The petroleum system of the Oudna field (offshore of northeastern Tunisia) in the geodynamic context of Sicilian-Tunisian Strait

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Abstract

The Oudna field part of the offshore northeastern Tunisia, straddles between two structural domains, the Tunisian Atlas to the north and the Pelagian Sea to the south. The study of this field has confirmed adequate petroleum system in Fahdene Formations (Albian-Cenomanian) and Birsa (Serravallian) resulting from the combination of several sedimentary, tectonic and thermal factors. To do this, we have identified on the different seismic profiles the horizons corresponding to the top of the tertiary formations. As a result, the isochron and isopach maps of these horizons that have shown the existence of three network faults represented by two main directions of NW-SE and NE-SW and a minor EW direction. The distribution of hydrocarbon indications in boreholes is controlled by NW-SE faults (pervious) and NE-SW faults (sealing). These lineaments are the result of the Alpine tectonics (Atlasic in Tunisia) which played a very important role in the structuring of the Gulf of Hammamet. During the Tortonian phase (NW-SE maximum horizontal stress), the region was characterized by reverse kinematic NE-SW faults and normal NW-SE faults contributed to structuring a hydrocarbon traps, associated with NE-SW trending faults. In Plio-Quaternary, the NW-SE grabens (as continental rift Pantellaria part of the Sicily Channel) were formed and associated with an alkaline volcanism. These grabens are the result from the migration of the subducting plate (slab) from west to east, at the Tyrrhenian Sea.

Keywords: Petroleum potential, Serravallian reservoir, Seismic data, Oudna field, North Eastern Part of Tunisia.

Résumé:

Le champs de Oudna faisant partie de l'offshore de la Tunisie nord orientale, est situé à cheval entre deux domaines structuraux, l'Atlas tunisien au nord et la mer pélagienne au sud. De nombreux travaux de recherches pétrolières par sismique réflexion et sondage profonds ont été réalisés en Tunisie orientale. La présente étude concerne l'interprétation des données sismique et des puits pétrolières qui a confirmé un système pétrolier adéquat dans les formations Fahdène (Albien-Cénomanien) et Birsa (Serravallien) résultant de l'association de plusieurs facteurs sédimentaire, tectoniques et thermiques. Pour ce faire, nous avons identifié sur les différentes sections sismiques les horizons correspondant au toit des formations tertiaires. Elaborée en conséquence, la carte en isochrone et en isopaques des ces horizons qui ont montré l'existence de trois réseaux de failles dont deux principaux de directions NW-SE à jeu normales et NE-SW à jeu inverses et un de moindre importance de direction E-W inverse. La répartition d'indices d'hydrocarbures dans les forages, est contrôlée par les failles de directions NW-SE (non étanches) et NE-SW (étanches).

Cette fracturation est le résultat de la tectonique alpine (Atlasique en Tunisie) qui a joué un rôle très important dans la structuration de cette zone du Golfe de Hammamet. Durant la phase de serrage tortonienne (contraintes compressives de direction NW-SE), la région a été caractérisée par des jeux inverses des failles NE-SW et des jeux normaux de celles NW-SE. Ceci a conduit à la formation de pièges structuraux d'hydrocarbures liés aux failles de direction NE-SW. Au Plio-Quaternaire, se sont formés des grabens de direction NW-SE (comme le rift continental de Pantellaria faisant partie du canal de Sicile) subsidents et associés à un volcanisme alcalin. Ils résultent de la migration de la plaque subduite (slab) de l'ouest vers l'est, au niveau de la mer tyrrhénienne.

Mots clés: Potentiel pétrolier, Réservoir serravallien, Données sismiques, Champ de Oudna, Tunisie nord orientale.

1- Introduction

Study area is located in the Gulf of Hammamet, located in the northeastern -part of Tunisia, 80 km east of the city of Nabeul (Cap Bon) and 30 km SW of the Italian island of Pantelleria, covering an area of 420 km2 an average water-depth of about 300 meters. Geologically, the study area is located astride a deformed area of the Tunisian Atlasic to the north and the Pélagian sea, characterized by rifts even continental rifts (Corti et al., 2006; Capitano al., 2011; Belguith et al., 2013) (Fig. 1). The continental rift of Pantellaria belonging to the Sicilian Channel is located adjacent NE of the study area. Study area is characterized by faults and folds with a NE-SW trend and grabens NW-SE trend (Fig. 2).

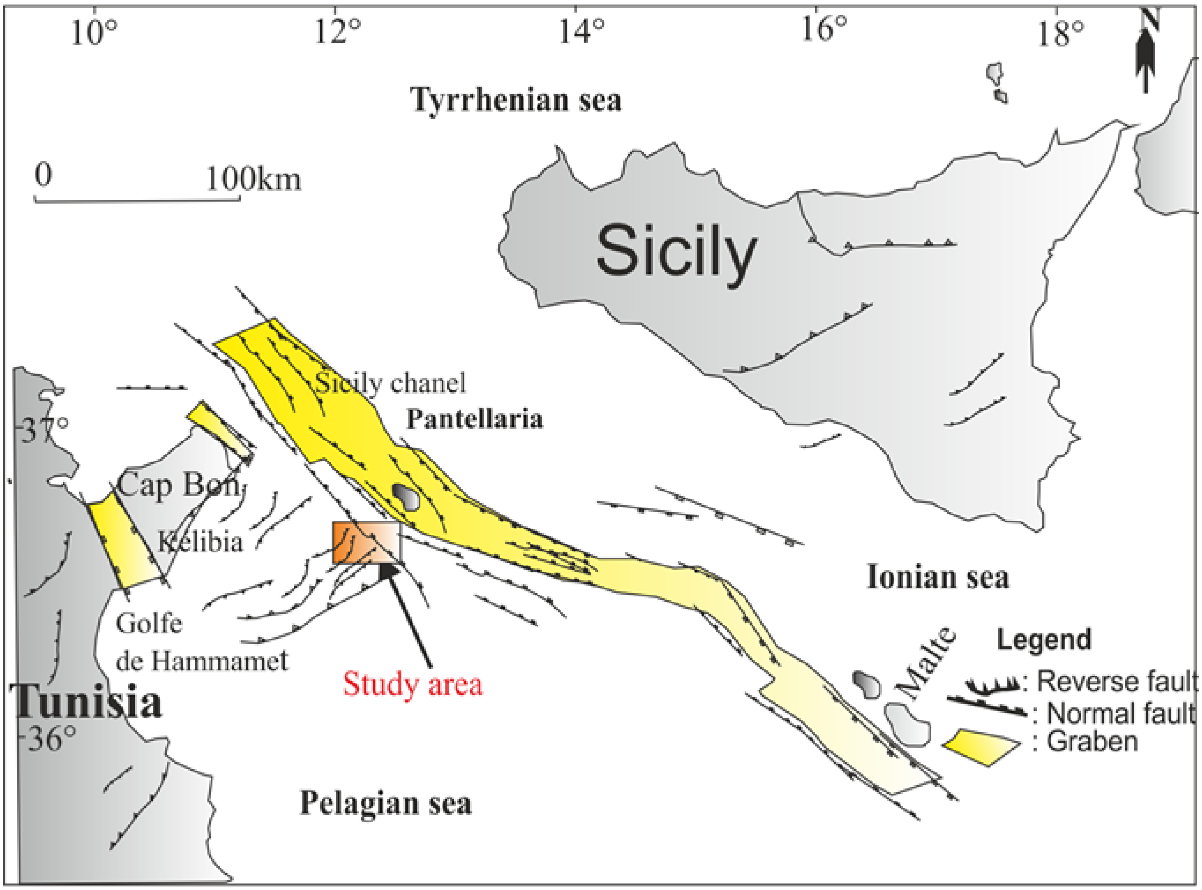

Figure 1) Structural map of the Sicilian-Tunisian Strait (Casero and Roure, 1994). Study area is indicated by an orange square.

The deep structure of the north eastern Tunisia is poorly known, due to both limited number of wells that reached this target and the generally poor quality of seismic profiles. And the relation between and sedimentary tectonic features and their impact on reservoir geometry has not been studied.

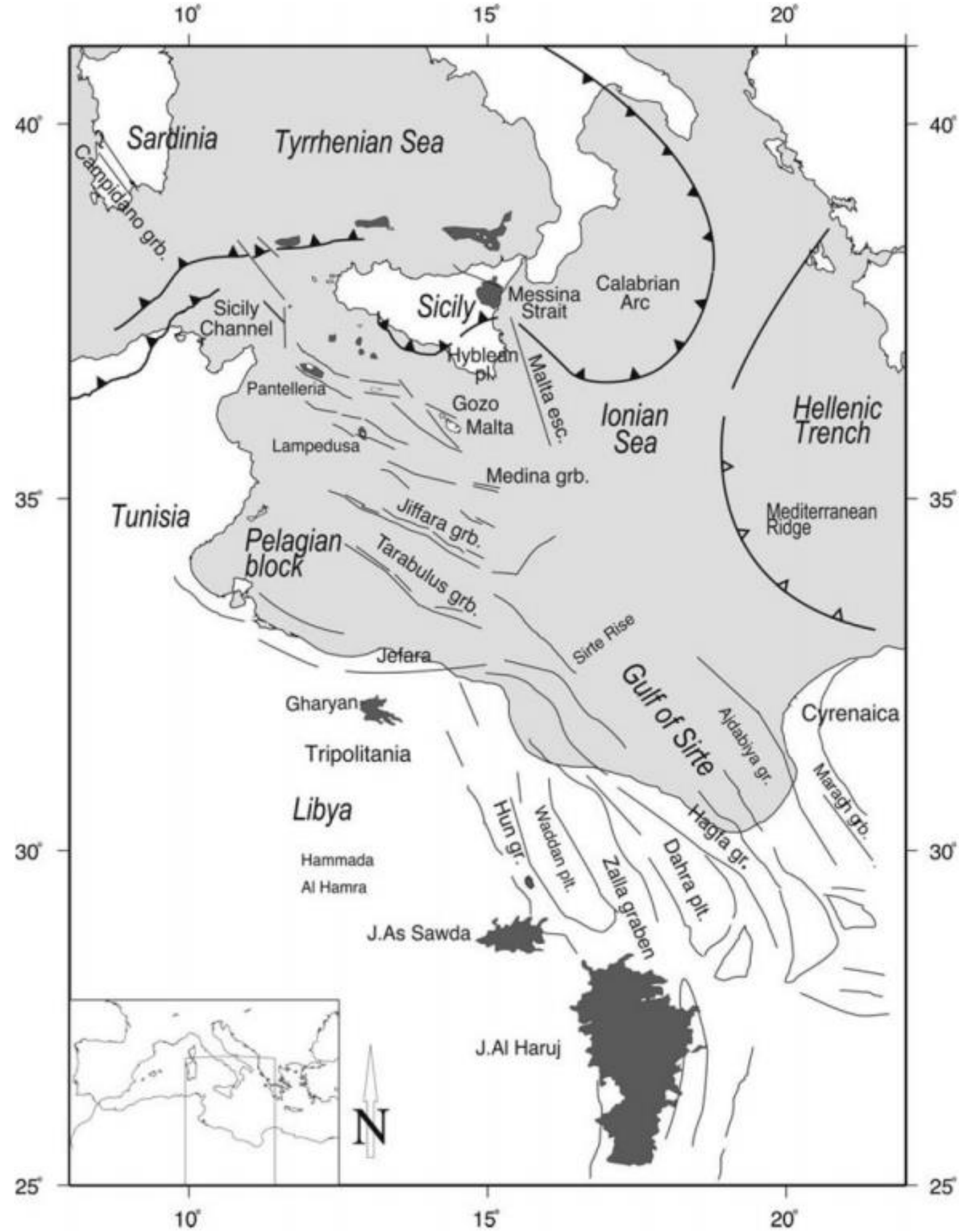

Figure 2) Tectonic map of Central Mediterranean Sea and Tripolitania–Sirte Basin, Libya. Grey areas represent volcanism, thin lines major lineaments, thick lines collisional fronts (Anketell, 1992;Finetti (1984).

This paper aims to study the petroleum system of the Oudna field from the combining analysis of geological and geophysical data, thus giving a description of the tectonic evolution, the role played by fault systems in the drainage and formation of structural traps of hydrocarbons.

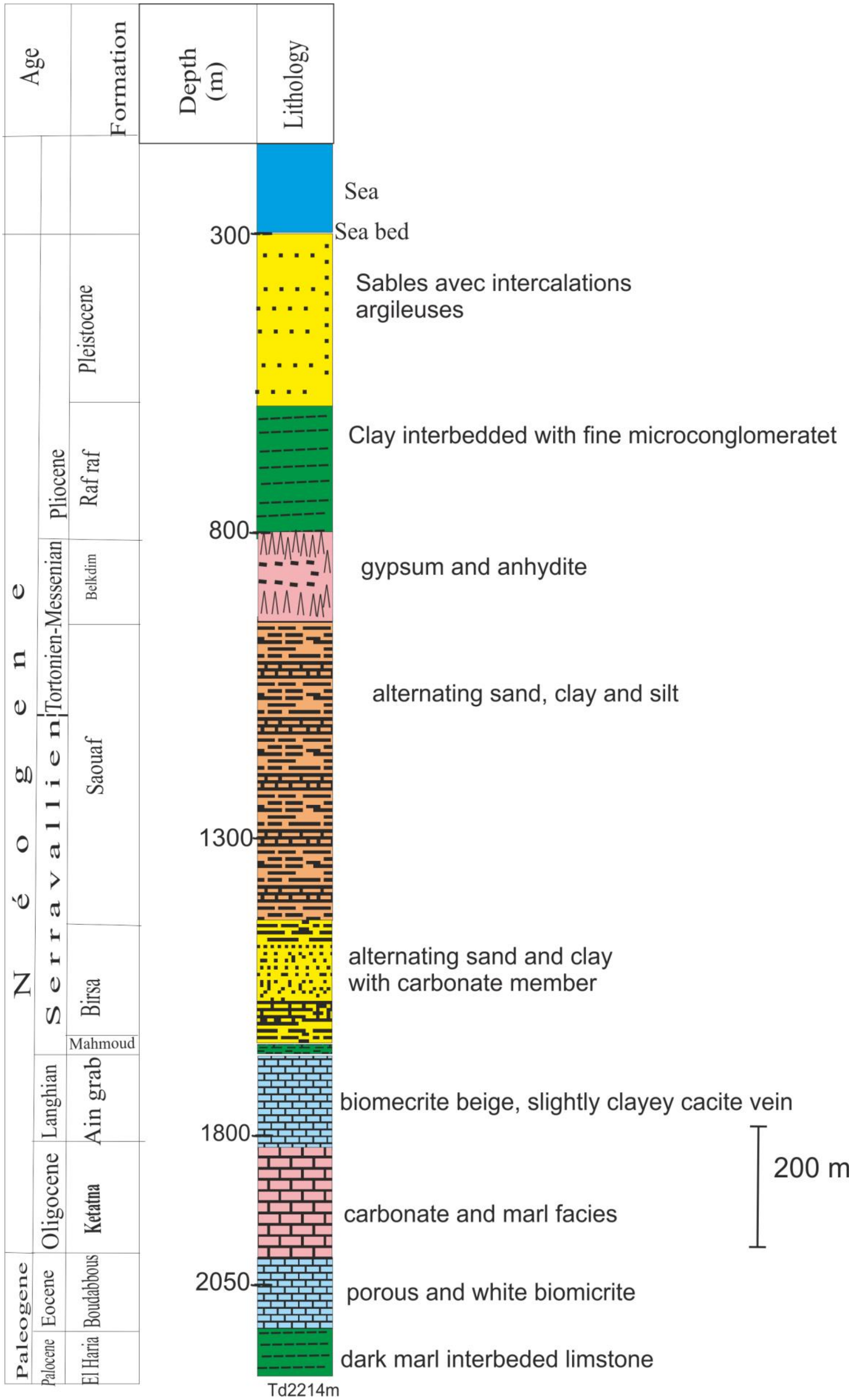

Figure 3) Lithostratigraphic Log of Well P1 in the Oudna field.

The geological study Well data were correlated in order to map the lateral and vertical distribution of the analysed stratigraphic series. The geophysical study involved the interpretation of seismic lines identifying the major reflectors corresponding to the formations tops. In the second step we characterize on seismic the major faults and trying to define their influence on the structuring of the area, the migration and trapping of hydrocarbons.

2- Methods

This study, based on the seismic interpretation of sections calibrated with data from wells which consist of lithostratigraphic logs from five wells that have reached the Jurassic Nara formation, allows following the lateral and vertical variation of sedimentary series, to determine the tectonics effect and reconstruct during of geological time, structural evolution in the study area. The third type of data to be used is the borehole logging data which indicates the basic parameters in the Serravalian Formation as the porosity (fluid-filled portion of the rock); the water, oil and gas saturations and the vertical extent of a productive hydrocarbon zone, or net pay In fact, with the seismic interpretation technique, we can better understand the nature of the identified tectonic event and its impact on the formation of hydrocarbon traps through the fault planes.

3- Geological and geophysical data

3.1- Lithostratigraphic analysis of the study area

Lithostratigraphic data, presented in this work, are derived from five wells that have reached the Jurassic Nara Formation, as the older series (outside the Oudna permit). In the Oudna permit, five wells (P1 (2214 m), P2 (2080 m), P3 (1640 m), P4 (1708 m) and PN (2343 m)) (Fig. 3) crossed the sedimentary following series, from the oldest to the youngest (Fig. 4):

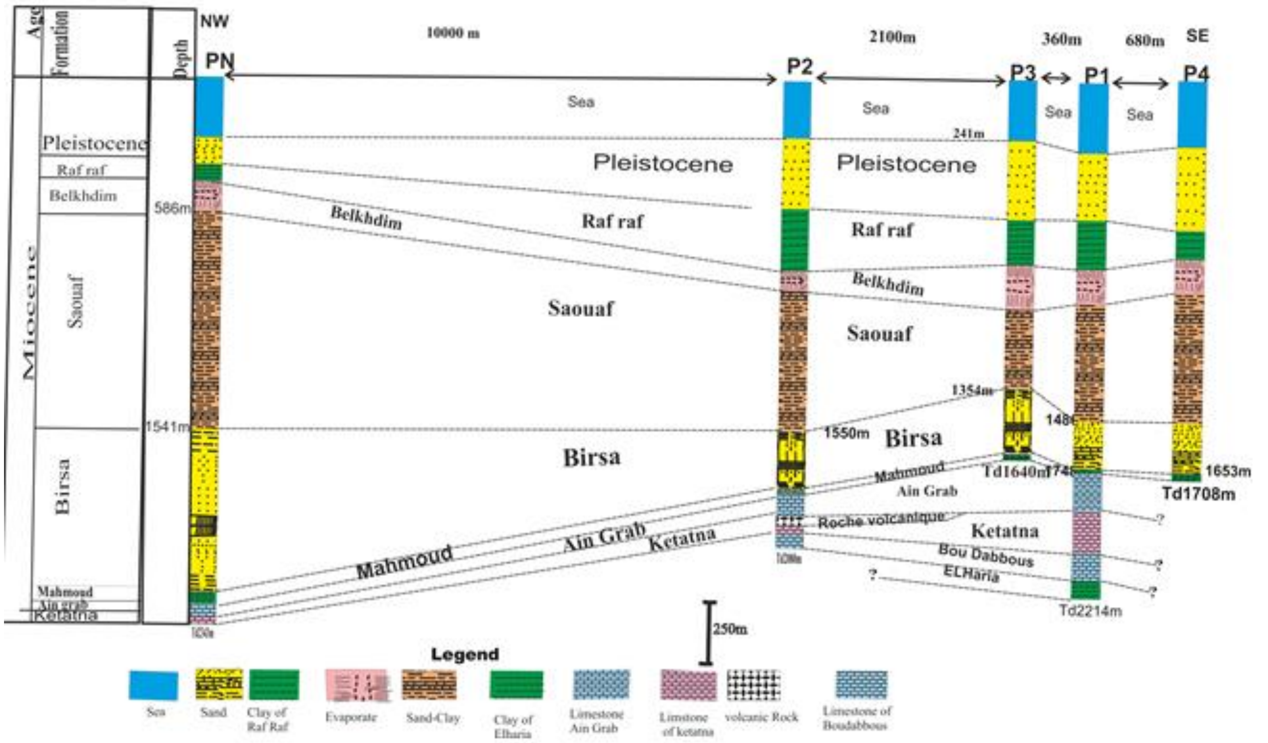

Figure 4) Lithostratigraphic log correlation between wells along north to south profile (in the Oudna field, reference= 0 marine).

-El Haria Formation (Paleocene-Middle Maastrichtian) is composed of a marl facies dark gray clay, rich in formanifera of the Globorotalia velascoensis species is plentiful (Burrollet, 1956);

- The Boudabbous Formation (Ypresian) is formed of porous white biomicrite, micrite brown clay and beige biomicrite, rich in-Globigerinae and Globorotaliae (Tayech, 1991);

- The Ketatna Formation (Oligocene) is represented by a carbonate facies with algea and large benthic foraminifera such as Nummilites, Echinoids and Pectinidae. (Bismuth, 1973);

- Ain Ghrab Formation (Langhian) is formed of a sandy-carbonate facies (Burollet, 1956);

- The Mahmoud Formation (Upper Langhian) is clayey and is traversed by all wells its thickness does not exceed some meters (Burollet, 1956);

- The Birsa Formation (Serravallian) is composed of a sandy facies interbedded with clay and it is recognized in the wells in the Gulf of Hammamet at varying depths of 1423 m (P4) to 1720.80 m (P2). It is the lateral equivalent of the Beglia Formation outcropping in Cap Bon (Ben Salem, 1992). Its good petrophysical parameters (porosity of approximately 25% and permeability is about 1 darcy) and its position relative to the impermeable seal layer, make it a very important reservoir of the petroleum system in the Gulf of Hammamet in general and in the Oudna field in particular;

- The Saouaf Formation (Serravallian p.p. – Lower Tortonien) is represented by gray clays, beige to brown, flaky, fine to medum- grained sand rich in lignite (Bismuth, 1984);

- The Belkhdim Formation (Messinian) is formed by lagunal-lacustrine deposits including clay-carbonate and evaporate facies (Bismuth, 1984);

- Raf Raf Formation(Pliocene) is represented by clayey deposits (Burrollet, 1956).

In Figure 4 the lithostratigraphic correlation of wells PN, P2, P3, P1 and P4, oriented NW to SE shows that:

•The Oligocene (Ketatna Formation) is reached in well P1, P2, P3 and PN. It is 40 m thick in the center (P2) and 160 m SE (P1) and deepens towards NW;

•The presence of volcanic rock between the Oligocene and lower Langhian in the center of the study area (P2);

•Langhian (Ghrab Ain Formation) is reached only in well P1, P2 and PN. It is 50 m thick in the NW (PN) and 200 m in the SE (P1) and deepens towards the NW;

•The top Langhian (Mahmoud Formation) is traversed by all wells. Its thickness is almost constant and deepened to 2000 m to NW (PN);

•The Serravallian (Birsa Formation) is an important thickening and reaching 660 m NW (PN). Therefore, in the northwest sector, this formation is deeper than the previous formations indicating subsidence invesion;

The Serravallian p.p - Lower Tortonien (Saouaf Formation) is traversed by all wells has a very important thickness up to 955 m NW (PN);

•The Messinian (Belkhdim Formation) unlike the previous two ages, it thickens to the south east (260 m in P3), which could indicate a second inversion in the subsidence.

The NW side of study area presents an important thickness of Miocene Deposits (Birsa and Saouaf Formations), reveals that this area is a subsidente area at Post Langhian (Mahmoud Formation).

In addition (Fig. 4), this correlation shows that the tectonic played an important role in the distribution of deposits in the geological periods. Indeed, subsidence during the Middle Miocene in the NW part was probably induced by normal faulting located between P1 and P3 and between P2 and PN.

3.2- Interpretation of seismic data

The geophysical data used are of two types: eighteen (18) 2D seismic lines for a total length of 698 km and distributed in a mesh of 0.5 * 0.5 km^2 (Fig. 5) with a poor to medium quality, petrophysical well-logs such us GR, sonic, density, porosity and resistivity. The interpretation of seismic data consisted of the following two steps:

- The first stage was devoted to the identification of seismic horizons matches the formation tops. This identification was realized by calibrating seismic data on the wells P1 and P2. Six horizons (h1 to h6) corresponding to formation tops were identified, and are here in Table 1.

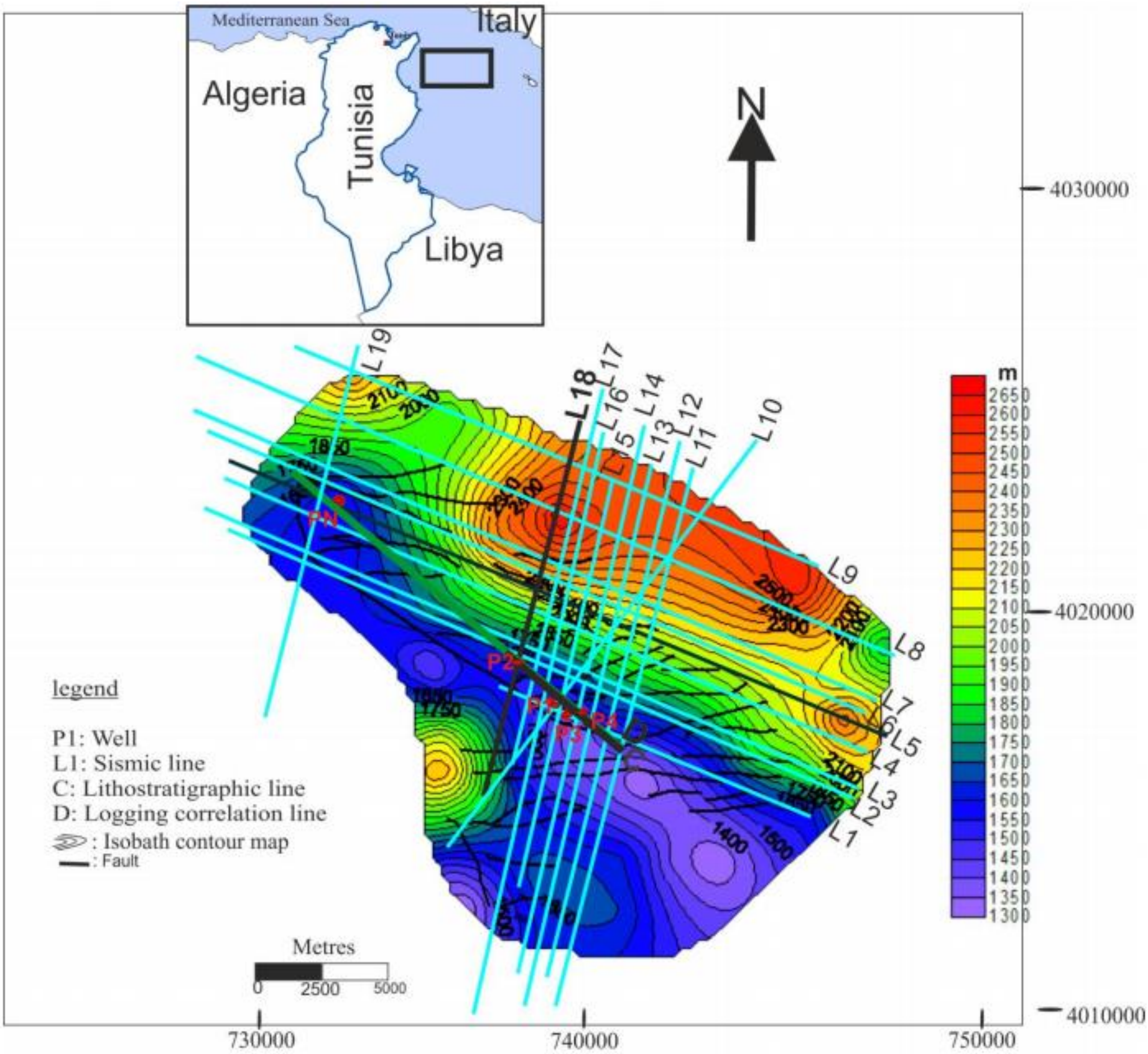

Figure 5) Map indicating the position of the analysed seismic lines. The position of the, lithostratigraphic correlation shown in Fig. 4 (C) and logging correlation (D) are shown.

Among all the available 2D-lines, the ones with NW-SE and NE-SW orientation (L5 and L18) show the main tectonic structures that characterize this region. Indeed, the interpretation of the line L18 (ties to P2), NE-SW direction extends over 7 km, and it passes through the center of the region. The Well of P2, just about 500m NE of the line, crossed all the Oligocene series Pliocene-Quaternary (Fig. 6). This profile shows a high zone (horst) in the center, limited on both sides by two low areas. This seismic section shows clearly the most accidents; a series of antithetic normal faults (F2 to F5 and F7) that affects the anti-Serravalian series. The seismic line L5 trending NW-SE extends 14km (Fig.6). It is located west of Oudna field (Fig. 6). The PN well, just about 100m SW of the line, crossed all Oligocene to Pliocene-Quaternary series. This profile shows two folded structures in faulted- faults.

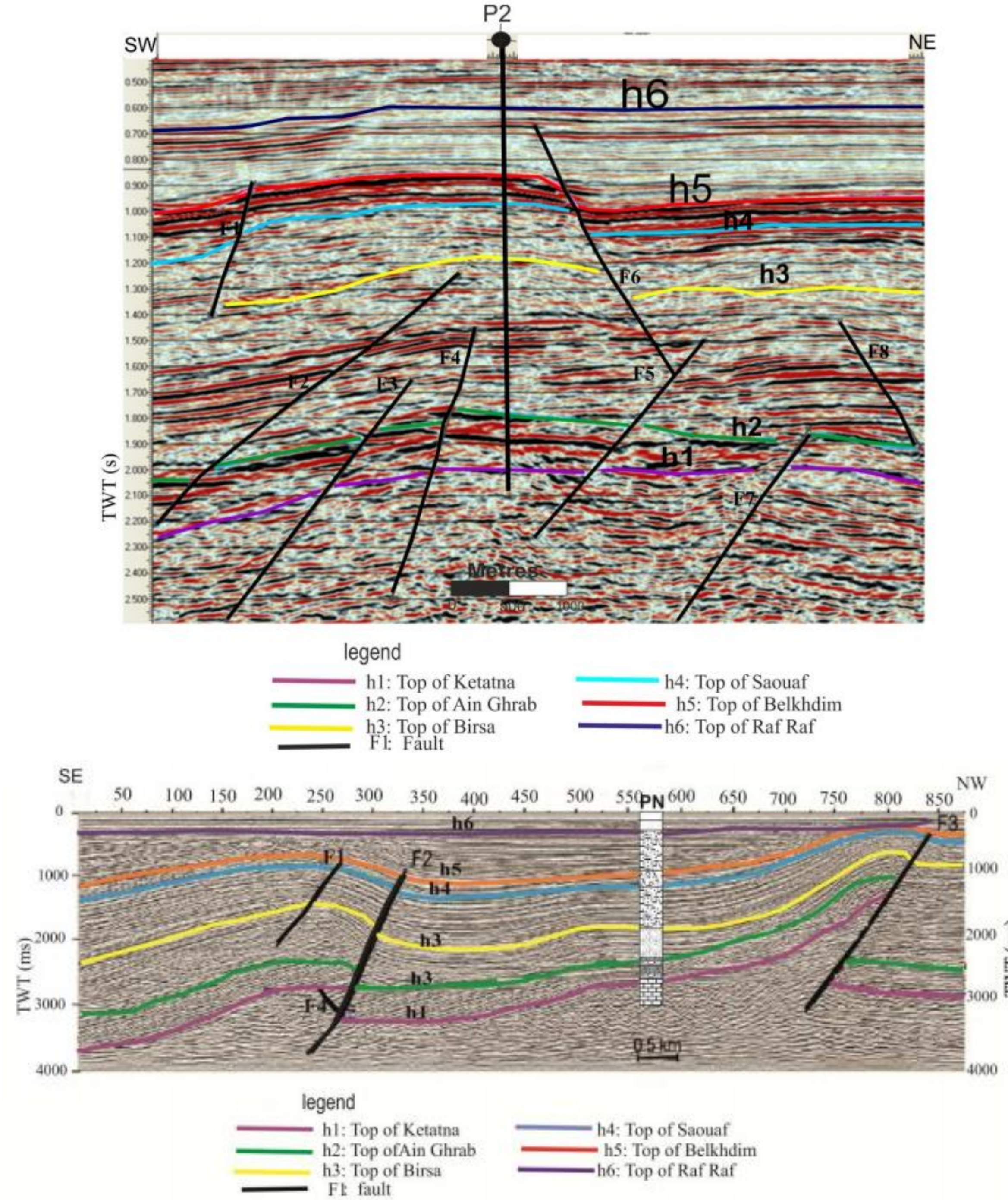

Figure 6a) Interpretation of seismic line L18 calibrated by well P2.b) Interpretation of seismic line L

It shows two sets of reverse faults: the SE side, with the F1 and F2 faults which dip to the SE and NW side, the F3 faults dip to the SE. F2 and F3 faults have affected all horizons Raf Raf (Pliocene), Belkhdim (Messinian), Saouaf (Serravallian p.p-lower Tortonian), Birsa (Serravalian), Ain Grab (Langhian) and Ktetna (Oligocene). The fault F1 affected only a Birsa and Saouaf Layers.

Table 1) Results of the seismic line L18 to well P2 ties.

Well P2 data		Seismic line L18 data		
Formation	Top depth(m)	Horizon	Two _way time (ms)	Sub_ sea (m)
Raf Raf	297	h6	363	272
Belkhdim	799,99	h5	908,304	774,99
Saouaf	979,987	h4	1046,94	954,982
Birsa	1720,81	h3	1638,29	1695,81
Ain Ghrab	1842,14	h2	1732,44	1817,14
Ketatna	1941,86	h1	1823,25	1916,86

- The second stage is devoted to monitoring these horizons on all the seismic lines and the establishment of the isobaths and isopachs contour map (h3) of Birsa Formation (Serravalian) (Figs.7 and 8).

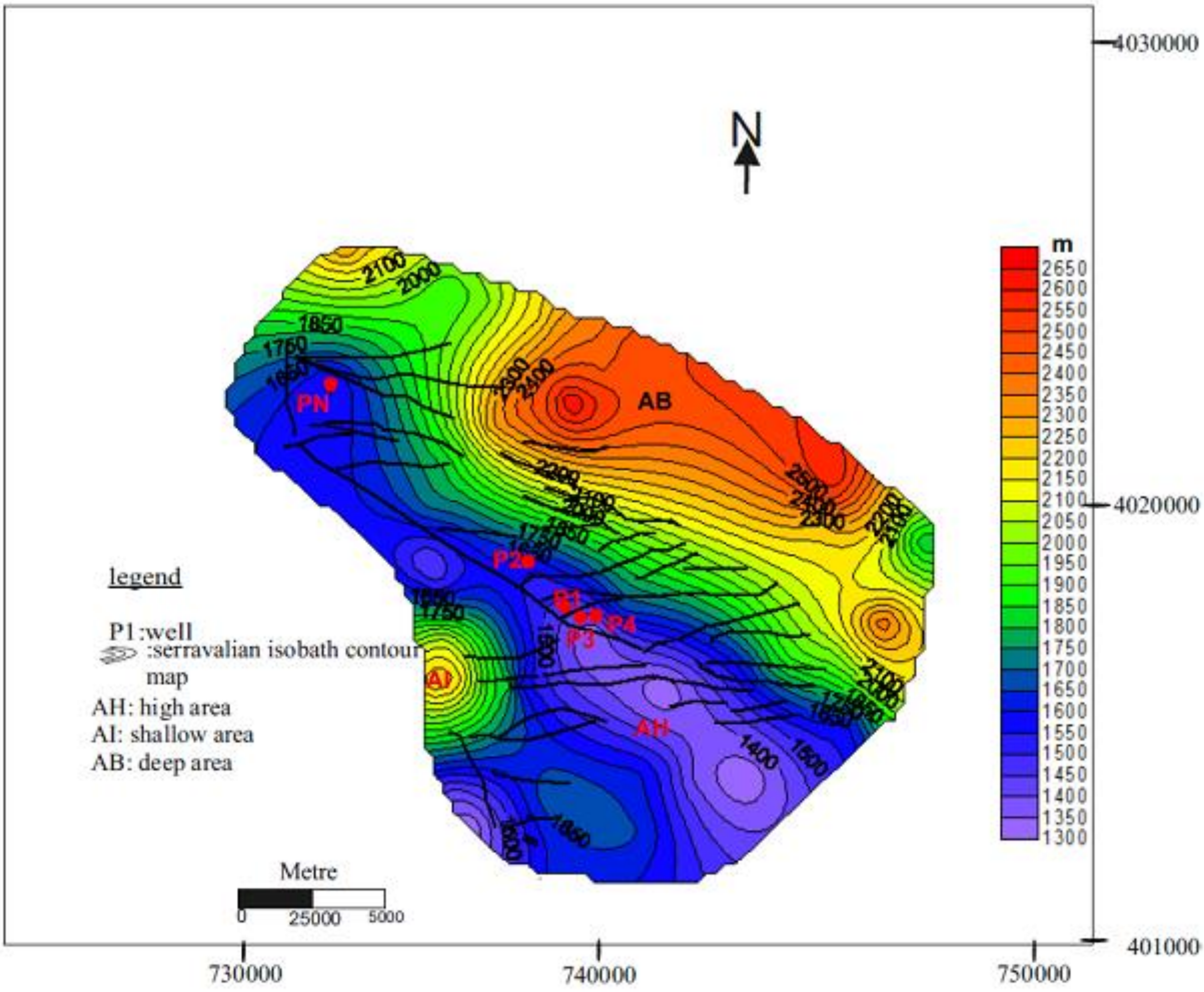

Figure 7) Isobath map of top Serravallian reservoir, Birsa formation (contour lines every 50 m).

The contours map in the top of the Birsa formation (Fig. 7) shows that the surveyed area has three areas at different depths: the low area (AB) is located north, next lengthened a NW-SE direction and has a significant depth of 2650 m to the north. The high area (AH) is located in the south east, is elongated in the NW-SE direction and has an elevation up to 1200 m to the southeast. The latter has in its southwestern part a gradual deepening reaching 2200m (AI).

Moreover, the survey area is affected by fault systems. Those of NW-SE are normal and those of NE-SW to W- E are reversed. The normal faults led to the structuring of the region horst (central zone) and grabens (eastern zone), as tilted blocks.

The isopachs map of Birsa formation (Fig. 8) shows a thikness of 750 m in the north-west and an area with a thickness of 600 m located in the north and elongated in a direction NW- SE. A general thinning (150m) can be observed in the northeast and also in the northwestern part of the study area.

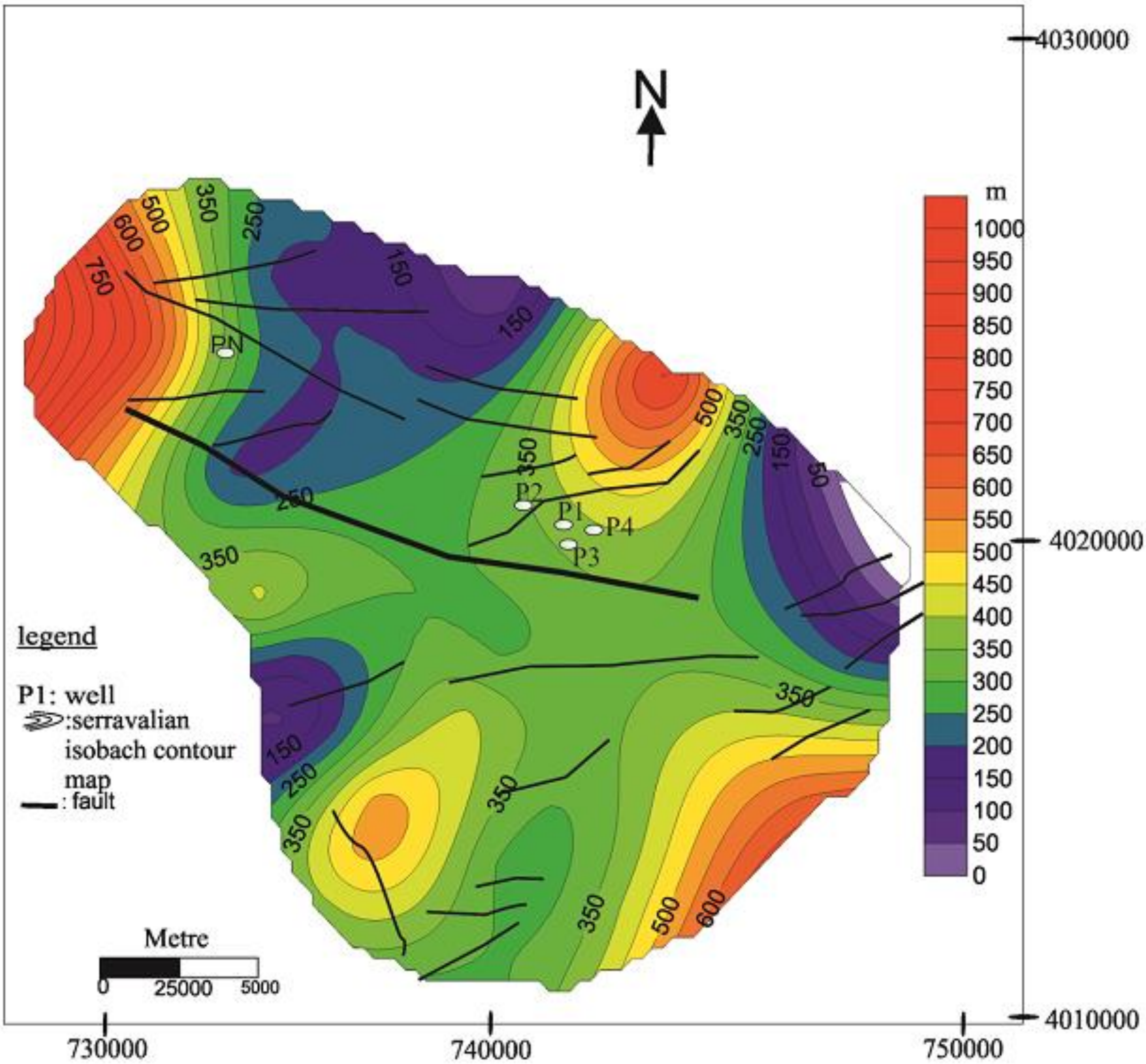

Figure 8) Isopach map of the Serravallian reservoir (Birsa formation) (contour lines every 50 m).

3.3- Interpretation of borehole logging data

The borehole logging records in the well P3 (Fig. 9), shows that the lower member of Serravallian (lower Birsa) can be divided into the following three levels, from top to bottom:

•The level S1 is constituted by sand impregnated with oil and a thickness ranging from 0.4 to 6.2 m. It shows low GR values to medium (30 to 40 API) that reflect a weak presence of clays and a high value of resistivity (1000 Ω.m) confirming the presence of hydrocarbon. The average porosity of S1 is of the order of 28% and its average water saturation is 46.33%;

•The sand level S2 is constituted by sand to very slightly fine clayey and thickness ranging from 1.4 to 9.1 m. It has a low value of GR (30 API) indicates the absence of clay, high neutron porosity value (20%), low density (1.95g/cm3), with an average porosity of 26% and an average water saturation 43%;

•The level S3 is formed by silty sands fine to very fine and thickness ranging from 2.3 to 5.2 m. It shows a range of values comparable with those measured in the S1 and S2 levels.

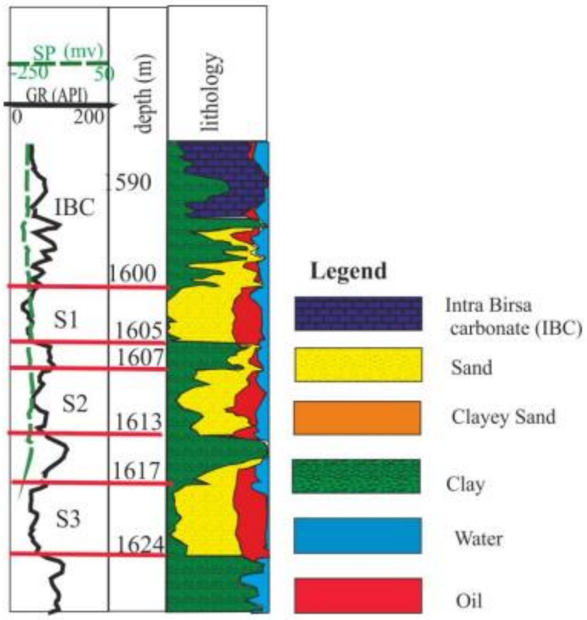

Figure 9) Serravallian reservoir division of the well P3.

A correlation of petrophysical well-logs in the Serravalian reservoir along the profile D to the NW- SE orientation, passing through the well P4, P1, P2 and P3 has been produced in order to map the lateral variation of the three levels above mentioned (Fig.10). Along this profile, the three levels (S1 to S3) are continuous, have a total thickness of about 20 m and are slightly deepening from both sides of the well P3 of 1600 m to 1795 m NW (P2) and up to 1666 m SE (P4). Consequently, identifying the reservoir in which the petrophysics values have the greatest effect is of great economic interest for petroleum exploration.

4- Discussion

During the Cretaceous, the eastern Tunisian (Sahel) and the Pelagian Sea were affected by normal faulting with a NW-SE direction. Alkaline volcanism was induced by this extensional tectonics (Winnok and Bea, 1979; Burrollet 1991; Ouazaa 1994; Mattoussi et al, 2009, Corti et al 2006. Bouaziz et al 2002). During the Middle Eocene-Miocene, the deepening of the formations from the west to the east may indicate the continuation of the distension and activity of theses normal faults. From the lower to the Middle Miocene, NW-SE to E-W trend, a series of grabens developed in the Tunisian Atlasic (graben Rohia- Sbiba, Foussana Kasserine,etc.; Philip et al, 1986; Ben Ayed, 1993; Chihi 1995). Their appearance is explained by extensional tectonics characterized by a stress axis of σ3 with NE-SW trend. In the study area, the depth map relative to the top of Serravallian (Birsa Formation) shows local lows (basins) that are related to extensional structures bounded by normal faults of NW-SE trend in the northern sector and escarpments and tilted blocks in the eastern sector.

During compressive Tortonian phase, called Atlasic phase (Philip et al, 1986;. Ben Ayed, 1993), the study area was subjected to compressive stresses with a NW-SE trend that induced the inverse movement of NE-SW faults (Casero and Roure, 1994) and normal movement of the NW-SE faults and formed a series of a folds with a NE-SW trend. In this sector, the coexistence of a compressional and distensional structural style was raised by Corti et al. (2006). This thrust fault system, which forms an active part of the Maghrebian fold-and-thrust belt since is interrupted by NW-SE trending Neogene grabens (Argnani, 2009; Soumaya et al, 2015). The compressive phase, due to the collision between the African and Eurasian plates, has resulted in the formation of high structures favorable to receive hydrocarbons. In the Plio- Quaternary, the migration of the subducting plate (slab) to the east, in the central Mediterranean, was contemporary with the opening of the Tyrrhenian Sea and the Sicily Channel (including continental rift of Pantellaria in the south (Civil et al, 2010; Faccenna et al, 2004; Lacombe and Jolivet, 2005; Fig. 11). Alkaline magmatic that was established from the Cretaceous to the Pliocene-Quaternary, is accompanied by a thermal effect and an increase in the geothermal gradient (Mattoussi et al, 2009; Jedidi, 2004) and heat flow in this region and contributed to the maturation of the organic matter distributed in the source rocks.

The strong values of geothermal gradient and heat flow are due to crustal thinning centered on the Sicilian Channel (minimum depth of the Moho; Grad et al, 2009). This volcanic activity is recent in the continental rift of Pantellaria (Peccerillo, 2005). The interpretation of seismic data has enabled a structural model in Oudna field that appears in the juxtaposition of high areas (horst) and low areas (grabens) folded and faulted.

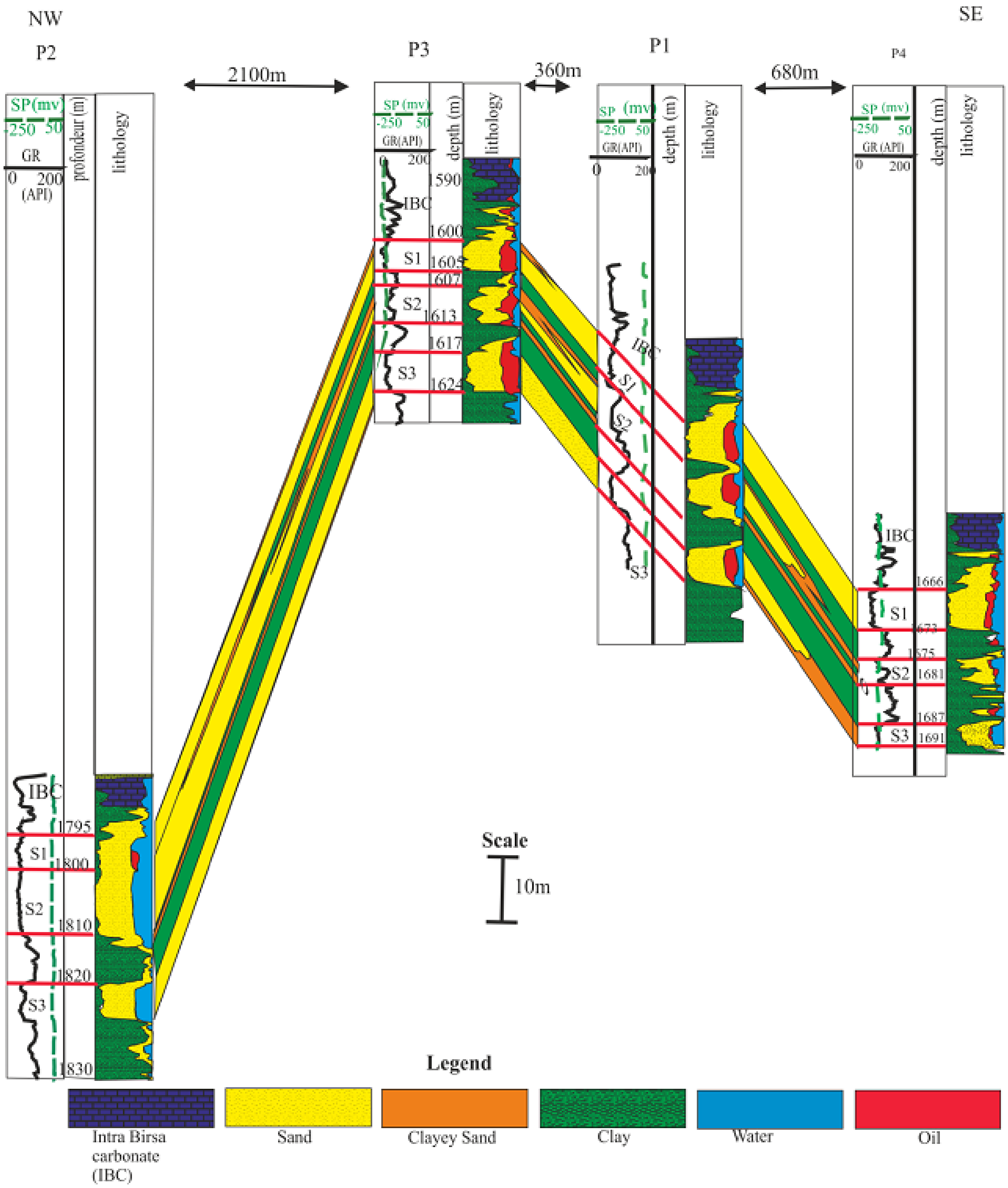

Figure 10) correlation of petrophysical well-logs in the Serravalian reservoir along the profile D.

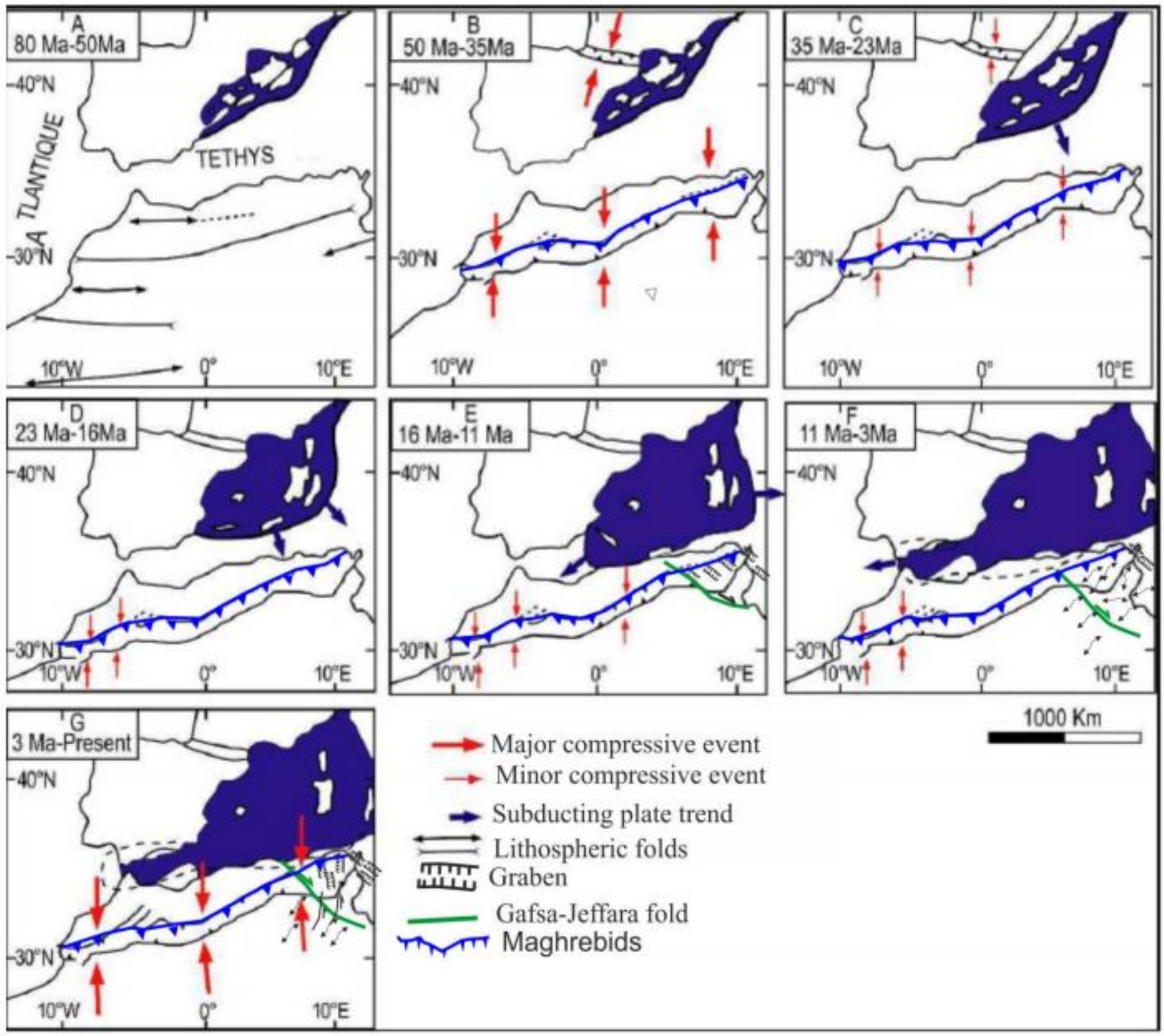

Figure 11) Geodynamic evolution of the western Mediterranean during the last 80Ma (modified from Frizon de Lamotte et al., 2000).

These are elongated in three main directions. The first relates to NW-SE normal faults rooted and delimit the continental rift of Pantellaria (Civil et al, 2010). The normal faults provides the hydrocarbons from the Albian-Cenomanian Source Rocks (Fahdene Formation) to the Serravallian reservoir (Birsa Formation). The second consists essentially in NE-SW reverse faults associated with folds of similar orientation, controlled the traps structuring.The third E-W trend is minor and characterized by the strike-slip dextral faults.

The study area has a hydrocarbon interest for most performed well, actually produces oil from the Serravallian Reservoir (Birsa Formation). In the western area of the Gulf of Hammamet, exploration has shown only the oil or gas indices except the area of Cap Bon which produced appreciable amounts of gas in sandy reservoir of Néocomien- Aptian. The maturity of organic matter in the source rocks of Albian-Cenomanian (Fahdène Formation) has been reached in the east, is near the continental rift of Pantellaria. The migration of hydrocarbons is related to the geodynamic events during the Atlasic Phase. The configuration of Miocene traps was strongly controlled by tectonic activity during the Pliocene (Hezzi, 2014).

The good petrophysical characteristics of the Serravallian reservoir, its substantial thickness and the presence of an impermeable seal layer formed by clay made it good reservoir, with the major structural traps associated with tight faults with a general NE-SW trend.

4-Conclusion

The compilation of seismic and geological data (derived from wells) license Oudna allowed the characterization of the petroleum system of the area and especially the Serravallian reservoir (the Birsa Formation). It shows that this formation constitutes a reservoir compartmentalized into high and low blocks, by faults activated and / or reactivated during the Tortonian compression which is characterized by a compression axis with NW-SE trend. Study area and its surroundings, which form a complex tectonic domain characterized by grabens limited by NW-SE to N-S normal faults, NE-SW reverse faults, and E-W trend striking faults. These structures, originated during late Miocene, are reactivated according the same directions during the NNW-SSE compressive Quaternary episode.

This structuring has controlled the variations of thickness and depth of the sedimentary series, especially the Birsa reservoir and the hydrocarbon migration from Albian-Cenomanian source rocks to the Serravallian reservoir in this field. In the identified potential prospects, the trap type is structural and associated with tight NE-SW trending faults.

The obtained results are a priori a solid basis for the development of the field and its surrounding on the optimization of a possible operation of Serravallian reservoir in this field. This optimization could be consolidated a posteriori by the performing the new wells for exploration and / or exploitation and acquisition of new seismic data resolution.

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