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The Chotts Fold Belt of Southern Tunisia, North African Margin: Structural Pattern, Evolution, and Regional Geodynamic Implications

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1. Introduction

At the North of the old African continent, craton and shields having more than two billion years, Tunisia, Algeria and northern Morocco underwent a complex geodynamic and structural evolution during the Mesozoic and Cenozoic times (Dercourt et al., 1985; Bouillin, 1986; Frizon de Lamotte et al., 2009). This evolution resulted in the development of varied paleogeographic fields, in relation with the Tethyan and Atlantic movements. Its end led to the genesis of the North-African alpine orogen (Dercourt et al., 1985; Martinez et al., 1990) formed by the Maghrebid and Atlassic domains (Fig. 1).

Tunisia occupies the eastern part of this orogen, located at the north of a large Saharan platform, developed on the stable African craton, not deformed during the alpine cycle and bounded by a major structural lineament « South Atlassic fault » composed of complex overlapping folds trending NE-SW, E-W and NW-SE (Caire,1971; Zargouni, 1985; Turki, 1988; Zouari et al., 1990; Ben Ayed, 1993; Boukadi, 1994; Bédir, 1995; Bouaziz, 1995; Zouari, 1995; Bouaziz et al., 1999, 2002; Abbès, 2004; Zouaghi et al., 2005a, b, 2011; Ouali, 2007; Melki et al, 2010).

Structures of the North African margin were usually subject of discussion. This domain could be considered as a passive margin, close to the oceanic opening, characterized by a strong subsidence marked by accumulations of prograding deposits (Dercourt et al., 1985; Biju-Duval et al., 1976). For others, it is a transform margin related to displacements of the African plate compared to the Eurasian plate. These movements generated opening of the Paleo-Tethys (Arthaud and Thomas, 1977). The Africa-Europe relative motions would be at the origin of the recent ocean floor spreading of the Mediterranean (Taponnier, 1977; Reading, 1980; Olivet et al., 1982; Alvarez et al., 1984; Ricou, 1994).

The study area belongs to the North African margin and the northern edge of the Saharan platform. Studies undertaken on Paleo-Tethys show the development of deformed and subsiding zones between the cratonic blocks and the basins (Caire, 1974; Arthaud and Thomas, 1977; Aubouin and Debelmas, 1980; Bernoulli and Lemoine, 1980; Durand-Delga and Fonrbote, 1980; Bousquet and Philip, 1981; Dercourt et al., 1992). The geodynamic aspects at the Mediterranean scale are the origin of the tectonic mechanisms responsible for the structural evolution of the study area during the Mesozoic and Cenozoic periods. These aspects correspond to: (1) Permian-Triassic Tethyan rifting. Mesozoic divergence between the blocks continues and results in opening of the central Atlantic and the Tethys ligure and development of the Mesogea following the fragmentation of the Pangea super-continent, which generates the Gondwana to the South and the Laurasia to the North. An extensional tectonic event was consequently generated during the beginning of Mesozoic times, recorded in the African and European margins. (Biju-Duval, 1980; Dercourt et al., 1985 and 1992). (2) During the Cenozoic times, blocks located on both sides of the Mediterranean Basin converge, involving compressional phases, which induced formation of the European alpine chains and the Maghrebides (Bouillin, 1977, 1986).

The tectonic polyphasage in North Africa domains presents one of the most discussed subjects from an area to another. Some interpretations concerning the role of inherited features , halokinesis and later inversion, showed by outcrop studies, remain still not well argued even if the majority of authors agree with the influence of the ante-Triassic basement on the sedimentary lapout. In this work we try to study the geometry and structural evolution of the various morphostructural units during extensional and contractional periods.

2. Paleogeographic summarize

The studies carried out on outcropping strata and on well data of southern Tunisia allow to identify the lithostratigraphic series from Paleozoic to the Quaternary one. However, there are some divergences between the authors concerning the age of various geological Formations (Burollet, 1956; Fournié, 1978; M'Rabet, 1987). The sedimentary series show lateral variations of thickness and facies and local gaps. In this section we try to describe and discuss briefly the sedimentary history of the study area.

The Paleozoic outcrops in the Tebaga mountain is represented only by Permian deposits. In addition the Paleozoic has been crossed by many petroleum wells in Saharan platform of Tunisia where various units have been identified. (Busson, 1969, 1970a, b; Ben Ismail, 1982, 1991). During the Paleozoic periods, the Saharan field is characterized by clayey detrital and sandy facies indicating a continental to margino-continental deposition (Fig. 2) with a general tendency to marine platform towards the North in the Djeffara domain (Bellini and Massa, 1980). For the southern Atlas, no information exists yet concerning the Paleozoic. But based on its lithostratigraphy, the Early Paleozoic could be marked by a progradational series followed by a transgressive interval corresponding to the clays of Silurian-Devonian known in the Saharan field (Busson, 1969, 1970a, b; Ben Ismail, 1982).

Except the Triassic, which keeps a relative homogeneity of facies from the South to the North (Kamoun et al., 2001), the Mesozoic paleogeographic scheme is characterized by a marginal platform environment with continental influence marked by detrital, carbonate-evaporite and evaporite to the South and by a marine deposition (clayey, more carbonated-clay, less evaporitic and sandy) to the North.

In Tunisia the Jurassic rarely outcrops and is classically represented by three carbonated members of the Nara Formation (Burollet, 1956; Soussi, 2002) (Fig. 2), indicating deposition in a moderate deep marine of external platform in central Tunisia. Towards the South, in the Saharan platform, presence of detrital and evaporite layers indicate fluvio-deltaic and lagunal internal platform under a restricted and confined marine environment. (Ben Ismail, 1982; Chandoul et al., 1993 ; Kamoun et al., 1999).

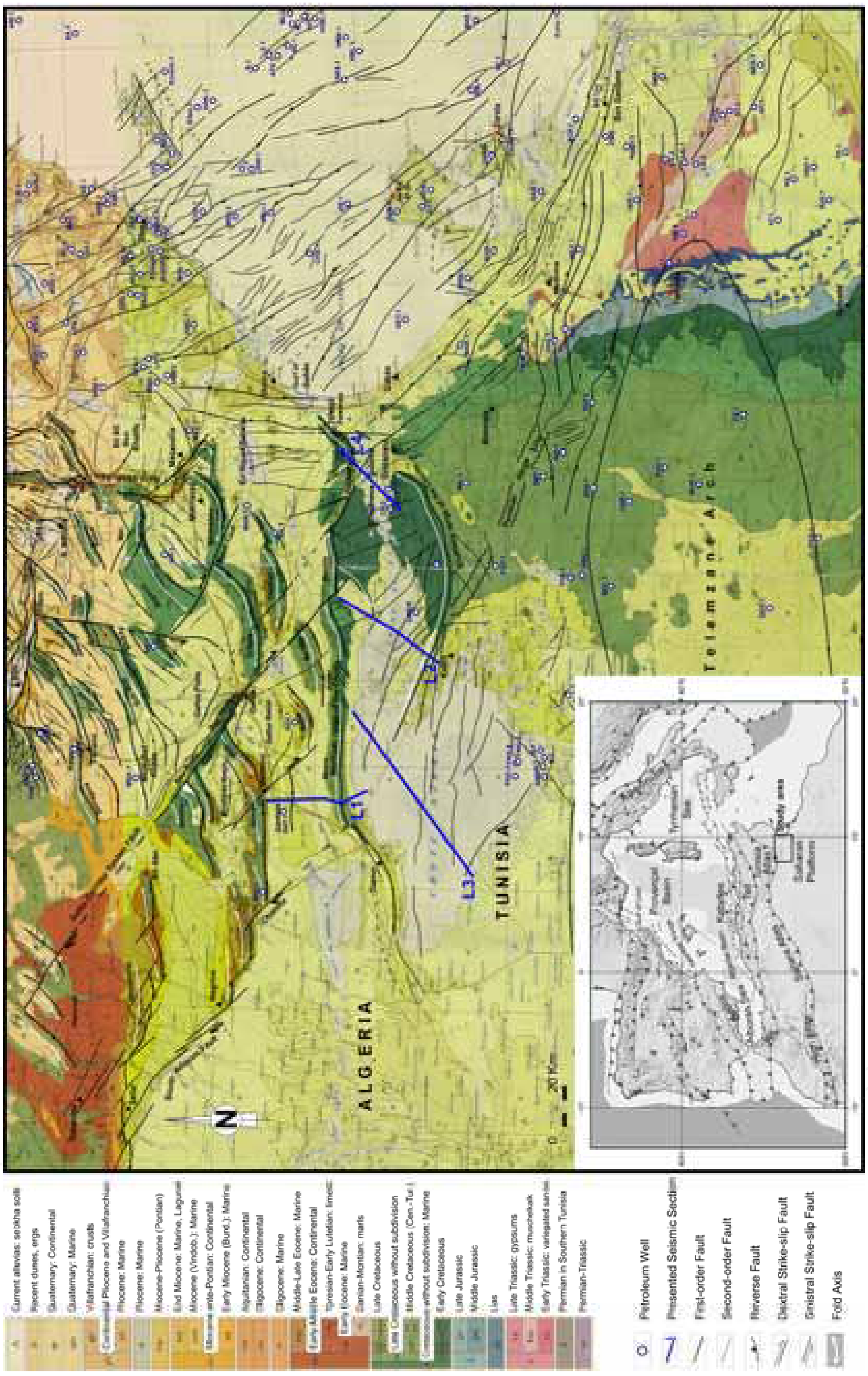

Fig. 1. Geological (Castany, 1951) and tectonic (Zargouni, 1985; Ben Ferjani, 1990; Bédir, 1995; Zouaghi et al., 2009, 2011) setting of the southern Atlas and Saharan platform of Tunisia and eastern Algeria showing distribution of anticline axis trends, location of main outcrops, deep faults and distribution of Mesozoic basins and paleohighs

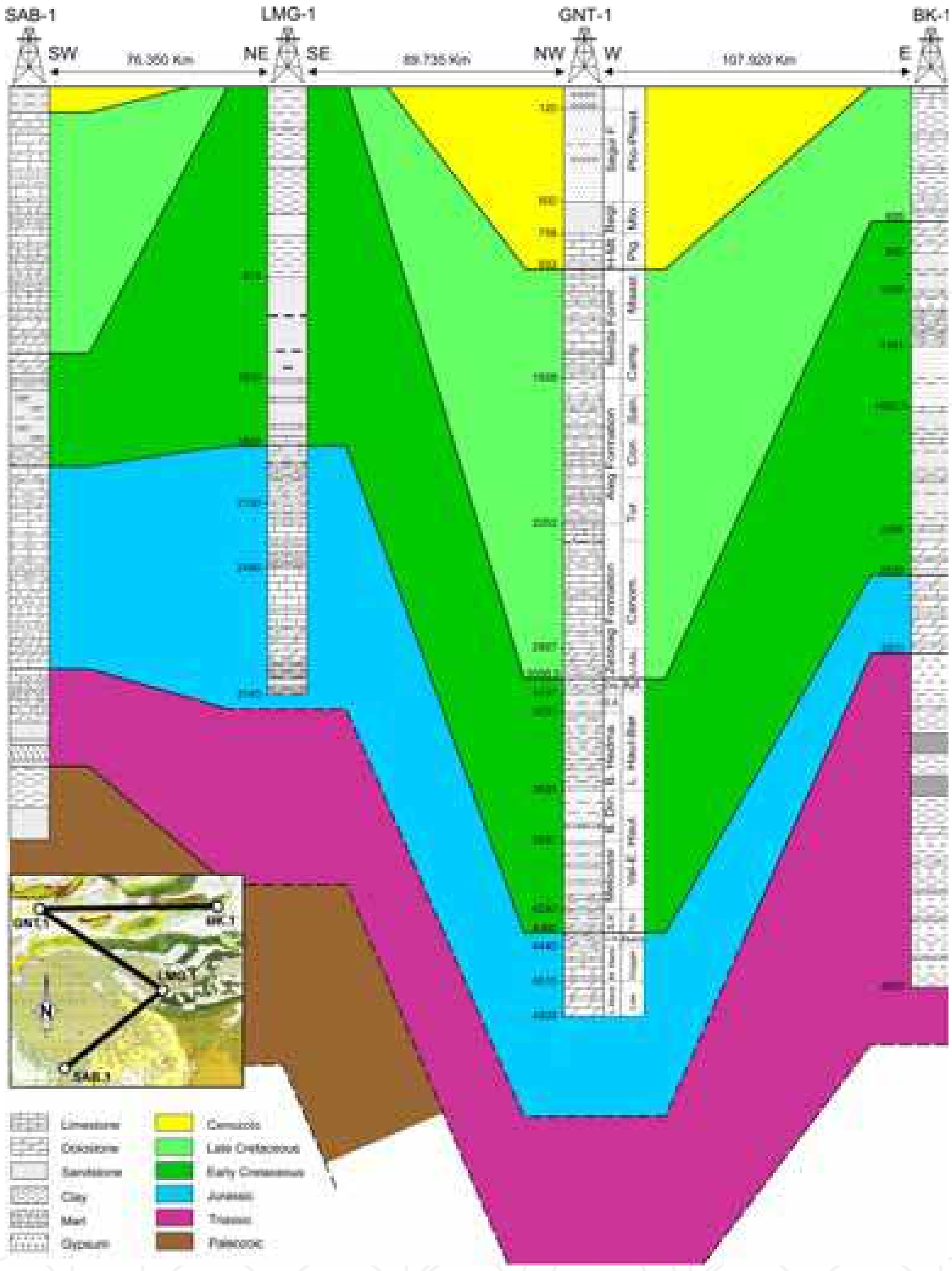

Fig. 2. Lithostratigraphic correlation of Paleozoic to Cenozoic series highlighted in the petroleum wells, showing thickness and facies variation between structures of southern Tunisia

The Cretaceous, which largely outcropped can be subdivided into two great mega-units: the first essentially clastic until Aptian corresponds to the lower Cretaceous fluvial and deltaic to marine environments (Marie et al., 1984; M'Rabet, 1987; Ben Youssef, 1999; Azaïez et al., 2007 ; Lazzez et al., 2008; Guellala, 2010; Zouaghi et al., 2011); the second represented by carbonates, clays and rare evaporitic layers, corresponds to the Late Cretaceous (Marie et al., 1984; Fakraoui, 1990; Abdallah et al., 2000). The southern part of Tunisia belongs to sub-continental field of Saharan platform, where the sedimentation rate is low to null in some localities of the vast stable platform (Burollet, 1956; Bishop, 1975; Ben Ferjani et al., 1990; Negra, 1994; Chaabani, 1995; Zouaghi et al., 2011).
The Paleogene represented by clays, carbonates and evaporites is identified in the Gafsa-Metlaoui phosphate basin (Sassi, 1974; Chaabani, 1995), showing varied thicknesses. The

Saharan platform domain and the Chotts zone, already emerged since the end of the Cretaceous, are deprived of Paleogene sedimentation (Fig. 2). The Cenozoic is represented in the Saharan domain by the Neogene-Quaternary continental sandy and silty deposits (Zargouni, 1985; Fakraoui, 1990; Addoum, 1995). The marine deposition has evolved to continental since the end of the Cretaceous. In the Atlassic domain, the marine environment continued at least until the end of the Eocene. It is marked by the clayey, carbonated and evaporite series of the Paleogene and changed to frankly continental detrital sedimentation during the Neogene and Quaternary periods.

3. Tectonic setting

Placed within the Maghrebin framework, Tunisia occupies a privileged geological position in the African structuring. It belongs to the old African frame by its southern Saharan part, and to the alpine field by its northern area. The boundary between these two domains is marked by the South-Atlassic morphostructural master fault system (Fig. 3).

3.1 Southern Atlas

The southern Atlas, extension of the western Saharan Atlas in Algeria, includes mountains of the Gafsa area trending E-W to NE-SW and NW-SE (Burollet, 1956; Boltenhagen, 1985; Zargouni, 1985; Abdeljaoued and Zargouni, 1985; Boukadi, 1994; Zouari, 1995; Bédir, 1995; Bédir et al.; 2001, Hlaiem, 1999; Bouaziz et al, 2002; Zouaghi et al., 2005a, b, 2009, 2011). These chains consist of overlapping folds poured to the South and separated by synclines filled with Neogene and Quaternary deposits (Fig. 1).

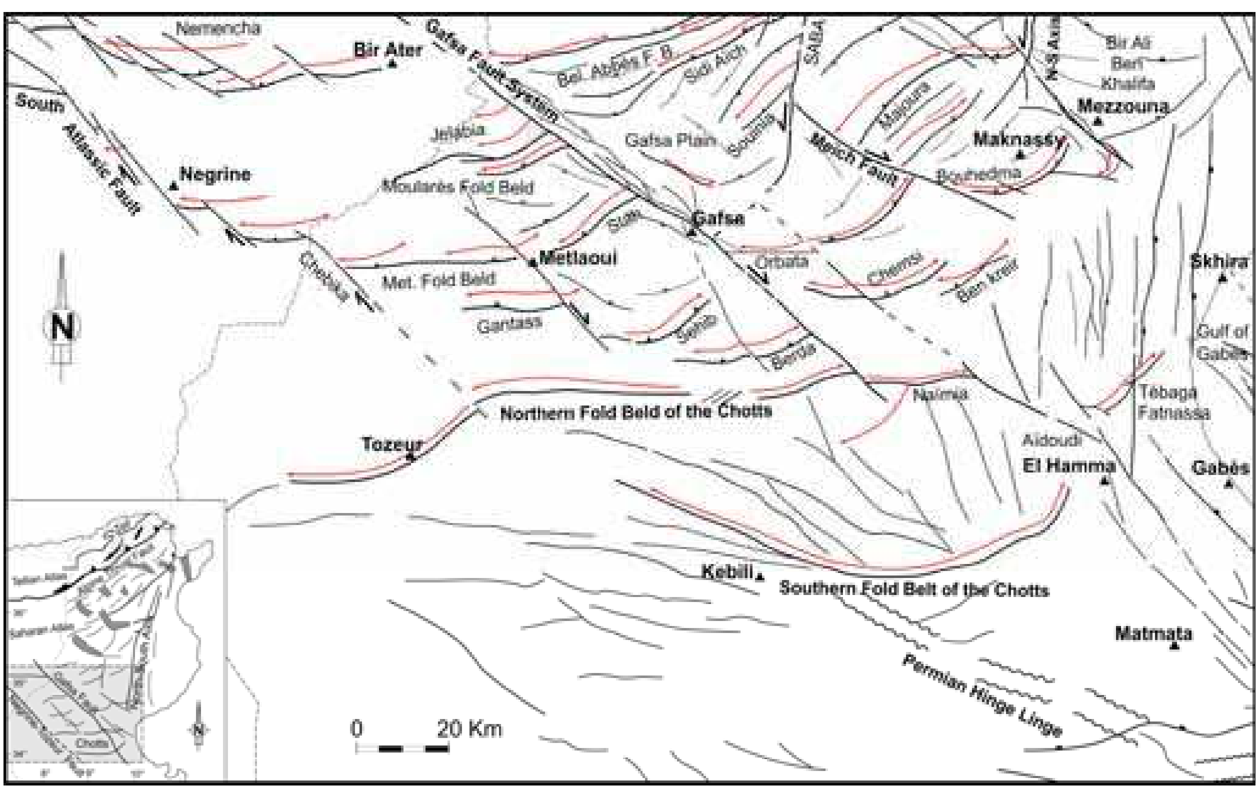

Fig. 3. Structural map, showing location of the master trending faults and folds. Rhombic structures are highlighted between the northwest-southeast and east-west right-steeping, dextral strike-slip faults (Zargouni, 1985; Ben Ferjani, 1990; Bédir, 1995; Zouaghi et al., 2009, 2011)

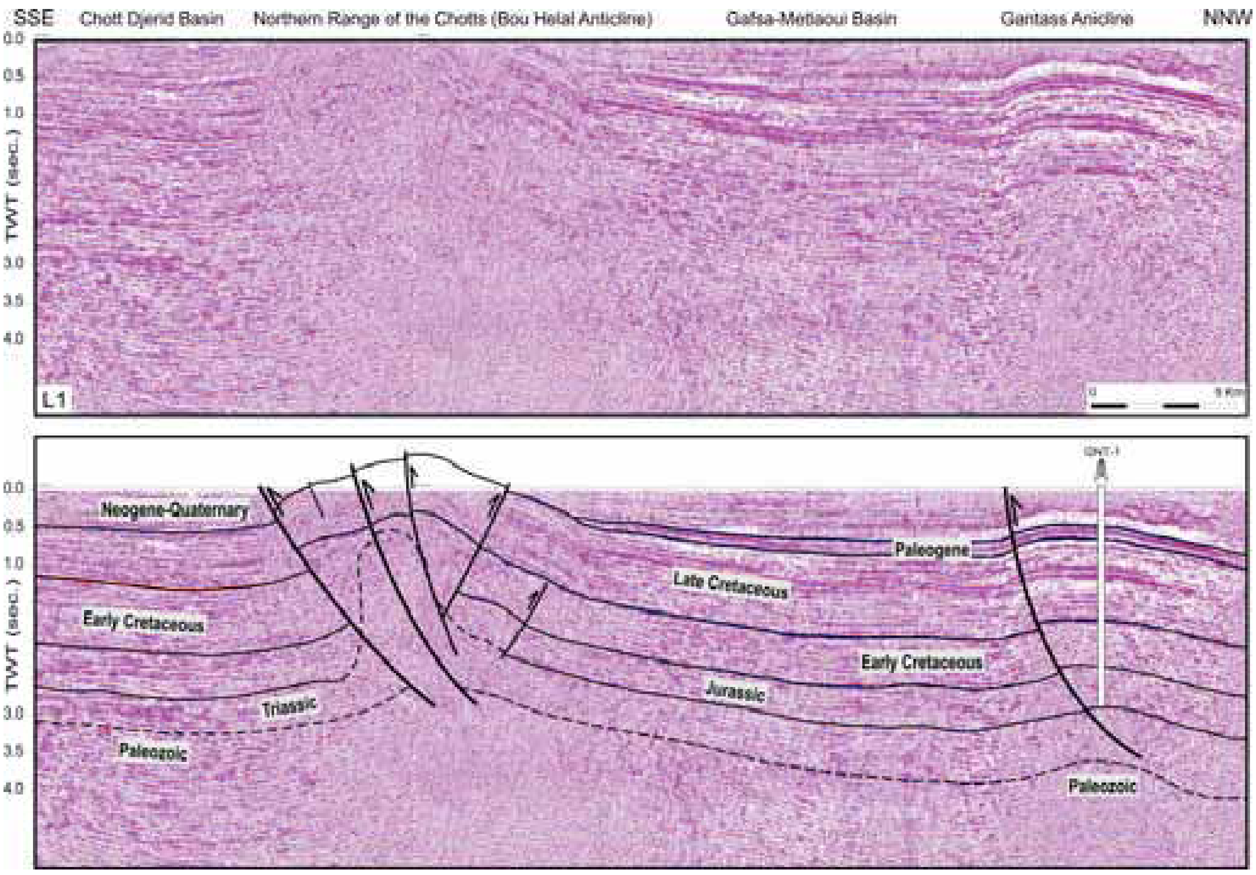

Fig. 4. NW-SE interpreted seismic section L1 crossing the Gantass and northern range of the Chotts. The reduction of thickness and unconformities are related to rejuvenation of master faults associated with Triassic evaporate risings

The Metlaoui tectonic bundle, which is made from West to East by the Bliji, Alima, Oum El Khecheb and Stah anticlines, is extended to the West in Algeria by the Mandra anticlines and is truncated to the East by the Gafsa master strike-slip fault. The Gafsa fold belt generally trending NW-SE is composed by the Moulares, Bou Ramli and Ben Younes anticlines and is crossed by the N120 Gafsa master dextral wrench fault (Zargouni, 1985; Zargouni et al., 1985; Boukadi, 1994; Bédir, 1995; Zouari, 1995; Boutib and Zargouni, 1998; Zouaghi et al., 2005a, b, 2009) (Fig. 1). The Orbata fold belt located at the East of Gafsa town is constituted by the Orbata and Bou Hedma anticlines, which are often asymmetric with sigmoidal shape (Boukadi et al., 1998 ; Bensalem et al., 2009). The Bou Hedma structure is affected to the West by the Mech dextral strike-slip fault. Between the Metlaoui and Orbata chains and northern range of the Chotts are located the Gantass, Sehib, Berda, Chemsi and Ben Kheir separated overlapping folds (Figs. 3 and 4).

The Chotts fold belt, which includes northern and southern chain of Chotts separated by the Chott El Fedjedj depocenter, is the most external structure of the Atlassic domain (Rabia, 1985; Zargouni, 1985; Abdeljaoued and Zargouni, 1985; Fakraoui, 1990; Ben Ayed, 1993; Bouaziz, 1995; Hlaiem, 1999). The eastern end of this fold belt is affected by several faults; the most significant one is that of Bir Oum Ali. The Hadifa diapir appears to be composed by Triassic saliferous located in the eastern end of northern chain of the Chotts shows the Triassic halokinesis in the study area.

These folded structures, located in northern edge of the Saharan platform, are affected and truncated by faults trending NW-SE and E-W (Fig. 3). They are often anchored on these lineaments and are characterized by axial virgations and echelon along a WSW- ENE axial direction (Rabia, 1985; Zargouni, 1985; Fakraoui, 1990; Ben Ayed, 1993; Bouaziz, 1995). The great anticline structures are asymmetric and marked by faulted southern side with steep dip (Fig. 4).

3.2 Saharan platform

Located on the northern edge of the African craton, this domain is composed of a Precambrian substratum surmounted by a thick Paleozoic cover (Figs. 4 and 5). However, Dahar field, high since the Carboniferous times is unconformably overlain by Mesozoic deposits on the Medenine Upper Permian, which is the only Paleozoic outcrop in Tunisia (Busson, 1967; Burollet and Desforges, 1982; Bouaziz, 1986; Ben Ayed, 1993; Bouaziz, 1995; Bouaziz et al., 1999). Except the upper Permian marine deposits of the Tebaga, the Precambrian and Paleozoic are recognized, in southern Tunisia by deep petroleum wells (Fig. 2). Mesozoic series of Dahar slightly tilted towards the West, have not recorded the Alpine and Atlassic shortening phases. To the East, the Djeffara plain, bounded by a NW-SE network of normal faults (Castany, 1954) and marked by Carboniferous and Permian high subsidence related to NE-SW extension (Ben Ayed, 1993; Bouaziz, 1995). The Talemzane Arch is the most significant structure appreciably trending E-W, corresponds to substratum of the Saharan platform and generated following the Hercynian tectonic phase (Busson, 1970a, b). On both sides of the Talemzane Arch, the Mesozoic strata, Triassic in particular, rest with angular unconformity on the eroded Paleozoic (Busson, 1967). This ridge extends from the Algerian Sahara crossing the Dahar structure of Southern Tunisian and constitutes the northern edge of the Ghedames basin and the limit between the Saharan craton and the extensive Mesogean domain to the North.

Study of seismic lines (Figs. 5, 6 and 8) shows that the transitional zone between the little deformed Saharan platform and the Atlassic folded zone, being complex with deep E-W direction in the Djerid Chotts area. This zone corresponded to a major lineament represented by North-Saharan faults and flexures separating the northern subsiding domain with relatively thick sedimentary cover in the Chotts and Gafsa basins from the southern domain with thin sediments.

4. Chotts structuring

4.1 Fold and fault geometry

The Chotts structures contain the Chott Djerid and El Fedjedj depocenters, which are bounded by the North and South chains. The Chotts domain generally trends E-W extending from the Gulf of Gabes in the East to the Nefta-Tozeur zone in the West of Chott Djerid.

On both sides of the chain of Chotts, the thicknesses and facies changed (Figs. 2 and 4). These significant and abrupt variations testify of pronounced subsidence in the Chotts furrow, controlled by normal faults during the Mesozoic times. The synsedimentary activity seems to be accompanied by Triassic halokinetic activity during the Jurassic and Early Cretaceous (Figs. 4, 5 and 8). Triassic saliferous facies moved and caused a local thickness variation of overlying series near the normal faults, inducing therefore an early structuring of the northern chain of Chotts.

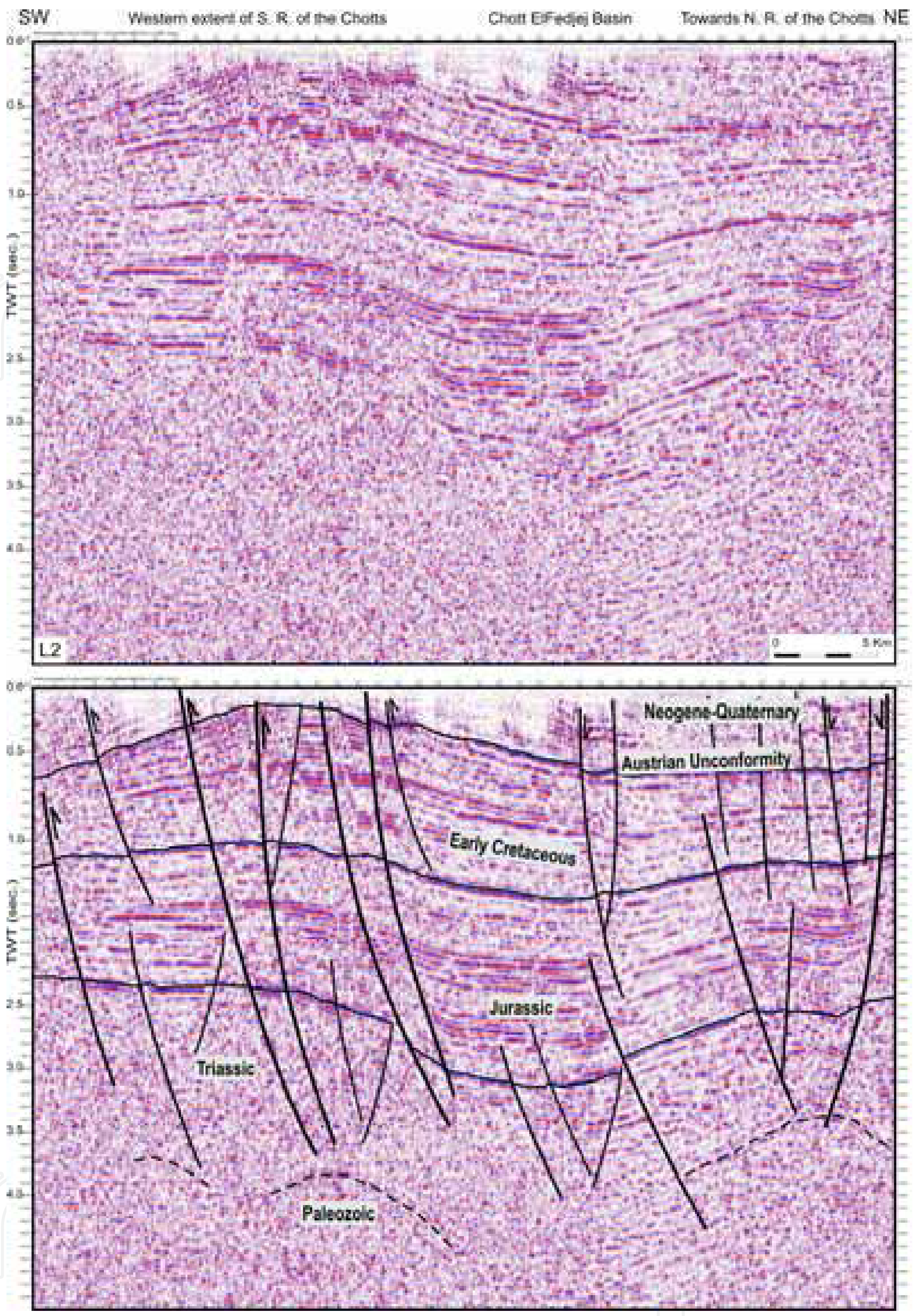

Fig. 5. Seismic section L2 of the Chott El Fedjaj, showing two positive flower fault structures trending east-west and evolution of Mesozoic series under faulting change and halokinesis of northern and southern range of the Chotts

The early halokinesis and its influence on the Chotts structuring was also observed in areas of the southern Atlas of Tunisia (Bédir, 1995; Boukadi and Bédir, 1996; Zitouni, 1997; Boukadi et al., 1998; Hlaiem, 1999; Bédir et al., 2000, 2001; Ben Timzal, 2000; Tanfous-Amri et al., 2005; Zouaghi et al., 2005a, b, 2007 ; Azeiez et al., 2007) and in the Saharan Atlas of Algeria (Vially et al., 1994). Thicknesses of the Mesozoic and Cenozoic series increase gradually from the Saharan platform to the Chotts depocenters (Figs. 5 and 6).

Study of seismic sections shows that the Djerid basin could has a half-graben geometry bounded to the North by a major fault of northern chain of the Chotts (Figs. 5 and 6). Towards the East, the Chott El Fedjej seems to correspond to a graben structure limited to the South and to the North by fault systems. In this area, seismic reflectors emphasize migration of depocenter from North to South since the Triassic until the Early Cretaceous. This inversion would be related to the synsedimentary tectonic and halokinetic activity of the Chotts faults during the extensional intervals. Inversion of structures has continued during Late Cretaceous and Neogene.

4.2 Major unconformities

The Hercynian unconformity defined by toplap structures of the eroded Paleozoic series is related to intense erosion which succeeded the Hercynian orogenesis (Figs. 4-6). The aggradational/ retrogradational onlaps mark the transgression of Early Triassic composed by sandy-clay, showing an angular unconformity. The seismic reflector, tilted to the North by slight slope, is characterized by continuous reflections and high amplitude.

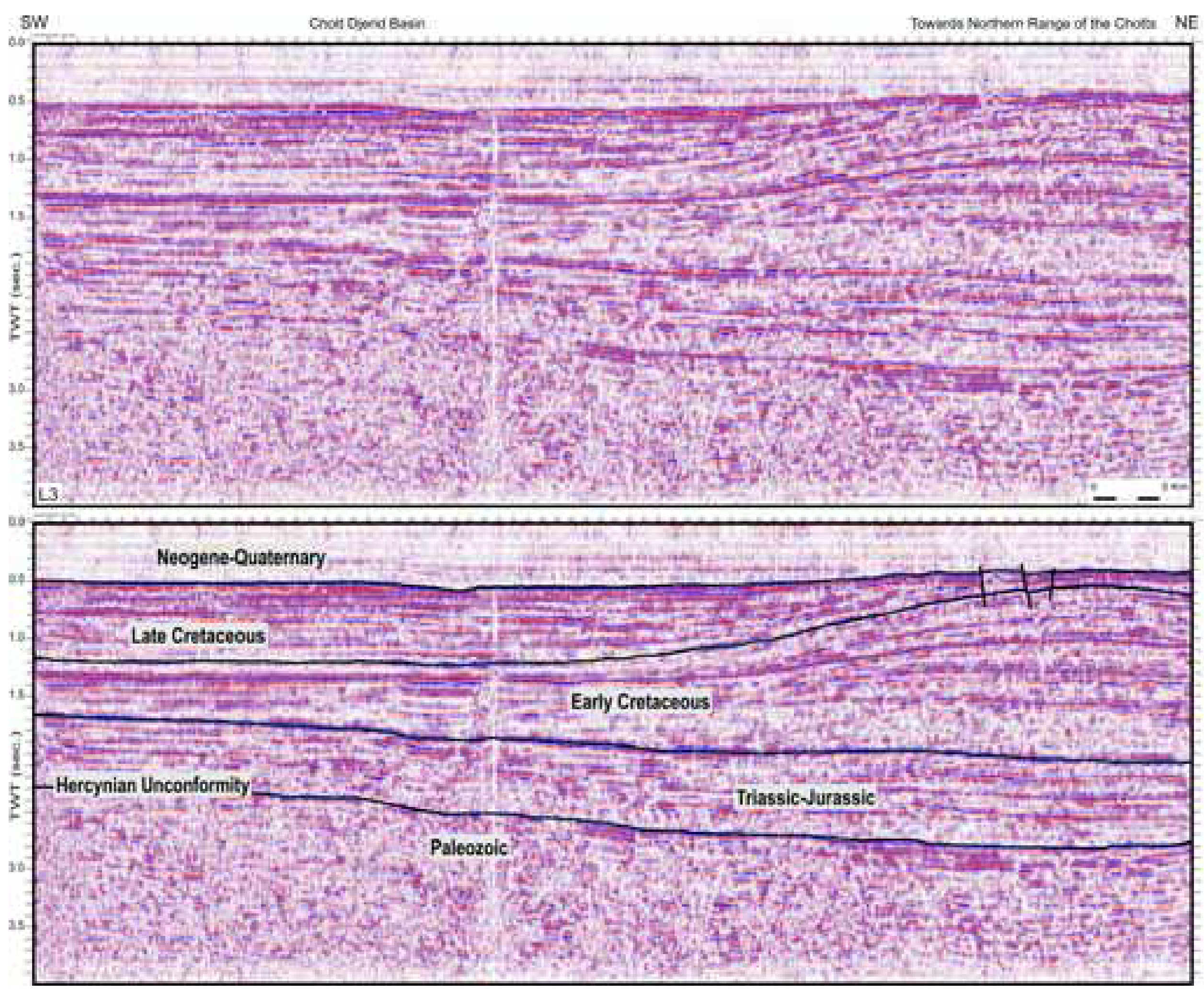

Fig. 6. Seismic section L3 of the Djerid Chott, illustrating distribution of major unconformities and their evolution towards the northern Chotts east-west strike-slip fault and associated Triassic salt intrusion (see Fig. 4)

The top of the Jurassic Nara dolomite formation is marked by moderate continuous and high amplitude seismic doublet (Fig. 6). This reflector is sealed by progradational downlaps of the overlying Neocomian fluvial continental series. This unconformity marked the change from a marine carbonate platform deposition to a fluvial continental one related to a regional marine regression, which reached central Tunisia.

The Late Barremian-Early Aptian erosional surface, which is observed on the entire Saharan platform, is defined by moderate to well continuous and high amplitude reflections forming locally seismic doublets (Figs. 4 and 6). The toplaps correspond to erosional truncation of the Barremian-Neocomian upper detrital series that are onlapped by Aptian to Cenomanian aggradational/ retrogradational transgressive carbonates and clays to the South. The occurrence of this regional erosional surface could explained by an uplifting generated by a tectonic deformation and a sea level fall.

The upper Cretaceous unconformity is characterized by basal toplaps, corresponding to upper strata of Senonian truncated by post-Cretaceous erosion. It is marked by moderate continuous and high amplitude reflections followed by the Neogene-Quaternary sandy-clay continental series deposed in angular unconformity by onlap structures (Fig. 6). Absence of all Paleogene strata indicates general elevation of the Saharan platform at the end of Cretaceous related to the Late Cretaceous-Eocene compressional tectonics associated with sea level falls.

5. Evolution and kinematics

Previous synthesis works described the geodynamic evolution of the southern margin of Maghrebid Tethys and established approximate models showing the relation between current structuring and the ancient Hercynian and later-Hercynian events. The outcrops results (Zargouni, 1985; Delteil et al., 1991; Boukadi, 1994; Zouari, 1995) seem agree with those elaborate in subsurface (Ben Ismail, 1991; Bédir, 1995; Zitouni, 1997; Jallouli and Mickus, 2000; Gabtni et al., 2005; Zouaghi et al., 2005a, b, 2009; Gabtni, 2006). These tectonic models, particularly related to the Tertiary and Quaternary deformations were used for deduce the geodynamic evolution of the Mesozoic basins.

5.1 Mesozoic rifting and extensions

Extensional tectonics started with the Carboniferous-Permian times known in the Dahar plateau and the Djeffara plain of South-East Tunisia (Bishop, 1975; Ben Ferjani et al., 1990 Bouaziz, 1995; Bouaziz et al., 1999, 2002). This extensional event continued and accentuated during Mesozoic periods in relation with the sub-meridian Tethyan extensional framework, which affected the whole of the North-African margin. The relatively thick sedimentary strata of Triassic, Jurassic and Early Cretaceous in the Chotts area, the Gulf of Gabes, and the Gafsa area (Figs. 2, 4-6) testify to an active subsidence during these periods.

Triassic structuring seems to be inherited from the Paleozoic. Mechanisms of the opening are accompanied by thick sedimentary sequences and probably volcanic in subsiding grabens with installation of progradational systems tracts of Early to Middle Triassic sandy-clay and carbonate sequences. The evaporites and salts of the upper Triassic sequences seem to be accumulated on down sides of faults bordering grabens. The Triassic NNW-SSE to

NW-SE oriented extension (Bouaziz et al., 2002) is associated with the alkaline magmatism documented from petroleum well data in the Chotts basin (Laaridhi-Ouazaa, 1994). Basin structuring and sedimentary lapout of the Triassic have been described in Algerian outcrops (Bouillin, 1977; Vila, l980; Obert, l984, 1986; Kazi Tani, 1986). This kinematic corresponds to the beginning of opening of the Tethys and the central Atlantic and therefore separation of Africa from Eurasia. This event coincides with the beginning of the anti-clockwise rotational migration of African plate towards the East (Olivet et al., 1982, Dercourt et al., 1985).

During the Jurassic and Early Cretaceous, the synsedimentary and halokinetic activity of faults, probably developed since Triassic, persists in relation with N-S extensional stage (Fig. 7). This activity involved formation of the pre-existing structures.

The opening of basins, which began with the Triassic has continued and accentuated during the Jurassic where the grabens and subsiding depocenters in southern Atlas showed a geodynamic mechanism similar to that prevailed with the Triassic. Synchronism between the opening of basins and the Jurassic halokinetic rising has accentuated the paleogeographic differentiation, which characterized by progradational deposits on sides of Rim Synclines (Figs. 4 and 5) and by carbonated reefal platforms appeared since the Jurassic.

The Early Cretaceous is marked by a notable change in the tectonic structuring, induced by the reorientation of tectonic extensional stress and sedimentary evolution. This change is fossilized by general unconformity marked by lower Cretaceous progradational downlaps of Sidi Khalif Formation above the Jurassic carbonates (Figs. 4-6). This discordance has been also highlighted in Algeria by Vila (1980) and Obert (1984, 1986). The opening movements observed during the Triassic and Jurassic, are clearly decreased and even sealed during the Early Cretaceous around the majority of Atlassic blocks. The deep fault network starts to undergone deviations of some directions following the strike-slip movements, the rotations of blocks and the rising of the Triassic intrusions and domes across master fault intersections (Zouaghi, 2008; Zouaghi et al., 2005b, 2011).

The Jurassic and lower Cretaceous kinematics show an influence of extensional stresses trending near NNW-SSE (Fig. 7), which is well integrated in the context of the Tethyan openings (Vila, 1980; Olivet et al., 1982; Obert, 1984, 1986; Dercourt et al., 1985).

During Late Cretaceous several complex deformations have been showed controlled by both extensional and compressional stages. The highlighted structures indicate irregularity of the tectonic and sedimentary mode in Tunisia. These intervals are marked by major Triassic evaporite extrusion indicating the saliferous movements and diapirism well characterized in northern Tunisia (Perthuisot, 1978; Vila, 1980). These deformations result in thickness and facies variations associated with unconformities and gaps recorded in middle and upper Cretaceous strata (Figs. 4-6 and 8) highlighted in many localities of the Tunisian Atlas. The end of the Late Cretaceous corresponds to the beginning of the compressional stresses marked by installation of several anticlines. This extensional stress change to strike-slip movements caused deposition of thick Albian-Cenomanian black shales rocks in the subsiding blocks and reefal carbonated platforms on the high blocks. Regionally, this evolution is related to the bringing together of the African plate with the Iberia to the West and Eurasia to the East, under the effect of its rotation but also related to the East-West relative movement of these plates (Olivet et al., 1982; Dercourt et al., 1985; Guiraud and Bosworth, 1997).

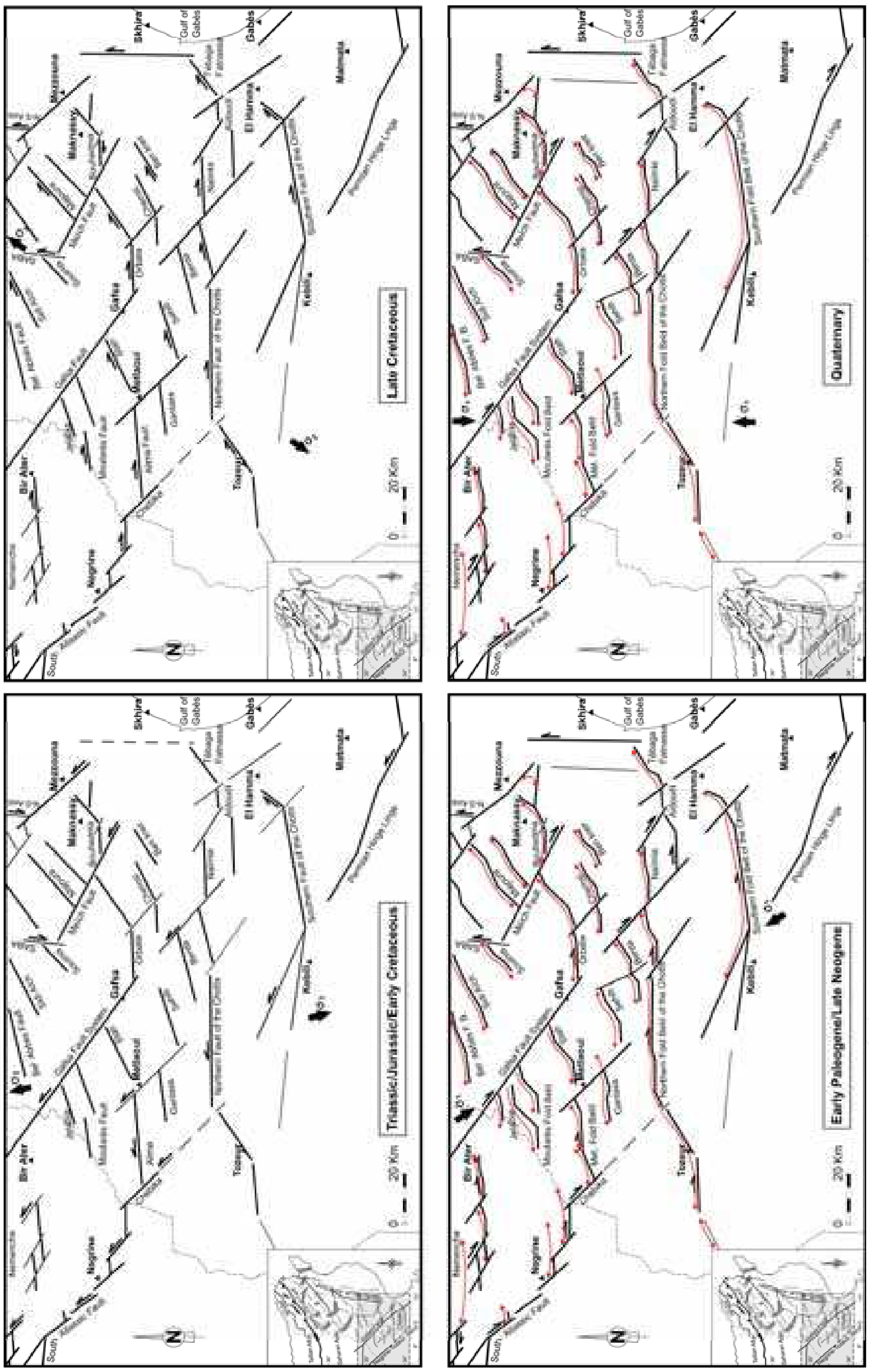

Fig. 7. Effect of the regional tectonic stress field on the geodynamic evolution integrating strike-slip movements, basin geometry, filling and Triassic halokinesis

5.2 Cenozoic inversions

With the beginning of Tertiary times and especially since the Eocene until Quaternary, the compressional events were largely highlighted in the Tunisian areas. These periods are marked by principal tectonic phases of compression trending NW-SE to N-S, which are related to the mechanisms of collision between the African and European plates.

The Eocene corresponds to the final emergence of the Saharan Platform, which started since the Late Cretaceous with the development of the Gafsa-Metlaoui intracontinental folds and synclines. During this period, the Saharan domain that is marked by absence of the Paleogene Sediments, is exposed to erosive action assigning upper strata of the Early Cretaceous (Figs. 4 and 6). Formation of the Eocene folded structures, are locally accompanied by the opening of grabens along the strike slip fault corridors (Ben Ayed, 1993; Melki et al., 2010; Zouaghi et al., 2010). The contractional regional constraint is still NW-SE generating transpressional dextral strike-slip movements on lineaments trending N90 and N120 (Figs. 3 and 7).

The Eocene contractional events detected on the southern Tunisian margin are related to formation of the alpine arc following collision of Europe with the Apulia margin and the accentuation of the Africa-Europe bringing together (Olivet et al., 1982; Dercourt et al., 1985)

At Late Miocene, contractional tectonics become more evident and fossilized by development of folded structures and infilling of the intracontinental basins in southern Atlas (Figs. 4, 5 and 8). The structures previously started by the halokinesis since the Jurassic are reactivated and accentuated during these compressional deformations. The NW-SE upper Miocene contractional events could be correlated to the processes of Africa and Europe bringing together and its collision. The Tortonian major contractional phase, which induces thrust sheets of the North African margin, is well documented (Vila, 1980; Obert, 1984, 1986).

The Quaternary is marked by complex structures resulting from the combined effect of the tectonic polyphasage dominated by the N-S contractional stress (Fig. 7) and saliferous tectonics. We think that it is the result of a combination of a cover tectonic style and deep basement movements.

6. Discussion

6.1 Fold belt of the Tunisia-Algeria Atlassic domain

The Atlassic folds and synclines seem to be evolved under three contractional tectonic events. The first, known as Pyrenean dated end Cretaceous-Eocene has NW-SE (N120 to N140) dominant paleo-stress, the second of Late Miocene named Alpine trending NW-SE, and the third corresponds to post-Villafranchian phase oriented N-S. Some authors have showed another minor and local contractional event dated of Late Pliocene and characterized by N150 to N160 direction of shortening (Zargouni, 1985; Fakraoui, 1990; Addoum, 1995; Bouaziz, 1995).

During the compressional events a local extensional episodes were highlighted. In particularly the Middle Miocene (Langhian-Serravalian) phase trending NE-SW, which induced the opening of the grabens of central Tunisia (Philip et al., 1986; Ben Ayed, 1993; Chihi, 1995; Zouaghi, 2008; Zouaghi et al., 2010, 2011). The N-S post-Villafranchian compressional phase, which largely marked the Atlassic structuring, is associated with normal faults in the Khenchla depression of the eastern Saharan Atlas (Addoum, 1995). In southern Atlas the Eocene-Paleocene phosphate series of the Gafsa-Metlaoui basin shows existence of synsedimentary normal faults (Bouaziz, 1995) that coexist sometimes with other reverse faults (Ben Ayed, 1993; Melki et al., 2010).

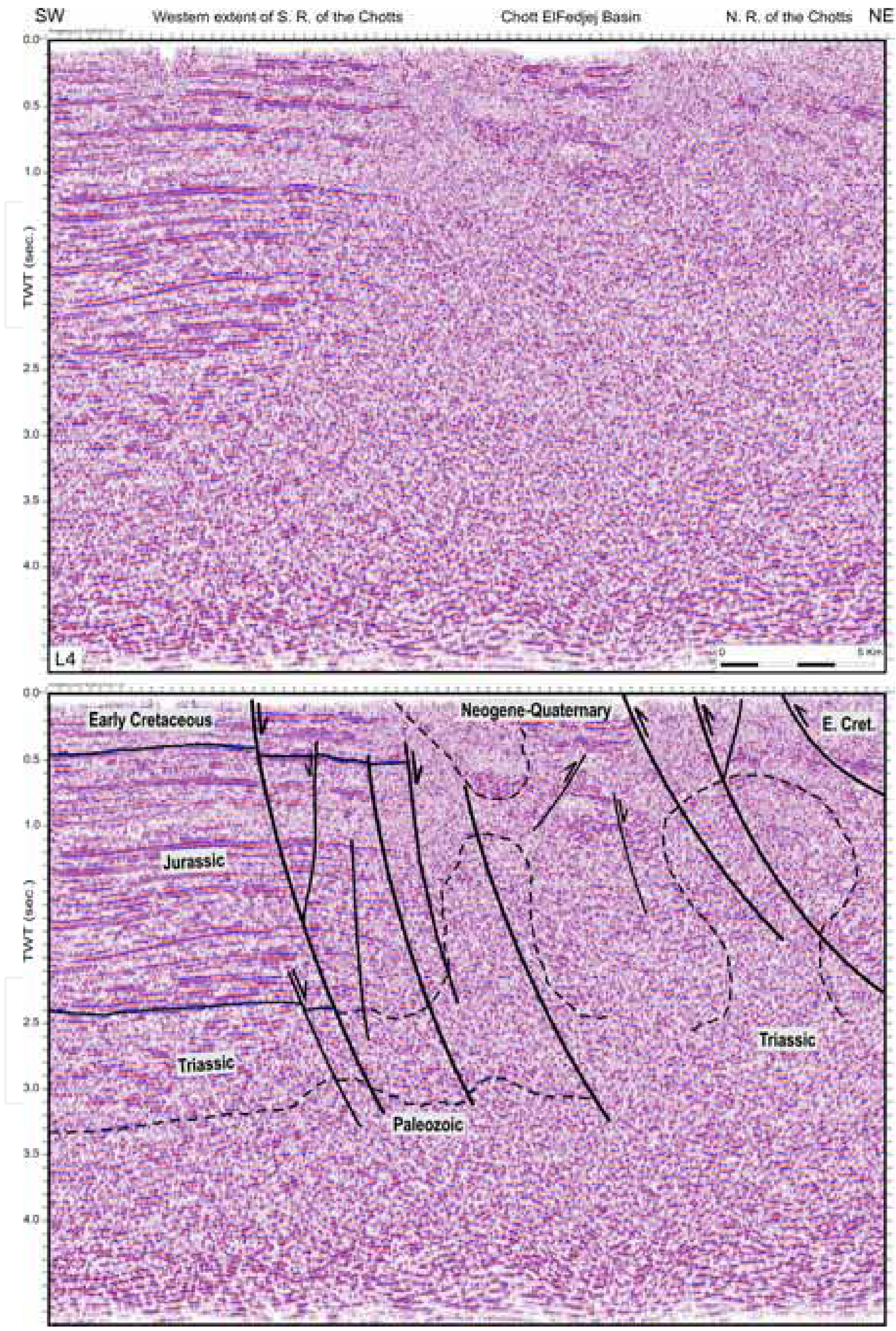

Fig. 8. Seismic section L4 across the El Fedjaj Chott, showing folding and wrench salt-intrusion at the intersection of the northeast-southwest Tebaga-Fatnassa and northwest-southeast Hadifa master lineaments

The main works established on the kinematic of deformation in the Atlassic domain (Creusot et al., 1992 ; Creusot et al., 1993 ; Outtani et al., 1995 ; Addoum, 1995) show the coexistence of two modes of folding; the first corresponds to the folds formed on inherited faults of the infra-Triassic basement, where the ancient extensional structures are reactivated and evolved to reverse faults during the compressional deformations; the second model of propagation folds was also highlighted.
Because the oblique position of the preexistent faults compared to the direction of tectonic stress (Fig. 7), formation of folds becomes more complex because of the strike-slip fault movements (Letouzey, 1990; Ben Ayed, 1993). This kinematic of deformation results in the positive flower-structures organized into overlapping fold belts recognized at the southern Atlas, the most known are the Metlaoui chains, the Chotts chains and the Gafsa chains. In fact, formation of the Atlassic chains was generated by interaction between the major effect related to reactivation in transcurrent and inversion of the old basement faults (thick-skinned style) and a surface effect related to decollement and overfolding of the supra-Triassic cover (thin-skinned style) (Hlaiem, 1999; Zouaghi et al., 2005b; Bensalem et al., 2009). Moreover the early halokinesis during Jurassic and Early Cretaceous associated with the synsedimentary activity of some normal faults contributed to pre-structuring and guiding the genesis of Atlassic fold belts.

6.2 Genesis of the Chotts fold belt

Lithostratigraphic column of the study area reveals the existence of several Formations, which could constitute potential levels of decollement of the overlying cover at the time of folding. Although the main level of decollement remains the Triassic evaporites (Hlaiem, 1999; Zouaghi et al., 2005b; Bensalem et al., 2009), the Cretaceous clays and sandy-clays are locally considered as levels of secondary detachments (Outtani et al., 1995).
The seismic reflection sections suggest a model of broken folds on break-thrusting associated with reverse deep-seated faults in the Triassic. We suggest than these folds are controlled by the basement inherited extensional structures (Figs. 4, 5 and 9).
The kinematic study on seismic lines allows to propose folded structures associated with reverse deep-seated faults reaching the Triassic strata (Figs. 4 and 8). Position and orientation of existing structures would be related to the position of ancient normal faults, which controlled genesis and evolution of the folds structures and associated reverses faults during the compressional events.
Thickness variations on sides of the master faults, which bounded the basins in southern Atlas during the Jurassic and Lower Cretaceous, suggest the existence of normal fault generated during the rifting and extensional phases and caused subsidence increasing (Figs. 5 and 6). The resulted in steps structuring seem to be in agreement with the Knowledge model, which characterizes the North Africa passive margin (Biju-Duval, 1980; Ben Ayed, 1993; Bédir, 1995; Zouaghi, 2008; Zouaghi et al., 2011).
The deep master faults, which are associated with the anticline structures could have a role in the structuring of the cover since the extensional periods by their synsedimentary and halokinetic activity inducing local structural anomalies marked by variations of thicknesses and facies, unconformities, pinching outs and gaps of depositions (Figs. 8 and 9). These inherited faults could influence the localization of the future Atlassic chains before starting of the compressional deformations (Vially et al., 1994).

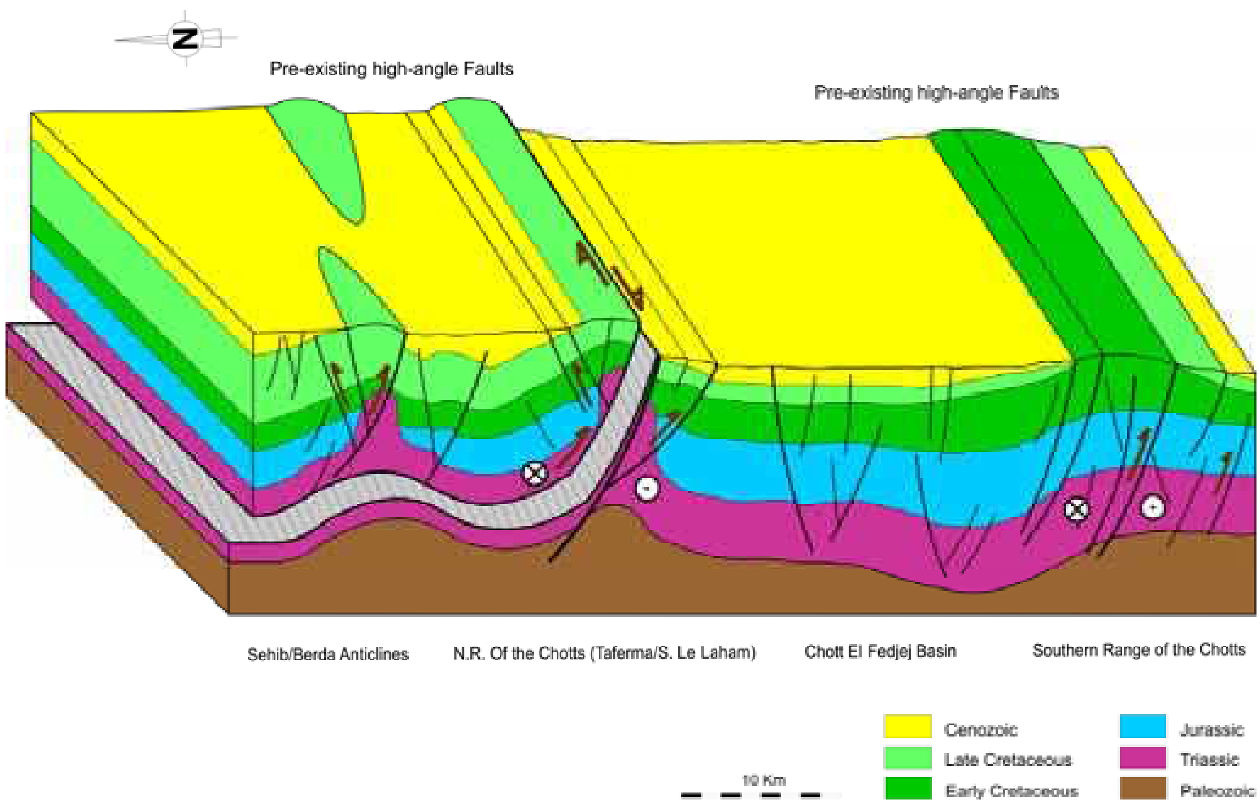

Fig. 9. Block diagram imaging the strain partitioning and resulted folds during the Cenozoic transpressional inversion of Chotts inherited structures

In addition to the role of Triassic halokinesis during the extensional periods that consist in a pre-structuring of the chains, the inherited normal faults would be reactivated and reversed and therefore control the evolution of folds during the contractional times. According to the seismic data we suggest that anticlines structures of southern Atlas are comparable to broken folds on break thrusts (Fig. 9). The slope is generated by the rejuvenation of pre-existing basement faults.

7. Conclusions

Study of major unconformities using the seismic reflections had permitted to identify the principal tectono-sedimentary events, which marked the history of infilling and deformation of the Chotts basins during the Mesozoic and Cenozoic periods. In spite of the local tectonic history, eustatism has marked Saharan craton, in particular during the great falls of sea level. The history of deposition of Chott domain recorded the combined effect of the tectonic deformation and eustatic change, which marked the Saharan platform.

The significant thickening of the Mesozoic series from the South to the North indicates a high subsidence in the Chotts areas controlled by master faults of the Chotts. The southern range of Chotts is characterized by a reduced Mesozoic sedimentation on the platform, which corresponded to a relatively resistant butte rests on the ante-Mesozoic substratum of the northern side of the Talemzane Arch. Increase of thickness in the distal zone to the North, suggests a reduction of deposition space to the South.

Deposition in the Saharan intra-cratonic and marginal basin suggests effect of the Chotts faults related to the regional geodynamic evolution of the peri-tethyan platforms in North Africa.

During the Cenozoic compressive phases trending NW-SE to N-S, rejuvenation of the major faults of Chotts is marked by dextral strike-slip movements, which generate the overlapping fold belts and overthrust folds on the cover of the North chain of Chotts. Structures resulted from deep tectonic deformations as Thick-skinned style and from tectonics of cover as Thin-skinned style are marked by folding and decollement of the sedimentary cover. The southern sides of the majority of chains are vertically straightened sometimes inverted, and transpressive structures are associated with reverse faults. The overlapping folds, which characterize the southern Atlas chains result from dextral strike-slip motion trending near E-W at the level of the basement.

Evolution of the structures around the tectonic blocks of Southern Tunisia from the Jurassic to the Neogene is guided by the rejuvenation of deep crustal lineaments trending E-W and NW-SE and have controlled geometry and evolution of the following sedimentary deposits.

Tectonic deformations have induced halokinesis along master inherited faults. Intersection of these faults during regional extensional and contractional events in the Triassic subsalt basement caused its vertical rising. Interaction of folding and salt diapirism accentuates overthrusting along strike-slip faults.

The strike-slip faults delimited the asymmetric tectonic blocks and differently moved during the geological history. The extensional and transtensional movements during the Triassic, Jurassic and Early Cretaceous, then contractional and transpressional from the end of Late Cretaceous, induced opening of quadratic basins and formation of platforms then closing of the basins and migration of subsiding depocenters, resulting sometimes in blocking stages with compressions following the ancient structural inheritances. The reorientations of the regional stresses along major tectonic discontinuities appear to be induced by movements of the African plate compared to the Eurasia and Iberia (Olivet et al., 1982; Dercourt et al., 1985). Thus we highlight the effects of the principal tectonic events related to the migration of the African plate since the Triassic-Jurassic rifting and the geodynamic answers to these movements at times of shortening on the Tunisian margin.

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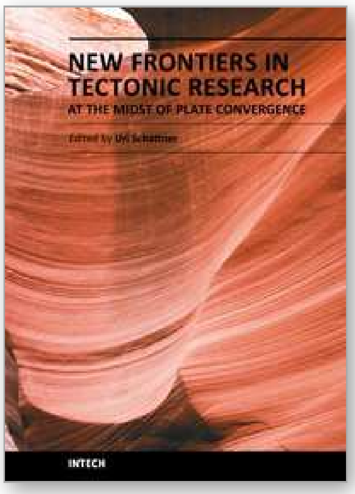

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Ocean closure involves a variety of converging tectonic processes that reshape shrinking basins, their adjacent margins and the entire earth underneath. Following continental breakup, margin formation and sediment accumulation, tectonics normally relaxes and the margins become passive for millions of years. However, when final convergence is at the gate, the passive days of any ocean and its margins are over or soon will be. The fate of the Mediterranean and Persian Gulf is seemingly known beforehand, as they are nestled in the midst of Africa-Arabia plate convergence with Eurasia. Over millions of years through the Cenozoic era they progressively shriveled, leaving only a glimpse of the Tethys Ocean. Eventually, the basins will adhere to the Alpine-Himalaya orogen and dissipate. This book focuses on a unique stage in the ocean closure process, when significant convergence already induced major deformations, yet the inter-plate basins and margins still record the geological history.