JAPAN INTERNATIONAL COOPERATION AGENCY
REPUBLIC OF TUNISIA

THE FEASIBILITY STUDY ON THE IRRIGATED AREA IMPROVEMENT IN OASIS IN THE SOUTH OF THE REPUBLIC OF TUNISIA

VOLUME II

FINAL REPORT

(ANNEXES)

AUGUST 1996

SANYU CONSULTANTS, INC.
NIPPON KOEI CO., LTD

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METEOROLOGY AND HYDROLOGY

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A.1 GENERAL

A.1.1 Climatic Classification

Based on the geomorphological setting and rainfall, the country is divided into three (3) hydrometeorological regions; Northern, Central and Southern Tunisia. The climate of Northern Tunisia, witch occupies approx. 25% of the territory, is influenced by the Mediterranean Sea, that brings about considerable rainfall (400 mm to 1,000 mm per year). The Central Region, which occupies approx. 15% of the territory, is located between the mountain ranges of the North Tunisia and the north latitude of approx. 34°30', where annual rainfall ranges between 200 mm and 400 mm. The Southern Region, which forms 60% of the territory, is so-called semi-arid zone with an annual rainfall of less than 200 mm per year.

A.1.2 Observation Stations

In this context, the Study area is located in the South Region or semi-arid zone. Meteorological observations in the Study area are shown in Table A.1.1.1. The rainfall data and other meteorological data such as temperature, relative humidity, maximum wind velocity, evaporation and sunshine data in Study area have been observed at four (4) stations of Gafsa, Tozeur, Kebili and Gabes. The figures in the table show the average of ten years from 1985 to 1994.

For agricultural purpose, especially for the estimation of the consumptive use of water by the crops, data on mean wind velocity, which are not included in the said table, are essential. To cope with this, information on mean wind velocity was separately collected at Institut Nationale de Meteorologic as shown in Table A.1.1.2 covering a period of ten years from 1985 to 1994.

A.2 METEOROLOGY

It is understood that there is a notable difference in the records among the four stations. Topographically, Gafsa is located near the border with the Central Region, and Tozeur and Kebili are situated inland, whereas Gabes is located near the sea.

Annual mean temperature of Tozeur and Kebili is higher than 20℃, which is attributed to the very hot months of June to August because of inland nature of climate, whereas that of Gafsa and Gabes shows rather low temperature of less than 20℃ due to favorable location of Gafsa (located northern area) and Gabes (located near the sea). On the contrary, relative humidity at Tozeur and Kebili is lower than that of Gafsa and Gabes. It is acknowledged that the former two stations are situated inland where very dry spell lasts long during the summer, and that the latter two stations located in the north and seashore where dry spell is rather short. Likewise, there is a distinct difference in rainfall pattern. For instance, records of the two meteorological stations of Tozeur and Kebili indicate that the annual rainfalls are as little as 86.9 mm and 73.6 mm, respectively. In contrast with the above, annual amount of rainfall in Gafsa and Gabes is more than two times, the former station recorded 174.3 mm, and the latter, 212.8 mm. Eventually, such differences in the climatological characteristics are reflected on the evaporation. Annual mean evaporation of Tozeur and Kebili is as high as 7.2 mm and 8.4 mm per day, while that of Gafsa and Gabes is 6.6 mm and 5.5 mm per day, respectively.

Very high wind velocity, especially during the summer from May to July is observed in Kebili, whereas more less the same mean monthly wind velocity is recorded in the three meteorological stations of Gafsa, Tozeur and Gabes.

As discussed in the above, the Study area can be classified into two sub-areas, in terms of meteorology, nonetheless it is located in the South Region as categorized nationwide. Governorates of Tozeur and Kebili are classified as hot and dry inland, whereas those of Gafsa and Gabes are classified as temperate and rather humid with some rainfalls.

A.3 HYDROLOGY

In view of hydrology, most of surface drainages are concentrated in the north Tunisia, as the precipitation and topography show. However, scale of drainage in this country is not so large. Inland basins which have no outlet to the sea characterize the Central and Southern Tunisia. There are small salt pans in the former and very large Chotts such as Chott El Jerid in the Southern Tunisia. The Oued El Melah is only the perennial river in the Study area.

Table A.1.1.1 (1) Meteorological Data

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
	GAFSA												
Mean temp. (°C)	9.4	11.1	13.5	17.0	21.6	26.3	29.1	29.0	25.2	19.7	13.8	10.2	18.8
Min. temp. (°C)	3.8	5.2	7.4	10.4	14.5	18.7	21.2	21.5	18.6	13.8	8.0	4.7	12.3
Max. temp. (°C)	14.9	16.9	19.6	23.6	28.6	33.9	37.0	36.4	31.7	25.6	19.6	15.6	25.3
Rel. humidity (%)	65	61	57	54	52	47	43	48	56	61	64	68	56
Min. rel. hum. (%)	44	40	34	30	27	24	20	24	31	39	44	48	34
Max. rel. hum. (%)	84	82	79	77	75	69	65	71	80	82	84	87	78
Max. wind velo. (m/s)	8	9	10	10	10	10	9	9	9	8	8	8	9
Precipitation (mm)	12.7	18.9	24.6	12.0	11.5	8.0	1.1	8.7	16.6	21.2	15.5	23.5	174.3
Rainy days	5	6	6	6	5	3	1	3	5	6	5	5	56
Evaporation (mm)	3.1	4.2	5.3	6.9	8.7	10.8	11.4	10.0	7.2	4.9	3.8	2.8	6.6
Sunshine (hrs)	6.8	7.4	7.9	8.8	9.9	10.6	11.3	10.8	9.3	8.1	7.4	6.6	8.7

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
	TOZEUR												
Mean temp. (°C)	11.4	13.5	16.2	20.0	24.6	29.4	32.1	32.0	28.2	22.3	16.3	12.2	21.5
Min. temp. (°C)	6.2	7.9	10.2	13.7	17.9	22.4	24.9	25.1	22.0	16.7	10.9	7.0	15.4
Max. temp. (°C)	16.6	19.1	22.2	26.3	31.2	36.4	39.2	38.9	34.3	27.9	21.6	17.4	27.6
Rel. humidity (%)	62	55	51	48	45	42	40	43	51	56	60	65	51
Min. rel. hum. (%)	42	34	29	25	23	21	18	21	28	34	39	45	30
Max. rel. hum. (%)	81	76	73	70	67	62	60	65	74	77	80	84	72
Max. wind velo. (m/s)	8	9	10	11	11	12	10	10	9	8	7	7	9
Precipitation (mm)	8.3	9.3	9.6	8.3	8.5	2.5	0.1	1.3	9.9	7.8	10.6	10.7	86.9
Rainy days	5	4	5	4	3	3	1	1	3	5	4	5	43
Evaporation (mm)	3.4	4.6	5.9	7.9	9.6	11.9	12.0	11.3	8.1	5.8	4.1	3.1	7.2
Sunshine (hrs)	6.7	6.9	7.7	8.2	9.2	9.3	10.6	9.9	8.8	7.7	6.7	6.4	8.2

Source: ALMANACH, Institut Nationale de Meteorologie

Table A.1.1.1 (2) Meteorological Data

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
	KEBILI												
Mean temp. (°C)	10.7	13.0	16.9	20.5	24.7	27.5	31.3	31.5	29.5	23.0	17.0	11.9	21.4
Min. temp. (°C)	5.0	7.1	10.1	13.4	17.2	20.5	23.6	23.6	24.6	16.5	10.7	6.0	14.7
Max. temp. (°C)	16.3	18.8	23.7	27.5	32.1	34.5	39.0	39.3	34.4	29.4	23.2	17.7	28.0
Rel. humidity (%)	66	55	52	50	50	47	46	46	55	58	59	68	54
Min. rel. hum. (%)	43	33	24	23	25	23	20	18	28	32	36	45	29
Max. rel. hum. (%)	87	77	78	75	72	70	72	74	79	84	81	89	78
Max. wind velo. (m/s)	13	11	13	19	13	20	13	16	16	13	13	9	14
Precipitation (mm)	7.3	0.0	3.6	0.1	3.4	6.4	0.0	1.5	4.4	0.3	19.3	27.3	73.6
Rainy days	4	0	1	1	1	2	0	2	3	2	8	6	30
Evaporation (mm)	3.4	5.1	7.0	9.1	12.0	13.4	13.8	12.6	9.5	7.2	5.2	2.5	8.4
Sunshine (hrs)	6.8	6.4	7.7	8.2	8.4	7.3	8.9	9.4	7.6	7.1	6.0	6.4	7.5

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
	GABES												
Mean temp. (°C)	12.0	13.3	15.0	17.6	20.8	24.2	26.7	27.6	25.7	21.6	16.6	13.1	19.5
Min. temp. (°C)	7.4	8.4	10.3	13.4	16.9	20.8	22.7	23.6	21.7	17.3	12.0	8.6	15.3
Max. temp. (°C)	16.5	18.2	19.6	21.8	24.6	27.5	30.6	31.5	29.6	25.8	21.2	17.6	23.7
Rel. humidity (%)	62	59	62	63	65	66	63	64	66	64	62	64	63
Min. rel. hum. (%)	44	39	41	44	47	50	4	47	49	47	44	47	45
Max. rel. hum. (%)	78	78	81	81	82	81	80	81	82	81	79	80	80
Max. wind velo. (m/s)	9	9	9	9	9	9	8	8	8	8	8	9	8
Precipitation (mm)	16.4	21.5	23.7	12.0	6.2	3.7	1.0	0.7	17.6	42.1	29.5	38.4	212.8
Rainy days	6	6	6	5	5	3	1	1	5	7	5	6	56
Evaporation (mm)	5.1	5.7	5.7	6.2	5.8	6.0	6.7	6.5	6.0	5.7	5.4	4.8	5.5
Sunshine (hrs)	7.0	7.5	8.0	8.9	9.8	10.7	11.8	11.2	9.3	8.2	7.5	6.5	8.9

Source: ALMANACH, Institut Nationale de Meteorologie

Table A.1.1.2 Mean Monthly Wind Velocity (km/day)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Gafsa	302.0	311.0	372.0	397.0	397.0	423.0	354.0	328.0	320.0	294.0	276.0	276.0	337.5
Tozeur	225.0	225.0	276.0	372.0	328.0	354.0	337.0	363.0	294.0	268.0	164.0	302.0	292.3
Kebili	290.0	363.0	509.0	541.0	606.0	726.0	559.0	481.0	475.0	478.0	334.0	187.0	462.4
Gabes	363.0	337.0	337.0	406.0	354.0	406.0	346.0	354.0	397.0	276.0	225.0	302.0	341.9

Source: ALMANACH, Institut Nationale de Meteorologie

ANNEX - B

GEOLOGY AND HYDROGEOLOGY

ANNEX B GEOLOGY & HYDROGEOLOGY

Contents

B1. Physiography & Geology

B1.1. Physiography in General

The Republic of Tunisia is situated at almost center of the long African northern shore line mostly facing to the Mediterranean Sea, with the territory of around 164,000 km^2 and 1,300 km of coastline. The Great Atlas Mountain Range rising at Morocco is just sinking into the sea at Tunisia.

North-south prolonged Tunisian territory is roughly divided into three physiographic or morphological provinces as i) The Saharan Platform, ii) The Atlasic Tunisia, and iii) The Eastern Tunisia. Those are briefly explained bellow;

<u>The Saharan Platform</u>

It is a flat plateau, dipping gently to the south-west where it is overlain by dunes of the Great Erg. On the northeastern side a series of cuestas limit the low lands of El Ouara and Jeffara. The northwestern limit is formed by very large salt lakes, Chott El Djerid and Chott El Gharsa, the latter being 17 m below sea level.

<u>The Atlasic Tunisia</u>

It includes the main mountains and ranges of Tunisia, with further three (3) prominent zones: E-W trending ranges in southern zone, N-S trending chains in eastern zone, and roughly SW-NE oriented high mountain ranges in the central zone called as "Tunisian Back-bone". The highest peak of Tunisia, Jebal Chambi (1,544m) is standing up at the southern hedge of the said Tunisian Back-bone.

<u>The Eastern Tunisia</u>

It is characterized by flat slowly subsiding lowlands, including both onshore and offshore parts. For onshore part, low hills, flat plains, and large salt pans (sebkhas) form the wide Kairouan, the Sahel, and the Sfax Plains. The eastern coast, the islands, and the large shallow shelf contain numerous ports and touristic resorts, and the important activity of the Tunisian fishing industry.

The Study Area consisted of four (4) prefectures of Gafsa, Tozeur, Kebili, and Gabes, occupies the northern margin of the first one, "The Saharan Platform", where is the most low lying area in Tunisia surrounding the Chott El Djerid and opening toward "Golfe du Gabes" (refer to Figure 1.1.1).

B1.2. Geology in General

1.2.1. General Geology and Stratigraphy

As same with the most of African countries, Tunisia also has a geological basement of Pre-Cambrian in age, mostly granite or metamorphic rocks. Those are, however, not exposed on the ground but only checked by several wells in the Saharan Tunisia. A practical basement of the country is Paleozoics, and the oldest formation outcrops in Tunisia is the Permian series which forms Jebel Tebaga near Medenine.

Covering the basement, almost all sequences of geological system were discovered and/or deduced, and a summary of the stratigraphy of Tunisia is briefed herein.

<u>A. Paleozoic</u>

Except for the Permian series of Jebel Tabaga, the Paleozoic does not outcrop in Tunisia. It is known from many wells drilled in the Saharan part of the country and the largest accumulation of oil comes from a Silurian source rock.

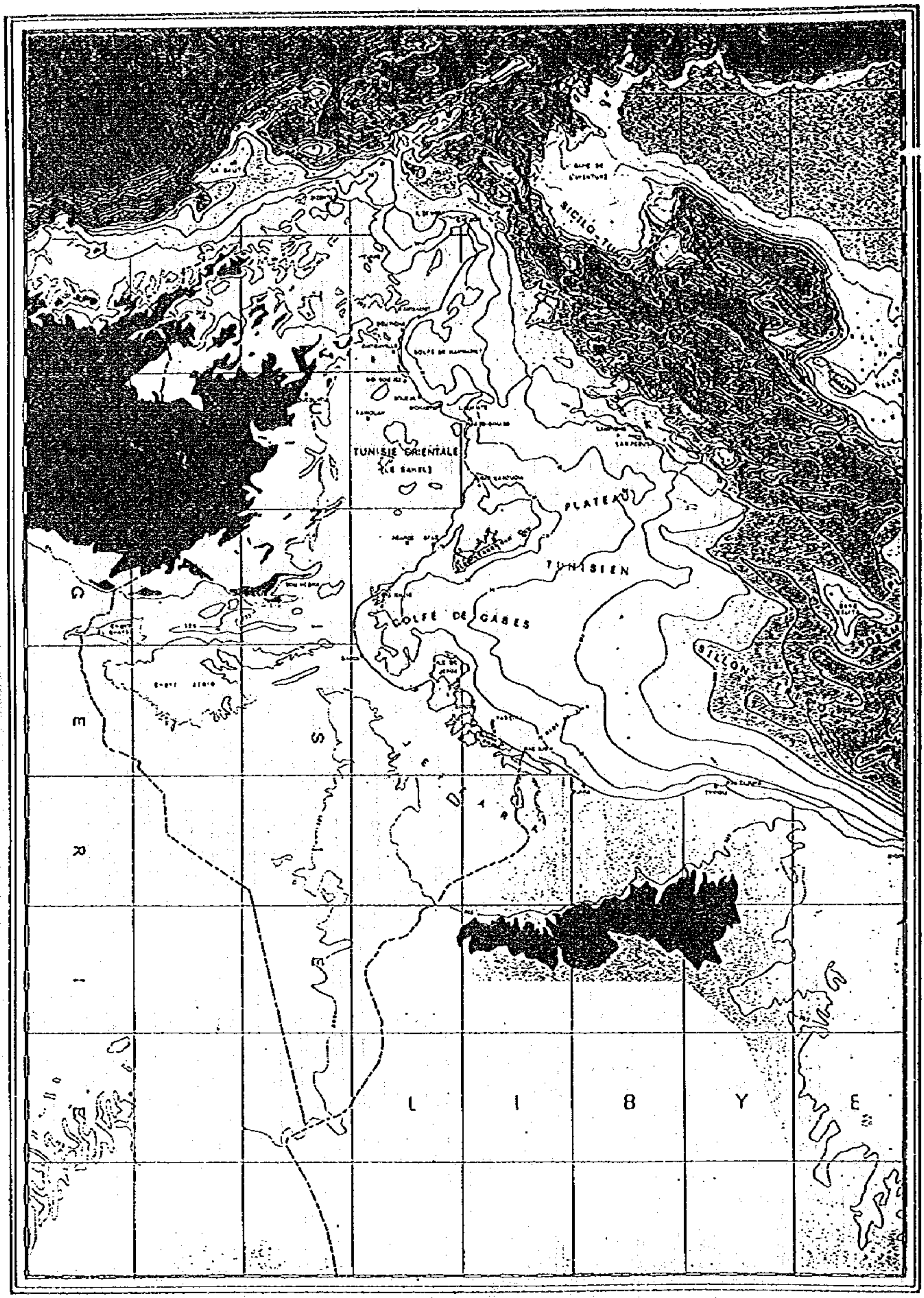


Fig.1.1.1. Geographic map with marine bathymetry

A-1. Cambrian :

The Cambrian series is an 800 to 1000m thick sheet of coarse to fine grain sandstone, arkosic in place and quartzitic, especially in the lower part.

A-2. Ordovician :

The series is marine and fossiliferous (Brachiopods, Crustaceans, Acritarchs, Chitinozoa, Histrichosphers, etc.). It may be subdivided into four formations, from the base upwards; Sanrhar, Kasbah Leguine, Bir Ben Tartar, and Jeffara Formations.

A-3. Silurian :

Known only in the bore-hole of the South Tunisia, the Silurian system consist of two main formations; the Tannezuft shale and the Acacus sandstone. Abundant Graptlites collected from cores allowed the stratigraphic zoning of the series.

A-4. Devonian :

In the deep south of Tunisia, the Silurian is overlain by Lower Devonian series. The total Devonian sequence was encountered in two wells, and the thickness of it may reach 1,245m at MG1. The sequence is consisted of mainly quartzose sandstone, interbedded with claystone or limestone sometimes.

A-5. Carboniferous :

The Carboniferous series is marine. In Libya, three formations were distinguished, from base to top, M'Rar Formation of shale, siltstone, and sandstone; Assedjeffar Formation of sandy shale; and Upper Carboniferous made up of shale, sandstone and **gypsum**. In Southern Tunisia only the M'Rar formation has been found by wells.

A-6. Permian :

The Permian is the only system of the Paleozoic which outcrops in Southern Tunisia, at Jebel Tabaga near Medenine. It is made of sandstone, shale and very fossiliferous carbonates: Gastropods, Pelecypods, Agae, dated Upper Permian.

B. Mesozoic

B-1. Triassic :

In Tunisia there are many Triassic outcrops; however quite "in situ" Triassic is known only in the Jeffara Plain between Medenine, Foum Tataouin, and the Libya border.

Lower Triassic is represented by interbedded red sandstone and claystone of Bir Mastoura Formation. Middle Triassic series have a wide extension, outcropping in Jeffara, made up of fluvial deltatic sand with minor clay. Upper Triassic is characterized by carbonates units and clastic or **evaporitic series**. Especially the uppermost part of Triassic are mainly **gypsum** and **anhydrite** in surface with thin interbedded varicolored clay and very thin layers of dolomite, called as "Bhir evaporites".

B-2. Jurassic :

The Jurassic presents great variations of facies from the north to the south. Its thickness exceeds 2,800m (Chott Fedjej CF). The series can be divided into three members roughly to the classical divisions: Lias, Dogger, and Malm.

The Lias (Lower Jurassic) is mainly made up of massive light to dark gray dolomitic limestone. The Dogger (Middle Jurassic deposition) continues with the deep marine facies seen in the Toarcian. It is formed by dark gray to reddish marl, argillaceous limestone and chert. Finally the Malm is corresponding to Upper Jurassic. On the Saharan Platform, the Upper Jurassic is formed by continental to delta and shallow marine Asfer Formation. In the south of the Gulf of Gabes, it is represented by M'Rabtine Formation, shallow marine, grading upwards to the Asfer series, and in Chott El Fejij there is a massive carbonate.

B-3. Cretaceous :

There is general gradation from the netritic, lagoonal and continental facies of the Saharan Platform south to the open marine and often deep sea facies on the northern side. Irregular subsidence, blocks tilting, and salt movements have given complex patterns of thickness and facies since the Aptian times. The Cretaceous System in Tunisia can be divided into two parts in relation to a major unconformity near the base of Upper Albian beds; Early and Late Cretaceous.

Early Cretaceous includes Asfer Formation, the Sened Group, Gafsa Group, M'Cherga Formation, roughly from base to upper. Later Cretaceous also includes several members such as Zebbag Formation, the Fehdene Formation, Aleg and Kef Formations, and Abiod Formation.

Among them, Asfer Formation which is made up of interbedded varicolored clay or shale, sandstone and a small quantity of limestone, dolomite and **evaporite**, has been described often as "Wealdian" or ***"Continental Intercalaire"***.

C. Cenozoic

The Cenozoic series of Tunisia may be subdivided into three parts of a) Paleocene and Eocene, b) Oligocene and Early Miocene, and c) Middle Miocene to Pleistocene, excepting for the Pleistocene and Holocene.

C-1. Paleocene and Eocene :

This time interval corresponds to a lithostratigraphic trilogy with, from base to top: El Haria shale, Metlaoui limestone, and Souar shale or its various equivalents.

El Haria Formation is made up of dark gray or black shale which is fissile with dark green weathering. Metlaoui Formation was defined in the Oued Seldja canyon, west of Metlaoui at the famous section where Ohilippe Thomas discovered the phosphates. Souar Formation consists of dark gray shale with a rich microfauna; in surface the weathering gives a beige or orange color which is a good means of identification.

C-2. Oligocene to Early Miocene :

This interval is represented in Central, Eastern, and Northern Tunisia by various facies, from deep sea flysch to continental beds. A large part of Tunisia stood devoid of any sedimentation, on the Saharan Platform, in Southern Atlas, and on the Kasserine Island.

C-3. Middle Miocene to Pleistocene :

These series are contemporaneous of main orogenic phase in Tunisia. Because of this, the paleogeography is far more complex than earlier, with various basins, gulfs, depocenters and foredeeps. The major members in this time period are Ain Grab and Mahmoud Formation, Beglia and Birsa Formation, Saouaf Formation, Segui Formation, Marine Pliocene series, and so forth.

In the Southern Tunisia, Beglia Formation of coarse sand, and Segui Formation made up of interbedded brownish clay and yellowish sand corresponding to a fluvial plain deposit are distributing.

C-4. Pleistocene and Holocene :

Compressional stress continued until present and neotectonic events caused some of the anticlines to be slightly uplifted and the synclinal zones to subside continuously. These movements associated with the semi-arid climate were the origin of many endoreic depressions, generally occupied now by playas or salt pans where the sediments coming from Central and Southern Atlas are trapped.

The standard stratigraphy of Tunisia (by Geological Service, Tunis) is shown as Table 1.2.1. at the following page.

1.2.2. Structural Unit

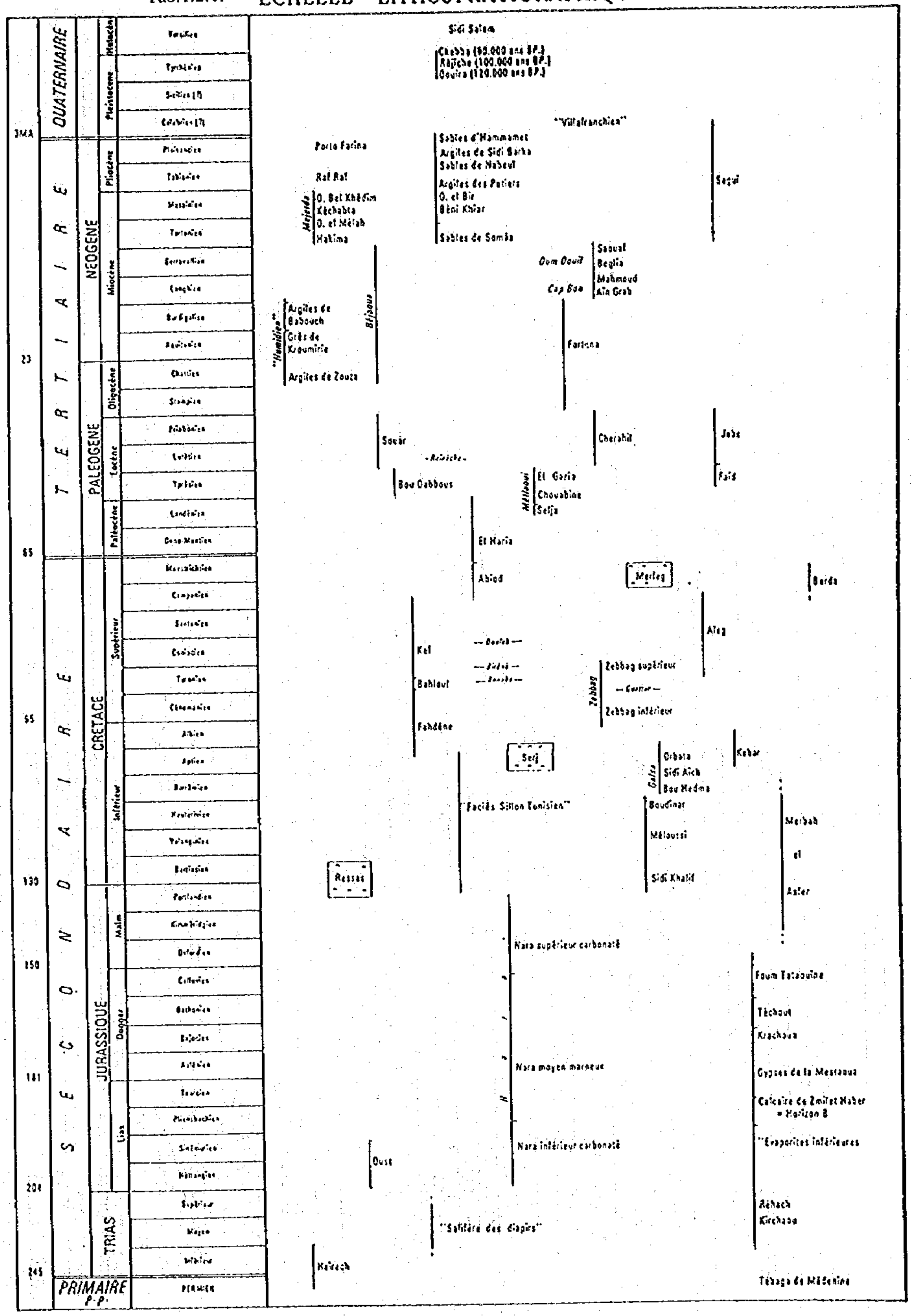
Tunisia, including the continental shelf, may be divided into several structural units. The major ones, from south to north, are Saharan Tunisia, Western Tunisia, and Eastern Tunisia as shown in the Figure 1.2.1. However, the structural unit in Tunisia shall be noted along with the traditional classification used in physiographical explanation such as Saharan Platform, Atlasic Tunisia, and Eastern Tunisia in this report.

In Saharan Platform, the Pre-Cambrian basement is overlaid with a thick Paleozoic sheet, mostly unfolded and gently uplifted at its central part. Only at the northern margin where is called as "Saharan transition zone", the Paleozoics are faulted in many steps. These practical basement in this area are covered directly by Quaternary.

As the geomorphological setting indicates, the geology in the Atlasic Tunisia is heavily complicated. This area is, however, used to be called as "Western Tunisia" as a contrast with the "Eastern Tunisia" in geological explanation. The area is well known as the eastern limb of the Atlas Movement which continues from Morocco to Tunisia for about 2,000 km along the northern hedge of African Continent. Mesozoics to Cenozoic rocks are folded and faulted heavily at anywhere but mainly SW-NE direction, excepting the southernmost and near the boundary with the Eastern Tunisia at where the directions of major geological movements are E-W and N-S respectively.

In contrast with the Atlasic Tunisia, the Eastern Tunisia shows very flat configuration and also very simple surface geology. Although the area is further subdivided into four sub-regions of the Gulf of Gabes, the Central Zone, the Gulf of Hammamet, and the Cap-Bon Peninsula, most of the area is underlain by Cenozoic, mainly Pliocene - Miocene sedimentary rocks, covered by Quaternary or directly exposed.

Tab.1.2.1. ECHELLE LITHOSTRATIGRAPHIQUE



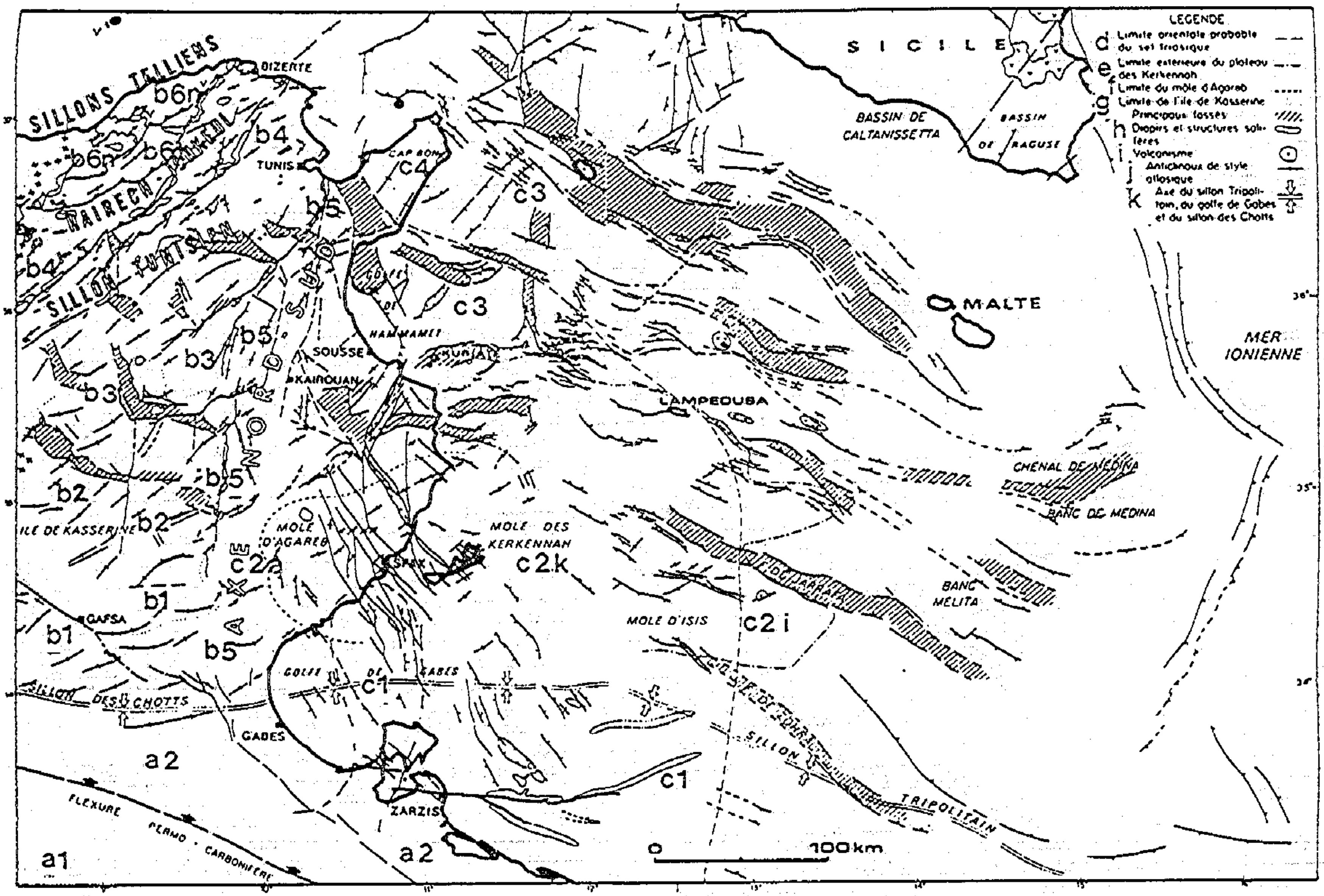


Figure I.2.1. Structural sketch (main structural elements)

B1.3. Physiography & Geology of Target Provinces

1.3.1. General

The Study Area consisted of four (4) provinces is usually called as simply "south" in Tunisia, and this region is just extended along the northern limit of the Saharan Platform, or slightly crosses the frontier into the Atlasic Tunisia (Gafsa Province and a part of Tozeur). The region is characterized by low-lying land as represented by Chotts and Golfe de Gabes, and this low morphology was caused by compressional stress by conflicting two Plates; the African Plate and the European Plate. According to the authority, the subsidence caused by such stress is still continued until present.

Most of the region is underlain by Mesozoics and covered directly by Quaternary deposits both fluvial and eolian. Rather long and low mountain ranges at both sides of Chott El Fedjadj and near around the Gafsa City, extended low mountainous zone at the south of Gabes City are consisted of Upper Mesozoics (mainly Cretaceous in age), and usually show typical and great cuesta landscapes. Only at the south-eastern side of Chott El Djerid, in where Kebili and Douz are included, Cenozoic (Oligocene - Miocene) covers the Mesozoics and crops out directly.

1.3.2. Gafsa

The Province situates at the southern-most of Atlasic Tunisia or the Western Tunisia (as physiographic and geological region respectively). This is an area of long ranges separated by wide plains, located between the huge salt lake of Chott El Djerid on the southern side and the "Kasserine Island" in the north. In general, the ranges trend E-W but, in detail, they are made of "en echelon" folds, each of them having a WSW-ENE or SW-NE axis.

Physiographically, the area of Gafsa Province is divided into two zones of north and south by one of such mountain range, although almost E-W trending as a total. The mountain range is disconnected at its almost central portion, at just where Gafsa City is located, and the eastern part is Jebel Alima (comes from Tamerza) to Jebel Ben Youner, the western part is called as Jebel Orbata to Jebel Biada. Northern zone of the range is vast and flat Sidi Aich basin, and south of it is also vast Oued El Melah basin which continues in WSW-direction to Chott El Gharsa.

Southern limit of the Province, the boundary with Tozeur Province, is also a range called as Jebel El Asker, and a small but Chott El Guettar locates in between the ranges of the central and the said southern range.

Geologically, the area is underlain and the ranges are formed by a series of Early Cretaceous called as Gafsa Group, Late Cretaceous series and some Tertiary members. The Gafsa Group forming mountains near around Gafsa City is made up of three formations, from base to top: Bou Hadma, Sidi Aich, and Orbata. The Late Cretaceous sequence consists of, in the same manner with above, Zebbag, and Aleg and Kef Formation. As the Cenozoic series, the El Haria Formation, the Metlaoui Formation, the Souar Formation, the Beglia and Birsa Formation, and the Segui Formation are distributing. Some of them having deep relation with the Study are briefed below;

<u>Bou Hadma Formation</u>

Its composite lithology is made up of interbedded elements: oolitic, fine grained, or bioclastic limestone, laminated dolomite; varicolored clay; gypsum and anhydrite; and fine grained sandstone.

<u>Sidi Aich Formation</u>

This is sandy unit widely spread in Central, Eastern, and Southern Tunisia. It overlies the Bou Hadma or M'rhila Formation in continuity of sedimentation. The sand is fine to medium grained, generally coarsening up, with interbedded silts and some clay.

Orbata Formation

In Central Tunisia, the Sidi Aich Sandstone is overlain by a thick series of carbonates named Orbata Formation, with a major unconformity. Usually the Formation is further subdivided into three members: the Lower, the Middle, and the Upper.

Zebbag Formation

The formation is made up of limestone/dolomite rich lower member, clay, marl, gypsum, and white limestone of middle member, and massive dolomite of upper member called as Gatter Formation.

Aleg and Kef Formations

It is thick series of gray marl and shale. Beida Formation characterized by evaporites is a lower member of Aleg Formation.

1.3.3. Tozeur

Tozeur Province is situated at just mid and the most western side of Tunisia, bordering with Algeria. Most of the area is occupied by two major salt lakes of Chott El Djerid and Chott El Gharsa, and the zone of human activity is limited into the narrow corridor between the said two lakes. Only a northern corner of the Province (Tamerza zone) is occupied by mountain range continued from Gafsa Province.

Tozeur City is located at almost center of the corridor, which is a low hill prolonged in WSW-ENE direction with very gentle slopes at both sides. It is an extension of Jebel Morra bordering with Gafsa Province, and across the two Chotts just as a bridge. The front zone with Algeria is mostly occupied by desert, a part of Grand Erg.

Most of Tozeur Province and the corridor, excepting the Jebel Morra, are underlain/consisted of Tertiary System, mainly Miocene to Pleistocene. The System distributing in this area is classified into two formations: the Begria and the Segui Formations. While, the Jebel Morra is formed by Late Cretaceous series.

Begria Formation

It is a thick sand body, overlying the Mahmoud Shale and is generally overlain by Saouaf Formation. The sand is coarse to medium grained, with some gravel beds and a few clay layers.

Segui Formation

This formation is made up of interbedded brownish clay and yellowish sand, corresponding to a fluvial plain deposit. It may also include conglomerates, very coarse in some places.

1.3.4. Kebili

Kebili is a very big province but more than half of the area is covered by sand desert of Grand Erg Oriental, and considerable areas at northwest and north are occupied by Chott El Djerid and Chott El Fejaj. Thus, the area of human activity in this Province is also limited at small zone along the eastern shore of Chott El Djerid where are slightly highlands as if a peninsula or islands in the Chott.

Jebel Tabaga, a quite characteristic cuesta mountain range forms a huge crescent shape hedging the Chott El Fedjaj at its south.

Southern part of Kebili is a desert highland of typical Saharan Platform, and the northern part occupied by the Chott is classified into Saharan transition zone from a view point of structural geology.

Geologically, the area is underlain by Cretaceous as a substantial base, and covered by Pliocene - Miocene sequence for most of the zone. Jebel Tabaga is made up by the Zebbag Formation of sequence of limestone, dolomite, clay, limestone, clay and marl, gypsum, limestone, and covered by massive cliff of dolomite. The eastern shore of Chott El Djerid, including major towns of Kebili Province, is underlain by El Haria Formation and further later Segui Formations. These are dark gray or black shale (El Haria), and interbedded brownish clay and yellowish sand (Segui). The Vast Saharan Platform is covered by thick Quaternary eolian deposits.

1.3.5. Gabes

Gabes is only the province facing to the sea, the Gulf of Gabes. North of the province is hilly highland which is an extension of the mountain ranges from Jebel Morra Tozeur), Jebel El Asker and Jebel Hachichina (Kebili). The main peak in the province is jebel Hdifa (579m). Central part of it is contrast of low-lying zone and highland; Chott El Fedjaj to sea shore Gabes, and the eastern half of Jebel Tebaga mountain range. Southern half of the area is characterized by NW-SE trending gentle mountains of Matmata. Along with shore line, some levels of Terraces are observed.

Geological setting of the Province is almost same with the one of Kebili Province; Cretaceous series as a practical base, overlain by Tertiary series and Quaternary. The mountain ranges of north, central and south, including Matmata mountains are formed by Cretaceous sedimentary rocks and evaporites. A part of northern highland is underlain by Tertiary, and the remaining flat or low-lying zone, including shore side, are underlain by Quaternary.

B1.4. Summary and Conclusion

1.4.1. Summary

The Republic of Tunisia situates at almost center of the long African northern shore line, facing to the Mediterranean Sea, at where the Great Atlas Mountain Range is sinking into the sea.

North-south prolonged Tunisian territory is roughly divided into three physiographic provinces as i) The Saharan Platform, ii) The Atlasic Tunisia, and iii) The Eastern Tunisia. The Study Area consisted of four prefectures of Gafsa, Tozeur, Kebili, and Gabes, occupies the northern margin of "The Saharan Platform", where is the most low lying area in Tunisia surrounding the Chott El Djerid and opening toward "Golfe du Gabes"

Tunisia has a geological basement of Pre-Cambrian in age, mostly granite or metamorphic rocks. Those are not exposed on the ground but only checked by several wells in the Saharan Tunisia. A practical basement of the country is Paleozoics, and the oldest formation outcrops in Tunisia is the Permian series which forms Jebel Tebaga near. Covering the basement, almost all sequences of geological system were discovered and/or deduced.

Widely at the South, sedimentary sequences from lower Cretaceous to Tertiary are prevailing. They are made up of interbedding of soft sediments such as marl, siltstone, clay or evaporites, and rather hard rocks such as limestone or dolomite, and the situation created the grand landscape of cuestas throughout the area.

The Study Area is just extended along the northern limit of the Saharan Platform, or slightly crossing the frontier into the Atlasic Tunisia. The region is characterized by low-lying land as explained above, and this low morphology was caused by tectonical movement. The subsidence of the area is still continued until present. Most of the region is underlain by Mesozoics and covered directly by Quaternary both fluvial and eolian. Mountain ranges at both sides of Chott El Fedjadj, near around the Gafsa City, and low mountainous zone at the south of Gabes City are consisted of Upper Mesozoics. Only at the south-eastern side of Chott El Djerid, Cenozoic covers the Mesozoics and crops out directly.

1.4.2. Conclusion

The Study Area is situated at the most low-lying zone of Tunisia, underlain mainly by sedimentary sequences from Cretaceous to Tertiary. The geomorphology was caused through tectonic movement, and the activity is not yet terminated. While, most of the sequences have evaporites such as gypsum, anhydrite, or rock salt sometimes. They may cause (or caused) some problems of groundwater contamination or accumulation of gypsum soil, however, there is no fatal risk to obstruct the promotion of this Project from view points of physiography and geology.

2. Hydrogeology

2.1. Hydrogeology in General

2.1.1. Hydrogeological Regions

Figure 2.1.1. shows a precipitation of Tunisia, and as it indicates, northern mountainous area has the highest precipitation and it becomes less and less towards south. Almost southern half of Tunisian territory has only less than 200 mm of yearly rainfall, and the desert area of south-west has less than 100 mm. Based on this situation and the geomorphological setting explained already, the country is subdivided into three (3) hydrogeological regions; Northern, Central, and Southern Tunisia as shown in Figure 2.1.2. And the each hydrogeological region has been further subdivided into two sub-regions. These hydrogeological regions, as well as the Provinces included, are shown below;

Northern Tunisia

a. North West Tunisia	- Jendouba
	- Beja
	- Le Kef
	- Siliana
b. North East Tunisia	- Bizerte
	- Ariana
	- Ben Arous
	- Zaghouan
	- Nabeul

Central Tunisia

a. Kairouan Sahel	- Kairouan
	- Sahel de Sousse
	- Monastir
	- Mahdia
	- Sahel de Sfax
b. Tunisia Central	- Kasserine
	- Sidi Bouzid

South Tunisia

a. South West	**- Gafsa**
	- Tozeur
	- Kebili
b. South East	**- Gabes**
	- Medenine
	- Tataouin

Thus the description on hydro-geology shall be denoted along this regions, and the Study Area is wholly included into the Southern Tunisia as indicated by bold letters.

2.1.2. Surface Water

As the precipitation and physiography show, the most of surface drainage are concentrated in the Northern Tunisia followed by the Central Tunisia. Further, the surface drainage in the Northern Tunisia Hydrogeological Region are mostly perennial, but more than half of the drainage in the Central Tunisia are seasonal, while the ones in the Southern Region are just wadi flowing water only when considerable rainfall has come. The situation, the length and density of drainage, are easily understood by the Figure 2.1.3.

Although the annual rainfall is rather limited as from 50 to 250 mm/annum, the total volume of surface water is estimated as 2,630 MCM/annum in Tunisia (FERSI, 1976). And only 140 MCM/annum (5.3%) is shared in the South as shown below.

The North	2,120 MCM
The Central	370 MCM
The South	140 MCM
Total	2,630 MCM/annum

Fig.2.1.1. Precipitation of Tunisia

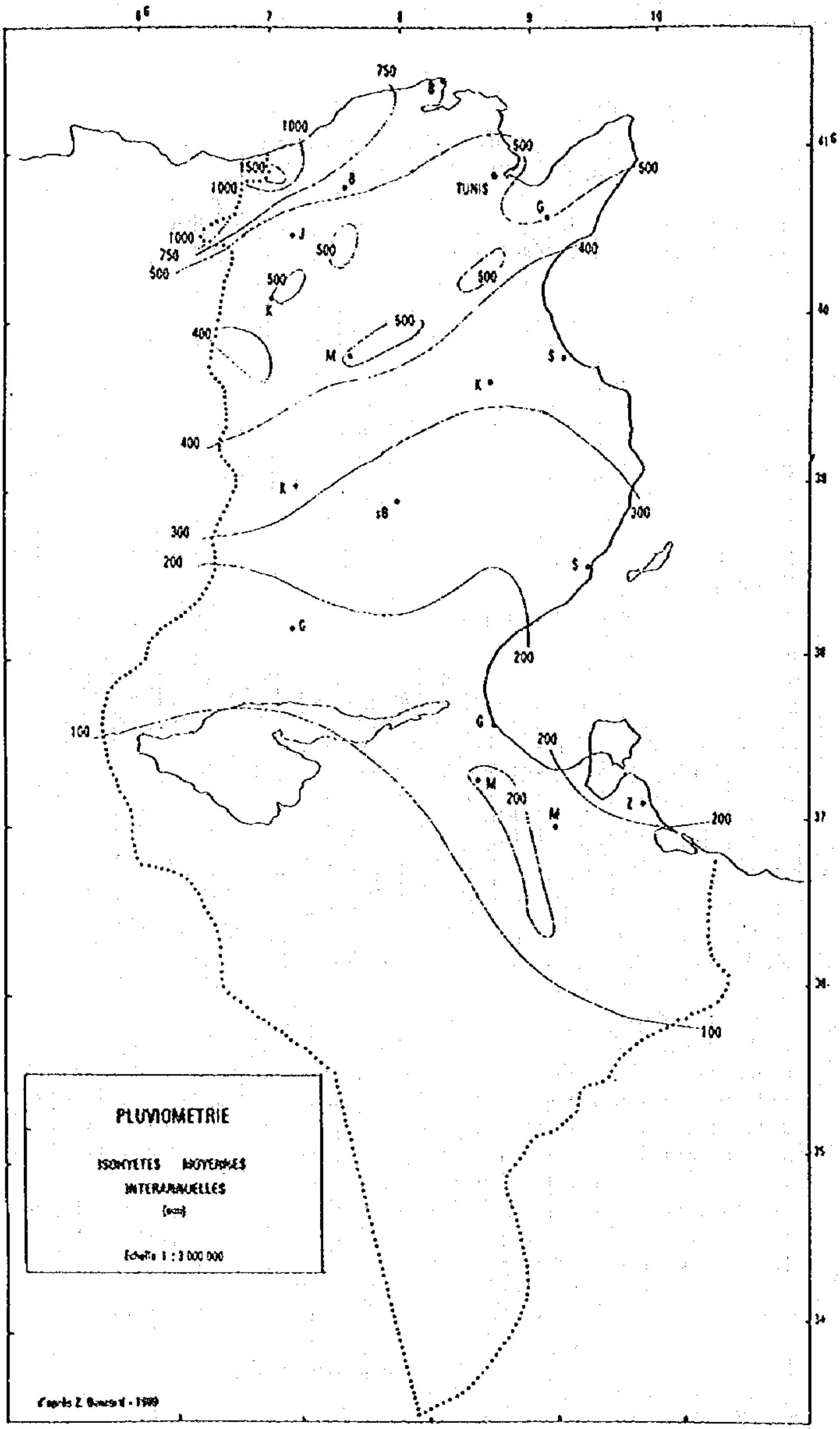


Fig.2.1.2. Hydrogeological Region of Tunisia

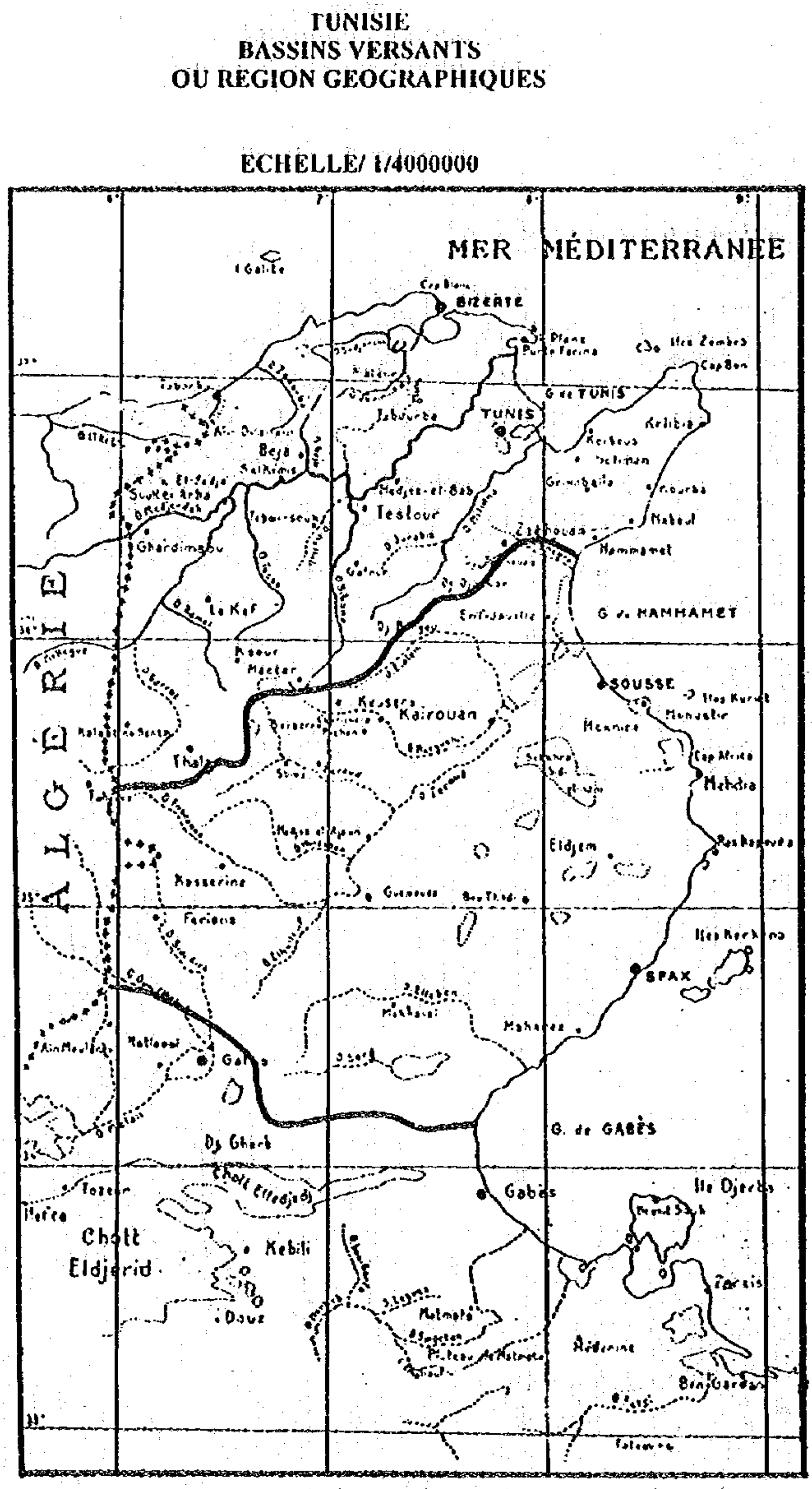
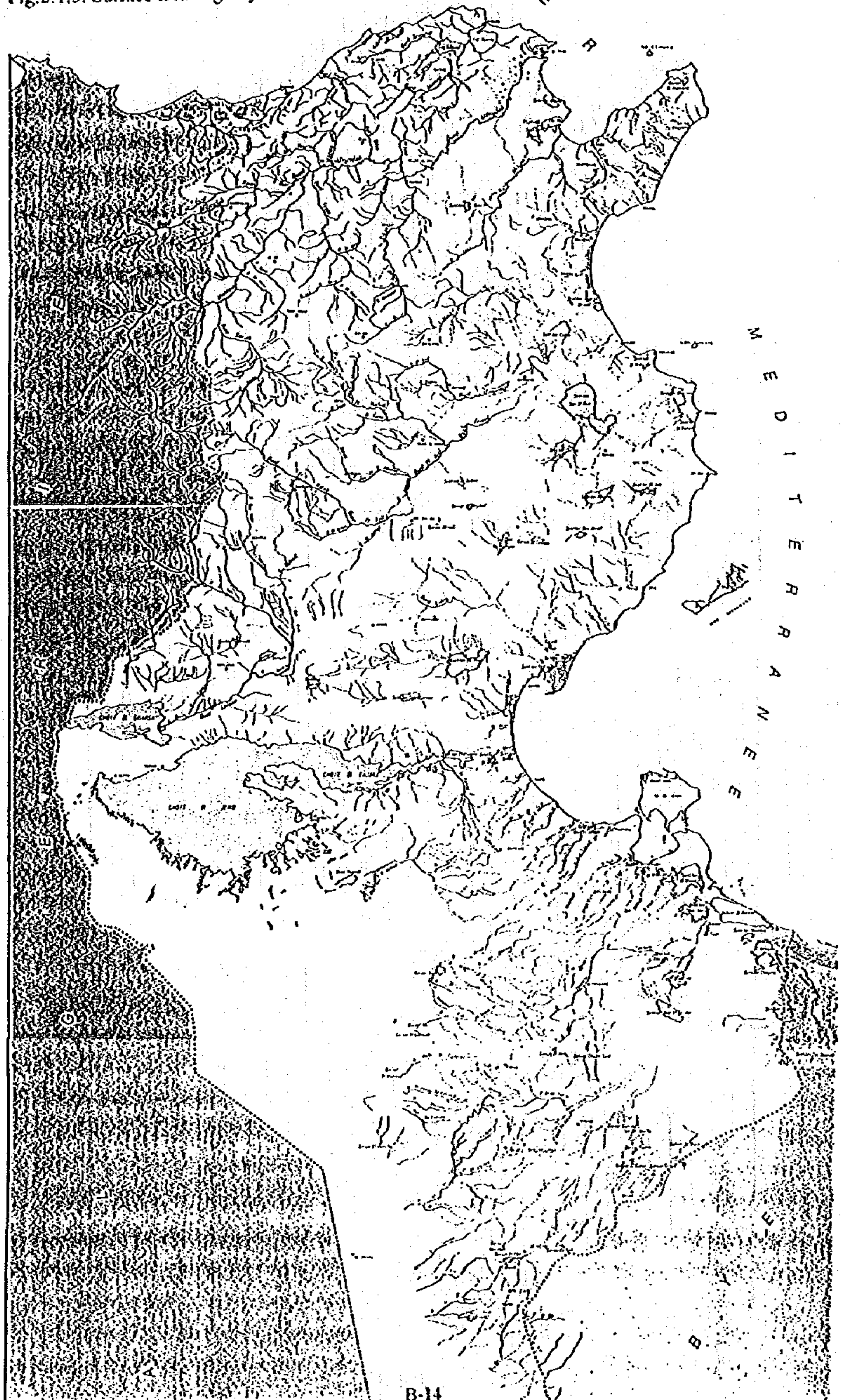


Fig.2.1.3. Surface Drainage System of Tunisia



In the South, around 75% of the very limited surface water resources is lost by surface runoff mainly into the Chotts (MAMOU, 1989).

2.1.3. Groundwater

At present, total 109,163 of shallow wells and 2,117 of deep tube wells are existing in Tunisia officially (Ressou National de piezometlique de Tunisie, 1994). And besides them, more than 800 of illicit deep tube wells are reportedly existed in the South.

In Tunisia, groundwater is usually classified into two types as "shallow" and "deep". The shallow groundwater means groundwater which has a free groundwater table within 50 m in depth, being utilized through dugwell, and the deep groundwater means the one having a groundwater table at deeper than 50 m regardless it's phreatic or artesian. While, aquifers are also classified into two categories as "phreatic" and "deep". The phreatic aquifer means an aquifer contains unconfined groundwater. And, the deep aquifer means an aquifer containing confined groundwater in it. The major deep aquifers in Northern or Central Tunisia lie between 100 m to 400 m in depth, but are found deeper than 1,000 m in the Southern Tunisia.

In the Northern or Central Tunisia, most of aquifers contain circulating groundwater, that is, the groundwater is recharged by a rain and renewable annually. Prevailing aquifers in these areas are i) Alluvial Plain, ii) Calcareous, and iii) Miocene Sandstone aquifers. On the other hand, nonrenewable or hardly rechargeable groundwater system called as "fossil water" is found in the Southern Tunisia. Major aquifer types prevailing in the later are i) Complex Terminal (C.T.) and ii) Continental Intercalaire (C.I.) which is included into the category of a fossil water.

In Northern/Central Tunisia

- Alluvial plain aquifer -(phreatic)

  This is the most common aquifer found out at almost everywhere. The system includes not only Alluvial but diluvial deposits. The groundwater is recharged by the rainfall, stored in the Alluvial (diluvial) sediments, flowing out gravitationally, and recharging the lower aquifer.

- Calcareous aquifer -(deep)

  The aquifer is contained in mainly calcareous rocks in Eocene, and this is included in the Complex Terminal in the Southern Tunisia.

- Miocene sandstone aquifer -(deep)

  The aquifer is so called Continental Terminal, one of the most prevailing aquifers in Africa. In the Southern Tunisia, this consists of a part of the Complex Terminal.

In Southern Tunisia

- Complex Terminal (C.T.) -(deep)

  The aquifer system covers the major part of the northern Sahara basin of about 350,000 km^2. The C.T. covers many aquifers which are located at different geological stages, however, the system generally flows in one of two litho-stratigraphic formation: the Senonian and the Carbonaceous Eocene, and the sandy Miopliocene (Continental Terminal). The model of geological cross section of the C.T. is shown in Figure 2.1.4.

- Continental Intercalaire (C.I.) -(deep)

  This aquifer is constituting one of the largest groundwater system in the world, spreading an area of some 600,000 km^2 in the African Continent. C.I. is comprising Upper Carboniferous to Lower

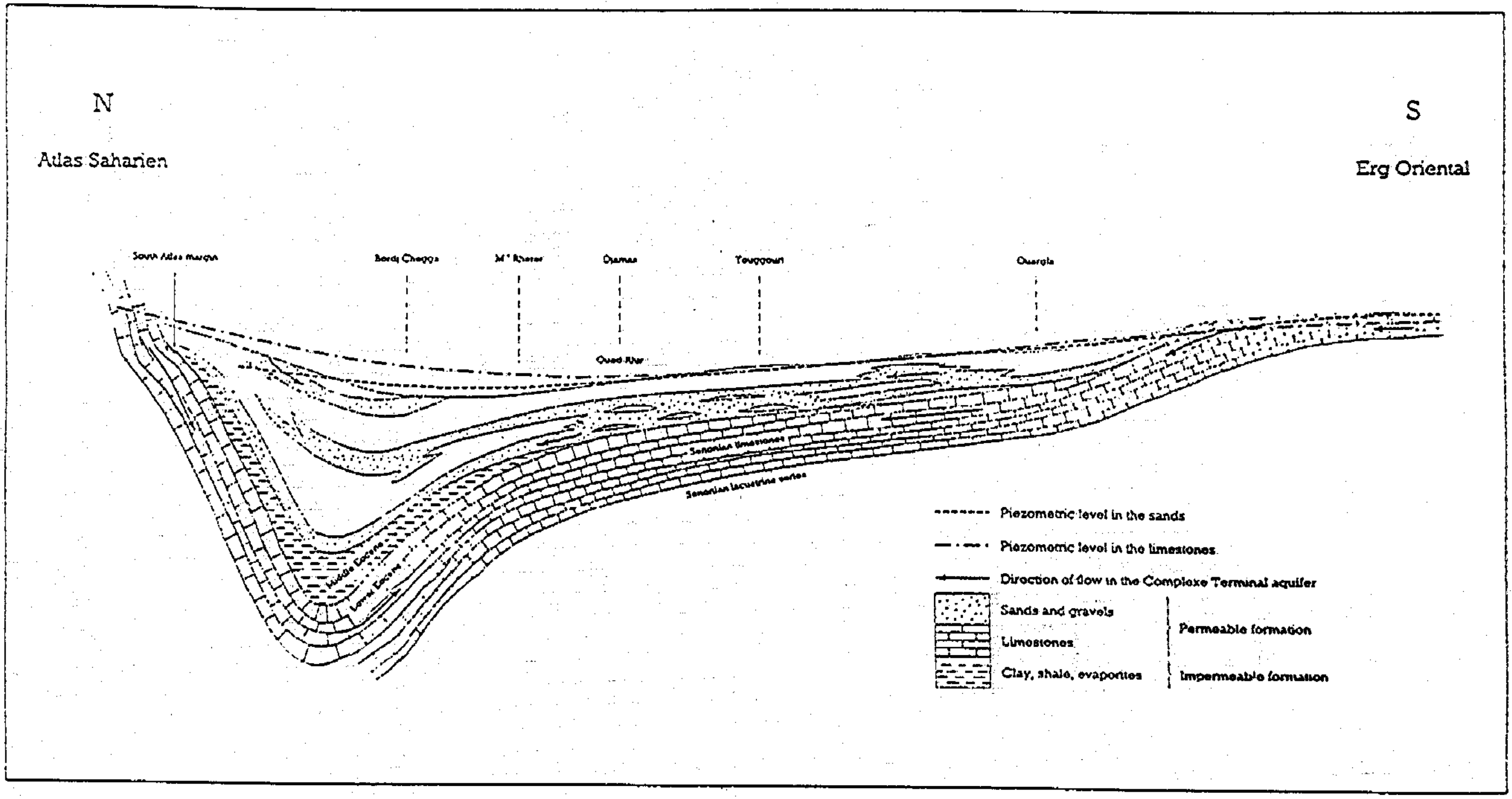


Fig.2.1.4.

Geological cross section through the Complexe Terminal aquifer

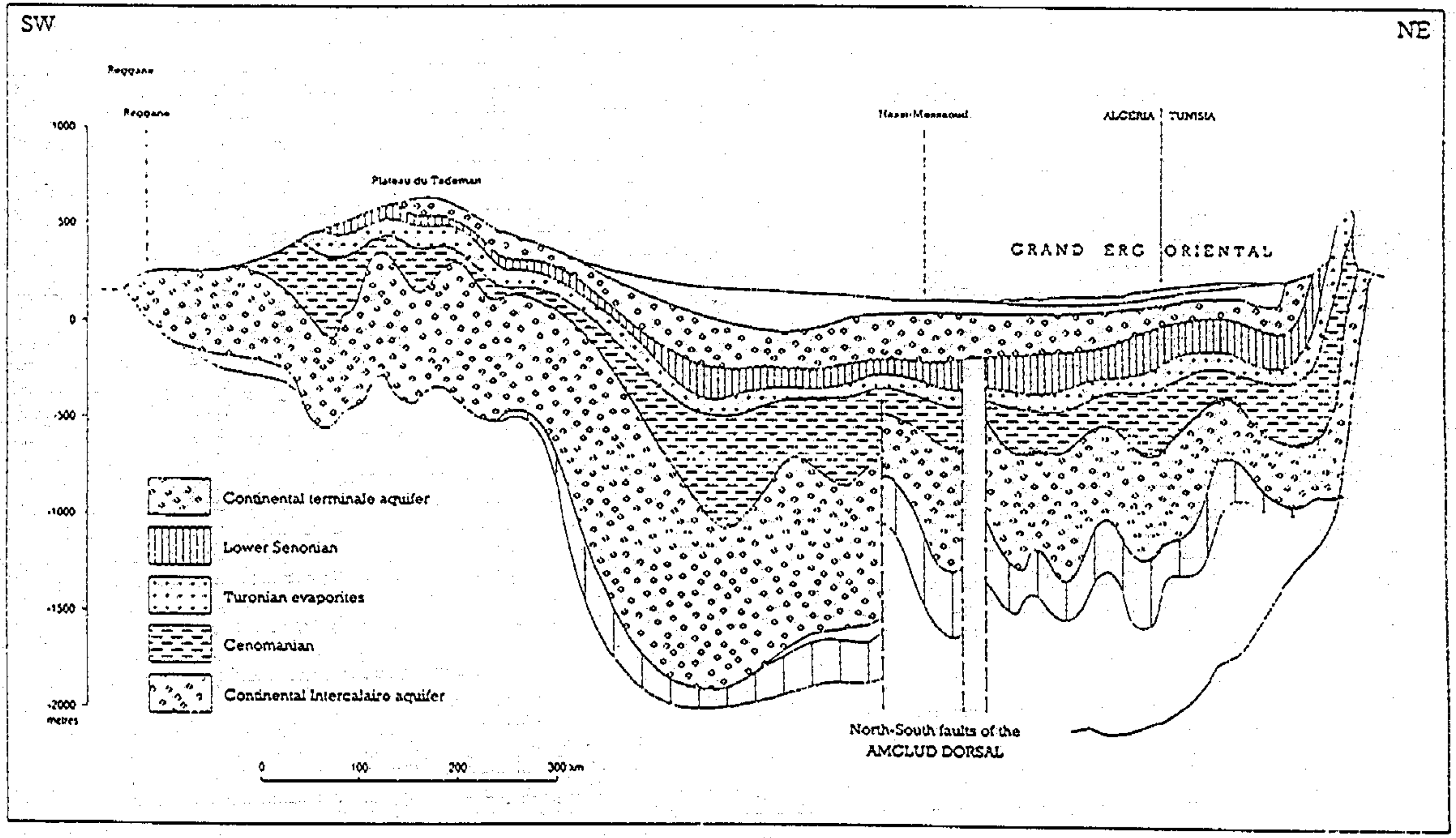


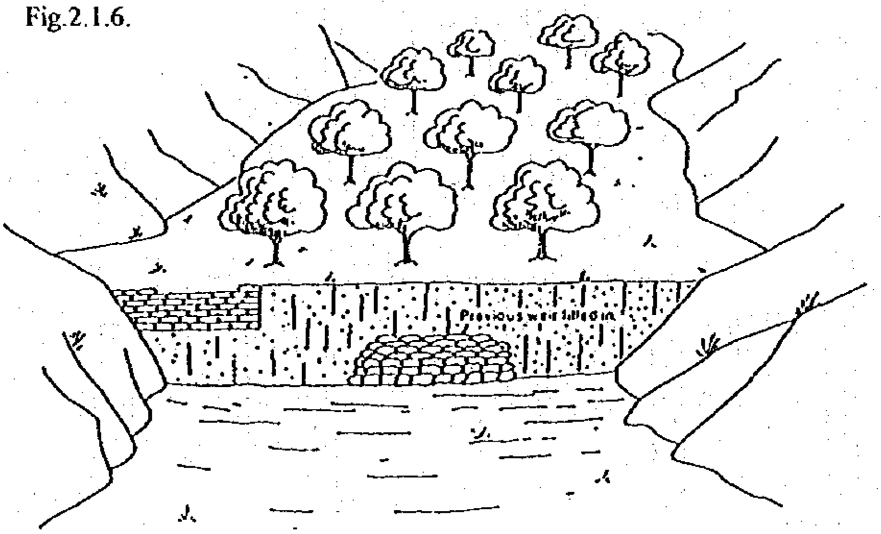
Fig.2.1.5. Geological cross section through the Grand Erg Oriental Basin.

Cretaceous rocks, and the largest reservoir of groundwater of the system is said as Lower Cretaceous. A simplified cross section through the Grand Erg Oriental Basin is shown as Figure 2.1.5.

Those aquifers are, however, further subdivided into several peculiar aquifers in each region, and systematically managed through overall coordination.

In the Study Area, it means in the Southern Tunisia, the groundwater has a special meanings and importance because a rainfall is not so abundant compared with the Northern or Central Tunisia. For most of the Oases in this region, groundwater is a sole water source available for irrigation, excepting the mountainous area of Tozeur where natural spring can irrigate the farmland as an old oasis condition. Under the situation, some quite traditional groundwater development/utilizing methods, such as "Foggara" or "Jessour", were exploited since the very old period. The foggara is a same kind of groundwater utilization method with "Quanat" or "Kalaze" in Middle East Asia, to dig the foot hill of mountain horizontally to meet with the groundwater level, that is to say, to make up spring water artificially. The jessour is believed as one of the most old concepts on underground dam scheme, to keep or reserve groundwater also artificially by constructing impervious barrier (see Figure 2.1.6.).

Fig.2.1.6.



Recently in the Southern Tunisia, above mentioned two types of aquifers becomes very important, because they are newly developed and still have an excellent yield, strongly confined and in artesian condition sometimes, and does not influence to numerous existing wells. However, these aquifers have peculiar disadvantages such as a deepness (around 600 m at C.T. and more than 1,000 m or 2,000 m at C.I.), a high salinity contents (1.5 to 2.5 g/l at C.T. and 2.5 to 5.0 g/l at C.I.), a geothermal water in the case of C.I. (around 70℃), and that an exploitation of them is just a mining as the most serious problem. These problems concerned to groundwater in the Southern Tunisia shall be discussed in the next phase.

2.2. Hydrogeology & Aquifers of Target Provinces

2.2.1. Gafsa

(a) Hydrogeology

Hydrogeological condition of Gafsa is severely restricted by the mountain ranges traversing the province in E-W direction at its almost central part. The ranges take a role of barrier for phreatic groundwater flow from north to south at the center of the province. Thus, ranges. Further, the southern half of the province has another mountain range along the boundaries with Tozeur and Kebili Provinces, and isolated mountain blocks in between the said two major ranges. And the configuration makes the hydrogeological situation of the area more complicated, especially the conditions of phreatic aquifer.

Two major mountain ranges of the central and the southern hedge are made up of Lower to Upper Cretaceous, while the other mountains are consisted of rather younger sequences, mainly Tertiary sediments. These outcrops are said to be the recharging zones on both "Continental Intercalaire" and "Complex Terminal", still very shallow and not in artesian condition. Thus, in the area a deep aquifer such as C.I. or C.T. was not utilized, and classified as deep but only middle range aquifers in Tertiary formations were developed besides the phreatic aquifers.

(b) Aquifer

Phreatic aquifers in the Province are roughly classified into two major aquifer systems of i) northern basin and ii) others, and they are further classified into nine aquifers from their locality:

i) Gafsa Northern Basin Aquifers

1. Garaat Sned Majoura (54150)
2. Alim Dakhila (54170)
3. Gafsa North (71520)

ii) Other Basin Aquifers

4. Gafsa South - El Guettar (73220)
5. Moulates - Redeyef (73310)
6. Oum Laksab (72110)
7. Chott El Charsa North (74210)
8. Bled Talah
9. Ouled Mansour (55210)

Deep aquifers in the area have closed relation with phreatic aquifers, and the classification system is also almost same with them as shown below:

i) Gafsa Northern Basin Aquifers

1. Gafsa North (71521)
2. Sidi Aich (71412)

ii) Other Basin aquifers

3. Gafsa South (73221)
4. El Guettar (73111)
5. Sidi Ahmed Zarrouk (73211)
6. Moulares (73311)
7. Redeyef (73312)
8. Chott El Gharsa North (74314)
9. Djebel Bel Khir (73521)
10. Bled Talah (55111)
11. Plio/Quaternary (73313)

(c) Water quality

All of the tube-wells supplying water in the target Oases tap at the deep aquifers of Gafsa North, Gafsa South, El Guettar, and Chott El Gharsa North. Water qualities of the aquifers are attached in Appendix, and the chemical components are summarized as Fig.2.2.1. (Trilinear Diagram)

2.2.2. Tozeur

(a) Hydrogeology

As same with the physiographic characteristics, the Province is deviled into three hydrogeological zones; the northern mountains, two of Chotts, and the central corridor.

The northern mountains zone is an extension of steep central mountain range of Gafsa, made up of heavily folded Lower Tertiary rocks (Eocene to Miocene). Two of Chotts are Chott El Gharsa at northwest and Chott El Djerid at southeast. The former is characterized by its low-lying situation (El. -17.0m), and the later is remarked by its hugeness. The central corridor is an extension of the Gafsa-Tozeur border mountain range, and separating the said two Chotts at almost center of the Province in NNE-SSW direction.

Hydrogeologically, the northern mountain zone is said as recharging zone on C.I and C.T. And the comparatively strong precipitation on the mountains keeps the groundwater level rather high level, which flowing out to the ground at their feet as natural springs. On the contrary, both Chotts are said as the discharge zones of C.I. and C.T. That is, the main resources of water for the Chotts are such deep aquifers, supplying vertically through any geological weak lines. While, the Chott is just an 'evaporation dish' under the arid or semiarid climate. The water in the Chott, as well as the surface inflow, was boiled down and the huge volume evaporites were precipitated through a long geological period just like as a grand saltpan. The current situation of these Chotts were made up thus, and the groundwater discharging from the bottom of the Chott is no longer fresh but contaminated by salts immediately. The central corridor, separating these Chotts, is consisted of original rocks of Early Tertiary, overlying the Cretaceous sequence. Some parts of the zone are also discharged by the deep aquifers through certain weak lines, to keep the groundwater level high or spring out sometimes.

(b) Aquifers

The major aquifers in the Province are three deep aquifers of the C.I., the C.T., and the Tamerza. The category of phreatic aquifer in this area is very minority, only a semi-artificial aquifer called as "Oasis Aquifer" recharged by irrigation water. Along the central corridor the C.I. or C.T. are utilized, and only at the northern mountain area the groundwater from the Tamerza aquifer, which is a local portion of C.T., is withdrawn.

(c) Water quality

Water qualities, of not all but only typical ones, are attached in Appendix, and the result of chemical analysis are summarized in Trilinear Diagram as shown in Fig.2.2.2.

2.2.3. Kebili

(a) Hydrogeology

Kebili Province is the next largest province after Medenine. However, around 2/3 of its area (south) is covered by sand dune belonging to the Great Erg Oriental, and about 1/4 of it (north) is occupied by the Chott El Djerid and the Chott El Fejaj. And fur-north of the province, northern bank of the Chott El Fejaj, is the border mountain range with Gafsa Province. The southern bank of the Chott is a huge crescent-like mountain range of Jabel Tebaga, and the western end of the range protrudes towards the Chott El Djerid as a peninsula. Thus, the area of human activity is just limited at along the eastern shore of the Chott El Djerid.

The mountain ranges of both banks of the Chott El Fejaj are formed by Cretaceous sedimentary sequences from Lower to Upper. In the western shore of the Chott El Djerid, Tertiary rocks of Pliocene to Miocene crop out widely, forming many isolated gentle hills as if islands in the Chott. As explained in the previous section, ranges in this area are recharging zone of the C.I. and C.T., and the Chott areas are discharging zone of those deep aquifers. The situations can be applied in this province also.

(b) Aquifers

Major aquifers in this area are only deep aquifers of the C.I. and the C.T., as same as the situation of Tozeur Province. Aquifers belonging to the phreatic are said as "Oasis Aquifer" and "Alluvial Aquifer", but both are quite minority, as negligible when compared to the deep aquifers for utilizing volume. Groundwater withdrawal from the C.T. is still higher than the C.I. overwhelmingly (almost 10:1).

C.T. and C.I. in this province are further sub-divided into some sub-basins as listed below;

- C.T. ...
  1. C.T. Basin East Chott El Djerid
  2. C.T. South, S-W of Chott El Djerid
  3. Miocene Rejim Maatoug
- C.I. ...
  1. C.I. Basin South
  2. C.I. Basin East of Chott El Djerid
  3. C.I. Garrat Bou Flidja

(c) Water quality

Water qualities of each aquifer, the chemical and the physical properties, are shown in Appendix, and the typical water qualities of those aquifers arranged in Trilinear Diagram are shown in Fig.2.2.3.

2.2.4. Gabes

(a) Hydrogeology

Among four target provinces, only Gabes Province is facing to the sea (Gulf of Gabes). Relief of the province is considerably gentle in comparison with the other provinces. It has three major mountain zones; Jabel Hafita at north, an extension of Jabel Tabaga at center, and Matmata mountain range at south, and all of them are quite gentle-sloping mountains or hills. In between Jabel Hafita and Jabel Tabaga, the Chott El Fejaj invades from Kebili Province the east but never reach to the sea.

The mountains mentioned above are mainly made up of Upper Cretaceous, not interesting from hydrogeological point of view. Only at the foot of Jabel Hafita, some Tertiary sequence is distributed. While, along to the Gulf several levels of coastal terraces are observed, and one of the wadi in this area dissecting the terrace, the Oued El Akarit, is the famous archaeological site as one of only five Mousterian (Neanderthal) sites known in North Africa (W. Delano Page, 1983).

(b) Aquifers

Main aquifers in the province are classified into seven phreatic aquifers and three deep aquifer groups; 13 deep aquifers, as shown below:

<u>Phreatic Aquifers</u>

1. Gabes North (81110)
2. Gabes South (81220)
3. El Hamma - Cenchou (91210)
4. Menzel Habib (75110)
5. Underflow Matmata (91310)
6. El Bhaier (91220)
7. Chareb - Sekra - Bouloufa (99930)

<u>Deep Aquifers</u>

A. Djeffara Aquifer Group
  a. Gabes North
    1. Senonian Marl-Gypsum (81111)
    2. Senonian Calcareous (81121)
    3. C.T. Sable Miocene/Senonian (81131)
    4. Sable Mio-Pliocene (81141)

b. Gabes South

5. Turonian Cenomanian (81221)

6. Senonian Inf.Marl-Gypsum (81231)

7. Senonian Inf.Calcarious (81241)

c. El Hamma - Cenchou (C.T.)

9. Turonian - Senonian (91221)

10. Senonian Inf.Calcarious (91231)

11. Miocene - Senonian Inf. (91241)

B. C.I. Group

12. C.I. Chott El Fejaj (91111)

C. Segui C.T. Group

13. Segui C.T. (55211)

(c) Water quality

Water qualities, the result of chemical analysis and the physical properties of each aquifer, are attached in Appendix. And some of typical groundwater qualities are summarized as Fig.2.2.4., Trilinear Diagram.

2.3. Oasis Hydrogeology

2.3.1. General

Nowadays, numerous oases are existing in the South and most of them are irrigated artificially using groundwater through deep tube wells. Originally, or historically in other words, an oasis has been developed spontaneously based on the natural spring or through a "Foggara" at the best. In terms of the said natural water resources, traditional oases shall be classified into several hydrogeological and geomorphological settings.

In this section, hydrogeological classification of Oases shall be tried through the view points of original water resources (hydrogeology) and physiographic setting of them (geomorphology).

2.3.2. Hydrogeological Conditions and Geomorphological Settings

Originally, an oasis has been occurred spontaneously at around the natural water source, and mostly it was a natural spring in the case of arid or semi arid area. Even though it is not flowing out to the ground surface, otherwise, a groundwater table must be enough shallow.

Hydrogeologically, the conditions that a groundwater springs out (or comes up beneath the ground surface) are only two cases as explained below;

1) When the groundwater table retained in the ground is crossed with the ground surface because of the different inclinations each other (call this as retention type).

2) When the groundwater contained in the confined aquifer with enough high piezometric head comes up to the ground surface or near the surface, through any geological weak zones such as faults or fissures (call this as artesian type).

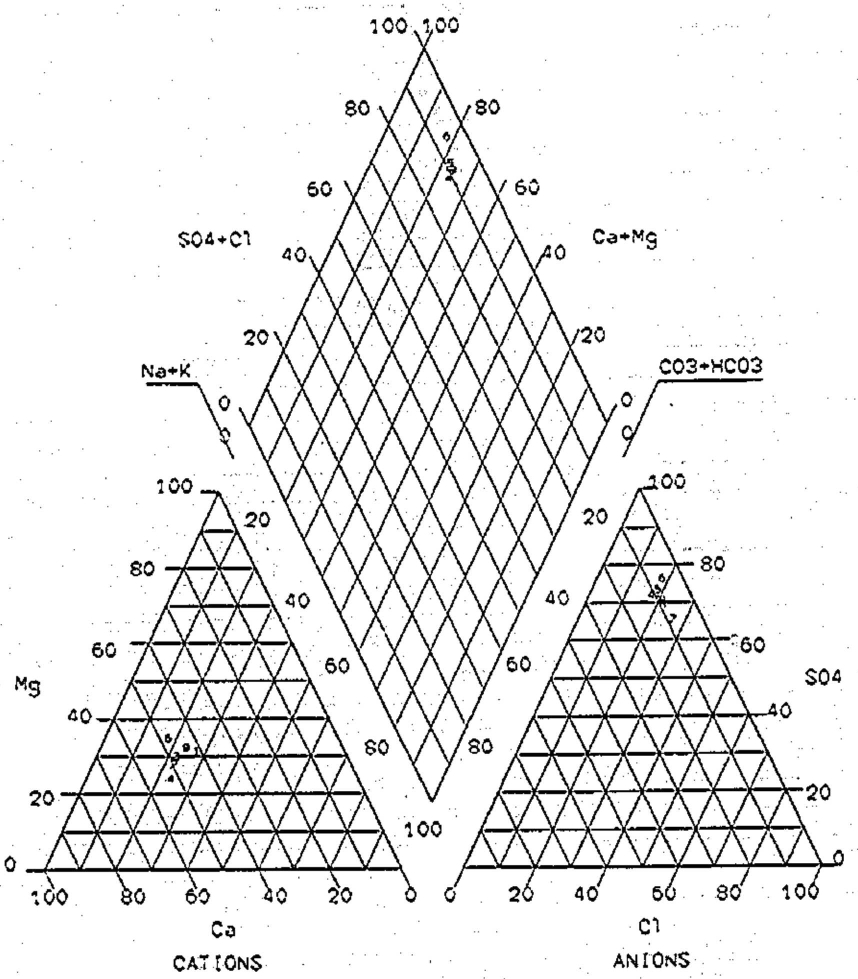
The former happens usually at the foot of mountains, along an apron of the fan, at the cavern, or the bases of terrace or escarpment. While, the latter may happen at any places if such high pressured confined aquifer is underlain.

Not only an oasis, most of the farm lands are allocated in flat area or at rather gentle slope. Such flat land or very gentle slope suitable to cultivate are classified into several occasions geomorphologically. Roughly they are classified into a) original and b) secondary ground surface, and further subdivided into several cases as follow;

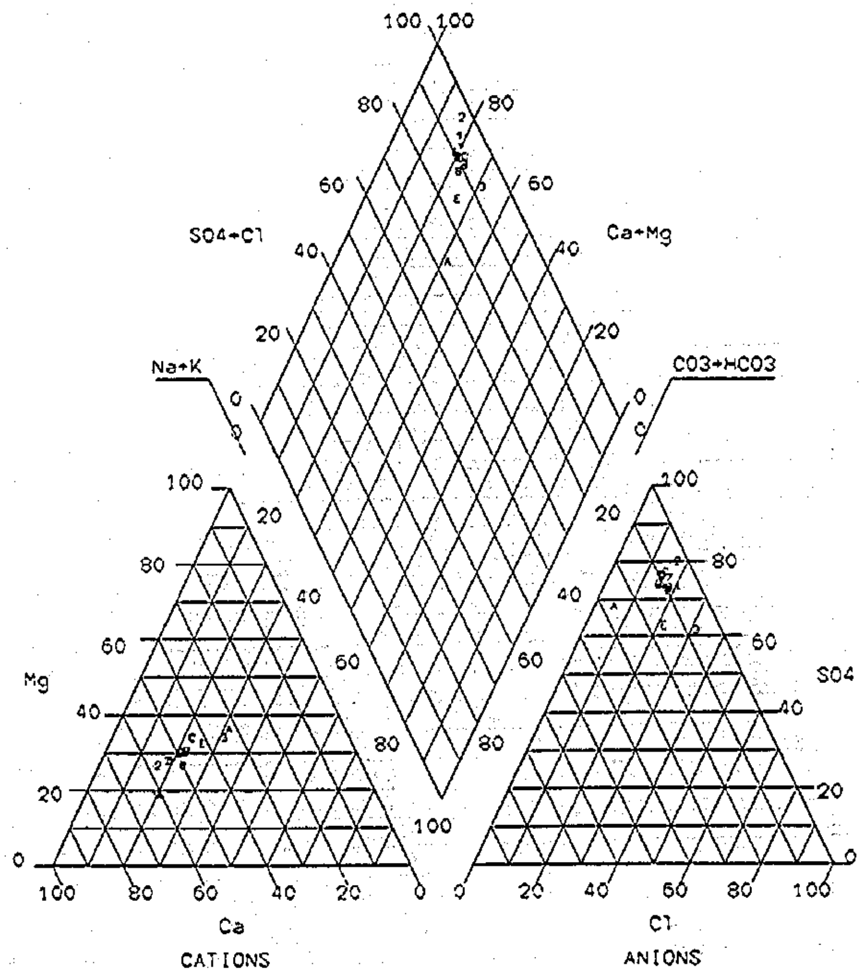
A) Original surface

1. Piedmont slope

2. Residual hill

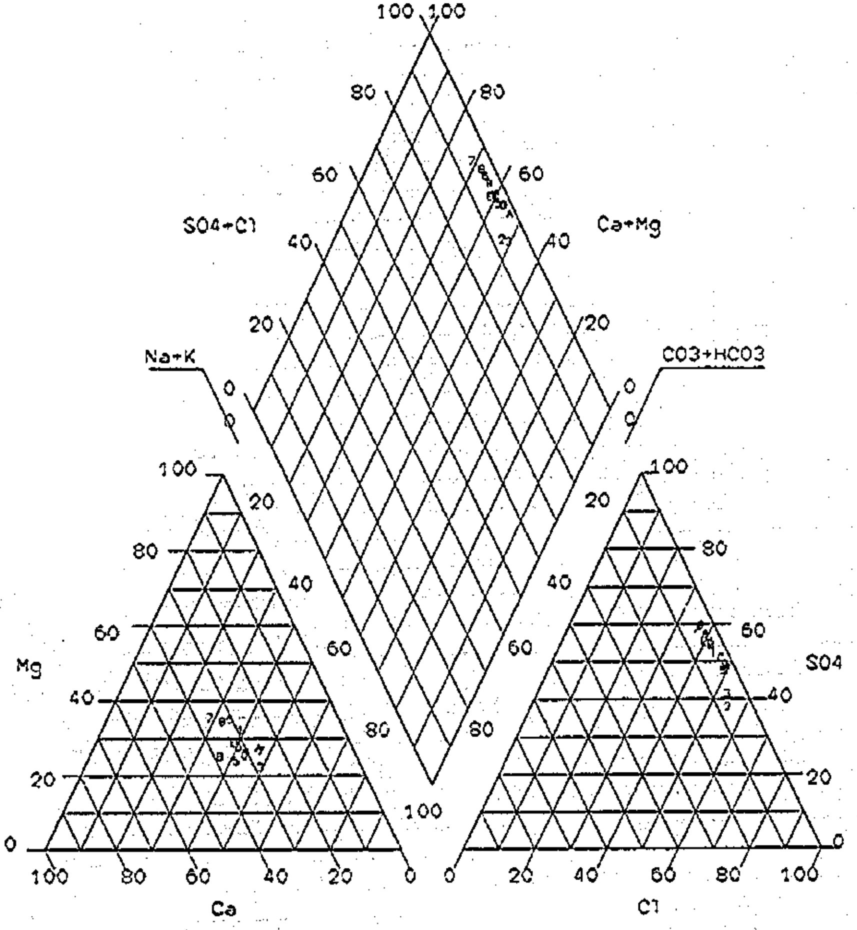


Label	Seq.No	Sample Identification
1	1	Lortess AIC
2	2	Lortess 6
3	3	G.S.R. 3
4	4	G.S.R. 6
5	5	G.S.R. 5
6	6	G.S.R. 2
7	7	G.S.R. 1
8	8	G.S.R. 4

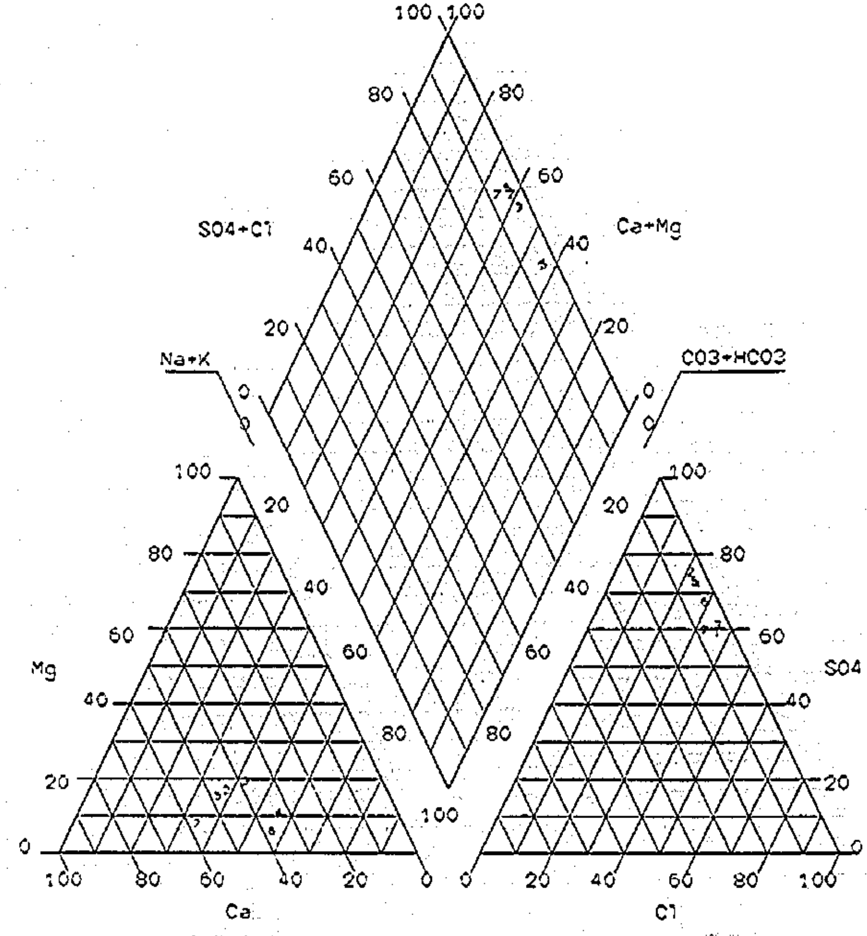


Label	Seq.No	Sample Identification
1	1	Ragouba P-8
2	2	Ragouba P-6
3	3	Ragouba P-7
4	4	Ragouba P-5
5	5	Ragouba P-4
6	6	Ragouba P-3
7	7	Ragouba P-9
8	8	Ragouba P-2
9	9	Ragouba P-1
A	10	Ragouba P-11
B	11	Ragouba 2 bis
C	12	Ragouba P-10
D	13	Doualy 2
E	14	G.R.N. 1

Fig.2.2.1. Water Quality of Gafsa

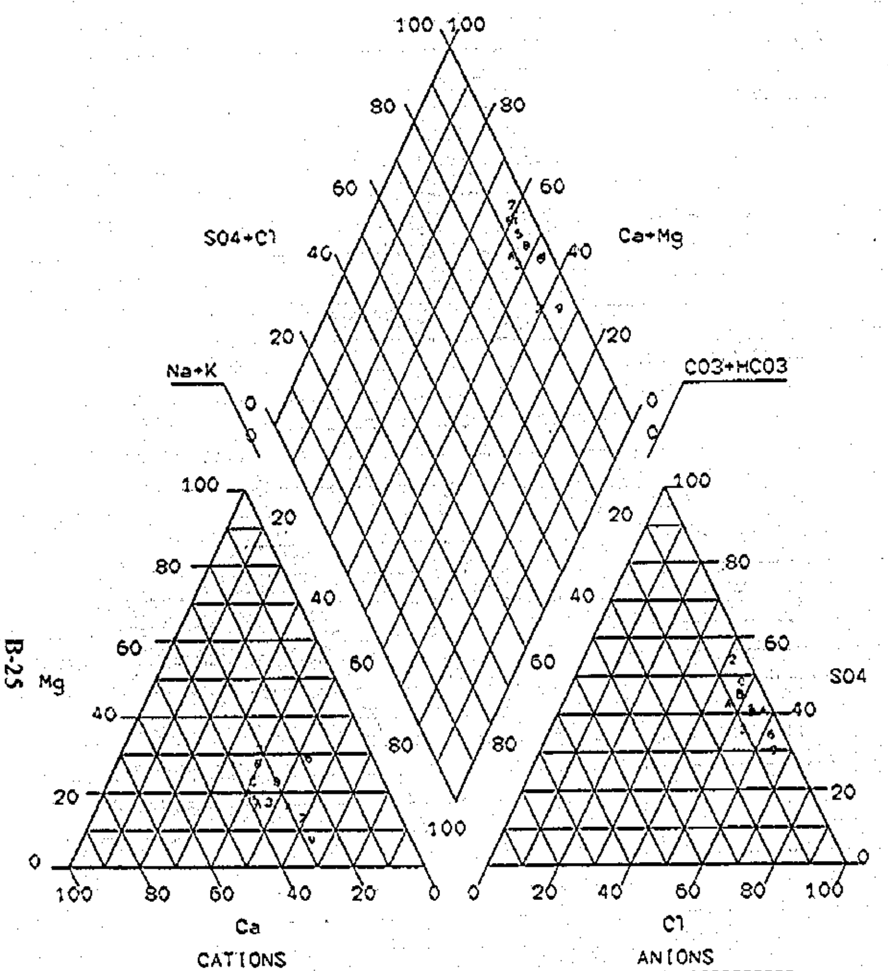


Label	Seq.No	Sample Identification
1	1	El Hamma 13
2	2	Cedada 6
3	3	Kastilia 4
4	4	Chouchet Zargua
5	5	Essouni
6	6	Tozeur 5
7	7	Tozeur 3
8	8	Tozeur 6
9	9	El Fawez
A	10	Chakmou 3
B	11	El Fraj
C	12	Bir Elmalah
D	13	El Mekmem
E	14	Zaafrane
F	15	Zaafrane

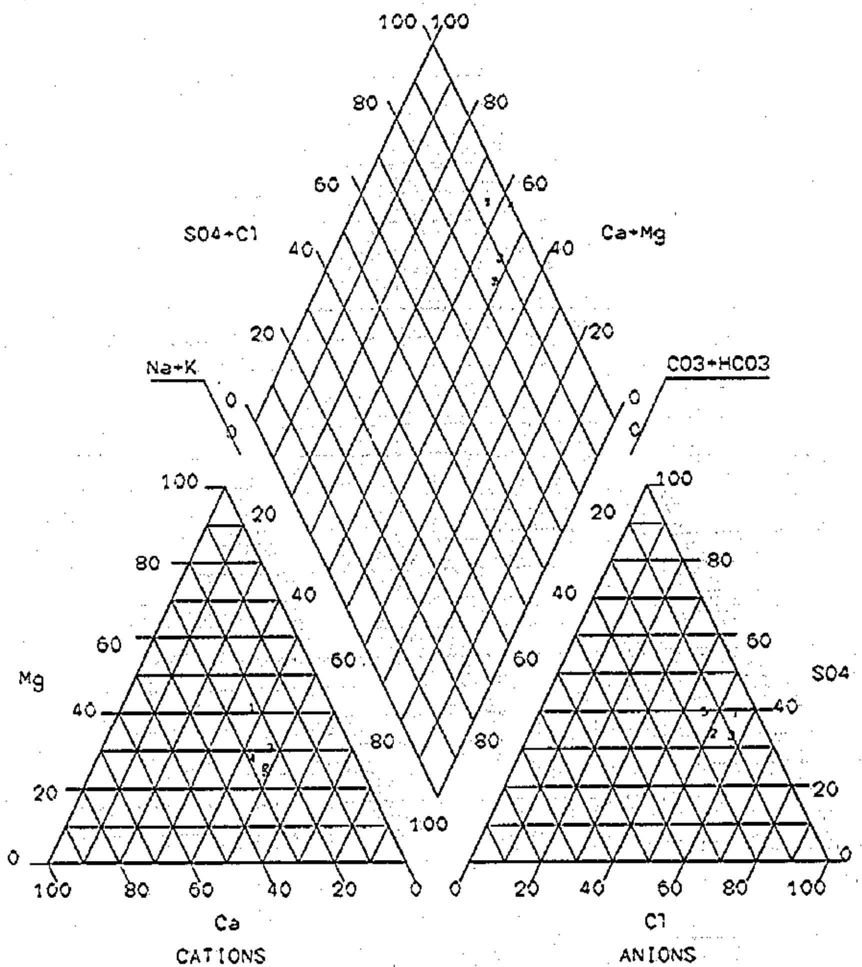


Label	Seq.No	Sample Identification
1	1	Degache CI 3
2	2	Neft CI 2
3	3	Neft CI 1
4	4	El Hamma CI 2
5	5	El Hamma CI 1 bis
6	6	Tozeur CI 2
7	7	Degache CI 1

Fig.2.2.2. Water Quality of Tozeur

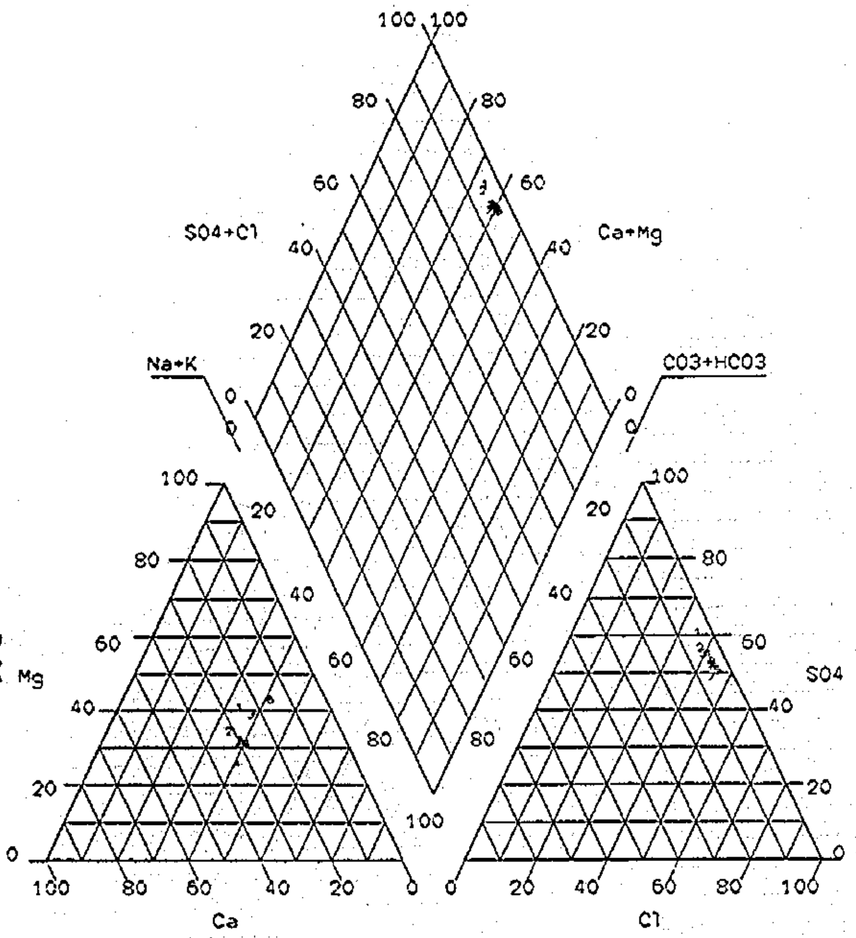


Label	Seq.No	Sample Identification
1	1	Taourga CI 2
2	2	Zouaya CI 5
3	3	Menchia CI 6
4	4	Menchia
5	5	Debabcha CI 14
6	6	Douz CI 18
7	7	Jemna CI 11
8	8	Bou Abdhalah CI 1
9	9	Douz CI 12
A	10	Souk Lahad CI 17
B	11	Mansoura CI 13
C	12	Bou Abdhalah CI 4



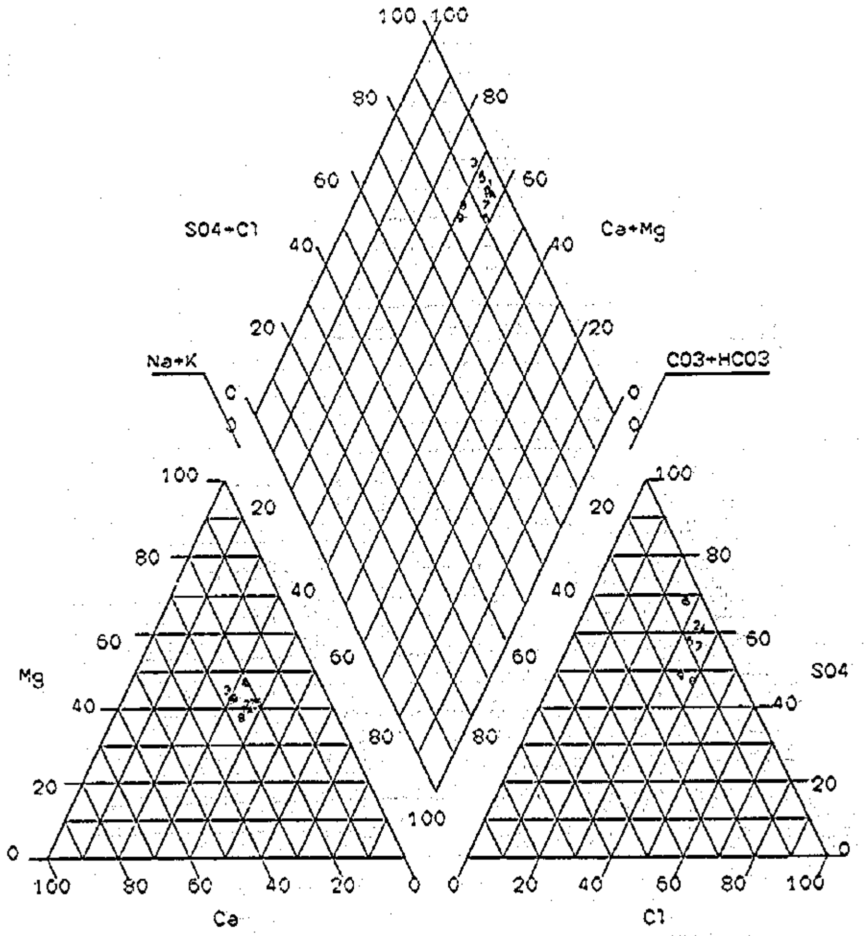
Label	Seq.No	Sample Identification
1	1	El Faouar 4
2	2	Tafaya El Ma
3	3	Dbaia SDZ 9
4	4	Sebria 3
5	5	El Faouar West

Fig.2.2.3. Water Quality of Kebili



Label	Seq.No	Sample Identification
1	1	Faycal 3
2	2	Seboui
3	3	Oued El Malah
4	4	Mazraa Gannouchi
5	5	Methouia 1 ter
6	6	Methouia 4 ter
7	7	Methouia 5 bis
8	8	Methouia 8 ter
9	9	Ouedref 19
A	10	Cotfa 2 bis
B	11	Cotfa 3 bis

Fig.2.2.4. Water Quality of Gabes



Label	Seq.No	Sample Identification
1	1	Matmata N1
2	2	Matmata 2
3	3	Taoujout
4	4	Matmata An2
5	5	Matmata An1
6	6	Oued sandouk
7	7	Tamezret
8	8	Chrarif 2
9	9	Chrarif 1 bis
A	10	Arram 1
B	11	Arram 2

3. Flush out plain
4. Others (high plain such as Plateau or Table Mountains)

B) Secondary plain
1. Alluvial plain
2. Terrace plain (river, sea shore, and along the Chott terraces)
3. Fan
4. Others (not suit to farm, such as desert or Chott)

2.3.3. Hydrogeological Oases Classification

Based on the above mentioned view points, both hydrogeological and geomorphological, the traditional oases can be classified into following seven (7) hydrogeological settings:

Case-a: Developed on valley deposits among a mountain ranges,
Case-b1: Developed on low terraces surrounding the Chotts,
Case-b2: Developed on comparatively low shore terraces,
Case-b3: Developed on very gentle foot slopes of mountains or hills,
Case-c: Developed on Alluvial fans or flood plains,
Case-d: Developed on "islands" in the Chott, and
Case-e: Others.

Among them, the majority of cases from -a to -c are included into so-called retention type hydrogeologically. However, some cases shall be mixed with the retention and artesian type when the ground retaining water is not enough high or thick. And the cases -c and -d are rather special cases only in this region. These cases are roughly explained as follows.

Case-a

Case-a is the most classical style of oasis, naturally irrigated by surface water or spring. The resource of surface or spring water is a rainfall precipitated in the mountain ranges, and the valley deposits is usually suited for farming. Five oases in Tamerza area are classified into this category.

Case-b1

The Tozeur corridor or the extension of Jebel Tebaga to Chott El Djerid are very gentle hills. However, the slopes of them are still steeper than the natural groundwater tables contained in the grounds, in most of the cases. When gradually inclining natural groundwater table of a certain hill crosses the slope, because of the difference of inclination, the groundwater springs out to the ground surface and irrigates the low-lying terrace plain. Case-b shall be caused thus.

And when the low-lying area at where the Oasis developed was a lake terrace surrounding the Chotts, it classified into Case-b1, and most of oases along Tozeur corridor and the said extension are included into. The represented oasis in this case is Tozeur Oasis.

Case-b2

The occasion of Case-b2 is also same with b1 explained above, and the difference from the case-b1 is that they are sea shore terraces. The most of oases along the Gulf of Gabes, represented by Oasis de Gabes, are included in this case.

Case-b3

Case-b3 is very similar to the other Case-b, however, the oasis is not on the terrace but on the very gentle slope or a piedmont hill of mountain. In short, the difference from the other Case-b is only that the oasis has been developed on substantial ground, not on the secondary plain such as terrace or Alluvial. Several oases along with the Tozeur corridor or Jebel Morra are included into this category.

Case-c

Three oases consisting the Oasis de Gafsa, for example, are existing on the foot of large alluvial fan deposits formed by Oued Sidi Aich and Oued El Kebir. The vast Sidi Aich basin is constricted at just upstream of Gafsa City by two ranges of Jebel Bay Younes and Jebel Orbata, as if an underground dam naturally constructed. The narrow path caused a huge alluvial fan at the immediately downstream, and the natural underground dam dammed up the groundwater of the basin and supplied water to the downstream through the fan deposits. Thus, the foot zone of the fan could have enough amount of groundwater constantly and oases had been developed. This is the Case-c. However, the south of Gafsa City is another vast and deep alluvial plain, and the shallow groundwater table easily goes down when the groundwater supply from upstream has been reduced. Nowadays, the groundwater table in this area is rather deep to require deep tube well for irrigation. Besides the said three oases of Gafsa, some oases located in the wide Oued Selja basin shall be allocated in this category.

Case-d

Along eastern shore of Chott El Djerid, there are many "island-like" small hills protruding from the environmental lowland, and most of them are covered (or ever covered) by green of oasis. Chotts of these area are the major discharge zones of Complex Terminal (CT), but it is easily contaminated by salt accumulated at the bottom of the Chott. While the said islands are made up of original formation, and only the CT water discharged out to the ground through original formation can be fresh and available for irrigation and/or domestic use. Thus, on the most of such islands a farming has been developed based on the spring of CT water. This is the Case-d, and many small oases along eastern shore of Chott El Djerid are classified into this category.

Case-e

Finally, Case-e of Others shall include many modern (or new) oases developed artificially, using groundwater through tube wells.

2.4. Groundwater Management & Aquifer Evaluation

2.4.1. General

For management and controlling the groundwater, as well as to evaluate the potential of groundwater resources, to grasp the exact situation of groundwater in four dimensionally (horizontally, vertically, and in time series) is quite indispensable. Tunisian authority knew the matter and its importance, and launched the monitoring of groundwater since middle of 70s but locally. To establish the nation-wide groundwater monitoring system became further essential since they touched to the deep, complicated, and international aquifers such as C.T. and C.I. The national monitoring network has been built up late 80s, and the yearly report "Annuaire piezometrique de Tunisie" was published by DGRE since 1991.

While, another important data on groundwater management, data of exploitation and utilization of groundwater has been collected through all of the rural offices of DRE, and arranged statistically by DGRE. The elaborate results were published yearly as "annuaire de l'exploitation des nappes profondes" since 1973. The data on the exploitation of wells concerned in this Study, extracted from the yearly book since from 1973 up to 1994, are summarized and attached in the Appendix.

To evaluate an aquifer potential is, as mentioned so far, quite substantial for a managing/controlling of the groundwater basin, an examining the current groundwater use, and for a formulation of the future water resources development project. Because of such importance, especially in the South, several attempts to evaluate the potential of ground-water resources have been conducted, for example, by UNESCO (1972) or B.Baccar, Poncet & Mamou (1987). Just now, one of the international research work on groundwater recharge is on going (Recharge Characteristics and Groundwater Quality of the Grand Erg Orientale Basin, British Geological Survey).

However, the study to evaluate the aquifer potential is very difficult, in particular at the southern Tunisia. The major reasons or situations making the study very hard are;

a. Horizontally, they are distributing in huge area beyond the border with Algeria (international aquifer). Further the main bodies and recharging zones of the aquifers are in Algeria.
b. Vertically, they consist very complicated leaky multi-layered aquifer complex. The complex involves even the shallow or phreatic aquifers in most of the cases.
c. Generally, they are deep and enough strongly confined as spring out to the ground surface. However, the most of natural discharge zones of them are occupied by the great salt lakes (Chotts).
d. They are classified into a category of "Fossil Water" which have extremely weak replenishment rate. And that means, the development of them are just mining type, never or hardly renewable.
e. Monitoring system, in particular with those deep aquifers, is still rudimentary, because of the difficulty to construct piezometric wells technically and financially.

Only one of the property or situation among the list mentioned above makes very hard to evaluate the aquifer potential precisely, nevertheless the major aquifers in this region have thus serious properties.

In the following section, some of such attempts are summarized, and then the current situation of groundwater resource are to be discussed.

2.4.2. Previous Studies

(1) ERESS.

"Etudes Resources en Eau du Sahara Septentrial (ERESS)" was elaborated by UNESCO in between 1968 and 1971, under the financial aid of UNDP. And it was reviewed 10 years later, July 1982. The study covered around 800,000 km^2 of the area in Algeria and Tunisia, and the framework of the study is as follows;

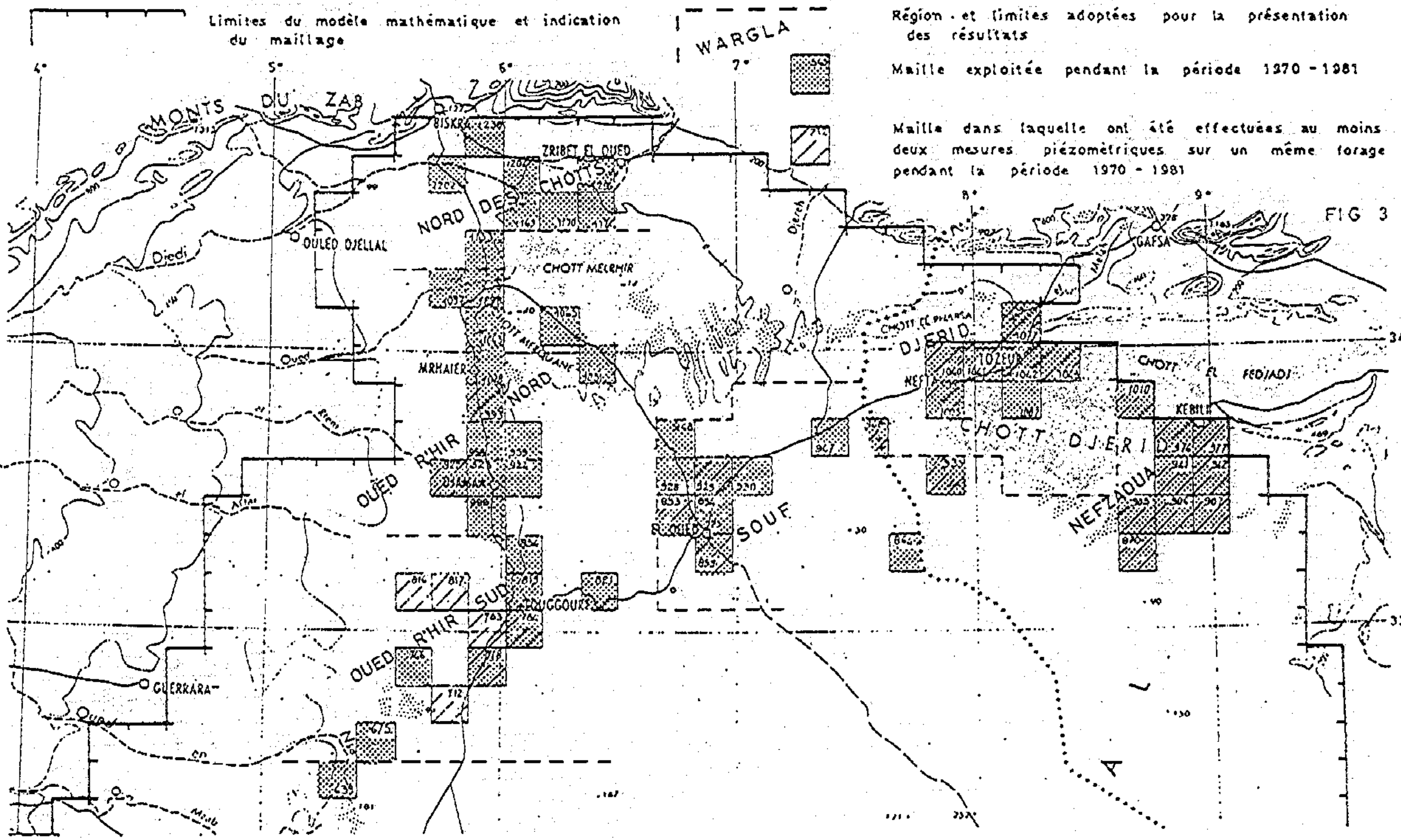
- Evaluation of total water demand in the Sahara by the year of 2000.
- Construction of mathematical and analogical models of each aquifer.
- Simulation study along with the suppositions of maximum and minimum exploitation.
- Forecasting the drawdown of piezometric heads of the aquifers and translating the results into an economic impact.

The area covered by the study is shown in Fig.2.4.1. The assumptions of storage coefficient of each mesh varies from $5x10^{-4}$ to $2x10^{-2}$. The forecasted water demands by the year 2010, for C.T. aquifer, is 55,756 lit/sec in total based on 14,722 lit/sec in 1981 as the maximum increase case (9,159 l/s and 11,509 l/s in Tunisia respectively). In the same manner, the forecasted water demands by 2010 for C.I. is total 28,663 l/s (4,741 l/s in Tunisia).

As the results of the study, the piezometric head of C.T. in Tunisia, by the year 2010, shall be 7 to 50 m below the ground surface in Djerid zone and almost 0 to 10 m higher than the ground surface (in artesian condition) in Nefzaoua zone. Piezometric head of C.I. by 2010 shall be plus 103 m in Djerid, plus 49 to 68 m in Nefzaoua, but 15 to 40 m below the ground surface in the extreme south. These results are summarized in Tab.2.4.1., (a) and (b). And the simulated drawdown of C.T. and C.I. are shown in Fig.2.4.2. (a) and (b).

NAPPE DU COMPLEXE TERMINAL – LOCALISATION DES DONNEES SUR L'EXPLOITATION DE LA NAPPE PENDANT LA PERIODE 1970 – 1981

Fig.2.4.1. The Area Covered by ERESS



Tab.2.4.1.(a) CT Aquifer - Results of the Simulation CT 13

Regions			Draw-down 2010-1981 (m)	Piezometric level 2010 according to the soil (m)	Piezometric level 2010 according to the level of the Chott
TUNISIA	DJERID	Hazoua	30 to 34	4 to 13 m under the soil	
		Nefta-Tozeur	22 to 43	21 to 45 m under the soil	
		N. of Chott Rharsa	42 to 56	36 to 60 m under the soil	
	NEFZAOUA	SO of Chott Djerid	12 to 27	2 to 13 m of pressure	13 to 21 m under the Chott
		Douz-Sabria	11 to 13	from 10 m under the soil to 13 of pressure	21 to 28 m under the Chott **
		Kebili	9 to 11	from 5 m under the soil to 3m of pressure	6 to 16 m under the Chott **

** For the meshes situated on the border of Chott Djerid (level + 22 m/sea)

Tab.2.4.1.(b) CI Aquifer - Results of the simulation CI 8

Regions		Draw-down 2010-1981 (m)	Piezometric level 2010 according to the soil (m)
TUNISIA			
Djerid		101 to 106	64 to 101 m of pressure
Nefzaoua	Nefzaoua	66 to 69	74 m of pressure
	Chott Fedjej	40 to 58	65 to 79 m of pressure
Extreme south	Eastern area	23 to 30	49 to 51 m under the soil of pressure
	Western area	15 to 44	22 m under the soil to 27 m of pressure

Fig.2.4.2.(a) Result of Simulation Study for C.T.

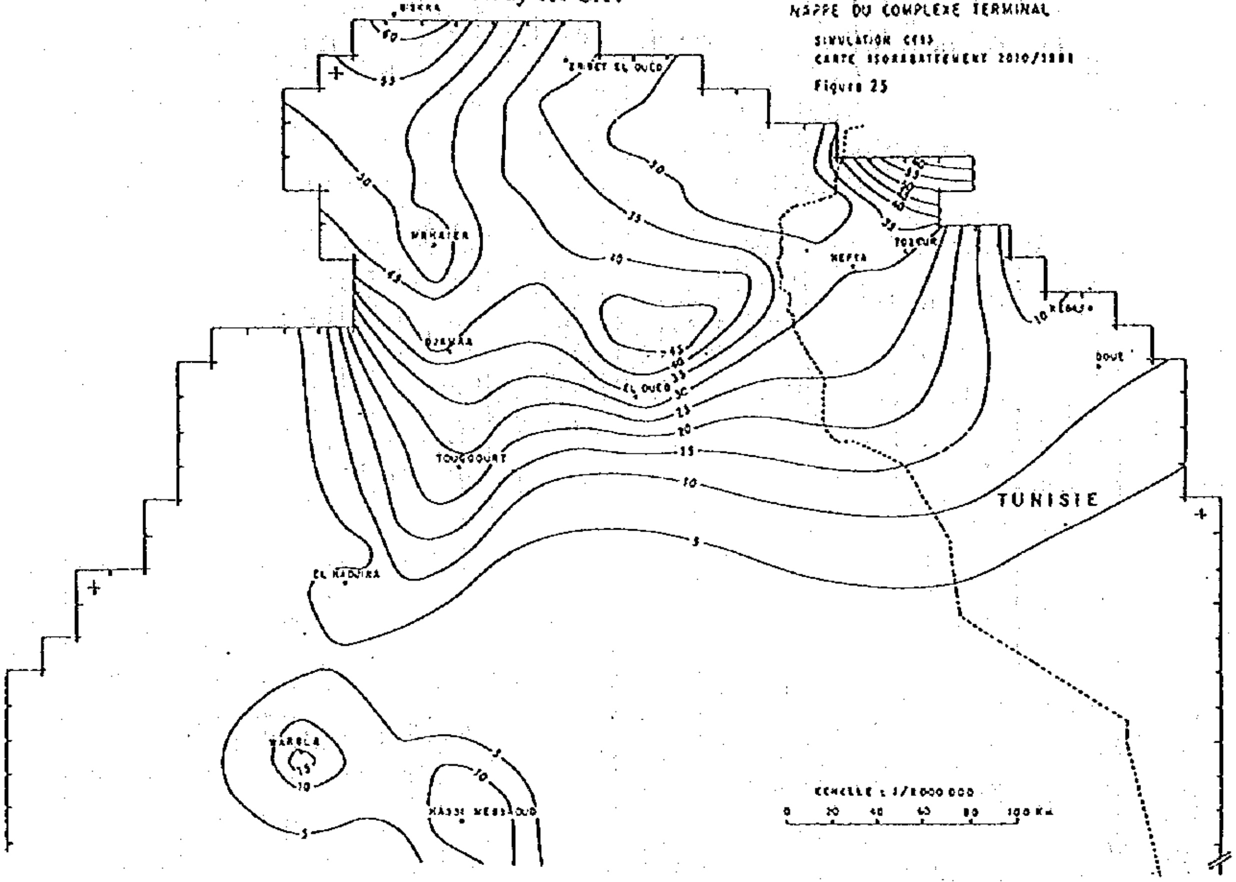
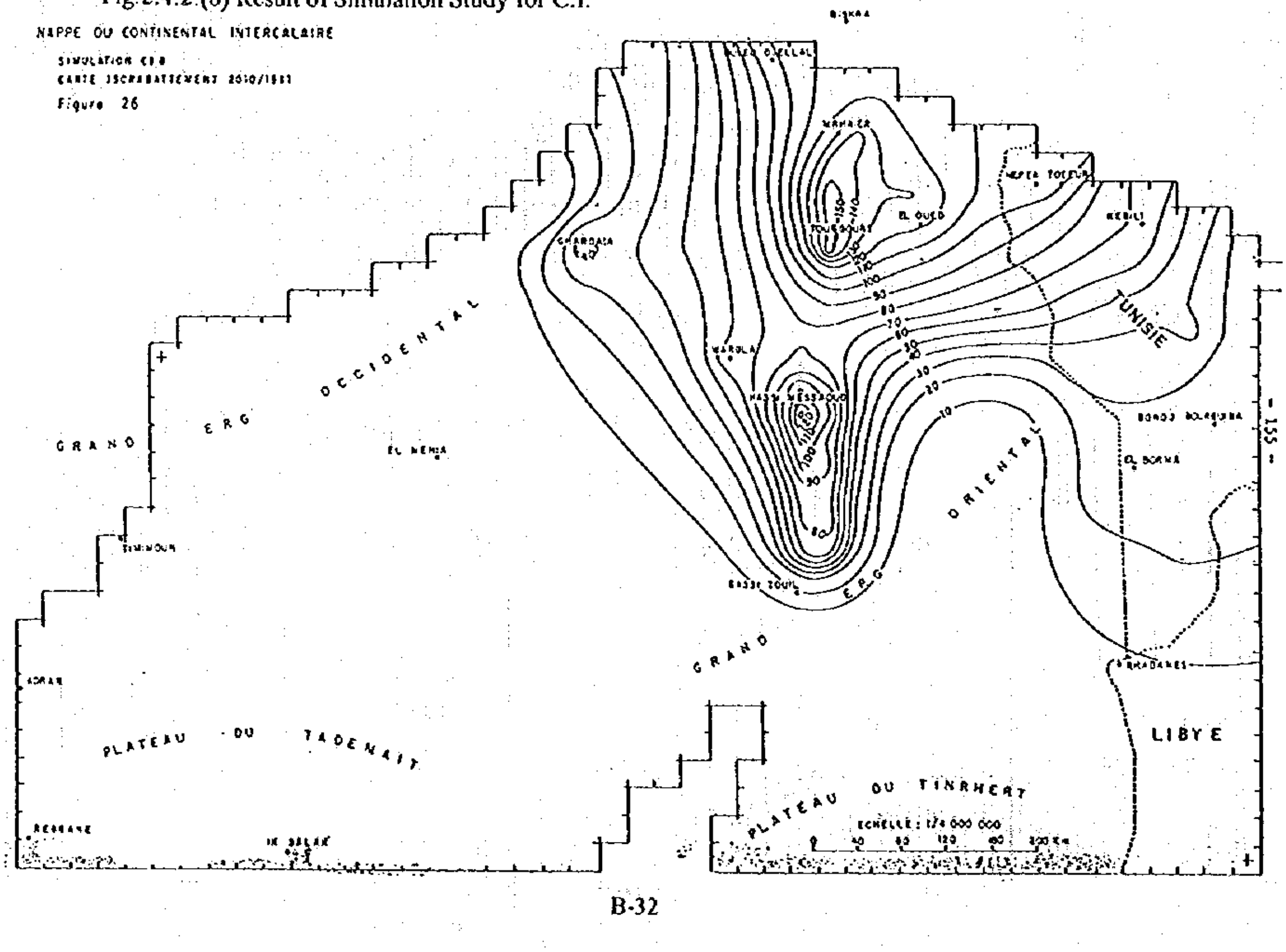


Fig.2.4.2.(b) Result of Simulation Study for C.I.



(2) Evaluation et Gestion des ressources en Eau des Nappe du Sud Tunisien

The author of the paper is the current director of groundwater div., DGRE. He evaluate roughly the surface and groundwater resources in the South, and forecasts the groundwater condition in the future.

Surface water resources

The surface water resources in the South is evaluated from 140 to 170 MCM/a, which is only 7% of the total surface water resources in Tunisia. Further, a controllable volume of surface water, for agricultural use or groundwater recharge, shall only be 26 MCM/a.

Phreatic groundwater

There are only two types of phreatic groundwater; a) Underflow aquifer of wadi when flood, and b) Alluvial aquifer which is the shallowest aquifer in the multi-layered aquifer complex.

Groundwater in these aquifer are recharged through rain water percolation downward and by leaking upward. The replenishment rate of them are 1 to 3% in the alluvial aquifer and 3 to 6% in the underflow aquifer.

Extraction from the phreatic aquifer is drastically increased, it was duplicated in this ten years (1980 - 1990). Currently around 12,870 of shallow wells are extracting groundwater from this aquifer, and the volume exploitation is more than 96% of the total potential. The situation shall turn to over-development soon. Only an improvement of aquifer, through an artificial recharging, may prevent an increasing of development cost and a deterioration of water quality.

Deep aquifer

Deep aquifers in the South can be classified into two categories; a) the major aquifers (C.T., C.I., and Djeffara), and b) the secondary aquifers which are limited in the scale/extension and complicated in the structure and development.

The aquifer potential of those and the current situation of development are summarized as Tab.2.4.2.

Table 2.4.2. Resources and development of deep aquifers in the South

NAPPE	Ressourcex exploitables		Exploitation		OBSERVATIONS
	$(l.s^{-1})$	(Mm^3)	$(l.s^{-1})$	(Mm^3)	
Nappes profondes (*) :					
- Continental Intercalaire	4000	126,1	1731	546	(*) Ressources non renouvelables. Mobilisation faite dans le cadre du Plan Directeur des Eaux du Sud.
- Complexe terminal	11000	346.9	10418	328.6	
- Djeffara	4500	141.9	3608	120.0	
	19500	614.9	15957	503.2	
Aquifères secondaires (**)					
- Aq.secondaires profonds	942	29.7	663	20.9	(**) Ressources renouvelables en grande partie. Nécessité de travaux de C.E.S. et de mesures de protection des nappes phréatiques.
- Nappes phréatiques	1652	52.1	1573	49.6	
	2594	81.8	2236	70.5	
TOTAL	22094	696.7	18193	573.7	
	100 %)		(82 %)		

Groundwater development plan

The volume of groundwater resources in the South is about 46% of all of Tunisia, in contrast with the surface water resources. And the current development rate of deep aquifer's groundwater reached 82% as shown in the above table. However, the severe hydrodynamic property that around 88% of those groundwater is not renewable and the type of the development is just mining must be taken into the consideration.

The water requirements in the region by the year of 2000 are forecasted as follows (MOA, 1986);

■ agricultural use :	20,838 l/s	(89.1%)
■ drinking water :	1,562 l/s	(6.7%)
■ industry :	975 l/s	(4.2%)
Total	23,375 l/s	(100%)

The forecasted water demand is, however, beyond the groundwater potential (22,094 l/s) which can be developed. In any rate, the overdevelopment in the deep aquifers must be avoided, because they are not renewable. Thus, the development plan or the future water demand must be reconsidered, especially the water use in agricultural aspect.

(3) Evolution de la Piezometrie et de la Salinite de la Nappe du Complexe Terminal dans la Nefzaoua.

Nefzaoua is the substantial area for human activity in Kebili Province. The area called as "Nefzaoua" is consisted of two zones in details; the main region of Nefzaoua at where the major C.T. aquifer is formed by Senonian Limestone, and the region of Western Nefzaoua (or Regim Maatoug region) at where the major aquifer is consisted of Mio-Pliocene Sandstone.

The aquifer C.T. was known since the beginning of the century by an excellent spring water. It was developed through natural springs at first, then through artesian tube wells, and later through pumping tube wells. By Mamou. A (1976), the first phase, when natural spring groundwater was utilized through "foggara" or "djazira", had lasted until 1946.

The groundwater extraction from C.T. in this area was increased drastically since the beginning this century, in particular after 80' as; 2510 l/s in 1900, 3350 l/s in 1950, 3968 l/s in 1960, 4195 l/s in 1970, 5934 l/s in 1980, 11547 l/s in 1990, and 11608 l/s in 1993. Further, the first illicit tube wells in this area were constructed in the beginning of 80' in accordance with the drastic expansion of oasis irrigation. The number of illicit tube wells had reached to 3000 in 1993 reportedly.

In parallel with the researching of groundwater extraction, monitoring of piezometric head of the aquifer, through several monitoring wells, was started since 1974. The yearly data on piezometric heads of those monitoring wells are shown in Tab.2.4.3. Almost coincidentally, measurement of mineralization (salinity contents) of groundwater through the same monitoring wells had been commenced. These data indicate the piezometric heads of C.T. has decreased some ten meters in an average during the period from 1971 to 1993. In this 13 years (1980-1993), the piezometric heads decreased around 18 m in the central zone, around 12 m in Jemna and Zercine zone, and 10 to 12 m in the peninsula Kebili. The water quality represented by salinity contents is degenerating year by year. The southern part of the area, Douz and El Hsay regions, have especially high salinity contents ranging from 2.6 to 4.0 g/l.

As the results of this study, the facts that the estimated groundwater potential of C.T. in Nefzaoua is less than 6500 l/s, while, the current development volume is more than 7340 l/s, obviously overdeveloping. Because of the overdevelopment, the piezometric heads are drastically decreased just recently, maximum 5 m in the last year (at the end of 1994).

(4) Recharge Characteristics and Groundwater Quality of the Grand Erg Orientale Basin.

The study was just commenced since the last year (1994), and the first progress report has been published in this year. It is carrying out under the cooperation

Sheet1

Tab.2.4.3. GROUNDWATER HYDRPGRAPH ON C.T. IN KEBILI

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
El Faou West							69.76	69.73	68.73	68.75	67.73	67.23	66.43	66.43	65.23	65.23		63.43	62.93	60.73	60.33	59.33	58.73
Smida													63.38	61.63	60.93	60.18		59.48	57.98	55.48	55.28	50.78	50.78
Zarcine 4																61.85		59.1	59	57	56.5	53	50.5
Ben Zit 1b												58.1	57.1	55.3	53.4			52.1	51.4	42.9			40.4
El Hsay 2	71.97				69.89	69.57	68.8	68.17	68.97	68.07	65.89	65.72	66.72		63.17								
Bou Hamza				69.06	68.86	68.36		67.44	67.36	66.49	65.31	65.24	64.14	63.14	62.59	60.24	60.44		58.24				
Guelliada 2	61.36			60.29	59.14	59	58.6	58.7	57.2	56.8	54.8	58.46	55.96	54.56	53.06	52.86		50.86	50.66				39.56
Dar Kouskai				44.7	44.3	44.1	43.95	43.2	42.95	41.35	41.5	40.55	40.2	40.6	40.6								
Tembib 4			42.5	41.25	39.7	39.85	39.04	39.88	40.18	41.52	38.82	38.78	39.99		35.49	35.29	33.19	29.99	29.59				
Telmine 3		45.32		43.47	41.11	42.62	43.59	42.34	42.59	41.52	38.82		39.52		35.52	35.32	33.42	30.42					
Blidet Son																		54.49	52.67	49.67	50.37	49.17	43.37
Derjin Elame								68.5	68.4	68.22	66.88	66.01		63.71		61.91		61.61	60.61	59.51	59.51	56.71	
Metouria 2						66.81	66.36	64.95	64.46	63.53	62.86	61.6	56.3		58	57.5		53.9	53.4	51.7		48.4	
El Goulaa												62.27			58.27	58.27	57.07	55.87	54.17	52.07		48.47	
Tarf Stil					69.88	69.18		67.59	67.34	67.36		64.14	63.64	62.74	61.81	60.04		58.74	57.94	56.54	55.54		50.34
Zaaf 3 bis													62.83	62.03	60.53	61.43	59.33	58.73	57.23	55.23	54.53	53.53	49.43
Fatnassa 1			36.45	35.55	34.75	35.25	35.7				36.25	32.05		33.05		30.75				27.5	24.55	24.93	
Om Somaa 1				35.12	33.82			32.52			32.73	31.98	31.57			33.02	30.52	28.42	28.32	27.62			
Bou Abd 1				33.27	32.27		34.27	34.02		34.72	30.45	30.1	29.87			29.19		28.47	28.47				
El Gleaa	38.91			36.91	36.31		36.91	36.77			34.51	34.68	36.71		32.91	32.81	31.96	29.21	28.96	28.91			
Guat 4 bis									57.95	54.09	53.34	46.72		46.72		47.92		37.82	37.62			32.17	
Ksar Teboul							36.28	38.45	38.2	36.3	38	34.5	32.2		31.25	34.5	34.2		31.5	27.8	27		
Bechini								67.68	67.48	67.2	66.68	66.58	63.98	63.38	62.38	62.38		61.08	59.98	58.59	58.18	55.18	53.98
Blidetto 3								63.58	62.88	62.54	60.54	58.55	56.96	55.49	55.25								
Guidma					68.08	68.08		65.28	66.58	65	65.21	64.68		63.38	63.08	63.08	60.78	60.68	59.08	57.58	57.28	54.48	53.48

with United Kingdom (British Geological Survey), Algeria (CDTN), and Tunisia (DGRE and ENIS).

The main objectives to the project are to define the limits of sustainable groundwater development in the aquifer system of the Grand Erg Orientale underlying eastern Algeria and southern Tunisia. The basin comprises several aquifers including the deep C.I., C.T., and the shallow phreatic aquifers. Sampling of the aquifer system will be used to provide detailed up-to-date geochemical cross sections of the aquifer. As well as attempting to determine modern rates of recharge, the interface between recent recharge and palaeowaters and the extent/risks of salinisation will also be examined. The study will provide a concise synthesis of the limits to development of the aquifer which is a type-basin for other parts of Northern Africa.

In the first year, field visits for several sites, around 50 of water sampling, and isotopic and geochemical analysis has been carried out. The water analyzed to date are generally of brackish to saline composition with TDS varying from 1.4 - 12.6 g/l in the Tunisian samples and 0.3 - 5.5 l/s in waters from Algeria. Sodium and Ca are the important cations and SO_4 and Cl the dominant anions. Although there is considerable overlap in the anion composition of C.I. and C.T. samples from Tunisia, those from the C.T. generally have Mg as an important cation in addition to Na and Ca. Several major and trace elements appear to be characteristic of each of the aquifer systems e.g. in general there is relatively high U and NO_3-N, and low K and Rb in the C.T. Some of the traverse also show good correlation of elements typically indicative of residence time (e.g. Li, Na) with depth, and these are being studied in detail to aid interpretation of geochemical processes as well as residence time indicators.

The study items to be done following are further detail water quality analysis and a recharge studies such as recharge to the Mio-Pliocene, recharge via dune sands, recharge via wsdis, recharge from the South Atlas, recharge of saline waters from Chotts, etc.

(5) Text of Hydrogeological Map of Tunisia

This is an explanation text on the "Hydrogeological Map of Tunisia, in the scale of 1:500,000.-". The text presents the explanation and legends on the map, and the study results on evaluation of water resources, situation of water resources development, and the prospecting of future development program.

According to the text, the estimated volumes of total water resources supplied as rainfall is around 36000 MCM/a, and the potential resources of surface water is about 2700 MCM/a, groundwater is around 1197 MCM/a as shown in Tab.2.4.4. and 2.4.5. respectively.

Table 2.4.4. Estimated water resources potential on surface water

Régions Naturelles		Ressources potentielles (M m3/an)
Grandes Régions	Sous Régions	
Tunisie du Nord	Nord-Est (Ichkeul et Cap Bon - Miliane)	605
	Nord-Ouest (Extrême nord et Medjerdah)	1 585
Sous total		*2 190 (81 %)*
Tunisie du Centre	Kairouanais - Sahel	180
	Tunisie Centrale	190
Sous total		*370 (14 %)*
Tunisie du Sud	Sud-Ouest	20
	Sud-Est	120
Sous total		*140 (5 %)*
Total Général		2700

Table 2.4.5. Estimated water resources potential on groundwater

Régions Naturelles		Nappes phréatiques (Mm3/an)	Nappes profondes (Mm3/an)	Total Eaux souterraines (Mm3/an)
Grandes régions	Sous régions			
Tunisie du Nord	Nord-Est	296	62	358
	Nord-Ouest	76	86	162
Sous total		*372 (55 %)*	*148 (28 %)*	*520 (43 %)*
Tunisie du Centre	Kairouanais - Sahel	118	126	244
	Tunisie Centrale	82	166	248
Sous total		*200 (30 %)*	*292 (55 %)*	*492 (41 %)*
Tunisie du Sud	Sud-Ouest	49	53	102
	Sud-Est	49	34	83
Sous total		98 (15 %)	87 (17 %)	185 (16 %)
Total Général		670 (100%)	527 (100%)	1197(100%)

As the situation of development, only 1285 MCM/a among total 2700 MCM/a of surface water resources is actually mobilizable. For groundwater, the most of phreatic aquifers, in particular the ones in the South, are already overdeveloped as shown in Tab.2.4.6. The actual groundwater developments on renewable aquifer and C.I. are still have some margins to the limit, but C.T. And it shall be more serious in now a day because the table is arranged from the data of 1990.

Table 2.4.6. Groundwater resources potential and actual development

Régions naturelles		Nappes phréatiques		Nappes profondes			
				Ressources renouvelables		Prélèvements sur nappes fossiles (Mm3/an)	
Grandes régions	Sous régions	Prélèvements par rapport aux ressources (Mm3/an)	Nombre de puits (équipés)	Prélèvement Mm3/an /Ressources	Nombre de forages	CT	CI
Tunisie du Nord	Nord-Est	324 / 296	42289 (61%)	40 / 62	321 -	-	-
	Nord-Ouest	58 / 76	7621 (57 %)	31 / 86	127 -	-	-
Sous total		*382 / 372*	*49910 (60%)*	*71 / 148*	*448* -	-	-
Tunisie du Centre	Sahel	110 / 118	31405 (49%)	86 / 126	300 -	-	-
	Centre	116 / 82	11734 (73%)	85 / 166	246 -	-	-
Sous total		*226 / 200*	*43139 (56%)*	*171 / 292*	*546* -	-	-
Tunisie du Sud	Sud-Ouest	55 / 49	6866 (61 %)	43 / 53	462 -	139 / 142	8 / 24
	Sud-Est	36 / 49	9248 (38 %)	14 / 34	249 -	305 / 345	51 / 94
Sous total		*91 / 98*	*16114 (48%)*	*57 / 87*	*711* -	*444 / 487*	*59 /118*
Totaux généraux		699 / 670 (57%)	109163	339 / 527 (76%)	1705	444/487	59/118

(6) Reseau Piezometrique de Tunisie.

The national network of piezometer is designed to follow the piezometry of the phreatic and deep aquifers of the country. Some parts of this network are used to control other hydrogeologic parameters such as a salinity or temperature of water. Actually, this network consists, besides the piezometers which are specific constructions for the observation of the groundwater, of shallow wells and tube wells that can be used.

This study aims at presenting the actual conditions of this network through the following parts;

- First part: Analysis of the actual condition of the network of piezometer presenting its structure and recommendation for its operation.
- Second part: Presentation of water location that serve for the supervision of the piezometry in every aquifer following a grouping in every district that shows the regional conception of the structure and management of the network.

The phreatic groundwater potential in the South-West is estimated as 48.1 MCM/a and it is developed actually 55.4 MCM/a through 5,046 shallow wells. The same on in the South-East is estimated as 48.3 MCM/a and developed 35.8 MCM/a through 6,735 shallow wells. Totally it is balancing, but the developing of ground-water in the South-West is far over the potential.

The water resources from deep aquifers in the South-West are estimated as 479.5 MCM/a and development is made at a rate of 469.5 MCM/a through 527 tube-wells, almost in balance. In the South-East, the water resources of deep aquifers are estimated as 236.3 MCM/a, and developed at a rate of 147.2 MCM/a through 287 tube wells.

<u>Gafsa</u>

The phreatic aquifers are developed through 3,595 shallow wells at a rate of 31.91 MCM/a with resources estimated as 24.10 MCM/a. The situation indicates an overdevelopment by 132% of the exploitable resources. These phreatic groundwater are interconnected with deep aquifers as a leaky multi-layered aquifer complex. And the deep aquifers are developed through 147 tube wells at a rate of 59.73 MCM/a against the estimated resources of 78.88 MCM/a.

The monitoring wells for phreatic aquifer are 204 shallow wells (5.6%), and the piezometric wells for deep aquifers are 29 tube wells as density of 19.6%.

In the case of El Guetter Aquifer, the piezometric heads has been decreased at the average rate of 0.7 m/year, however, it shifted 1.0 to 1.5 m/year recently (after 1988).

<u>Tozeur</u>

Water resources potential of phreatic aquifers is estimated as 19.6 MCM/a, while the actual development from the aquifers is around 24.3 MCM/a through 872 shallow wells, as of 124% of overdevelopment. The deep aquifers having an estimated potential of around 173 MCM/a are now actually developed at the rate of about 164 MCM/a, some 95% of the potential.

Piezometric heads of C.T. in this province are decreasing at the rate of 0.2 to 0.74 m/year.

<u>Kebili</u>

In the province, the predominant aquifers are deep, C.T. and C.I. The development of phreatic aquifers is thus only 1.6 MCM/a, against the estimated potential of around 4.8 MCM/a. While the development amount from deep aquifers is reaching 250 MCM/a against the resources of 233 MCM/a, around 107 % of overdevelopment now. As a break-down, C.T. is developed for 222

MCM/a against 205 MCM of potential, and C.I. is developed for 24.8 MCM/a against 27.7 MCM/a.

Beside those formal wells, there are more than 800 of illicit wells extracting about 3,000 l/s reportedly.

Gabes

In Gabes, there are 7 phreatic and 4 deep aquifers. The phreatic aquifers are developed through 1299 of shallow wells at a rate of 16.61 MCM/a, while the resources are estimated as 24.3 MCM/a, and the development rate is 68.4%. The deep aquifers are developed at a rate of 109.82 MCM/a through 170 tube wells, against the exploitable resources are estimated as around 158 MCM/a. The development rate of deep aquifers is nearly 70%.

2.4.3.Phreatic Aquifers

The phreatic aquifers in the South are less essential compared with the deep aquifers such as C.T. and C.I. Tab.2.4.7. shows the number of wells extracting from the phreatic aquifers, volumes of actual developing and the estimated potentials of water resources for the four of target provinces.

Table 2.4.7. Current situations of phreatic aquifers

Province	Number of wells	Number of wells equipped pump	Actual develop (MCM/a)	Potential resources (MCM/a)	Develop-ment rate (%)
Gafsa	4,028	3,893	31.92	24.10	132.4
Tozeur	814	812	24.3	19.6	124.0
Kebili	382	150	1.6	4.8	33.3
Gabes	2,153	1,412	16.61	24.3	68.4
Total	7,377	6,267	74.43	72.8	89.53

As shown in the table, Gafsa and Gabes have rather many wells and some significant volume of extraction from the phreatic aquifers, among the four provinces. Groundwater developments for the phreatic aquifers in Tozeur and Kebili are almost negligible, in particular for Kebili. And the table indicates that it is far overdevelopment in Gafsa but the one in Gabes still has some margin to the maximum development. One of the major reason for overdevelopment from the phreatic aquifer is pumping up, around 97% of the shallow wells in Gafsa and almost 100% of the ones in Tozeur are equipped by motor pump as shown in the table. Mechanical pumping up is, in general, inappropriate for development of phreatic aquifers.

In any rate, the situation of groundwater development for the phreatic aquifers must be said that it's already beyond the resources potential. There is no space to further development on the phreatic aquifers. And not only that, it must be reduced until the total extraction balances to the potential. Otherwise, the aquifer condition must be improved till it can bear the current extraction through artificial recharging or underground dam scheme. By preliminary consideration, it may have no chance to construct an underground dam scheme in Tozeur, however, Gafsa region shall have possible underground dam sites.

Currently, non of the target oases is utilizing the phreatic aquifer (formally), but it is sure the overdevelopment on phreatic aquifers shall harm the hydrogeological balance between the exploitation and the groundwater potential of underlying deep aquifers if the situation shall be continued in the future.

2.4.4. Deep Aquifers

(a) Current situation of development

Deep aquifers in the South are of course representative by C.T. and C.I. In contrast with the condition of phreatic aquifers, the development condition on the deep aquifers is said that it still has some margins to further development in general, because of the hugeness of the aquifers. The replenishment rates of C.T. and C.I. are estimated as very small as $1.6x10^{-5}$ and $5.1x10^{-5}$ respectively, however, those aquifers spread out enormously as several hundreds of thousands square kilometers and the thickness are also huge. Thereby the estimated groundwater resources potential becomes rather big amount nevertheless the quite small replenishment rate. Tab.2.4.8. shows the summary of current situation of groundwater development on deep aquifers.

Table 2.4.8. Current situation of deep aquifers development

Pro- vince	No. of well/spring			Actual exploitation				Estimated	Development Percent	
	equipped (nos)	artesian (nos)	spring (site)	pump up (mcm/a)	artesian (mcm/a)	spring (mcm/a)	total (mcm/a)	resources (mcm/a)	all (%)	pumping (%)
Gafsa										
C.T.	143	4	5	64.59	0.73	2.94	68.26	89.0	76.7%	72.6%
C.I.	0	0	0	0	0	0	0	-	-	-
Total	143	4	5	64.59	0.73	2.94	68.26	89.0	76.7%	72.6%
Tozeur										
C.T.	115	18	0	114.79	14.04	0	128.83	141.1	91.3%	81.4%
C.I.	1	10	0	0.85	6.2	0	7.05	17.3	40.7%	4.9%
Total	116	28	0	115.64	20.24	0	135.88	158.4	85.8%	73.0%
Kebili										
C.T.	54	149	8	73.27	166.57	0.56	240.4	205.4	117.0%	35.7%
C.I.	36	5	3	1.32	32.64	0.3	34.26	31.6	108.4%	4.2%
Total	90	154	11	74.59	199.21	0.86	274.66	237.0	115.9%	31.5%
Gabes										
C.T.	103	50	8	57.3	33.9	0.81	92.01	115.1	79.9%	49.8%
C.I.	1	10	2	0.02	18.92	0.13	19.07	34.1	56.0%	0.1%
Total	104	60	10	57.32	52.82	0.94	111.08	149.2	74.5%	38.4%
Total										
C.T.	415	221	21	309.95	215.24	4.31	529.5	550.6	96.2%	56.3%
C.I.	38	25	5	2.19	57.76	0.43	60.38	83.0	72.7%	2.6%
G.Total	453	246	26	312.14	273	4.74	589.88	633.6	93.1%	49.3%

As shown in the table, the current development situations are still within the estimated potential, excepting the case of Kebili. However, it is also clear that at least the current situation of groundwater development on C.T. aquifer is almost reached to the limit as the averaged development rate of 96.2% is suggesting. The averaged development rate on C.I. is still around 73%, however, it shall easily and quickly be affected for both quantity and quality when the development on C.T. deviates its potential.

(b) Groundwater hydrograph

Table 2.4.8. suggests the groundwater development on deep aquifers is almost reached to the limit, and already stepped into an overdevelopment stage in Kebili. Even in the other provinces, the piezometric heads of deep aquifers are decreasing year by year, as explained in the previous section.

As a typical case, the historical trend of piezometric heads (time series groundwater hydrograph) on C.T. in Nefzaoua, Kebili Province is illustrated in Fig.2.4.3., at next page, and the data are presented as Tab.2.4.9. The figure obviously indicates the decreasing of piezometric heads in recent 5 years became quite large compared with the previous 5 years. In the case of Smida, the yearly rate of decreasing piezometric head in the period from 1978 to 1987 was slightly less than 1.0 m/year, while the one in the latest 5 years was around 1.7 m/year. The fact that the decreasing rate of the piezometric head is accelerating means clearly the state of overdevelopment on the aquifer.

Figure 2.4.4. is illustrated from the same data but showing the relative water level from the ground surface. The figure presents the change of artesian condition of C.T. Still now, around 35% of deep wells tapped to C.T. aquifer are in artesian condition (more than 70% in the case of Kebili), but they are reducing the artesian head and losing artesian condition itself. The artesian heads of C.T. at 20 years ago were ranged from 20 to 40 m above ground surface, and now they reduced their heads at the level from 20 to less than 10 m. If this trend continues, almost all of the C.T. wells shall lose artesian condition within 10 years.

(c) Water quality

Results of groundwater chemical analysis, of deep aquifers of all four provinces, are attached in Appendix. Some water qualities of C.T. and C.I. aquifers are arranged in Trilinear Diagram and shown as Fig.2.4.5. As the figure clearly indicates, the water qualities of them are not so different, rather in same category of Type-III, so called "$CaSO_4$ or $CaCl_2$ Type". The water quality is typical for a hot spring in Japan. In Tunisia also, the water from C.I. is just a hot spring water (called as geothermal water here) with a temperature reaching to some 70 degree C. The reason why the water qualities of them are almost same, nevertheless the hydrogeological properties of those are quite different, is that they consist a leaky aquifer complex.

Fig.2.4.5.
Water quality of C.T. & C.I.

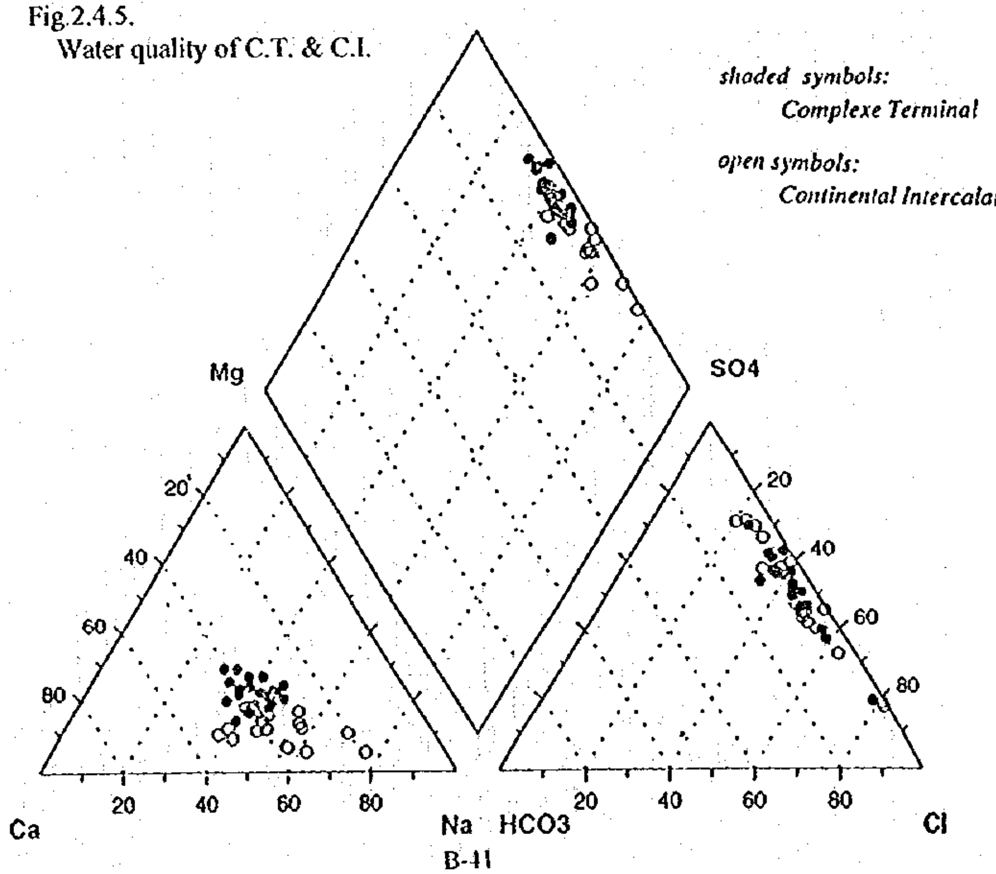


Fig.2.4.3.

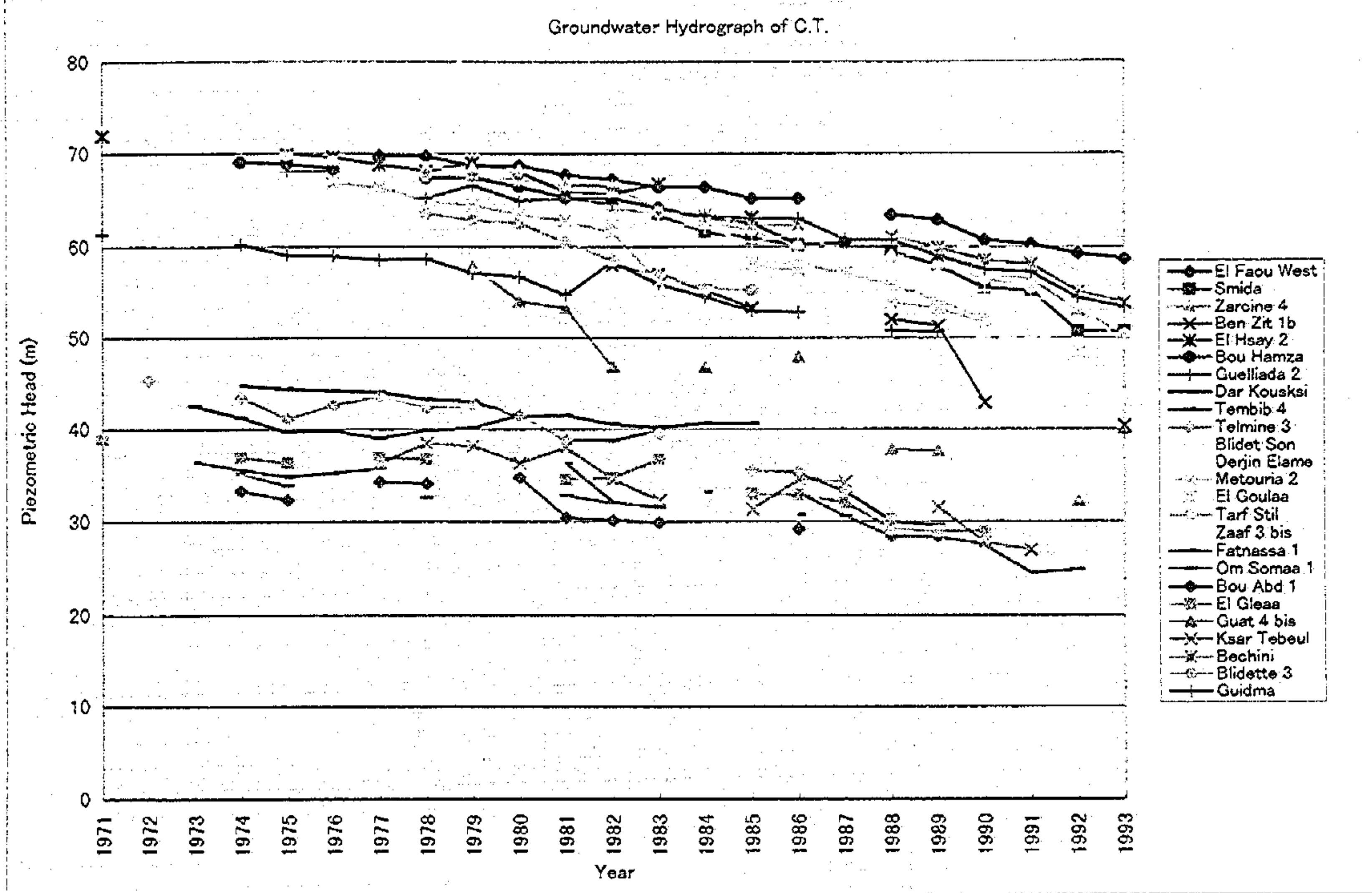
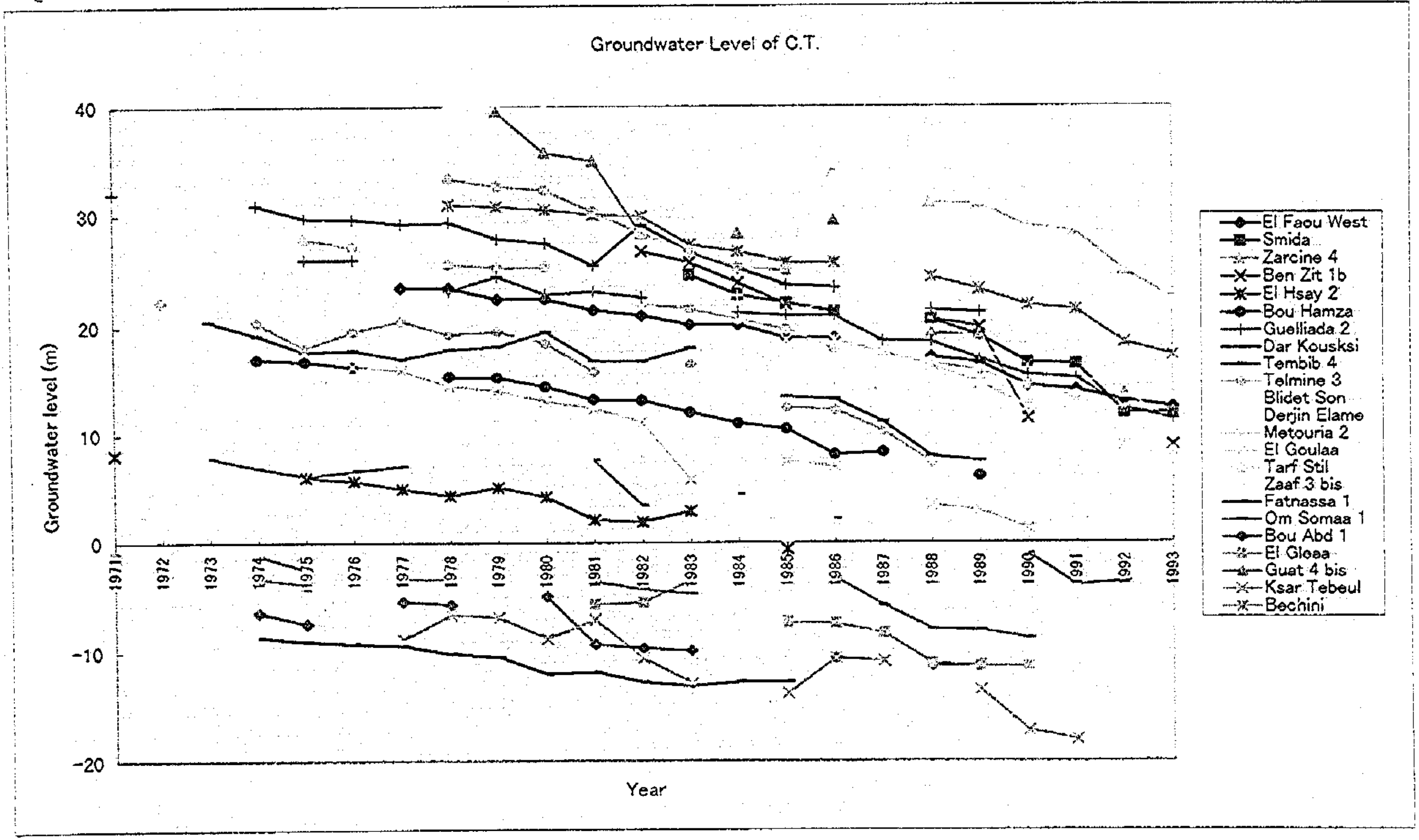

Groundwater Hydrograph of C.T.
Piezometric Head (m)
80
70
60
50
40
30
20
10
0
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Year
El Faou West
Smida
Zarcine 4
Ben Zit 1b
El Hsay 2
Bou Hamza
Guelliada 2
Dar Kousksi
Tembib 4
Telmine 3
Blidet Son
Derjin Elame
Metouria 2
El Goulaa
Tarf Stil
Zaaf 3 bis
Fatnassa 1
Om Somaa 1
Bou Abd 1
El Gleaa
Guat 4 bis
Ksar Tebeul
Bechini
Blidette 3
Guidma

Fig.2.4.4.


Groundwater Level of C.T.
Groundwater level (m)
40
30
20
10
0
-10
-20
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Year
El Faou West
Smida
Zarcine 4
Ben Zit 1b
El Hsay 2
Bou Hamza
Guelliada 2
Dar Kousksi
Tembib 4
Telmine 3
Blidet Son
Derjin Elame
Metouria 2
El Goulaa
Tarf Stil
Zaaf 3 bis
Fatnassa 1
Om Somaa 1
Bou Abd 1
El Gleaa
Guat 4 bis
Ksar Tebeul
Bechini

During the first stage of the Study, each five sites for the four provinces (total 20 sites) have been selected for soil and water quality tests. Samples were taken by the Team and sent to the laboratory of ENIS, Sfax. The details of the results are explained in the sector report on Soil, and the results on the water quality analysis are summarized in Trilinear Diagram and Wilcox Diagram as Fig.2.4.6. and 2.4.7. respectively. The chemical components in the Trilinear Diagram are in almost same tendency with the one shown in Fig.2.4.5, mostly included in Type-III. While, the characteristics in Wilcox Diagram are "very high salinity" and "medium sodium" hazards, excepting only one sample from Kebili indicating "very high sodium hazard".

(d) Evaluation of water resources potential

Based on the current groundwater development situation and the aquifer characteristics of C.T. and C.I., the following matters are said as a conclusion;

- Groundwater in deep aquifers in the South are classified into "Fossil Water" characterized by extremely small replenishment rate, however, just because of their hugeness they have very high water resources potential.
- Groundwater development on the deep aquifers has been accelerated drastically in this ten years, formally and illicitly. And the total groundwater exploitation from C.T. has reached to the limit of development potential, or already passed through the limit into the overdevelopment stage locally.
- Because of a difficulty to touch, very high piezometric head, and geothermal property, C.I. has not yet developed fully (about 73%). However, it has closed relation with C.T. through leaky aquifer complex, a development on C.I. accelerates the overdevelopment on C.T., and a further development on C.T. directly affects to the aquifer condition of C.I. inversely. Thus, the situation of development on C.I. must be said as already arrived at the limit.
- Water quality of the deep aquifers is not so excellent, classified into Type-III; $CaSO_4$ or $CaCl_2$ type, medium sodium hazard buy very high salinity hazard, and having geothermal property in the case of C.I., it is not fatal for agricultural use though.
- Because of the almost maximum (partly over) development on the deep aquifers, piezometric heads of them are decreasing rapidly. Still now around 35% of C.T. wells are in artesian condition, but they shall lose the artesian condition within 10 years if the exploitation from the deep aquifers shall be continued in same level.

2.5. Summary and Conclusion

2.5.1. Summary

North-south prolonged Tunisian territory is divided into three major hydro-geological regions, namely a) Northern Tunisia, b) Central Tunisia, and c) South Tunisia. And further they are sub-divided into each two sub-regions, as shown below, and the target four provinces are included in South Tunisia, Gabes is in South East and the others are in South West sub-regions;

Northern Tunisia

a. North West Tunisia
b. North East Tunisia

Central Tunisia

c. Kairouan Sahel
d. Tunisia Central

South Tunisia

e. South West
f. South East

In the South, a water resources potential of surface water is very poor, and the essential water resources for domestic, agricultural, and industrial uses are owed by groundwater.

Groundwater in Tunisia is classified into "shallow" and "deep" from the depth to water table, while an aquifer is classified into "phreatic" and "deep" from the aquifer characteristics whether confined or unconfined. The North or Central Tunisia have both phreatic and deep aquifers but the significant aquifers in the South is only the deep aquifer consisted of major two aquifers of C.T. (Complex Terminal) and C.I. (Continental Intercalaire).

C.T. is a huge international aquifer covering 350,000 km^2 of the northern Sahara basin. It includes "Continental Terminal" which is one of the most prevailing aquifers in Africa, and further earlier calcareous sequences. It is strongly confined aquifer and around 35% of deep wells tapped to the aquifer are in artesian condition. C.I. is one of the largest groundwater system in the would, spreading in an area of some 600,000 km^2 in the African Continent. Most of the wells tapped to C.I. are in strong artesian condition, sometime more than 200 m of relative piezometric head, and the water is in highly geothermal condition with around 70℃. These aquifers consist leaky multi-layered aquifer complex, involving further shallow aquifers.

The most of target oases, excepting some oases in Gabes and Tozeur, utilize the groundwater from the deep aquifers. Although the deep aquifers in these provinces are C.T. and/or C.I., they are further classified into sub-groups and controlled systematically in accordance with the groundwater sub-basin. Oases near around Gabes and in Tamerza region are irrigated by the groundwater from phreatic aquifers, because they were developed on the thick alluvial deposits.

From the view point of hydrogeology, and geomorphology, the target oases are classified into five groups as follows;

Case-a: Developed on valley deposits among a mountain ranges,
Case-b1: Developed on low terraces surrounding the Chotts,
Case-b2: Developed on comparatively low shore terraces,
Case-b3: Developed on very gentle foot slopes of mountains or hills,
Case-c: Developed on Alluvial fans or flood plains,
Case-d: Developed on "islands" in the Chott, and
Case-e: Others.

In the South, the development of groundwater is very important, however, to evaluate their water resources potential is very difficult, because;

a. Horizontally, they are distributing in huge area beyond the border with Algeria (international aquifer). Further the main bodies and recharging zones of the aquifers are in Algeria.
b. Vertically, they consist very complicated leaky multi-layered aquifer complex. The complex involves even the shallow or phreatic aquifers in most of the cases.
c. Generally, they are deep and enough strongly confined as spring out to the ground surface. However, the most of natural discharge zones of them are occupied by the great salt lakes (Chotts).
d. They are classified into a category of "Fossil Water" which have extremely weak replenishment rate. And that means, the development of them are just mining type, never or hardly renewable.
e. Monitoring system, in particular with those deep aquifers, is still rudimentary, because of the difficulty to construct piezometric wells technically and financially.

Nevertheless such difficulty on the evaluation, several attempts to evaluate the groundwater resources potential in the South, represented by ERESS (UNESCO, 1982), have been conducted by international organizations and the government agencies of Tunisia. In accordance with these studies, the data on groundwater utilization, or the monitoring data of piezometric heads, the groundwater development on the phreatic aquifer is already fallen into the overdevelopment, and the one on the deep aquifer reached to the limit except Kebili Province. In the case of Kebili, groundwater developments on both C.T. and C.I. have already been in the stage of overdevelopment. If the exploitation from the deep aquifers shall be continued in the current level, the artesian condition of almost all wells tapped to C.T. shall be lost within 10 years.

2.5.1. Conclusion

Through the field survey, reviewing on the previous studies, and arranging or reconsidering on collected data/information, the following matters are figured out as a conclusion:

- The significant water resources in the South is only groundwater, however, the groundwater development on the phreatic aquifer is already fallen into over-exploitation.
- Groundwater in deep aquifers in the South are classified into "Fossil Water" characterized by extremely small replenishment rate, however, just because of their hugeness they have very high water resources potential.
- Groundwater development on the deep aquifers has been accelerated drastically in this ten years, formally and illicitly. And the total groundwater exploitation from C.T. has reached to the limit of development potential, or already passed through the limit into the overdevelopment stage locally.
- Because of a difficulty to touch, very high piezometric head, and geothermal property, C.I. has not yet developed fully (about 73%). However, it has closed relation with C.T. through leaky aquifer complex, a development on C.I. accelerates the overdevelopment on C.T., and a further development on C.T. directly affects to the aquifer condition of C.I. inversely. Thus, the situation of development on C.I. must be said as already arrived at the limit.
- Water quality of the deep aquifers is not so excellent, classified into Type-III; $CaSO_4$ or $CaCl_2$ type, medium sodium hazard buy very high salinity hazard, and having geothermal property in the case of C.I., it is not fatal for agricultural use though.
- Because of the almost maximum (partly over) development on the deep aquifers, piezometric heads of them are decreasing rapidly. Still now around 35% of C.T. wells are in artesian condition, but they shall lose the artesian condition within 10 years if the exploitation from the deep aquifers shall be continued in same level.