Role of preexisting faults in the geodynamic evolution of Northern Tunisia, insights from gravity data from the Medjerda valley

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Abstract

The middle Medjerda valley belongs to the Tellian zone of Tunisia; it behaves as a post-orogenic basin where surface structural indices are almost completely absent. It is noteworthy to recall that Alpine and Atlasic tectonic prints are well expressed on both sides of this basin.

This paper presents an integrated study comprising geology and gravity data. Subsurface geological modeling was based on gravity data interpretation including the complete Bouguer anomaly, upward continuation, residual and derivatives. 2.5D gravity modeling was essential for subsurface geometric features characterization.

In spite of its sub-horizontal and smooth topography and the low density of the homogenous Quaternary series covering the area, well contrasted and variable gravity responses are observed reflecting the heterogeneities of the geological substratum. The enhanced horizontal gravity gradient confirms structural systems that are already evidenced by surface geology. It supports, also, the presence of new masked fault systems.

The main structural features inferred are (i) NW directed Grabens located at Mellegue and S. ez Zaouam depressions, (ii) Triassic diapirs associated to NE thrust faults of El Merdja, Bousalem, Ben Bechir and Mjez el Assa. These structures are generally covered by the Quaternary series.

The presence of both distensive and compressive structures within a compressive regime is explained by the solicitation of preexisting fault systems in the area. During the NW directed shortening occurred at the Upper Miocene age, the geodynamic evolution of Northern Tunisia was dominated by strike-slip thrust movements through the reactivation of deep major inherited faults: e.g. (i) the dextral EW oriented fault system of Ghardimaou-Thibar, and (ii) the sinister NS accident of Dehmani – Bousalem – Ras Rajel. These accidents shaped the Medjerda basin and contribute to its complex geological architecture.

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1. Introduction

Since the emergence of the modern plate tectonic theory, numerous studies have been focused to reconstruct the evolution of the Mediterranean basins in the context of the Alpine orogeny (Rosenbaum et al., 2002).

Indeed, the geological evolution of the western Mediterranean presents complicated architectures tightly associated with the orogenic processes; this is the case of the Apennines and the Maghrebides chains (Rosenbaum et al., 2002) that are closely bounded to the African and Eurasian plate convergence (Dercourt et al., 1986; Guiraud et al., 2005).

The northern Tunisia region constitutes an orogenic segment of the Northern African Alpine belt (Maghrebides) (Fig. 1) whose structural organization was affected by the shortening regime during the Miocene time (Bouaziz et al., 2002; Chihi, 1995; Rouvier, 1977).

When the African plate changed its movement, assuming a northwest orientation, it induced important thrusting and dextral transpression which were well expressed along the northern African–Arabian plate margins especially during the upper Miocene (Guiraud et al., 2005). The E–W fault systems were reactivated into strike slip dextral motion (Ben Ayed, 1994; Guiraud et al., 2005) whose pattern was modeled as pull-apart basins mainly in central Tunisia (Chihi, 1995).

At the northern portion, the dominance of the compressive tectonic is at the origin of the NE trending folds and thrust-faults which are generally associated with Triassic outcrops (Perthuisot, 1978). In the mean time, some NW oriented troughs, parallel to the compressive main constraint system, were evidenced, e.g. the Tessa Graben (Hamdi Nasr et al., 2008) (Fig. 2); this was interpreted as having taken place in the same context as those of the central Tunisia. In the other hand, some authors (Ben Ayed, 1994; Kadri and Ben Haj Ali, 1999) suggested the intervention of the conjugated EW and NS
strike slip faults along the major deep dislocations, to explain the arrangement of compressive and extensive structures at the same time.

In fact, the structural modelings integrating the Corso–Sarde bloc displacement (Arthaud and Matte, 1977) as well as the relative lateral motion of the Tyrrenhian arch (Bousquet and Philip, 1981) are in favor to the occurrence of strike slip faulting in Northern Tunisia (Ben Ayed, 1994) (Fig. 1).

The study area is located in the Medjerda Basin (Fig. 2) which belongs to the Tellian domain. It consists of a Quaternary depression limited by the nappe zone to the north (Ben Ayed, 1986; Rouvier, 1977) and the diapiric zone called also Triassic province (Fig. 2) to the south (Perthuisot, 1978; Ghanmi, 1980).

In spite of the absence of expressed surface geology indices within the basin (Fig. 3), from geological field, Ben Ayed (1994) and Rouvier (1977) specified that the evolution of the Medjerda depression is guided, mainly, by the Neogene tectonic that has shaped the observed patterns of occidental Mediterranean.

The aim is (i) to provide information about the basin architecture, (ii) to characterize its structural pattern and (iii) to investigate its geodynamic evolution and much up its kinematics in the context of the combined African and European plate movements, especially within the occidental Mediterranean basin.

The integration of geological features and high-resolution gravity data helped to characterize the relationship of the underlying structural alignments of the zone and facilitate making coherent all...
described tectonic phases, while explaining the juxtaposition of compressive and extensive structures in the mean time.

Hence, the integrated study of gravity and surface geology information, enabled to define major lineaments and structures allowing to elaborate thus a synthetic tectonic model of the Medjerda basin consistently with the classic analogical models (Harding, 1974) while helping the integration of the study area in the overall regional context induced by the combined African and European plate movements.

2. Regional structural evolution

The structure of Northern African margin originated from complex tectonic events dating since the Late Permian, beginning with the breakup of Pangea and ending with the later Cenozoic Alpine orogeny, that gave rise to the Maghrebides (Bouaziz et al., 2002; Guiraud et al., 2005). In the region, the Alpine belts erected along the northwestern African-plate border during a series of compression episodes that initiated during the Santonian (Ben Ayed, 1986; Bouaziz et al., 2002; Guiraud et al., 2005; Sartori et al., 2004). This episode was recognized on a plate scale, as a major tectonic event (Guiraud et al., 2005) that has caused: (i) inversion along mostly EW to ENE directed faults, (ii) SE-vergent thrusts, (iii) folding and basin deformations by the action of dominant compression directed to the southeast, and (iv) subsequent shortening described in previous work by Guiraud et al. (2005).

At the eastern portion of the Maghrebides, the Alpine tectonic structures were built-up under the action of an intense tectonic activity, characterized everywhere by a Middle Miocene paroxysm (Ben Ayed, 1986; Bouaziz et al., 2002; Chihi, 1995; Guiraud et al., 2005), engendering the push out of the Tellian SE-vergent thrust sheets (Fig. 2) and their displacement over “autochtonous” marly series (Rouvier, 1977).

The second major compression occurred during the Lower to Middle Tortonian and would have continued throughout the Pliocene. This active orogeny which correlates with the southwestward migration of the Grande and Petite Kabilies microplates (Fig. 1) and collision against the North-African plate margin was associated with the opening of Algerian-Provençal, and neighboring Alboran basins (Fig. 1) (Bouaziz et al., 2002; Chihi, 1995; Guiraud et al., 2005; Tlig et al., 1991).

These major compressions induced folding everywhere in Atlasic domain of Tunisia associated to strike-slip movements along the main basement lineaments (Ben Ayed, 1986; Rouvier, 1977). The development of troughs in the foreland of the Alpine domain represents the first indices of thrusting and even subduction relaxation (Chihi, 1995) in northern Tunisia. These «pull apart» structures, directed NW (Ben Ayed, 1986; Chihi, 1995), are associated to EW dextral fault zones (Ben Ayed, 1994; Bouaziz et al., 2002; Chihi, 1995; Guiraud et al., 2005). In reality, these troughs belong to a vast domain that covers eastern Algeria, Tunisia and includes the Pelagian Sea (Fig. 2) (Chihi, 1995; Guiraud et al., 2005).

The 1/500 000 scale simplified structural map of northern Tunisia (Fig. 2) indicates grabens organized as staircase sequences with reduced lateral extension toward the north. The expressed reduction is consequent to the dominance of NE directed faults, characterized by important thrust component in northern Tunisia (Ben Ayed, 1994). This disposition proves that the structural pattern of Tunisia is tightly guided by the strength of the stress field acting during the compressive and extensive phases offering complex architectures and distinct geological provinces.

In fact, the accentuation of tectonic compression during and after the Miocene contributed largely in shaping northern Tunisia. This zone was the subject of numerous studies explaining the mode of adjustment of its structural units. Authors discussed the thrusting size and the importance of tangential movements (Ould Bagga, 2003; Rouvier, 1977), the Triassic extrusion mechanisms (Ghanmi, 1980; Hamdi-Nasr et al., 2009; Jalilouli et al., 2005; Perthusiot, 1978; Vila et al., 1994) and the adjustment of the foreland basin (Burollet, 1951).

In order to make coherent the described mechanisms that have given rise to the formation of several structural features in the Tellian zone, Ben Ayed (1994) highlighted the importance of the conjugated strike-slip faults along deep dislocations. The EW and NS convergent strike slip movements would explain the arrangement of the compressive and extensive structures of the Alpine domain of Tunisia (Ben Ayed, 1994).

Fig. 3. Geological map of the study area.

*Fig. 3.* Geological map of the study area.
3. Major fault systems

This paper focuses in the Medjerda basin that belongs to the Tellian domain and which is sided by the nappe zone to the north and the Triassic province to the South (Fig. 2). It is a post-orogenic basin (Ben Ayed, 1986; Rouvier, 1977) whose structural indices are almost completely masked by Quaternary deposits (Fig. 3).

Previous field works suggest that the Medjerda basin is bordered by EW and NS to NE directed major deep faults (Ben Ayed, 1994; Kadri and Ben Haj Ali, 1999; Perthusiot, 1978; Rouvier, 1977). These lineaments that controlled the Triassic outcrops contributed mainly in the deformation of the study area and northern Tunisia (Ben Ayed, 1994). Hence, they are organized in conjugated faults systems reactivated in strike slip thrusts during the Miocene compressions.

Indeed, the southern edge of the Quaternary depression is shaped by an important EW system fault that prolongs from Souk Ahras in Algeria (Devaux, 1969) to the Thibar region in Tunisia (Ben Ayed, 1994). This Dextral strike slip thrust accident is expressed in the surface by a relay of faults injected by Triassic material.

The Eastern limit of the basin is also truncated by the NS senesral fault system of Dehmani–Bousalem and Ras Rajel lineament (Fig. 2). This discontinuity, which length approximates 120 km, is made of three segments: the Dehmani segment, the Bousalem segment (expressed by Balta and O. kaaseb faults) and the Rass el Rajel segment (Kadri and Ben Haj Ali, 1999).

These structural features are required in a sector generally characterized by NE oriented structures taking place as response to the NW Neogene shortening regime. The concentration of compressive stress at the conjugate strike slip thrust fault intersection allows and facilitates the outcropping of Triassic material characterized by irregular thickness (Ben Ayed, 1994; Kadri and Ben Haj Ali, 1999). The curvature and the dipping to the SE of the flower structure of Thibar–Oued Zarga is a consequence of the emplacement of Triassic series at the crossing of NS and EW directed convergent faults (Ben Ayed, 1994).

In addition to these compressive structures, field studies reveal the existence of grabens oriented in the same direction as the compressive stress field. Some of them were considered as associated to E–W major fault system; those are comparable to grabens identified in central Tunisia, i.e. the Tessa graben (Hamdi Nasr et al., 2008).

Other authors proposed a different structural model to explain the adjustment of some troughs in North Tunisia. The NW directed grabens would be associated to a conjugated strike slip fault system. Grabens are generally developed in the shear corridor of crossing zones, Sidi Abdallah, Bouhartma (Ben Ayed, 1994) and Dehmani (Kadri and Ben Haj Ali, 1999) offer good examples of these structures.

4. Gravity source analysis

High-resolution gravity data acquired in the Medjerda basin were obtained from the Office National des Mines (ONM) of Tunisia. A total of 1245 stations covering an area of 1220 km² were measured; so the approximately mean density is one observation per square km. A bifrequential global positioning system (Leica made) in a differential mode was used to locate stations horizontally as well as vertically.

A Lambert North projection using the Clark ellipsoid 1880 and Carthage datum was adopted.

Free-air and Bouguer gravity corrections were performed using sea level datum and a reduction density of 2.4 g/cm³; this value results from the comparison of several methods (ONM, 2000).

- Direct measurement of densities done on 150 samples coming from five mining wells provided by ONM. The average bulk density has been valued to 2.4 g/cm³.
- The indirect method was performed using Nettleton profiles: three profiles were acquired. They have been realized over representative formations of the area of study and presenting an important altitude difference. The Bouguer anomaly profiles were computed using eight density values ranging from 2.36 to 2.5 g/cm³ using a sampling rate of 0.02 g/cm³. A 2.4 g/cm³ density value leads to the least topographic contaminated profiles.

Moreover, the good correlation between the density derived (from Nettleton profiling and rock samples measurements) allowed choosing a regional density of 2.4 g/cm³.

Bouguer and terrain corrections were calculated automatically using a digital elevation model obtained by digitizing 1/50,000 scale topographic maps. Taking into account the quality of the gravity and positioning measurements, we found that the accuracy of the survey is around 0.02 mGal for gravity measurements and 0.1 m for positioning. The near topographic corrections – zone A to zone C – were calculated after direct evaluation of local topographic variation. The faraway corrections – zones D to M – were determined using the previously determined Digital Elevation Model. A quality control of the topographic data digitization was performed through comparison with the acquired GPS data.

All computations and representations were performed using Geosoft software. All gravity values were gridded using minimum curvature technique (Briggs, 1974).

In the following the areas names as well as town, rivers and structures will be used to describe the location of the anomalies and lineaments observed on the gravity maps.

A first analysis of the complete Bouguer anomaly map (Fig. 4) indicates that the gravity responses reflect the heterogeneity in the subsurface density distribution. Thus, contrasting with its quite fairly flat and smooth nature of the plain topography and the light density of the Quaternary cover of the plain, the Medjerda basin expresses quite variable gravity distributions contrasts e.g. the Bousalem and El Merdja positive gravity anomalies.

The gravity values range from —15 mGals in the Southeastern portion to +11 mGals in the Northern part. The Bouger anomaly includes effects from sources of a local and shallow nature as well as regional and deep structures.

The separation of the corrected gravity field into regional and residual components forms an important step in the geological interpretation and subsurface modeling of the data (Blakely, 1996).

In order to isolate shallow sources, the residual anomaly was obtained by subtracting to the Bouguer anomaly the regional field. Upward continuation, based on spectral filtering, was used to obtain regional field (Blakely, 1996; Jacobsen, 1987; Jacoby and Smilde, 2009).

The upward continuation to 30 km of the Bouguer anomaly expresses a very smooth gravity pattern (Fig. 5). Very long-wavelengths are highlighted. The gravity values decrease towards the SW; these are certainly associated to the deep crustal structure. Indeed, a deep seismic geotraverse program performed in this area showed a thickening of the earth crust towards the SSW (Buness et al., 1992). Regional gravity models for the Northern Tunisia, (Mickus and Jallouli, 1999) indicate crustal thickness in agreement with the evoked seismic refraction results.

The residual map (Fig. 6) comprises the response of the relatively shallow upper crustal structures. To the SW, the residual map indicates the presence of a mass deficiency located at the Mellegue valley; the gravity low can be interpreted as a composite anomaly with a NS directed anomaly to the South and a NE elongated anomaly to the NE. Another negative anomaly, located at S. ez Zaouam, limited to the NW by a NW directed lineament, presents practically the same behavior than that of Mellegue, except for the reduction of its lateral extension.

This mass deficiency is interpreted to be due to the presence of light density sedimentary in fill essentially of Miocene, Pliocene and Quaternary ages.

Indeed, the average density of the Plio-Quaternary series as determined from a density log of a deep petroleum exploration well drilled in the El Merdja area approximates 2.15 g·cm⁻³.
Fig. 4. Complete Bouguer anomaly.

Fig. 5. Regional gravity field (upward continuation at 30 km).
Measurements performed on outcropping Miocene samples lead to an average density value of 2.25 g·cm$^{-3}$ (ONM, 2000). This bulk density is lower than that used as reduction density (2.4 g·cm$^{-3}$) characterizing the shallow geological formations of the region. This low density can explain the mass deficits associated with the negative anomalies. It is important to highlight that the observed residual anomaly distribution is very sensitive to shallow sources and in particular it bears information about the thickness of the light Miocene-Pliocene sediments. In addition, the above-mentioned exploration well cut a thick and dense Triassic anhydrite bodies, with an average density of 2.6 g·cm$^{-3}$; we assume it is associated to the observed positive gravity anomalies.

Fourier analysis helps investigating the behavior of the measured field in terms of wavelengths (Bhattacharyya and Leu, 1977; Blakely, 1996; Qiu et al., 2007). The spectral analysis enables estimation of major density contrasts and depth of the gravity anomalies (Bhattacharyya and Leu, 1977).

The logarithm of radial average of the energy spectrum is plotted versus the radial frequency. The extracted spectrum can be interpreted in terms of statistical mean depth to the tops of the set of sources present in the subsurface.

Indeed, the slopes of the linear segments of the radial average spectrum correspond to separated levels (Nouck et al., 2006). The slope of each segment provides information about the depth to the top of a set of gravity bodies (Kivior and Boyd, 1998).

The radial average spectrum (Fig. 7) exhibits three linear segments reflecting respectively; the deep sources component (3400 m), the shallow sources component (1000 m) and the noise component.

5. Subsurface discontinuities and associated structures

The horizontal and vertical derivatives enhance short wavelength information (Blakely, 1996; Jacoby and Smilde, 2009) and help to delineate lineaments associated with boundaries of rock units or faults (Blakely, 1996; Schoeffler, 1975).

In the present study we applied the enhanced horizontal gradient method (EHG) in order to detect lateral boundaries to infer the main subsurface discontinuities (Fedi and Florio, 2001). Amplitudes maxima of the enhanced gravity signal were expected to reflect the structural discontinuities and the edges of gravity sources (Blakely, 1996; Fedi and Florio, 2001).

The computed EHG map (Fig. 8) reveals the existence of three major lineaments bordering the Medjerda basin, expressing the
maximum amplitudes of the enhanced horizontal gravity gradient. We can observe a NE directed lineament (F1) which borders the southern limits of the J. Hairech, J. Rebia and the Zeflana anticlines. We can also observe an EW directed gravity alignment (F2) located at the southern border of the Medjerda plain which consists of two well expressed parallel major EW trending several kilometers long lineaments; this lineament-pair undergoes flexure before splitting into an EW branch and a NE–SW one around el Merdja anomaly. A third major gravity alignment (F3) directed NS is illustrated by well individualized branches in the eastern edge of S. Bou Bker syncline as well as around O. Kasseb to the north.

In addition to those organized major alignments, gravity data evidences quite some short wavelength lineaments characterized by a variety of orientations. The positive anomalies of El Merdja and Ben Bechir zones are limited to the north by NE directed lineaments. Badrouna and M.Assa areas are limited to the south by EW directed lineaments. NW direction is also revealed by EHG map at the eastern edge of S. ez Zaouam and around the negative anomaly of O. Mellegue.

Correlation between gravity lineaments and surface expressed faults leads to geologically characterize some EHG evidenced gravity lineaments. Lineament F2 is superimposed to the Ghardimaou–Thibar EW dextral fault system (Fig. 8) as described by authors (Ben Ayed, 1994; Devaux, 1969). F3 is the expression of the Bousalem segment (Fig. 8) of the NS Dehmani–Bousalem fault system limiting S. Bou Bker structure to the west (Kadri and Ben Haj Ali, 1999). Thus, the gravity amplitude maxima F2 and F3 which are expected to reflect the structural discontinuities (Blakely, 1996; Fedi and Florio, 2001) coincide with the described surface fault systems. This technique allows the attribution of the observed amplitude maxima on the EHG map to fault systems: surface and subsurface faults.

Indeed the northern edge of the Medjerda plain is shaped by a well individualized NE major fault system (F1), non reported in the geological maps, that represents the limit of the Alpine zone, called also “nappes zone” (Rouvier, 1977).

Moreover, beneath the Quaternary sediments subsurface fault systems were identified:

- NE and EW directed faults: the faults bordering the Merdja, Ben Bechir and M. Assa anomalies.
- NW directed faults: the faults bordering O. Mellegue and S. ez Zaouam anomalies.

The integrated interpretation of the geological mapped outcrops together with the near surface gravity responses enable a direct correlation between gravity anomalies and subsurface sources. The superposition of the Triassic outcrops on the residual map (Fig. 6 — Black polygons) help identify subsurface geological structures originating the positives anomalies distribution within the Medjerda plain.

The Triassic outcrop of J. Rharmouha, which is a mixture of dolomites, gypsum, limestone and clays (Fig. 3), is superimposable with a positive gravity response (Fig. 6). The latter, extends to the west as an EW directed lineament and to the east to the positive anomaly of El Merdja area. Based on the above calibration, the observed positive gravity response of El Merdja area would be the expression of the occurrence of shallow Triassic melted rocks beneath the Quaternary deposits.

Petroleum exploration well delivers a depth approximating 800 m. Triassic is covered by Plio-Quaternary sediments.

Similarly, the geometry and the amplitude of the positive anomalies of Badrouna, Bousalem, Ben Bechir and M. Assa areas would reflect the presence of the same melted Triassic rocks underneath the alluvial and silty Plio-Quaternary series. Contrasting-ly, the negative gravity anomalies are interpreted as due to the thick Miocene sand-shale series.

![Fig. 8. Enhanced horizontal gradient.](image-url)
6. 2.5D gravity modeling

The residual gravity anomalies were interpreted in terms of density distribution. Negative anomalies are attributed to negative density contrasts characterizing thick light material essentially made of Mio-Plio-Quaternary deposits. Positive anomalies are correlated with the denser Triassic dolomites, gypsum, limestone and clays. The global energy spectrum indicates that the shallow Triassic interfaces are situated at a mean 1 km depth. In order to quantitatively characterize the topography of the bottom of the Medjerda basin a 2.5D gravity modeling was performed.

Considering the non-uniqueness of the gravity models due to the implication of different parameters (density, geometry, depth, and size), borehole calibrated seismic reflection data was integrated to constrain the basin shape to elaborate meaningful geological models.

The selection of the gravity profile position is tightly guided by the available seismic data. Three profiles were established: two of them (P1 and P2) are perpendicular to the main structural direction. P3 would enable qualifying the observed mass deficiency area in the residual gravity field (Fig. 6).

Specific densities for each stratigraphic unit (Table 1) were deduced from the measured density well log in the study area. The adjusted final models (Fig. 9) indicate that negative anomalies are associated to the thick sequence of the Mio-Plio-Quaternary series. In particular, the Plio-Quaternary and Miocene sediments have respective density contrasts of $-0.25$ and $-0.15$ g·cm$^{-3}$. According to profile (P3), the Mellegue anomaly (Fig. 6) conveys a depressed structure lodging Miocene deposits infill which is sealed by recent Quaternary sediments. This trough is delimited by two faults which are well expressed by steep gradients in the computed response.

The positive anomalies are associated to Triassic diapirs which are almost unconformably covered by Plio-Quaternary sediments. The positive density contrast between the Triassic and the Quaternary rocks accounts for the positive gravity response expressed by the computed anomalies for all three experienced models.

The quantitative modeling of gravity profiles supports the previously shown qualitative interpretation. Indeed, the observed negative anomalies over the Medjerda basin are expression of the thick accumulations of Mio-Plio-Quaternary low-density sediments. Positive responses are associated to the coexistence of thinner Miocene series and dense Triassic rocks located at around 1 km depth under the Plio-Quaternary deposits.

7. Discussions and conclusion

Gravity provides information that helps to characterize the subsurface geology. The identified features constitute themselves new constraints to study the evolution of the geological architecture of the area. This information can be used to better establish the structural model in order to infer the tectonic evolution of the Medjerda basin which is strongly linked to the western Mediterranean geodynamic evolution. Indeed, the interpretation of the gravity maps allowed gathering a synthetic overview of the underlying structures in the area that are largely destroyed by the activity of the existing multi-direction fault systems.

The positive anomalies of M. Assa, El Merdja, Ben Bechir and Bousalem, which are interpreted as resulting from positive density contrast of the diapiric Triassic material underlying the Quaternary series, are generally associated to the NE and EW directed faults. The kinematic of these faults is characterized by a reverse component (Perthuisot, 1978). These faults correspond to the major direction of dislocation drawn by Triassic outcrops in Northern Tunisia. Thus, the described subsurface Triassic bodies rose within a compressive environment that prevailed through a NW directed shortening.

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<th>Table 1</th>
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<td>Age interval</td>
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<td>Plio-Quaternary</td>
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<td>Miocene</td>
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<td>Triassic</td>
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latter has to be occurred during the well described upper Miocene tectonic phase (Ben Ayed, 1994). These intervals are sealed by the Plio-Quaternary series. Subsurface Triassic bodies have irregular spatial distribution; the widest anomaly is expressed at El Merdja zone (Fig. 10).

The identified faults bordering Mellegue and S. ez Zaouam anomalies help clarifying the organization of these structures. They consist on NW directed negative anomalies, already well expressed in the residual gravity maps. The enhanced horizontal gradient (Fig. 8) illustrates the presence of NW directed faults characterized by an extensional movement which is responsible of the partition of the region into blocks. Thus, the arrangement of the NW directed faults allows identifying two grabens in the study area (Amiri, 2008) which are disposed parallel to the Atlasic shortening field stress perpendicular to the Tellian structures.

This complex disposition expressed by the coexistence of compressive and extensive structures is due to the occurrence of a compressive regime in the overall area; the study area is bounded by the previously described faults F1, F2 and F3. Ben Ayed (1994) described an EW dextral strike slip accident called Ghardimaou-Thibar which locates on F2. Kadri and Ben Haj Ali (1999) recognize the NS directed sinistral dislocation belonging to Dehmani–Bousalem–Ras Rejel fault system which is homogeneous with F3. These systems were reactivated as strike slip faults during the Miocene compressions (Ben Ayed, 1994).

The presented gravity analysis clarifies the identified inherited dislocations of Ghardimaou–Thibar fault system F2 which consists of two parallel major faults acting as compressive relays dragging Triassic rocks pushup and sealed by the Quaternary. Some of these Triassic intervals are outcropping in the K. Rakram and the J. Rharmoula zones (Fig. 10). F2 and F3, which cross around Thibar region, behave as conjugate strike slip systems. This organization provokes at the same time a strike slip motion and an important shortening well expressed by numerous compressive structures.

The cumulative compressive stress in the area of interference for both convergent strike-slip systems gives rise to shear corridors that originate the development of compressive structures with important structural extension, i.e. El Merdja bulge.

The depressions initiated within this compressive shear environment are characterized by variable lateral extension; the S. ez Zaouam trough which is located near the zone of interference is less extended than the Mellegue trough (Fig. 10).

Indeed, the analyzed general structural architecture is conformal to the classic analogical model of Harding (1974) of which the interference of two conjugated strike-slip faults generate compressive structures together with the development of the perpendicular extensive structures, parallel to the compressive constraint direction (Fig. 10).

These mechanisms are highlighted as EW and NS convergent Strike-slip fault system giving rise to the development of the Tellian zone structural features (Ben Ayed, 1994). The conjugated movements explain the arrangement of the compressive and extensive structures of the Alpine domain of Tunisia (Raoult, 1974). The most significant reactivations of the conjugated strike-slip faults are posterior to the tangential tectonism (Ben Ayed, 1994). The associated structures are interpreted as the consequence of the NW compressive constraints of the upper Miocene tectonism that results from the southwestward migration of the Grande and Petite Kabilies microplates, and the collision against the North-African plate margin (Cohen et al., 1980).

Therefore with the installation of the most important Miocene compressive regime, which has been verified to correlate with plate margin collision between North Africa and Southern Europe (Guiraud et al., 2005), followed by the opening of Algerian-Provençal and neighboring Alboran basins (Tlig et al., 1991), the geodynamic evolution of northern Tunisia has been dominated by strike-slip thrust movements, through the reactivation of the deep major inherited faults, generating some deformations comparable to those

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Fig. 10. Inferred structural map.
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