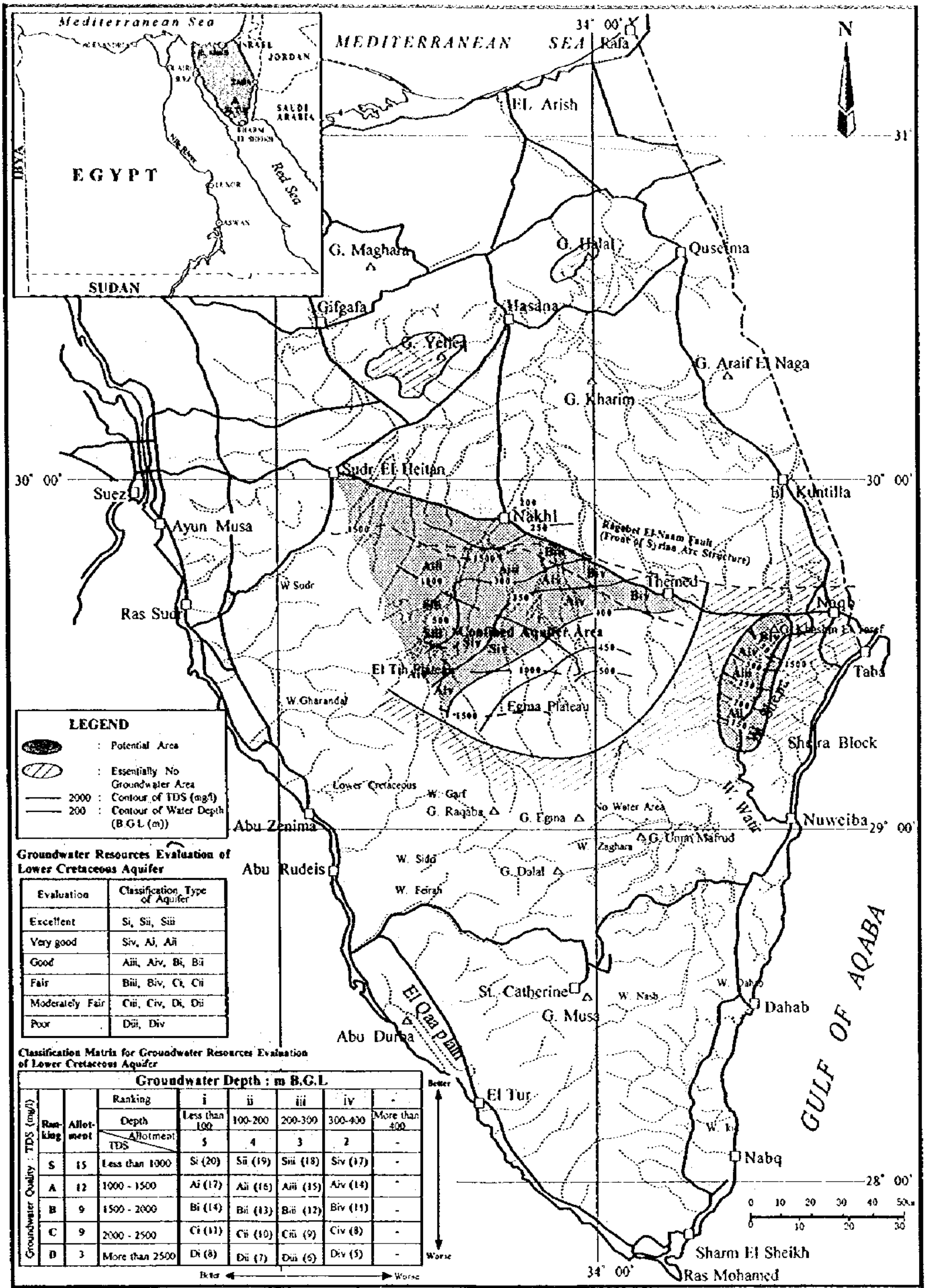
Classification Matrix for Groundwater Resources Evaluation of Lower Cretaceous Aquifer

			Groundwater Depth :B.G.L (m)				
		Ranking	I	II	III	IV	-
Ranking	Allotment	Depth	Less than 100	100-200	200-300	300-400	More than 400
		TDS / Allotment	5	4	3	2	-
S	15	Less than 1000	Si (20)	Sii (19)	Siii (18)	Siv (17)	-
A	12	1000 - 1500	Ai (17)	Aii (16)	Aiii (15)	Aiv (14)	-
B	9	1500 - 2000	Bi (14)	Bii (13)	Biii (12)	Biv (11)	-
C	6	2000 - 2500	Ci (11)	Cii (10)	Ciii (9)	Civ (8)	-
D	3	More than 2500	Di (8)	Dii (7)	Diii (6)	Div (5)	-

Groundwater Quality TDS (mg/l)

Better ← → Worse

Fig. 3.5-18 Groundwater Evaluation for Drinking (Lower Cretaceous)



LEGEND

- ● : Potential Area
- ▨ : Essentially No Groundwater Area
- —— 2000 : Contour of TDS (mg/l)
- —— 200 : Contour of Water Depth (B.G.L (m))

Groundwater Resources Evaluation of Lower Cretaceous Aquifer

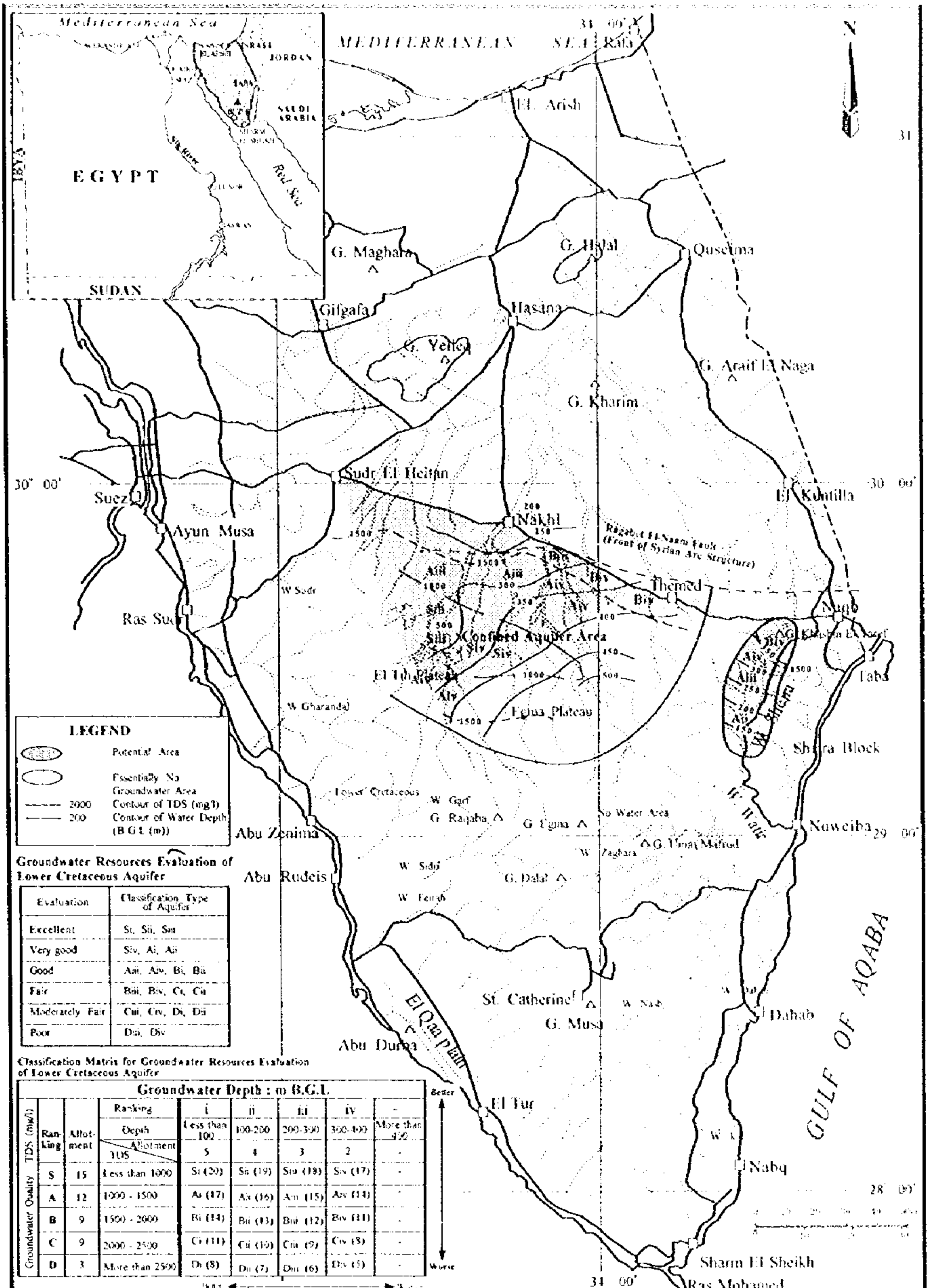
Evaluation	Classification Type of Aquifer
Excellent	Si, Sii, Siii
Very good	Siv, Ai, Aii
Good	Aiii, Aiv, Bi, Bii
Fair	Biii, Biv, Ci, Cii
Moderately Fair	Ciii, Civ, Di, Dii
Poor	Diii, Div

Classification Matrix for Groundwater Resources Evaluation of Lower Cretaceous Aquifer

Groundwater Quality : TDS (mg/l)			Groundwater Depth : m B.G.L					
	Ranking	Allotment	Ranking	i	ii	iii	iv	-
			Depth	Less than 100	100-200	200-300	300-400	More than 400
			Allotment / TDS	5	4	3	2	-
	S	15	Less than 1000	Si (20)	Sii (19)	Siii (18)	Siv (17)	-
	A	12	1000 - 1500	Ai (17)	Aii (16)	Aiii (15)	Aiv (14)	-
	B	9	1500 - 2000	Bi (14)	Bii (13)	Biii (12)	Biv (11)	-
	C	9	2000 - 2500	Ci (11)	Cii (10)	Ciii (9)	Civ (8)	-
	D	3	More than 2500	Di (8)	Dii (7)	Diii (6)	Div (5)	-

Better ← → Worse

Fig. 3.5-19 Groundwater Evaluation for Irrigation (Lower Cretaceous)



LEGEND

▨	Potential Area
○	Essentially No Groundwater Area
- - - - 2000	Contour of TDS (mg/l)
—— 200	Contour of Water Depth (B.G.L (m))

Groundwater Resources Evaluation of Lower Cretaceous Aquifer

Evaluation	Classification Type of Aquifer
Excellent	Si, Sii, Siii
Very good	Siv, Ai, Aii
Good	Aiii, Aiv, Bi, Bii
Fair	Biii, Biv, Ci, Cii
Moderately Fair	Ciii, Civ, Di, Dii
Poor	Diii, Div

Classification Matrix for Groundwater Resources Evaluation of Lower Cretaceous Aquifer

Groundwater Quality TDS (mg/l)			Groundwater Depth : m B.G.L					
			Ranking	i	ii	iii	iv	-
	Ranking	Allotment	Depth	Less than 100	100-200	200-300	300-400	More than 400
			TDS / Allotment	5	4	3	2	-
	S	15	Less than 1000	Si (20)	Sii (19)	Siii (18)	Siv (17)	-
	A	12	1000 - 1500	Ai (17)	Aii (16)	Aiii (15)	Aiv (14)	-
	B	9	1500 - 2000	Bi (14)	Bii (13)	Biii (12)	Biv (11)	-
	C	9	2000 - 2500	Ci (11)	Cii (10)	Ciii (9)	Civ (8)	-
	D	3	More than 2500	Di (8)	Dii (7)	Diii (6)	Div (5)	-

Better ◄———► Worse

Fig. 3.5-19 Groundwater Evaluation for Irrigation (Lower Cretaceous)

3.6 Paleozoic

The Paleozoic Formations are widely distributed in the upstream area of the Wadi Zalaga and the Wadi Garf. The Paleozoic Formation is completely overlain by the younger formation in the Wadi Gharandal area. Distribution of the aquifer is cut by the fault in the west and continues to the El Tih Plateau area in the east.

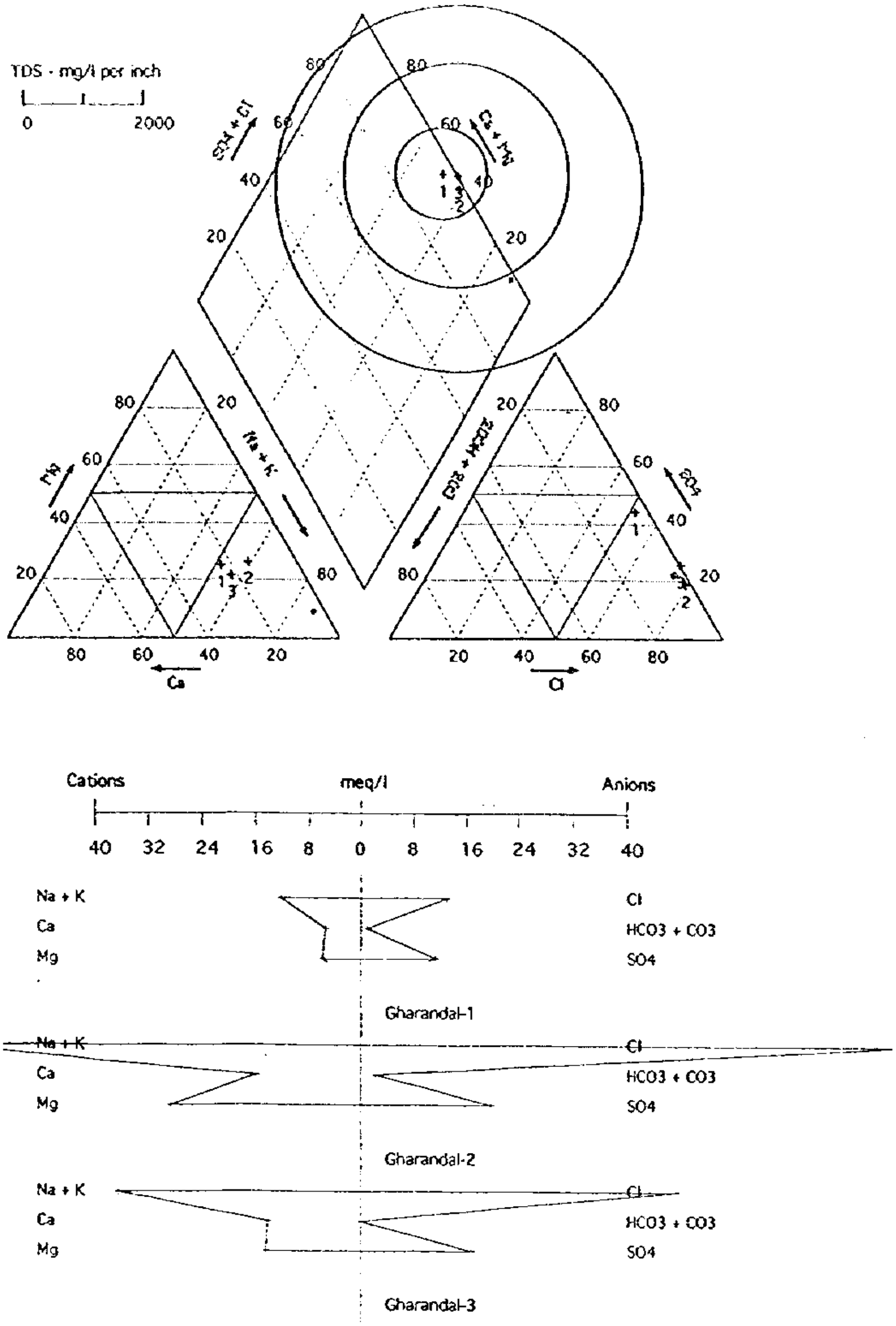
The well Gharandal-3 reached the Paleozoic Formation. Its facies is sandstone. Groundwater level is 96.9 mBGL, while the screen was installed from 656 to 770 m depth. Thus, groundwater in the Paleozoic aquifer is confined.

TDS value of the aquifer is 5,060 mg/l which is much higher than that of the Drinking Water Standard. Ion compositions of groundwater in the Wadi Gharandal are also plotted in Fig. 3.6-1 together with that of the Upper Cretaceous and the Lower Cretaceous aquifers. They are plotted in the similar position. It is suggested that groundwater of these aquifers are mixed each other. It may be caused by the geological turbulence in the area.

The Paleozoic Formation is also confirmed in other wells, Sheira-1 and J-5. However, screen was not installed in these wells.

In addition, some dug wells may collect groundwater in the Paleozoic Formation in the Wadi Garf, however, most of dug well in the area are dug into the Quaternary Formation. The Paleozoic Aquifer is recharged by rain and flood water in the Wadi Garf because the Aquifer crops out widely in the catchment area.

As mentioned before, the Paleozoic Aquifers may be recharged by surface water in the Wadi Zalaga and the Wadi Garf.



Gharandal-1: Lower Cretaceous aquifer
Gharandal-2: Upper Cretaceous aquifer
Gharandal-3: Paleozoic aquifer

Fig. 3.6-1 Piper and Stiff Diagram (Wadi Gharandal)