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Role of N-S strike-slip faulting in structuring of north-eastern Tunisia; geodynamic implications

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A B S T R A C T

Three major compressional events characterized by folding, thrusting and strike-slip faulting occurred in the Eocene, Late Miocene and Quaternary along the NE Tunisian domain between Bou Kornine-Ressas-Msella and Cap Bon Peninsula. During the Plio-Quaternary, the Grombalia and Mornag grabens show a maximum of collapse in parallelism with the NNW-SSE SHmax direction and developed as 3rd order distensives zones within a global compressional regime. Using existing tectonic and geophysical data supplemented by new fault-kinematic observations, we show that Cenozoic deformation of the Mesozoic sedimentary sequences is dominated by first order N-S faults reactivation, this sinistral wrench system is responsible for the formation of strike-slip duplexes, thrusts, folds and grabens. Following our new structural interpretation, the major faults of N-S Axis, Bou Kornine-Ressas-Messella (MRB) and Hammamet-Korbous (HK) form an N-S first order compressive relay within a left lateral strike-slip duplex. The N-S master MRB fault is dominated by contractional imbricate fans, while the parallel HK fault is characterized by a trailing of extensional imbricate fans. The Eocene and Miocene compression phases in the study area caused sinistral strike-slip reactivation of pre-existing N-S faults, reverse reactivation of NE-SW trending faults and normal-oblique reactivation of NW-SE faults, creating a NE-SW to N-S trending system of east-verging folds and overlaps. Existing seismic tomography images suggest a key role for the lithospheric subvertical tear or STEP fault (Slab Transfer Edge Propagator) evidenced below this region on the development of the MRB and the HK relay zone. The presence of extensive syntectonic Pliocene on top of this crustal scale fault may be the result of a recent lithospheric vertical kinematic of this STEP fault, due to the rollback and lateral migration of the Calabrian slab eastward.
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1. Introduction

The western Mediterranean corresponds to a plate convergence zone with a dynamic subduction of Africa below Eurasia which led to complex tectonic in the surface and active dynamic in the deep mantle (Jolivet and Faccenna, 2000). There are about 30 million years, when the Mediterranean history began, marked by series of continental collisions which induced to the formation of the Alpine chains (Serpelloni et al., 2007; Jolivet et al., 2008; Meghraoui and Pondrelli, 2012).

This complex event succession is essentially controlled by the internal dynamics of the mantle and the Slab performance (Jolivet and Faccenna, 2000). The nature of the Atlassic contractional deformation in Tunisia and the rest of the Maghrebian region is strongly debated (e.g. Rouvier, 1977; Ben Ayed, 1993; Zargouni, 1985; Bousquet and Philip, 1986; Anderson, 1996; Melki et al., 2011; Zouaghi et al., 2011; Bracène and Frizon de Lamotte, 2002; Gharsalli et al., 2013; Meghraoui et al., 2013; Essid et al., 2016; Tricart et al., 1994). In parallel, strike-slip systems have received growing attention because of duplexing and associated pull-apart structures that are closely linked to petroleum systems and mineral concentrations (e.g., Kim and Sanderson, 2006). Woodcock and Fischer (1986) suggested two end-member theoretical models for the strike-slip duplex system: (1) a strike-slip system with a

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contractional imbricate fan at both the trailing and the leading ends, and a contractional duplex in the central segment and (2) a strike-slip system with an extensional imbricate fan at both the leading and trailing ends, with an extensional duplex in the central segment.

In North-eastern Tunisia, it is clear that a model referring to strike-slip fault duplexing and associated systems is pertinent and can successfully explain structures formed during shortening phases in this area (Boccaletti et al., 1988). Following this concept, based on structural shape and geophysical data (e.g., Turki, 1985; Boccaletti et al., 1988; Morgan et al., 1998; Hadj Sassi et al., 2006), we suggest here that the strike-slip fault systems reactivated during the Atlassic deformation phase (Late Miocene) must have exercised a major control on structural deformation in North-eastern Tunisia.

The Bou Kornine-Messella (MRB) and Hammamet-Korbous (HK) faults in North-eastern Tunisia have the characteristics of the theoretical strike-slip duplex systems of Woodcock and Fischer (1986). Strike-slip faults reactivated during the compressive Eocene and Atlassic (Tortonian) phases have had a large control on the structural style in North-eastern Tunisia (Ben Ayed, 1993). The structural scheme of this region contains adjacent extensive and compressive structures: NNW-trending Grombalia graben, the N-trending MRB thrust belt and HK sinistral strike slip fault.

The goal of this paper is to examine relationships between observed fault kinematics and the tectonic evolution of North-east Tunisia zone. Based on available geological and geophysical data, we try to understand the important role of strike-slip systems in the structural configuration of the study area. Finally we identify how the geodynamic evolution of the Europe-Africa convergence exerted a first-order tectonic role during the Cenozoic period on the deformation style in the study area.

2. Regional geology and tectonic framework

The North African Tethyan margin is similar to the deformed European margin regarding the importance of tectonic inversion and structural evolution (Scandone and Patacca, 1984; Savostin et al., 1986; De Graciansky et al., 1989; Morgan et al., 1998). The structural framework of the Northern Tunisian foreland is controlled by the post-collision deformation of the “passive” northern continental margin of the African plate (e.g., Rouvier, 1977; Cohen, 1980; Burollet, 1956, 1991; Boccaletti et al., 1988; Ben Ayed, 1993; Soumaya et al., 2015). In North-eastern Tunisia, there is strong evidence for tectonic activities on north-trending normal faults during the Trias and Early Jurassic (Doglioni, 1992; Morgan et al., 1998), in particular along the «North-South Axis» (Ouali, 1984). These submeridian faults represent the eastern boundary of a Jurassic carbonate platform (Morgan et al., 1998). This limit was edified during the opening of the Tethys (Boccaletti et al., 1988). The North-trending Tethyan faults were reactivated by strike-slip movements during rifting in the African-European rift domain. In Lower Cretaceous, the Bou Kornine-Ressas belt (Fig. 1) corresponded to a palaeohigh domain (Turki, 1985; Morgan et al., 1998). The Upper Cretaceous to Eocene sedimentary sequences of Tunisia are characterized by thickness and facies variations with thin and condensed sequences in Bou Kornine and Grombalia (Turki, 1985) and further south in Enfidha region (Saadi, 1990).

The structural architecture of the Atlas belt in northern Tunisia is characterized by northeast - trending faults and major folds affecting Mesozoic and Tertiary sedimentary deposits (Ben Ferjani et al., 1990; Burollet, 1991; Ben Ayed, 1993). The MRB belt is a north-trending domain of particularly intense faulting and folding located toward the north-eastern side of the Atlas domain (Fig. 2). It is a thrust-belt structure with decreasing amplitude of deformation toward the coast (Morgan et al., 1998). Further east, this structure is surrounded by the NNW-trending Grombalia graben. Also it has been regarded as the northern part of the “«North-South Axis»”, an important tectonic line in Tunisian central Atlas (Boccaletti et al., 1988; Burollet, 1991; Ben Ayed, 1993; Dhahri et al., 2015). The N-S Axis corresponds to a deep fault system described as STEP fault (Slab Transfer Edge Propagator) by Soumaya et al. (2015) within a structural high characterized by tilted blocks, sedimentation gaps, reduced or condensed sequences and cretaceous volcanism (Burollet, 1991).

The tectonic frame defining the structure of Bou-Kornine-Ressas and Grombalia graben is the result of the tectonic inheritance of two compressional phases of Eocene and upper Miocene (e.g., Jauzein, 1967; Ben Ayed, 1993; Bouaziz et al., 2002; Khomsi et al., 2006; Melki et al., 2011) and Oligocene – Pliocene extensional regimes (Bédir, 1988; Ben Ayed, 1993; Melki et al., 2011).

In result, the distribution of structures is essentially controlled by two N-S trending major features (Fig. 1): the MRB major fault, HK fault and the secondary NW-SE trending Grombalia fault (Cap Bon peninsula). The Tortonian to recent kinematics of the Mediterranean system is relatively well established (Savostin et al., 1986) and seems to be controlled by the north-south convergence of the southern plate with respect to Europe (e.g., Nocquet, 2012).

3. Ancient faults-kinematic and Mesozoic tectonic stress

The Meso-Cenozoic paleogeography is accompanied by several periods of sedimentary anomalies which reveal the existence of synsedimentary tectonic activity, (Marie et al., 1982; Viterbo, 1983). Sedimentation occurred in an active tectonic setting, as indicated by the presence intra-formational breccias along the N-S faults of Jebel Bou Kornine-Ressas and disappearing laterally. Sediments contemporaneous with these tectonic instabilities were deposited on faulted slopes with a chaotic structure and the presence of intra-formational breccias and mass flows in land as soft-sediment deformation structures associated to the Mesozoic-Cenozoic faults.

3.1. Tectonic control of Triassic sedimentation

In Tunisia, the different paleogeographic domains of Upper Triassic (Burollet, 1956; Marie et al., 1982; Viterbo, 1983) show an organization of sedimentation areas in two distinct environments: a carbonate platform with marine sedimentation occupies the Cap Bon Peninsula and the Pelagian Sea, and evaporatic basins with evaporitic facies characterize the entire Atlas area (Fig. 2). The diapiric structures of Jebel Ressas and Jebel Messella were formed by the mobilization of these Triassic evaporates (Turki, 1985). However, the carbonate Triassic facies found in the Cap Bon Peninsula allows explaining the absence of halokinetic structures in this region.

In the study area, the limit between these evaporitic and carbonated areas approximately coincides with the major HK fault (Fig. 2), which seems to control this important facies variation. The tectonic setting during the Triassic is characterized by an extensional tectonic regime, with a minimum horizontal stress (Shmin) oriented N20-N30°E (Ben Ayed, 1993), which activated the HK fault (Fig. 2).

3.2. Tectonic control of Jurassic sedimentation

The Jurassic paleogeographic environment in northern Tunisia corresponds to a deep marine and subsiding domain (Bonnefous, 1972; Marie et al., 1982; Rais, 1995). But in our study region, the carbonate sedimentation in this period is characterized by the intercalation of several intraformational breccias sets (Bujalka et al.,

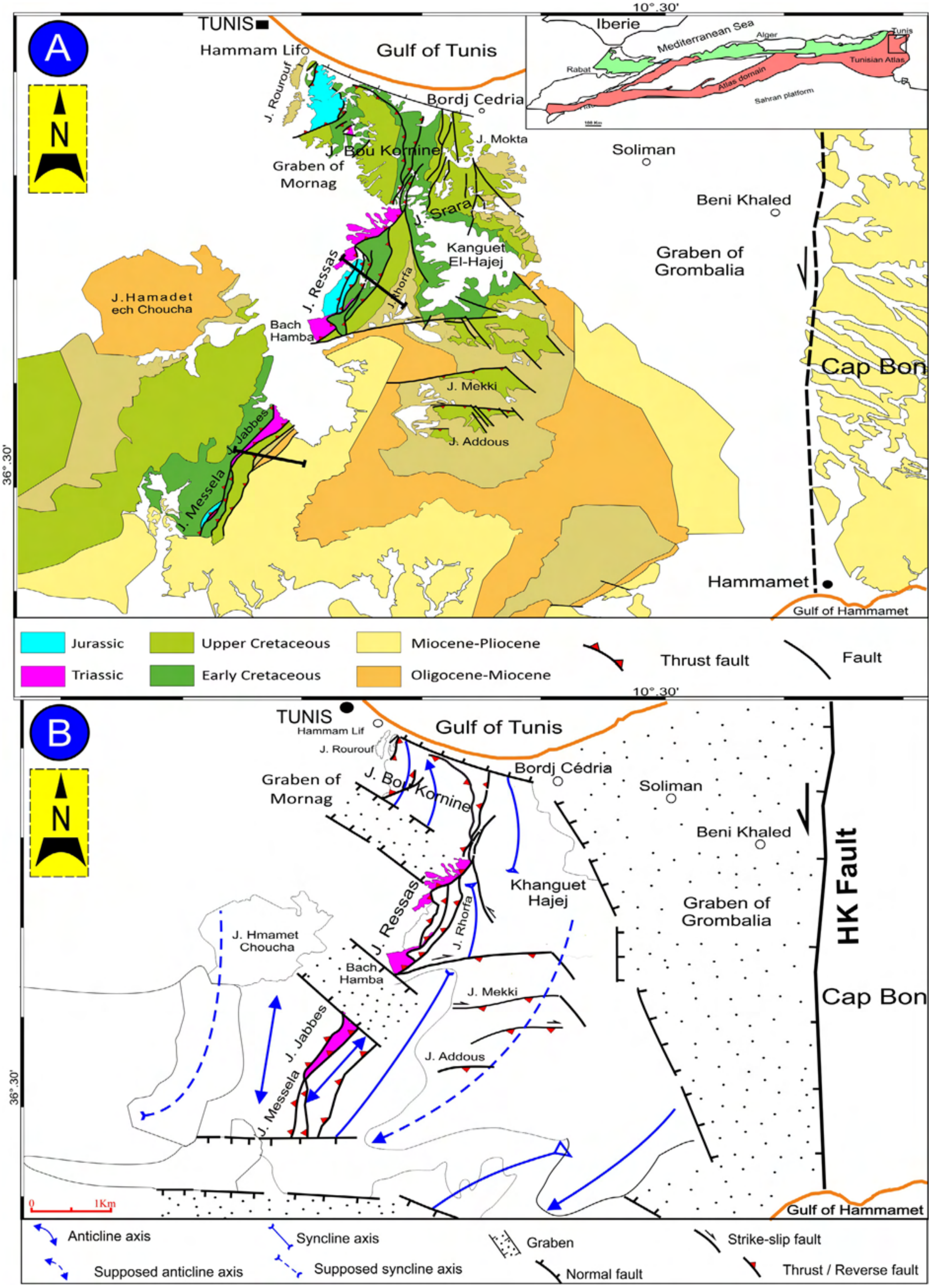

Fig. 1. Study area framework; (A) geological context (Bujalka et al., 1971, modified), (B): structural sketch.

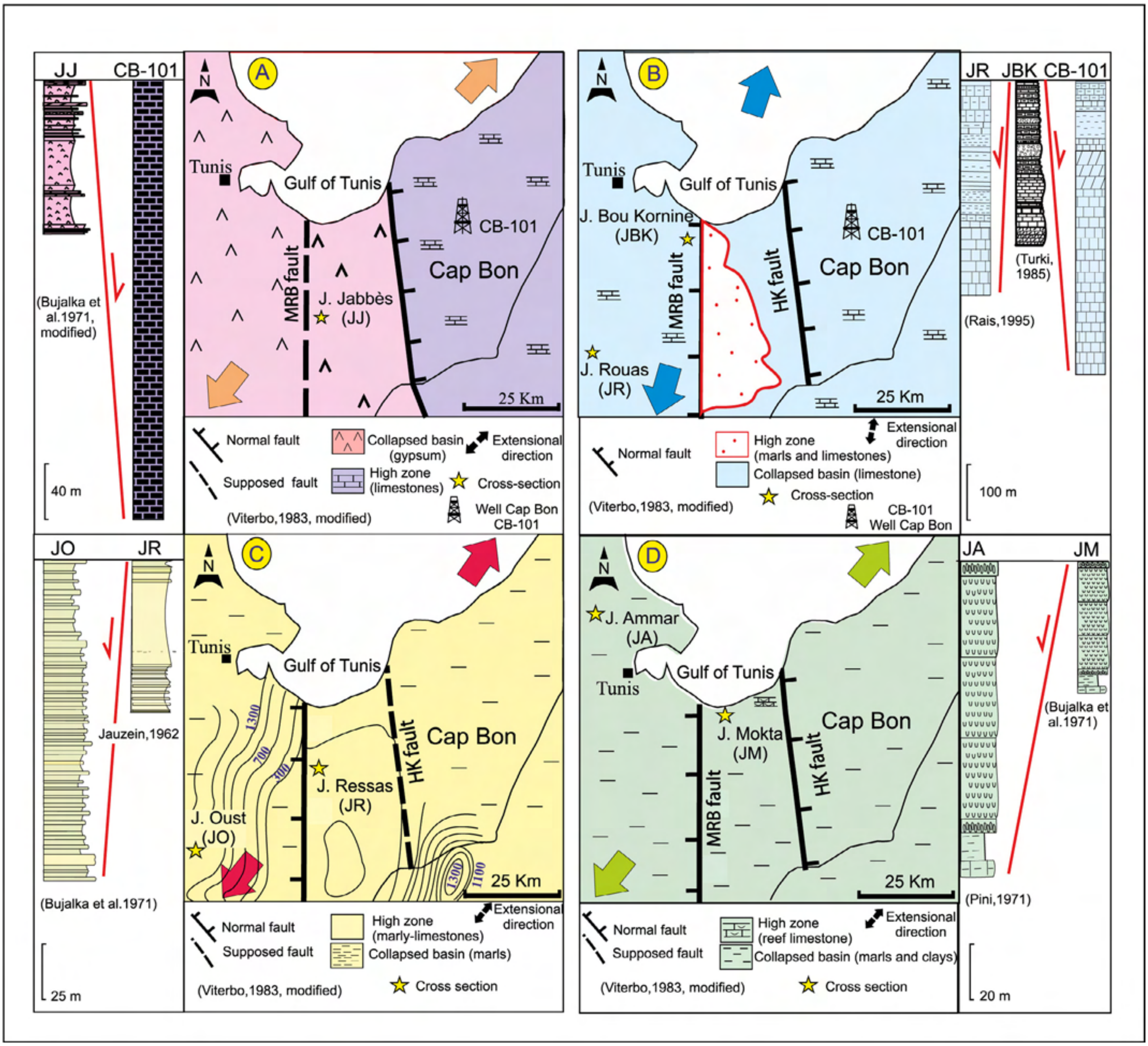

Fig. 2. Paleogeography and tectonic control of sedimentation within the study area during Mesozoic periods; (A): Trias, (B): Jurassic, (C): Barremian-Aptian, (D): Cenomanian - Maastrichtian.

1971; Cossey and Ehrlich, 1978) which appear along the MRB fault. The periods of instability are associated with synsedimentary tectonic manifestations during Kimmeridgien, Berriasian and Valanginian ages (Schamel and Mellgard, 1982). The Jurassic tectonic events, with an extensional regime and a Shmin oriented N10 to N30°E (Ben Ayed, 1993), reactivated the MRB fault by normal-oblique slip. Correlation of stratigraphic logs of this period confirms the hypothesis of the presence of an emerged zone (Bonnefous, 1972; Fuchs, 1973; Soussi, 2003; Turki, 1985), corresponding to a horst developed in the top the Bou Kornine-Ressas tilted block (Fig. 2).

3.3. Tectonic control of Aptian-Barremian sedimentation

During the Barremian-Aptian, the sedimentary environment was characterized by the development of deep basins and horsts, limited essentially by N-S faults (Ben Ayed, 1993). At this time, the study area evolved as a horst domain, bounded on the west and east by the sub-meridian MRB and HK faults respectively. On this horst, these faults isolated a shallow environment, characteristic of a reef platform domain, which developed around an emerged area (Marie et al., 1982).

The tectono-sedimentary markers preserved from this period corresponding to gravity tectonics (Marie et al., 1982; Turki, 1985) locally occurred along the N140°E fault which borders the Grombalia trench: olistolithes and monogenic breccias are encountered in the Barremian and slumping figures developed in the Aptian clays of the Bou Kornine massif (Fig. 2).

The tectonic activity starts with an extensional regime in the lower Aptian and evolves during the Albian-Aptian into a compressive regime, characterized by an E-W maximum horizontal stress SHmax (Ben Ayed, 1993). Correlation of the Albian-Aptian stratigraphic logs evidences an emerged area near the southern part of MRB fault and reduced/condensed sedimentation on the elevated compartment (Fig. 2).

3.4. Tectonic control of Cenomanian-Campanian sedimentation

In study area, the Cenomanian-Turonian sedimentation is characterized by para-reef bioclastic limestone (Isis member), deposited in an external platform (Marie et al., 1982). The para-reef limestone is separated from the deep basin of Mornag by the MRB fault (Fig. 2). This accident seems to control sedimentation, separating a deep depositional environment in west from a limestone reef to the east (Fig. 2). Further east, the limestone reef thickens, towards the HK fault, before grading into clays with planktonic microfauna in the Cap-Bon, characteristic of open sea (Marie et al., 1982). Thus, the study area is limited again by two north-south major faults which control the sedimentation during the Cenomanian-Turonian. Tectonic activity of this period is characterized by an extensional tectonic regime, with a minimum horizontal stress (Shmin), oriented NE-SW (Ben Ayed, 1993) (Fig. 2). The extensional tectonic regime continues during the Campanian-Maaestrichtian, generating synsedimentary faults recognized in several regions of Tunisia (Ben Ayed, 1993; Bédir, 1988; Negra, 1984; Dlala, 2002).

4. Tectonic stress evolution

4.1. Eocene compressive phase

The major North-South MRB and HK faults zones, which acted as paleogeographic limits during the Mesozoic, are part of a large strike-slip corridor called the "«North-South Axis»", extending from the Saharan platform at the South to the Gulf of Tunis at the North. It separates the Atlas area from the Pelagian Block (Burollet, 1991; Ben Ayed, 1993; Bédir, 1988; Boccaletti et al., 1988). In this structural context, our study area is located in a relay between two major strike-slip faults (HK and MRB, Fig. 3). This is a contractional duplex and a privileged place of stress concentration and development of local stress field. Numerous authors are in agreement that the Eocene compression in the Tunisian Atlas domain is oriented NW-SE (e.g., Touati, 1985; Ben Ayed, 1993; Kadri et al., 2001; El Ghali et al., 2003; Khomsi et al., 2004; Mzali and Zouari, 2006). In the Bou Kornine-Ressas-Messella belt, the Eocene shortening phase is expressed by the angular unconformity of the Upper Eocene over different units of the Cretaceous (Jauzein, 1967). In this context, the average SHmax orientation is NW-SE in a compressive tectonic regime (Ben Ayed, 1993; Boccaletti et al., 1988). This shortening remobilizes the major N-S faults in an oblique slip way, causing tectonic inversions and generating sub-meridian thrusting (Fig. 3).

At the pre-existing deep N-S fault of MRB, the trajectory of SHmax is deviated from the NW-SE, to become perpendicular to the two large sub-meridian faults (Fig. 3). This E-W stress direction generated the emerging overlap of Ressas-Messella and a blind thrust in the Mesozoic deposits (Creusot et al., 1992; Boccaletti et al., 1988; Morgan et al., 1998) (Figs. 3 and 4). This stress perturbation also developed submeridian reverse faults that can be connected in depth to form "flower structures" (Mercier et al., 2011). In the central part of this contractional duplex, the SHmax direction re-oriented into an N-S direction and generates nearly E-W reverse faults and overlapping zones (Jauzein, 1967; Ouahchi et al., 1993).

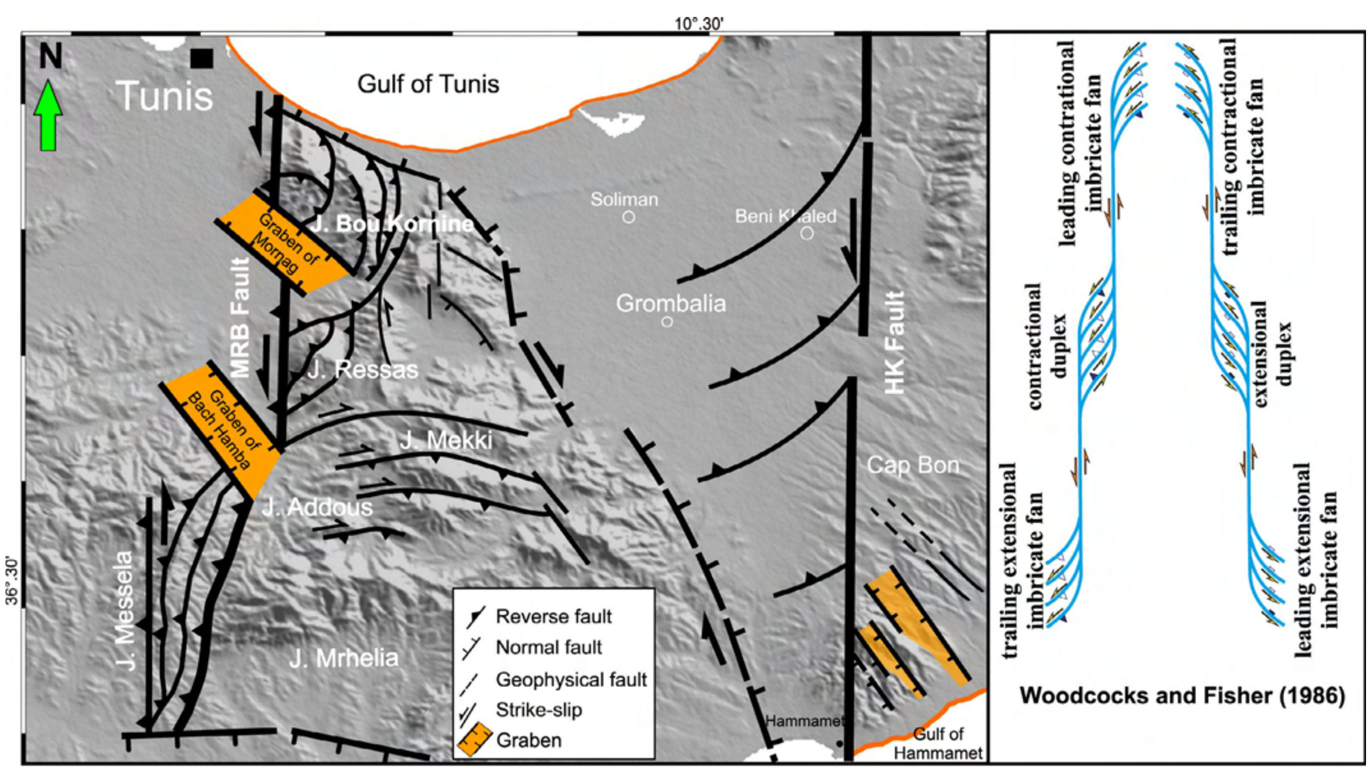

Fig. 3. Structural model for the Eocene; (A): Structural sketch of the area during the Eocene (Chebbi, 1995; ETAP, modified), (B): Kinematic model of strike-slip (Woodcock and Fischer., 1986).

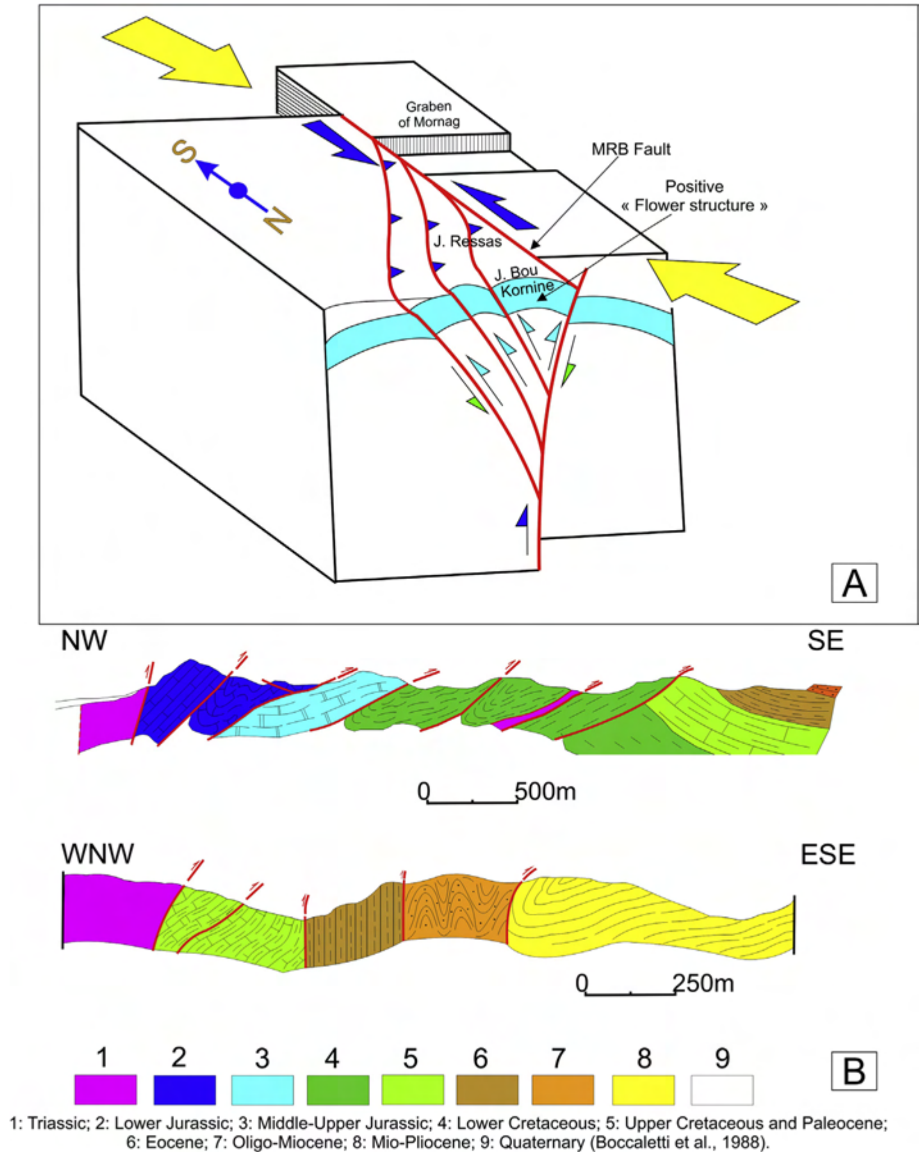

Fig. 4. (A): Sketch of the positive flower structure associated a strike slip of Bou Kornine-Ressas- Messella during the Eocene, (B): Geological cross-section (see position in Fig. 1A) showing NNE-SSW overlaps a positive flower structure (Boccaletti et al., 1988).

At the Messella structure, a new local compressional relay zone appears along the major N-S strike-slip fault of MRB and allows the development of NNE-SSW overlaps (Fig. 3). During the same period the NW-SE grabens of Mornag opened in parallelism to the general SHmax direction (Fig. 3).

The NW-SE SHmax of the Eocene compressional phase is oblique to the N-S HK fault, reactivating it as sinistral strike-slip and producing the contractional imbricate fan in the restraining bend recognized by the petroleum exploration in the Beni-Khalled - Soliman region (Chebbi, 1995). At the southern edge of this sinistral strike-slip, the decline of deformation creates extensional structures. There are trailing imbrications fan of normal and strike-slip faults represented by the NW-SE graben system of the Hammamet-Nabeul region (Fig. 3).

Thereby, in our study area, the imbricate fault system consists of NNE-SSE to NE-SW reverse faults, overlapping and strike-slip faults, a part of the contractional duplex situated between the two major sinistral strike-slip faults of MRB and HK. The leading contractional imbricate fan along the MRB fault (Fig. 3), generated during the Eocene shortening, may be interpreted such as positive flower structures (Fig. 4). The spatial distribution of overlaps associated with asymmetric flower structure, and their location on the East compartment of the Messella-Ressas Bou Kornine (MRB) fault is easily explained when considering the collapse of asymmetrical graben system of Mornag just before the intervention of folding phases.

4.2. Oligo-Aquitanian extension and graben formation

Within clay-sandstone series of Oligocene age, the synsedimentary faults are identified north of the Bou Kornine structure. These are normal faults oriented N130-N170°E related to an extensional tectonic episode with a NE-SW Shmin (Ben Ayed, 1993). Geophysical investigation in the Grombalia plain shows that the Oligocene extensional tectonic continued during the Aquitanian (Hadj Sassi et al., 2006).

During the Oligo-Aquitanian, the HK fault was reactivated and synthetic normal faults oriented N140-170°E were created (Fig. 7).

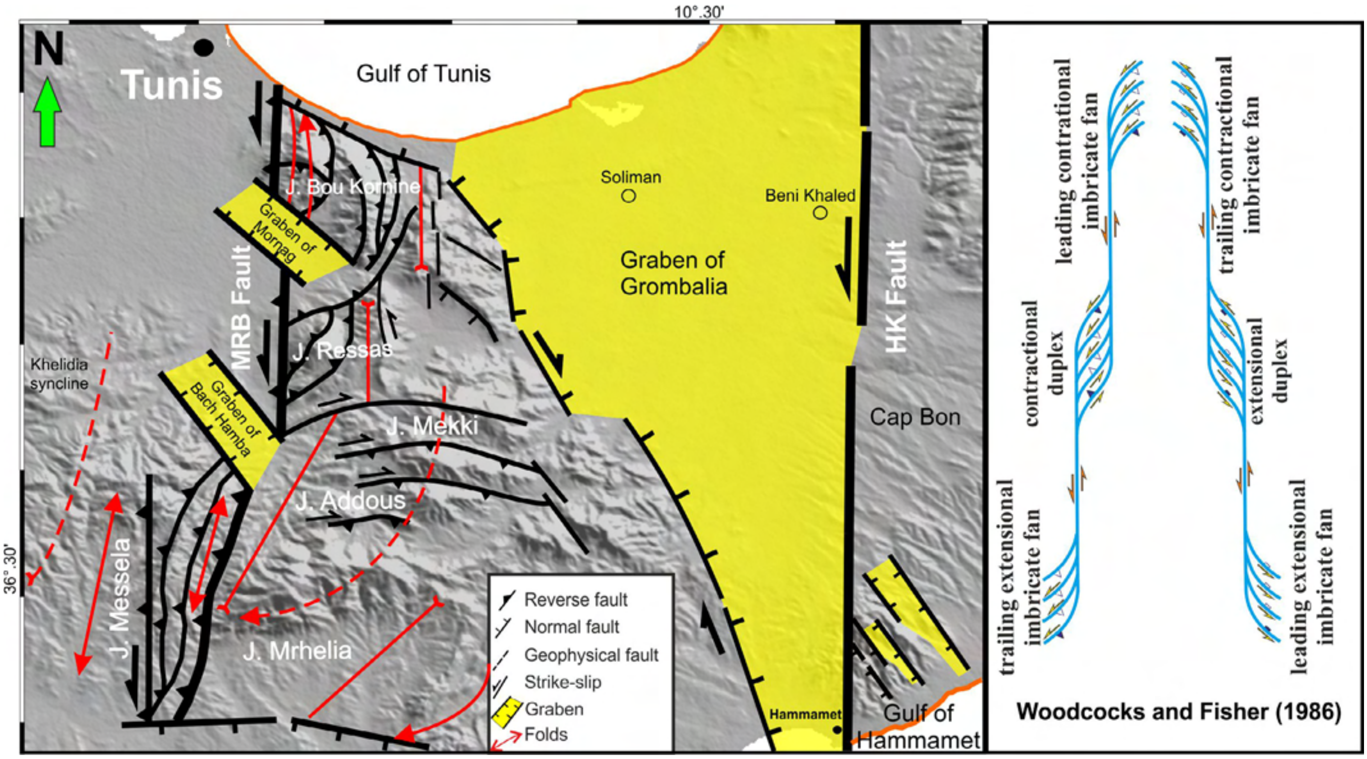

Fig. 5. Structural model for the Upper Miocene (A): Structural sketch of the study area during the Upper-Miocene, (B): Kinematic model of strike slips (Woodcock and Fischer., 1986).

There form negative flower structures with (half) grabens associated with the HK fault (Hadj Sassi et al., 2006). These types of structures will accentuate and promote the active post-Burdigalian subsidence in the Grombalia graben.

4.3. Reactivation of inherited structures in the Tortonian

In the whole domain of the Atlas, the upper Miocene compression is oriented in a NW-SE direction, recognizable since the Tortonian (Colleuil, 1979; Ben Salem, 1992). This Atlassic folding phase creates NE-SW folds and thrusts, well known in the Maghrebide chain (Tell) and its Atlassic foreland. (e.g., Jauzein, 1967; Richert, 1971; Zargouni, 1985; Ben Ayed, 1993; Rouvier, 1977; Perthuisot, 1978; Bédir, 1988; Boukadi, 1994; Ghanmi, 1980; Turki, 1985; Chihi, 1995).

During the Upper Tortonian, the fault system inherited from the Eocene epoch was reactivated and a new tectonic inversion remobilized the N-S trending faults known in the study area. In the Bou Kornine-Ressas domain, the reactivation as oblique reverse faults (leading imbricate fan) along the major N-S strike-slip generated a large positive flower structure (Fig. 5). In the strike-slip movements, Triassic diapirs appeared in the relay zones (compressive and extensive) to evolve in asymmetric flowers structures during the Miocene folding. The N-S blind thrusting of Eocene age was reactivated by tangential tectonics, giving rise to submeridian (NNE) overlaps that reach the surface (Fig. 5).

During this period, narrow and overturned N-S folds appeared, occasionally without an overturned flank. These folds are associated with the major flower structure of Bou Kornine, appointed by ancient authors as “Anticlinorium of Bou Kornine” (Castany, 1952; Bujalka et al., 1971; Turki, 1985). At smaller scale, the overlaps and reverse faults can be connected to form ramps and landings structures (Creusot et al., 1992; Morgan et al., 1998).

In the Messella structure, reactivation of the compressional relay provides both reverse faults and folds oriented NE-SW (Fig. 5). In front of this compressive domain and during the Upper Miocene, large folds appear with regular terminations, but whose axial planes underwent a significant deviation, changing from NE-SW at Messella to N-S in the Bou Kornine structure. In the vicinity of some pre-existing faults oriented N110-130°E, folds are developed without periclinal closure in the eastern part of the Bou Kornine-Ressas belt (Fig. 5). At the southern tip of the HK fault, normal oblique trending NW-SE faults (Fig. 6) are reactivated. They provide a NW-SE graben structures in the Gulf of Hammamet (Bédir, 1988) and half-grabens with a similar orientation in the Nabeul region (Colleuil, 1979). However, the imbrications of NE-trending reverse and strike-slip faults (Eocene age) in Soliman-Beni-Khalled region are buried under the thick Oligo-Miocene series of the Grombalia graben (Figs. 6 and 7). This is an asymmetrical rift with no-parallel border faults, a western part limited by antithetic trending N140°E fault (Fig. 7) and an eastern part occupied by the N-S synthetic HK fault (Fig. 5).

4.4. Opening and collapsing of Quaternary grabens

During the Early Quaternary, the Atlas area was affected by a new submeridian compressive phase (e.g., Burollet, 1956; Jauzein, 1967; Kamoun et al., 1980; Zargouni, 1985; Bousquet and Philip, 1986; Ben Ayed, 1993; Soumaya et al., 2015). This shortening event reactivated the pre-existing structures and accelerated the erosion process while Quaternary deposits filled valleys and depressed areas. During this time, the Grombalia and Mornag grabens continue to open in parallelism with the NNW-SSE SHmax direction and developed as 3rd order distensives zones within a global compressional regime. This relaxation local event is expressed by the grabens collapse (Figs. 6 and 7) in North-eastern

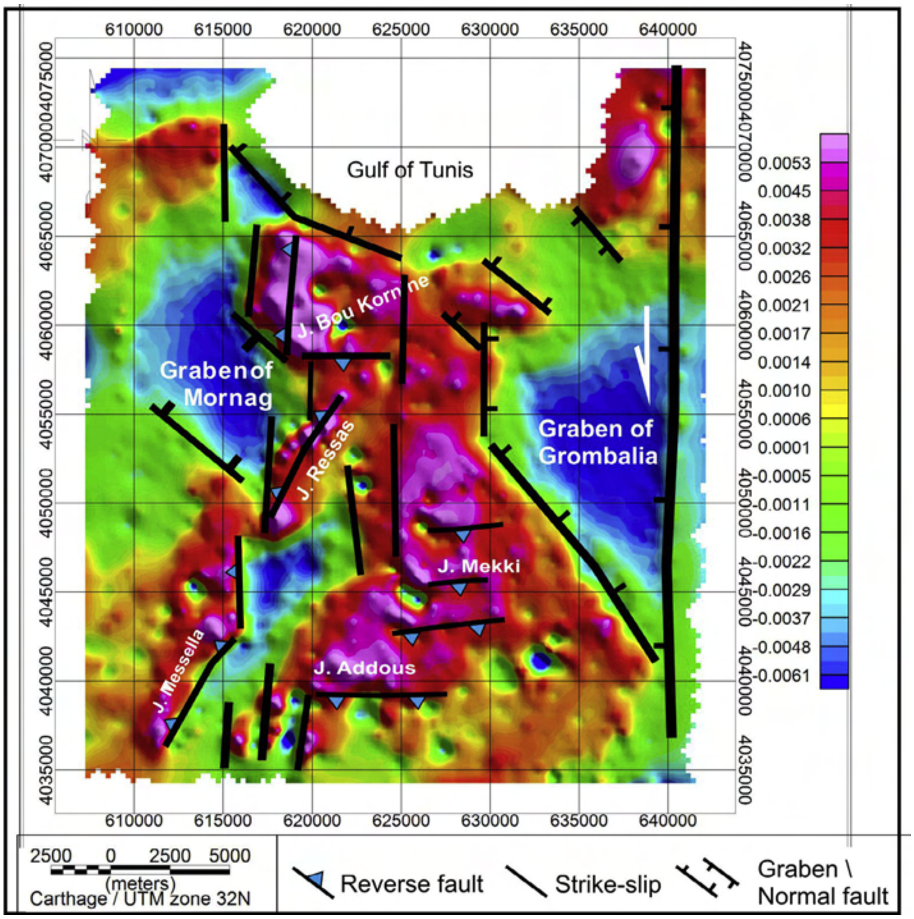

Fig. 6. Gravimetric map showing the major faults and grabens in the study region.

Tunisia and the Pelagian block (Soumaya et al., 2015). At this period, an active subsidence is established within these small rifts with accumulation of over 500 m of fluvial sediments in some regions (e.g., Castany, 1952; Burollet, 1991; Jauzein, 1967; Richert, 1971; Philip et al., 1986). Following this Quaternary collapse, the sea invaded the Grombalia graben once again during Late Quaternary to form the "Old Gulf of Grombalia" which occupies the current plain (Castany, 1952).

4.5. Stress inversion of fault-slip data

Fault-kinematic investigations of the Northeast Tunisian region by Ben Ayed (1993) suggest that the N-trending HK and MRB faults bordering the Grombalia depression are dominated by left-lateral movement under a strike-slip regime with a general NW-SE horizontal compression (Tortonian phase). Here, we propose a more complete revision of fault-kinematic data in the study area and related paleo-stress inversion results based on new field data compilation and their stress inversion. Brittle data (fault planes with slip line and slip sense) have been measured at several sites along the Hammamet-Korbous and Bou Kornine-Ressas fault systems and analyzed for reconstructing paleo-stress tensors with the program Win Tensor (Delvaux, 2011), using the procedure described in Delvaux and Sperner (2003) and derived from Wallace (1951), Bott (1959) and Angelier (1989, 2002).

The inversion of the fault slip data collected in the Bou Kornine-Ressas-Messella structure gives a strike-slip to compressive stress tensors with an average NW-SE SHmax (Fig. 8 and Table 1). Stereoplots characterizing this area shows a directional control by the reactivation of N-S to NE-SW (leading contractional imbricate fan) and E-W faults with reverse and strike-slip kinematics, which form dominant tectonic features in this zone. These features are N-E to N-S overlaps and strike-slip faults inherited during the Mesozoic time (Jauzein, 1967; Turki, 1985; Ben Ayed, 1993; Morgan et al., 1998) and reactivated during the Eocene and Upper Miocene NW-SE compressive phases (e.g., Turki, 1985; Boccaletti et al., 1988).

Further east, in the surrounding of the Grombalia graben and along the HK fault, the stress inversion results evidence a distensive to strike-slip stress tensors with NE-SW trending Shmin (Fig. 8 and Table 1). This average extensional to transtensional stress regime is obtained by reactivation, during the Pliocene-Quaternary (Ben Ayed, 1993), of NW-SE (trailing extensional imbricate fan) to N-S ancient and master strike slip fault system. These results are coherent with the interpretation of seismic profiles which shows thick Plio-Quaternary deposits within the Grombalia graben and along the major HK fault (e.g., Castany, 1952; Hadj Sassi et al., 2006) (Figs. 7 and 8).

4.6. Reconstitution of stress trajectory

From faults slip data and their stress inversion, we reconstructed the stress field during upper Tortonian, considering that the punctual data of paleo-constraints had a regional scale meaning (Figs. 8 and 9). Tectonic and microtectonic index of this period corresponding to a NW-SE compression associated with NE-SW

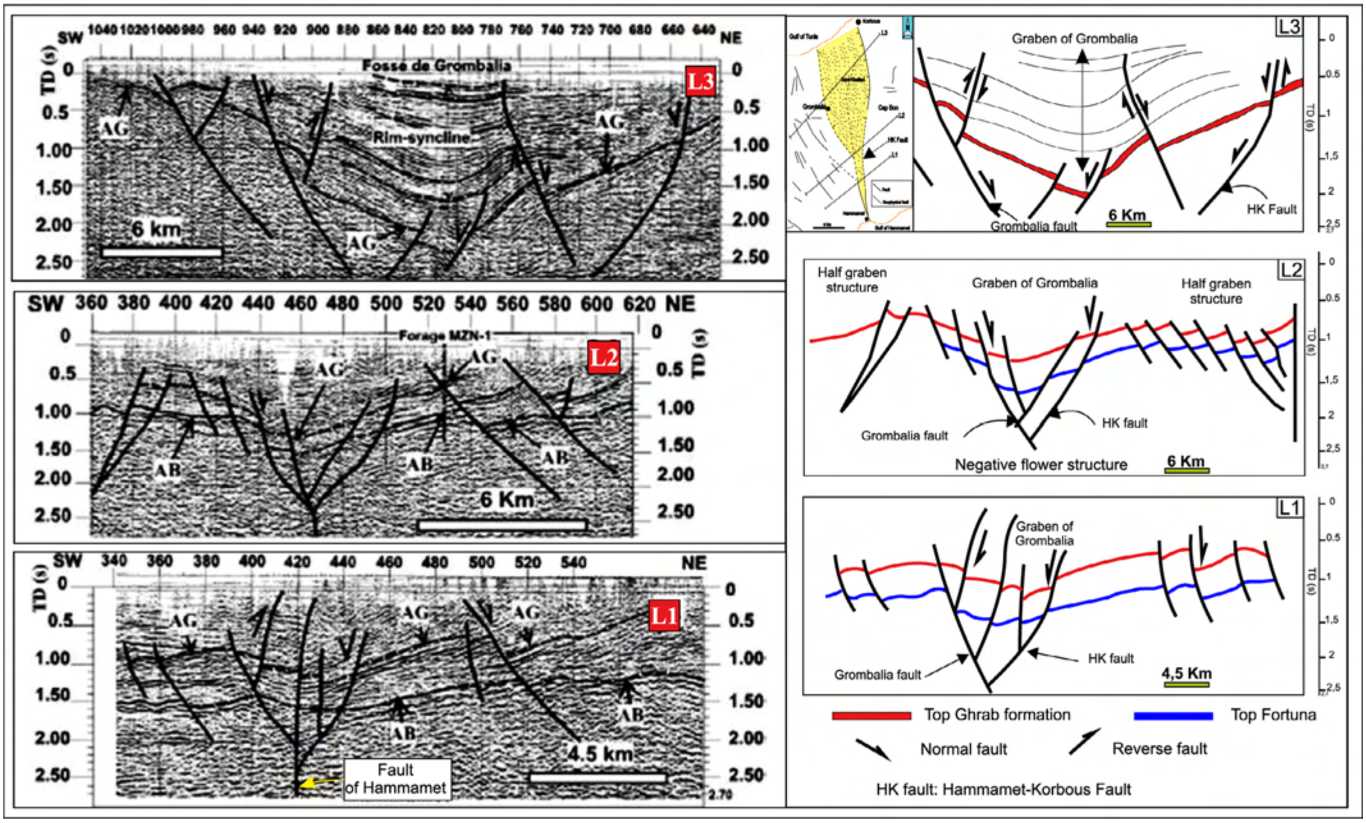

Fig. 7. Cross-section showing a negative flower structure in the graben of Grombalia (Hadj Sassi et al., 2006; modified).

extension which occurs locally, allowing the formation of NW-SE grabens.

The stress field of the upper Tortonian period has an average NW-SE SHmax direction on the entire region. But, the SHmax trajectories stress describe a range from the edges of the wrench system towards the main strike slip zone (Fig. 9). They are disturbed along the N-S faults MRB and HK, where SHmax is close to E-W, perpendicular to these major faults. This significant deviation of the stress field can explain the local formation of folds and submeridian overlaps in the vicinity of these major faults.

Inside the strike-slip zone, the orientation of the σ1 stress presents variations associated with the disturbance of the regional stress field. The average trending NW-SE SHmax, shows a deviation around the master N-S faults that could explain the varied directions of folds and overlaps axes within the strike-slip band (Fig. 9).

Locally, we note also the existence of a local extensional disturbance of the regional stress regime, with an average Shmin oriented NE-SW (Fig. 9). It is associated to NW-SE Mornag and Grombalia grabens, which were opened parallel to SHmax, inside and outside the main strike-slip zone (Fig. 9).

5. Discussion

5.1. Tectonic role of major strike-slip faults

With integrated analysis of the characteristics of the strike-slip structures in North-eastern Tunisia, we found that MRB and HK faults form a typical strike-slip fault system (Fig. 8). The leading part is dominated by the MRB fault segment represented by NNE-trending contractional imbricate fan. The trailing part is expressed along the HK fault defined at the Grombalia and Nabeul grabens by a NW-SE extensional imbricate fan. All these structures are integrated in a N-S strike-slip contractional duplex.

During the Mesozoic, the master faults of HK and MRB largely controlled the paleogeography and tectono-sedimentary activities in the study area by lateral variation of sedimentation and facies type. This domain was structured into N-S trending horst and grabens during Cretaceous in a dominant extensional regime. In Eocene, a contractional sinistral strike-slip duplex formed with a trailing strike-slip-compressional imbricate fan along the Bou-Kornine Ressas segment while a leading strike-slip-extensional imbricate fan was initiated on the HK fault. During the NW-SE Upper Miocene compression, reactivation of this contractional strike-slip system occurred with the development of the NE-trending fold-and-thrust belt. Near the northern edge of the Bou Kornine-Ressas belt, folds and overlapping structures have are trending NNE to NS. These compressional features appear as positive flower structures related to the sinistral MRB strike-slip fault. This can be interpreted as witnessing a deviation of the SHmax trajectory towards an E-W orientation near the N-S ancient deep fault of MRB. These structures, inherited during Eocene and late Miocene, are reactivated according the same directions during the NNW-SSE compressive Quaternary phase (Ben Ayed, 1993; Soumaya et al., 2015). Further east, a collapse of Grombalia graben (Hadj Sassi et al., 2006) occurred essentially in Northern part near the Gulf of Tunis. There is thus a coexistence of distensive and compressive structures within a general NW-SE to NS compressional tectonic regime.

As a result, a leading contractional imbricate fan developed around the northern master fault segment of STEP fault relay (Bou Kornine-Ressas-Messella) and a trailing extensional imbricate fan dominated the eastern segment of the Hammamet-Korbous fault.

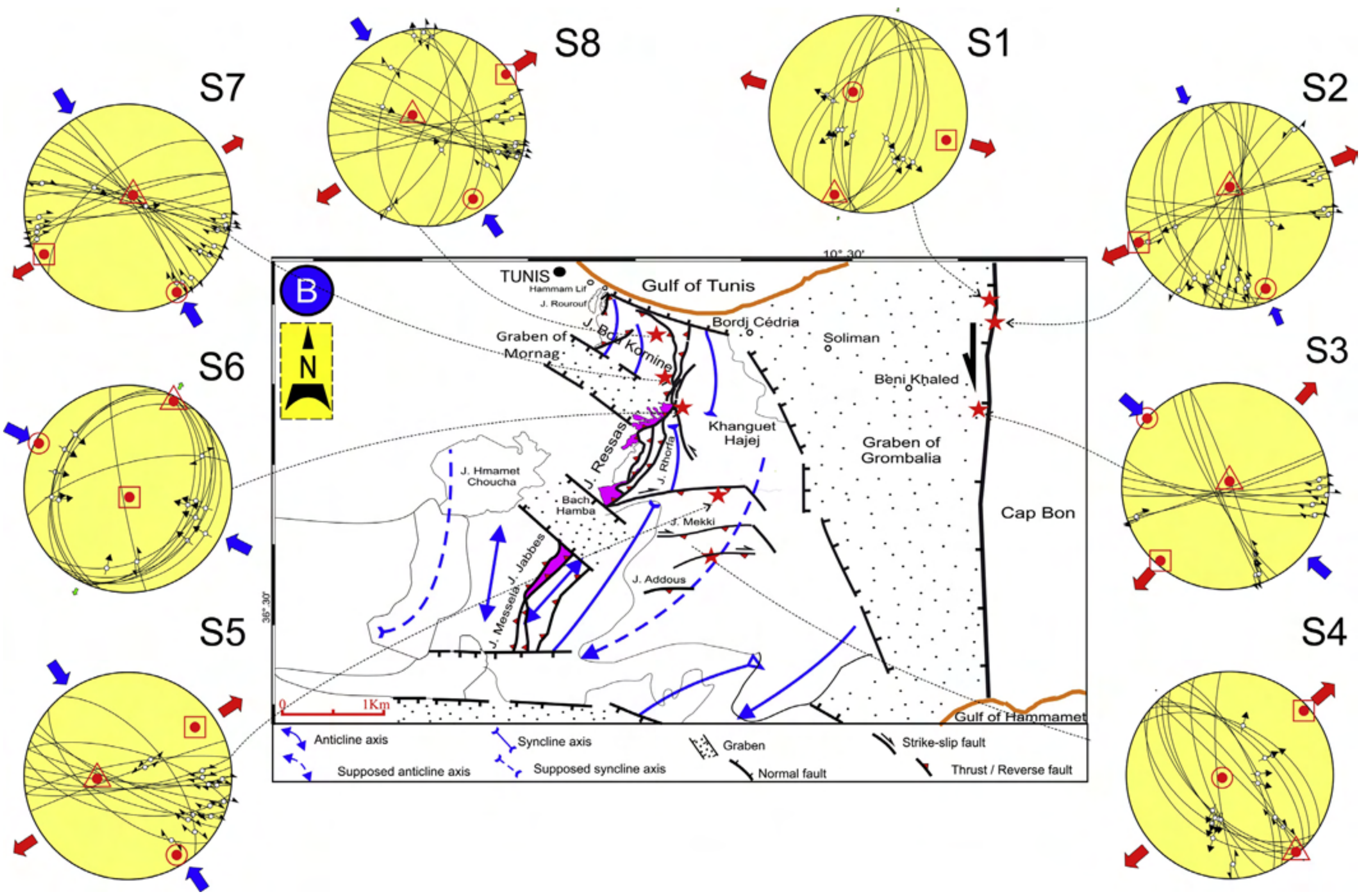

Fig. 8. Paleostress stress tensors inverted from fault-slip data on the sites located in the study region during the Upper Miocene.

At a large scale, these imbricate fan systems belong to a sinistral strike-slip system duplex under an overall compressive tectonic regime with NW-SE SHmax. All these deformations occurred under the Cenozoic NW-ward Africa-Eurasia convergence.

This model can readily explain why and how the Bou-Kornine-Ressas-Messella Mountains are the only such structurally elevated region with N-S direction, forming a rhomboedric horst surrounded by the large Grombalia graben. An alternative interpretation is that the HK and MRB faults form the west and east boundaries of a left lateral strike-slip duplex (Fig. 4) in which the extensive and compressive tectonic features coexist under an overall convergent regime with NW-SE SHmax. Our interpretation is different from that proposed by Creusot et al., (1992) and Morgan et al., (1998) who consider that NNE-SSW overlaps of MRB as simple frontal ramps.

Table 1
Parameters of the paleo-stress tensors inverted from fault-slip data.

Site name	n	σ_1	σ_2	σ_3	R′	SHmax	Shmin	Reg
(S1)	14	71/173	18/018	07/285	0.45	012	102	NF
(S2)	17	14/157	75/000	04/248	1.21	158	068	SS
(S3)	15	04/126	71/012	19/218	1.87	126	036	SS
(S4)	14	84/251	02/139	06/049	0.55	139	049	NF
(S5)	14	11/148	66/265	21/254	1.55	146	056	SS
(S6)	14	04/297	05/027	83/170	2.24	117	027	TF
(S7)	17	07/150	79/022	08/241	1.67	150	060	SS
(S8)	17	15/147	74/311	24/256	1.47	146	056	SS

(n): number of data used in the stress inversion; (σ_1, σ_2, σ_3): orientation of the principal stress axes in plunge/azimuth format; (Reg) stress regime according to the World Stress Map, (SHmax, and Shmin): respectively, maximum and minimum horizontal principal stress directions; (R′): stress regime index, (limiting factor): the factor that is limiting the quality of the result. These parameters are described in more details in Delvaux and Sperner (2003) and Delvaux and Barth (2010).

5.2. Geodynamic implications

Based on our interpretation and previous works, we can relate the surface deformation and faults kinematic within the study area to the geodynamic and internal dynamic processes in Central Mediterranean. The Tertiary and Quaternary tectonic regimes in the Pelagian and Atlassic foreland included our study sector are influenced by the subduction and dynamics of internal forces beneath the complex Maghrebide mobile belt. The first order compressive to strike-slip tectonic regime in Northern Tunisia is due to the reactivation of inherited structures (reverse/strike-slip faults) mostly formed as a result of the slab detachment and its roll-back towards the Calabrian arc during the Cenozoic (e.g., Faccenna et al., 2007; Billi et al., 2011; Soumaya et al., 2015). The tectonic stress resulting from the slab roll-back and the active Africa/Eurasia convergence may be the first responsible for the reactivation of the major N-S strike-slip fault in North-eastern of Tunisia, with sinistral movement and creation of a compressional relay between HK and MRB faults (Fig. 10). In this region, a transtensional tectonic regime developed after the slab segmentation and eastward migration, 5–4 Ma ago (Lucente et al., 2006; Argnani, 2009; Faccenna et al., 2005; Soumaya et al., 2015), contemporary with the opening of the Strait of Sicily "rift zone" further East (Billi et al., 2011). This transtensional third order regime remains currently active by the

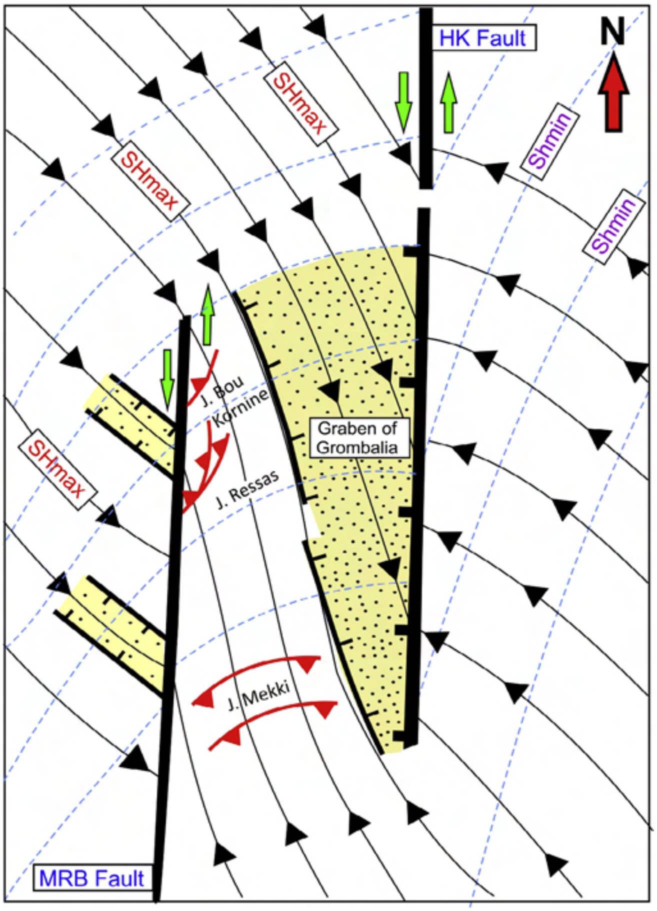

Fig. 9. SHmax and Shmin stress trajectories near major strike-slip faults and associated structures within the study area during the Upper Miocene.

cohabitation of strike-slip and extensional earthquakes events (Soumaya et al., 2015).

Seismic tomography images show that the STEP fault of «North-South Axis» – Hammamet-Korbous (Fig. 10; section AA') coincides with the eastern boundary of the positive anomalies attributed to the residual Slab of Tunisia (e.g.; Govers and Wortel, 2005; Soumaya et al., 2015) and the western edge of the "Slab windows" of the Sicilian Channel (Jolivet and Faccenna, 2000; Piromallo and Morelli, 2003; Faccenna et al., 2005). Here, we suggest a primary role of this preexisting weak zone (STEP fault), which is a lithospheric scale structure and active as subvertical tear fault during the retreat or African slab, in the active geodynamic of the study area. This first order major structure of STEP fault, with magmatic leading (Burollet, 1991) and a left lateral slip forms a compressional relay of second order in Grombalia-Bou Kornine-Ressas region (Fig. 10). On the other hand, along the eastern segment of this STEP fault system in Grombalia zone, the presence of E-W Plio-Quaternary extensive tectonic activity may be the result of a recent vertical lithospheric motion in response to the lateral migration of the Slab eastward to Sicily Channel (Faccenna et al., 2007). The upper mantle flow pattern beneath North-eastern Tunisia, as revealed by SKS fast splitting directions (Faccenna et al., 2004), is parallel to the NE-SW to E-W orientation of the Shmin found in the study area, matching closely the Plio-Quaternary extensional orientation in Central Mediterranean (Soumaya et al., 2015). In addition, the third-order extensional to transtensional regime observed in the Grombalia graben and around the Gulf of Tunis can also be due to the lithospheric removal process and upraise of sublithospheric mantle beneath the topographic highs (Göğüş and Pysklywec, 2008; Soumaya et al., 2015).

The strike-slip kinematic of the STEP fault system, together with the layer-slip movement on top of the asthenosphere beneath North-eastern Tunisia layer-block, caused inversion of the tensile stress in Bou Kornine-Ressas-Messella block into compressional stress, forming contractional duplexes within this area.

We suggest that the lithospheric discontinuity (STEP fault) and small scale mantle flow pattern played an active role in the paleostress variations and deviation near the major strike-slip system of the study area and on the distribution of different Cenozoic and Quaternary tectonic regimes.

6. Conclusion

Our scenario aims at integrating field and geophysical data within a common the tectonic evolution model for proposing a new structural interpretation of North-eastern Tunisia. The Bou Kornine-Ressas-Messella belt and Grombalia graben was formed by three major compressional events in the Eocene, Late Miocene and Quaternary, alternating with extensional periods in the Oligocene, Early–Middle Miocene, and Pliocene-Early Quaternary. The principal structural elements of the wrench pattern in the study area are N-S strike-slip duplexes, N-S to NE-SW-trending en-echelon fold and thrusts, and NW-SE- oriented normal faults. Faults kinematic data and geometric structural reflect the general NW-SE-shortening direction during the Tertiary in North-eastern Tunisia. The wrench-dominated Cenozoic transpression with sinistral kinematics is responsible for the formation of the strike-slip duplexes, folds, and thrusts that control/deform the Cretaceous sedimentary sequences in this area. As a whole, its main tectonic reactivation occurred during the Eocene to Late Miocene.

We present a model supporting that faults relay (Fig. 10) of N-S Axis, MRB and HK form a strike slip duplex associated with positive flower structures, NE-SW directed overlap and NW-SE trends grabens. In this wrench system, we demonstrate three kinds of structures: (1) a first order of N-S trending strike-slip fault of Bou Kornine-Ressas and Hammmet-Korbous; (2) a leading contractional inbricate fan dominated by NE-SW reverse faults along the main Bou Kornine-Ressas accident; (3) a trailling extensional imbricate fan dominated by the NW-SE graben along the major Hammamet-Korbous fault; (4) a tanspressional strike-slip duplex or relay results from differential movements between the two sides of master N-S fault blocks. Field data provides a maximum principal stress axis approximately horizontal and NW to NNW trending, whereas the minimum principal stress axis is horizontal and NE trending.

At a large scale, we evidence the major role played in the geodynamic evolution of the study area by the deep tearing of N-S Axis, Bou Kornine-Ressas and Hammamet-Korbous, which corresponding to an N-S STEP fault known in the Central Mediterranean and revealed by the seismic tomography images. The reactivation of this STEP fault can exert an important effect in some local crustal extension and stress state variation such as a lithospheric removal event and stress trajectory deviation near the preexisting deep fault system (i.e., Bou Kornine-Ressas-Messella).

We suggest also a major role of this part of N-S trending STEP fault relay in the tectonic control of cretaceous sedimentary sequences, the geometric structures, Cenozoic kinematic faults and the establishment of strike-slip duplex and associated structures within Northeastern Tunisia.

Finally, the MRB and HK strike-slip in the Northeastern Tunisia corresponds to a typical sinistral strike-slip system formed by a strike-slip-contractional imbricate fan in the leading part, a strike-slip-extensional imbricate fan in the trailing part and a strike-slip-

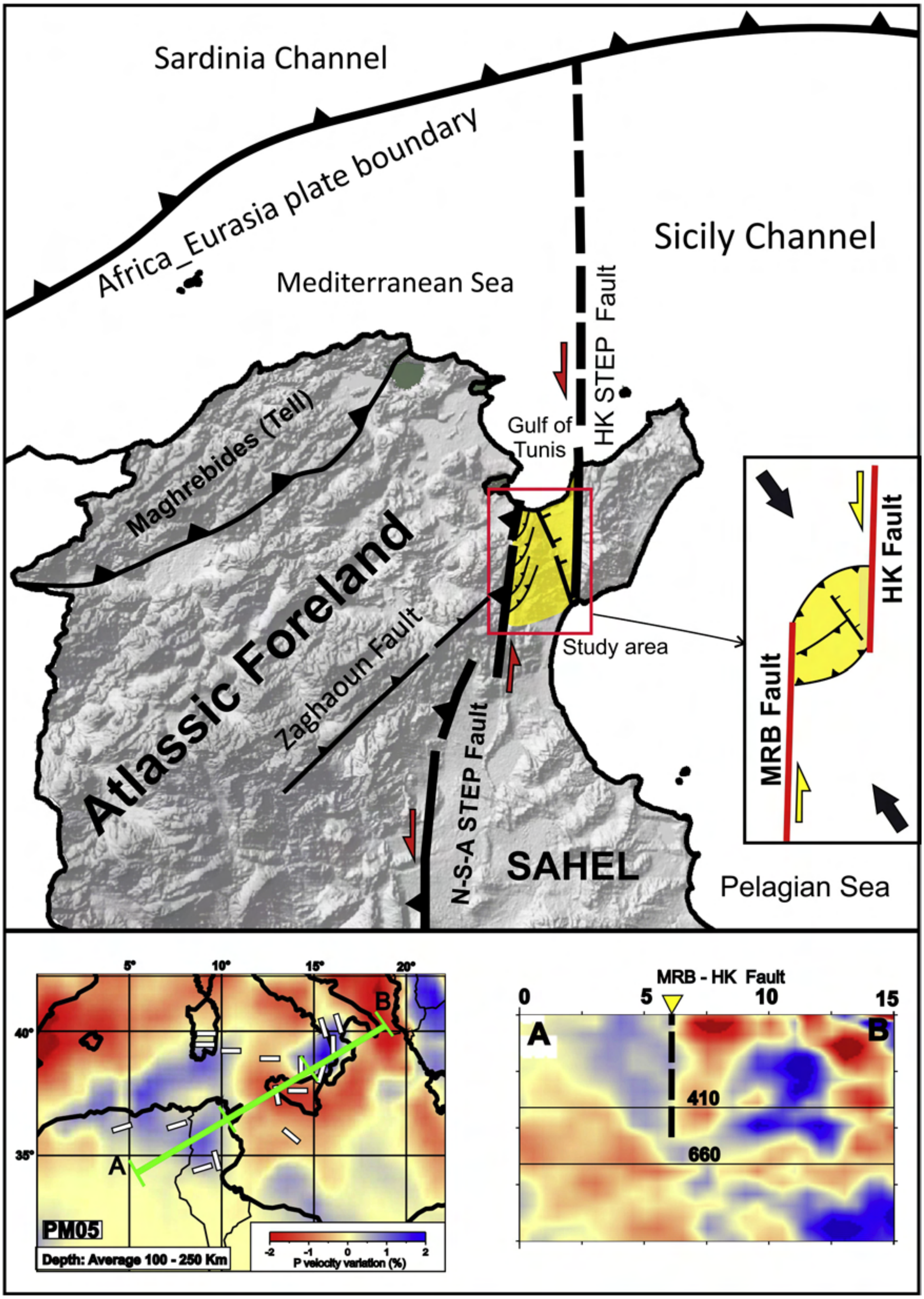

Fig. 10. Reconstitution of the kinematics of main geodynamic elements in the study area.

contractional duplex in the central part. This system is controlled by deeper layer slip of STEP fault and deep-seated movements of the lithosphere beneath Northeast Tunisia.

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References

Anderson, J.E., 1996. The Neogene structural evolution of the western margin of the Pelagian Platform Central Tunisia. J. Struct. Geol. 18, 819–833.

Angelier, J., 1989. Tectonique cassante et néotectonique. Ann. Soc. Géol. Belg. 112 (2), 293–307.

Angelier, J., 2002. Détermination du tenseur des contraintes par inversion de mécanismes au foyer de séismes sans choix de plans nodaux. C. R. Géosci. 334 (1), 73–80.

Argnani, A., 2009. Evolution of the southern Tyrrhenian slab tear and active tectonics along the western edge of the Tyrrhenian subducted slab. Geol. Soc. Lond. Spec. Publ. 311 (1), 193–212.

Bédir, M., 1988. Géodynamique des bassins sédimentaires du Sahel de Mahdia (Tunisie orientale) de l'Aptien à l'Actuel Sismo-stratigraphie, sismotectonique et structurale. Répercussions pétrolières, hydrologiques et sismiques. Rev. Sci. Terre (Tunisia) 9, 242.

Billi, Faccenna, C., Bellier, O., Minelli, L., Neri, G., Piromallo, C., Presti, D., Scrocca, D., Serpelloni, E., 2011. Recent tectonic reorganization of the Nubia-Eurasia convergent boundary heading for the closure of the western Mediterranean. Bull. Soc. Geol. Fr. 182 (4), 279–303.

Ben Ayed, N., 1993. Evolution Tectonique de l'Avant-pays de la Chaîne Alpine de Tunisie du Début du Mésozoïque à l'Actuel. Ann. Mines Géol. Tunis. 32, 286. Available at: https://tel.archives-ouvertes.fr/tel-01009784.].

Ben Ferjani, A., Burollet, P.F., Mejri, F., 1990. Petroleum Geology of Tunisia. ETAP, Tunis.

Ben Salem, H., 1992. Contribution à la connaissance de la géologie du Cap Bon : stratigraphie, tectonique et sédimentologie. Thèse de 3ème cycle. Fac. Sci. Tunis.

Boccaletti, M., Cello, G., Tortorici, L., 1988. Structure and tectonic significance of the north–south axis of Tunisia. Ann. Tect. 2 (1), 12–20.

Bonnefous, J., 1972. Contribution à l'étude stratigraphique et micropaléontologique du Jurassique de Tunisie. Thèse Doct. 3éme cycle. Univ. Paris-VI, p. 397.

Bott, P., 1959. The mechanics of oblique slip faulting. Geol. Mag. 96 (02), 109–117.

Bouaziz, S., Barrier, E., Soussi, M., Turki, M.M., Zouari, H., 2002. Tectonic evolution of the northern African margin in Tunisia from paleo-stress data and sedimentary record. Tectonophysics 357 (1), 227–253.

Boukadi, N., 1994. Structuration de l'Atlas Tunisien: Signification Géométrique et Cinématique des nœuds et des zones d'interférences structurales au contact de grands couloirs tectoniques. Thèse Es Sciences. Univ de Tunis II Fac. Sc, Tunis, p. 251.

Bousquet, J., Philip, H., 1986. Neotectonics of the Calabrian arc and Apennines (Italy): an example of Plio-Quaternary evolution from island arcs to collisional stages. In: Wezel, F.C. (Ed.), The Origin of Arcs, vol. 19. Elsevier, Amsterdam, pp. 305–326.

Bracène, R., Frizon de Lamotte, D., 2002. The origin of intraplate deformation in the Atlas system of western and central Algeria: from Jurassic rifting to Cenozoic–Quaternary inversion. Tectonophysics 357 (1), 207–226.

Bujalka, P., Johan, Z., Krivy, M., Rakus, M., 1971. Carte géologique de Grombalia 1/50 000 (feuille N°29) Notice explicative. Direction des Mines et de l'Energie (Service Géologique de la Tunisie).

Burollet, P.F., 1956. Contribution à l'étude stratigraphique de la Tunisie centrale. Ann. Mines Géol. Tunis. 18, 352.

Burollet, P., 1991. Structures and tectonics of Tunisia. Tectonophysics 195 (2), 359–369. C. R. Geosciences., 334(1), 73–80.

Castany, G., 1952. Paléogéographie, Tectonique et orogénèse de la Tunisie. XIXème Congr. Géol Intern. Alger Mon. Rég Tunis. 1, 64.

Chebbi, A., 1995. Geophysical Final Well Report. Unpublished report, Marathon Petroleum Grombalia, LTD Soliman-1, ETAP, 43 p.

Chihi, L., 1995. Les fossés néogènes à quaternaires de la Tunisie de la mer pélagienne: leur signification dans le cadre géodynamique de la méditerranée centrale. Thèse de Doctorat d'Etat. Université de Tunis II, p. 324.

Cohen, C.R., 1980. Plate tectonic model for the oligo-miocene evolution of the western mediterranean. Tectonophysics 68 (3), 283–311.

Colleuil, B., 1979. Etude stratigraphique et néotectonique des formations néogènes et quaternaires de la région de Nabeul-Hammamet (Cap Bon, Tunisie). Mém. D. E. S. Fac. Sci. Tech. Univ. Nice 93.

Cossey, S.P., Ehrlich, R., 1978. Growth fault-controlled submarine carbonate debris flow and turbidite deposits from the Jurassic of northern Tunisia: possible canyon fill sequences. In: Sedimentation in Submarine Canyons, Fans, and Trenches. Stroudsberg, Pennsylvania, Dowden Hutchinson and Ross.

Creusot, G., Mercier, E., Ouali, J., Turki, M.M., 1992. Héritage distensif synsédimentaire et structuration chevauchante: apport de la modélisation du chevauchement alpin de Zaghouan (Atlas tunisien). C. R. Acad. Sci. Paris, Ser. II 314, 961–965.

Delvaux, D., 2011. EGU General Assembly. Win-tensor, an Interactive Computer Program for Fracture Analysis and Crustal Stress Reconstruction, vol. 13. Geophysical Research Abstract, Vienna.

Delvaux, D., Barth, A., 2010. African stress pattern from formal inversion of focal mechanism data. Tectonophysics 482 (1), 105–128.

Delvaux, D., Sperner, B., 2003. New aspects of tectonic stress inversion with reference to the Tensor program. Geol. Soc. Lond. Spec. Publ. 212 (1), 75–100.

Dhahri, F., Tanfous, D., Gabtni, H., Boukadi, N., 2015. Structural and geodynamic study in central Tunisia using field and geophysical data: new structural interpretation of the N–S axis and associated Atlasic structures. Int. J. Earth Sci. 104 (7), 1819–1835.

Dlala, M., 2002. Les manifestations tectono-sédimentaire d'âge Campanien Maastrichtien. Tunisie : implication sur l'évolution géodynamique de la marge nord-africaine. C. R. Géosci. 334, 135–140.

Doglioni, C., 1992. The Venetian Alps thrust belt. In: Thrust tectonics. Springer, Netherlands, pp. 319–324.

El Ghali, A., Ben Ayed, N., Bobier, C., Zargouni, F., Krima, A., 2003. Les manifestations tectoniques synsédimentaires associées à la compression éocène en Tunisie : implications paléogéographiques et structurales sur la marge Nord-Africaine. C. R. Geosci. 335, 763–771.

Essid, E.M., Kadri, A., Inoubli, M.H., Zargouni, F., 2016. Identification of new NE-trending deep-seated faults and tectonic pattern updating in northern Tunisia (Mogodos–Bizerte region), insights from field and seismic reflection data. Tectonophysics 682 (6), 249–263.

Faccenna, C., Piromallo, C., Crespo-Blanc, A., Jolivet, L., Rossetti, F., 2004. Lateral slab deformation and the origin of the western Mediterranean arcs. Tectonics 23, TC1012. http://dx.doi.org/10.1029/2002TC001488.

Faccenna, C., Civetta, L., D'Antonio, M., Funiciello, F., Margheriti, L., Piromallo, C., 2005. Constraints on mantle circulation around the deforming Calabrian slab. Geophys. Res. Lett. 32, L06311. http://dx.doi.org/10.1029/2004GL021874.

Faccenna, C., Funiciello, F., Civetta, L., D'Antonio, M., Moroni, M., Piromallo, C., 2007. Slab disruption, mantle circulation, and the opening of the Tyrrhenian basins. Geol. Soc. Am. Spec. Pap. 418, 153–169.

Fuchs, Y., 1973. Sur les relations entre émersion et concentration métallifère (quelques exemples tunisiens). Ann. Mine Géol. Tunis. 26, 479–509.

Ghanmi, M., 1980. Etude géologique du Djebel Kebbouch (Tunisie septentrionale). Thèse de Doctorat 3ème cycle. Univ. Paul Sabatier, Toulouse, p. 141.

Gharsalli, R., Zouaghi, T., Soussi, M., Chebbi, R., Khomsi, S., Bédir, M., 2013. Seismic sequence stratigraphy of Miocene deposits related to eustatic, tectonic and climatic events. Cap Bon peninsula, north-eastern Tunisia. C. R. Geosci. 345 (9), 401–417.

Govers, R., Wortel, M.J.R., 2005. Lithosphere tearing at STEP faults: response to edges of subduction zones. Earth Planet. Sci. Lett. 236 (1), 505–523.

Göğüş, O.H., Pysklywec, R.N., 2008. Mantle lithosphere delamination driving plateau uplift and synconvergent extension in eastern Anatolia. Geology 36 (9), 723–726.

De Graciansky, P.C., Dardeau, G., Lemoine, M., Tricart, P., 1989. The inverted margin of the French Alps and foreland basin inversion. Geol. Soc. Lond. Spec. Publ. 44 (1), 87–104.

Hadj Sassi, Zouari, M., Jallouli, C., 2006. Contribution de la gravimétrie et de la sismique réflexion pour une nouvelle interprétation géodynamique des fossés d'effondrement en Tunisie: exemple du fossé de Grombalia. C.R. Géosci. 338, 751–756.

Jauzein, 1967. Contribution à l'étude géologique des confins de la dorsale tunisienne. Thèse d'état, Paris, p. 475.

Jolivet, L., Faccenna, C., 2000. Mediterranean extension and the Africa-Eurasia collision. Tectonics 19 (6), 1095–1106. http://dx.doi.org/10.1029/2000TC900018.

Jolivet, L., Augier, R., Faccenna, C., Negro, F., Rimmele, G., Agard, P., Robin, C., Rossetti, F., Crespo-Blanc, A., 2008. Subduction, convergence and the mode of backarc extension in the Mediterranean region. Bull. Soc. Géol. Fr. 179 (6), 525–550.

Kadri, A., Ben Haj Ali, M., Braham, A., Chihi, L., Ben Ayed, N., 2001. La compression Pyrénéenne (Paléocène p.p-Yprsien) au Jebel Lessouda et aux abords de « l'le de de Kasserine » (Tunisie centrale), 68. Notes Serv. Géologique, Tunis.

Kamoun, Y., Sorel, D., Viguier, C., Ben Ayed, N., 1980. Un grand accident subméridien d'âge post-Tyrrhénien en Tunisie orientale: le décrochement sénestre de Skanès (Monastir)-Hammamet. C. R. Acad. Sci. Série D. T. 220, 647–649.

Khomsi, S., Bédir, M., Ben Jemia, G.M., Zouari, H., 2004. Mise en évidence d'un nouveau front de chevauchement dans l'Atlas Tunisien oriental de Tunisie par sismique réflexion. Contexte structural régional et rôle du Trias salifère. C. R. Géosci. 336, 1401–1408.

Khomsi, S., Bédir, M., Soussi, M., Ben Jemia, G., Ben Ismail, Lattrache, K., 2006. Mise en évidence en subsurface d'événements compressifs Eocène moyen –supérieur en Tunisie orientale (Sahel): généralité de la phase atlasique en Afrique du Nord. C. R. Géosci. 338, 41–49.

Kim, Y.S., Sanderson, D.J., 2006. Structural similarity and variety at the tips in a wide range of strike–slip faults: a review. Terra Nova 18 (5), 330–344.

Lucente, F., Margheriti, P.L., Piromallo, C., Arruol, G., 2006. Seismic anisotropy reveals the long route of the slab through the western-central Mediterranean mantle. Earth Planet. Sci. Lett. 241 (3), 517–529.

Marie, J., Trouvé, P., Desforges, G., Dufaure, P.H., 1982. Nouveaux éléments de paléogéographie du Crétacé de Tunisie. Cretac. Res. 3 (1), 167–170.

Meghraoui, M., Pondrelli, S., 2012. Active faulting and transpression tectonics along the plate boundary in North Africa. Ann. Geophys. 55, 5. http://dx.doi.org/10.4401/ag-4970.

Meghraoui, M., Maouche, S., Timoulali, Y., Bouhadad, Y., Bouaziz, S., 2013. Active folding and thrusting in North Africa: a framework for a seismotectonic model of the Atlas Mountains. EGU General Assem. Conf. Abstr. 15, 8303.

Melki, F., Zouaghi, T., Harrab, S., Sainz, A.C., Bédir, M., Zargouni, F., 2011. Structuring and evolution of Neogene transcurrent basins in the Tellian foreland domain, north-eastern Tunisia. J. Geodyn. 52 (1), 57–69.

Mercier, J., Vergely, P., Missenard, Y., 2011. Tectonique. Dunod, pp, 3ème éd..
Morgan, M.A., Grocott, J., Moody, R.T.J., 1998. The structural evolution of the Zaghouan - Ressas structural belt, northern Tunisia. In: Macgregor, D.S., Moody, R.T.J., Clark- Lowes, D.D. (Eds.), Petroleum Geology of North Africa, vol. 132. Spec. Publ. Geological Society, London, pp. 405–422.
Mzali, H., Zouari, H., 2006. Caractérisation géométrique et cinématique des structures liées aux phases compressives de l'Eocène au Quaternaire inférieur en Tunisie: exemple de la Tunisie nord orientale. C. R. Géosci. 338, 742–749.
Negra, M.H., 1984. Paléoenvironnement et Diagenèse des faciès récifaux à rudistes au Jebel el Kébar. Tunisie centrale (Doctorat de Spécialité), Université d'Orsay, Paris-Sud.
Nocquet, J.M., 2012. Present-day kinematics of the Mediterranean: a comprehensive overview of GPS results. Tectonophysics 579, 220–242.
Ouahchi, A., Bismuth, H., Turki, M.M., 1993. Nouvelles données sur le Crétacé et l'Eocène des environs de Grombalia (Tunisie nord-orientale). Géol. Méditerr. 20, 25–43.
Ouali, J., 1984. Evolution et géodynamique du chaînon Nara-Sidi Khalif (Tunisie centrale). Thèse de 3ème cycle. Université Rennes-1, p. 120.
Perthuisot, V., 1978. Dynamique et pétrogenèse des intrusions triasiques en Tunisie septentrionale. Thèse. Doct.. Es-Sci. Labo. Géol. E.N.S. Paris, p. 359.
Philip, H., Andrieux, J., Dlala, M., Chihi, L., Ben Ayed, N., 1986. Evolution tectonique mio-quaternaire du fosse de Kasserine (Tunisie centrale) : implications sur l'évolution géodynamique récente de la Tunisie. Bull. Soc. Geol. Fr. 2 (4), 559–568.
Piromallo, C., Morelli, A., 2003. P wave tomography of the mantle under the Alpine-Mediterranean area. J. Geophys. Res. 108 (B2).
Rais, J., 1995. Géodynamique, paléoenvironnement et microfaciès du dépôt Jurassique en bordure Sud-est de la Téthys Magrébine. Thèse. Univ. Tunis, p. 255.
Richert, J.P., 1971. Mise en évidence de quatre phases tectoniques successives en Tunisie. In: Notes du Service Géologique de Tunisie, 34. Travaux de Géologie tunisienne, pp. 114–121, 4.
Rouvier, H., 1977. Géologie de l'extrême Nord Tunisien: tectoniques et Paléogéographies superposées à l'extrémité Nord-orientale de la chaine maghrébine Thèse d' Etat. Univ. Paris-VI, p. 898.
Saadi, J., 1990. Exemple de sédimentation syntectonique au Crétacé inférieur le long d'une zone de décrochement NS. Les structures d'Enfidha (Tunisie nord-orientale). Géodynamique 5 (1), 17–33.
Savostin, L.A., Sibuet, J.C., Zonenshain, L.P., Le Pichon, X., Roulet, M.J., 1986. Kinematic evolution of the tethys belt from the Atlantic ocean to the pamirs since the triassic. Tectonophysics 123 (1), 1–35.
Scandone, P., Patacca, E., 1984. Tectonic evolution of the central mediterranean area. Ann. Geophys 2 (2), 139–142.
Schamel, S., Mellgard, A., 1982. Structure and stratigraphy of Dj. Zaghouan and adjacent areas. In: The Structural Style of the Tunisian Atlas. Workshop Notes and Guidebook (pt. C).
Serpelloni, E., Vannucci, G., Pondrelli, S., Argnani, A., Casula, G., Anzidei, M., Gasperini, P., 2007. Kinematics of the Western Africa-Eurasia plate boundary from focal mechanisms and GPS data. Geophys. J. Int. 169 (3), 1180–1200.
Soumaya, A., Ben Ayed, N., Delvaux, D., Ghanmi, M., 2015. Spatial variation of present-day stress field and tectonic regime in Tunisia and surroundings from formal inversion of focal mechanisms: geodynamic implications for central Mediterranean. Tectonics 34 (6), 1154–1180.
Soussi, M., 2003. Nouvelle nomenclature lithostratigraphique «événementielle» pour le Jurassique de la Tunisie atlasique. Geobios 36 (6), 761–773.
Touati, M.A., 1985. Etude géologique et géophysique de la concession Sidi El Itayem en Tunisie orientale (Sahel de Sfax): histoire géologique du bassin et évolution de la fracturation et des structures, du Crétacé au Plio-Quaternaire (Doctoral dissertation).
Tricart, P., Torelli, L., Argnani, A., Rekhiss, F., Zitellini, N., 1994. Extensional collapse related to compressional uplift in the Alpine Chain off northern Tunisia (Central Mediterranean). Tectonophysics 238 (1-4), 317–329.
Turki, M.M., 1985. Polycinématique et contrôle sédimentaire associé sur la cicatrice Zaghouan-Nebhana. Thèse és. Sci. Univ. Tunis, p. 262.
Viterbo, 1983. Evolizione Paleogeografica Della Tunisia Meridionaledal Carbonifero Al Trias Superiore. Studi Paleogeorafici Nell Area Mediterranea. Adriatica Editrice, Bari, p. 23, 1983.
Wallace, R.E., 1951. Geometry of shearing stress and relation to faulting. J. Geol. 118–130.
Woodcock, N.H., Fischer, M., 1986. Strike-slip duplexes. J. Struct. Geol. 8 (7), 725–735.
Zargouni, F., 1985. Tectonique de l'Atlas méridional de la Tunisie de la Tunisie. Evolution géométrique et cinématique des structures en zone de cisaillement. Rev. Sci. Terre 3, 300. I.N.R.S.T. Tunis.
Zouaghi, T., Bédir, M., Melki, F., Gabtni, H., Gharsalli, R., Bessioud, A., Zargouni, F., 2011. Neogene sediment deformations and tectonic features of north-eastern Tunisia: evidence for paleoseismicity. Arabian J. Geosci. 4 (7–8), 1301–1314.