Structural dynamics in northern Atlas of Tunisian, Jendouba area: insights from geology and gravity data

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Abstract

This paper presents a new interpretation of the geometry of Triassic alignment of J. Sidi Mahdi –J. Zitoun in Medjerda Valley Plain (Northern Tunisia) based on detailed analysis of gravity and seismic reflection data. The main results of gravity analysis do not show a distinguish gravity anomaly over Triassic evaporites bodies. The positive gravity anomaly seems to be related to the entire structure containing Triassic evaporites and Cretaceous carbonates and marl strata. Horizontal gravity map highlights NE-SW and NW-SE two prominent directions that surround Triassic outcrops and their bordering strata. Specifically, the seismic sections show a structural evolution and halokinesis in our study area. Analysis of seismic lines associated to interval iso-velocity sections highlight Triassic rising structures related to Mesozoic and Cenozoic tectonic control. The resulted structures are interpreted as original Mesozoic diapirs followed by a lateral outpouring above the late Cretaceous to Eocene series.

Keywords: Northern Tunisia; Triassic, Rising; Seismic Interval Velocity; Salt Outpouring.

1- Introduction

The NE-SW salt bodies in northern Atlas of Tunisia (Fig. 1-A) are interesting for mining prospects and have been the subject of several works concerning their mode of emplacement. Some of them are considered as vertical structures (diapirs, salt domes...) (e.g., Ben Assi *et al.,* 2006; Jallouli *et al.*,, 2005; Chikhaoui, 2002; Daly, 1981; Perthuisot, 1978; Rouvier, 1977), others as horizontal structures "salt glaciers, salt canopy structure" (e.g., Masrouhi *et al.*,, 2007; Ghanmi, 2003 ; Vila *et al.*,, 1994 to 2002). These salifereous outcrops have been controlled by several tectonic events, which produced genesis of different high and subsiding structures. The Late Miocene major contractional events are represented by NE-SW trending Atlassic folds interpreted as thrusting, fault propagation fold / fold related fault; the direction of the fault is the same of fold axis (NE-SW). The fold and fault axis direction are perpendicular to the major Atlassic shortening direction (NW- SE) (Ben Ayed, 1993; Turki, 1988; Rouvier, 1977; Zargouni, 1977). In Tunisian Atlas, several geophysical studies (Atawa *et al., 2016*; Zouaghi *et al.,* 2011; Melki *et al.,* 2010; Masrouhi *et al.,* 2007; Bouaziz *et al.,* 2002; Boukadi and Bédir, 1996) and geological studies (Haji *et al.,* 2014; Zouaghi *et al.,* 2011; Melki *et al.,* 2010; Ben Mehrez *et al.,* 2009; Masrouhi *et al.,* 2007; Abdessalem

Gharbi *et al.,* 2005; Bouaziz *et al.,* 2002; Ghanmi *et al.,* 2001) demonstrated the effect of NE-SW and N-S faults on the tectonic instability of this domain illustrated by several variation of facies and series during the Pyrenean and Alpine/Atlassic tectonic phases. These faults have evolved during tectonic periods associated with the movement of Mesozoic evaporites (Masrouhi *et al.,* 2007; Ghanmi *et al.,* 2001; Bédir *et al.,* 2000; Boukadi and Bédir, 1996).

2- Geological setting

The Jendouba study zone is located in Medjerda valley plain in Northern Tunisian Atlas. This domain is characterized by the major Triassic alignment of J. Sidi Mahdi- J. Zitoun. Stratigraphic series in the study area range from Triassic to Jurassic in age. Cretaceous and Tertiary sediments, which are dominant in the flanks study area and bordered Triassic outcrops (Fig. 1B) are generally composed by chaotic deposits including salt layers (e.g., Bouaziz *et al.,* 2002; Adil, 1993; Ben Hadj Ali, 1979, 1993). The Early Cretaceous consists of black marls and limestones alternated with some sandstone layers, followed by the upper Cretaceous clayey marls and carbonates. The Cenozoic deposits consist of clays, marls and sands (e.g., Ben Mehrez *et al.,* 2009; Masrouhi *et al.,* 2007; Ghanmi *et al.,* 2001; Chikhaoui *et al.,* 1998; Daly, 1981; Ben Hadj Ali, 1979). The exploration well (Mej-1) located in the Medjerda Valley encountered Triassic evaporites under the Pliocene-Quaternary deposits (Fig. 1B). The current tectonic framework of northern Tunisia (e.g., Amiri *et al.,* 2011; Melki *et al.,* 2010; Hamdi Nasr *et al.,* 2010) was guided essentially by NE-SW trending master faults, which are related to saliferous outcrops and affected the structuration of the study zone. Thus, the tectonic contact of the Triassic series and the surrounding cretaceous and Neogene series was demonstrated on geologic cross section established in Jendouba area (Fig. 2). These sections show the geometry of two anticline structures with Triassic extrusion interrupted by cretaceous series of J. Sfa Bou Bker (Fig. 2). To the NW part of the sections AA' and BB', a tectonic contact manifests between Pliocene and Triassic series.

In this paper we focus on the understanding of the complex salt structures in Jendouba area related to the geodynamic evolution of major features based on the contribution of geophysical data.

3- Data and methodology

Since 1997, the availability of new gravity data constrained by the "Office National des Mines "(ONM)" in Jendouba area and based on a reduction density of 2.4 g/cm3, allowed us to accomplish the gravity study in order to understand the structural context in this zone. The seismic and well data are obtained from "Carthago Oil" Company and provided by ETAP "Entreprise Tunisienne des Activités Pétrolières". The exploration well used in our study allowed the calibration and correlations of seismic horizons. First, in this study we focus to highlight the contribution of gravity methods to identify the major structural directions and trends in Jendouba area associated to Triassic salt bodies (J. Sidi Mahdi- J. Zitoun structure). Second, to understand the geodynamic evolution of the study zone and we will conclude with the re-interpretation of Triassic structures in this zone using both gravity and seismic reflection data. A 2-D seismic interpretation approach was based on seismic reflector geometry, calibrated with outcrop and exploration well data (Mej-1).

4- Results

4.1- Gravity analysis

Analysis of the complete Bouguer anomaly map (Fig. 3) show gravity values that range from -

12.5 mGals in the south and west to +8.7 mGals to the east. The calculation of the regional anomaly consists of decomposing the Bouguer anomaly into two superimposed components caused by geological structures with different depths and dimensions.

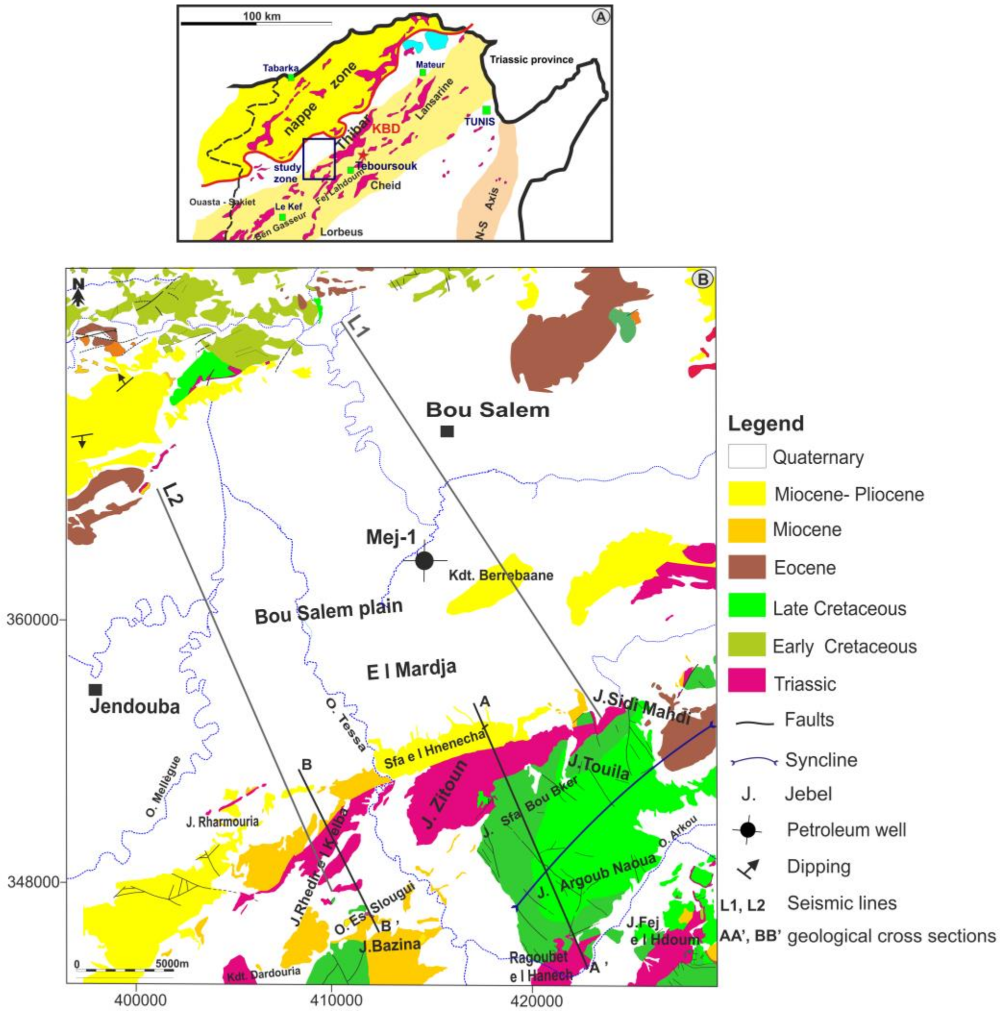

Figure 1A) Map of location of study area and salt extrusions in Northern Tunisia, B) Geological map of Triassic outcrops in the study area [after Ben Hadj et al., 1993], (J.) = Jebel. This map shows the position of used exploration well and seismic lines.

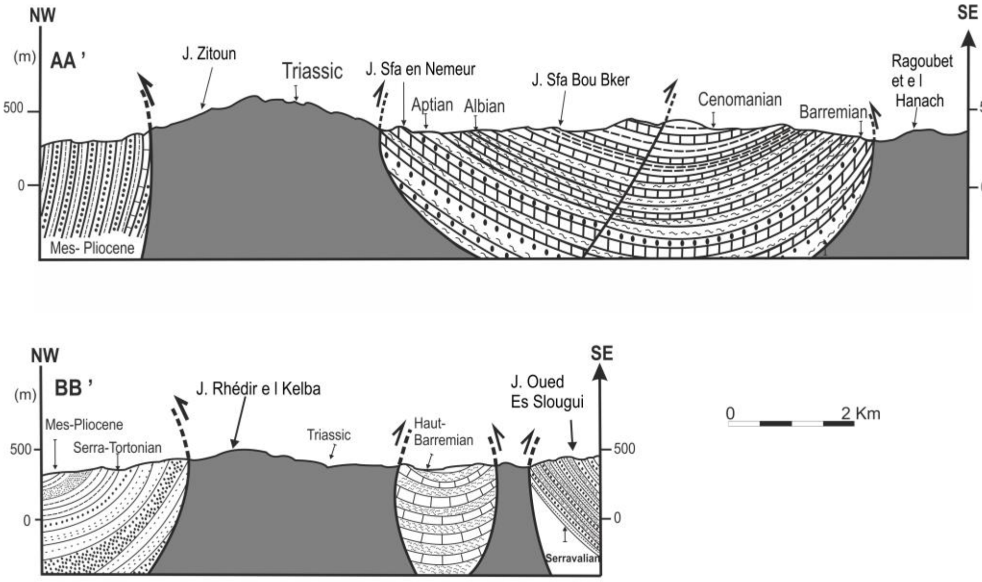

Figure 2) Geological cross-section in the study area (J. Zitoun area) showing the relation between Triassic materiel and its surrounding series.

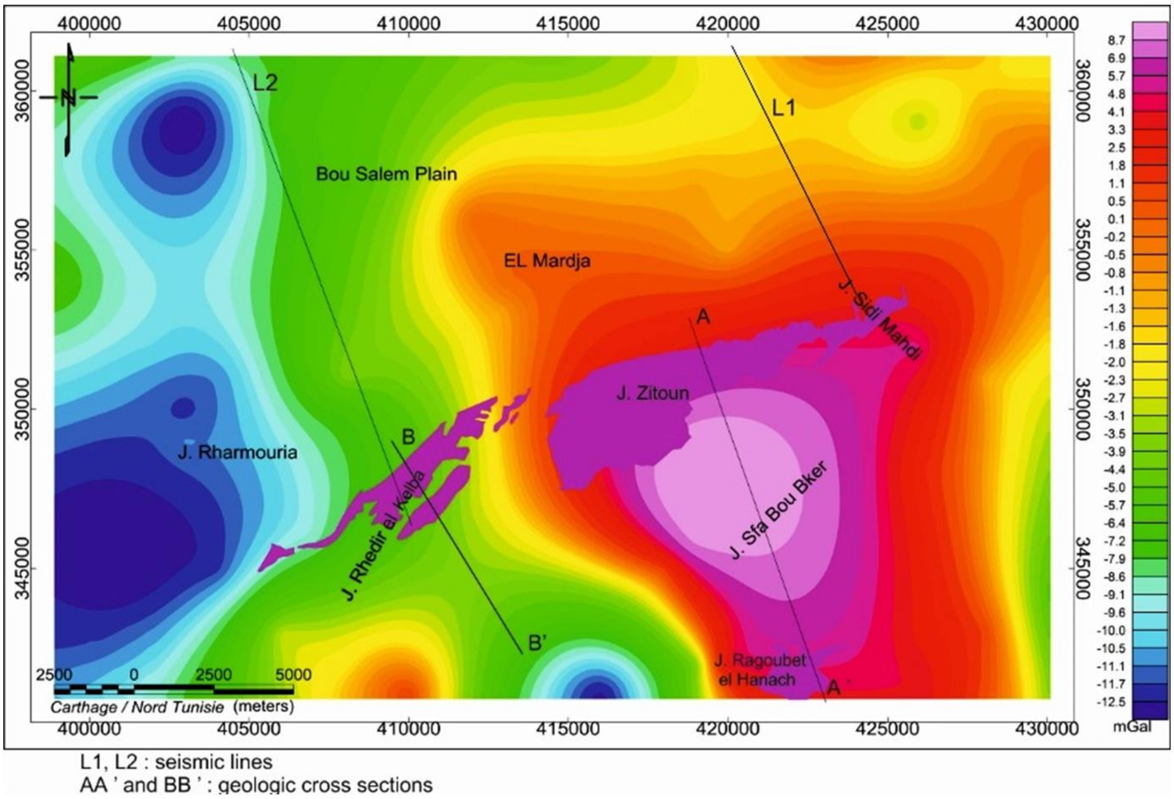

Figure 3) Complete Bouguer gravity anomaly map of the study zone.

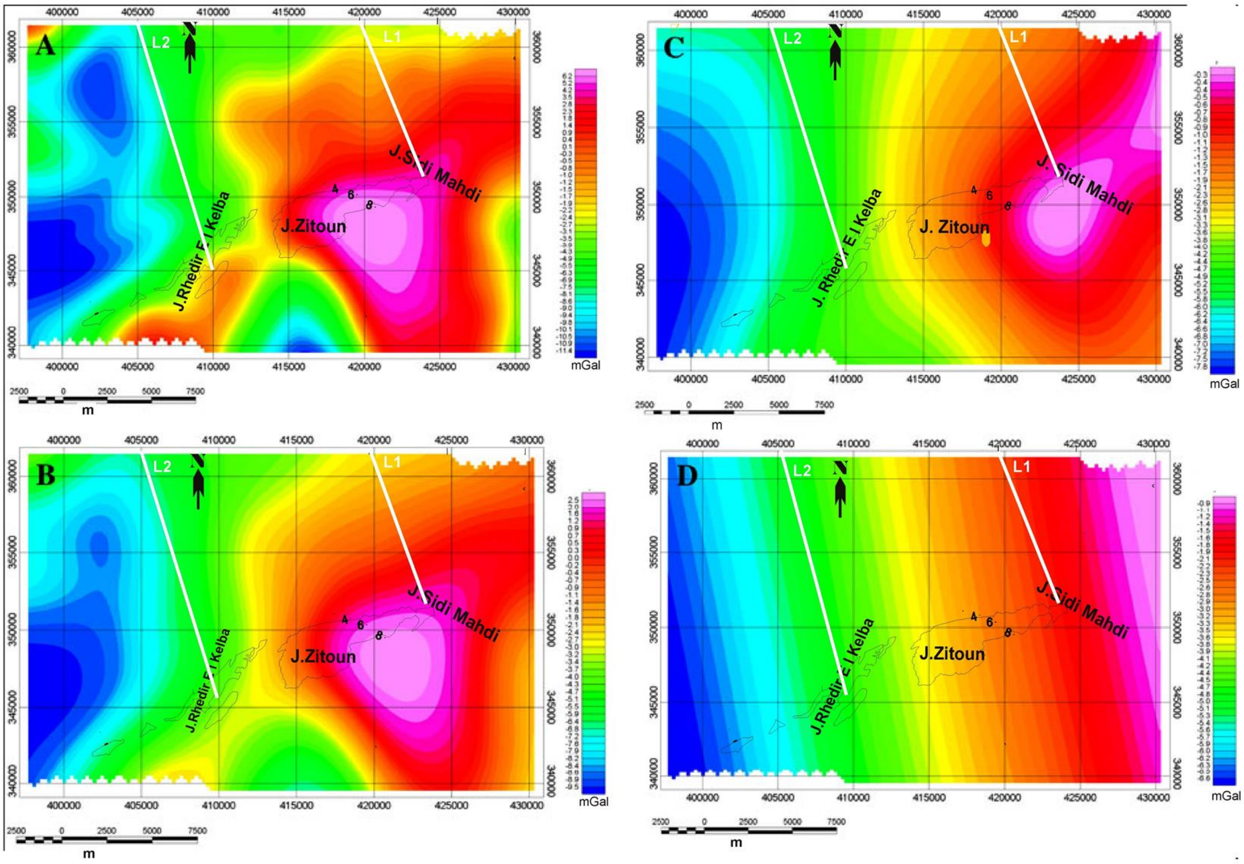

Figure 4) Upward continuation maps showing a regional gravity field: A- 1000 m, B- 5000 m, C- 10000 m, D- 27000 m.

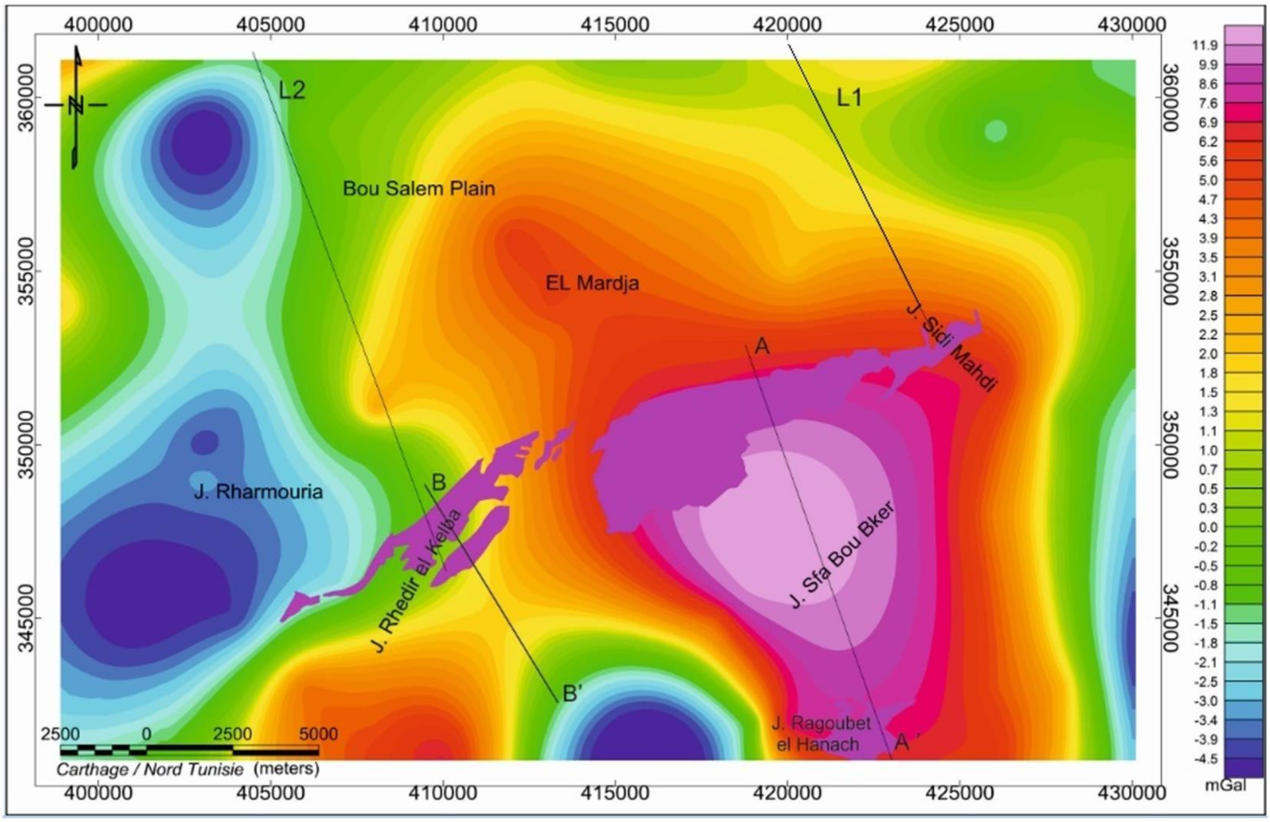

Figure 5) Residual gravity anomaly map.

To determine the regional-residual anomaly separation, we can use several techniques. For the present work, we used upward continuation method, which is a powerful low-pass filter, to deduce a regional gravity anomaly that gradually decreases toward the west (Fig. 4). The regional anomaly corresponds to the Bouguer anomaly, prolonged upwards of 27 km (Fig. 4D) and show smooth and identical gravity isoGal curves of long wavelength with an E-W general gradient confirmed by Jallouli *et al.*, (2000). A residual anomaly map (Fig. 5), which highlights a response of superficial sources results from the subtraction of this regional anomaly to the Bouguer anomaly. On this map the positive anomalies are located in the north, in the southeast and in the center of the map (Fig. 5) and correspond to high structures, which contain Triassic and lower Cretaceous outcropping series. On the other hand, negative amplitude anomalies are located in southwestern and northwestern part of the map and generally coincide with quaternary deposits. A thorough examination of the residual anomalies shows a positive anomaly with N-S direction over the J. Sidi Mahdi - J. Zitoun that are marked by Triassic facies associated with the lower Cretaceous series composed by marls and sandstones (Ben Hadj Ali , 1979). In order to highlight the lateral limits of gravity responses and to locate the lateral boundaries of density contrasts (Blakely and Simpson, 1986) the horizontal gradient maxima method is used. Using this technique coupled with the upward continuation allows the identification and the localization of the faults, which present usually a lineate contact (Fig. 6) in relation with their dip. At every level, the horizontal gradient maxima are determined. Thus, the deepest contacts are represented by highest levels of continuation and vice versa (Atawa *et al., 2016*; Ayed Khaled *et al.*, 2015, 2012; Amiri *et al.*, 2011; Hamdi Nasr *et al.*, 2010; Ben Assi *et al.*, 2006 and 2013; Vanié *et al.*, 2004). The resulting gravity lineaments interpreted as faults highlighted four families of direction NW–SE, NE–SW, E–W and N–S that controlled the geologic structuring of our study zone related to their intensity and their geometry.

The new structural map interpreted from gravity data (Fig. 7) shows a NE-SW and NW-SE major and deep lineaments limited the salifereous structure of J. Sidi Mahdi- J. Zitoun. Furthermore, two contacts with NE-SW direction surrounded the Triassic structure of J. Rharmouria in the west and a N-S fault system limited the Fej El Hdoum Triassic outcrop in the south (Fig. 7). The northwestern part is controlled by a frequent NW-SE direction. The E-W direction is highlighted in the northwestern zone of the map over the quaternary deposits of Mellègue river plain (Fig.1-B). Although the gravity method does not lead to a single solution concerning the deep geometry of the Triassic bodies, a seismic study appears more useful. Seismic profiles carried out in the Medjerda Valley domain allow us to determine and to compare the deep structures and their evolution.

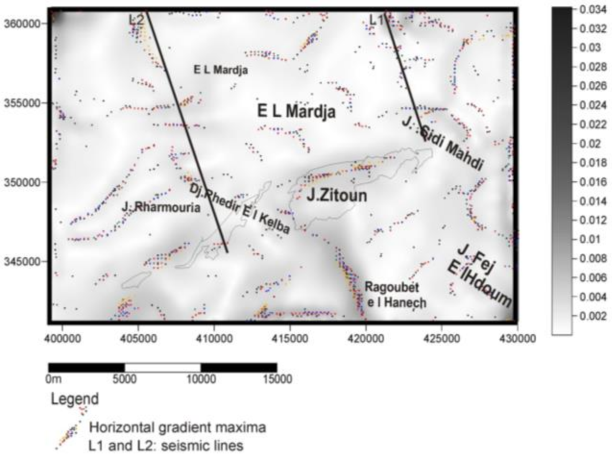

Figure 6) Maxima of the horizontal gradient of the Bouguer anomaly and their extended upwards at different altitudes illustrating the interpreted gravity lineaments: black points (0 m), red points (250 m), blue points (500 m), Yellow points (1000 m), green points (1500 m) and brown points (2000 m).

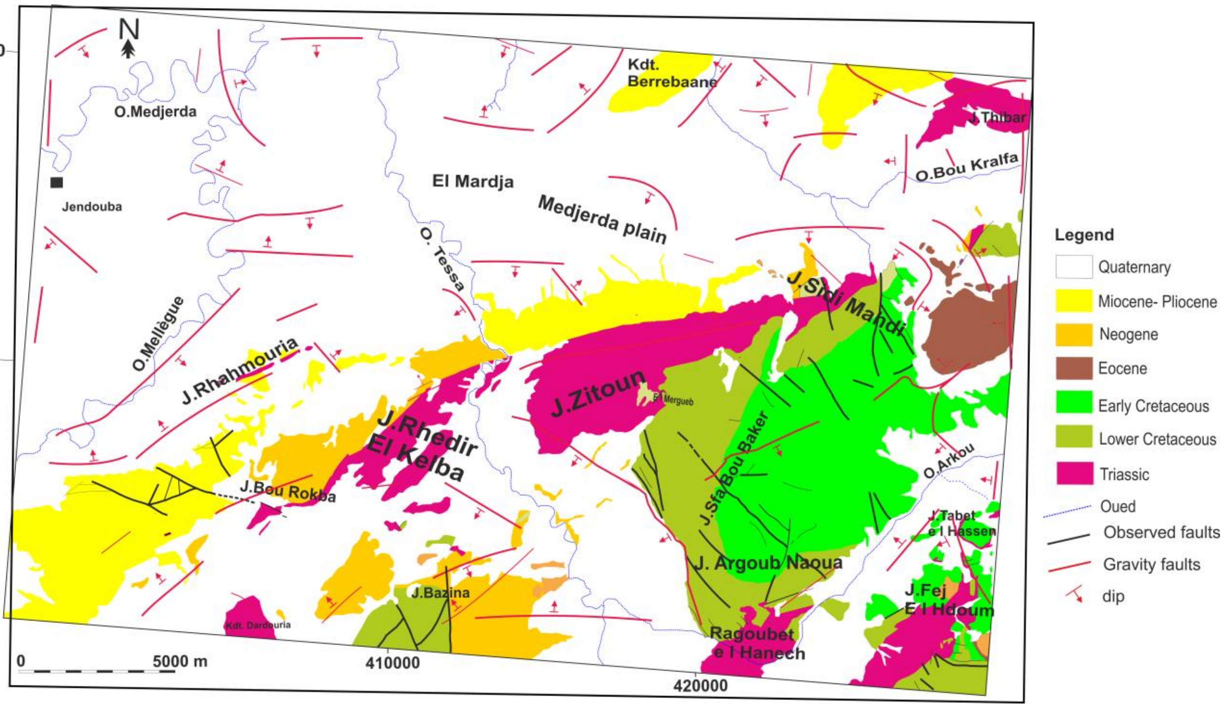

Figure 7) Gravity lineaments map superimposed the geological map of the study area.

4.2- Seismic analysis

The second approach in our geophysical study is based on the interpretation of the 2D seismic profiles. Lithostratigraphic analysis was calibrated using well calibration from projected (Mej-1). Analysis and correlation of seismic reflectors determine seismic units bounded by major unconformities such as erosion and hiatuses (downlap/onlap/toplap).

This geophysical study aims to determine structuring of the basin and their filling. The NNW-SSE seismic line L1 and the NW-SE seismic line L2; crossing transversally the Medjerda Valley; illustrate a NE-SW trending folds and steep reverse faults. The corresponding structures are organized into highs and synclines (Figs 8 and 9). The NE-SW master fault, which bordered the Medjerda Valley to the NW, has major effects on the distribution of the Mesozoic and Cenozoic sedimentary series. The geometry of major faults and folds exhibit the reverse displacement (Fig. 8). On these lines, a chaotic seismic facies correspond to Triassic evaporates, indicating therefore, its ascension at the borders of the depocenters (Figs. 8 and 9). On L1 and L2 seismic line, the Neogene series are marked by a great expansion and show important stratigraphic lacuna on the top of paleohighs. At deep depocenters, Triassic salt bodies, sealed by the Late Cretaceous, Tertiary and Quaternary deposits, reveals sedimentary contacts. Correlation of seismic reflectors on Medjerda Valley seismic sections shows Triassic material covered by late cretaceous series (Fig. 8). The seismic facies shows the allochtonous Triassic deposits to the east and the west along a few kilometers far from the diapiric structures. Outpourings episodes of Triassic series within the Late Cretaceous series are marked by sedimentary contacts compared to the salt glacier phenomena. The NE-SW master fault, which limited the Medjerda Valley plain to the NW, has major effects on the distribution of the Mesozoic and Cenozoic sedimentary series (Figs. 8A, B and 9A, B). In addition, NW-SE direction that bordered Bou Salem plain was marked on north part of line L2 (Fig. 9A).

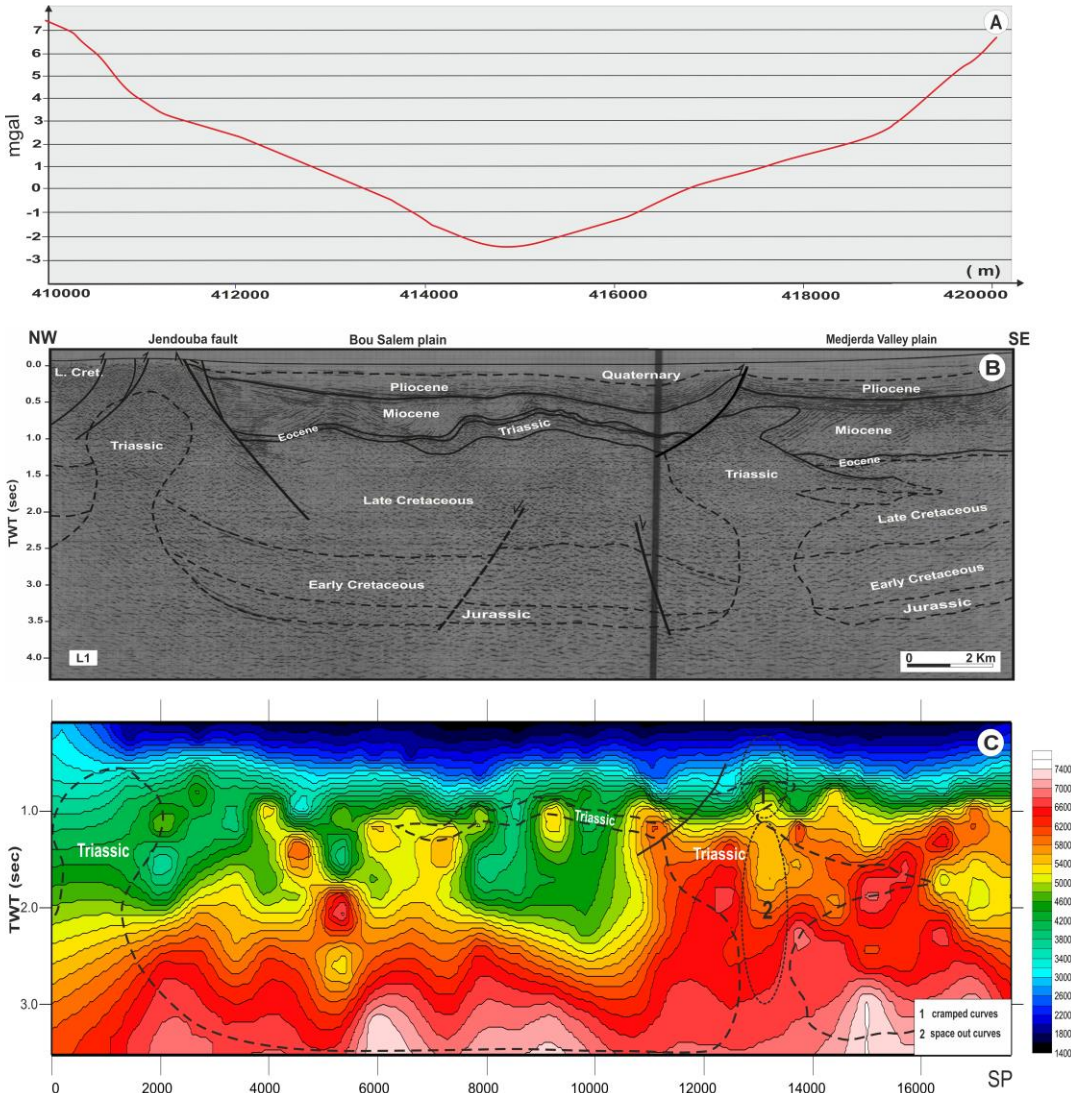

Figure 8A) Residual gravity anomaly section, B) Interpreted seismic line (L1) of the Medjerda Valley Plain domain, C) Interval velocity section of the seismic line (L1).

The geometry of major faults and folds exhibit the reverse displacement (Figs. 8B and 9B). Thus, the sudden changes associated to iso-velocity curves corresponding to Triassic horizons (Figs. 8C and 9C), are slightly and spaced out towards the northern part of sections and reveal a varying evolution of layers (Zouaghi *et al.*, 2007) between the uplift and sedimentary deposits. The analysis of these curves confirm so the ascending movement of Triassic materiel in our study zone.

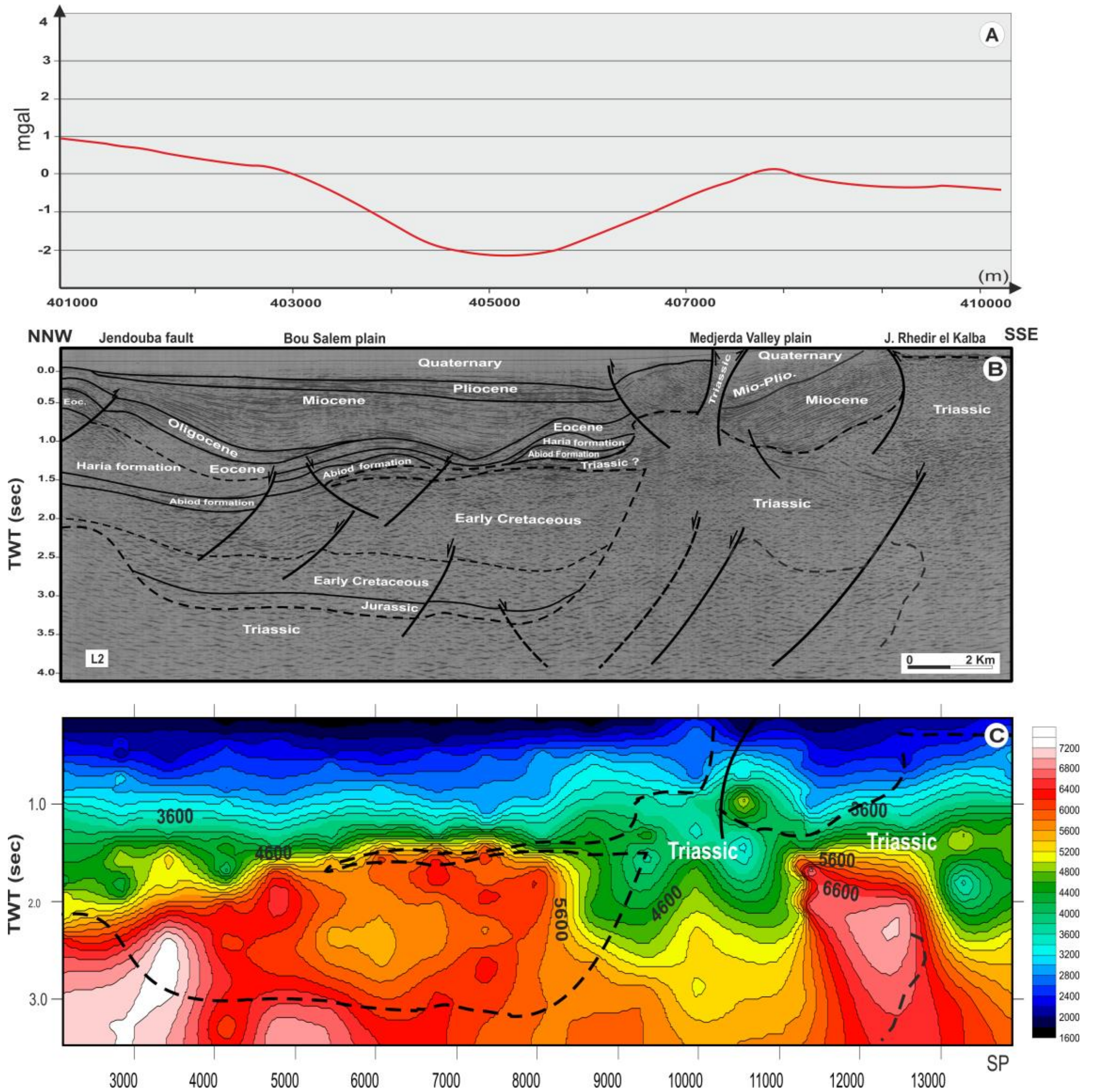

Figure 9A) Residual gravity anomaly section, B) Interpreted seismic line (L2) of the Medjerda Valley Plain domain, C) Interval velocity section of the seismic line (L2).

5- Discussion

The gravity and seismic analyses in Jendouba area highlight all directions, which are previously recognized in northern Tunisia (e.g., Chihi, 1995; Ben Ayed, 1994; Bouaziz *et al.*, 2002; Melki *et al.*, 2010). Iso-velocity sections obtained from seismic reflection data highlight some important layers with diverse evolutions between the existing paleogeographic zones, which indicate Triassic lithostratigraphic lateral changes. These structures are bounded by Jendouba NE-SW master fault and Bou Salem NW-SE faults that isolate structural blocks with a variation in sediment distribution causing, therefore, different paleogeographic evolutions. In addition, interval velocity maps indicate the lateral extension of the Triassic facies in the study area. After a general NE-SW rifting during late Permian- Middle Triassic and during the Jurassic and Early Cretaceous, the structure of J. Sidi Mahdi- J. Zitoun has undergone an initial stage. Then a short transpressional period occurred at the Aptian–Early Albian time. These events were regionally reported through the Northern Tunisian Atlas (Bouaziz *et al.,* 2002; Ghanmi *et al.,* 2001; Ben Ayed, 1994). The ascension of the Triassic evaporites was associated to a tectonic movement with vertical component. Then, during the Cenomanian, an extensional period has affected the study area (e.g., Bouaziz *et al.,* 2002; Ghanmi *et al.,* 2001; Vila *et al.,* 1994). The presence of topography, still perceptible on the studied seismic lines, testifies to a preexistent inclined structure facilitating the gravitation salifereous flow and their discharge. The same regional NE–SW extension continued during the Cenomanian - Early Maastrichtian geological period, and the study structure shows a lateral outpouring with a sedimentary contact within the Late Cretaceous time. This extrusion model of the Triassic material is in concordance with the northern Atlas tectonic evolution. The Late Maastrichtian-Paleocene period constitutes a compressional period, in which the inversions started in Northern Tunisia. The Late Eocene period (Atlassic phase) is characterized by a compressional event. A clear unconformity of Eocene series on the Late Cretaceous (Fig. 8) expresses this tectonic event on the studied seismic lines. The result of this shortening phase was the generation of Atlassic structures, among them the J. Sidi Mahdi- J. Zitoun study area. These results confirm those announced by several authors in the Tunisian Atlas (Perthuisot, 1978; Turki, 1988; Boukadi and Bédir, 1996; Masrouhi *et al.*, 2007). This period was considered as the major phase of the installation of the halokinesis structures.

6- Conclusion

The analysis of both gravity and seismic reflection data contributed to define the gravity context of Jendouba area in northern Tunisian Atlas and to better understand the geometry Triassic structures. Bouguer's anomalies map, as well as the residual anomalies, clearly show a positive anomaly over the high folded structures, which are marked by Triassic rising. According to the analysis of seismic reflection lines, the core of this structure presents a chaotic facies and indicates an intense fracturing with injections of Triassic evaporates, which are concentrated at plumbing of these major features. Indeed, these deep flaws are rooted and connect in depth, thus facilitating the rising of Triassic material. This geophysical study highlights salt pillows at the Jurassic, salt domes and diapirs at the Early Cretaceous followed by lateral outpouring during the Late Cretaceous. This mode of emplacement does not reminds that already described by Vila *et al.,* (1994 to 2002) and proposed for some outcropping salt structures of North-West Tunisia and North-East Algeria. However, in our case, the Triassic bodies of Jendouba area were considered as a Mesozoic diapiric followed by Late Cretaceous salt outpouring.

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