

Groundwater investigation in the southern part of Gabes using resistivity sounding, southern Tunisia

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Received: 11 January 2011 / Accepted: 18 July 2011 / Published online: 28 August 2011
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Abstract The groundwater hydrogeology of southern Tunisia emphasizes two main groundwater bodies so-called Zeuss-Koutine and south Gabes. These groundwater bodies yielding economically important storage of useful water present complex internal architecture and heterogeneity allowing exchange flows throughout permeable or/and fractured bodies. A geophysical survey using resistivity soundings was carried out along this area to describe in detail the field structure and the 3D extent of these groundwater bodies by the hydrogeological new data and detailed subsurface mapping based on resistivity sounding and seismic data. This survey discusses also the potentialities of some permeable layer in water storage and purposes potential favorable areas for optimum groundwater mining.

Keywords Groundwater potentiality · Resistivity sounding · Gabes · Tunisia

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Introduction

The investigated region of south Gabes makes part of the Jeffara plain and extends between the longitudes of $8^{\text{G}}56'$ to $8^{\text{G}}96'$ and the latitudes of $37^{\text{G}}12'$ to 37^{G} . It makes the northern periclinal closure of the NW-SE dome of Jeffara in southern Tunisia which constitutes the eastern limb of the Dahar anticline (Fig. 1). This limb is collapsed to the east and overlaid by recent continental Mio-Plio-Quaternary deposits which overlay unconformably Cretaceous series within NW-SE and NE-SW fractures.

The Mediterranean Sea forms northern and eastern borders of this coastal plain, and the highland of the Saharan Dahar forms its southern and western extents. Due to the particular geographical location of the investigated area, its arid climate is influenced by the Mediterranean Sea in the eastern coastal border (Gulf of Gabes) and by the Saharan Desert in the southern interior. Annual rainfalls are irregular and torrential and increase by the NE-SW wet winds imminent from the Gulf of Gabes (Ayadi 1979).

The conceptual hydrogeological model for this area was estimated based on previous studies, geological and hydrogeological data. This approach highlights main results on the precision of the geometry of the studied groundwater bodies. In fact, hydrogeological wells are infrequent all along the region and still insufficient to characterize the most aquifers. Accordingly, we undertook a geophysical survey using resistivity sounding to verify, precise, and complete the results of geological and hydrogeological studies.

The resistivity sounding is a geophysical exploration technique that measures electrical resistivity of reservoir formations (Keller and Frishknecht 1966; Urish 1983;

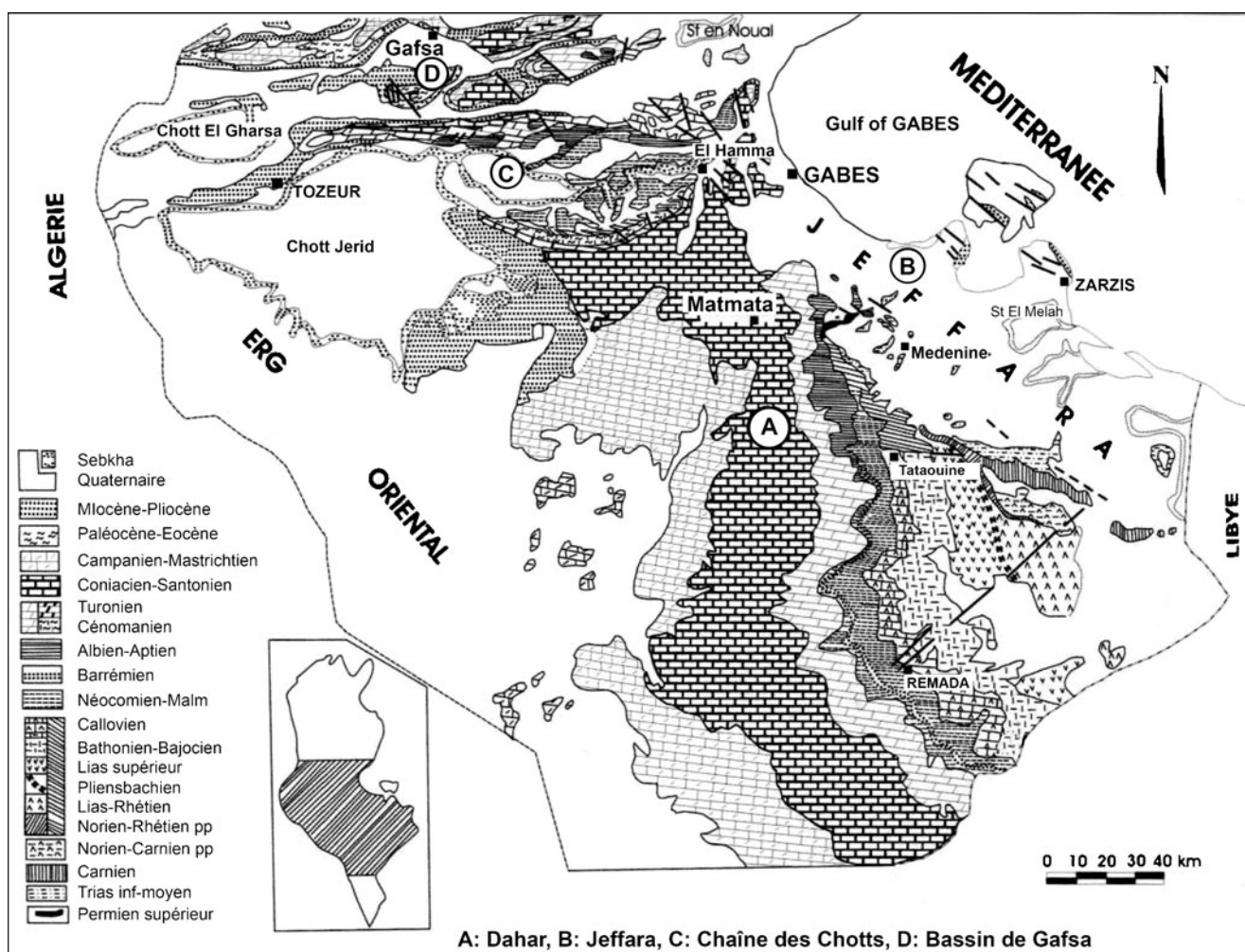


Fig. 1 Geological map of southern Tunisia (Bouaziz 1995)

Van Overmeeren 1979; Shaaban 2001; Pham et al 2002; Alain Tabbagh 2006; Hussein and Awad 2006; El Kashouty et al. 2010). This method, largely used in water prospection, gives precision about the subsurface structure and helps to identify, evaluate, and understand subsurface lithography and their fluid content. In fact, regarding the consistent results highlighted by several recent studies carried out in central and southern Tunisia (Gasmi et al. 2001; Gasmi 2002; Mhamdi 2003; Mhamdi et al. 2005a, 2006; Gouasmia. 2008), this method using an instrument of model SYSCAL R2, IRIS Instruments, France seems to be with great success.

Geological setting

The Tunisian Saharan platform constitutes an unfolded area of tectonic stability, gently uplifted in its northern part which limits the folded domain of the Atlassic chain of Tunisia to the north (Bouaziz 1995). The

studied region constitutes the northeastern part of this area (Fig. 1).

The outcropping stratigraphic series are of Permian to Quaternary in age. The only Permian outcrop at Tunisian scale is the one of Jebel Tebaga in southern extent of the study area (Fig. 1). It is about shallow water marine facies; deposits are mainly clay, sandstone, and limestone. The Triassic series outcrop only southern to Tebaga as sandstone, clay, and dolomite. Jurassic and Cretaceous series occupy western and eastern terrains and are mainly within the carbonated facies. From Miocene to Quaternary, deposition is mostly clastic and alluvial usually within a clay matrix.

The Tunisian Saharan platform comprise (a) the structure of the Permian monocline of Tebaga sealed by the Mesozoic series and concerned by directional faults, (b) the large dissymmetric anticline of the Dahar Dome thrusting unconformably the Permian structure of Tebaga, and (c) the Jeffara plain extended from the Gulf of Gabes to the Libyan Boundary and constituted the

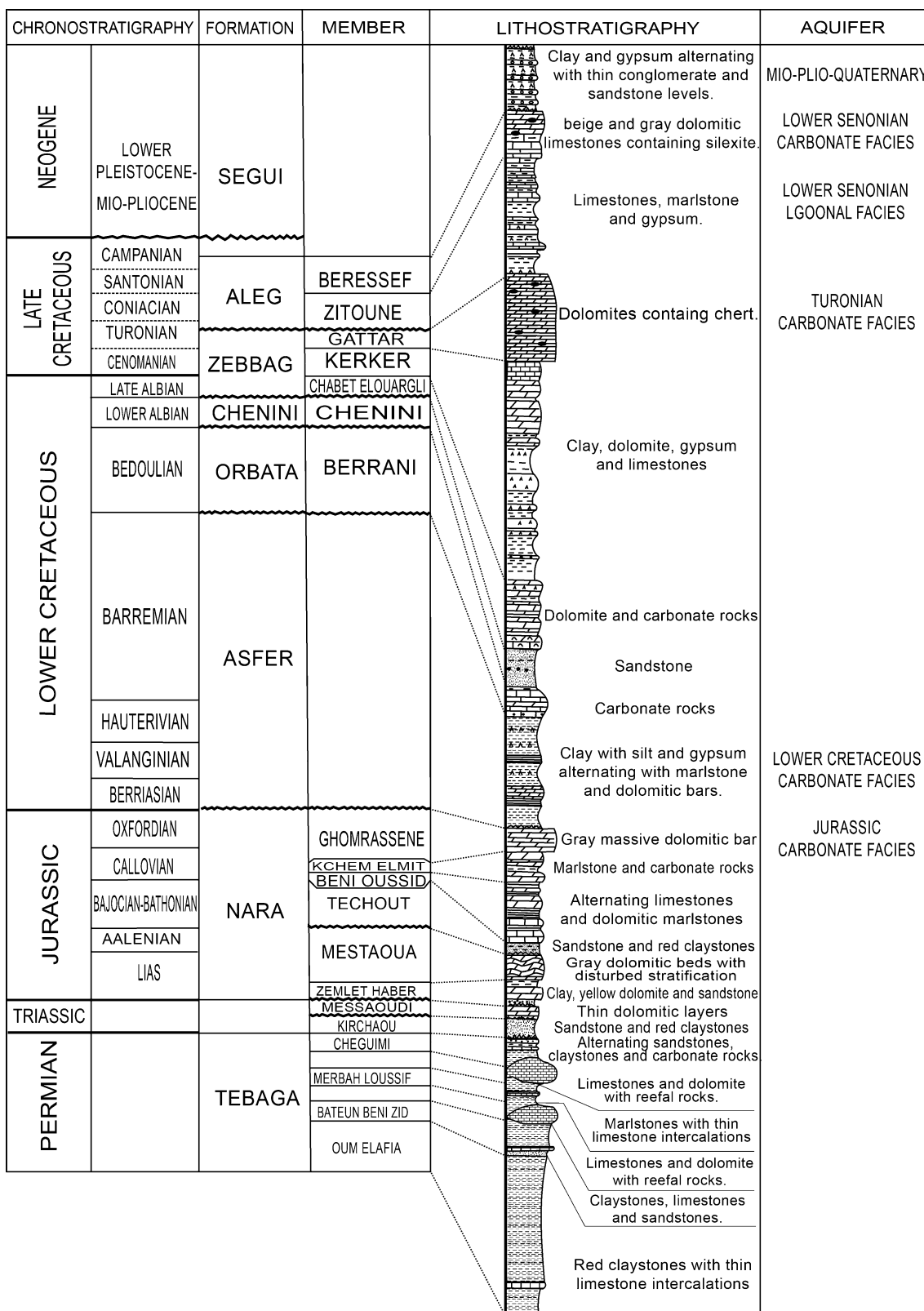


Fig. 2 Lithostratigraphic column of the study area (modified after Ghanmi et al 1988)

eastern collapsed limb of the Dahar Dome. This collapse is due to one normal fault elongating the

structure to the east and overlaid by the Mio-Plio-Quaternary deposits.

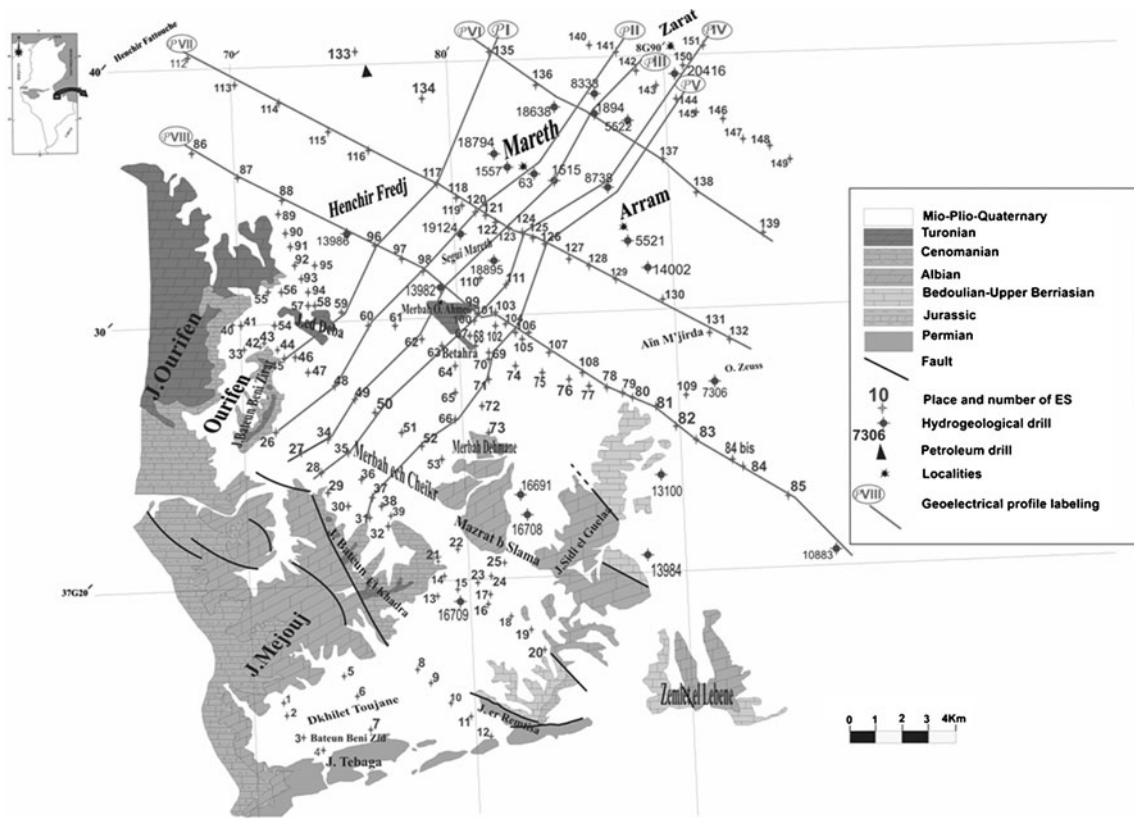


Fig. 3 Geological map of the study area with the location of the electrical soundings

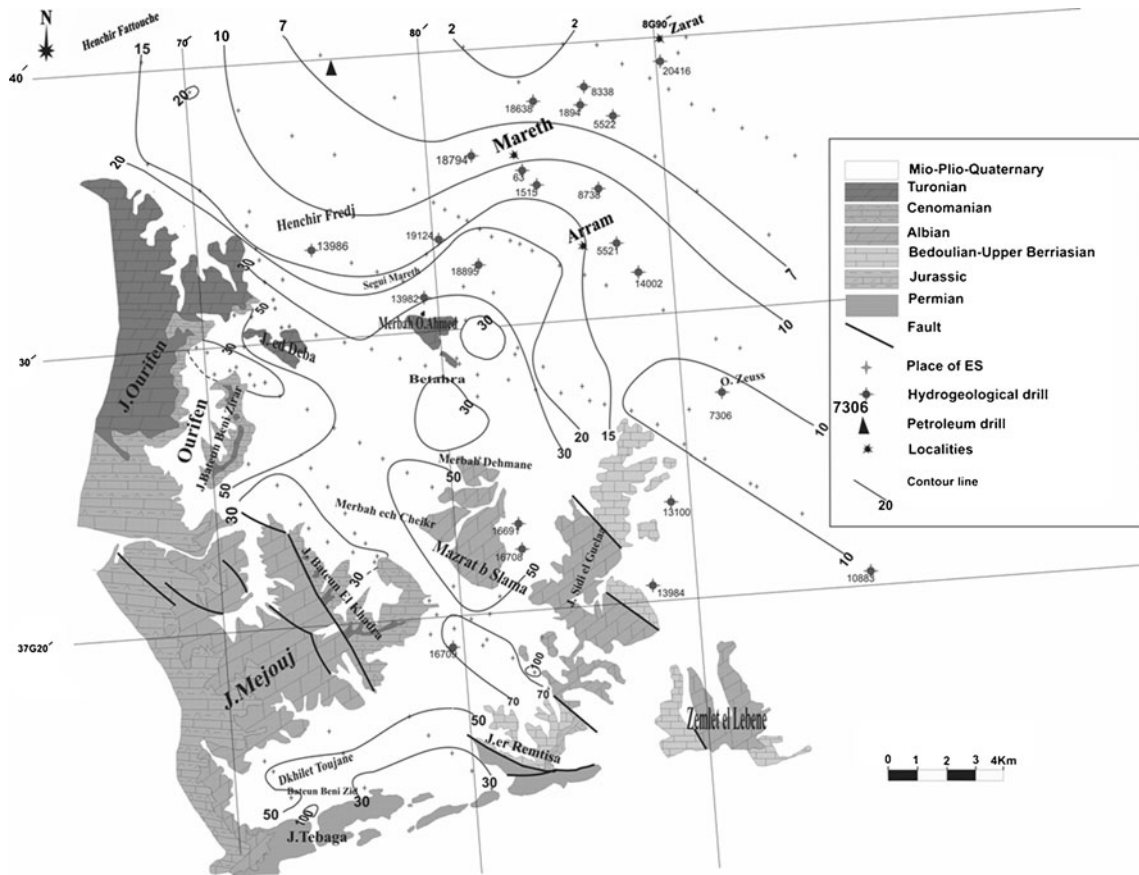


Fig. 4 Isoresistivity map of the study area drawn with AB/2=50 m

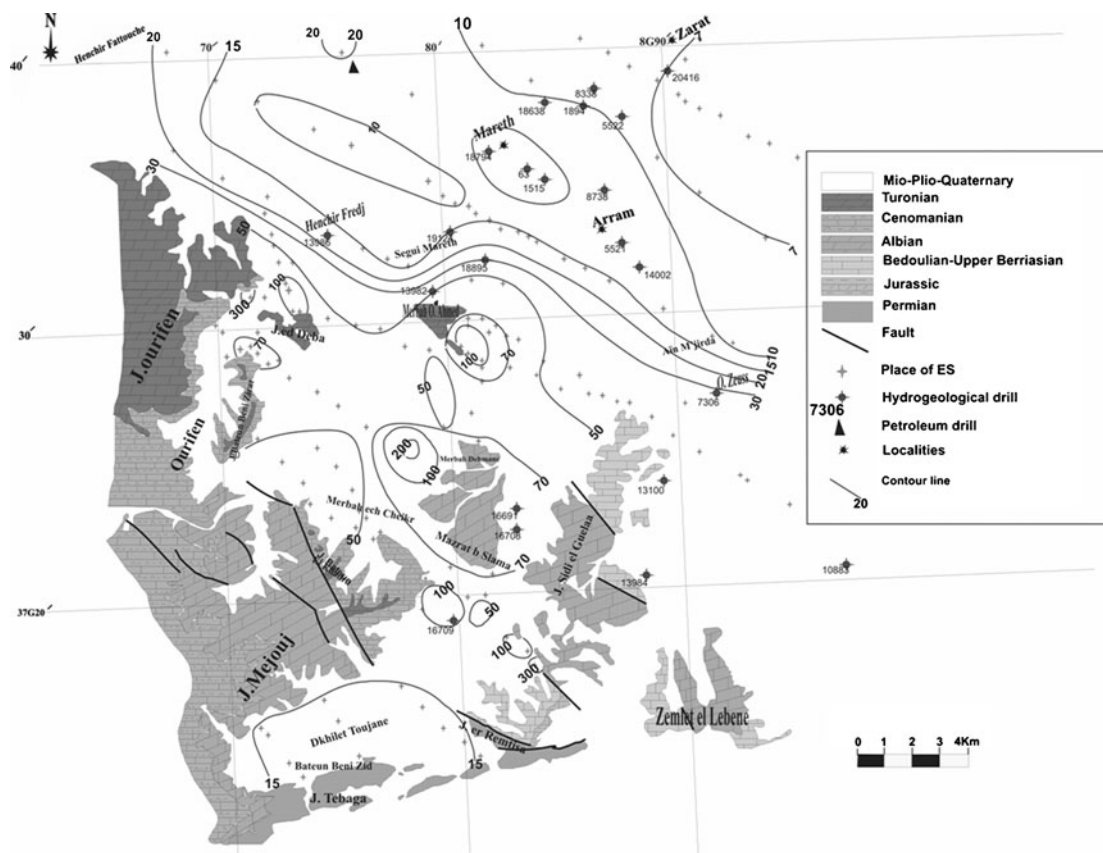


Fig. 5 Isoresistivity map of the study area drawn with AB/2=400 m

Hydrogeological setting and groundwater potentialities

The regional subsurface aquifers of the south Gabes reveal serious complexity, first within the lithostratigraphic unit that shows lateral facies variation and second within its structure affected by a complex fault network. Previous studies (E.R.E.S.S 1972a, b, c, d; Borgi et Ben Baccar 1980; Ben Baccar 1982; Mamou 1990; Mhamdi 2003; Abidi 2004; Mhamdi et al. 2005a, b) highlighted the

existence of two groundwater bodies of Zeuss-Koutine and south Gabes. The first one is contained within the carbonated facies of the Jurassic series. The second one is restricted in the fractured limestones of the Lower Senonian reservoir.

The geometry and the structural arrangement of these reservoirs allow external water exchange especially as surface groundwater flow and recharge from the Continental Intercalaire known at the Tunisian–Algerian

Table 1 Correlation of Henchir Titoun drill and ES1 calibration through the lithology and resistivity values measured on correlated stratigraphic level

Henchir Titoun drill IRH N° 16709/5			Calibration ES			Chronostratigraphy
Level	Thickness (m)	Lithology	Level	Resistivity (Ω m)	Thickness (m)	
1	10	Clay and sand	1	200	3	Mio-Plio-Quaternary
			2	10	5	
2	20	Marlstone	3	23	20	Cenomanian
3	55	Limestone	4	331	55	
4	40	Marlstone and limestone	5	13	40	Albian–Aptian Upper Jurassic–Lower Cretaceous
5	135	Limestone, dolomite and sandstone	6	153	135	
6	52	Dolomite	7	75	75	Jurassic
Not reached			8	10	–	

Saharan scale (Edmunds et al. 2003; Trabelsi et al 2008; Abid et al. 2009) and captured to the west and the north out of the study area. In addition, along the lithostratigraphic column at the study area scale (Fig. 2), numerous permeable lithostratigraphic units constitute serious potential aquifer such as the Jurassic karst dolomitic limestone and the sandstone facies of the Continental Intercalaire groundwater body which constitute a significant aquifer collapsed downstream the Medenine fault eastern the Permian monocline of Tebaga. Cretaceous deposits include other potential aquifers, especially the thick carbonated Cenomanian–Turonian and Albian–Aptian layers. The Lower Senonian series contain two aquifer facies (Fig. 2): (a) the lagoonal facies as interbedded limestones unit having a minor capacity, marlstones, and gypsum and (b) the carbonate facies as a limestone unit with a good karst index. The specific discharge from this last one aquifer reaches $92 \text{ l s}^{-1} \text{ m}^{-1}$ from several drillings so it is considered an aquifer with high interest to southern Gabes. At the top of the lithostratigraphic column (Fig. 2), the conglomerate and sandstone levels of the Neogene deposits constitute other potential aquifers with a good porosity.

Results and interpretation

A totality of 152 Schlumberger electrical soundings (ES) was carried out, AB ranges from 800 to 2,000 m (Kunietz 1966; Astier 1971; Koeford 1979; Parasnis 1997; Fig. 3). Completed data allow us to draw five apparent isoresistivity maps for $\frac{AB}{2} = 50 - 400 \text{ m}$ (Figs. 4 and 5), geoelectric and electrostratigraphic profiles (Figs. 7 and 8), and isopach and isobath maps (Figs. 9, 10, 11, 12, and 13).

Isoresistivity maps

The isoresistivity maps of Figs. 4 ($\frac{AB}{2} = 50 \text{ m}$) and 5 ($\frac{AB}{2} = 400 \text{ m}$) demonstrate that:

- Resistant sediments are located around the Turonian and the Albian outcrops.

- Resistive features are located in Mareth, Arram, and Zarat areas.
- Resistivity values of Zarat area are low due to the lateral facies variation and the salinity increase from the west to the east (coastal border).
- On the profound layers ($\frac{AB}{2} = 400 \text{ m}$), sediments become more resistant and the facies is probably carbonate rocks.
- The lower resistivity values ($<2 \Omega \text{ m}$) are recorded in Zerkine Sebkhia in result of its high salinity.
- The isoresistivity maps show sometime a disruption of several resistivity contours which can be explained by the impact of the faults overlaid by recent sedimentation.

The interpretation of $\rho\alpha = f\left(\frac{AB}{2}\right)$ diagrams helps to identify potential aquifers and to precise their stratigraphic succession. This allows us to figure resistive layers and evaluate their thickness and depth. We can also conclude their true resistivity and their lithology.

To sustain this method of investigation, given results should be calibrated and correlated within a closest drilling data. Then we can draw geoelectric profiles and isopach and isobath maps for the identified potential layers.

Along the study area, several ES calibration are realized within variable depth and focalized on different lithostratigraphic levels. Two electrical sounding are selected to be used for calibration: the Henchir Titoun drill IRH N° 16709/5 (drill depth=302 m; dry residue= 2.012 g l^{-1} ; well capacity= 25 l s^{-1} ; water table= -105.68 m) (Table 1) and the Zarat2 drill (drill depth=565 m; dry residue= 2.43 g l^{-1} ; specific surface discharge= $6.17 \text{ l s}^{-1} \text{ m}^{-1}$; water table= $+22.27 \text{ m}$) (Table 2) (Fig. 6). The levels correlated to these calibration drills allow the correlation of lithostratigraphic unit and the precision of their ages.

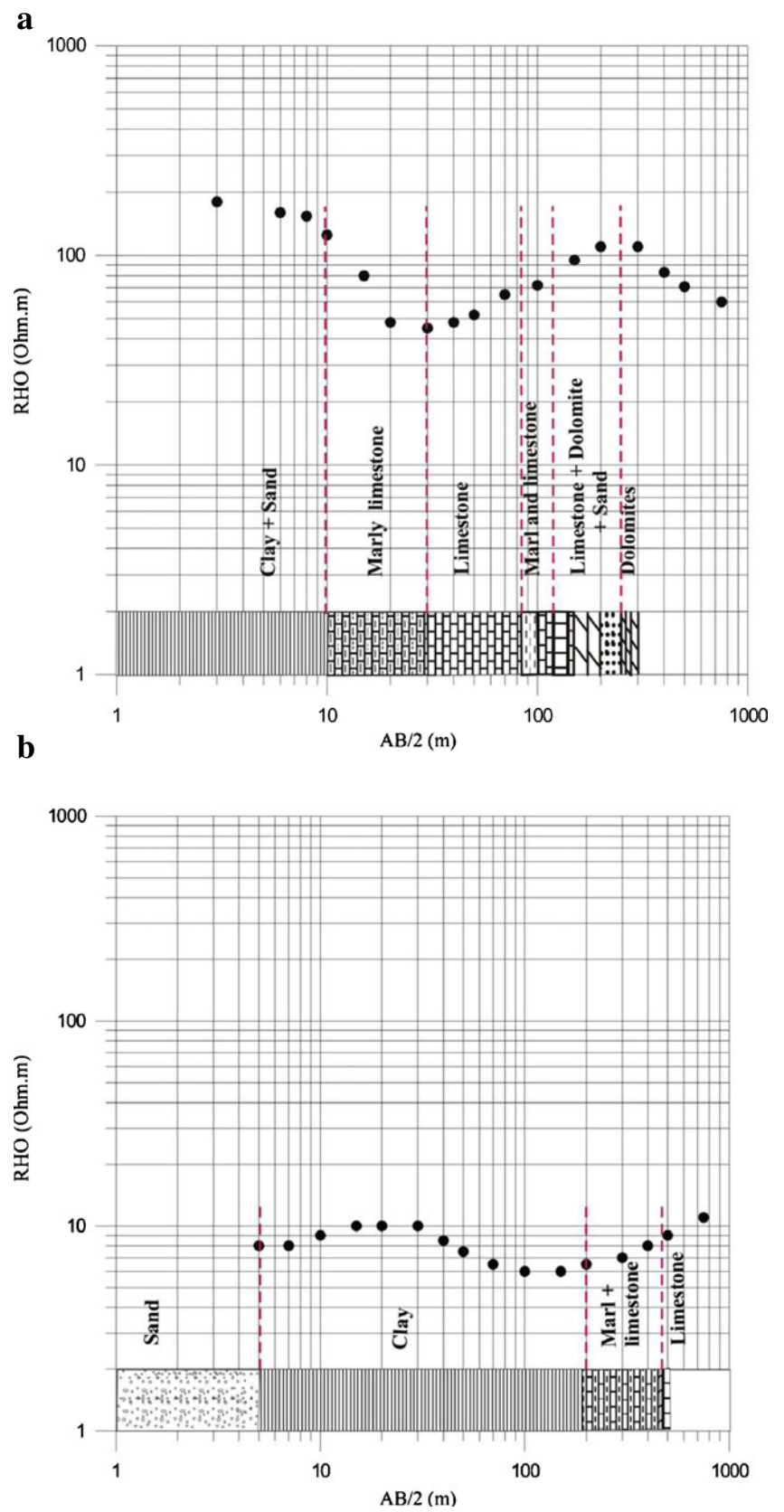
Geoelectric and electrostratigraphic profiles

Gathered data allow us to draw geoelectric and electrostratigraphic profiles. Two representative profiles (NW-SE and NE-SW) are discussed (Fig. 7).

Table 2 Correlation of Zarat2 drill and ES3 calibration through the lithology and resistivity values measured on correlated stratigraphic level

Zarat2 drill IRH N° 5522/5			Calibration ES			Chronostratigraphy
Level	Thickness (m)	Lithology	Level	Resistivity ($\Omega \text{ m}$)	Thickness (m)	
1	4	Sand	1–2	6–15	4	Mio-Plio-Quaternary
2	193	Clay	3	3	73	
			4	14	120	
3	260	Limestone and marlstone	5	7	260	Carbonate Lower Senonian
4	48	Limestone	6	>20	–	Lagoonal Lower Senonian

Fig. 6 Calibration of the ES with the drill data: **a** drill of Henchir Titoun (N° 16709/5), **b** drill of Zarat2 (N° 5522/5)



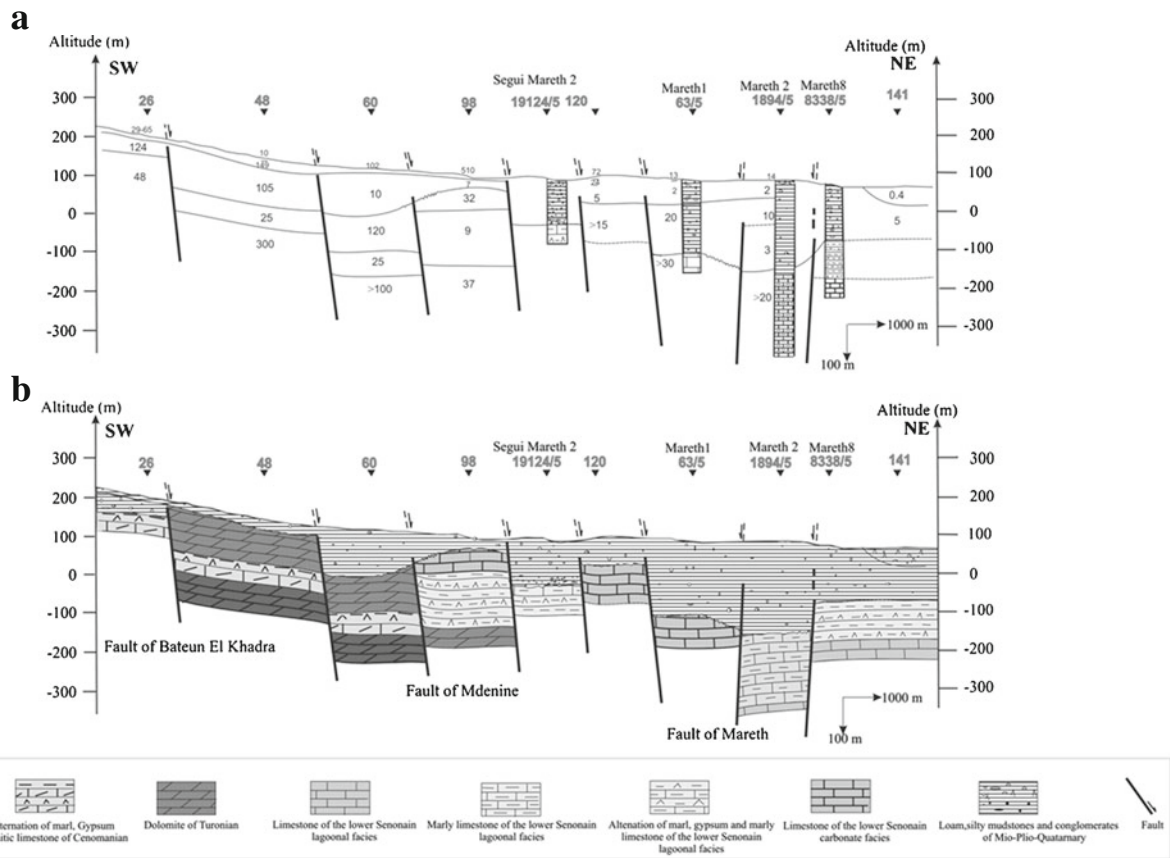


Fig. 7 SW-NE oriented geoelectric (a) and electrostratigraphic (b) profiles along the profile II of Fig. 3

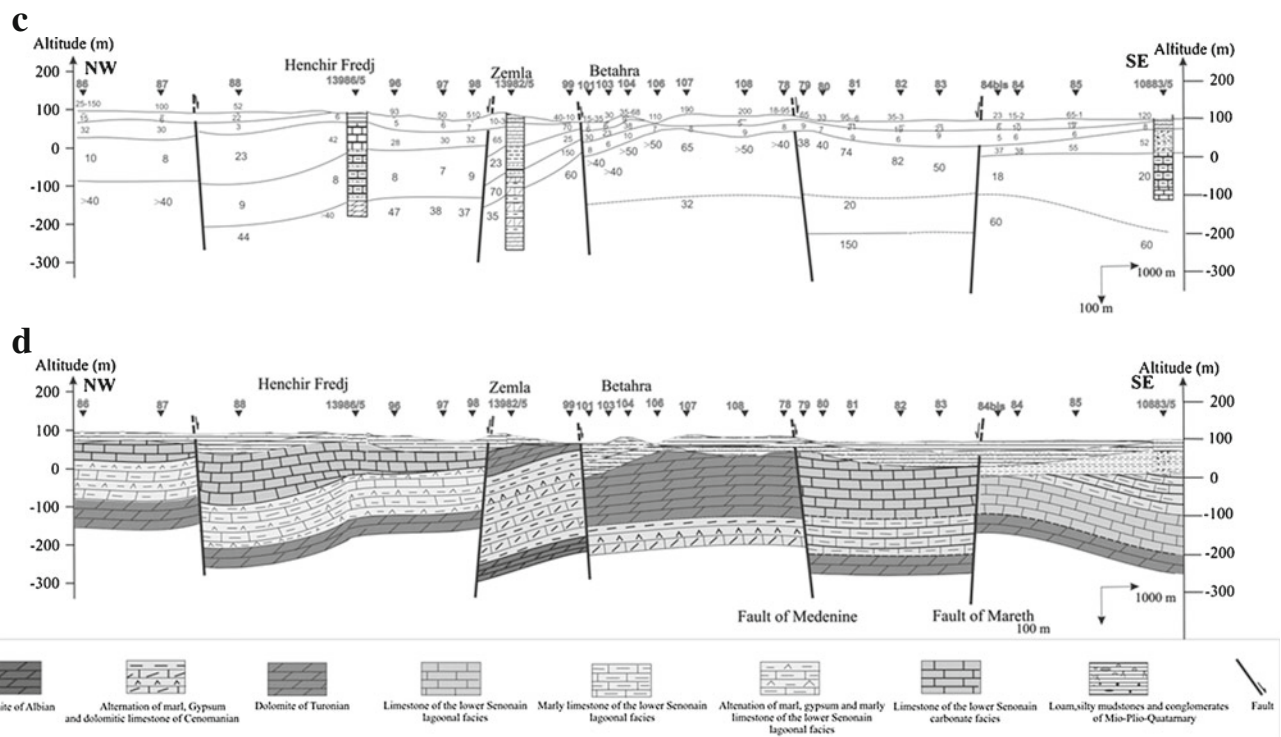


Fig. 8 NW-SE oriented geoelectric (c) and electrostratigraphic (d) profiles along the profile VIII of Fig. 3

NW-SE profiles are shown in Fig. 3. These profiles expose resistive and resistant stratigraphic levels from the superficial Quaternary deposits to the Albian dolomitic layer downward. In correlation to lithostratigraphic data of the Mareth8 N° IRH 8338/5 drill, the Lower Senonian series at the northeastern extent of the ES141 profile should be comprised of limestone, shale, and gypsum deposits.

The structural background of the study area is characterized by some main faults such as these of Medenine fault found between ES98 and the drill of Segui-Mareth2 N° IRH 19124/5, Bateun El Khadra fault flanked by ES26 and ES48 and Mareth fault between the ES calibration of ES63/5 and ES1894/5. In addition, this study pointed out five NE-SW normal faults. These faults engender successive NE collapse and create small grabens around ES63/5.

NE-SW profile (Fig. 3) shows comparable resistive and resistant levels as revealed along NW-SE profiles. In addition, this profile illustrates subsurface lithostratigraphic and structural precision. A thickness reduction of the Mio-Plio-Quaternary series is remarkably revealed. The Lower Senonian series are comprised especially of limestone and shale facies at the southern extent of the profile VIII (Fig. 8).

This profile shows also NW-SE normal faults which create horst and graben structures (Fig. 8). The Henchir Fredj graben is limited to the northwest by the fault between ES87 and ES88 and by the fault between ES98 and the ES calibration of ES13982/5 to the southeast. Another graben bordered by the normal faults of Medenine and Mareth is filled, respectively, from recent to ancient by the Mio-Plio-Quaternary series, the Lower Senonian series, the Lower Senonian series, and the Turonian dolomites. The profile shows also a horst between ES98 and ES101 which is in accord with the uprising of Turonian dolomitic unit at this locality (Fig. 8).

Isobath and isopach maps

Isobath and isopach maps are drawn for lithostratigraphic layers with high aquifer potentials. Seismic data of Mobil Exploration Company (1976) are presented to support the results.

The Lower Senonian isobath map (Fig. 9) shows that the depth of the top of this aquifer varies from 50 to 250 m. The depth increases from west to east approving the thickness increase of the Mio-Plio-Quaternary series eastward.

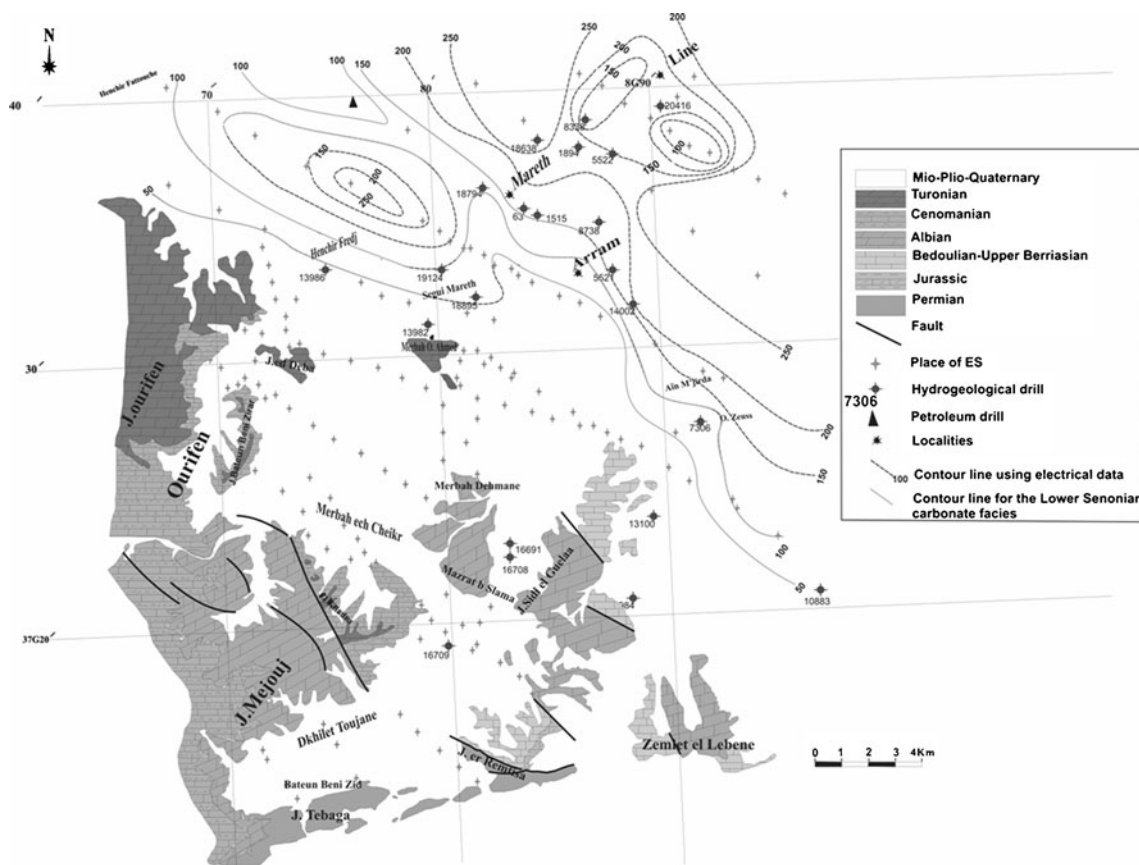


Fig. 9 Lower Senonian isobaths map of the study area

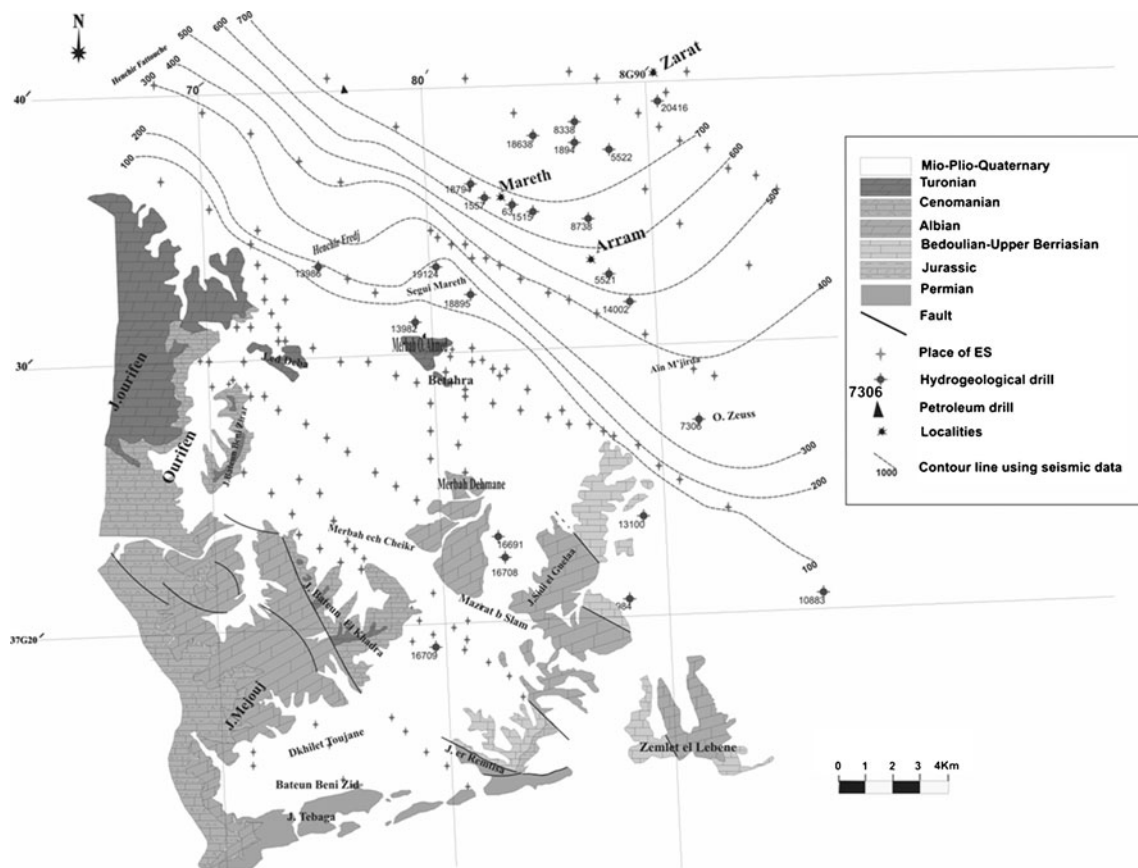


Fig. 10 Lower Senonian isopach map of the study area

The disruptions that affect several depth contour appears along faults such as these of Zerkine, Mareth and Mareth2 to the north and Zarat and Oued Zigzaou to the northeast.

The Lower Senonian isopach map (Fig. 10) shows that the series thickness ranges from 100 to 700 m, respectively, from the south to the north. This thickness variation is the cause of the depth increasing eastward.

The Lower Cretaceous isopach map (Fig. 11) demonstrates that the Cretaceous series evolve comparably as the Lower Senonian ones. The top of the Cretaceous series situated at a depth of 20 m around the Albian outcrop of Merbah Dehmane and Merbah Cheïkr Merbah (Fig. 11) drift downward to 1,500 m to the east. Fault lines can be drawn from the disruption affecting the isopachous lines especially along the Medenine fault which coincide within the highest depth gradient (Fig. 11).

The isopach map of Lower Cretaceous series (Fig. 12) emphasizes an important thickness variation ranging from 300 m to the south (Mazrat ben Slama and Oued Zeuss areas) to 500 m to the north (Mareth, Arram, and Zarat areas). The Jurassic isobath map (Fig. 13) shows that the lower depth of the top of the Jurassic series is located

around Mazrat ben Slama and Dkhilet Toujane areas, but it can reach 2,000 m to the north.

Synthesis and discussion

Gathered data permit to draw a synthesis map (Fig. 14) which can be useful for water exploration in southern Tunisia. This map gives evidence for subsurface fracturing that engenders successive collapses, graben, and horst structures. It helps also to define optimal areas for potential water mining from appropriate aquifer layers:

- The Lower Senonian limestone unit seems to be the most attractive target in south Gabes regarding to its significant groundwater potentiality. This unit demonstrates good karst index and laterally variable thickness. Unfortunately this unit is partially eroded earlier than the deposition of the Mio-Plio-Quaternary series.
- The lagoonal Lower Senonian comprised of limestone, shale, and gypsum is less interesting aquifer but the limestone layer contained in still a serious aquifer while

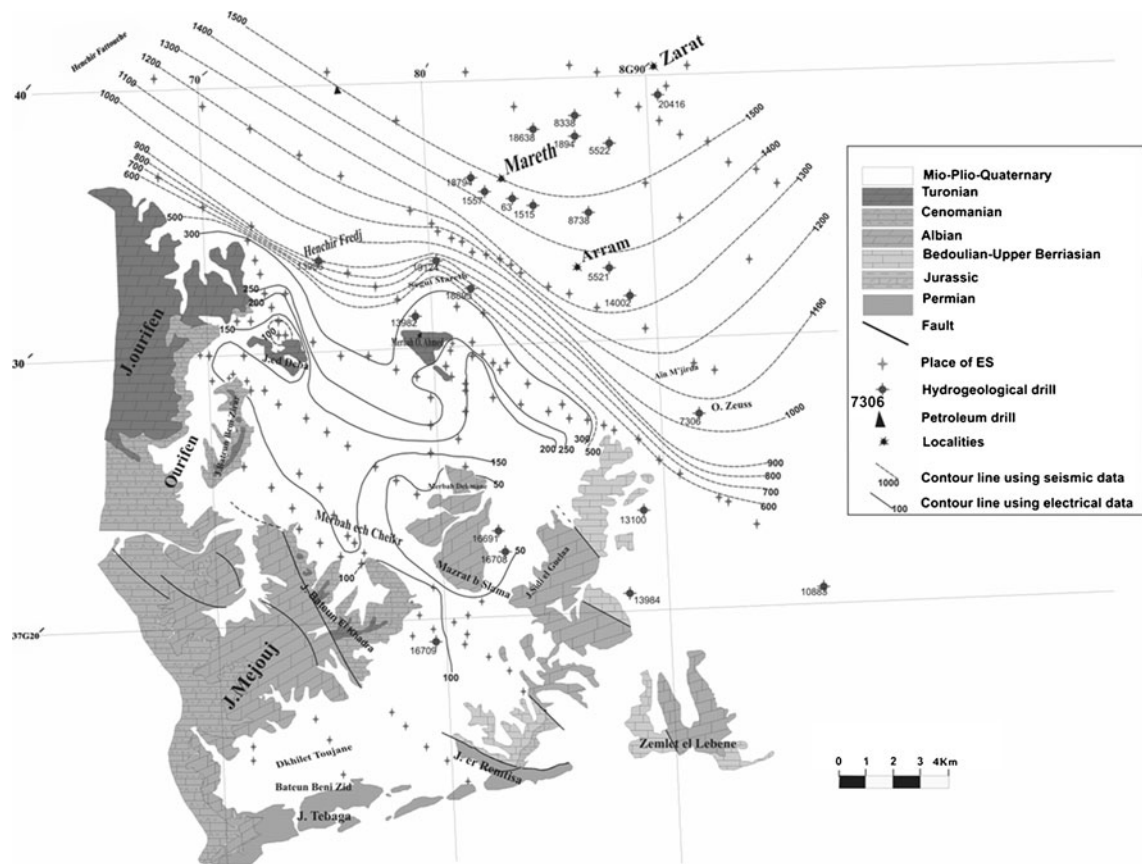


Fig. 11 Lower Cretaceous isobath map of the study area

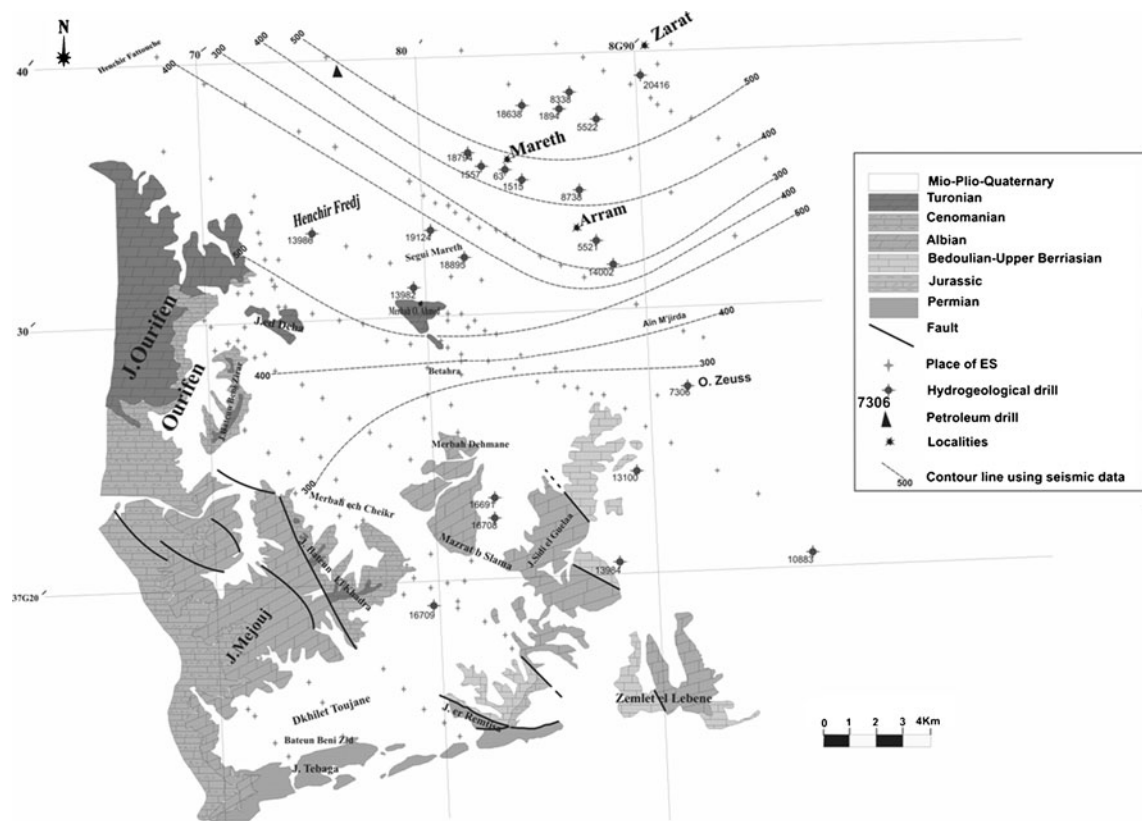


Fig. 12 Lower Cretaceous isopach map of the study area

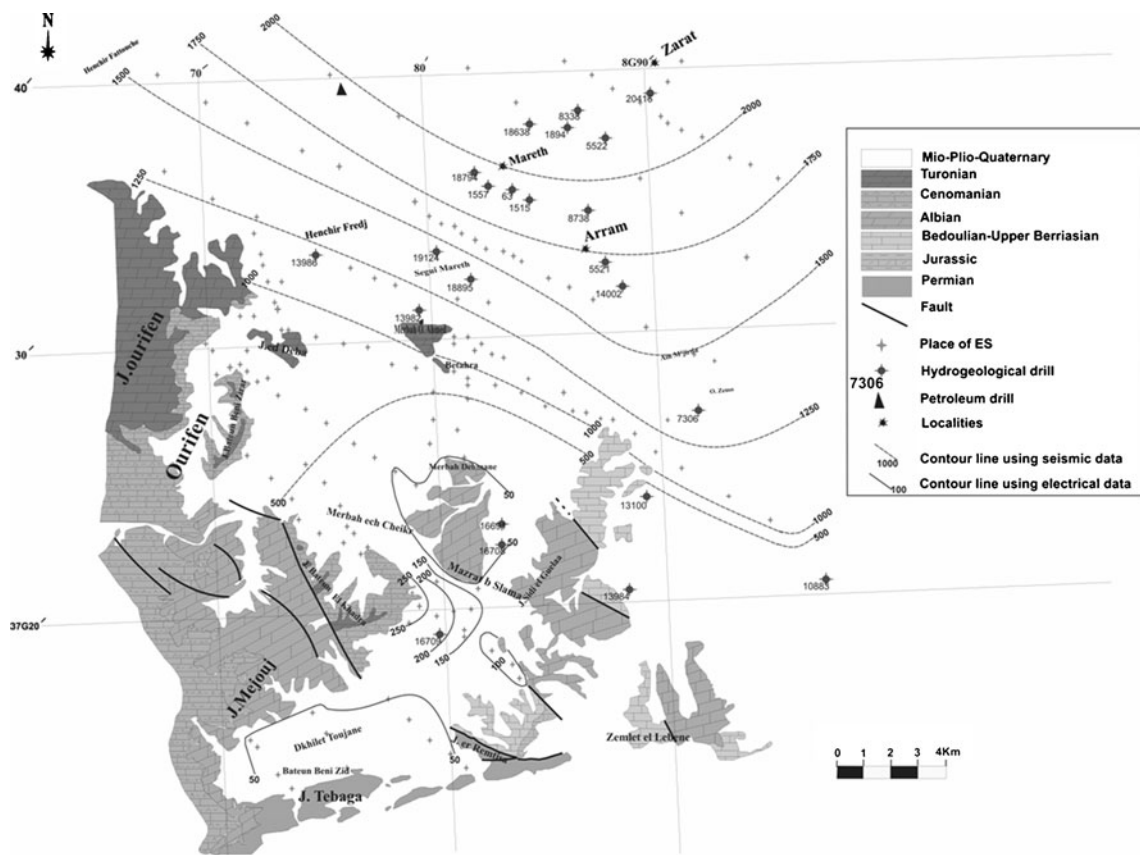


Fig. 13 Jurassic isobath map of the study area

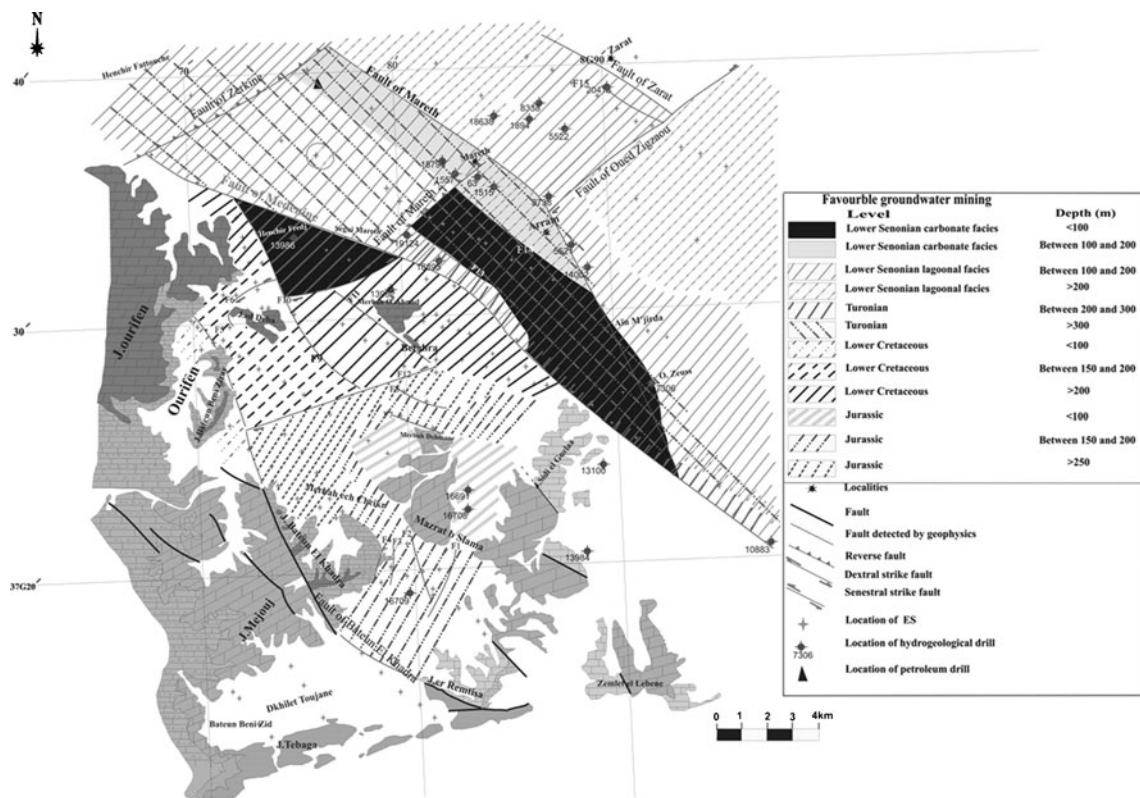


Fig. 14 Groundwater synthesis map of the southern part of Gabes

it is overlaid by a resistive marlstone level ($<8 \Omega\text{m}$) or a resistant carbonated level ($\geq 15 \Omega\text{m}$). The water mining from the lagoonal Lower Senonian aquifer should be focalized on favorable zones due to its lateral and vertical heterogeneity. Henchir Fredj and the downstream zone of Medenine fault seem to be suitable for this groundwater mining.

- The Turonian carbonate facies form an interesting aquifer due to its high resistivity and the important depth of its top. It can be abstracted at several locations at variable depths.
- The Lower Cretaceous constitutes a potential underground aquifer allowing water abstraction at variable depth.
- Quantitatively, the Jurassic still the main important target due to its high resistive dolomitic limestone facies which have good karst index. This aquifer can be drilled in several variable depth areas.

Conclusions

The Zeuss-Koutine and south Gabes groundwater bodies are contained in particular geologic domain in southern Tunisia. Their excellent groundwater potentialities are closely appended to their lithostratigraphic and structural configuration which allows profound and surface groundwater exchanges. The resistivity sounding is used to characterize resistive and resistant levels and gives precisions about the lithostratigraphy and the structure of the investigated area. So many privileged water prospecting targets, mainly due to their high karst index and their significant thickness, are identified such as The Lower Senonian carbonate facies, the lagoonal Lower Senonian, the Turonian carbonate facies, the Lower Cretaceous carbonate facies aquifer, and the high resistive dolomitic limestone facies of Jurassic.

This paper confirms some results of previous study and exposes new precisions about the lateral and vertical extents of the groundwater bodies of Zeuss-Koutine and south Gabes in southern Tunisia. It purposes also some favorable areas for groundwater mining.

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