Table 8.3.2-1 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	290.38	253.62	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			

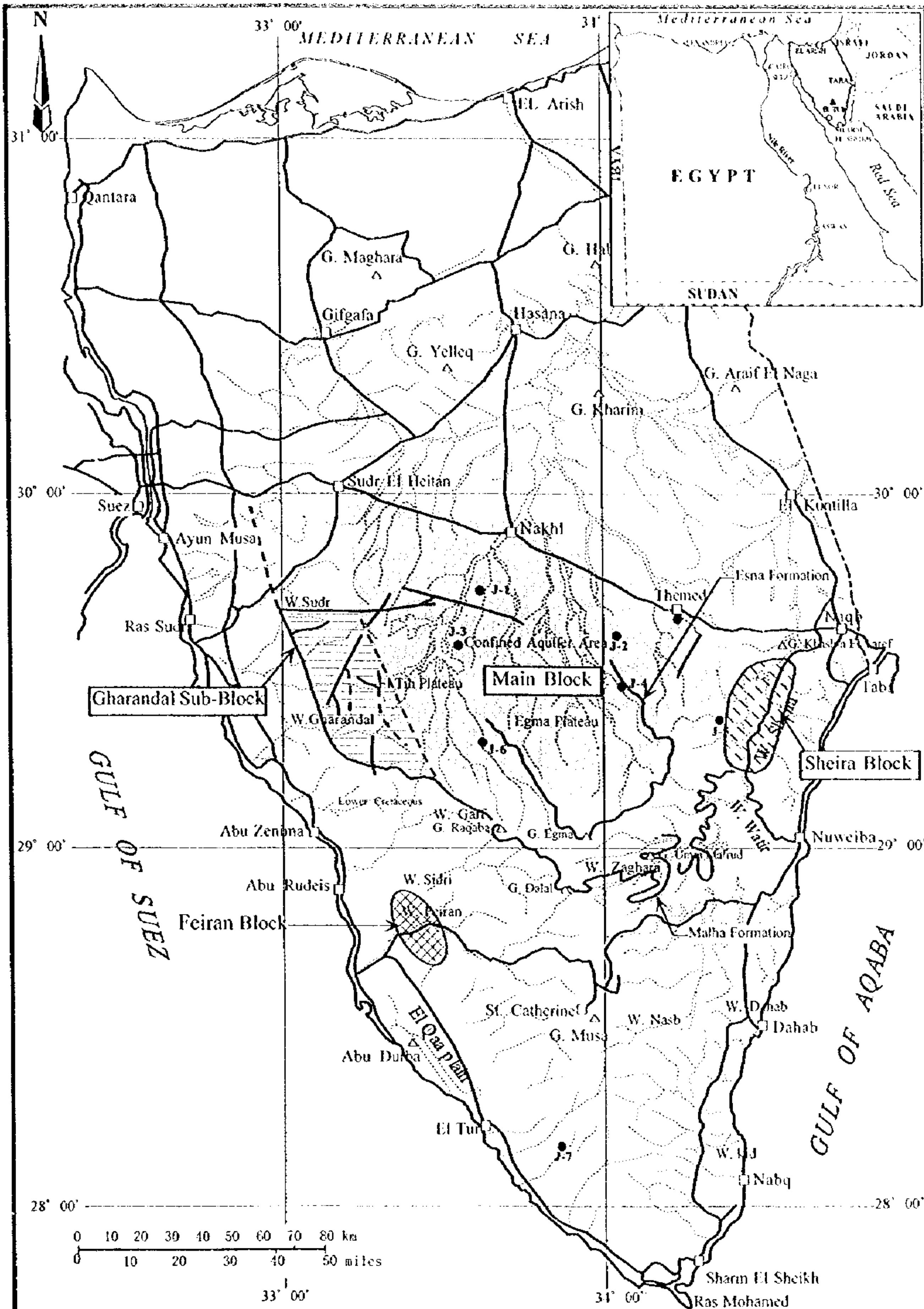


Fig. 8.3.2-1 Distribution of Lower Cretaceous Aquifer

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

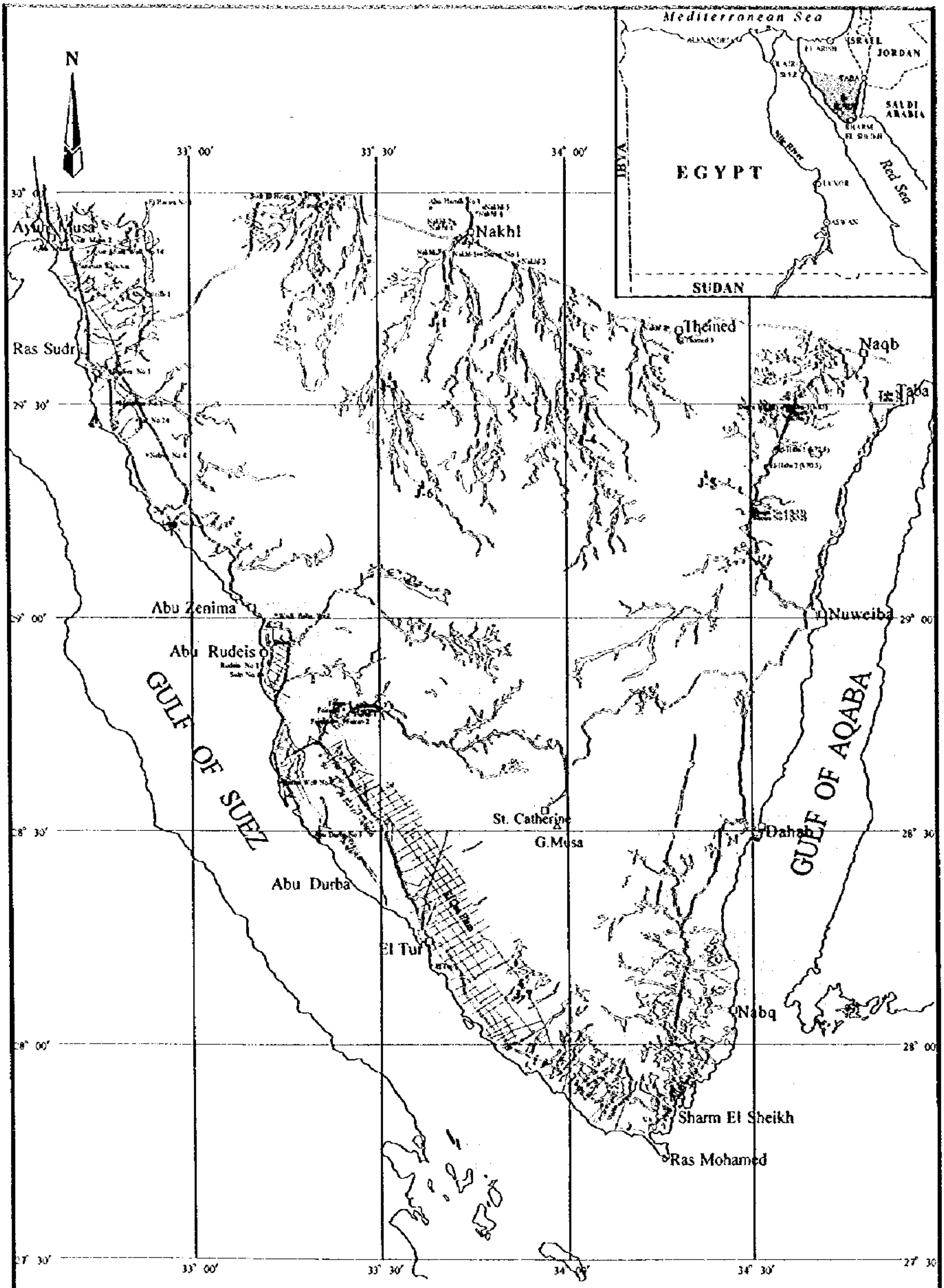


Fig. 8.3.2-2 Well Location (Key Map : Lower Cretaceous)

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

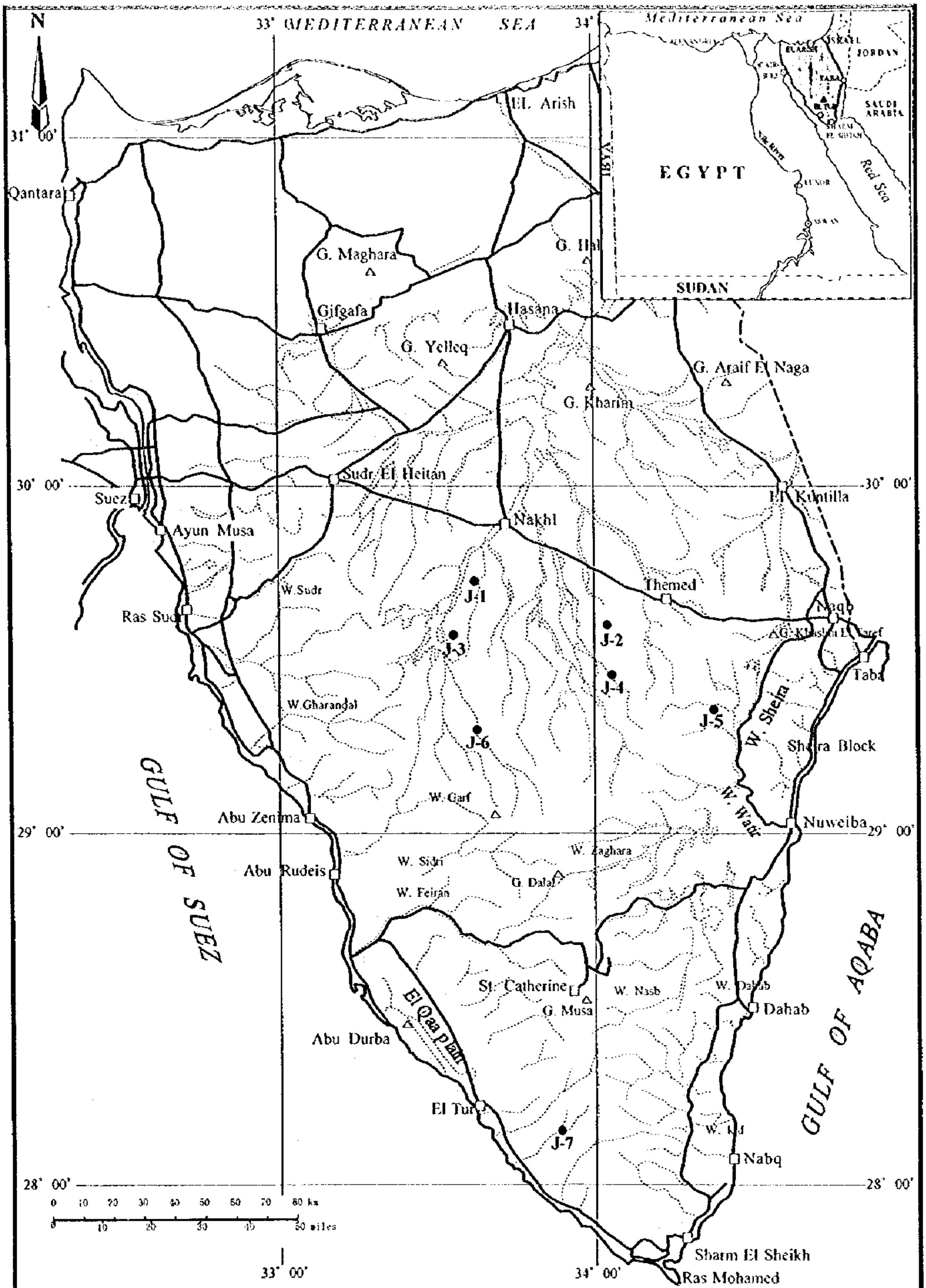


Fig. 8.3.2-3 Well Location (JICA Wells : Lower Cretaceous)

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

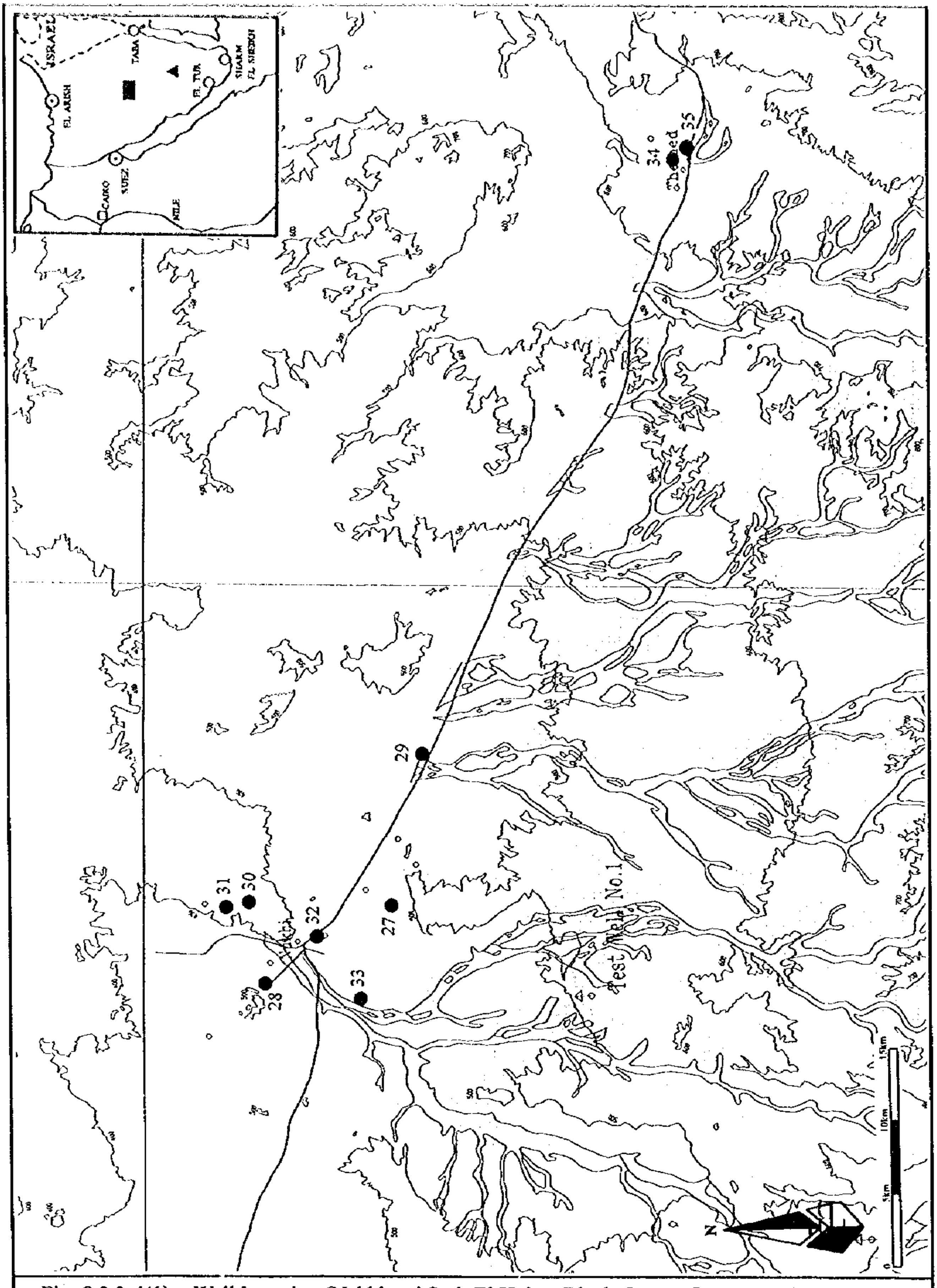


Fig. 8.3.2-4(1) Well Location (Nakhl and Sudr El Heitan Block: Lower Cretaceous)

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

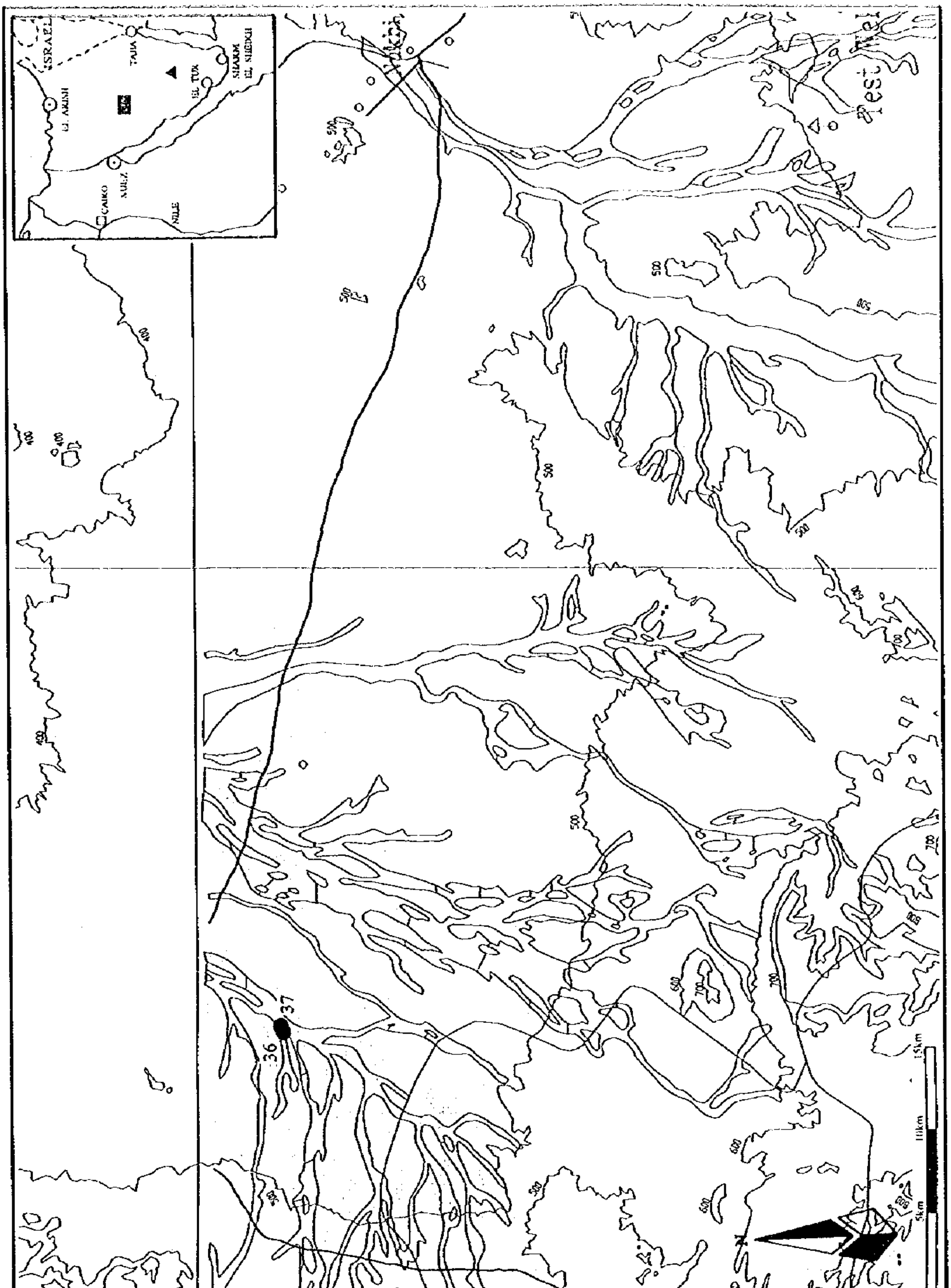


Fig. 8.3.2-4(2) Well Location (Nakhl and Sudr El Heitan Block: Lower Cretaceous)

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

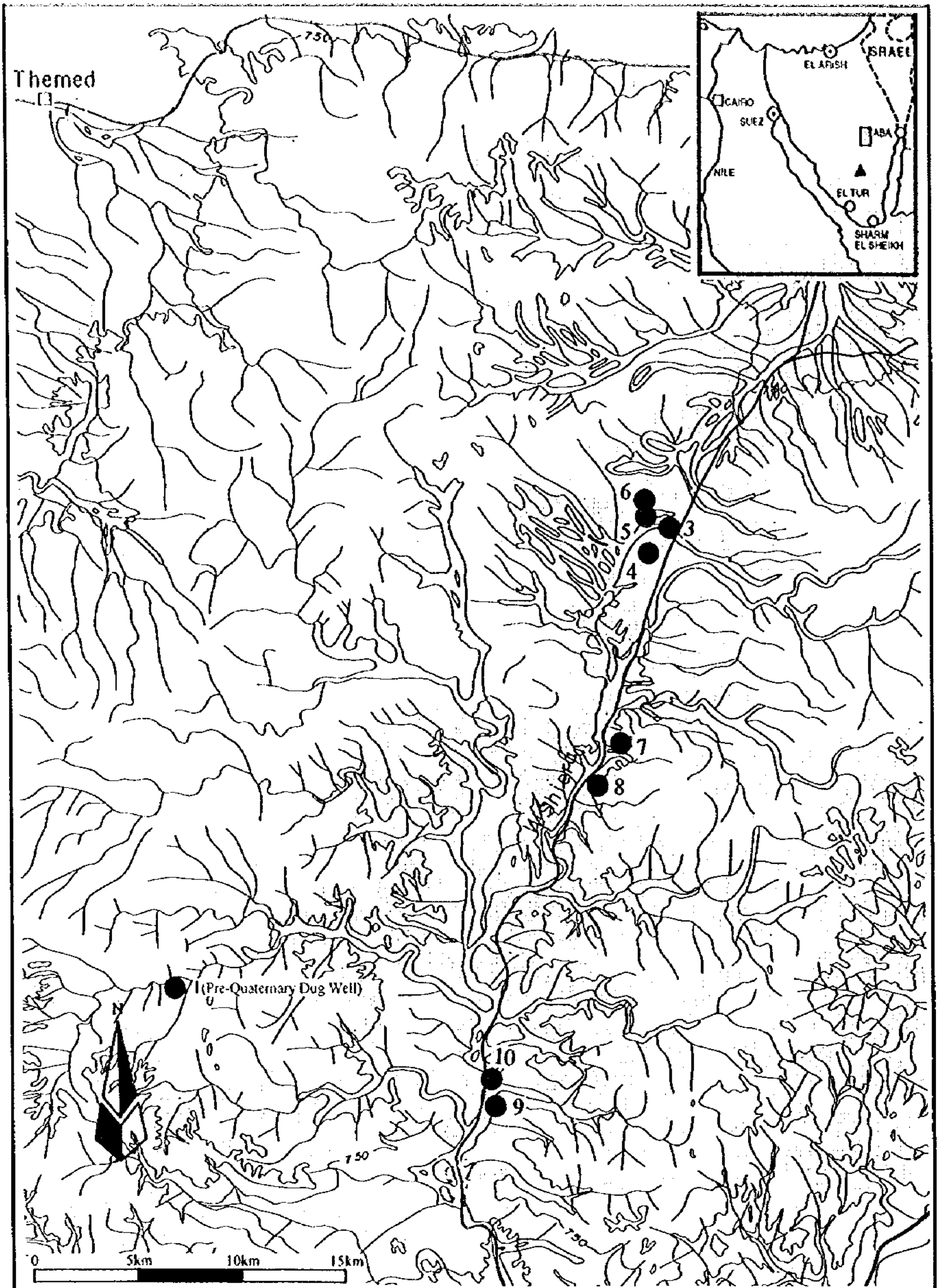


Fig. 8.3.2-5 Well Location (Sheira Block: Lower Cretaceous)

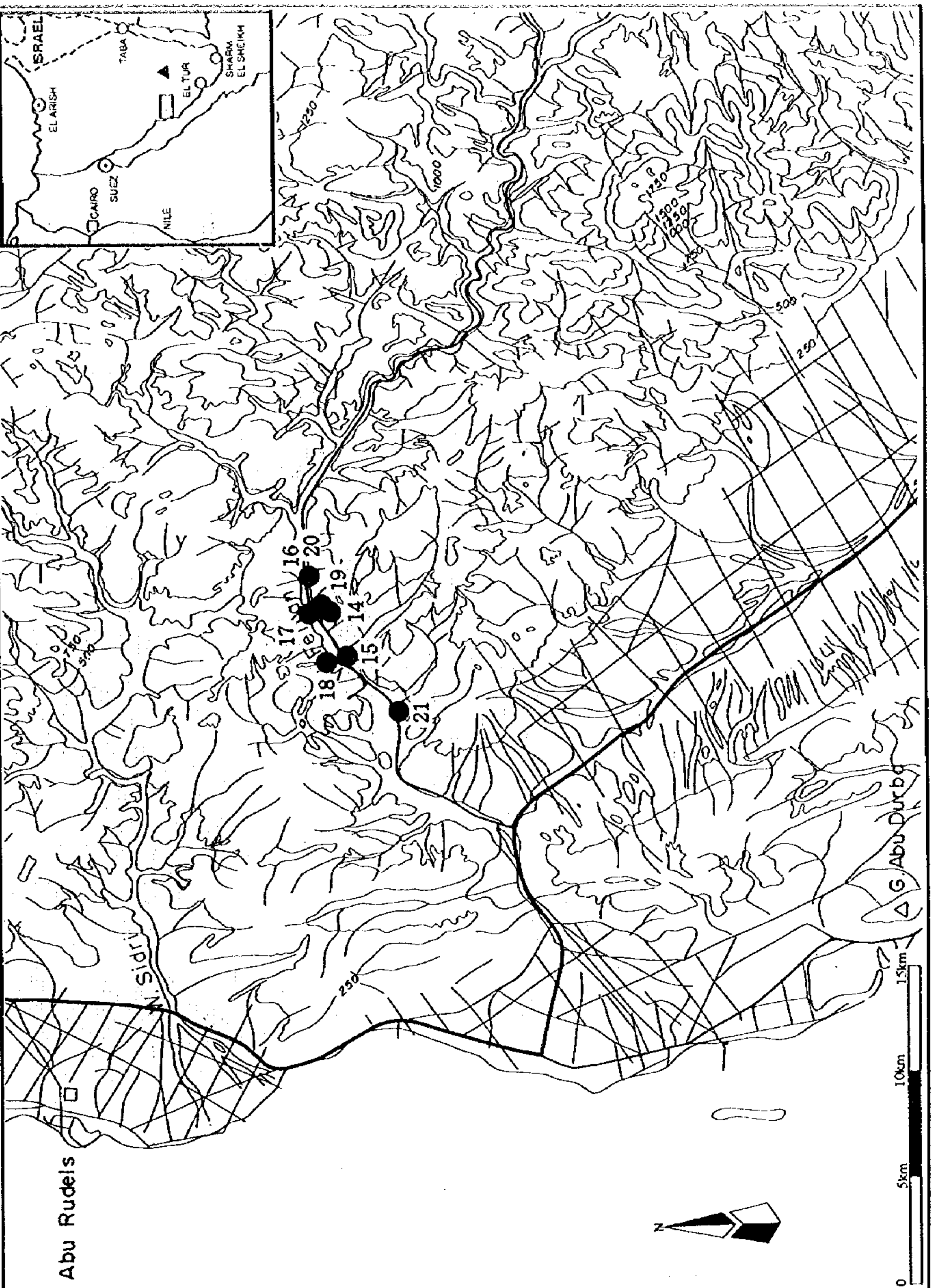


Fig. 8.3.2-6 Well Location (Feiran Block: Lower Cretaceous)

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

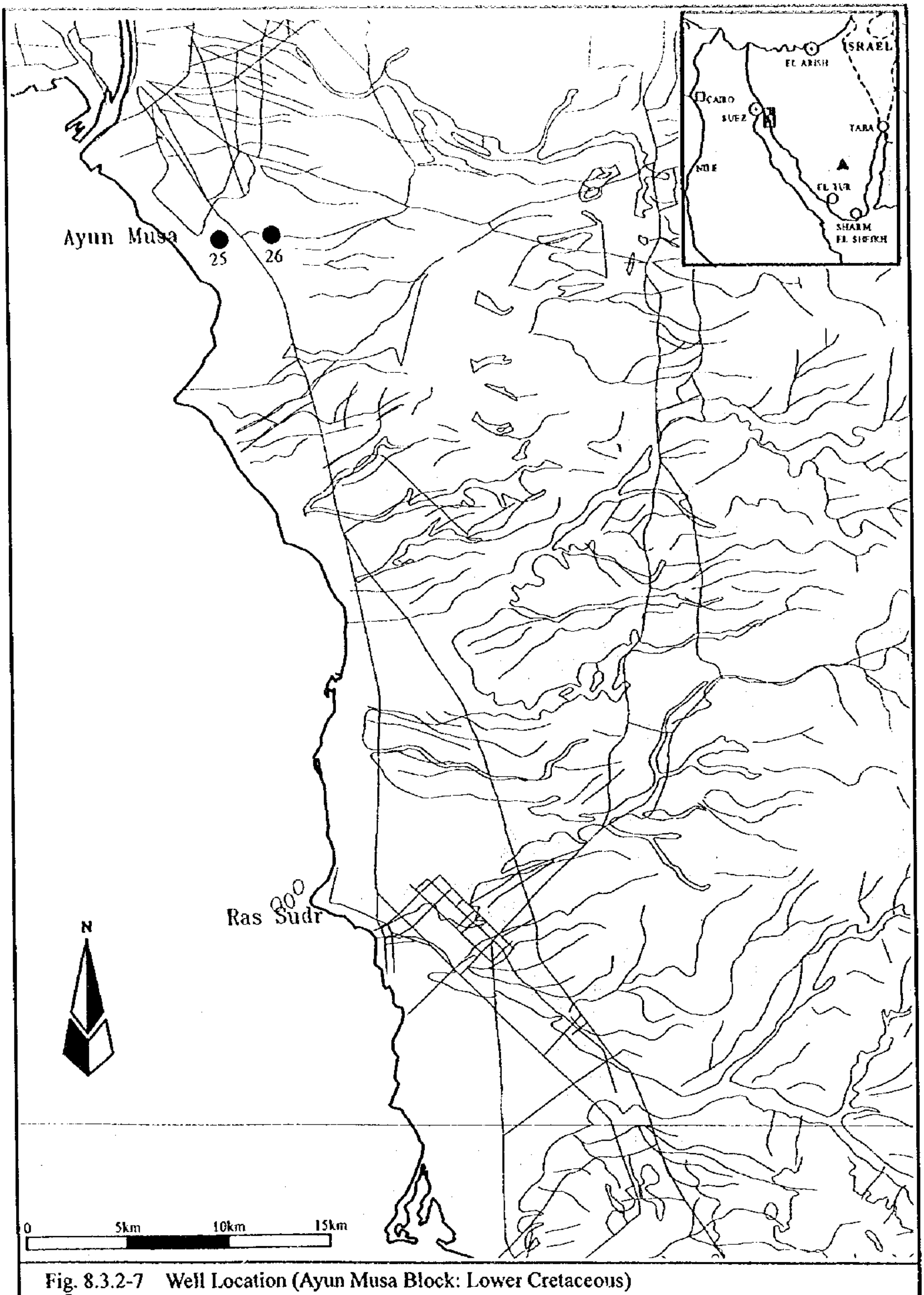


Fig. 8.3.2-7 Well Location (Ayun Musa Block: Lower Cretaceous)

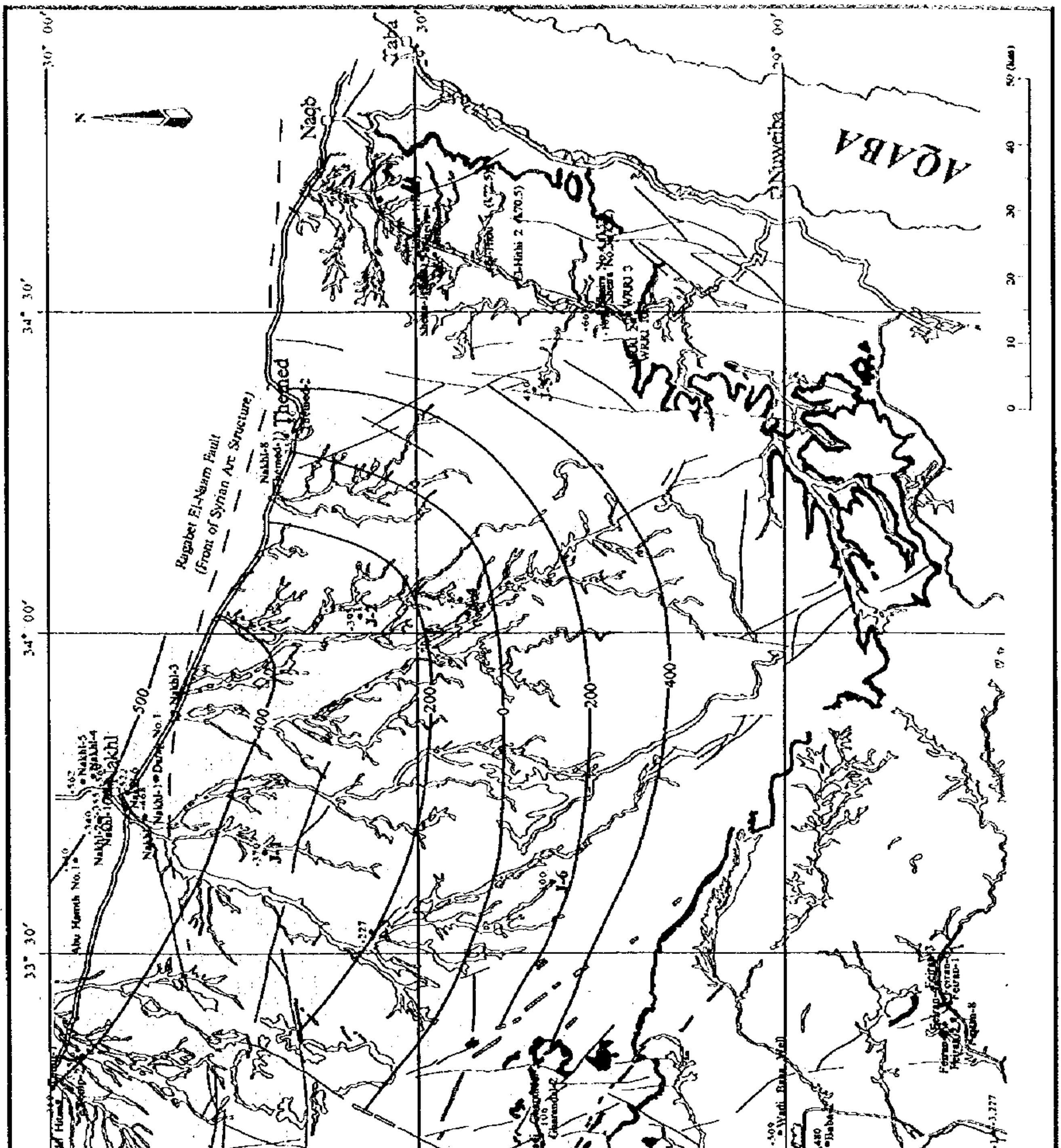


Fig. 8.3.2-8 Top of Lower Cretaceous

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

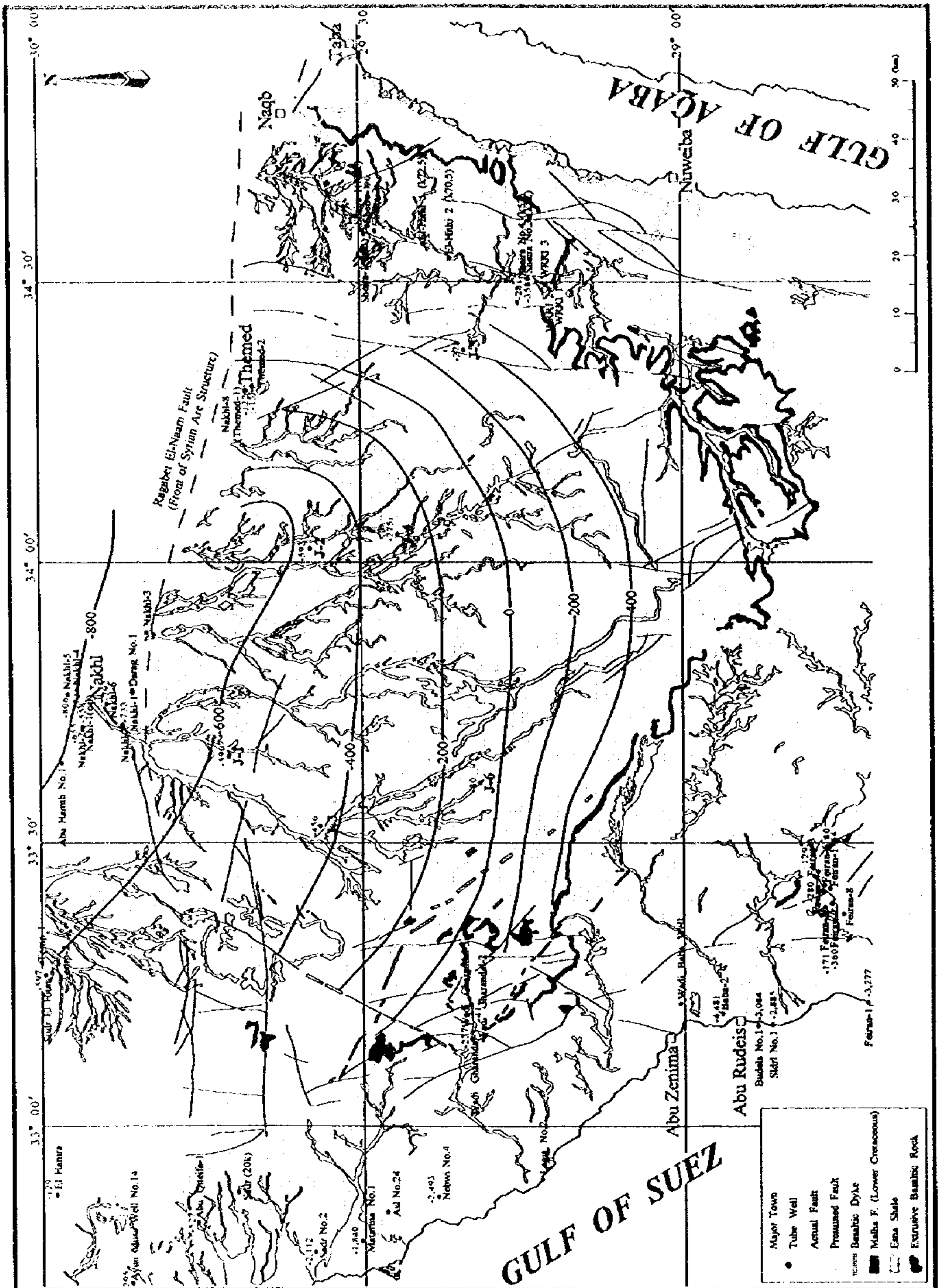


Fig. 8.3.2-9 Bottom of Lower Cretaceous

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

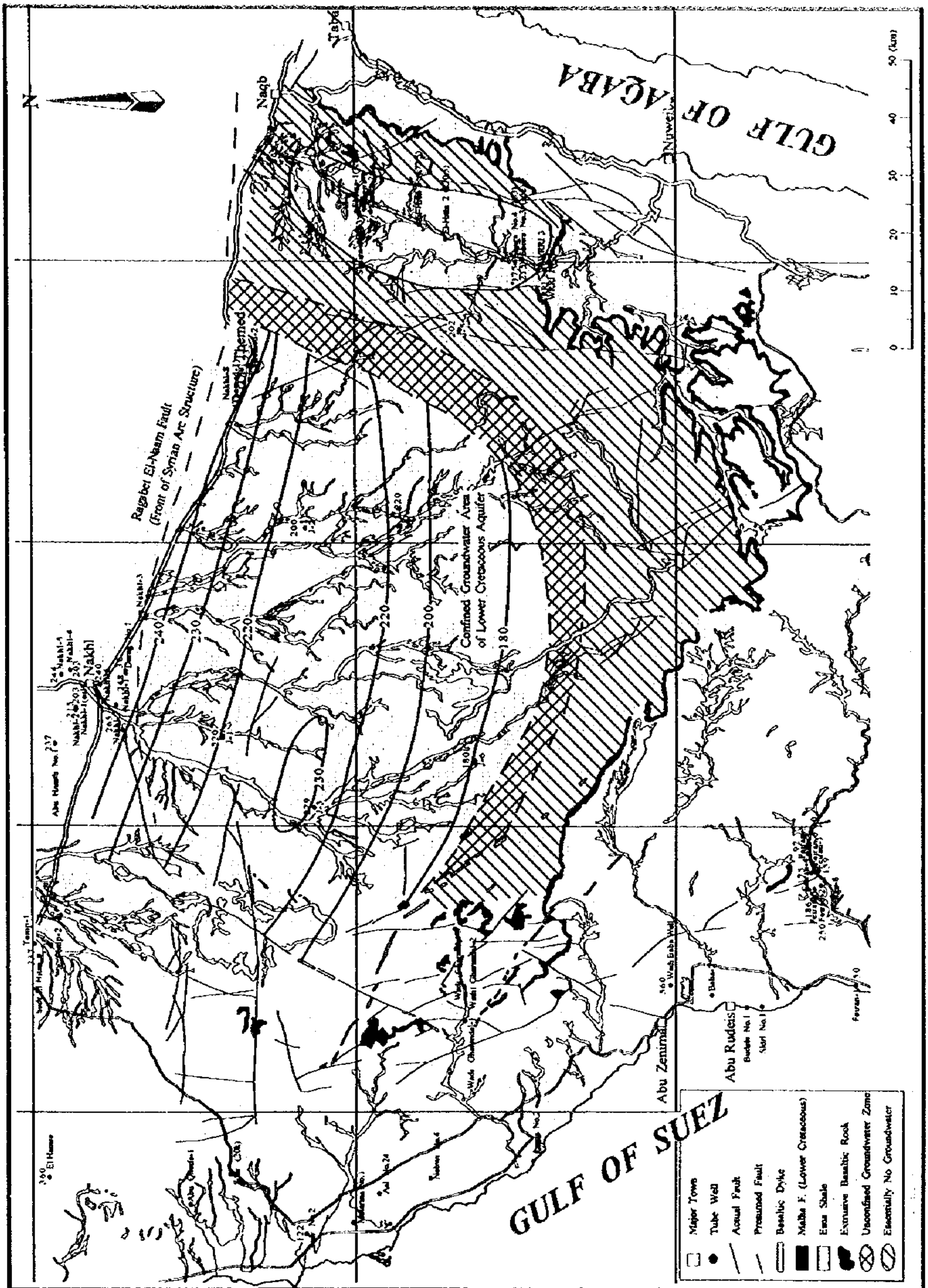


Fig. 8.3.2-10 Isopach Map of Lower Cretaceous

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

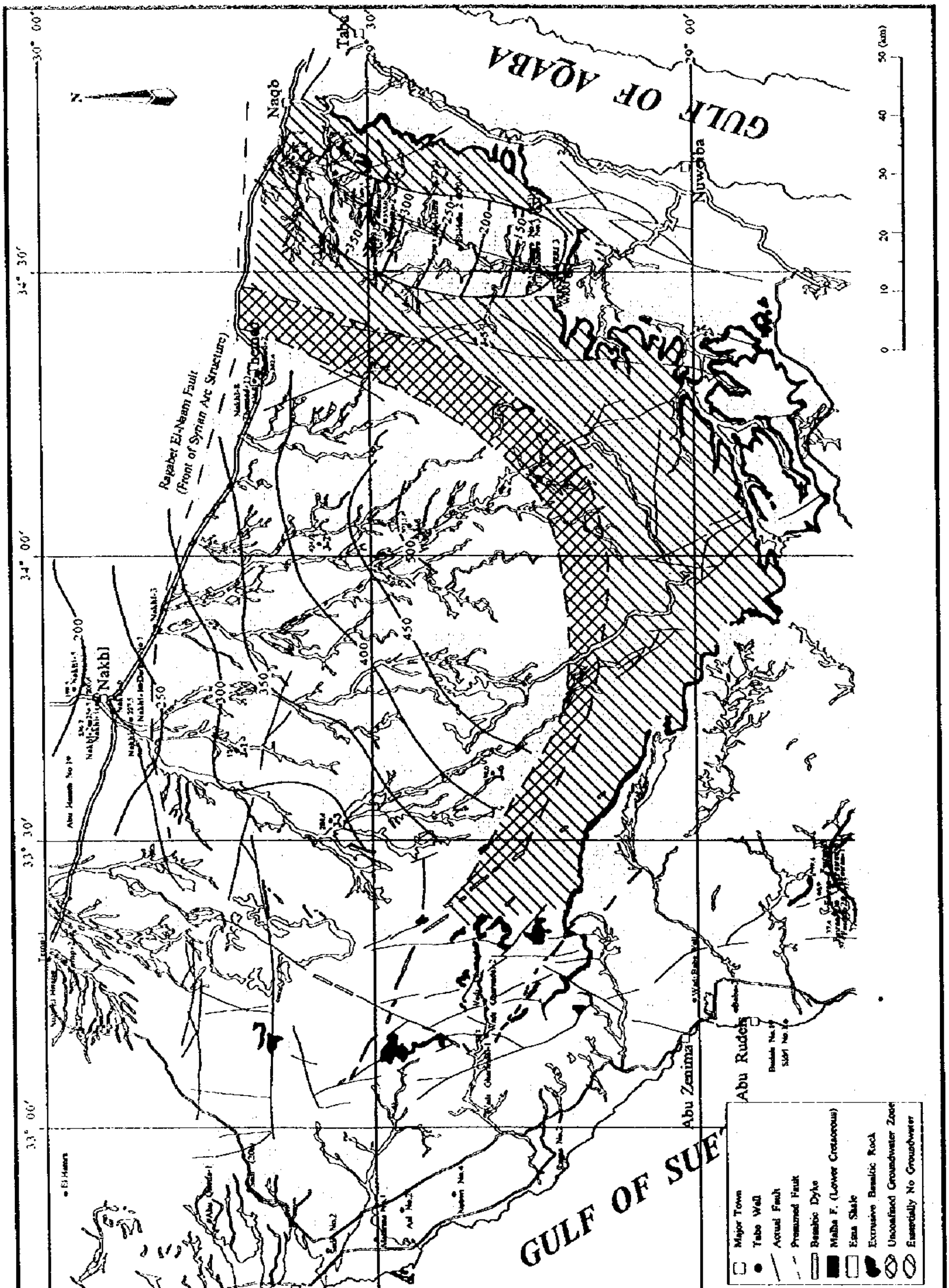


Fig. 8.3.2-11 Groundwater Level (m B.G.L : Lower Cretaceous)

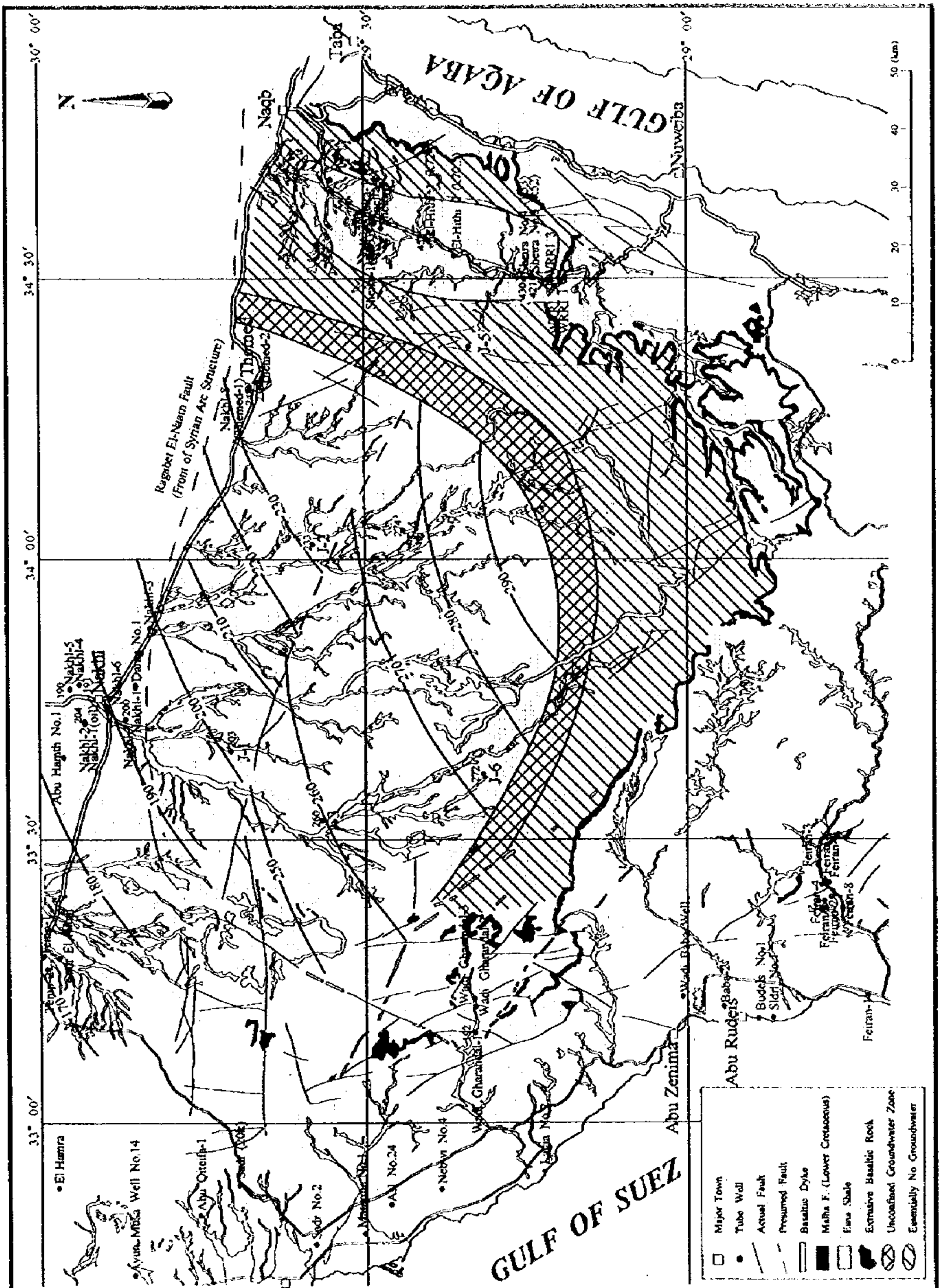


Fig. 8.3.2-12 Groundwater Level (m A.S.L : Lower Cretaceous)

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

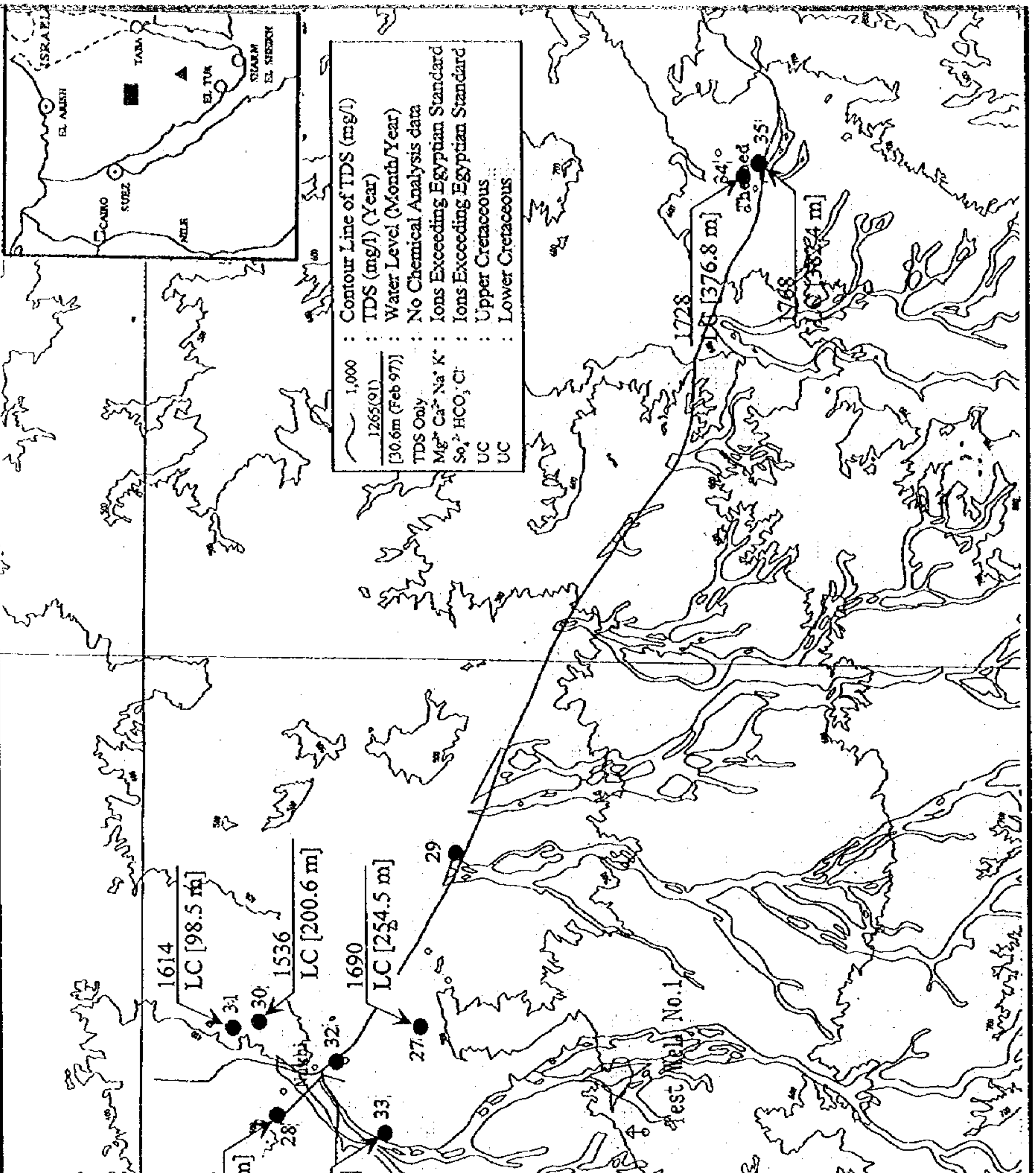


Fig. 8.3.2-13(1) Groundwater Level/Quality (Nakhl and Sudr El Heitan Block: Lower Cretaceous) (Unit: mBGL)

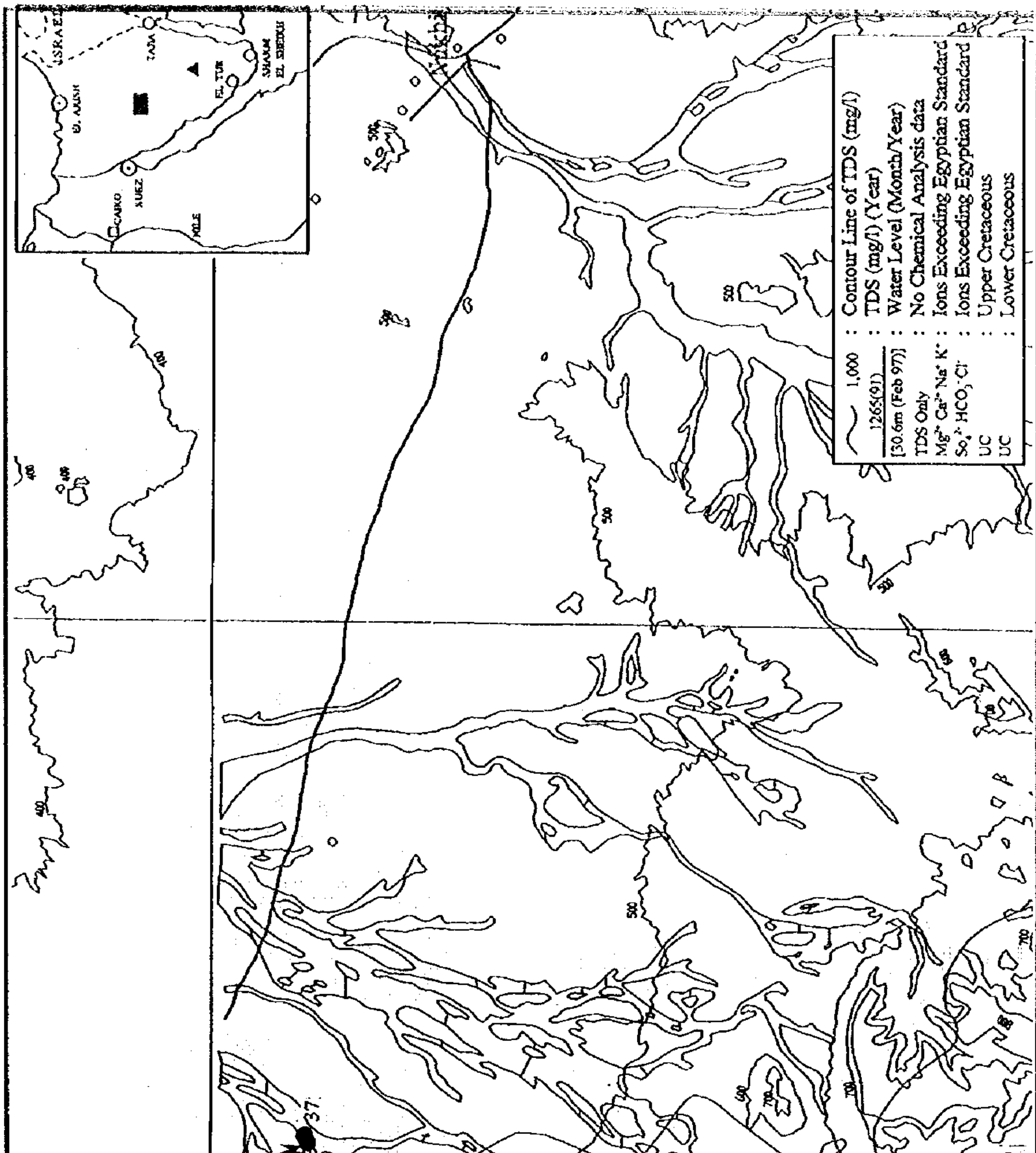


Fig. 8.3.2-13(2) Groundwater Level/Quality (Nakhl and Sudr El Heitan Block: Lower Cretaceous) (Unit: mBGL)

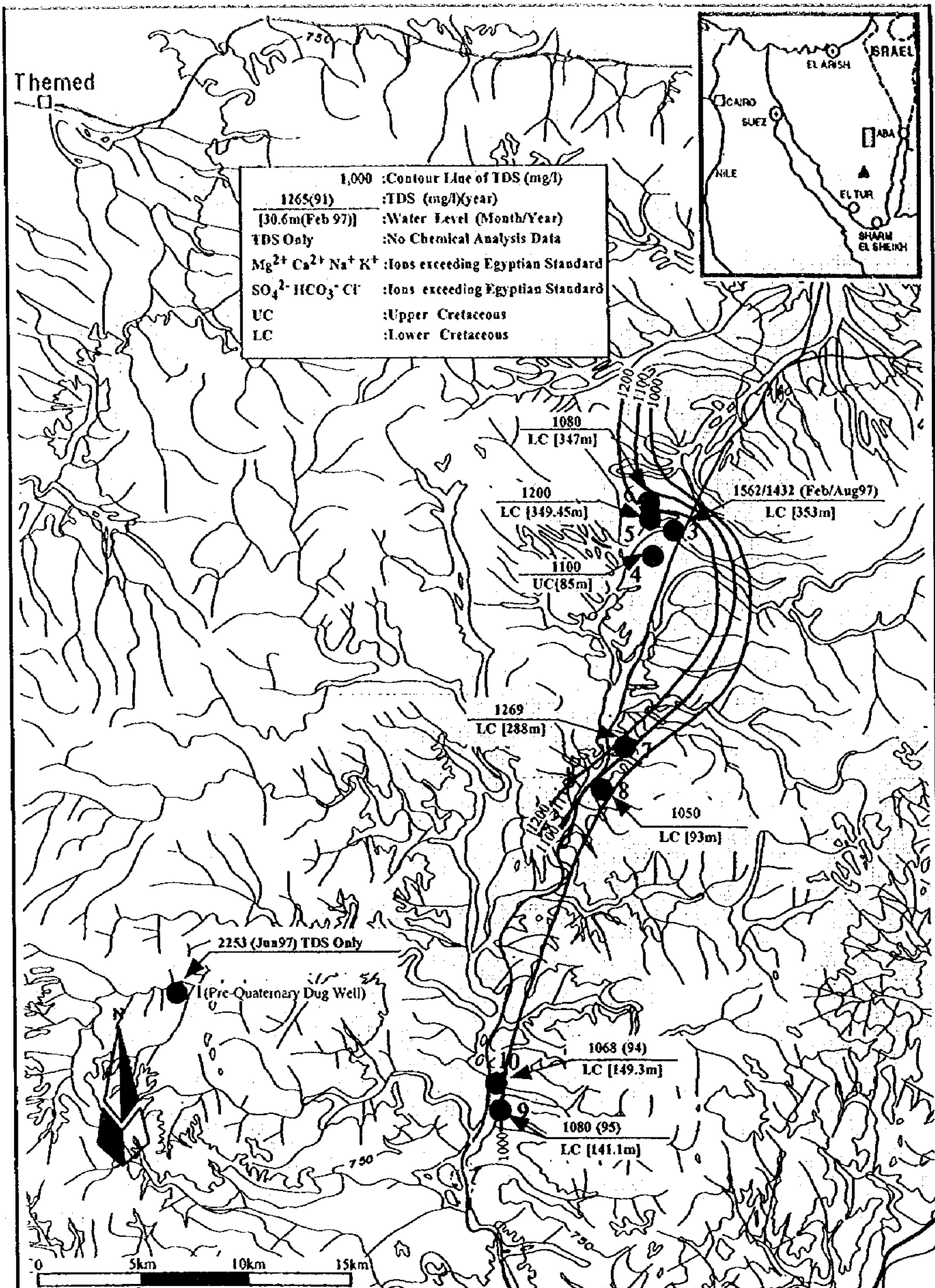


Fig. 8.3.2-14 Groundwater Level/Quality (Sheira Block: Lower Cretaceous) (Unit: mBGL)

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

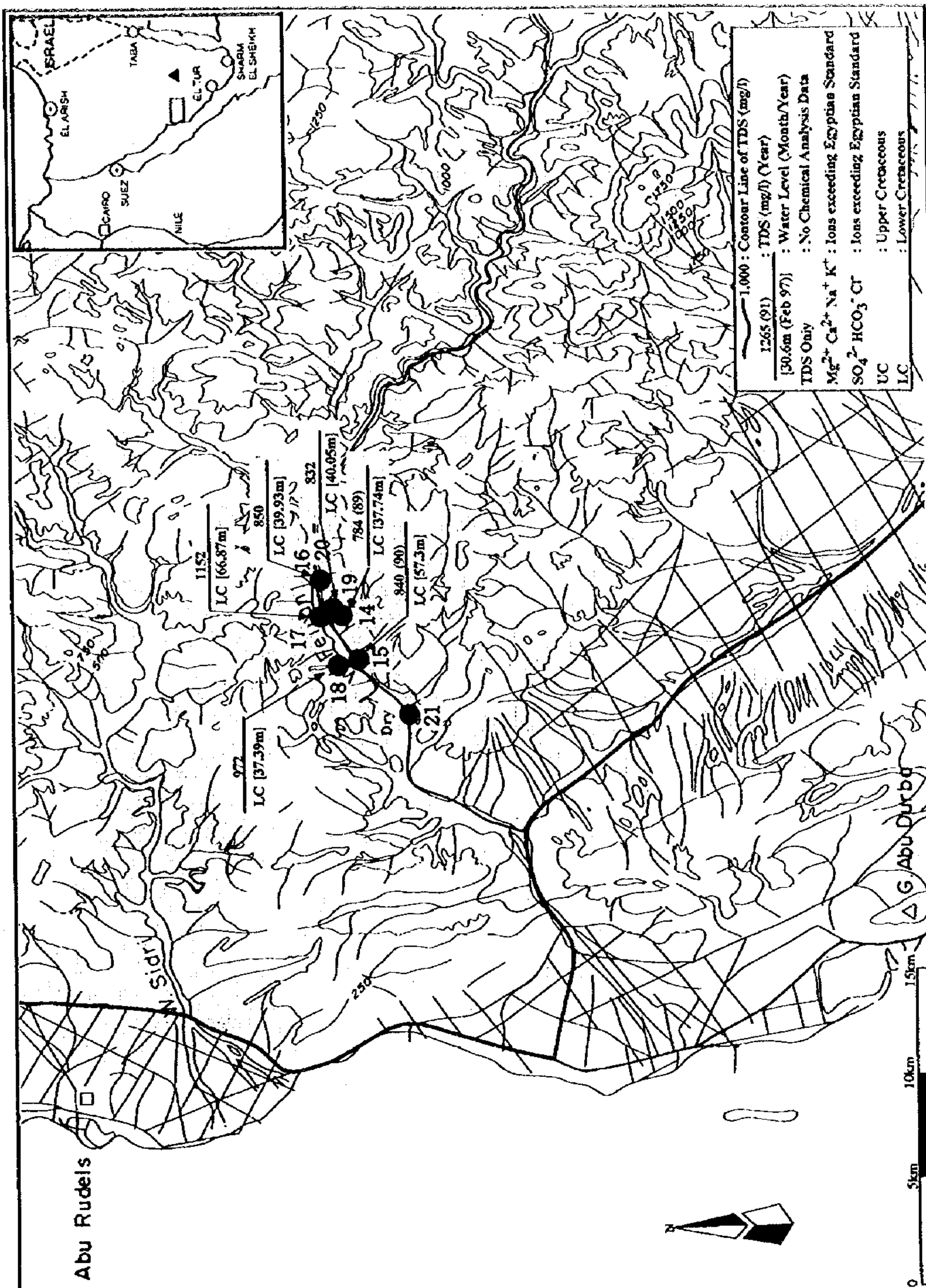


Fig. 8.3.2-15 Groundwater Level/Quality (Feiran Block: Lower Cretaceous) (Unit: mBGL)

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

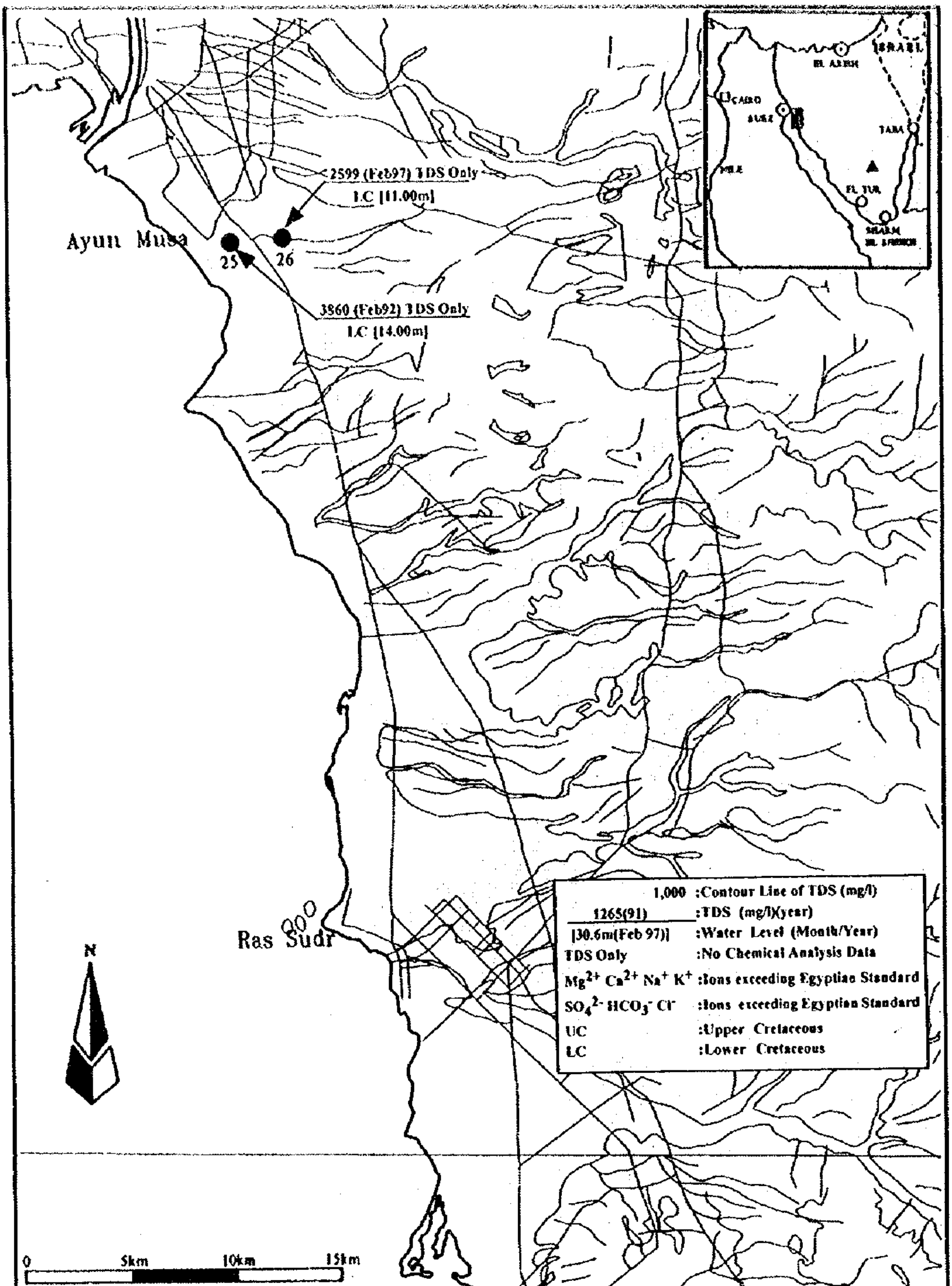
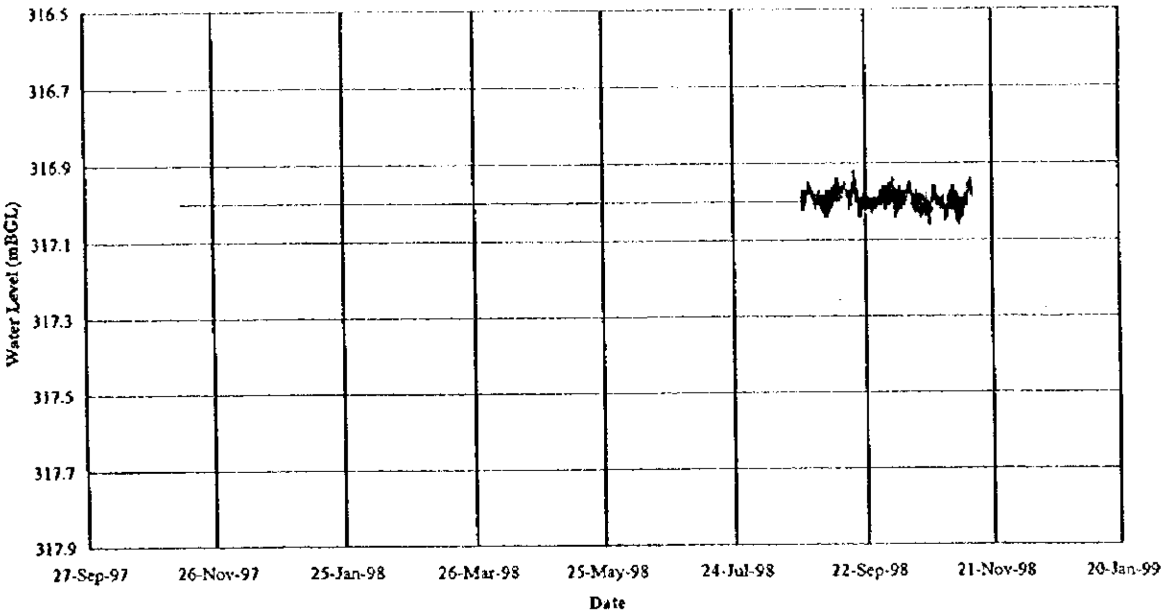


Fig. 8.3.2-16 Groundwater Level/Quality (Ayun Musa Block: Lower Cretaceous) (Unit: mBGL)

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

J-1



J-2

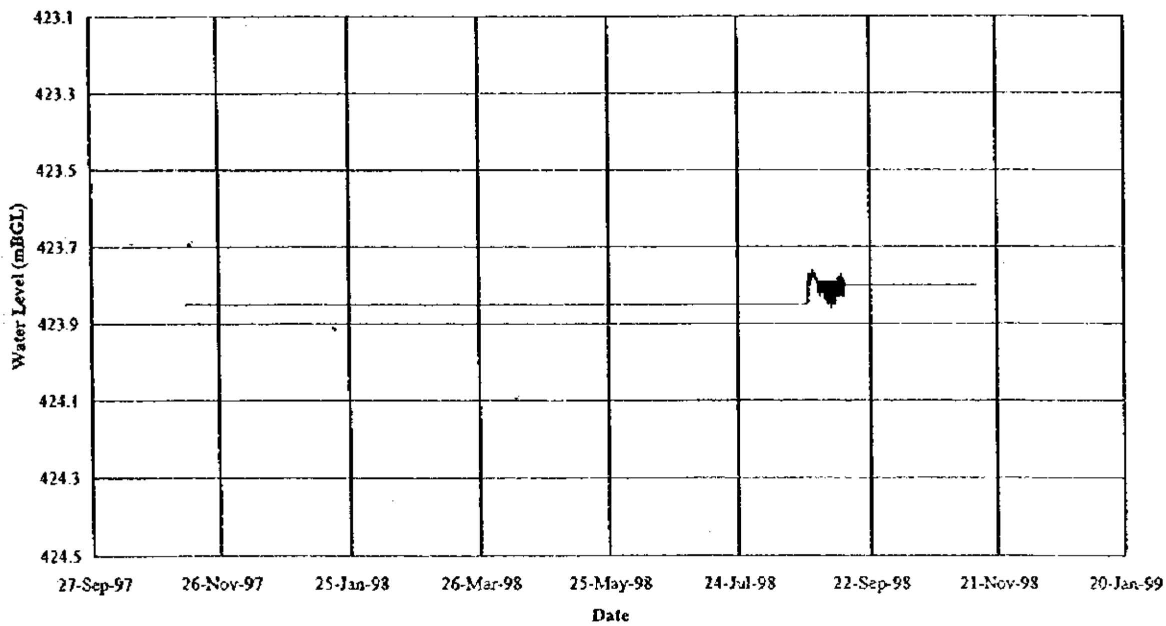
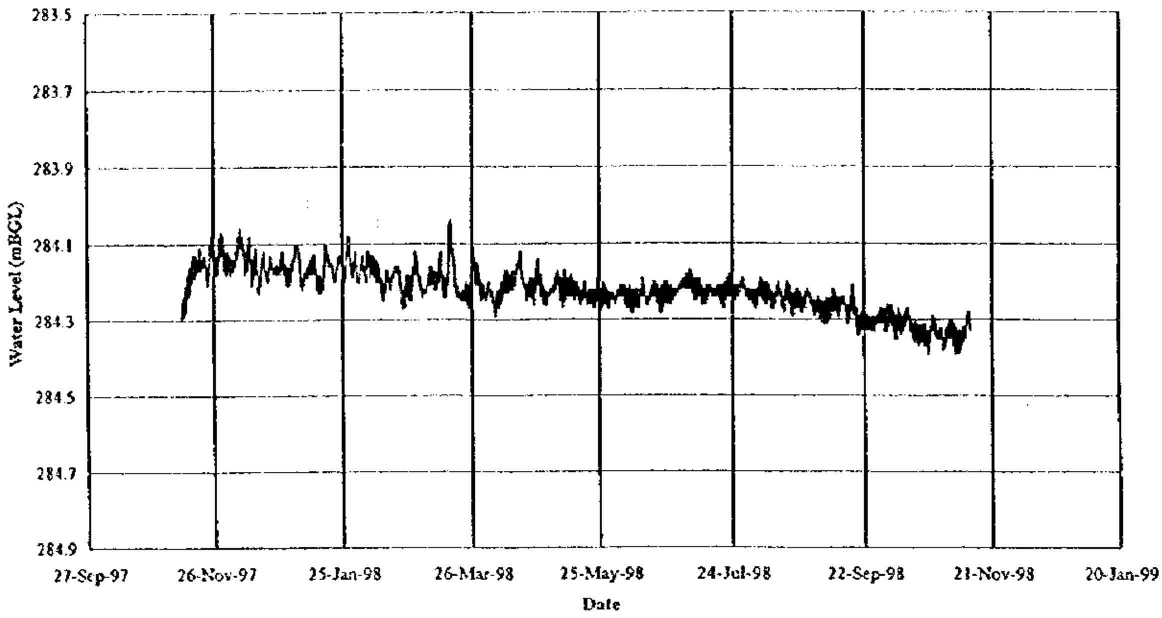


Fig. 8.3.2-17 Groundwater Table Oscillation (J-1 and J-2)

J-3



J-4

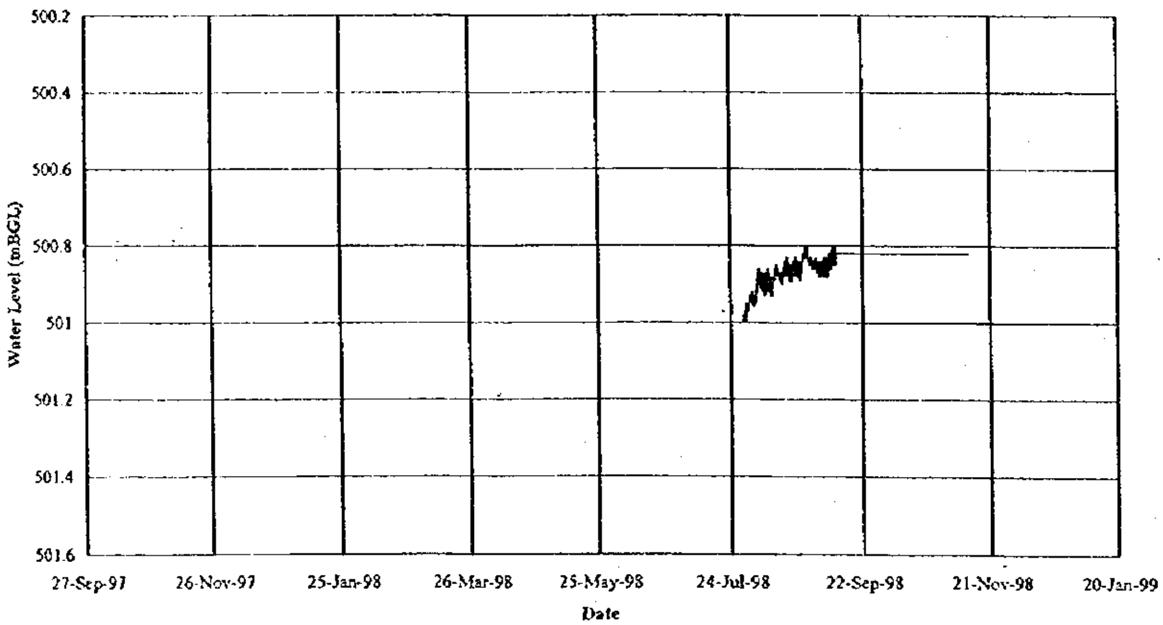


Fig. 8.3.2-18 Groundwater Table Oscillation (J-3 and J-4)

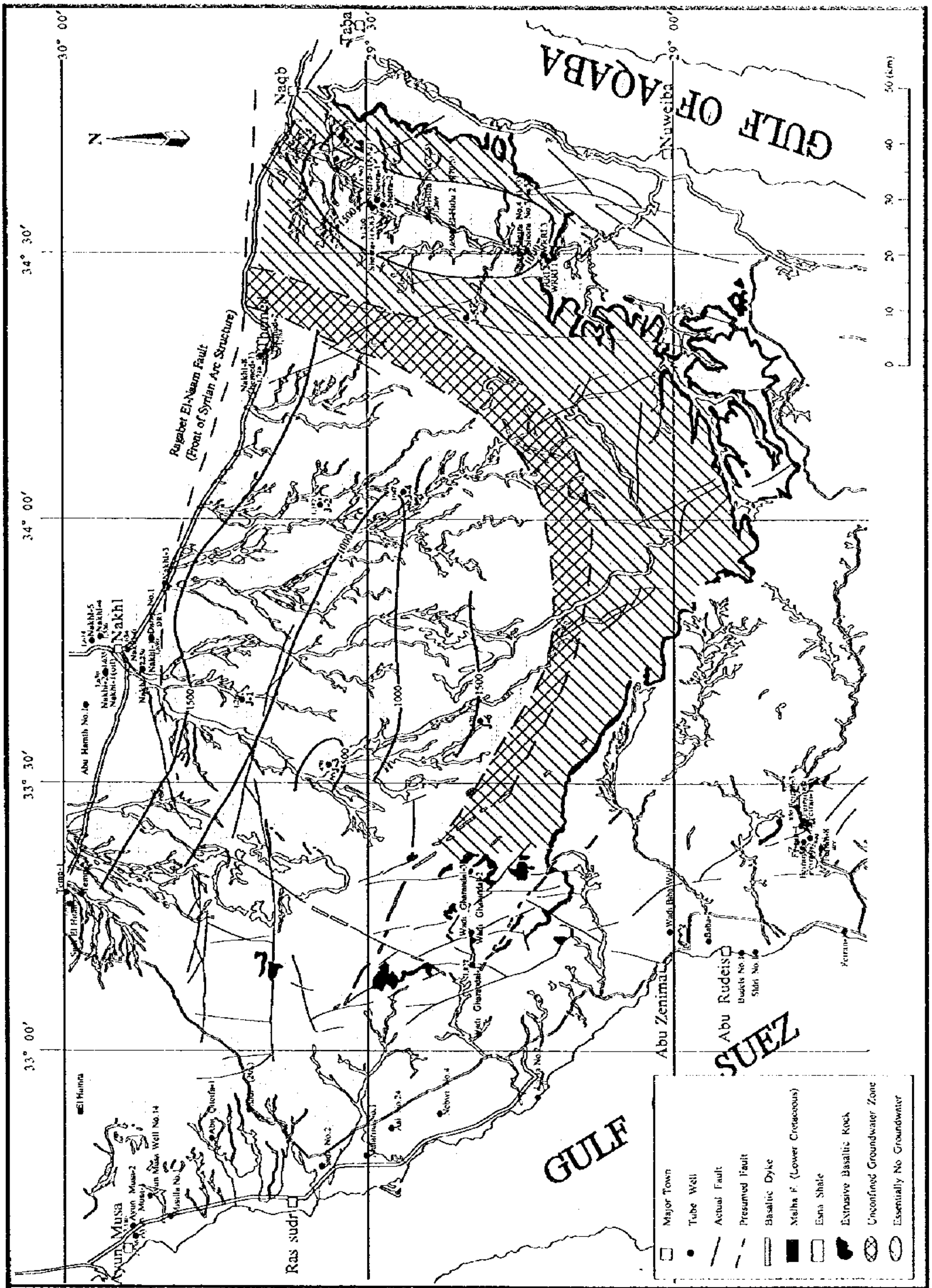


Fig. 8.3.2-19 Groundwater Quality (Lower Cretaceous)

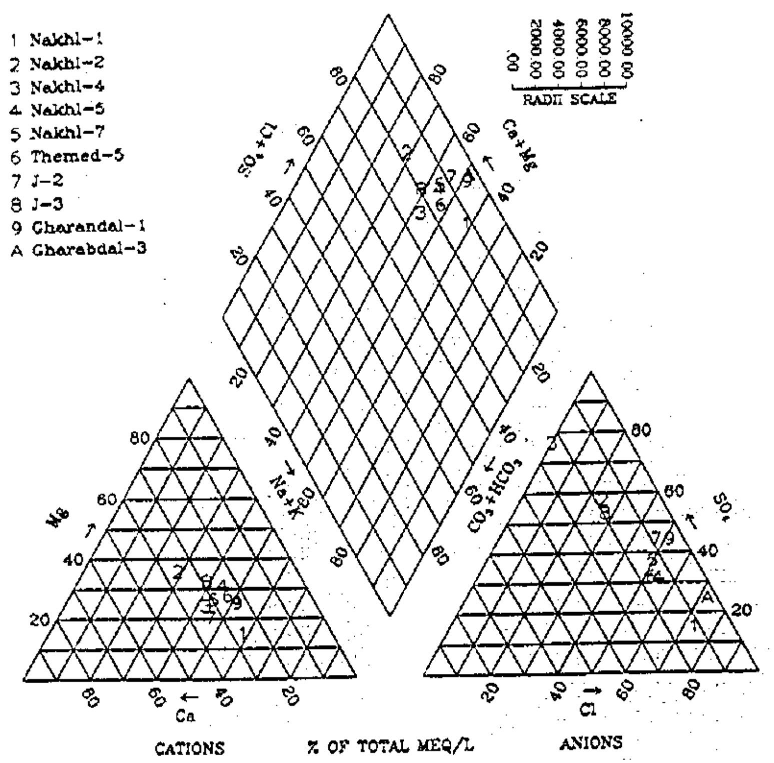


Fig. 8.3.2-20 Piper Diagram (Main Block: Lower Cretaceous)

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

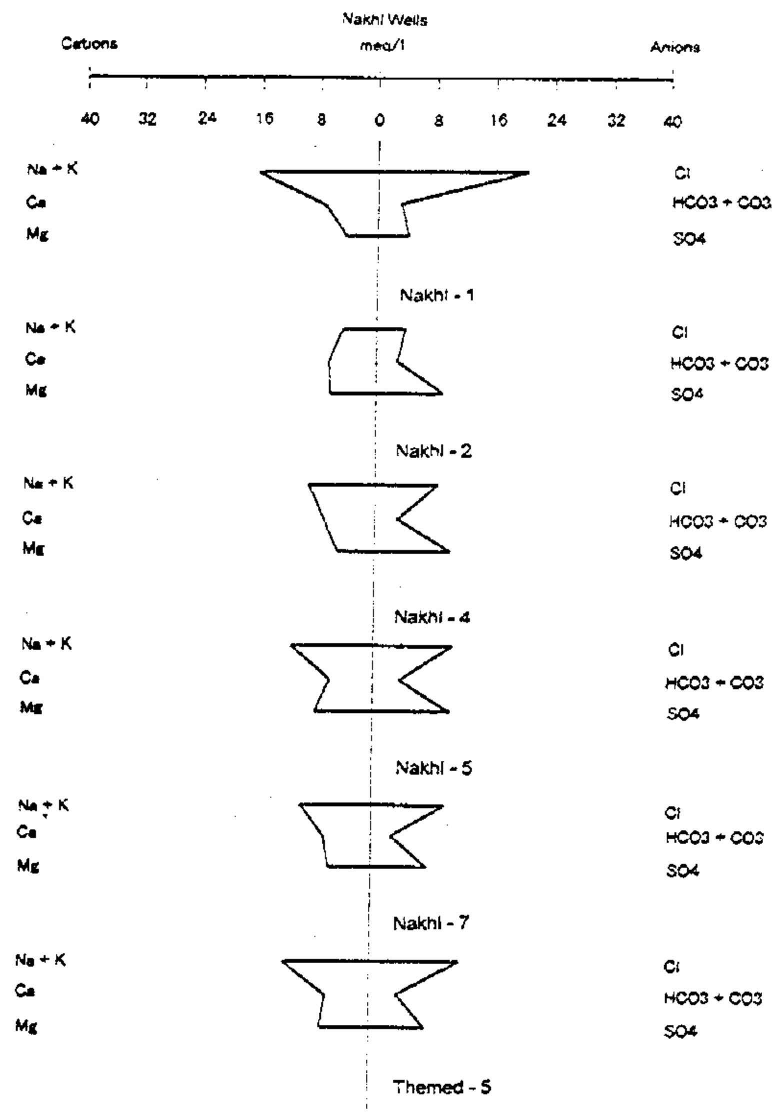
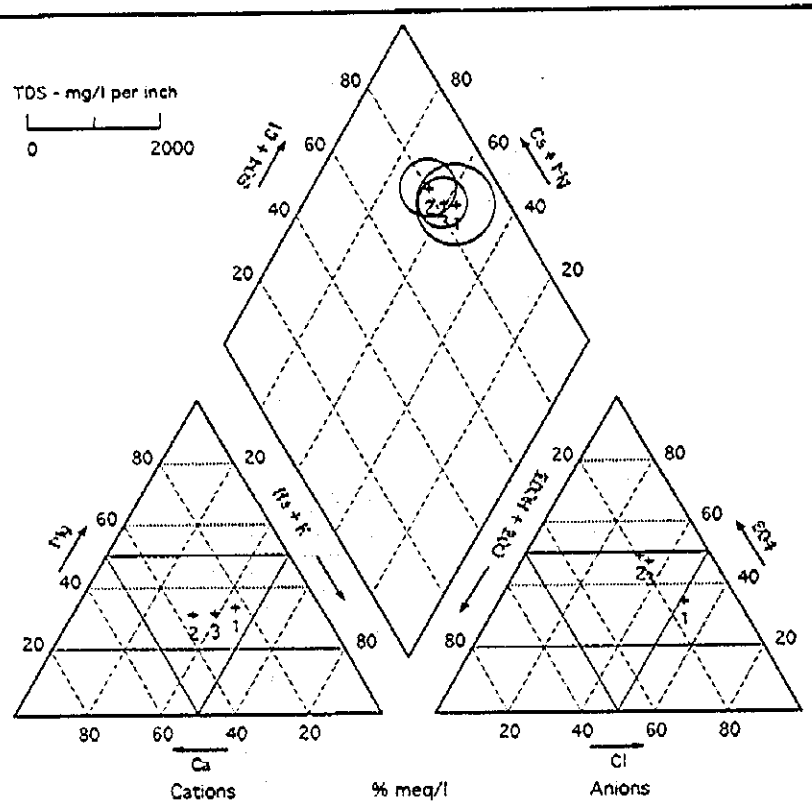


Fig. 8.3.2-21 Stiff Diagram (Main Block: Lower Cretaceous)

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



Sheira Deep Wells

No.	TDS	Sample	No.	TDS	Sample
1	1228	Sheira-1 (Aug/1994)			
2	899	Sheira-3 (km52)(Dec/1995)			
3	793	Sheira-4 (km53)(Jul/1994)			

Fig. 8.3.2-22 Piper Diagram (Sheira Block: Lower Cretaceous)

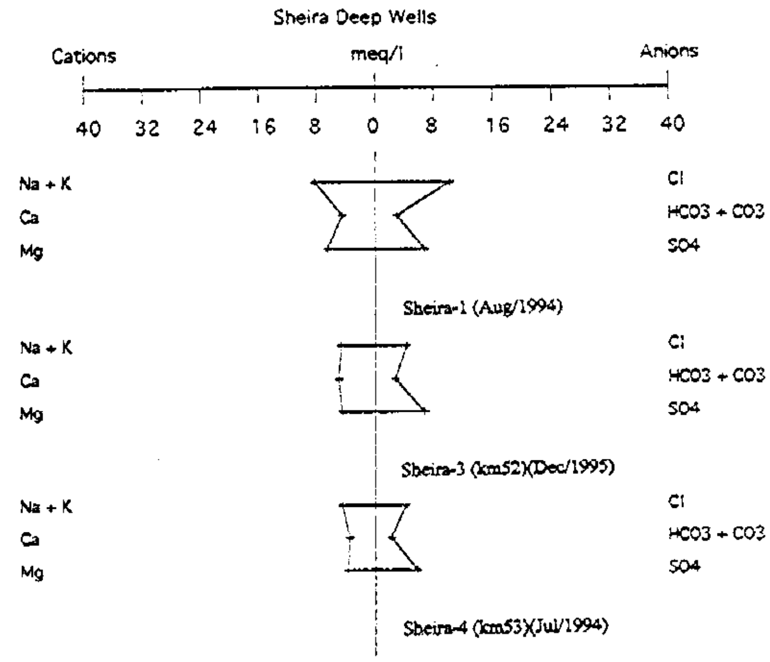
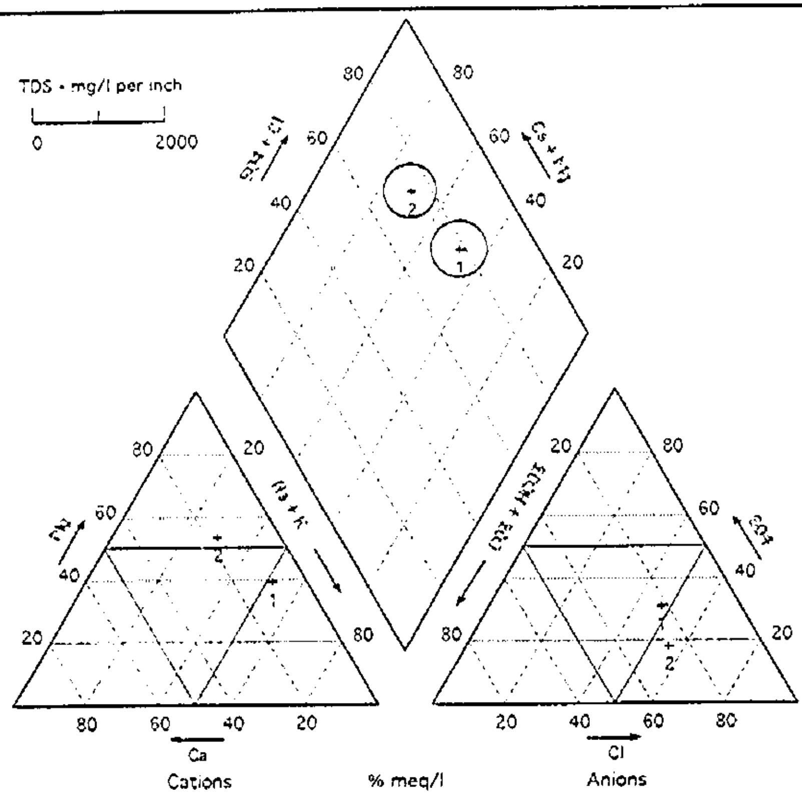


Fig. 8.3.2-23 Stiff Diagram (Sheira Block: Lower Cretaceous)



W. Feiran Deep Wells					
No.	TDS	Sample	No.	TDS	Sample
1	862	Feiran-2(Feb/1990)			
2	848	Feiran-1(Nov/1989)			

Fig. 8.3.2-24 Piper Diagram (Feiran Block: Lower Cretaceous)

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

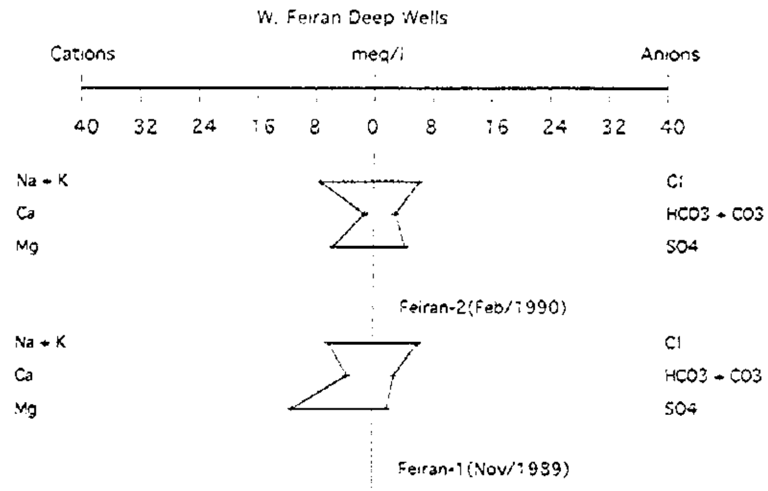


Fig. 8.3.2-25 Stiff Diagram (Feiran Block: Lower Cretaceous)

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

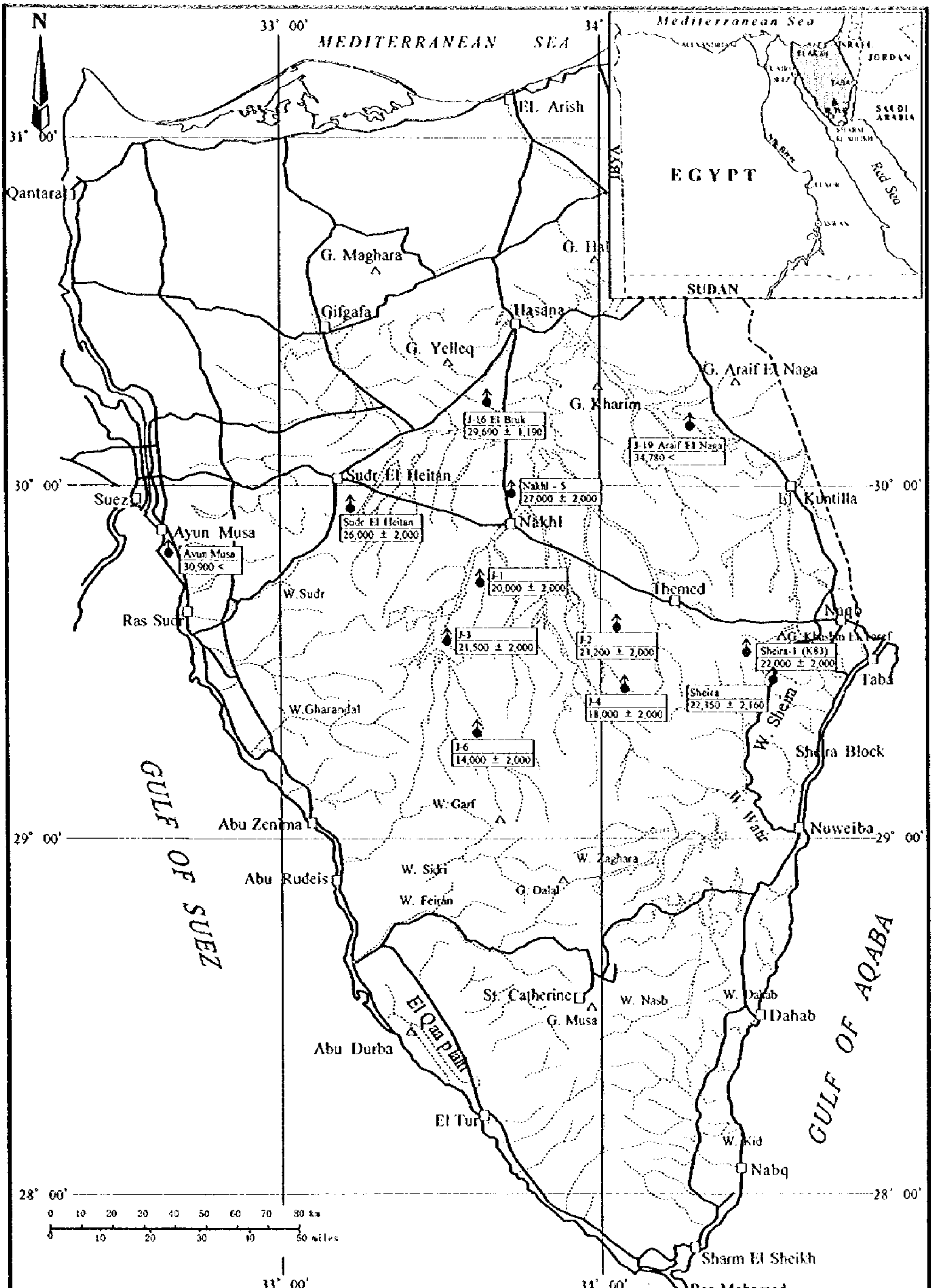
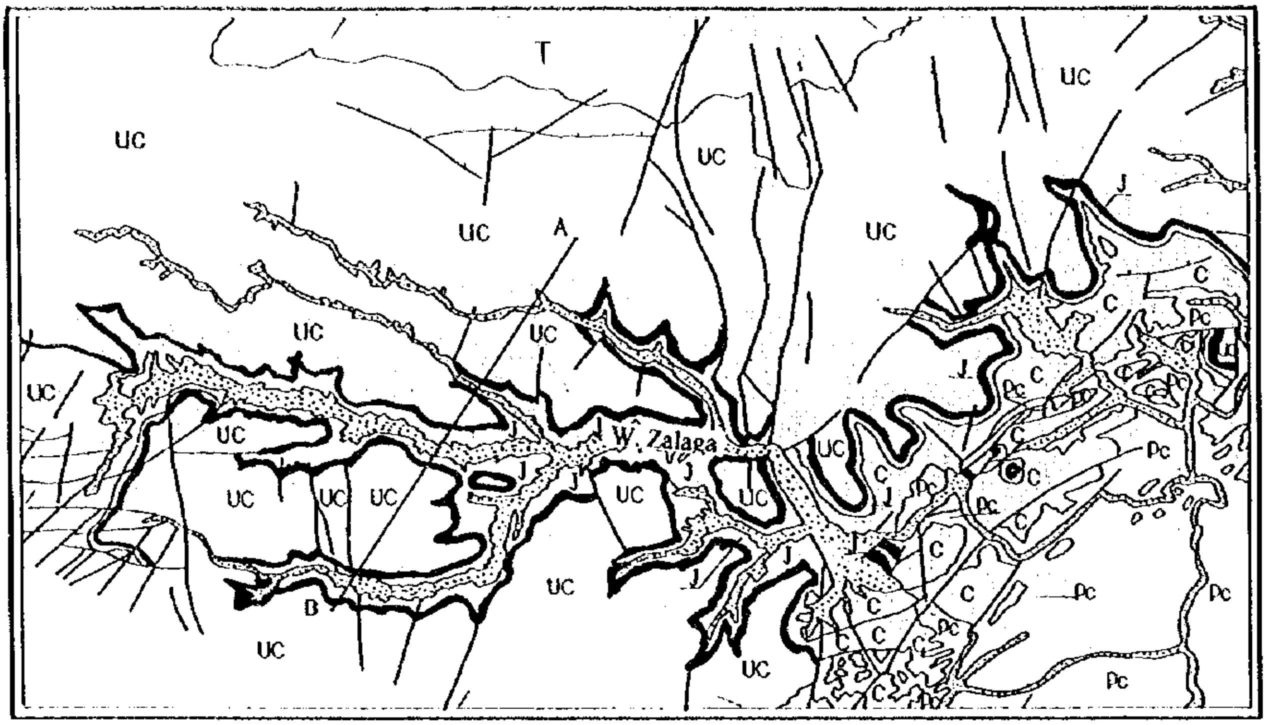
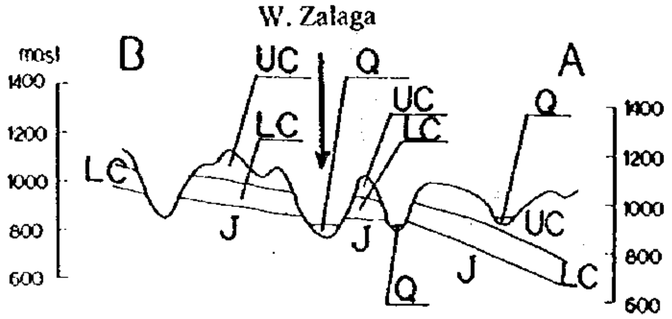


Fig. 8.3.2-26 Groundwater Age (Lower Cretaceous)





Legend

Q	Quaternary
T	Tertiary
UC	Upper Cretaceous
LC	Lower Cretaceous
J	Jurassic
C	Carboniferous
PC	Precambrian
(line)	Fault

Fig. 8.3.2-27 Geological Map (Wadi Zalaga)

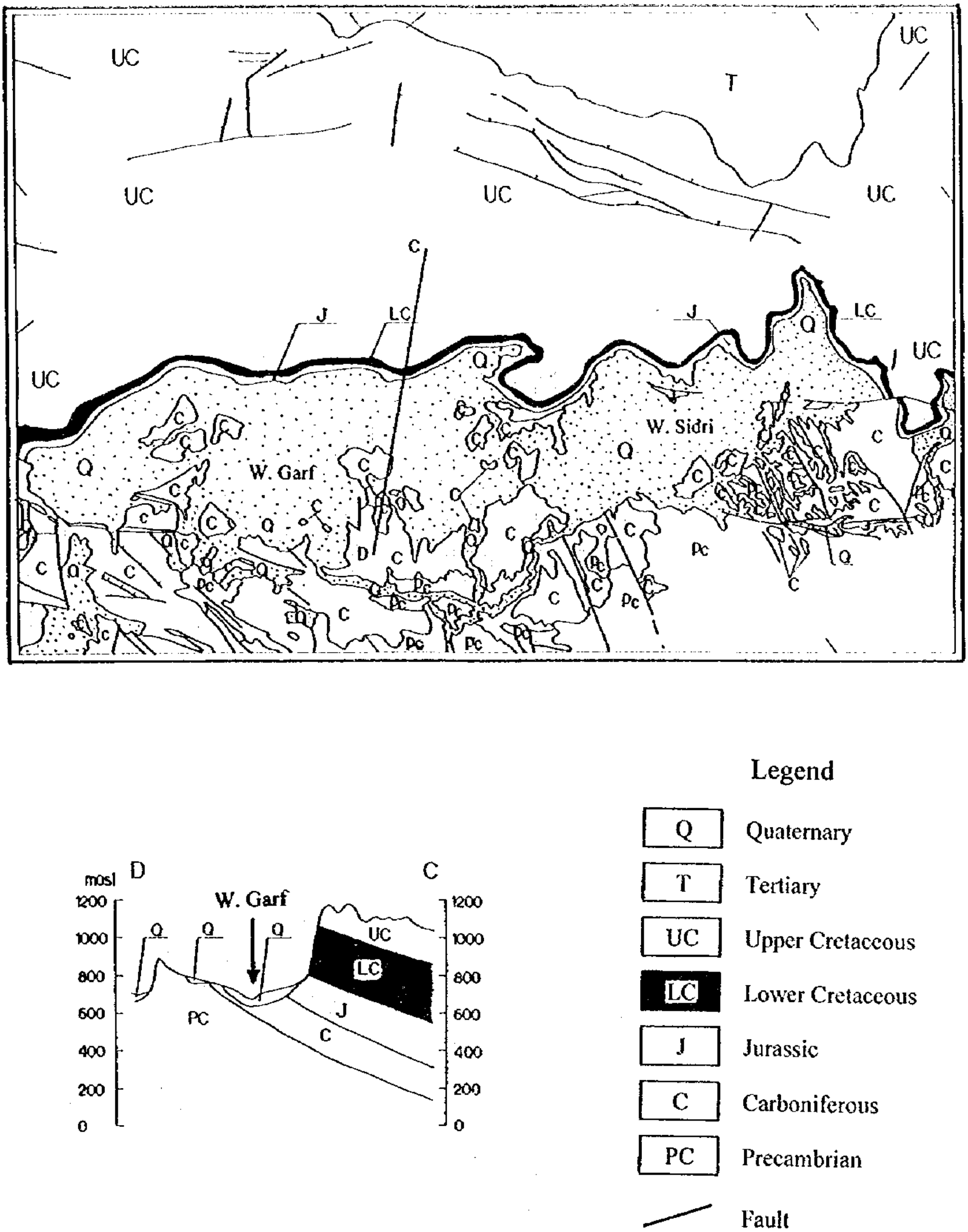


Fig. 8.3.2-28 Geological Map (Wadi Garf)

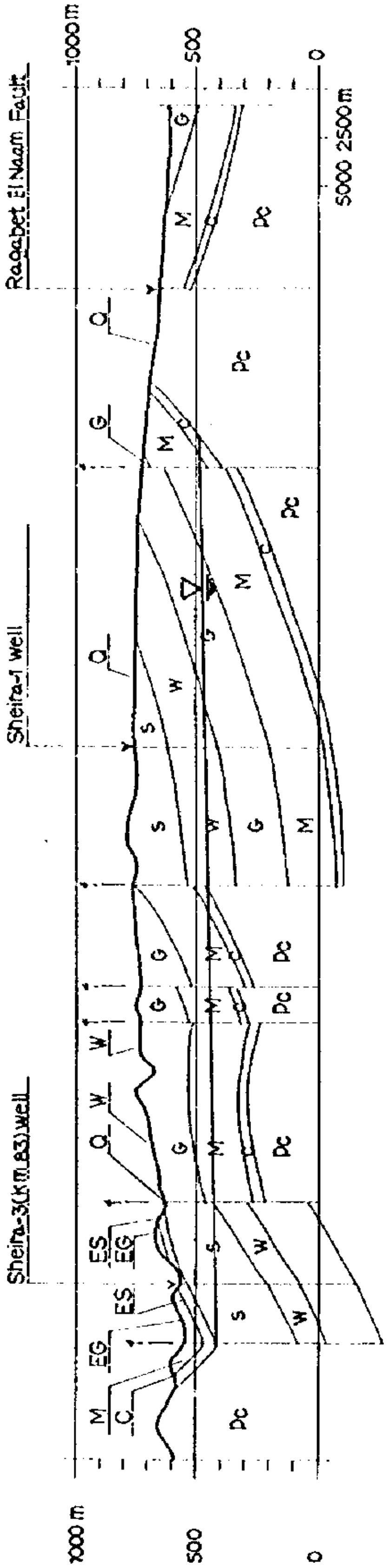


Fig. 8.3.2-29 Geological Profile (Sheira Block)

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

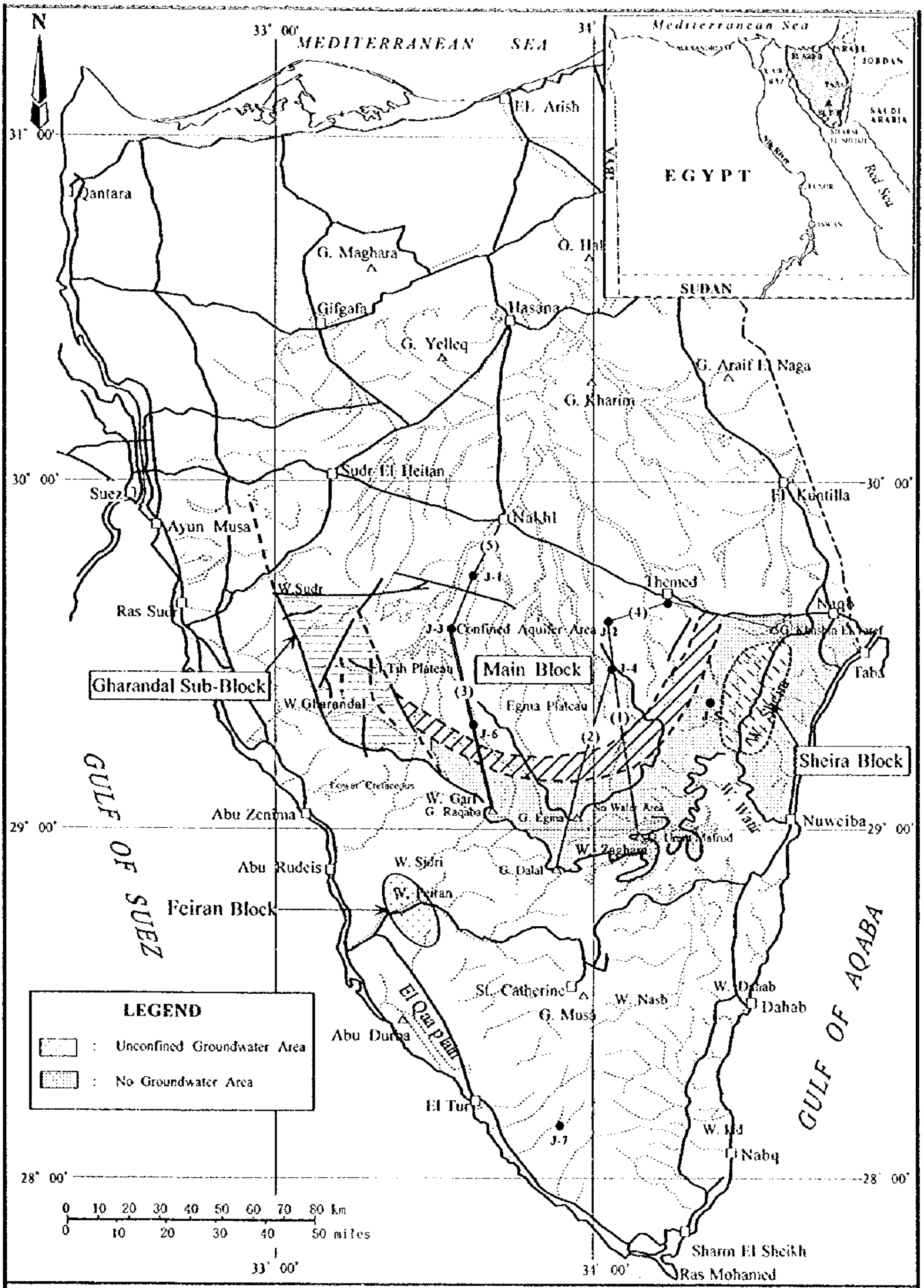
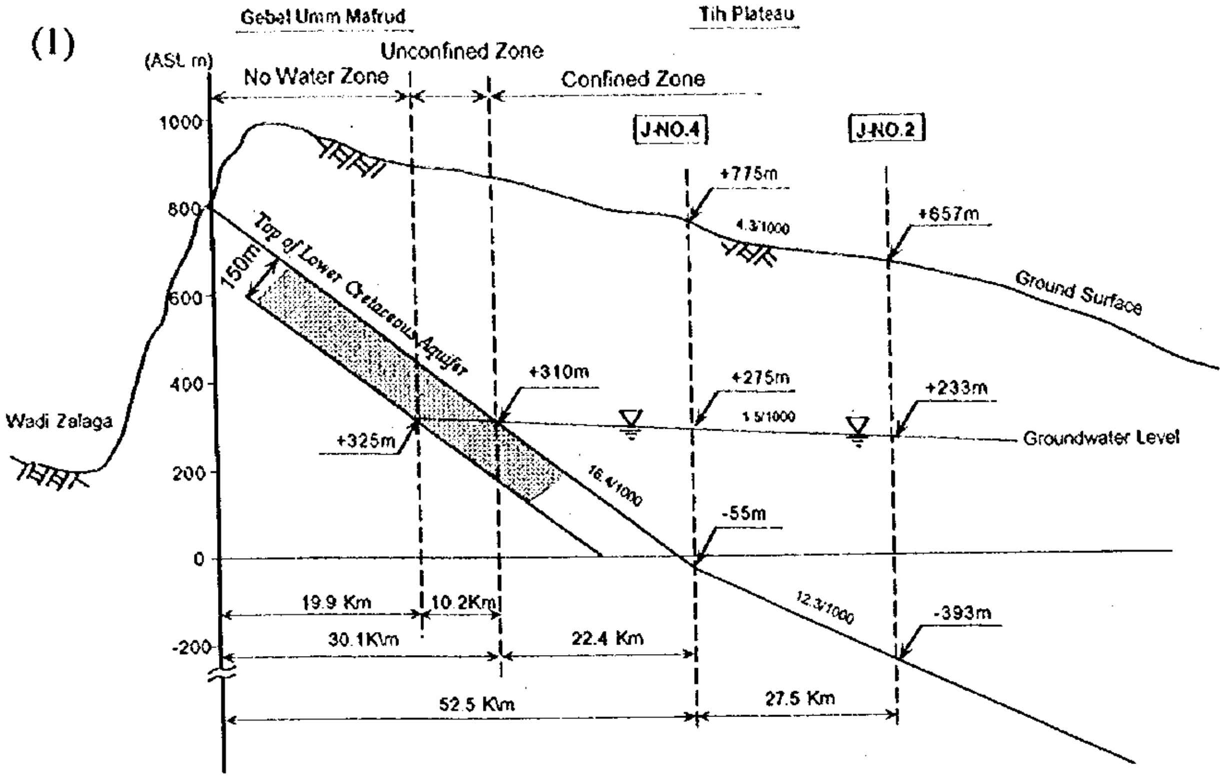


Fig. 8.3.2-30 Differentiated Groundwater Zone in Main Block (Lower Cretaceous)

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

(1)



(2)

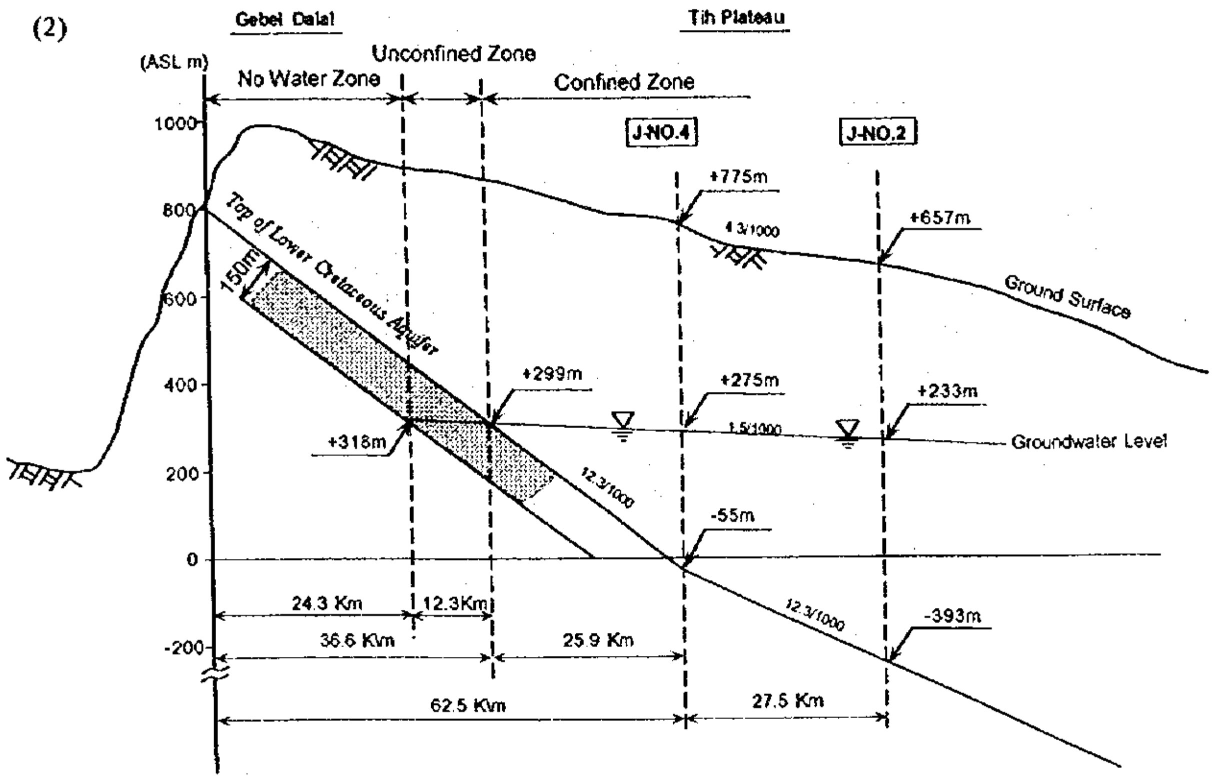
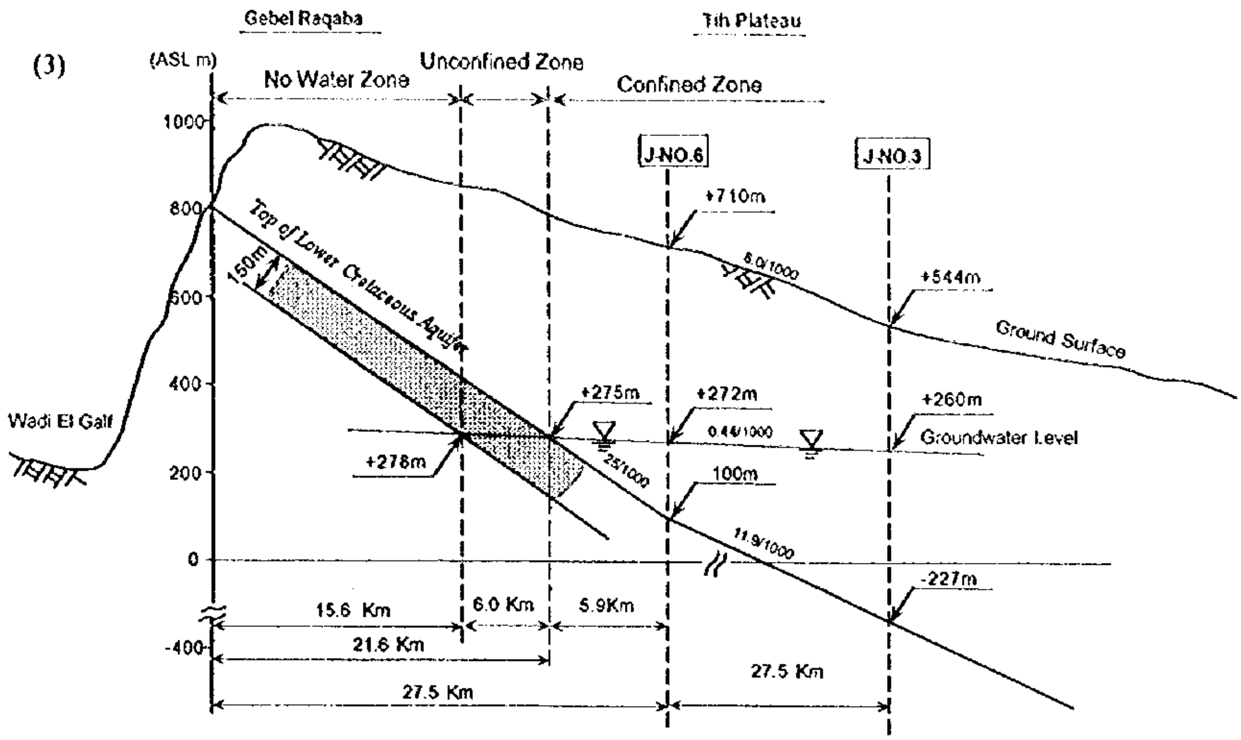


Fig. 8.3.2-31 (1) Section of Groundwater Table (Lower Cretaceous)

(3)



(4)

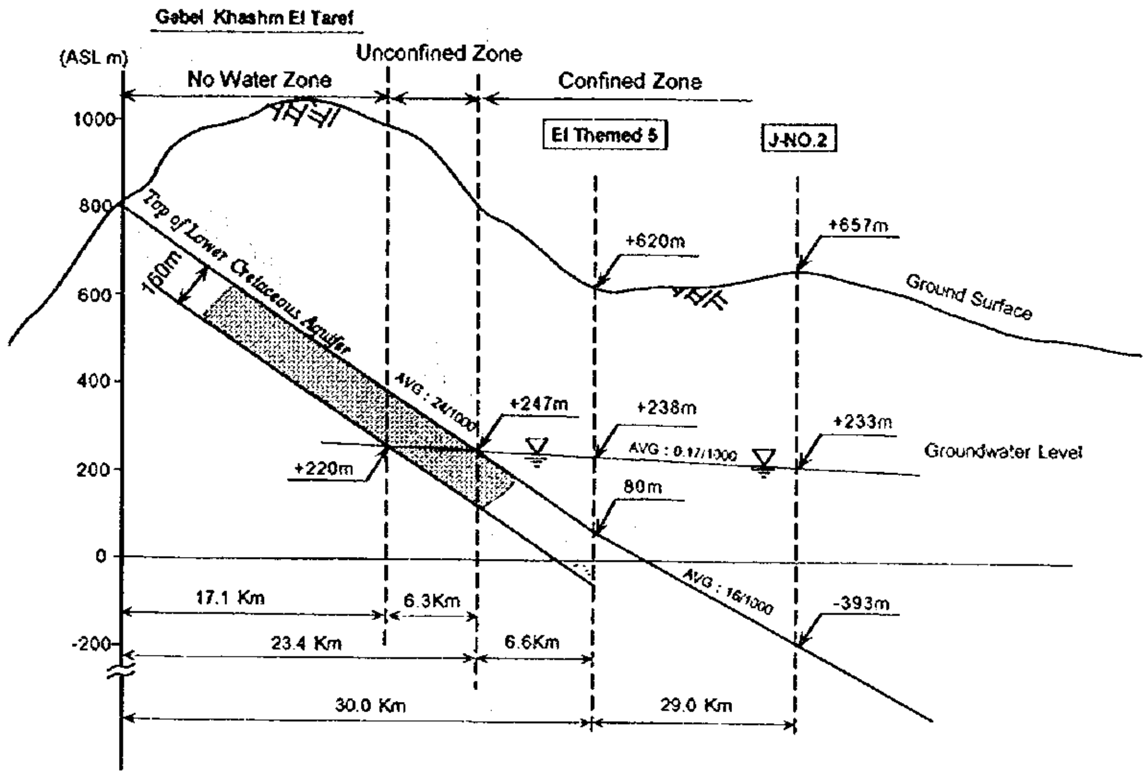
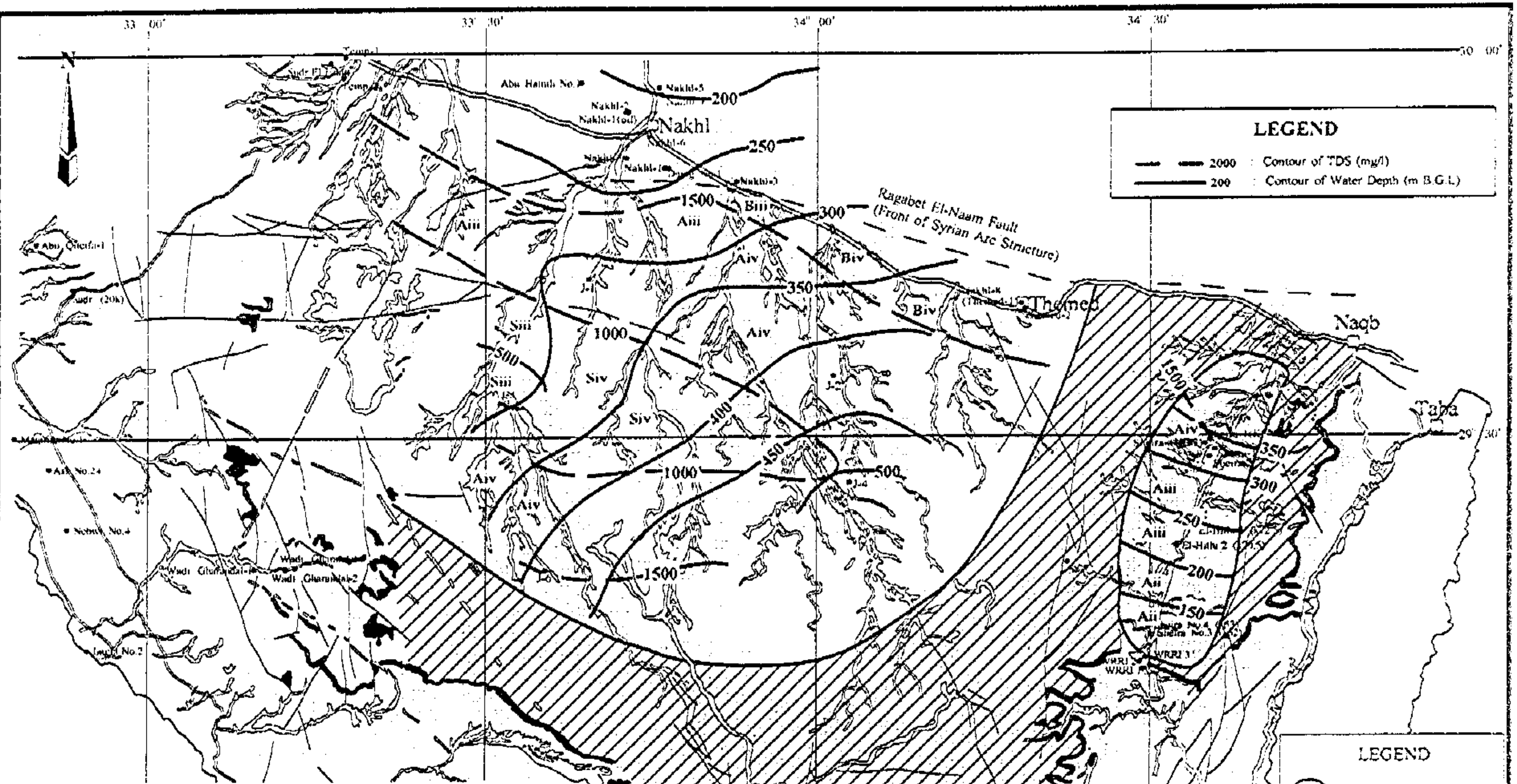


Fig. 8.3.2-31 (2) Section of Groundwater Table (Lower Cretaceous)



Classification Matrix for Groundwater Resources Evaluation of Lower Cretaceous Aquifer

		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
		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)	-

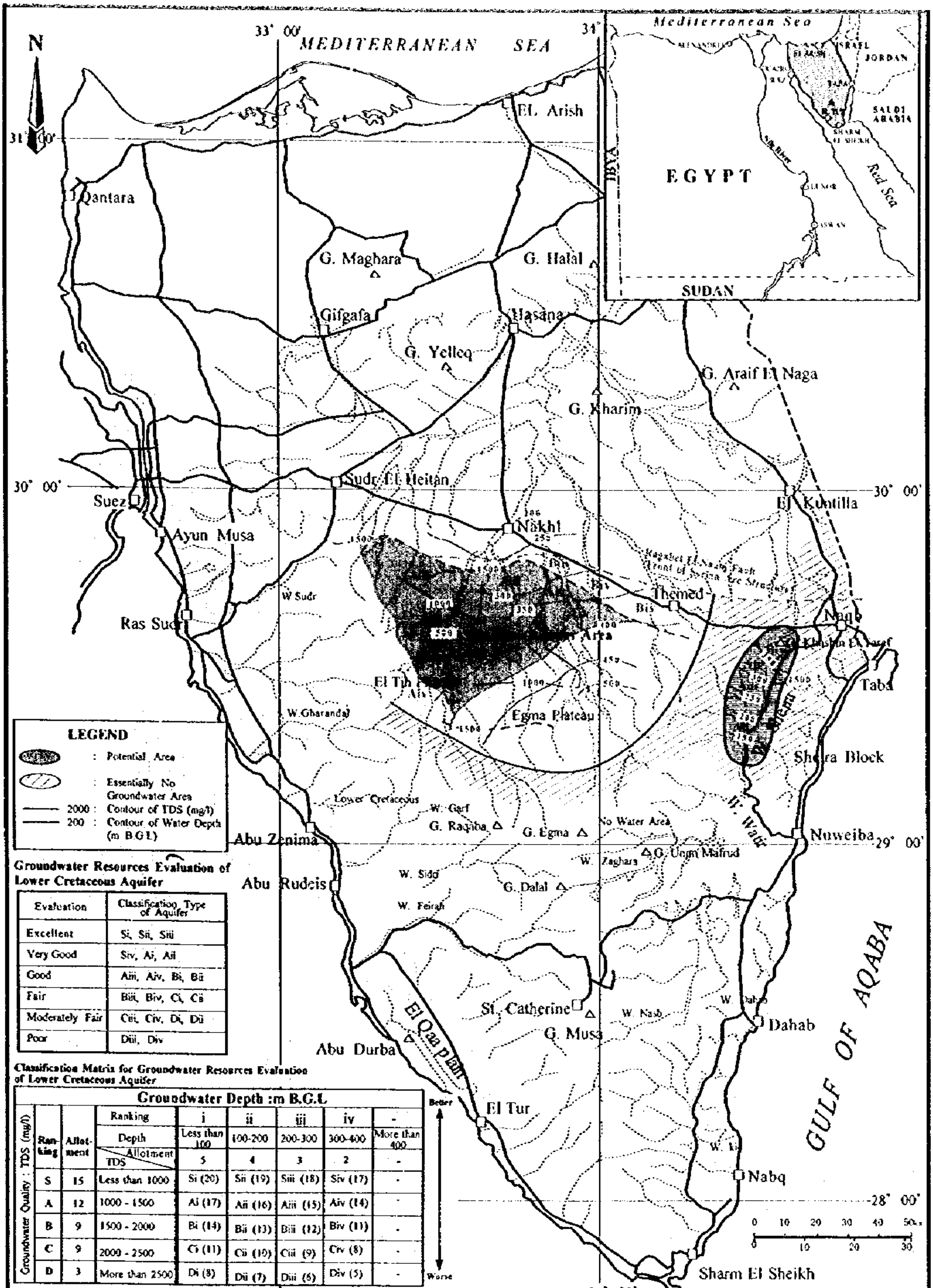
Groundwater Quality TDS (mg/l)

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. 8.3.2-32 Groundwater Evaluation Map (Lower Cretaceous)



Groundwater Resources Evaluation of Lower Cretaceous Aquifer

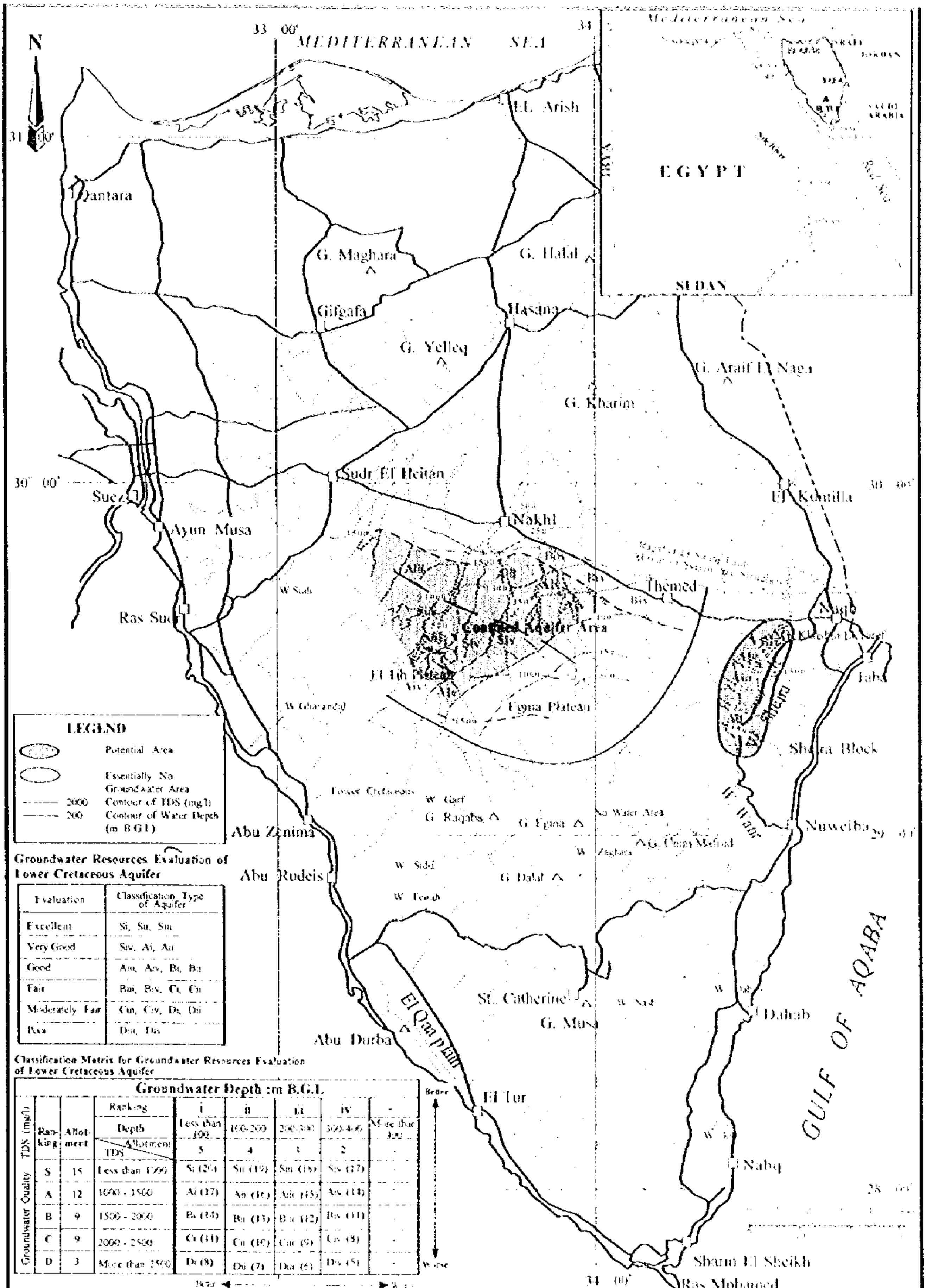
Evaluation	Classification Type of Aquifer
Excellent	Si, Sii, Siii
Very Good	Siv, Ai, Aii
Good	Aiii, Aiv, Bi, Bii
Fair	Biii, Biv, Ci, Cii
Moderately Fair	Ciii, Civ, Di, Dii
Poor	Diii, Div

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
		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 (depth); Better ↑ ↓ Worse (quality)

Fig. 8.3.2-33 Groundwater Evaluation for Drinking (Lower Cretaceous)



LEGEND

(shaded ellipse)	Potential Area
(open ellipse)	Essentially No Groundwater Area
------ 2000	Contour of TDS (mg/l)
------ 200	Contour of Water Depth (m BGL)

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
		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. 8.3.2-33 Groundwater Evaluation for Drinking (Lower Cretaceous)

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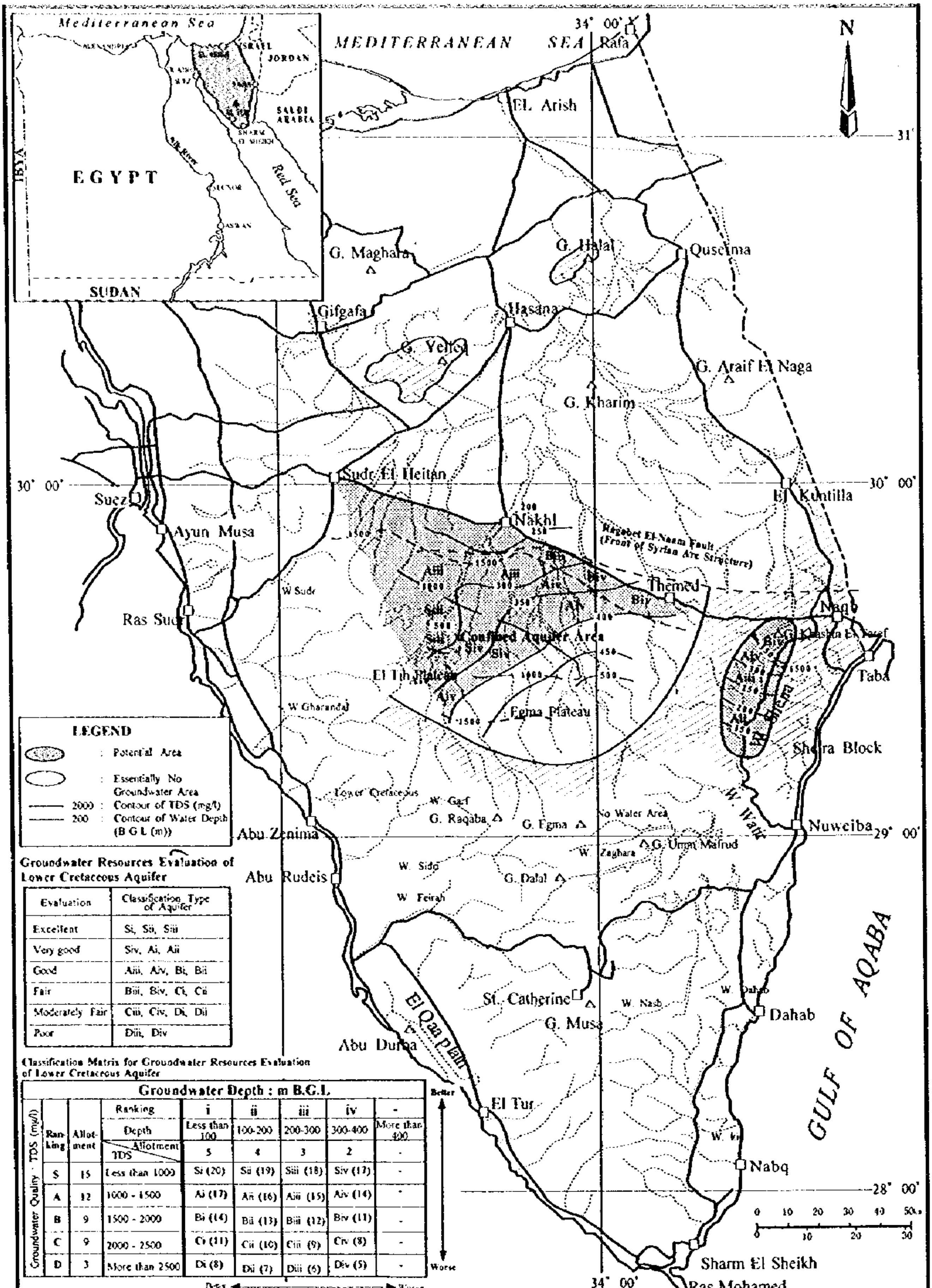

Groundwater Resources Evaluation of Lower Cretaceous Aquifer

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. 8.3.2-34 Groundwater Evaluation for Irrigation (Lower Cretaceous)

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8.3.3 Paleozoic

The Paleozoic Formations widely distribute in the upstream area of the Wadi Zalaga and the Wadi Garf. However, no deep well was penetrated into the Formation. The Paleozoic Aquifer is known in the Wadi Gharandal. 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.

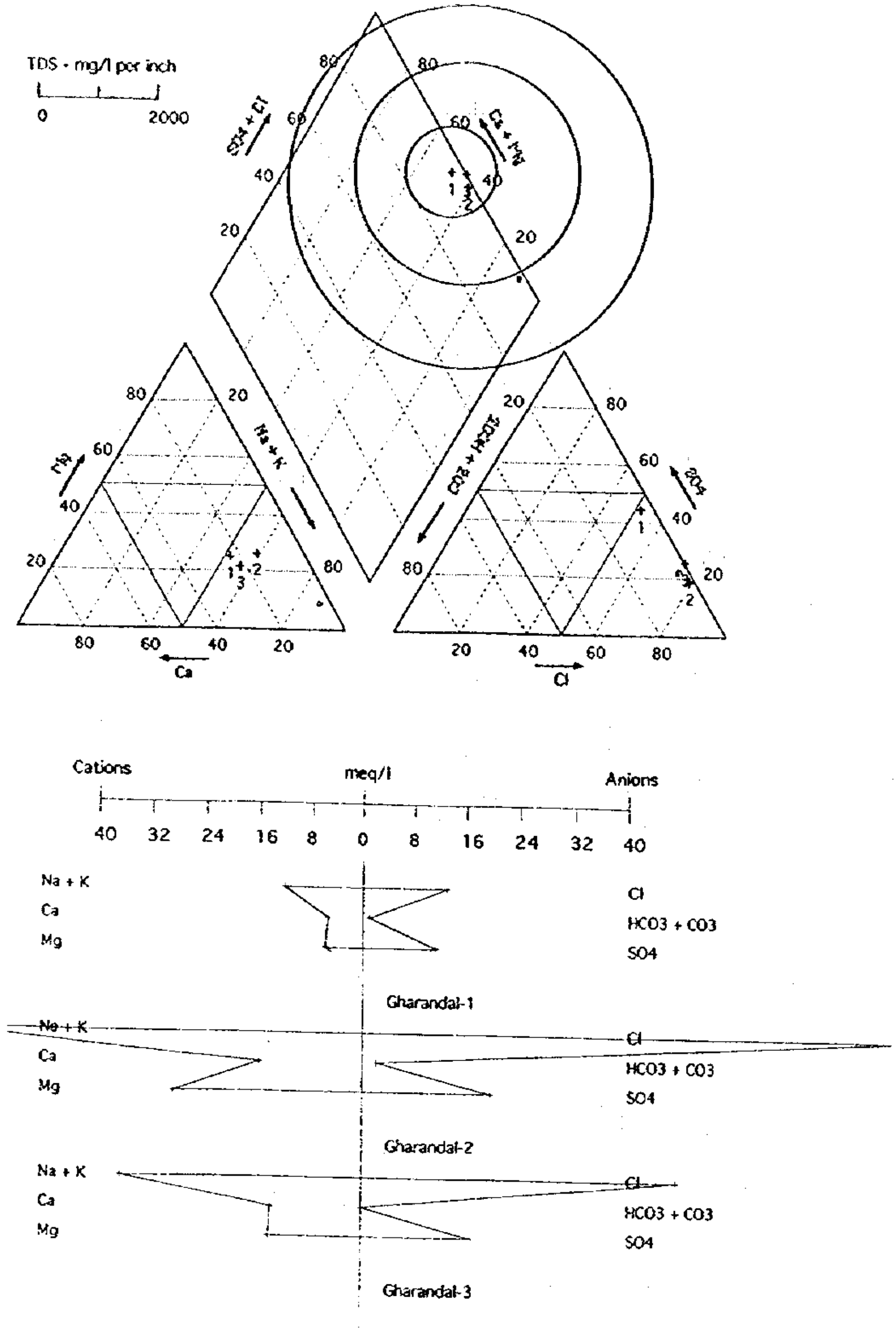
The well Gharandal-3 reached the Paleozoic Formation. Facies is sandstone. Location of this well is shown in Fig. 8.3.3-1 together with Gharandal-1 (Lower Cretaceous Aquifer) and Gharandal-2 (Upper Cretaceous Aquifer). This well is only one (1) well in which screen was installed in Sinai. Static water 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 in Egypt. Ion composition is plotted in piper and stiff diagrams as shown in Fig. 8.3.3-1. Ion compositions of the Upper Cretaceous and the Lower Cretaceous aquifer in the wadi are also plotted in the same figure. 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 wells 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. 8.3.3-1 Piper and Stiff Diagram (Wadi Gharandal)

8.3.4 Precambrian Rocks

Only one (1) well was drilled into the weathered Precambrian Rocks in the Taba area. However, water quality (TDS) was extremely high. No well is extracting groundwater from the Precambrian Rocks. Some springs are occurred in the area such as Ras Sudr, St. Catherine and Wadi Watir areas. A typical case is Spring Umm Ahmed located in the upstream of the Wadi Zalaga, where groundwater spring out from the contact zone between granite and dolerite dykes. Dorelite dykes in the area are impervious. Therefore, groundwater is dammed up by the dykes and spring out after reaching to the spring through the fissures and joints in the granitic basement rocks.

As mentioned in Chapter V, intensively developed lineament and dykes are observed in the Precambrian Rocks in several areas (Fig. 8.3.4-1);

(A) Ring structure

(B) Area, where minor lineaments are concentrated

(C) Area, where conjugate faults are well developed

Several springs are occurred in/around these structures. They are as follows;

	Structure	Area	Spring/Dug well
(A)	Ring structure	Ain Qaseby	Ain Qaseby, Ain El Malhah
(B)	Minor lineaments	G. Mikeimin/G. Mileihis	Ain Furtaga, Ain Umm Ahmed, Ain El Khudra, etc.
(C)	Conjugate faults	Oasis Feiran	A group of dug wells in Oasis Feiran and Tarfa

The Precambrian Rocks are impervious, however, groundwater will infiltrates to the fissures, joints and faults formed in the Rocks and flows down reaching to the Quaternary Wadi Deposits. Thus, the Precambrian rocks act as the sources of recharge to the Quaternary Aquifers.

Some of springs and dug wells seem to be controlled by the existence of dykes; Dykes with open cracks will gather groundwater and dykes with no open cracks will act as a barrier of the groundwater flow in the fissures, joints and faults in the Precambrian Rocks. The groundwater in the Precambrian Rocks, after all, discharges to the Quaternary aquifers in the wadis.

Basically it is almost impossible to develop groundwater directly from the Basement

Rocks by wells. There springs are occurred in the Precambrian Basement Rock area. Most of origin of groundwater of these springs is Precambrian Rocks, while most of groundwater are extracted from the Wadi Deposits. It is suggested that the Precambrian Basement Rocks act as conduit of groundwater to the Quaternary Aquifer. From this point of view, large scale of groundwater development in the Precambrian Rocks seems to be difficult.

Therefore, the evaluation of the Precambrian Rocks may be concluded to the evaluation of the Quaternary aquifers in main wadis.

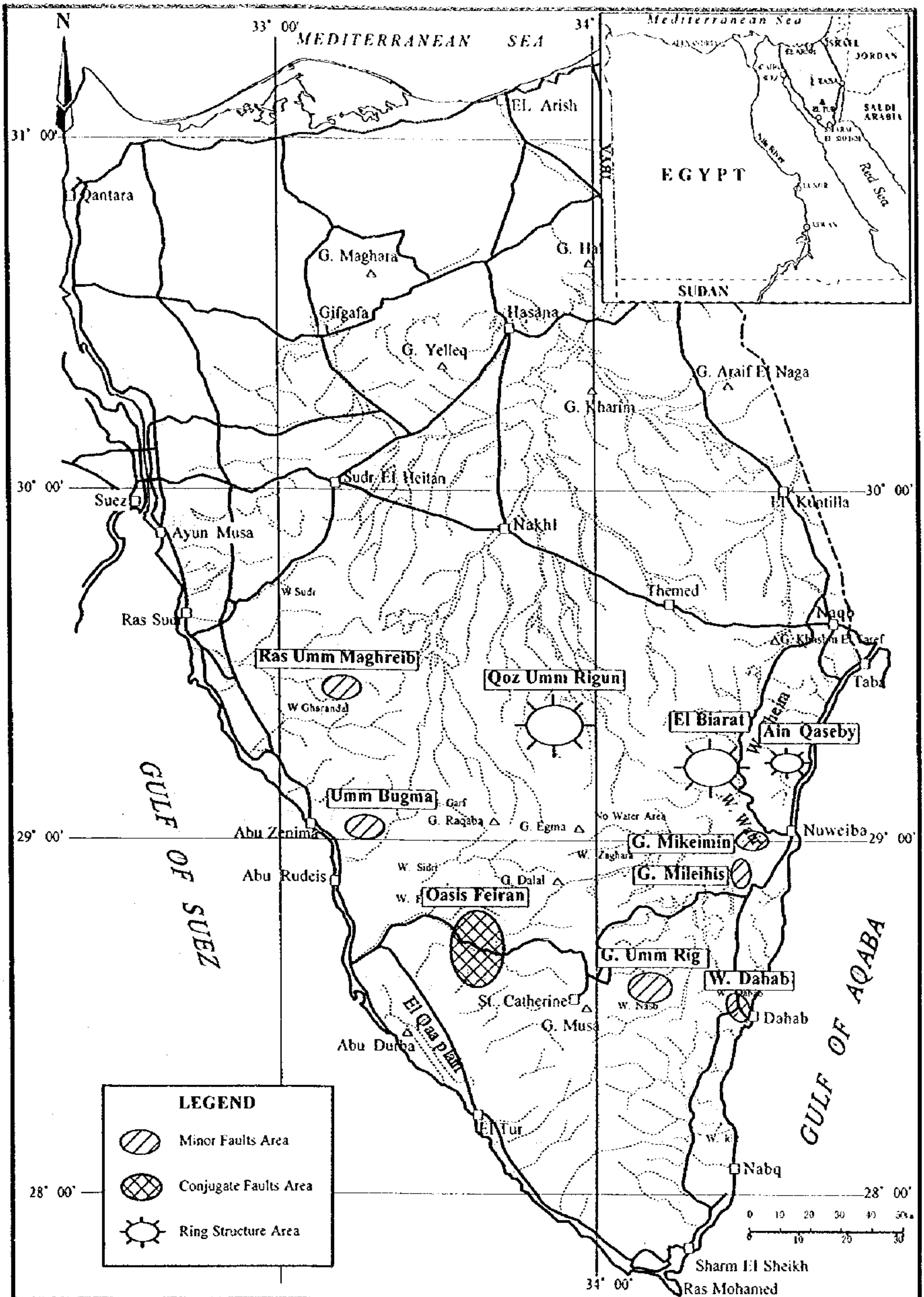


Fig. 8.3.4-1 Location of Typical Structures

8.4 Isotope Analysis

Isotope analysis was conducted to grasp the age and characteristic of groundwater in the study points as shown in Fig. 8.4-1 and its results are listed on Table 8.4-1. Isotope analysis is divided into radioactive isotopes and stable isotopes.

1) Radioactive Isotopes Used for Age Dating

Tritium, ^3H, is an unstable isotope of hydrogen with a half-life of 12.3 year. Prior to 1953, rainwater had less than 10 tritium units (TU: $^3H/\ ^2H = 10^{-18}$). For example, it was 5TU in Rafa in 1992. Tritium can be used in a qualitative manner to date groundwater in the sense that groundwater with less than 2 to 4 TU, is dated prior to 1953.

Since the tritium unit of all Lower Cretaceous sites is very low, it is considered that a groundwater recharge to them is extremely limited at least from 1953. On the other hand, it can be regarded that the recharge to the wells in El-Qaa Plain and springs are made by recent precipitation.

Radiocarbon dating methods can be applied to obtain the age of groundwater. Carbon exists in several naturally occurring isotopes, ^{12}C, ^{13}C and ^{14}C. Carbon 14 is formed in the atmosphere by the bombardment of ^{14}N by cosmic radiation. The ^{14}C forms CO_2, so that the atmospheric CO_2 has a constant radioactivity due to modern ^{14}C. The half-life of ^{14}C is 5730 year.

According to the result of radiocarbon dating in Table 8.4-1, the age of the groundwater in the lower Cretaceous aquifer ranges from 14,000± 2,000 Y.B.P to 27,000±2,000 Y.B.P (year before present). The age of them tends to be older from south to north in the study area. It is recorded more than 30,000 Y.B.P in the north Sinai. It depends on groundwater movement. Moreover, the age means that the recharge to the aquifer was done by ancient precipitation in the Würm glacial stage. (refer to Fig. 8.4-3)

The age of quaternary aquifer and springs is less than 1, 000 Y.B.P but it seems to be almost recent time.

2) Stable Isotopes

In general, five elements; hydrogen, oxygen, carbon, nitrogen and sulfur can be used to study geological process and surface water. Hydrogen and oxygen are selected in this study.

Results of stable-isotope studies are expressed as deviation (δ) in parts per thousand (‰) as a following formula. If the value of positive, the sample is enriched with the heavy isotope relative to the standard; a negative is isotopically light.

$$\delta = \frac{R_{sample} - R_{standard}}{R_{standard}} \times 1000$$

Important ratios include $^{18}O/^{16}O$ and $^{2}H/^{1}H$. These isotopic ratios from environmental water sample can be compared with the isotropic ratio of standard mean ocean water (SMOW). The comparison is made by means of the parameter δ, which is defined as

$$\delta^{18}O(‰) = \left[\frac{(^{18}O/^{16}O)_{sample}}{(^{18}O/^{16}O)_{SMOW}} - 1 \right] \times 10^3 \qquad \delta^{2}H(‰) = \left[\frac{(^{2}H/^{1}H)_{sample}}{(^{2}H/^{1}H)_{SMOW}} - 1 \right] \times 10^3$$

When $\delta\,^{2}H$ is plotted as a function of $\delta\,^{18}O$ for water found in continental precipitation, an experimental linear relationship is found that can be described by the equation (Yurtsever & Gat, 1981)

$$\delta^{2}H = 8.2\delta^{18}O + 10.8$$

This is known as the global meteoric water line. Continental precipitation samples will tend to group close to this line. Precipitation falling in areas with lower temperatures will tend to have lower $\delta\,^{2}H$ and $\delta\,^{18}O$ values.

Fig.8.4-2 shows that A group wells close to the global meteoric line but B group is somewhat away from the line. J-6 is located between A and B. A group consists of the lower Cretaceous aquifer's well and B group includes the quaternary aquifer's well and spring. Then paleo-temperature of the lower Cretaceous was cooler than B group. There's another evidence supporting above as shown in Fig.8.4-3.

Relation between Mean Annual Air Temperature and $\delta\,^{18}O$ is expressed as following formula.

$\delta\,^{18}O = 0.3387T - 11.99$

On the basis of the figure, Mean Annual Air Temperature of A and B group ranges from 8.9°C to 12.5°C, 16.7°C to 20.3°C respectively. The groundwater of A group's aquifers was recharged in about 8°C cooler environment than B group in the Würm glacial stage.

It is well known that the seawater level went down in glacial stage all over the world. Fluctuation of seawater level in the Würm glacial stage is shown in Fig. 8.3.4. The age range of the groundwater in the Lower Cretaceous Aquifer is shown in the figure. It indicates that the aquifer was recharged around the climax of the glacial stage.

Table 8.4-1 Results of Isotope Analysis

Site Name	Nature	Type of Aquifer	Aquifer Depth (m) B.G.L	Lithology	Sampling Date	^{14}C-Age (year)	^{3}H T.U	PMC (%)	δ^{18}O (SMOW)	δ^{2}H (SMOW)
JICA-1	well	Lower Creta.	907-1,081	sandst.	30/12/97	20,000±2,000	n.d	2.24	-8.41±0.05	-58.6±1
JICA-2	well	Lower Creta.	1,107-1,245	sandst.	23/ 2/97	23,200±2,000	0.1±2	2.65	-8.43±0.05	-56.9±1
JICA-3	well	Lower Creta.	801-950	sandst.	25/ 2/97	21,500±2,000	0.2±2	1.44	-8.12±0.05	-55.1±1
JICA-4	well	Lower Creta.	863-1,068	sandst.	3/ 1/98	18,000±2,000	n.d	4.70	-7.77±0.05	-53.4±1
JICA-6	well	Lower Creta.	613-768	sandst.	29/12/97	14,000±2,000	1.5±2	5.70	-6.20±0.05	-42.8±1
Neckel-5	well	Lower Creta.	1,049-1,180	sandst.	28/ 9/97	27,000±2,000	0.3±2	1.44	-8.99±0.05	-57.9±1
Sahl El-Qaa 8	well	Quaternary	65-95	sand & gravel	23/ 9/97	<1,000	3±2	-	-6.11±0.05	-33.5±1
Sahl El-Qaa 12	well	Quaternary	60-90	sand & gravel	23/ 9/97	<1,000	2±2	-	-6.33±0.05	-31.9±1
Sadr El-Hetan	well	Lower Creta.	858-990	sandst.	22/ 9/97	26,000±2,000	0.2±2	1.11	-8.44±0.05	-53.0±1
Ain Mir	spring	Wadi Deposit	-	sand & gravel	23/ 9/97	<1,000	6±2	-	-5.13±0.05	-17.7±1
Ain Umm-Ahmed	spring	Wadi Deposit	-	sand & gravel	22/ 9/97	<1,000	4±2	-	-5.25±0.05	-23.0±1
Wadi Sheira	well	Lower Creta.	720-804	sandst.	22/ 9/97	22,000±2,000	0.1±2	2.97	-8.04±0.05	-54.4±1
Saint Catherine(Ain El-Raba)	spring	Precambrian	-	ganite	22/ 9/97	<1,000	5±2	-	-6.11±0.05	-24.6±1

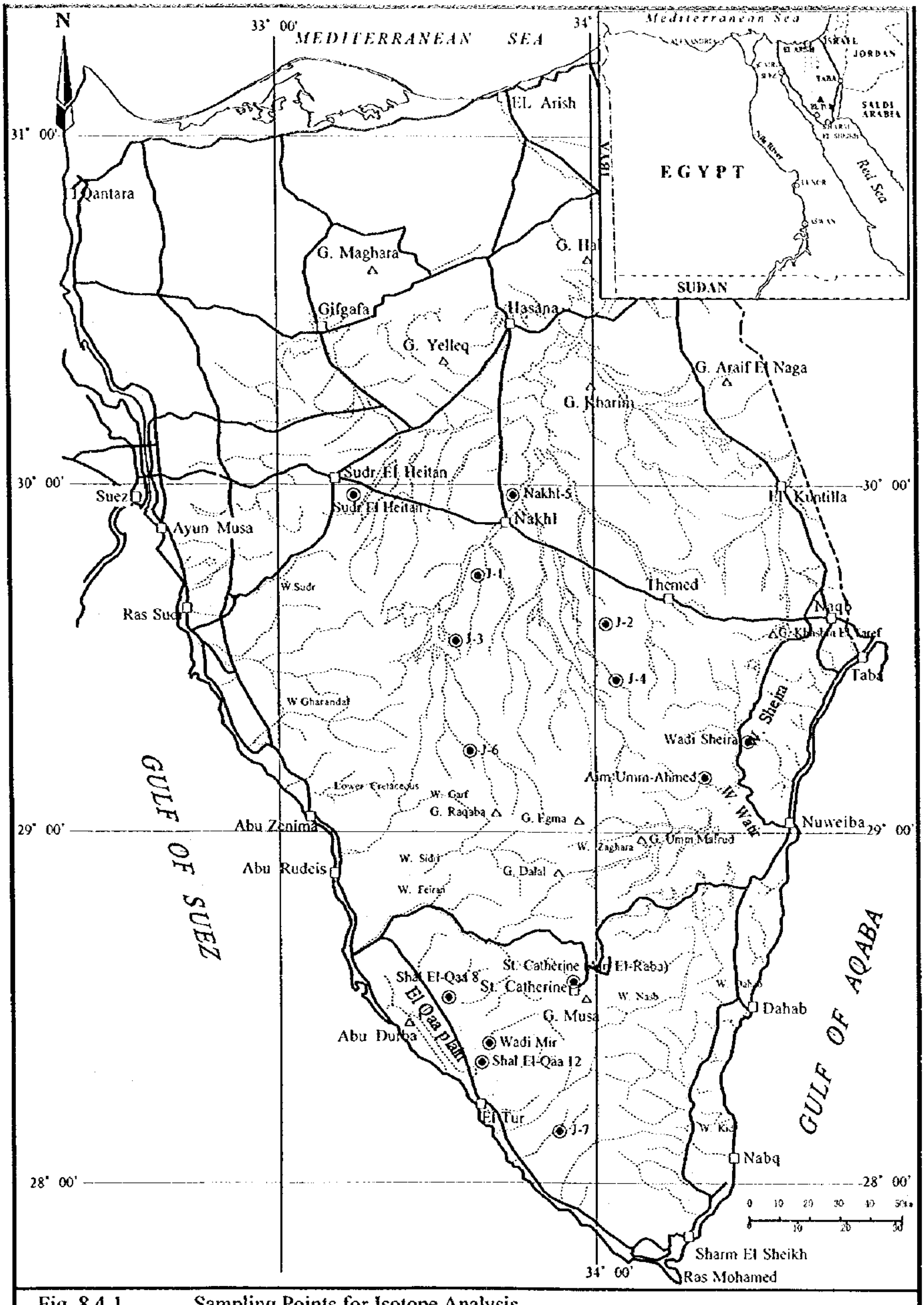


Fig. 8.4-1 Sampling Points for Isotope Analysis

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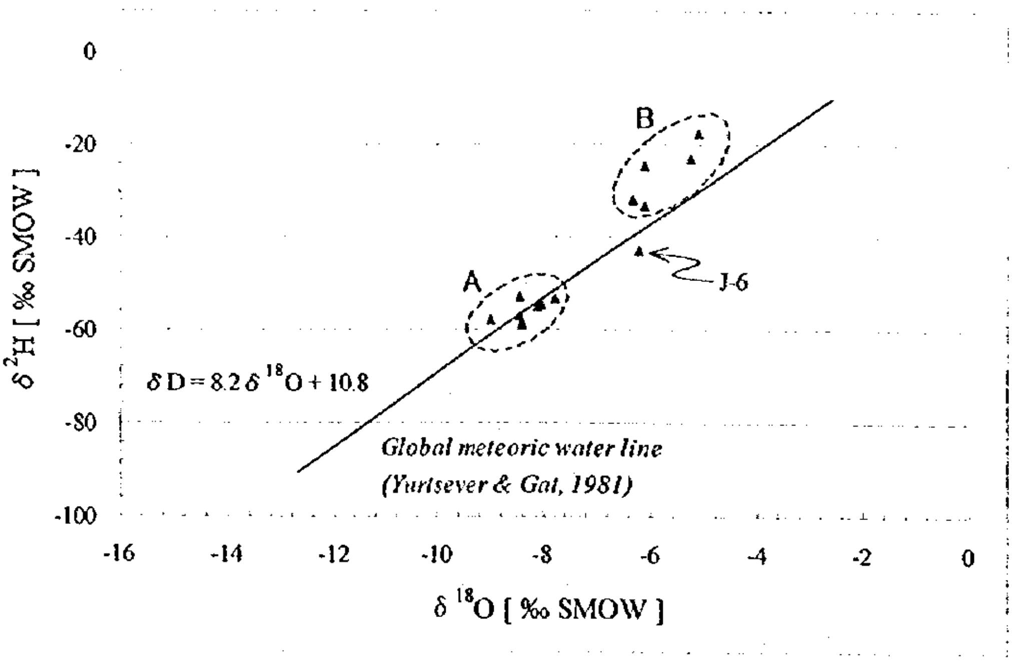

Fig. 8.4-2 Relationship between δ^2H and $\delta^{18}O$

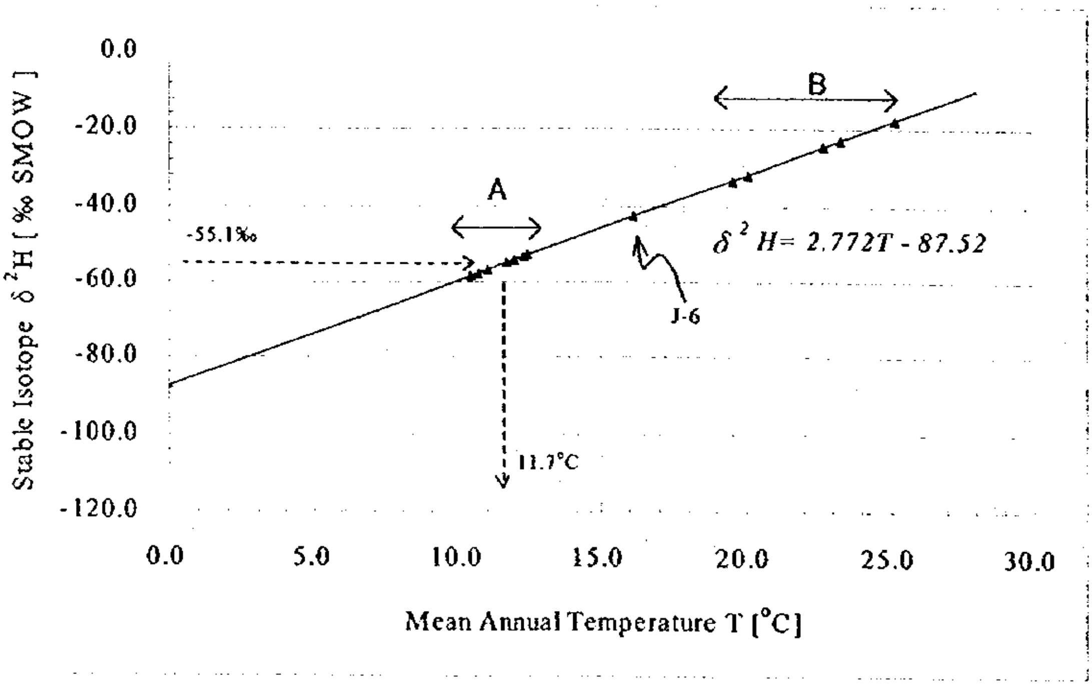

Fig.8.4-3 Relationship between δ^2H and Mean Annual Temperature

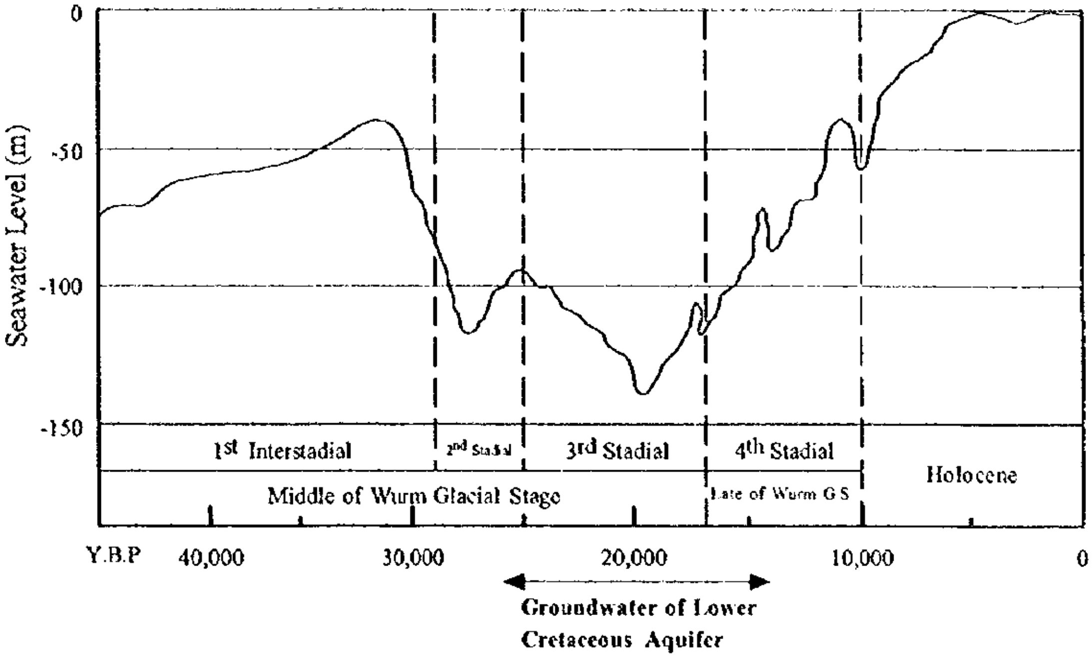

Fig. 8.4-4 Fluctuation of Seawater Level in the Würm Glacial Stage and Groundwater Age of Lower Cretaceous Aquifer