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Tectonosedimentary framework of Upper Cretaceous–Neogene series in the Gulf of Tunis inferred from subsurface data: implications for petroleum exploration

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Abstract: The objective and the main contribution of this issue are dedicated to using subsurface data to delineate a basin beneath the Gulf of Tunis and its neighbouring areas, and to investigate the potential of this area in terms of hydrocarbon resources. Available well data provided information about the subsurface geology beneath the Gulf of Tunis. 2D seismic data allowed delineation of the basin shape, strata geometries, and some potential promising subsurface structures in terms of hydrocarbon accumulation. Together with lithostratigraphic data obtained from drilled wells, seismic data permitted the construction of isochron and isobath maps of Upper Cretaceous–Neogene strata. Structural and litho-stratigraphic interpretations indicate that the area is tectonically complex, and they highlight the tectonic control of strata deposition during the Cretaceous and Neogene. Tectonic activity related to the geodynamic evolution of the northern African margin appears to have been responsible for several thickness and facies variations, and to have played a significant role in the establishment and evolution of petroleum systems in northeastern Tunisia. As for petroleum systems in the basin, the Cretaceous series of the Bahloul, Mouelha and Fahdene formations are acknowledged to be the main source rocks. In addition, potential reservoirs (Fractured Abiod and Bou Dabbous carbonated formations) sealed by shaly and marly formations (Haria and Souar formations respectively) show favourable geometries of trap structures (anticlines, tilted blocks, unconformities, etc.) which make this area adequate for hydrocarbon accumulations.

Keywords: Gulf of Tunis, seismic, well data, isochron, isobath, petroleum system.

Introduction

The Gulf of Tunis is located in northeastern Tunisia (Fig.1), west of the Sicilian segment of the Apenninic–Maghrebian Orogen. The strata beneath the Gulf of Tunis constitute an off-shore basin that developed during the Neogene Africa–Europe collision (Dart et al. 1993; Lentini et al. 1996; Catalano et al. 2011). The geological history of this area is linked to the evolution of the North African margin guided by transtensional plate movements between Africa and Eurasia during the Mesozoic, followed by plate collision during the Neogene (Stampfli & Borel 2002; Brunet & Cloetingh 2003; Patriat et al. 2003; Laville et al. 2004; Abrajevitch et al. 2005; Dhahri & Boukadi 2010; Melki et al. 2010; Catalano et al. 2011; Roure et al. 2012; Masrouhi et al. 2014; Dhahri et al. 2015). The architecture of the Gulf of Tunis basin developed mainly during the Mesozoic, and then was greatly deformed during the Neogene leading to the inversion of extensional structures and to the redistribution of subsidence locations. As a part of Northern Tunisia, this area recorded the Early Mesozoic rifting resulting in the Tethys opening and created extensional structures such as horsts and grabens. Subsequent to the Neogene closure of the Tethyan Ocean, folding and thrusting occurred together within strike-slip movement and pull-apart basins to make complex structural configurations within the Neogene basins (Patriat et al. 2003; Roure et al. 2012).

After the first hydrocarbon discovery was made in the Jebel Abderrahman structure of the Cap Bon peninsula in 1948, northeastern Tunisia was an attractive area for hydrocarbon exploration and several international companies conducted several onshore and offshore exploration activities with the partnership of the ETAP (Entreprise Tunisienne d'Activités Pétrolières). On the basis of several seismic surveys and drillings, this exploration led to several offshore and onshore oil and gas discoveries in the Gulf of Hammamet and Cap Bon peninsula (Birsa, Yasmin, Tazerka, Belli). These discoveries were certainly a motivating reason for petroleum companies to enhance exploration activities in northeastern Tunisia. The recognized petroleum systems range from Mid-Upper Cretaceous to Tertiary series (Mejri et al. 2006; Craig 2009). The Albian–Turonian petroleum system is well-known in North and West Africa (Macgregor 1996; Luning et al. 2004). In Tunisia, this system comprises the Bahloul, Mouelha and Fahdene source rocks (Fig. 2). The Abiod Formation Campanian–Maastrichtian in age is documented as a chalky limestone fractured reservoir in northeastern and offshore Tunisia (Bishop 1988; El Euchi et al. 2002). It shows several accumulations within the Gulf of Hammamet (i.e. Dougga and Tazerka) (Craig 2009). The Eocene petroleum systems

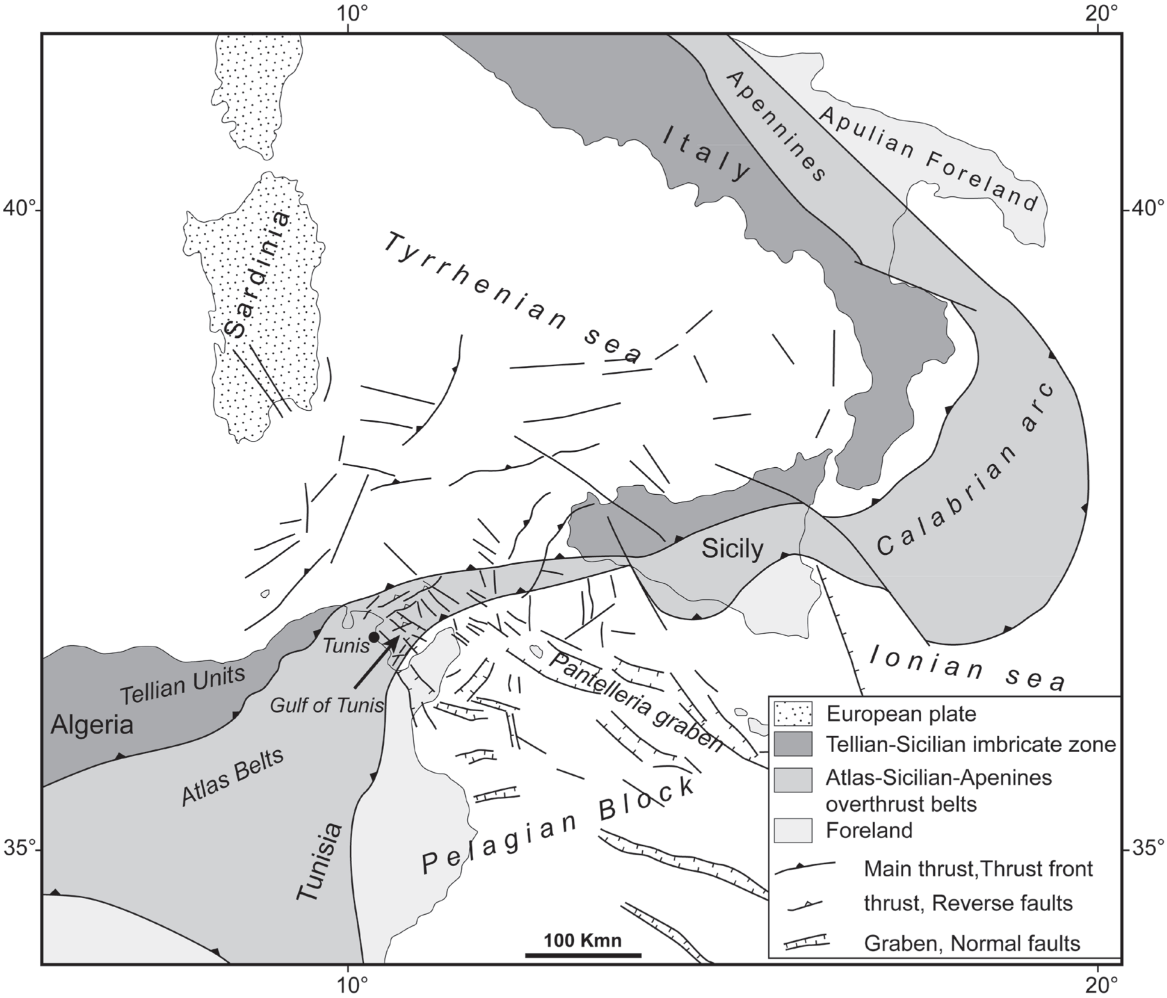

Fig. 1. Tectonic map of the central Mediterranean with main offshore structural features (modified after Ben Avraham et al. 1990; Sartori et al. 2001; Pepe et al. 2005; Mejri et al. 2006 and Melki et al. 2010).

comprises two reservoirs: the Halk el Menzel Formation Middle to Late Eocene in age and the Fractured limestone of the Bou Dabbous Formation Ypresian in age (i.e. Belli, Al Manzah and Beni Khalled fields onshore around Cap Bon). In the Gulf of Hammamet, the sandy Birsa Formation Miocene in age exhibits excellent reservoir quality and yields several oil fields (i.e. Dougga, Tazerka, Oudna, Birsa, Cosmos and Yasmin).

In the Gulf of Tunis, the presence of Cretaceous source rocks (Bahloul, Mouelha and Fahdene formations) and potential reservoirs (Fractured Abiod and Bou Dabbous carbonated formations) sealed by shaly and marly formations (Haria and Souar formations respectively and Late Eocene in age) (Fig. 2) with favourable geometries of trap structures (anticlines, tilted blocks, unconformities, etc.) make this area adequate for hydrocarbon accumulations. However, the fact that the structure of this area is complex and consistent regional structural and stratigraphic evaluations are lacking make its petroleum geology poorly understood. In this paper, we use offshore and onshore wells and seismic data to bring out new precisions on the tectonosedimentary evolution and basin configuration of the Gulf of Tunis with emphasis on its hydrocarbon potential.

Geological setting

The Gulf of Tunis and its onshore restrictions (areas of Bizerte, Tunis and the Cap Bon Peninsula) are located in northeastern Tunisia (Fig. 3), southeastward of the Tellian-Sicilian imbricate zone (Fig. 1). This domain represents the northeastern extension of the Atlas fold belt of Tunisia. It is tectonically complex and shows various structures which largely influenced the deposition since Mesozoic times (Ben Ayed 1993; Bédir et al. 1996; Melki et al. 2010). In this area, two main fault directions were highlighted; NE–SW thrust faults and NW–SE normal faults that delimit several subsiding grabens. In fact, these structures are comparable to these of the Atlas fold belt of Tunisia, and several structural features highlighted within the Gulf of Tunis can be clearly interpreted as offshore extensions of these known at its onshore restrictions as much as the Zaghouan thrust and the Grombalia graben.

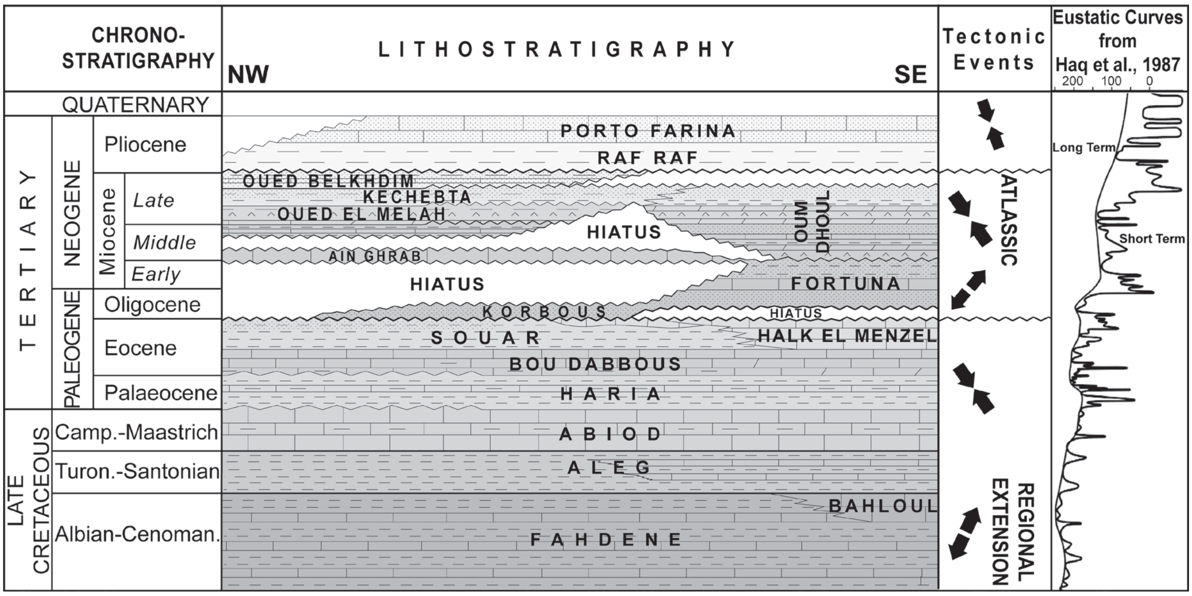

Fig. 2. Synthetic scheme of the Gulf of Tunis lithostratigraphy (from Late Cretaceous to Neogene) showing several Neogene hiatus and lateral facies variations.

Further to the northeast, this structural pattern seems characterizing regionally the Pelagian Sea with the remarkable NW–SE-oriented grabens of Pantelleria-Malta area (Boccaletti et al. 1990; Catalano et al. 1995; Accaino et al. 2011).

The Gulf of Tunis belong to the African continental margin between Sicily Island and northeastern Tunisia where the Meso–Cenozoic series consist of deep and shallow water carbonatic and terrigenous rocks designated as the Sicilian–Maghrebian units (Catalano et al. 1995; Pepe et al. 2005; Accaino et al. 2011). In this location, the analyses of the sedimentary sequence driven from well data, shows many tectonosedimentary events as well as stratigraphic gaps, unconformities, reworked rocks and fauna and thickness variations. The oldest crossed series are these of Middle to Late Triassic (Norian–Landinian) with carbonates and gypsum facies reached at the depth of 1080 m in the well 2 (Fig. 3) where they are unconformably overlaid by a Palaeocene series. The well 5 crosses more than 900 m of Cretaceous series (from 1400 m to 2361 m depth) (Figs. 4 and 5). These series are assigned to Hauterivian–Maastrichtian times and comprise four lithostratigraphic formations of open marine environment: the M’Cherga Formation (Valanginian–Aptian) made of marls, shales and limestones, the Fahdene Formation (Albian–Cenomanian) comprising shales, limestones and marls including the terminal horizon of the Bahloul facies made up of about 15 m of thin laminated organic rich limestone forming the top of the Cenomanian stage and acknowledged as an excellent source rock in north-central Tunisia, the Aleg Formation (Turonian–Santonian) made of marls and shales alternating with thin limestones layers, and the Abiod Formation (Campanian–Maastrichtian) dominantly made up of limestones with argillaceous basinal level.

The Abiod Formation is sealed by the open marine marls and shales of Haria Formation of Maastrichtian–Palaeocene age. The Lower Eocene series (Bou Dabbous Formation) consists of deep water dark micritic carbonates which is overlain by the Middle to Upper Eocene series made up of shales and marls (Souar Formation). This latter evolves eastward, to rich shelf carbonate facies with nummulitic limestones and dolomites (Halk El Menzel Formation) in the Pelagian Shelf (Bonnefous & Bismuth 1982). The Oligocene series overlay unconformably the Miocene ones. They display considerable thickness reduction and are absent in several localities (i.e. in wells 2 and 5) (Fig. 4). They are made of silstones, mudstone and sandstones forming a siliciclastic sequence acknowledged as Fortuna Formation assigned to Oligocene–Early Miocene age. Near the Cap Bon peninsula, the Oligocene series are made of rich fauna sandstone acknowledged as the Korbous Formation. The complete Neogene series begins with the Fortuna Formation succeeded by the siliciclastic Messiouta (Burdigalian), then the transgressive conglomeratic lumachellic Aïn Grab Formation (Burdigalian) (Ben Ismail-Lattrache & Bobier 1984) and Oum Douil group (Langhian–Messinian) (Biely et al. 1972). This latter is made of a mixture of sands, clays, gypsum and carbonates. It is commonly divided into several formations that fluctuate laterally to respective partial lithostratigraphic equivalents (Fig. 2). In the Gulf of Tunis Oum Douil group comprise an evaporitic sequence topped by carbonate strata Serravalian in age (Mellaha Formation) and a sequence of clays with carbonates (Kechabta Formation). To the north of the study area, petroleum wells cross a rich coquina sequence of grey shale with some sandy beds and gypsum acknowledged as Souaf Formation Serravallian–Early Tortonian in age (Burollet 1956). According to Burollet (1951), Pliocene series are mainly made of sands and sandstones with few intercalations of clays and carbonates. Near the Gulf of Tunis and the Bizerte coast they begin with an evaporitic unit called Oued Bel Khedim Formation followed

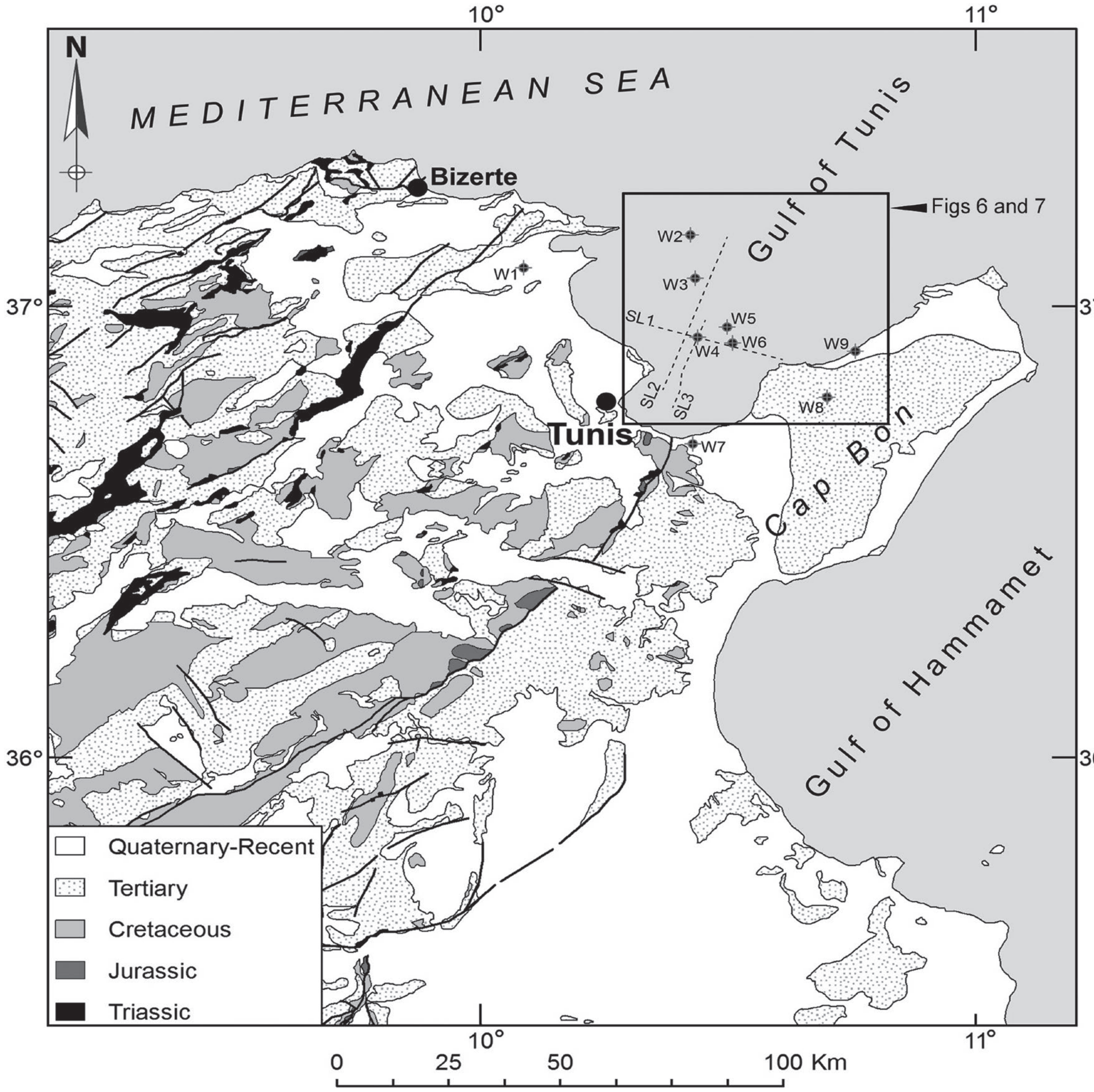

Fig. 3. Simplified geological map of northeastern Tunisia with location of used data: W1–W9: petroleum wells, SL1–SL3: seismic lines.

by a transgressive rich planktonic microfauna unit of grey shale Zanclean–Early Piacenzian in age (Raf Raf Formation). This latter contains locally a conglomeratic basinal level and some interbedded sandy lenses. It is overlaid by a shallow marine facies made of bioclastic calcareous sand with some clay intercalations (Porto Farina Formation) (Burollet 1951).

Data set and methodology

In the Gulf of Tunis several seismic sections and petroleum wells (Fig. 3) were carried out after geophysical surveys performed by petroleum companies. Seismic surveys have delineated several subsurface features and seismically mapped anomalies that deserve more recognition. It is why several wells were drilled in selected zones to explore some promising structures and reservoir targets and to calibrate seismic sections. For most of the drilled wells in the Gulf of Tunis, the fractured formations of the Campanian–Maastrichtian (Abiod) and the Eocene (Bou Dabbous) were the primary objectives of exploration. After the consultation of available subsurface data in the ETAP, petroleum wells allowed us to draw litho-stratigraphic columns used to correlate the lateral variations of facies and thickness and to calibrate seismic section. Seismic data are used to examine the structure of the study area and to draw isochron and isobath maps. Structural mapping has been the most important application of seismic data. Nevertheless, stratigraphic and structural interpretation of seismic lines consists in the selection of sets of seismic horizons on different wells to extract subsurface geological information. The structural interpretation of a complete seismic survey allows us to draw isochron maps commonly used for interpreting changes in thickness between interpreted horizons and to furnish 3D representation (X, Y, time) of the geological setting of the study area. Throughout the structural interpretation of seismic lines, the information on sediment velocities allows us to convert the isochron maps into isobath maps (X, Y, depth) (Rey & Galeotti 2008). These latter were produced by converting isochron maps using the velocity information derived from checkshot data. In this work, the compilation and treatment of data have been performed using the KINGDOM Software marketed by the software company Seismic Micro-Technology Inc. This tool let us to delineate and interpret several horizons in order to define and describe better the structural development of the study area. Formation tops from well data have been used for guidance in the seismic interpretation and isochron and isobath maps have been created for the top of the Bou Dabbous and Abiod formations by plotting the horizons corresponding to respective reflecting levels on the available seismic sections. These maps are used to give an idea of the structural configuration at depth (Majithia 1997). Four onshore petroleum wells (W1, W7, W8 and W9), five offshore ones (W2, W3, W4, W5 and W6) are used for calibration of 2D seismic sections (Fig. 3). W3 and W6 wells do not reach the Cretaceous series it is why they are not illustrated within the correlations. W3 reached the Upper-Middle Miocene series at a total depth of 2328 m. however W6 reached the Upper Eocene series at a total depth of 1418 m. Depth measurements are commonly referenced for all wells to the Rotary Kelly Bushing (RKB) which coincide with the depth origin “0 m” (Figs. 4 and 5).

Results and discussions

Lithostratigraphy and deposition

To understand the stratigraphy and the spatial variation of deposition of Late Cretaceous–Neogene series in the Gulf of Tunis, two correlation lines (Figs. 4 and 5) were drawn using both onshore and offshore petroleum wells along the N–S and WNW–ESE directions.

The N–S oriented correlation line (Fig. 4) starts from the offshore well 2 to the north, to the onshore well 7 to the south. However the WNW–ESE one (Fig. 5) starts from the onshore well 1 to the WNW to the onshore well 8 to the ESE near the northern coast line of the Cap Bon peninsula and passing by the offshore wells 4 and 6 (Fig. 2). These correlations show that to the north, ~1080 m thick of Palaeocene–Pliocene series overlay unconformably a thick Triassic salt body (from 1080 m depth to the final depth of 3705 m). In this locality, the Eocene series are absent and a hiatus is highlighted between the conglomeratic lumachellic carbonates of Aïn Grab and the clays of Haria Formation. Both 5 and 7 wells cross the Upper Cretaceous and Neogene series. They are (and so well 4) used for the description and the correlation of the Upper Cretaceous series. Based on the thickness and facies description, the Upper Cretaceous series seem to be less impacted by the tectonic and eustatic factors compared to the Neogene series. However three complete Upper Cretaceous formations are recognized within wells 5 and 7 (Fig. 5). The correlation of these formations shows that their amount of thickness increases from north (370 m in well 5) to south (520 m in well 7). This thickness variation can be interpreted as a result of tectonic activity during the Late Cretaceous. According to Melki et al. (2010) the thickness of Cretaceous series near the Gulf of Tunis shows considerable variation from 2341 to 477 m indicating high and low zones structures guided by faults. The thickness of the Abiod Formation increase from ~120 m in well 5 to ~256 m in well 7. This is indeed due to the tectonic activity but the fact that this formation ends with an erosion surface in well 5 make ambiguous the precision of the faults offset value. In fact, the eastern margin of the Tunisian domain was subjected to an extensional tectonic regime during the Cretaceous. The Early Cretaceous extension is a continuance of the Triassic–Early Cretaceous rifting known at Tethys scale and resulted in the occurrence of normal and strike-slip faulting, graben, subsidence, halokinesis and volcanism (Guiraud et al. 1987; Boccaletti et al. 1990; Laaridhi-Ouazza 1994; Laaridhi-Ouazza & Bédir 2005; Gabtni et al. 2011). However the Late Cretaceous extension is related to another rifting oriented NE–SW related to a tectonic motion between the African and Eurasian plates and responsible for NE–SW crustal extension and magmatism along NW–SE basement faults (Fairhead 1988; Guiraud & Maurin 1992; Guiraud et al. 2005). In eastern Tunisia, NW–SE extensional structures have been highlighted and are associated with a high geothermal gradient and numerous oil and gas fields (Laaridhi-Ouazza 1994; Laaridhi-Ouazza & Bédir 2005; Gabtni et al. 2011; Mattoussi-Kort et al. 2015). Given that the crustal extension of the eastern margin of Tunisia prevailed until the Late Cretaceous, it led to a basin configuration that was controlled the deposition of post-Cretaceous series as much as Ypresian ones.

The transgressive Haria Formation seems to be spread throughout the Gulf of Tunis despite a nearby uplifted area, where the Triassic bodies like as in well 1 where probably totally eroded. Based on well data that crosses this formation, its thickness ranges from 73 m in well 2 (partially eroded) to 245 m in well 5. This thickness variation is due to local total or partial erosion and to the inherited basin floor configuration characterized by high and low zones during the Late Cretaceous (Melki et al. 2010). Unfortunately, few wells crossed the total thickness of the Eocene series. The Lower Eocene series recognized in the offshore petroleum wells of the Gulf of Tunis show some similarity to the globigerina facies acknowledged for the Ypresian shaly limestones of north-central Tunisia. However, based on planktonic microfauna content the facies encountered within the offshore wells near the Gulf of Tunis seems to come from deeper water conditions with an open marine connection. The Souar Formation is crossed by three offshore wells (4, 5 and 6) in the central part of the Gulf of Tunis where its thickness does not exceed 152 m. However, in the onshore well 7 it reaches a thickness of 323 m (Fig. 5). In fact this Formation shows considerable thickness variations and it is topped by an erosion surface. It is missed in several localities (i.e. wells 1, 2 and 5), nevertheless, it can reach 800 m in the onshore Cap Bon area (Ben Ismail-Lattrache & Bobier 1984). The Oligocene series are generally missing in

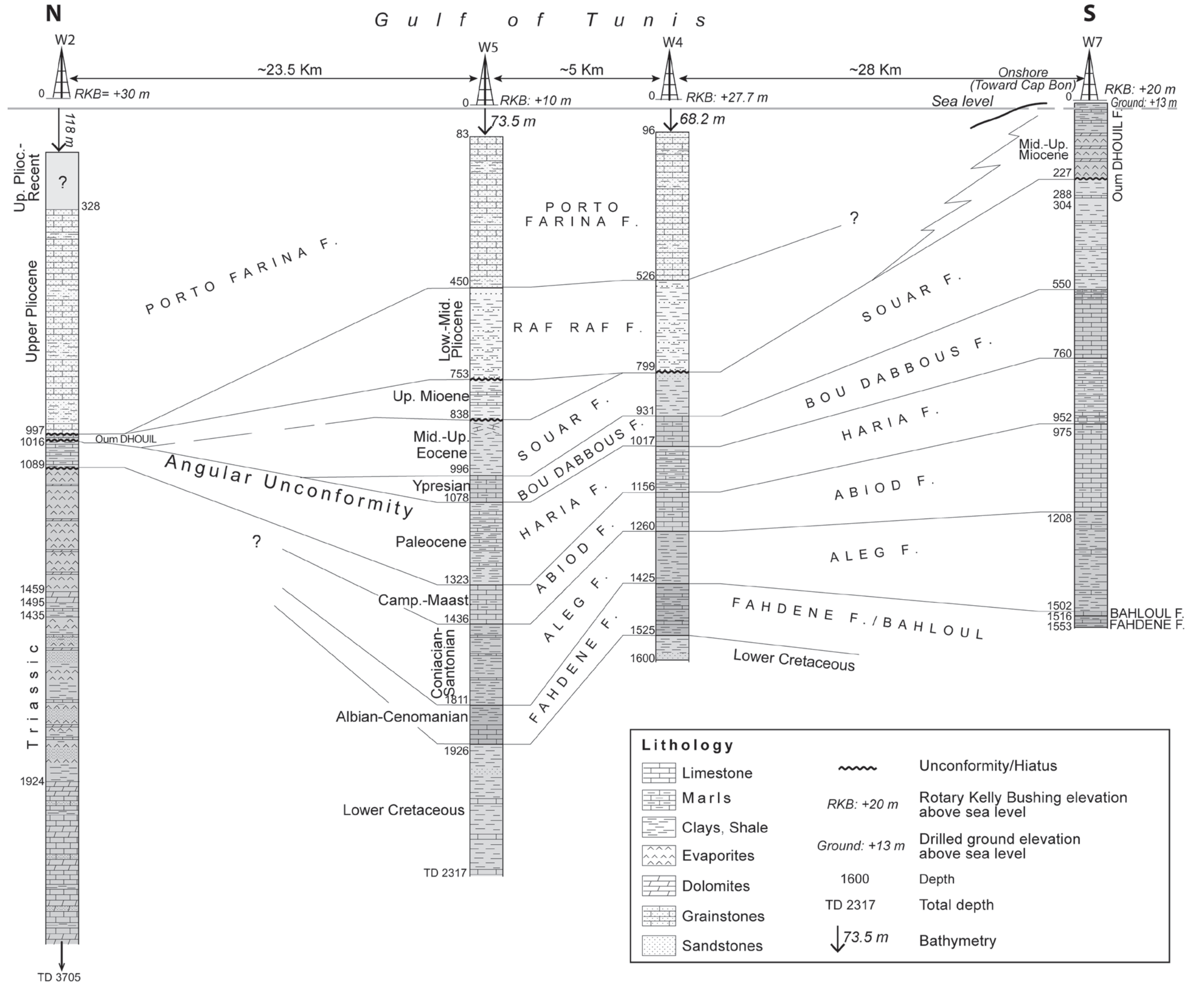

Fig. 4. N–S oriented correlation line showing that deposition is affected by halokinesis to the north of the Gulf of Tunis. However Upper Cretaceous to Eocene series correlates well in its central and southern parts.

the offshore wells of the Gulf of Tunis except in well 6 where they reach shallow marine facies 600 m thick (Korbous Formation). In fact, the gap of the Oligocene series is correlated to a regional hiatus highlighted for a large part of Tunisia (Burollet 1956; Yaich et al. 2000). Toward the Cap Bon, these series evolve into their siliciclastic equivalent of the Fortuna Formation (Fig. 2). The Oligocene deposition seems to be controlled by coeval tectonic activity responsible for a high zone to the northwest of the study area. The Miocene series also shows considerable thickness and facies variation from the northwest to the southeast of the study area with erosion at both basinal and top surfaces. The thickest series were crossed in wells 1, 3 and 8 with thicknesses of 1019 m, 1175 m and 711 m respectively. To the northwest, these series show a facies of marine marginal setting with fluvial sediments input. They are made up of four distinctive formations superimposed downwards as follow: Oued Bel Khedim, Kechabta, Oued El Melah and Mellaha (Fig. 5, W1). To the southeast and near the Cap Bon area, these formations evolve progressively into siliciclastic and shallow marine facies of Fortuna and Oum Dhouil formations. Farther, in the Gulf of Hammamet, the Miocene series comprises the so-called Birsa Formation Serravalian in age and made of a sequence of sands deposited within a shoreface to lower shoreface environment acknowledged as the dominant reservoir within this area (Portolano et al. 2000). In the central part of the Gulf of Tunis (well 3), the Late Miocene series are made of claystone and exceeds a thickness of 1170 m making it the thickest sequence known in this part of the Mediterranean and it seems to be tectonically controlled.

Based on wells data, the Pliocene deposition seems to be widespread in the Gulf of Tunis (Figs. 4 and 5). They occur with the two discernible facies of Raf Raf and Porto Farina formations described above. The Raf Raf Formation was deposited in privileged area extending from the northwestern part of the study area (near well 1) to the central part of the Gulf of Tunis near wells 3, 4 and 5 (Figs. 2, 4 and 5). In this area, the Raf Raf Formation maintains an average thickness near 300 m but it is absent to the southeast. However the Porto Farina Formation which overlays the Raf Raf Formation in

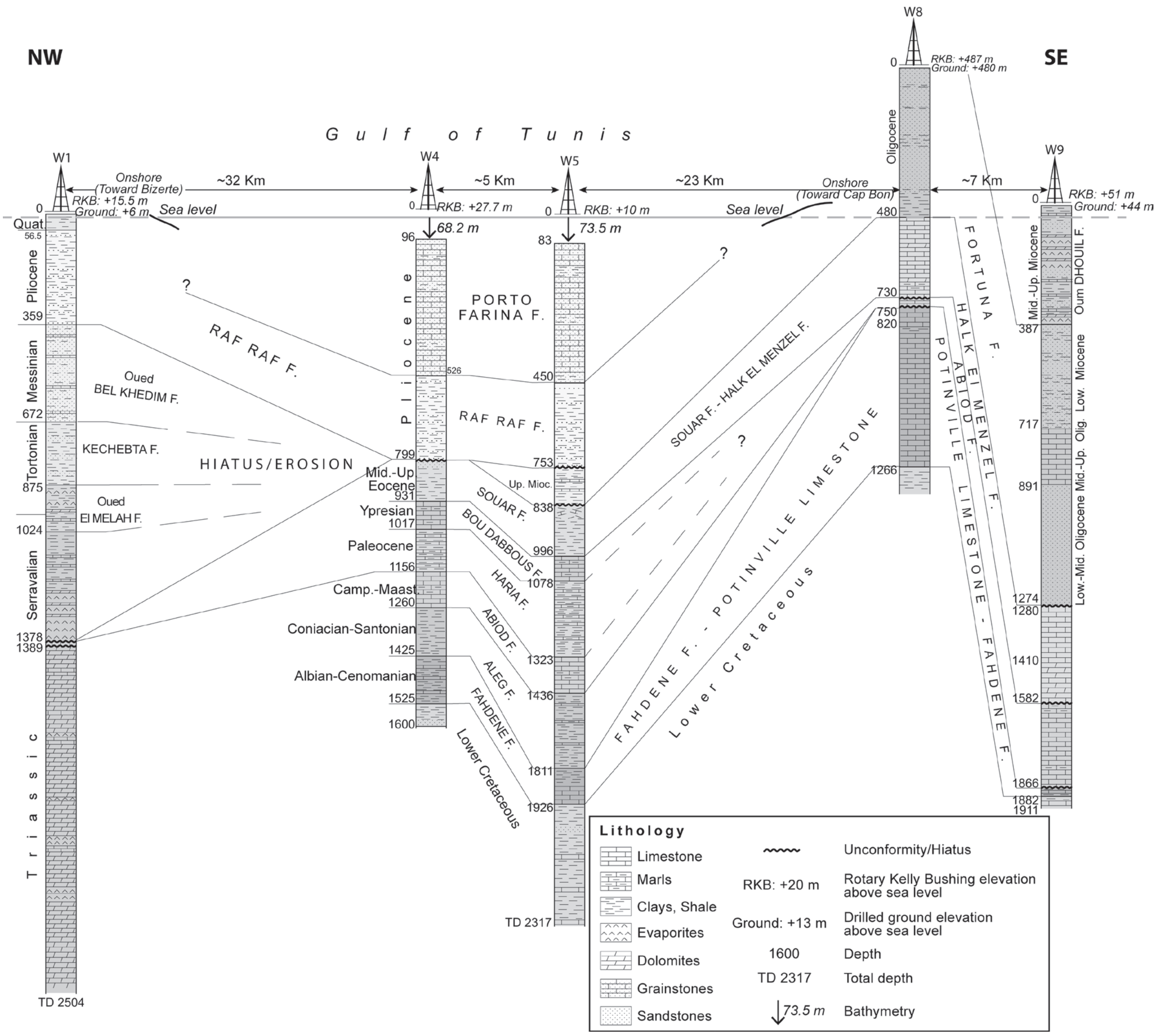

Fig. 5. WNW–ESE oriented correlation line showing significant facies and thickness variations from the northwest to the southeast borders of the Gulf of Tunis. Several hiatus and gaps are recorded especially within Tertiary series.

wells 4 and 5 occupies the northern and the central part of the study area and it exhibit considerable thickness variations (i.e. 669 m in well 2 versus 296 m in well 6). The crossed lithostratigraphic section in well 3 shows an abrupt lithological change and disappearance of fossils at the base of the Pliocene series which is interpreted as a stratigraphic hiatus.

Based upon thickness variations and facies analyses, the lithostratigraphic sequences of the Gulf of Tunis (at least from the Late Cretaceous) exhibit several local gaps, erosion surfaces, hiatus and subsiding zones. This configuration confirms the coeval eustatic and tectonic control on the sedimentation. This latter seems to have occurred on horst and graben structured basins where deposition and tectonics are coeval. This configuration is also documented by Melki et al. (2010) in northeastern Tunisia.

Structural background and hydrocarbon potential

The analysis of well data provided interesting information about deposition, facies and thickness variations along the study area. Based on that, some interpretations are attempted above. However wells give detailed control on borehole. This control is nevertheless local when we consider the lateral evolution of deposition specially in wide well spacing condition. This is why we attempt a mapping effort using seismic data to draw isochron and isobath maps. Isochron and isobath maps (Figs. 6 and 7) drawn for both tops of the Bou Dabbous and Abiod formations together with seismic lines (Fig. 8) are used to determine the structural configuration of the Gulf of Tunis area and to highlight the tectonic control of the deposition from Late Cretaceous to Neogene. These maps show that both Abiod and Bou Dabbous formations were deposited within a fault-assisted basin with horst and graben structures delineated by three main fault directions NE–SW, NW–SE and E–W. This structural configuration in horsts and grabens explains the remarkable variations in thickness of the deposition described above.

Concerning the top of the Abiod Formation (Fig. 6), a zone of maximum depth is defined approximately by the 1.7 second isochron (Fig. 6a) matching with a depth exceeding 2250 m below sea level. In the middle and southern parts of the Gulf of Tunis, this zone is made up of several graben structures enclosed by NE–SW and NW–SE abrupt foredeep wedges. However, it seems to be limited by gentle sea floor slope to the northeast of the study area (Fig. 6a). Out of this zone (less than 0.8 second), the Abiod Formation is overlain by a relatively thin post-Cretaceous deposition (less than 1500 m) (Fig. 6b). This occurs along the offshore part of the study area and

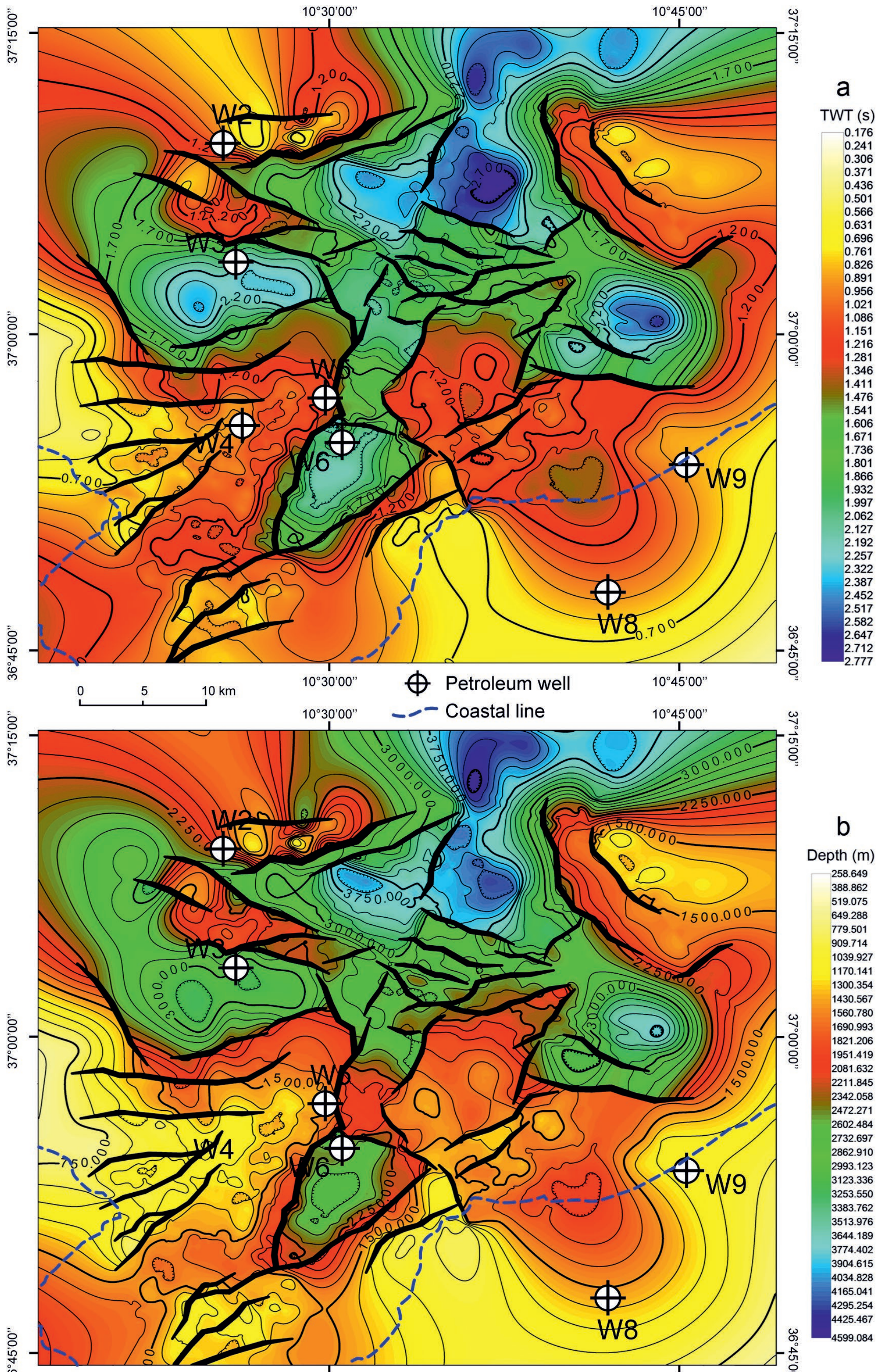

Fig. 6. Isochron and isobath maps of the Abiod Formation top showing the structural configuration of the Gulf of Tunis with the main subsiding area during the Late Cretaceous.

Cainozoic palaeohighs mainly made of horst, tilted blocks and Triassic bodies (Melki et al. 2010). Concerning the Bou Dabbous Formation (Fig. 7), the subsiding zone and palaeohighs match almost with these highlighted for the Abiod Formation (Fig. 6). However, slopes and wedges between distinct blocks seem to be gently amortized compared to these observed for the top of the Abiod Formation. In addition, the NE–SW fault system is less expressed. The zone of maximum

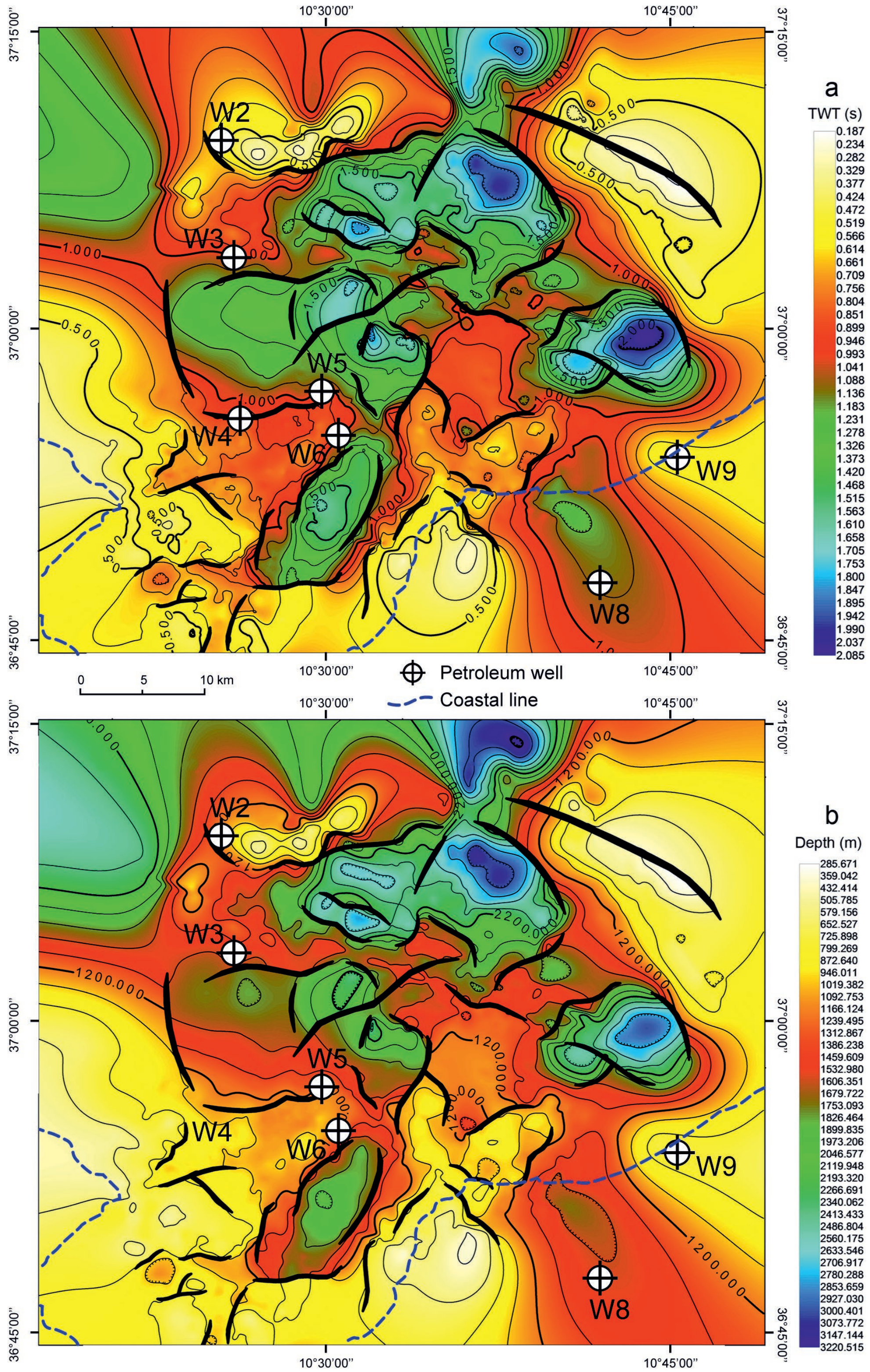

Fig. 7. Isochron and isobath maps of the Bou Dabbous top showing the structural configuration of the Gulf of Tunis with the main subsiding area during the Early Eocene.

depth is defined approximately by the 1.5 second isochron matching with a depth exceeding 2000 m below the sea level. This zone delimits several depocentres that coincide with graben structures. This implies a continuous tectonic control guided by the same fault system responsible for the structural configuration of the Gulf of Tunis as described by Melki et al. (2010).

Several seismic lines were considered to map the tops of the Abiod and Bou Dabbous formations. Three seismic lines (SL1, SL2 and SL3) are presented in Figure 8. Given that the main significant faults controlling the structural configuration of the Gulf of Tunis are arranged within two main perpendicular directions NE–SW and NW–SE, we choose to present respectively interpreted NW–SE and NE–SW-oriented seismic lines that crosses near the centre of the Gulf of Tunis, to intersect the maximum of structural features (Fig. 8).

The NW–SE-oriented seismic line (SL1) (Fig. 8a) shows that the thickness of post-Cretaceous deposition increases to the east toward a deep depocentre delineated by several subvertical normal faults. This depocentre coincides with the eastern graben structure shown on the isochron and isobath maps of Figures 6 and 7. The western and eastern sides of this graben can be considered as palaeohighs with thin Upper Cretaceous–Lower Eocene deposition. This thickness decrease is due to the tectonic control amplified by halokinesis and erosion as highlighted for the Abiod Formation to the northwest of the study area within the offshore well 1. The post-Ypresian deposition records some compressional events especially above main normal faults in testimony of their Neogene inversion as occurred in the Northeastern Tunisia and the Pelagian province after the Africa–Europe convergence (Morgan et al. 1992; Guiraud 1998; Piqué et al. 1998; Brunet & Cloetingh 2003; Melki et al. 2010; Dhahri & Boukadi 2010; Dhahri et al. 2015). However, these deformations are sealed by an uppermost horizontal level Pliocene–Quaternary in age suggesting a low angle unconformity above the deformed zone (Fig. 8).

The first SW–NE-oriented seismic line (SL2) (Fig. 8b) shows an asymmetrical graben structure to the north, limited by a steeper slope on its northern side affected by subvertical NE–SW faults, whereas the southern side shows gentler scarps. This graben constitutes a depocentre in which Maastrichtian–Ypresian deposition is relatively thicker than on both sides regarded as Upper Cretaceous palaeohighs. The middle part of this seismic line also has a prograding-slope toward the north on which the post-Ypresian series are deposited. This slope is associated with erosion surfaces.

The second SW–NE-oriented seismic line (SL3) (Fig. 8c) is parallel to SL2 (Fig. 3). This line ends toward the north without crossing the illustrated graben structure northern SL2 (Fig. 8b). However, it illustrates well the progradation and erosion highlighted on the southern side of the graben structure within SL2. In fact, along the prograding-slope a significant angular unconformity is well illustrated: the shales of Souar Formation overlays unconformably the Eocene to Upper Cretaceous series respectively from south to north. This configuration is favourable for the occurrence of unconformity traps within dipping strata of the Bou Dabbous and Abiod fractured limestones when they are truncated by overlying bedded sealing lithology as much as the Souar Formation. In such condition, these unconformities have good prospects for hydrocarbon accumulation.

Conclusions

Seismic interpretation, isochron and isobath maps together with well data show that the Gulf of Tunis is affected by three main fault systems with NE–SW, E–W and NW–SE directions (Figs. 6 and 7). These fault systems acts together to create an irregular network of juxtaposed tectonic blocks with markedly different lithostratigraphic sequences. The deposition rates depend largely on the amount and the sense of the fault offset bordering each block. The Cretaceous tensional tectonic regime is responsible for the establishment of horst and graben structures which controlled later deposition within the Gulf of Tunis until Ypresian times. At least four depocentres limited by uplifted areas are prefigured since the Cretaceous and prevailed until the Ypresian (Fig. 7). It is why the Upper Cretaceous–Ypresian deposition records remarkable thickness and facies variations with several unconformities, gaps and erosion along palaeohighs and uplifted blocks versus thick sequences near the graben structures. The seismic lines show moderate Neogene shortening events responsible for gentle folds and inversion of some previous normal faults especially near the depocentres borders (Fig. 8).

Indeed, the principal targets of the drilled wells in the Gulf of Tunis were the Eocene Bou Dabbous and the Upper Cretaceous Abiod formations. Unfortunately no significant oil reserves were encountered within these formations in all studied wells. But there are certainly promising hydrocarbon reservoirs in northeastern Tunisia. This area comprises several petroleum systems within Mid-Upper Cretaceous to Tertiary series (source rocks of Bahloul, Mouelha and Fahdene formations, fractured reservoir of Abiod, Bou Dabbous and Halk el Menzel formations, siliciclastic reservoir of Birsa Formation). The real challenge is to understand the structure and the lithostratigraphy of Cretaceous–Neogene series within this area to reveal adequate zones for hydrocarbon accumulations. Based on the interpretations highlighted within this paper, it seems that the tectonic control widely conditioned the petroleum geology in northeastern Tunisia. It is why structural surveys should be done with more care and with emphasis on halokinesis to enhance our knowledge of petroleum systems in this area.

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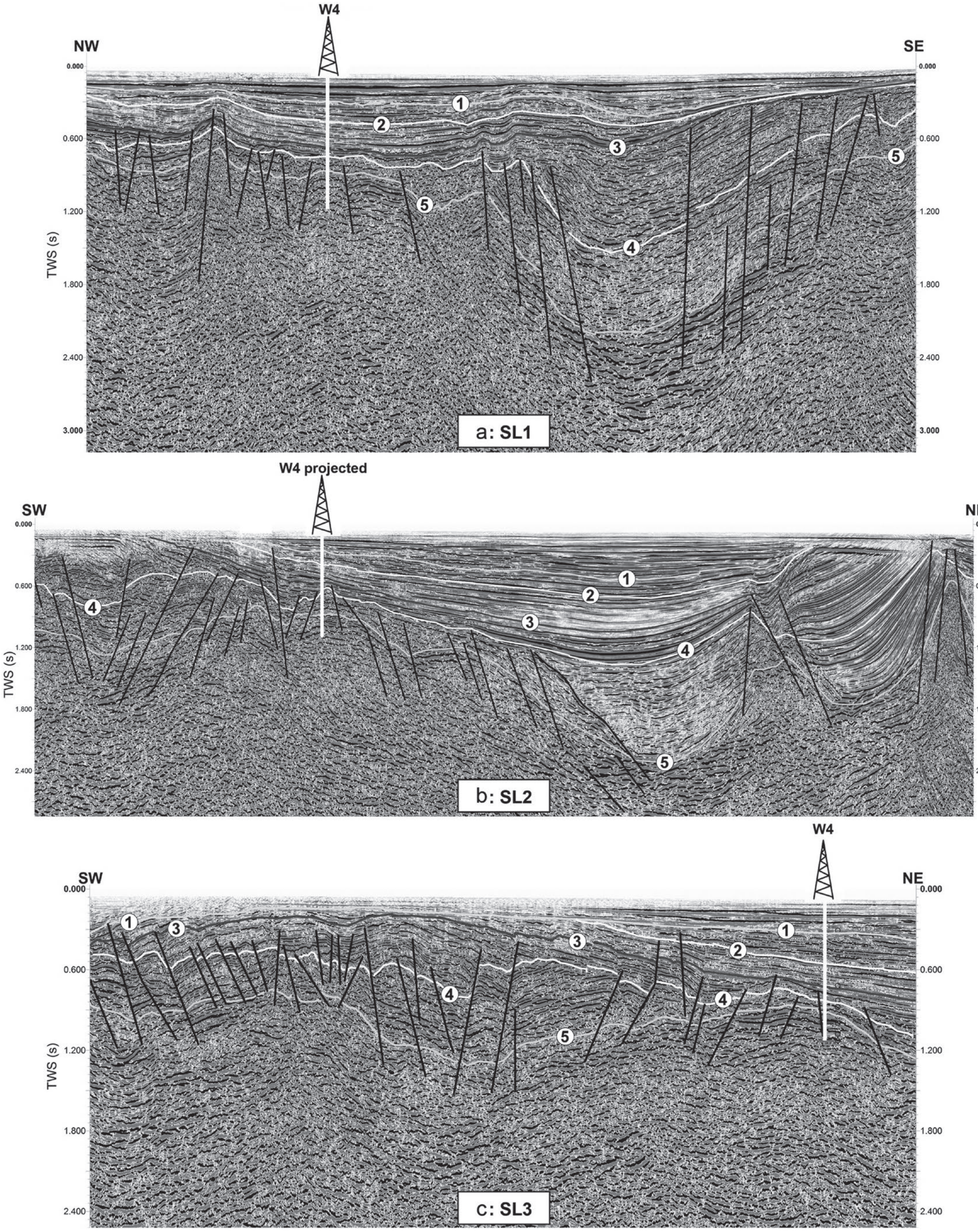

Fig. 8. Seismic lines showing the main structures of the Gulf of Tunis with the tectonic controls of deposition and thickness variations since the Late Cretaceous. 1 — Top Porto Farina Formation, 2 — Top Raf Raf Formation, 3 — Top Upper Eocene series, 4 — Top Ypresian series, 5 — Top Cretaceous series, black lines — faults.

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