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Interconnection salt diapir–allochthonous salt sheet in Northern Tunisia: the Lansarine–Baoula case study

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Abstract

Surface and subsurface data are used to illustrate the halokinetic style, structural evolution and kinematics of the Lansarine–Baouala salt structure in the Alpine domain of Tunisia. It corresponds to a salt structure showing a large salt canopy overhanging buried diapir. The salt structure is located along the main fault systems, inherited from the southern Tethyan passive margin periods. The Northern domain of Tunisia is undergoing diapirism, which has been recognized as active during the Upper Aptian and Lower Albian periods. Above the diapir apex, salt flows outward and spreads by gravity downslope. A minibasin has formed during this period of salt outward evacuation. The minibasin has a thickness practically correlated to the budget of salt evacuation toward the diapiric structure. During Cenozoic times, compressional deformation stages do not reflect active diapirism. The Lansarine–Baouala salt structure, consisting of connected salt sheets, was passively transported on the Southeast-verging major thrusts that are deeply rooted in the salt beneath the Mateur basin. The Northern Atlas of Tunisia reveals, as many others salt provinces, an interconnection of salt diapirs and significant laterally spreading allochthonous salt sheets (canopies?). In this domain, the inherited allochthonous Triassic salt sheets interlayered within recent series and connected to buried diapir have a significant role in the shallow structural complexity observed in the sedimentary cover during the subsequent contractional events.

Keys-words: North Tunisian Atlas; diapir; allochthonous salt sheets; mini-basin; thrust

1. Introduction

Rifts and continental margins are usually characterized by salt deposition followed by salt tectonics, which strongly influence their structural styles (e.g. Talbot et al., 1991; Weijermars et al., 1993; Jackson and Vendeville, 1994; Hudec and Jackson, 2007; Callot et al., 2012). Salt tectonics is currently recognized to have a crucial role in the deformation of several geologic systems around the word in both active and passive margins (e.g. Rowan et al., 2003; Hudec and Jackson, 2007; Alsop et al., 2015; Moragas et al., 2017). Rift and passive continental margins tectonic style and/or evolution were the subject of new tectonic concepts developed during the last 40 years (e.g. Bally, 1983; Allen and Allen, 1990; Brune et al., 2014). These geologic systems are commonly described as dominated by intra-basin growth listric normal faults in control of an asymmetrical seafloor that is characterized by repetitive depocenters. The intra-basin faults system is responsible for the basin's geometry that is characterized by hanging-wall rollovers, rafts, salt-related features and important thickness and facies variations of sedimentary sequences. These systems are frequently inverted and deformed by subsequent compressions hence the area is subject to tectonic inversion. The presence of salt is usually involved in the deformation of several inverted systems such as the Alpine orogens of Europe, the Betics, the Pyrenees, the North African alpine belts, Zagros (e.g. Canerot et al., 2005; Masrouhi and Koyi.; 2012; Callot et al., 2014; Saura et al., 2015). The early interpretations of salt tectonics that predominated during the first half of the 20th century were also updated by the upsurge of the thrust tectonics models. This evolutionary trend has modernized salt tectonic concepts. Recent improvement in drilling and seismic technologies led to a surge of large allochthonous salt on deep water passive margin. Although salt structures are being recognized as having large overhangs (e.g. Jackson and Talbot, 1989; Talbot et al., 1991; Talbot, 1993), several hundreds of salt overhangs are known to exist now (e.g. Wu et al., 1990; Talbot, 1993; Fort and Brun, 2004; Hudec and Jackson, 2004, 2006, 2009) and are confined to only a few of the many sedimentary basins containing salt (Gulf Coast, Campos basin, Angola margin, Red Sea). Past salt overhangs are neglected in literature because they are usually comprised within orogens.

After a while, the interaction between salt diapir and salt sheets has been studied by several works in a large proportion of salt provinces: Australia (e.g. Hearon et al., 2015; Rowan et al., 2019), Iran (e.g. Heydarzadeh et al., 2020), Turkey (e.g. Kergaravat et al., 2016), Central Europe (e.g. Warsitzka et al., 2019), the Algarve Portuguese basin (e.g. Ramos et al., 2017), Mexico (e.g. Giles and Rowan, 2012), USA (e.g. Gradmann and Beaumont, 2017) and among others. Processes of mobilization of salt usually assists gravitationally driven deformation of rock mass associated with this growth. In passive margin setting,

during sedimentation a wide range of gravity driven structures in successive depositional events are generated along the slope. Salt is itself associated to this evolution in which the overburden moves with gravity spreading driven by the differential load of tectonic blocks (Alsop and Marco, 2014). The half-graben, which usually characterizes this growth, develops salt diapir in case of sufficient buried underlaying salt budget. When the salt reaches the sea floor, the interaction of several parameters guides the evolution of the structure such as the rate of salt evacuation versus the sedimentation rate (Fernandez et al., 2020), the impact of base-salt relief on salt flow (Dooly et al., 2018), Extension versus sedimentation rate (Allen et al., 2020)…

The Maghreb exposes numerous salt structures and is described as one of the largest worldwide salt provinces. Salt structures are more abundant in the eastern part of this province which corresponds to the Northern Tunisian Atlas. This 10000 km^2 area exposes more than 40 structures, most of them are hundred square kilometers structures (Fig. 1). Salt structures in this region have been the subject of controversial geologic interpretations (e.g. Perthuisot et al., 1988; Vila et al., 1994; Masrouhi et al., 2014a). In this province, two different types have been proposed to explain the salt growth and configuration: (1) the salt pierces the overburden and the sequences' thickness is reduced in the limbs of the structure which define the diapir or dome model (Bolze 1950; Perthuisot 1978; Perthuisot et al. 1998; Jallouli et al. 2005; Benassi et al. 2006). This model corresponds to the means of 1970s ideas based on buoyancy -driven convection. Halokinetic movement was attributed to autonomous, isotactic rise of salt and vertical salt movement versus its overburden due to Rayleigh-Taylor instabilities. (2) Allochthonous salt interpretation (Ghanmi et al. 2001; Vila et al., 2002; Slama et al., 2009; Masrouhi and Koyi, 2012; Zouaghi et al., 2013) which suggests a setting with salt flowing at the sediment–water interface through a feeder frequently acknowledged as the normal faulting affecting the sedimentary cover over the Triassic salt. The normal synsedimentary faults, formed during the thin-skinned Cretaceous extension of the southern Tethyan passive margin, create a space for salt to reach the surface during their motion and then flows on the surface, thus defining a salt glacier structures. Although the interconnection between salt domes–salt glaciers is well documented in many passive margins, the interconnection between those two types of structures has never been identified in the Northeastern Maghreb salt province.

This study presents such an interconnection for the first time in this province and demonstrates a reappraisal of the structure and the diapirism growth style with significant allochthonous salt sheet (canopy?) spreading laterally from the diapir stem during the lower Cretaceous period. We present new

surface and subsurface data for both diapir growth and the salt sheet-related structures, which are now partially obliterated by subsequent Tertiary compressions that need to be considered in the study of salt tectonics in the Northern African area.

2. Geological setting

2.1. Structural framework

The Northern Tunisia Atlas is the eastern segment of the Maghreb folds-thrust belt known as the Maghrebides chain (Fig. 1). The Maghrebides is an Alpine belt; occupying the Northwestern African plate, which is related to the Africa–Eurasia convergence during Tertiary–present-day period. After a long Mesozoic extensional Tethyan period, the positive inversion of the basins in Tunisia is recognized to operate during Late Cretaceous (Guiraud and Bosworth, 1997; Masrouhi et al., 2008). During the Cenozoic compressional history, the first significant contractional event is dated as Middle-Late Eocene and accepted as the Atlassic compression (e.g. Vila et al., 1975; Frizon de Lamotte et al., 2000). The Atlassic event is well traced by regional unconformity on the entire Tunisian Atlas (Masrouhi et al., 2007; Gharbi et al., 2015). During the Oligocene–Lower Miocene period, the Atlas domain shows a post compressional tectonic quiescence stage. The Oligocene–Miocene sequences are deposited in distinguished sub-basins such as the Numidian Basin and the Medjedra basin. The tectonic setting seems to be well correlated to the West-Mediterranean geodynamic setting (Corsica–Sardinia and the Algerian–Provencal Miocene back-arc basin opening (e.g. Vergés and Sàbat, 1999; Frizon de Lamotte et al., 2009; Roure et al., 2012; Van Hinsbergen et al., 2014). The Oligocene–lower Miocene extension is caused at the scale of the margin by the retreat of the slab (e.g. Jolivet and Faccenna, 2000; Deverchere et al., 2005). In the Tunisian Northern Atlas, the paroxysmal compressional event is considered to have occurred during Middle Miocene to present-day times by several authors (e.g. Dlala, 1992; Chihi, 1992; El Ghali et al., 2003; Gharbi et al., 2014). All authors who worked in this region agree that this event is the major compressional tectonic event deforming the Atlassic domain of Tunisia (e.g. Gharbi et al., 2014; Bahrouni et al., 2014; Soumaya et al., 2015; Masrouhi et al., 2019). The main regional compression direction was identified by several studies as NW-trending during Miocene-Pliocene and N-Trending during the Late Pliocene-Quaternary (e.g. Dlala and Hfaiedh, 1993; Billi et al., 2011; Gharbi et al., 2014; Soumaya et al., 2015). The northern Atlas of Tunisia shows major NE–trending thrust systems, with three most important traced fronts from North to South being (Fig. 1): the tell thrust range front, the Teboursouk Thrust Unit Front (TTUF) and the Zoughan-Ressas Thrust Unit Front (ZRTUF). The structural style of this belt has recently been identified as the result of the inversion of Mesozoic

inherited structures of the earlier passive margin basins and/or sub-basins along the south Tethyan margin (e.g. Jaillard et al., 2017; Naji et al., 2018a; Masrouhi et al., 2019).

The inherited system is well linked to the Jurassic and Cretaceous periods with the southern margin of the Tethys (Boughdiri et al., 2007; Frizon de Lamotte et al., 2013). The long Tethyan evolution generated major basins from Morocco to Tunisia during the Late Permian–Late Cretaceous (Roure et al., 2012; Moragas et al., 2016, 2017; Naji et al., 2018a). The long Mesozoic evolution began with Triassic basins from an epicontinental environment and characterized by evaporitic facies covering the entire Maghreb sub-basins (e.g. Soto et a., 2017). The Triassic sub-basins frequently display subordinate basalts preserved in several localities in Tunisia (Laaridhi-Ouazâa, 1994) that are interpreted as the result of rift-related magmatism (e.g. Mattoussi Kort et al., 2009). During the Jurassic period, a well-documented main N-trending regional extension was associated to the development of main basins (e.g. Boughdiri et al., 2007; Saura et al., 2014; Martin-Martin, 2017; Soussi et al., 2017; Moragas et al., 2018). These basins are subject to significant thickness and facies variations (Peybernes et al., 1994; Boughdiri et al., 2007). During Early Cretaceous a NE-SW regional tectonic extensional setting became dominant (e.g. Jaillard et al., 2017; Naji et al., 2018b). This evolution from E-W (present-coordinates) to NW-SE shape is well-matched to E-W transform faults of the Atlantic that change to NW-SE in the Alpine Tethys (e.g. Rosenbaum et al, 2002; Masrouhi et al., 2019). During the lower Cretaceous, a paleogeographic differentiation was established with a continental platform in the south and center and a deep domain in the north. This differentiation is associated with volcanic and salt structures, all of them characterized by a passive margin context (e.g. Mattoussi Kort et al., 2009; Masrouhi et al., 2013; Jaillard et al., 2017; Dhahri and Boukadi, 2017).

Halokinetic signature in the Maghreb domain has long been recognized and mostly interpreted as Cretaceous–related structures (Bolze, 1954; Perthuisot, 1988; Vila et al., 1994; Masrouhi et al., 2014b). This belt corresponds to one of the largest worldwide salt provinces in which a debate has been active for decades between two main interpretations i.e. “vertical” diapir structures [autochthonous emplacement] and salt sheets [allochthonous mobile evaporites emplaced at younger stratigraphic levels]. This paper presents new data of the LBSS to highlight a new model of relationship between the allochthonous salt canopy and the autochthonous diapir feeder, in which the relationship is partially obliterated by Tertiary compressions.

2.2. Lithostratigraphic successions

Mesozoic and Cenozoic series outcrop along the LBSS region and comprise sequences from Triassic to quaternary deposits.

The mainly evaporitic Triassic series shows a thickness that varies from 150 to 1000 m. The Jurassic series consist of classic limestones Oust, Zaghouan, Staa, Zaress and Beni klab Formations (Peybernes et al., 1996; Boughdiri et al., 2007). These series are reduced in the southern part of the LBSS compared to their southern equivalent outcropping in the Tunisian Dorsale (Soussi et al., 1999). They vary from 40 to 450 m in outcropping series near the LBSS and include stratigraphic gaps linked to the tilted block geometry characterizing this margin during Mesozoic times (Naji et al., 2018b). In the northern domain, the Jurassic reach a 1000m thickness in the Mateur – Ichkeul area (Alouani et al., 2006). In this area, the Jurassic sequences usually indicate the presence of siliceous radiolarites revealing an important oceanic depth (Cordey et al, 2005).

The Tithonian-Berriasian displays a facies made of debris-flow and mud-flow sandstones and siltstones sequences. The Valanginian–Hauterivian is made of siliciclastic carbonate usually covered by mixed shelf deposits that are dated as Hauterivian and defined as Seroula Formation (Peybernes et al., 1996). The Barremian sequences are described in this region to contain a lower tempestites unit followed by a thick carbonate unit and topped by storm deposits and black-shales parasequences (Khessibi, 1967, Souquet et al., 1997). In northern Tunisia, the Valanginian–Aptian series are defined as M'Cherga Formation (Burollet, 1956; Ben Ferjani et al., 1990). The Aptian–Early Albian sequences are typically of deep-water environment made of gray to black marls. They also habitually contain abundant slumps and nodules features usually interpreted as related deep and irregular sea floor. This period (Aptian–Albian are the two longest epochs of the lower Cretaceous) is interpreted as displaying the maximum extensional rate of the Tethyan basin in northern Tunisia (Masrouhi et al., 2014b, Jaillard et al., 2017; Naji et al., 2018a). Moreover, more than 80% of the salt structures appeared to be active during Aptian–Albian (e.g. Perthuisot, 1988; Vila et al., 1994; Ghanmi et al., 2001; Masrouhi et al., 2014a).

After the lower Cretaceous deposition variation, the northern Tunisian domain shows a late Cretaceous homogenous facies cover the entire basin with no significant facies variation. The late Cretaceous basin is mainly consisting of pelagic to hemipelagic facies. The basin reflects a transgression that invaded and sealed the aforementioned lower Cretaceous configuration. This deposition of the top of former dislocation is attested by significant thickness variation along the entire basin. The thicknesses vary considerably from some meters to hundreds of meters for the same interval from an area to another.

This period is characterized by homogenous facies with shales, marls and limestones characteristic of post rift sedimentation (Fig. 2). The post rift sedimentation started in late Cretaceous times and smoothly sealed tilted blocks geometries, shaped and accentuated during Early Cretaceous by major synsedimentary normal fault systems. This second cycle shows limestone and marl alternations at the base dated as Albian–Cenomanian and defined as Fahdene Formation. These sequences are topped by organic-rich limestones thinly laminated defined as Bahloul member. On the Fahdene Formation, the Turonian–Early Campanian Aleg Formation is formed by marl and shale with fine-grained limestones (Burollet, 1956). Upper Cretaceous sequences, defined as Abiod Formation, display Campanian–Maastrichtian chalky limestones deposits covering the entire basin of Tunisia (Burollet, 1956).

The Tertiary consists of the following sequences: marine black shale series dated as Paleocene and defined as the El Haria Formation. El Haria Formation is frequently overlain by the lower Eocene Formation made of limestones. Then, middle to upper Eocene thick series of marls and shales corresponding to the Souar Formation. Due to the tectonic history (large thrust systems), the upper Eocene does not outcrop in the Lansarine region. Oligocene sequences involve deltaic siliceous sandstones. The Neogene sediments are made of thick marine Aquitanian–Burdigalian formations. The upper Miocene–Pliocene sequences are continental strata recognized as the result of the large erosion during Cenozoic uplifting and cover unconformably the Neogene and Cretaceous Formations.

3. Field data and results

The structural analysis based on a study of detailed geologic maps, controlled by field cross-sections. Interpretations are based on the detailed geological map (1:25 000 scale) form existing data and data prepared for this study. Work consists also of the use of the existing detailed micropalaeontological data from the formations, in order to date the lithologies and illustrate the position of the Triassic salt relative to the surrounding Mesozoic and Cenozoic sequences. the characteristics and behavior of the contact between salt and other strata is detailed to draw back the nature of salt (vertical diapir and/or horizontal salt sheet). Fault kinematics analysis is conducted in some areas, to quantify the brittle deformation and the tectonic regime contemporaneous to the salt body evolution.

The ~ 360 km2 LBSS corresponds to the second largest salt body in the north Tunisian salt province. In order to highlight the significant variations of the salt geometry in different areas, we will first discuss the salt contacts in key-zones and then present the structural style by segment.

In the northern part of the LBSS, all the southeast part of the Triassic salt body is in contact with Cretaceous strata. The Triassic salt overlies Albian sequences in the south (Wadi Maiou). In this region, lower Albian dips 45° to the NW under the Triassic units that are parallel to the Cretaceous layers and do not show an extrusive character (Fig. 4). The parallelism between salt contact and Albian layers was the subject of the most curious interpretations by former study of Bolze (1954) which attribute an Albian age to the Triassic salt. This parallel contact can be mapped along more than 2 km from Wadi Maiou to Wadi Tell and, regarding the ravinant character, was interpreted as a“ conformable contact” between Triassic salt and Albian Sequences due to an extrusive flow of salt (Masrouhi et al., 2013). This terminology was used to qualify the bottom or the top contact of the salt sheet that flowed over the sea water-sediment interface or was covered by later deposition. This contact is genetically different from a sharp vertical diapiric contact. In the northwestern part, salt is joined in an anticline structure without the classical complication of salt (Fig. 4). The Jebel Bou Djebbah anticline structure shows once more a salt with conformable contact and a cretaceous series that plunges under the Triassic sequences. Northward, in the Wadi El Ahmer locality, an Aptian sequence crops out in the main salt structure. This outcropping Cretaceous series was initially described and dated by Masrouhi et al. (2013) as an upper Aptian sequence. For the first time in this region, a work highlighted a fold structure in which Triassic salt is incorporated in recent series. The Wadi El Ahmer locality shows a NNE-trending anticline structure including upper Aptian Triassic salt cover sequences (for dating see Masrouhi et al., 2013) without the typical salt folding. In the middle part of the large salt outcrop, an Aptian sequence was also identified as the bedrock of the Triassic evaporites (Fig. 4). This anticline shows a “conformable” Triassic contact (ravinant, glauconitic and reworked Triassic insoluble elements) at a dipping angle of 30° subparallel to the above Aptian sequences. Far northwest, the Lella Selilia offers an outcrop of salt sheet with a salt contact subparallel to its cover that is constituted by a normal stratigraphic succession from upper Aptian to Campanian sequences. In the northeastern part (the Sebaa Regoud) a “lower conformable contact” (with respect to the salt position) crops out in this entire region.

The central part of this structure shows the main salt body of Lansarine in contact with two cretaceous outcrops i.e. the Ain El Karma Locality and the Jebel Djedaria (Fig. 5): At Ain el Karma, the Triassic salt covers dark greenish clays with many nodules associated with slumps (a) themselves covering limestones (b). For 2 km from the south to the north, the base of the Triassic salt is in contact only on the term (a). This series has long been regarded as overturned middle Albian series by all authors (Jauzein, 1962; Zargouni, 1975; Perthuisot, 1978). Masrouhi et al. (2013) presents a detailed

micropaleontological association in which a distinction has been established with lower Albian in the base and middle Albian in the upper part, confirming a normal stratigraphic succession. The Jebel Djedaria shows the only southern outcrop of Cretaceous sequences under the tertiary complex configuration of the Jebel Lansarine. This locality offers an outcrop showing a reduced Cretaceous sequence (compared to their equivalents in northern Tunisia) covering Triassic salt. This section is formed by Upper Albian to Santonian sequences with normal lithostratigraphic polarity. Thickness and contact nature (glauconitic, transgressive and phosphatic) testify to a transgressive Cretaceous sequence on an existing submarine salt sheet that was extruded on a water–sediments interface. The interbedded position confirms a rapid salt spreading (1 to 2 Ma). Moreover, the Lansarine central part shows a 500m thick Triassic salt sequence in the East (Ain Karma) and 150 m thick sequences in the Jebel Kef Debba (Fig. 5), possibly indicating a northwestward thinning of salt and thus a possible northwestward spreading.

The LBSS corresponds to the second largest Triassic salt body in contact with only a few Mesozoic outcrops, making the interpretation of this structure difficult. The geologic maps and field data (Figs. 3-6) display evidences that the LBSS is a curved deformed zone bounded mainly by NE- to E-trending faults systems. Its northern side is affected by the 8-km long N40°E-trending Baouala fault. In the main salt body this fault is well identified by microfolding along the fault trace. Along the southeastern side of the Jebel Malouia this fault is confirmed as the main thrust in this region, delimiting a hanging-wall with Triassic salt and a footwall formed by Campanian to Miocene sequences. The offset is estimated to be between 1 and 2 km, regarding the salt position versus the Cretaceous sequences and Miocene sequences. This thrust bounds two varied domains in relation to the salt position: to the northwest the Triassic salt overlies upper Aptian (described afore in Wadi el Marir, Wadi Ahmer, Jebel Bou Djebbah and Sebbaa Regoud) and to the southwest salt overlies Albian sequences (Wadi Maiou). The folding curves and the related structures attest a post Miocene shortening. Three fault sites in this region were analyzed and display a major NW-SE Miocene to quaternary compression state. Using the fault diagram (Fig. 4), the first site (sf_1) indicates a compressional tectonic regime locally characterized by N337°-trending maximum stress axis (σ1). The second site (sf_2) measured in the Campanian limestone forming the footwall of the Baouala thrust indicates a similar compressional tectonic regime locally characterized by N145°-trending maximum stress axis (σ1). The third site (sf_3) measured in the Miocene limestones also indicates a compressional tectonic regime locally characterized by N343°-trending maximum stress axis (σ1). These three sites are compatible with the majority of the tectonic studies in northern Tunisia illustrating a NW-trending Miocene to present day main compression (e.g.

Melki et al, 2011; Soumaya et al., 2015; Booth-Rea et al., 2018). The fault kinematics analysis is compatible with field data illustrating a southeast verging of the Baouala thrust.

The Lansarine region of northern Tunisia shows a plateau with horizontal Eocene sequences resting on a well-outcropping marine Miocene series on its southern side and overlapping a detritic series of the Fortuna formation commonly attributed to the Oligocene (Fig. 6). The Fig.6 shows the configuration and reproduces the geological history of this region. The Oligocene–lower Miocene sequences cover a Cretaceous unit of the Jebel Djedaria and show a moderate angular unconformity of about 15°. The Paleogene (Paleocene and Eocene) subhorizontal sequences of Lansarine consist of two units forming the so-called "Lansarine nappe" (Masrouhi et al., 2007). The previous mapping estimates a southeastward advance of about 10 km from the peel thrust of Mateur, themselves are displaced, which therefore constitutes a minimum estimation based on erosion limits. The thrust overlaps are well fossilized in the entire Lansarine plateau. The top of the Miocene sequences under the thrust was dated as Serrevalian. This implies that this configuration attests at least two tertiary compressional events. A first Eocene episode with a moderate folding which corresponds to the well-known Atlassic compressional event (Masrouhi et al., 2008) recognized on the overall scale of the Maghreb (Frizon de lamotte et al., 2000; Dhahri and Boukadi, 2010). A second paroxysmal Tortonian compression (the Alpine phase) is responsible for the present structure and deformations observed along this region (Chihi, 1992; Bouaziz et al., 2002; Bahrouni et al., 2014, Gharbi et al., 2014; Ahmadi et al., 2019).

The second characteristic, well identified by maps and geometric relationships between entities, is the E-trending fault systems. This Atlassic domain shows active N110-120° E-trending faults systems involved in the tertiary deformation affecting all sediments including the Mio-Pliocene sequences, which confirms their recent activity. This system frequently displays a multiphase striation for which the first one is classically related to the Mesozoic extensional period. This system is usually associated to thickness variations, slump folds and conglomeratic horizons indicative of their early Mesozoic evolution. Using the fault diagram, we rotated the collected fault data (Fig. 7) to restore the bedding plane to its horizontal orientation. We also used the back-tilting fault kinematics analysis of Naji et al., (2018b) carried out in the northern Tunisian domain. The back-tilting result shows that these faults were normal faults predating the Cenozoic tilting (Fig. 7). Back-tilting of the measured lower Cretaceous fault population indicates a normal faulting that result from an extensional tectonic regime locally characterized by NE-SW minimum stress axis (Fig. 7). The back-tilting of the Aptian–Albian measured fault population indicates a normal faulting that result from an extensional tectonic regime locally

characterized by E-W to NE-SW minimum stress axis (Fig. 7). This phase is mainly characterized by NW-trending fault systems and associated sub-basins. This change from lower Cretaceous to Aptian-Albian periods, is interpreted in Tunisia as the translation from the Jurassic E-W (present-coordinates) dominant shape to Early Cretaceous NW-SE shape, which is concordant with the general E-W transform faults of the Atlantic that translate to NW-SE during the Alpine Tethys faults (Rosenbaum et al, 2002; Frizon de Lamotte et al., 2013; Masrouhi et al., 2019). The tectonic regime changes during the late Cretaceous post-Rift period. Locally, the Lansarine domain seems to be controlled by normal faults characterizing a NW-SE to N-S tectonic extension (Fig. 7).

4. Seismic interpretation

Three seismic profiles are used and interpreted, for which some of them are composite ones. The seismic sections were provided by ETAP Petroleum National Company and the Carthago Oil Company Tunisia. For some section the acquisition was carried out by Shell-Tunirex Company in 1983. Seismic profile data are used to correlate the fault systems and/or tectonic blocks with the above-described sedimentary sequences. These Seismic profiles were correlated by petroleum wells as well as the stratigraphic sequences and outcrops established by the present-study fieldwork.

In this section, seismic profile interpretation is used to document the presence of allochthonous salt sheets and a buried salt diapir in the study area. Three seismic profiles are used to highlight the geometry at depth, halokinetic type and entities relationship. The seismic section L18 is a composite section derived along the Lansarine–Baouala region (Fig. 8). The ~ 35 km long NW-SE L18 profile crosses the LBSS near the Baouala structure (Fig. 3). Furthermore, two seismic profiles are used to highlight the distribution and the relationship between entities that are respectively the NE-SW L05 profile in the northern part and the NE-SW L11 profile in the southern part (with respect to the salt structure). These seismic profiles were analyzed and interpreted using calibration from the W-1, W-2 and W-3 petroleum wells (see Fig. 3 for location). The internal geometry of the shallow portion of the profiles in the LBSS is calibrated by the surface observations of this study.

The seismic section L18 highlights the Teboursouk and the Baouala fault zone that is characterized by a deep north-dipping basement fault and shallow listric normal faults within inferred Triassic evaporites, which confirms previous results (Rigo et al., 1996; Masrouhi et al., 2013). This basement fault zone was mostly active as a normal fault during Mesozoic times, allowing the deposition of a thick sedimentary pile in this northern Tunisian domain, reaching up to a thickness of 6 km. This major basement normal

faulting controls Mesozoic basin with associated changes in thickness well observed for the Jurassic and lower Cretaceous sequences. Structurally, it is clear that the present tectonic style of the area is the result of a post Cretaceous structural inversion. In this zone, the thick sedimentary cover is deformed by thrusts and large-scale folding above the southeastward major thrusts connected in the interface basement-cover (Triassic salt?). Thrusts are superimposed on deep seated basement faults which were active during Mesozoic times as major normal deep faults. The diapir, detected at depth for the first time, seems to be a minor complicating factor in Tertiary shortening deformations. Geometry, thickness variations, together with Triassic evaporites associated to a major thrust, suggest that the basement-cover interface geometry of this domain is poorly deformed (Fig. 8). The profile shows major thrust systems developed beneath the Chouigui basin at the base of the basement–cover interface. The far northern part shows an imbrication of southeast-verging thrusts and gently dipping asymmetric folds filled by Oligocene-Miocene series (Fig. 8). The absence of the lower Cretaceous series in the hanging-wall and the base of these minor thrusts suggest a Cenozoic development. They probably do not correspond to inverted faults. In between, major southeast verging thrust systems are developed and major normal fault between Baouala block and Mateur plain are preserved. This seismic section underlines a buried diapir at depth. This stem of the LBSS is revealed as a salt body now buried under the complex thrust configuration of the LBSS. The main information highlighted by this seismic section is the compatibility between surface and subsurface data showing the presence of allochthonous salt sheets detected on the surface and their thinning towards the north. The salt sheet is detached from its autochthonous original position. A salt sheet (canopy?) is interlayered between lower Cretaceous beds. This 8 to-10 km-long salt sheet is actually located in the hanging-wall of the main southeastward thrust. The seismic section also highlights that salt tectonics seems to be controlled by Mesozoic normal faulting associated with well-developed rim synclines (salt mini-basins?) in lower Cretaceous thick sequences around the main salt body. Salt mini-basins are actually well recognized as being associated to salt movement in many worldwide salt provinces (Hudec and Jackson, 2007; Callot et al., 2012; callot et al., 2016). Mini-basins were likely formed as the result of the synsedimentary upward movement of Triassic salt conducted by the differential sedimentation loading itself guided by the major normal faulting. At present, the absence (or thinning?) of salt under Mateur plain may be explained by the lateral flow of salt from the main stem during Mesozoic times. This phenomenon, called salt evacuation, is well known in many other salt provinces (e.g. Gulf of Mexico, Santos basin …).

The seismic section L05 crosses the northern domain and mainly shows an extensional geologic setting in this area (Fig. 9). This section was interpreted by Booth-Rea et al., (2018) as one of the low angle fault

systems named the Ghezala fault characterizing the extensional late Miocene collapse of northern Tunisia. This work interprets the major low angle normal faults as associated to high-angle faults producing a geometry characterized by half-graben and hanging-wall syncline basins during the late Miocene times. This interpretation of extensional collapse in the Atlas system during the late Cenozoic African-Eurasian convergence setting was related to deep mantle tectonic mechanisms in the concomitant extension of Tyrrhenian basin to East. While we agree with the core interpretation of Booth-Rea et al., (2018), we enhance and add some details in this section. The Miocene extensional system appears to be connected down on a major normal fault system (affecting both basement and cover, Fig. 9) such faults are probably inherited from the former Mesozoic Tethyan extensional period later reactivated during late Miocene times. This section highlights a lower Miocene extensional period. This extension, which occurred after the short Eocene compression, is mainly accommodated by large extensional faults connected down on basement faults systems that seem to be inherited from the former Tethyan basin.

The NE-SW seismic line L11 is located in the front of the thrust systems of LBSS and shows a narrow basin filled by Mio-Plio-Quaternary sediments reaching a 3 km of thickness (Fig. 10). In opposition to the northern domain, this section mainly exhibits high-angle normal fault systems. This narrow basin is mainly recorded by Miocene syntectonic strata. Regarding the position (between the Baouala thrust and the major Teboursouk thrust), the connected high angle normal faults and the sequences in this narrow basin are all interpreted as an orthogonal extension in which the thrust strongly influences the development of normal faults. This section exhibits a strong variation in thickness associated to faults. In addition, the thickness variations are remarkable for Jurassic and lower Cretaceous sequences, which testifies that this fault is inherited from Mesozoic times.

The seismic data seems to be well correlated with gravity results recently presented by Sarsar et al. (2017). According to the superimposition of the Euler solutions to Bouguer Anomaly map used to present the distribution of anomalies and curved gravity lineaments about positive anomalies and also estimate the depth of those anomalies, Sarsar et al. (2017) suggest that the west of the LBSS corresponds to a fault concentric zone and provides the evidence of a pre-existing diapiric geometry body located at the depth between 1 and 2 Km and later buried by Mesozoic and Cenozoic sediments. The NW-trending of the main gravity contours reach a depth of 2 km and confirm the existence of the Teboursouk fault as a major thrust fault system. This system is probably inherited from Mesozoic times and acted as the main control in favor of diapir upward (for more details see Sarsar et al., 2017). The

399 concentric behavior in the west of the LBSS is probably connected downward to the Teboursouk thrust,
400 which explains the presence of sub-Triassic structures in this belt.

401 **5. Discussion**

402 ***i. Previous interpretations***: Several interpretations were made separately by several authors to
403 explain the diapiric structure that may be summarized as follows: 1- Bolze (1954) suggests a salt move-
404 up because of space creation via normal faulting, 2- Zargouni (1975) suggests a scenario in which salt
405 intrudes forcefully into its overburden during Mesozoic and Eocene times, and 3- Perthuisot (1978)
406 suggests a way in which salt intruded forcefully into its overburden during late Cretaceous-Eocene
407 compression. This structure, called by all previous studies "the Lansarine diapir », was presented as a
408 cylindrical, 45 km long and 15 km-wide vertical diapir. Our field mapping does not support this
409 hypothesis of a single 15 km-wide vertical diapir. The structure and the salt budget do not permit to
410 interpret it as one rooted salt structure. 4- Truillet and Delteil (1982) propose a large thrusting system.
411 Based on the observation that the Triassic salt is interbedded and subparallel to the Cretaceous layers,
412 this work propose that all this region corresponds to a large tectonic nappe and must be integrated to
413 the front of the Numidian allochthonous zone. 5- Finally Masrouhi et al. (2013) propose a salt canopy
414 model. This model proposes a scenario in which extension induces normal faults that provide routes to
415 the salt to reach the surface and flow downslope.

416 ***ii. Field data discussion and tectono-sedimentary features***: Field work, together with the
417 interpretation of seismic profiles, shows that the present LBSS may result from a long-time polyphasic
418 geological history. This 45 km-long and 15 to 5 km-wide salt structure was likely passively transported on
419 major thrusts during the Atlassic and Alpine shortening. These main tectonics events are recognized to
420 occur during the Late Eocene (Atlassic) and Miocene–to present-day for the alpine event (e.g. El Ghali et
421 al., 2003; Masrouhi et al., 2008; Dhahri and Boukadi, 2010). The present structure is also the result of
422 considerable erosion and probably dissolution during late Cretaceous and Cenozoic times. It likely
423 covered a wider area during Mesozoic times. In this study we confirm by seismic examination the
424 presence of a salt diapir body deeply buried under a complex thrust system which was absent in the
425 previous interpretation. We also confirm by surface data that the outlines of the Triassic salt are
426 commonly subparallel to the bedding of the adjoining rocks succession of the northern and southern
427 parts. The contacts of the Triassic rocks are not discordant with them. Geologic map and field cross
428 sections are consistent with an allochthonous sheet of Triassic salt emplaced over the Early Cretaceous
429 successions. For the LBSS, field data emphasizes the absence of radial faulting that is usually associated

with diapirism growth well observed and documented in others salt province (e.g. Rowan et al., 2003; Yin et al., 2009). Based on field investigations, we therefore suggest (for the central and northern part) a composite salt sheet covering Early Cretaceous sediments. Established by seismic interpretation, a diapiric stem is detected under the LBSS large salt sheet. In the LBSS area, Early Cretaceous sediments are characterized by considerable variation in thickness and exhibit numerous sedimentary features (nodules reworking, slumps and conglomerates lenses) within an active extensional tectonic regime (Naji et al., 2018b). This created an irregular seafloor resulting from normal faulting. In the LBSS area, several preserved extensional structures as small-scale sealed normal faults constitute a useful marker for this tectonic activity. Structurally, the LBSS structure occupies a position in the intersection of the major faults systems i.e., the E-trending strike-slip and the NE-trending thrusts fault systems. Surface data together with the seismic profile interpretation highlight–a general shallow north-dipping high-angle normal fault above a major deep listric one. Mechanically, this can explain the weakened overburden of the Triassic salt. The LBSS corresponds at present to a complex structure involving Triassic salt and bounded by north dipping fault systems (Figs. 7-10). It seems to be the stem of the LBSS diapir during Mesozoic time before the Atlassic shortening. This emplacement was likely driven by normal faulting, which affected both the cover and the basement, along with differential loading. This context fits with the southern Tethyan passive margin setting well documented by previous studies (e.g. Souquet et al., 1997; Jaillard et al., 2013; Soua, 2014; El Amari et al., 2016; Naji et al., 2018a).

iii. Diapirism style: Taking in account the overall structure, the LBSS shows strong similarities to those recently described by authors around many salt provinces (e.g. Saura et al., 2014; Alsop et al., 2015; Martin-Martin et al., 2017; Jaillard et al., 2017; Zucker et al., 2019). The halokinesis process was particularly active during the rifting stage, in which tilted block geometry was responsible for differential loading. During the Alpine compression, diapiric salt corresponds to weak surfaces used by the Alpine thrust systems. Structural analysis indicates that the LBSS emplacement was guided by a basement normal fault system related to the south Tethyan rifting. The general framework of this margin, together with similarities between the LBSS and recently published diapirs from other salt provinces, led to the proposal of polyphase diapirism history. Within the Maghreb framework (e.g. Soussi et al., 2017; Dhahri and Boukadi, 2017; Ahmadi et al., 2019), the Jurassic–Early Cretaceous extensional context of the south Tethyan margin in Tunisia allows a reactive mobilization of salt layers. This tectonic setting offers two conditions allowing salt to extrude onto the sea-floor. (1) The extension weakens the overburden by normal faulting creating space for salt to rise forming the diapir structure and (2) induces thickness variations leading to differential loading which initiate the salt movement (Fig. 11). During the Tethyan

462 rifting period, lower Cretaceous extensional tectonic regime induced thick depositional basin sediments
463 controlled by major basement normal faults. Within this structural setting, well recorded in North
464 Tunisia, the salt's overburden was weakened by faulting creating space, along with salt (acknowledged
465 to be Newtonian fluid at depth) withdrawing from the weakened zone by faulting. Accumulation of thick
466 salt overburden in subsiding area acts as a rapid differential loading that encourages salt flow from the
467 diapir stem. This evolution corresponds to a reactive diapir (sensu Vendeville and Jackson, 1992b), which
468 extruded along the main fault system (Fig. 11). Active diapirism would correspond to a short lower
469 Cretaceous event, currently not observable because it has been overprinted by tectonic compressional
470 deformations. The basement fault movement, salt withdrawal and growth of diapir itself; all of them
471 may have induced a significant asymmetry creating salt mini-basins well recognized as associated to salt
472 movement in many worldwide salt provinces. Above-mentioned observations indicate a structural
473 configuration that led to lateral spreading onto the depositional surface over the LBSS diapiric stem (Fig.
474 11). It corresponds to a well-known salt process that could be active both in submarine (Fletcher et al.,
475 1995) and sub-aerial environments (Talbot, 1998).

476 ***iv. Regional consideration***: The structural style of the LBSS seems to be very similar to other
477 structures recognized as being the result of basement faults movement, on which extensional thin-
478 skinned deformation is connected. The trigger mechanism of salt migration of the LBSS can be compared
479 to other similar salt provinces: e.g., Pyrenean orogen (Canérot et al., 2005; Saura et al., 2016), the
480 Eastern Betics (Roca et al., 2013; Rubinat et al., 2013), Nordkapp Basin (Koyi et al., 1995), or North Africa
481 (Bouchouata et al., 1995; Saura et al., 2013, Masrouhi et al., 2014a, Moragas et al., 2017, 2019). The
482 original criteria of the Salt structure is preserved likely because it was passively transported on major
483 thrusts, superimposed on deep seated basement faults, during the Atlassic and Alpine shortening
484 periods. The Northeastern Maghreb domain is one of the world's least-known areas in terms of salt
485 tectonics (Hudec and Jackson, 2007). It appears similar to many others inverted salt provinces, for which
486 it is difficult to interpret the original geometry and evolution of salt diapirs. In this domain, the
487 buoyancy–driven halokinetic model has long been considered as the unique way of salt growth. This
488 model postulated an autonomous isostatic rise of salt and piercement of the overburden due to the
489 Rayleigh–Taylor instabilities. Based on this model, the diapirs of North Tunisia have been considered to
490 expose only ''vertical ''diapir structures (Perthuisot, 1978; Perthuisot et al., 1998; Rouvier et al., 1998;
491 Jallouli et al., 2005). Recently, an allochthonous salt model has been documented by Masrouhi et al.
492 (2013) in the Alpine thrust front of Teboursouk (Teboursouk thrust unit, Fig. 1). The authors suggest a

493 scenario where salt broke out at the sediment–water interface or below a thin layer of marine
494 sediments forming an allochthonous extrusion, similar to the present-day salt tectonics described in the
495 deep–water Gulf of Mexico (Fletcher et al., 1995) or Angola margin (Fort et al., 2004; Ge et al., 2019).
496 Later, the pre-existing allochthonous salt was deformed during Miocene–present day Alpine
497 compressions that used the weakness of the salt sheet as thrust décollement. The interconnection
498 between these two types (i.e. vertical diapir and large connected salt sheet) has never been described
499 yet.

500 ***v. The LBSS style***: The LBSS clearly shows asymmetric overhangs flowing northward (the subsiding
501 area). The first part of the LBSS evolution for the sheet connected to the Lansarine salt diapir can be
502 easily distinguished as an extrusive advance (*sensu* Hudec and Jackson, 2006), in which an exposed salt
503 sheet spreads at the water–sediment interface without any roof. Above the apex of the diapir, that
504 corresponds to the feeder, salt flows outward and spreads by gravity downslope (Fig. 11). The
505 overburden on the salt may have formed a synclinal minibasin on top of the salt sheet (Fig. 11). In this
506 case, the minibasin had a thickness usually determined by the salt evacuation budget forming in some
507 cases a salt weld (e.g. Diegel et al., 1995; Schuster, 1995; Callot et al., 2012). In this domain, the low-
508 amplitude syncline of Chouigui (Fig. 9) is likely the minibasin developed by evacuation of allochthonous
509 Triassic salt during Mesozoic times (see Fig. 11). From late Cretaceous to Eocene time, the onset of the
510 compressional Atlassic stage (e.g. Guiraud and Bosworth, 1997; Frizon de Lamotte et al., 2000) resulted
511 in widespread shortening associated with the inversion of the normal faults and probably without
512 significantly compressing the LBSS. The diapir was passively transported above the southeast-verging
513 major thrust which is deeply rooted in the salt beneath the Mateur plain (Fig. 11). During this period, the
514 LBSS was eroded due to fold-related uplifting.

515

516 **6. Conclusion**

517 Based on the results of detailed field work and seismic profiles' interpretation of the Lansarine-Baouala
518 Salt Structure in the Northern Atlassic domain of Tunisia, the following conclusions can be made:

519 • Salt diapirism in Northern Tunisia appears to be contemporaneous with tectonic extension. The
520 Jurassic–Early Cretaceous extensional tectonic context of the southern Tethyan margin induced
521 thick depositional basin sediments controlled by major basement normal faults. The extension

522 weakens the overburden by normal faulting and the thickness variations leading to differential
523 loading which allow a reactive mobilization of Triassic evaporites,

524 • During Mesozoic diapirism phase, a significant allochthonous salt spreads laterally from the diapir
525 stem. Salt flows outward and spreads by gravity downslope highlighting an extrusive sheet
526 advance. In this domain, the low-amplitude syncline of Chouigui seems to be a minibasin
527 developed in conjunction with the evacuation of allochthonous Triassic salt during Mesozoic
528 times,

529 • Compressional deformation stages do not reflect active diapirism. The Lansarine diapir and its
530 connected salt sheet were passively transported on the southeast-verging major thrust deeply
531 rooted in the salt beneath the Mateur plain during the Atlassic and Alpine shortening. In the north
532 Tunisian domain, the identification of allochthonous Triassic salt sheets connected to buried
533 diapir have a significant role in the shallow structural complexity observed in the sedimentary
534 cover during the subsequent contractional events.

535

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Figure captions

Figure 1: (a) Geodynamic setting of the Maghreb fold-thrust-belt and location of north Tunisian domain. (b) Simplified sketch of the Tunisian Atlas showing the major tectonic units, major thrust systems, main outcropping Triassic salt and the location of the LBSS.

Figure 2: Stratigraphy of the north Tunisian domain with indication of average thickness variation, lithostratigraphic short description, the average density of main units and the regional tectonic regime.

Figure 3: Detailed geological map of the LBSS and its surrounding areas showing the main units, their relationships, the Triassic salt shape, the location of the detailed maps of figs 4 and 5 and the location of seismic profiles of figs 8-10.

Figure 4: Detailed geological map of the northern part of the LBSS showing the salt contact, the main outcrops of Cretaceous that constitutes the bedrock of the large salt canopy, and fault kinematics analysis of few fault sites highlighting a major NW-SE Cenozoic compression.

Figure 5: Detailed geological map of the central part of the LBSS showing the salt contact, the main outcrops of Cretaceous that constitutes the bedrock of the large salt canopy (Ain el Karma) and the cover of the Triassic salt (Jebel Djedaria), under the thrust systems of the Lansarine structure.

Figure 6: Panoramic view looking northeastward of the Jebel Djedaria structure shows the configuration and reproduces the geological history of this region with (a) uninterpreted and (b) interpreted section. In the south, the Triassic is covered by normal polarity Cretaceous sequences, themselves unconformably covered by Oligocene–Lower Miocene (15-20° angular Atlassic unconformity). The Oligocene–Lower Miocene sequences are overthrusted by southeast-verging the Lansarine nappe formed by Paleocene shale and Eocene limestone.

Figure 7: fault kinematics analysis of abundant meso-scale synsedimentary faults within the Cretaceous sequences. The Stereonets are back-tilted faults that indicate a NE-SW Aptian–Albian tectonic extension; E-W to NE-SW late Cretaceous tectonic extension; and Santonian NW-SE to N-S tectonic extension.

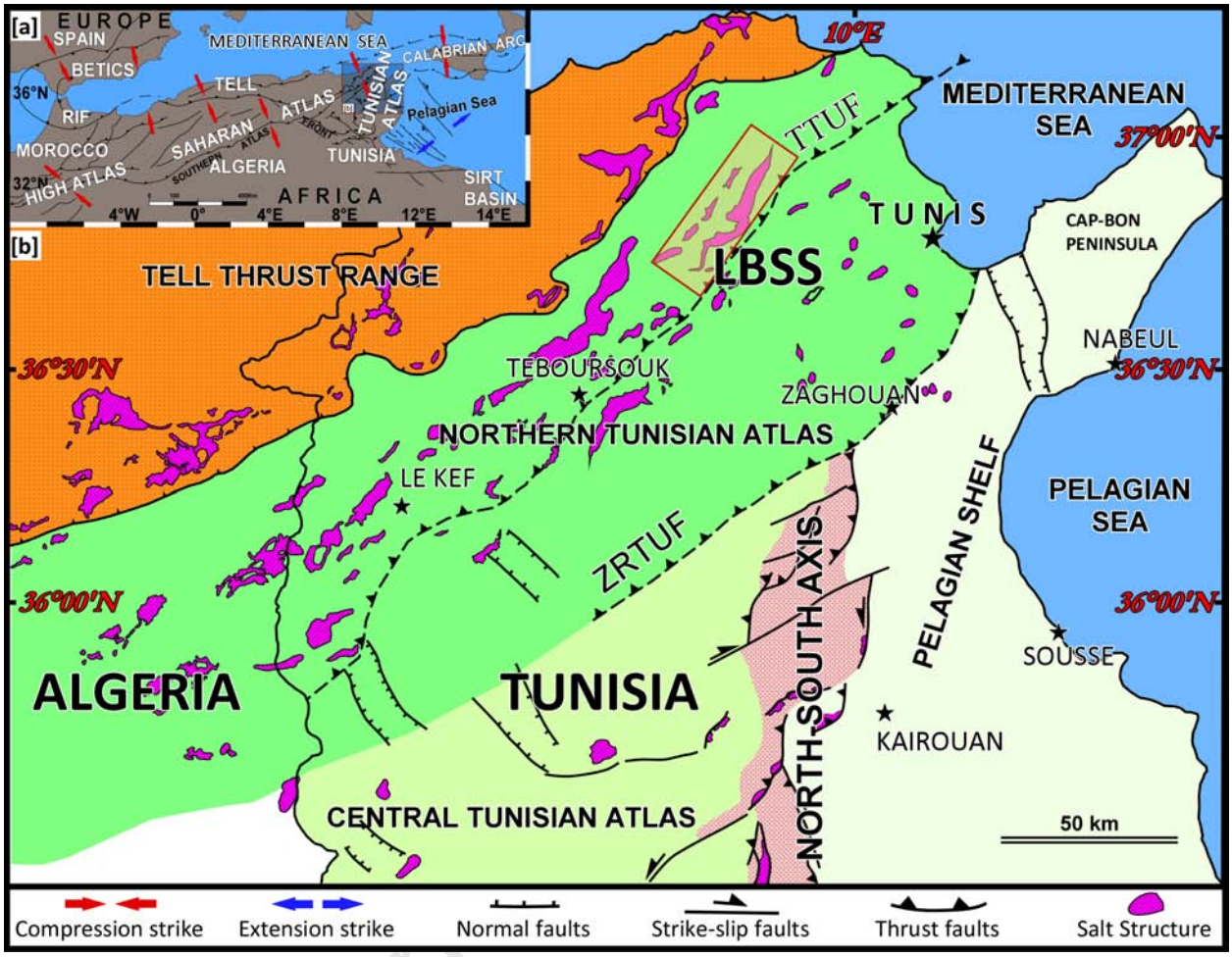
Figure 8: (a) Uninterpreted, migrated, depth-converted seismic reflection data from the LBSS area. (b) Interpreted seismic line of L18A and L18B showing the preserved extensional Chouigui mini-basin to the south associated with the major Teboursouk thrust fault. Note that the thrust fault systems are connected to intra-basement detachment normal fault. The salt sheet covers a Cretaceous sequences at

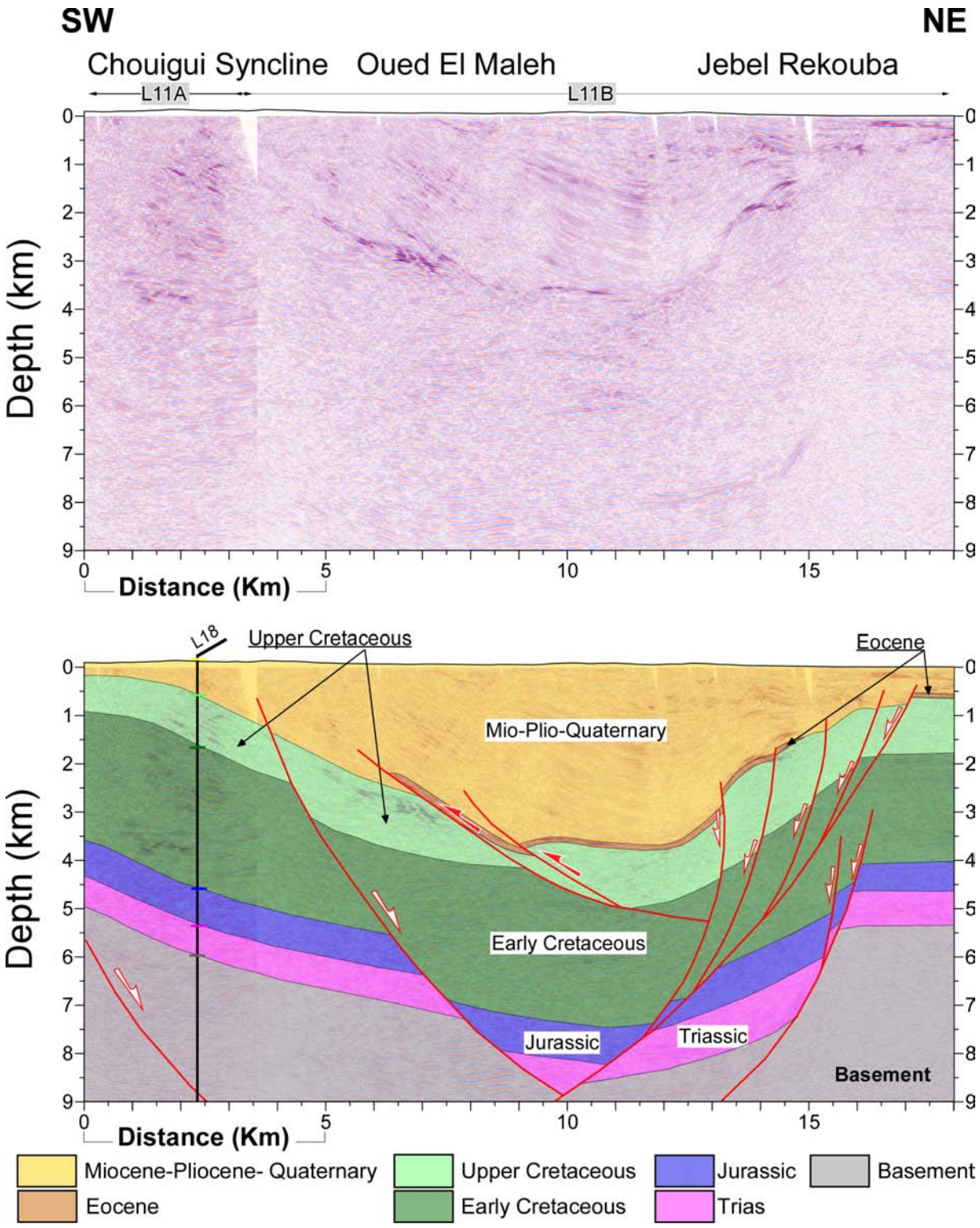
927 depth. Under Lansarine structure the velocity and the shape of reflectors seem to highlight a salt body
928 (Lansarine diapir). The thrust fault is connected at depth to rollover anticline limited by the listric normal
929 fault connected to the intra-basement detachment all of them are inverted structures.

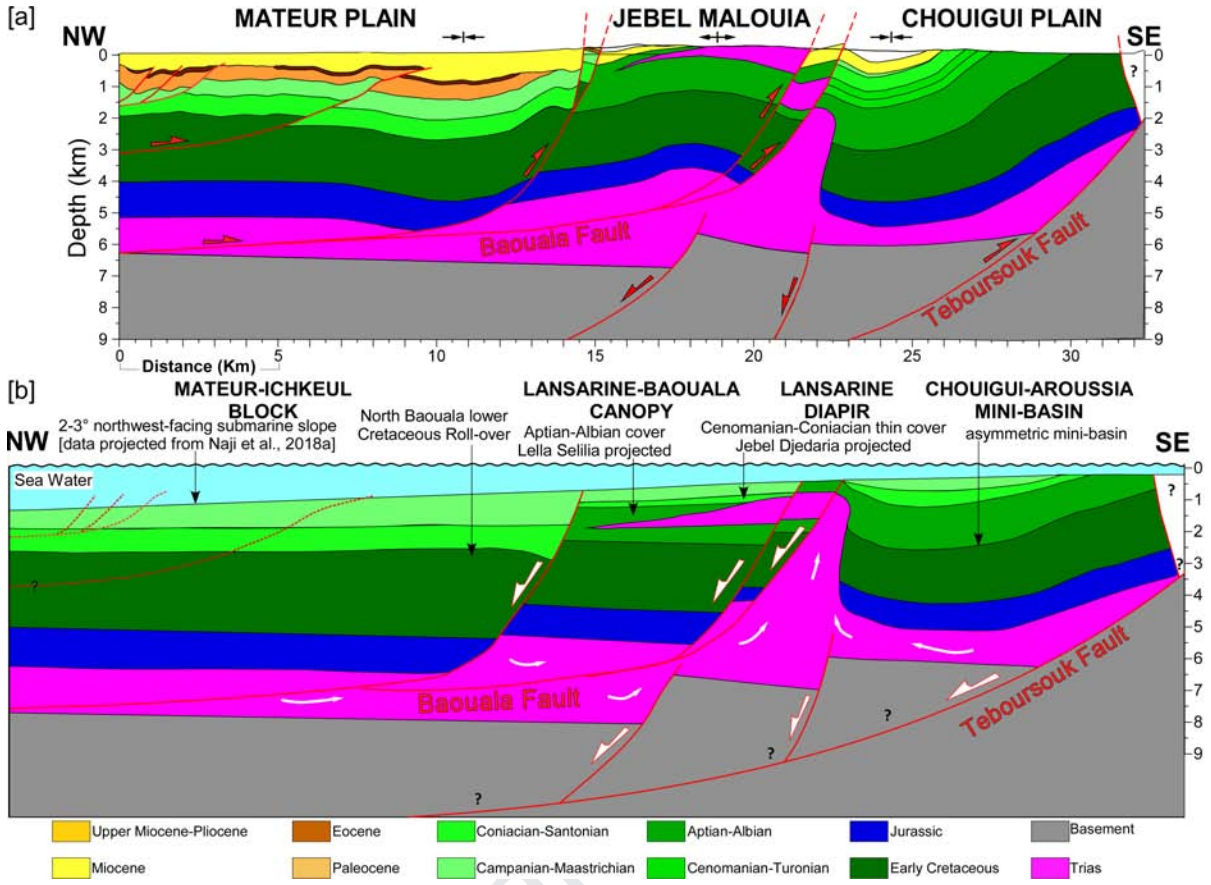
930 Figure 9: seismic section L05 crosses the northern domain. It mainly shows an extensional geologic
931 setting in this area with the low angle fault systems characterizing the extensional late Miocene collapse
932 associated to high-angle faults producing a geometry characterized by half-graben and hanging-wall
933 syncline basins

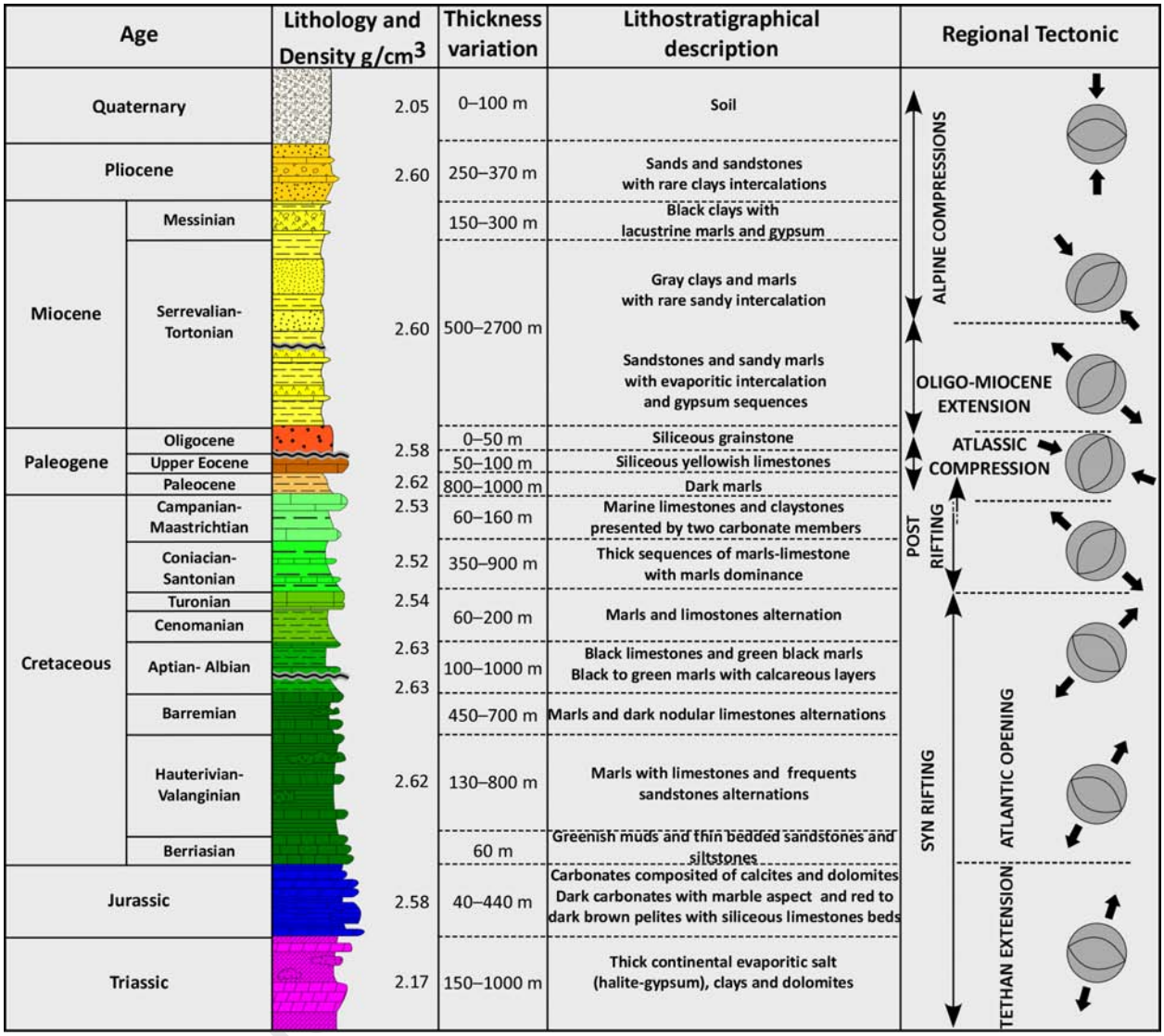
934 Figure 10: NE-SW seismic line L11 located in the front of the thrust systems of LBSS showing a narrow
935 basin filled by Mio-Plio-Quaternary sediments reached a 3 km and mainly recorded by Miocene
936 syntectonic strata. The high angle connected normal faults and the sequences in this narrow basin are
937 interpreted as an orthogonal extension in which the thrust strongly influences the development of
938 normal faults.

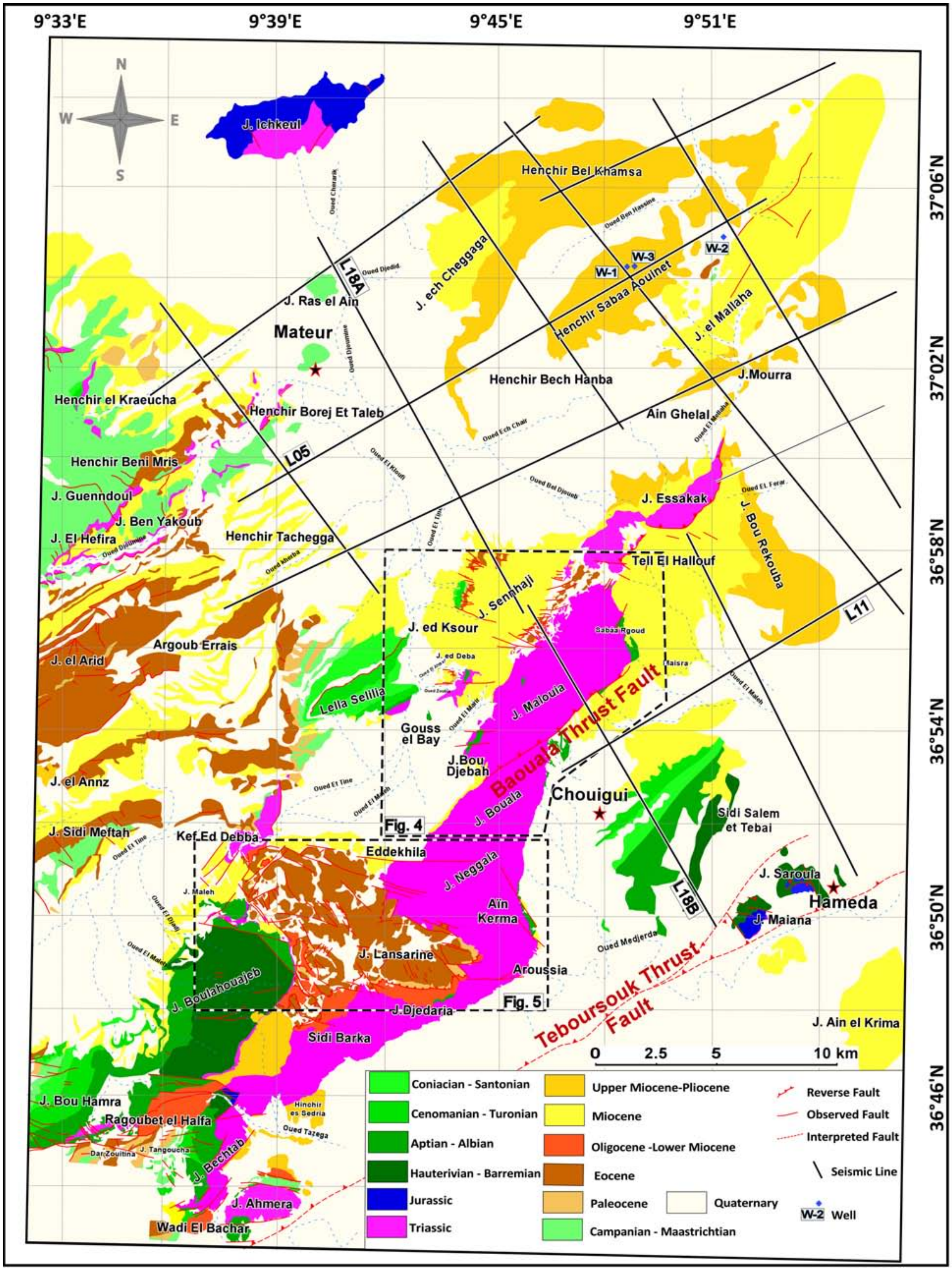
939 Figure 11: simplified Palinspastic stages reconstruction cross-section. (a) Present-day. (b) Late
940 cretaceous state. Shortening amount is hypothesized to be ±6.5 km (~ 17-18%). See text for detail on
941 halotectonics stages and styles.

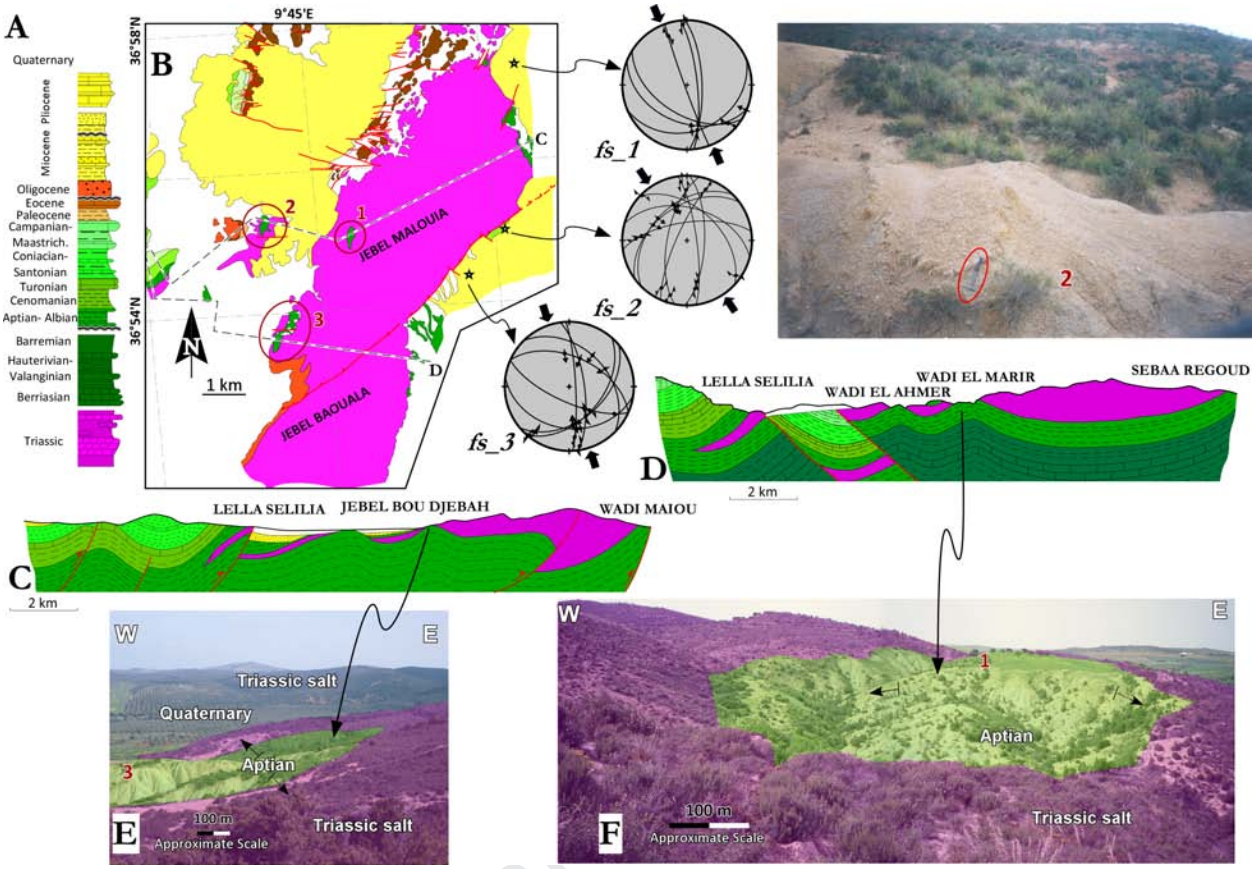


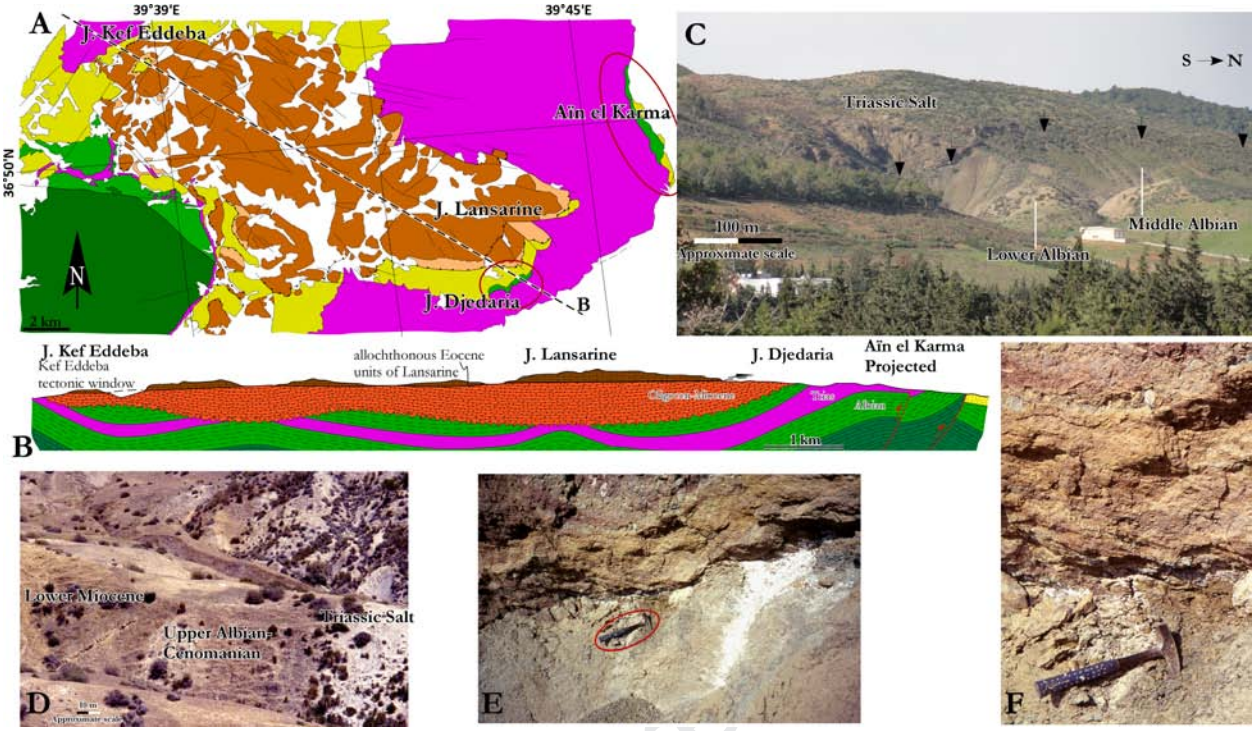

SW
NE
Chouigui Syncline
Oued El Maleh
Jebel Rekouba
L11A
L11B
Depth (km)
Distance (Km)
L18
Upper Cretaceous
Eocene
Mio-Plio-Quaternary
Early Cretaceous
Jurassic
Triassic
Basement
Miocene-Pliocene- Quaternary
Upper Cretaceous
Jurassic
Basement
Eocene
Early Cretaceous
Trias

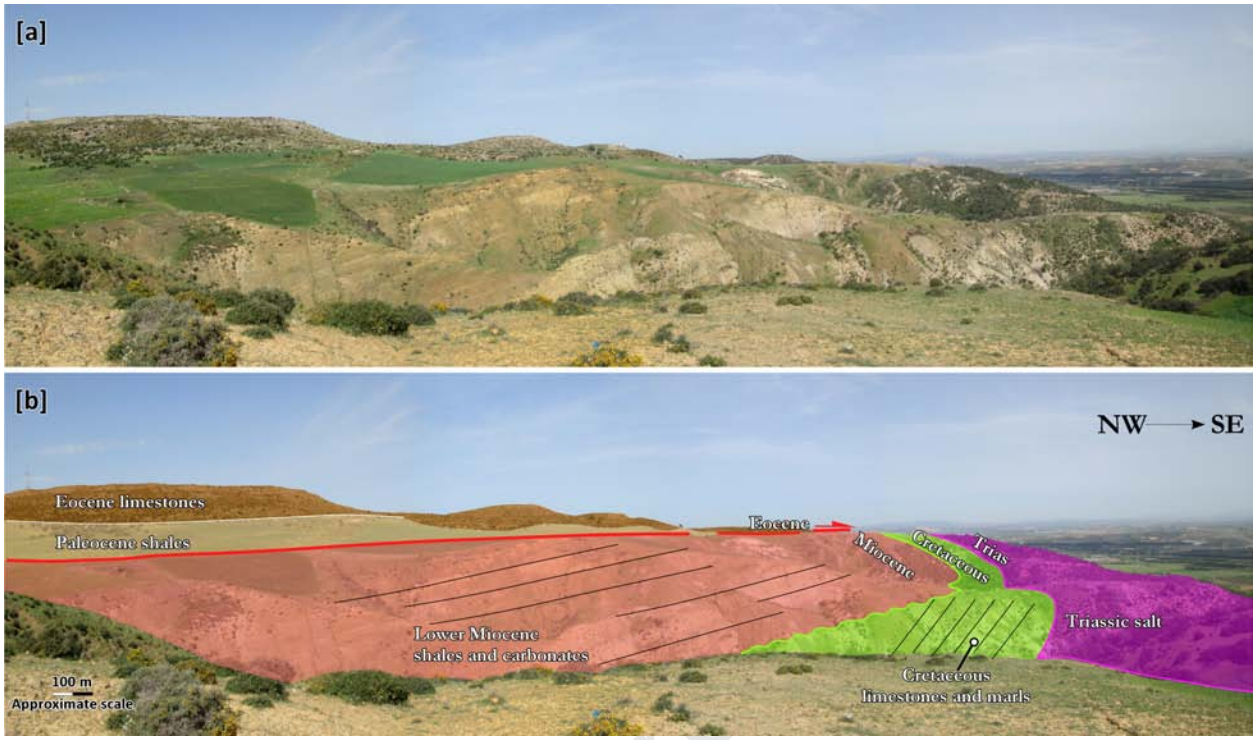

[a]
MATEUR PLAIN
JEBEL MALOUIA
CHOUIGUI PLAIN
NW
SE
Depth (km)
Distance (Km)
Baouala Fault
Teboursouk Fault
[b]
MATEUR-ICHKEUL BLOCK
2-3° northwest-facing submarine slope [data projected from Naji et al., 2018a]
North Baouala lower Cretaceous Roll-over
LANSARINE-BAOUALA CANOPY
Aptian-Albian cover
Lella Selilia projected
LANSARINE DIAPIR
Cenomanian-Coniacian thin cover
Jebel Djedaria projected
CHOUIGUI-AROUSSIA MINI-BASIN
asymmetric mini-basin
NW
SE
Sea Water
Baouala Fault
Teboursouk Fault
Upper Miocene-Pliocene
Miocene
Eocene
Paleocene
Coniacian-Santonian
Campanian-Maastrichian
Aptian-Albian
Cenomanian-Turonian
Jurassic
Early Cretaceous
Basement
Trias

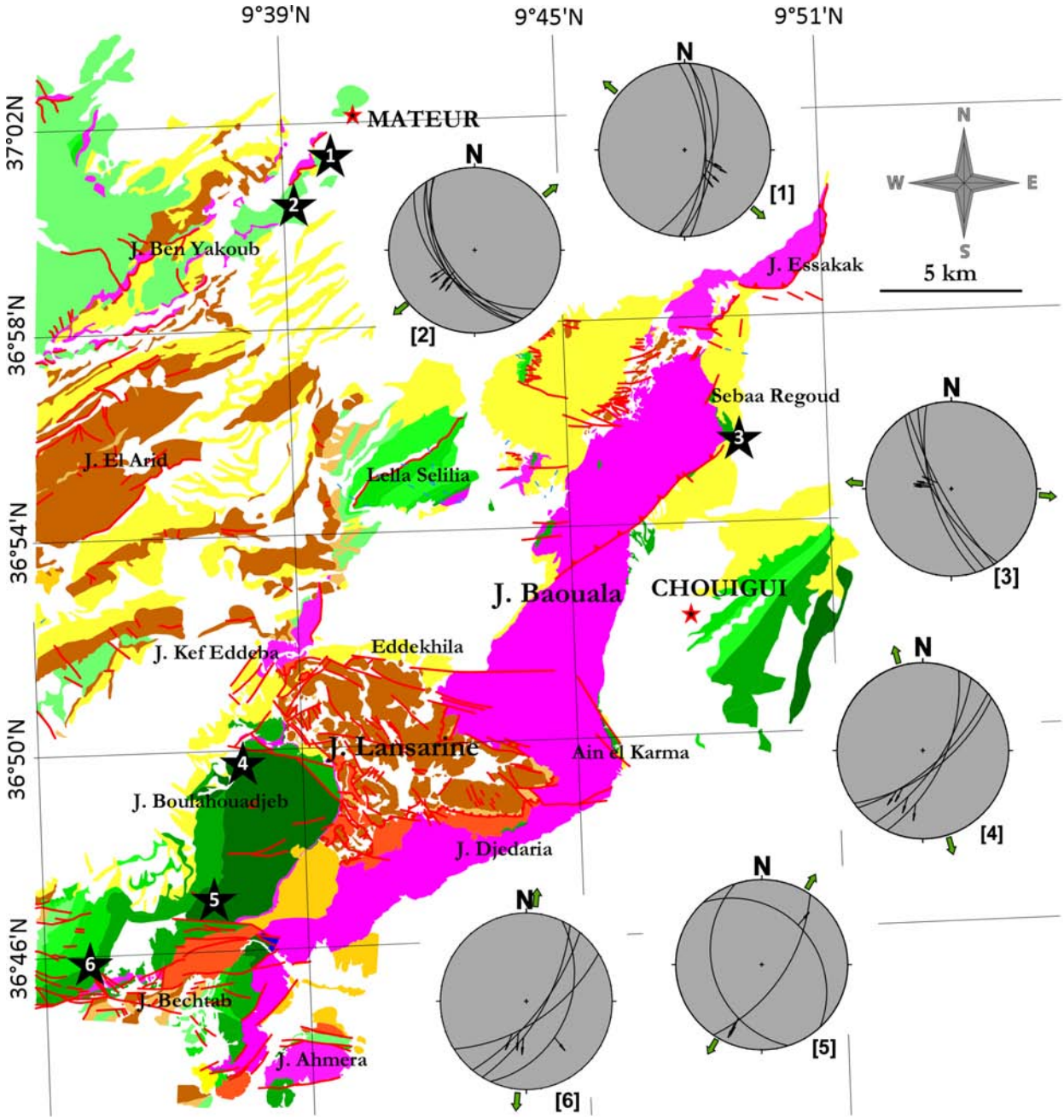

Age
Lithology and Density g/cm3
Thickness variation
Lithostratigraphical description
Regional Tectonic
Quaternary
2.05
0–100 m
Soil
Pliocene
2.60
250–370 m
Sands and sandstones with rare clays intercalations
Miocene
Messinian
150–300 m
Black clays with lacustrine marls and gypsum
Serrevalian-Tortonian
2.60
500–2700 m
Gray clays and marls with rare sandy intercalation
Sandstones and sandy marls with evaporitic intercalation and gypsum sequences
Paleogene
Oligocene
2.58
0–50 m
Siliceous grainstone
Upper Eocene
50–100 m
Siliceous yellowish limestones
Paleocene
2.62
800–1000 m
Dark marls
Cretaceous
Campanian-Maastrichtian
2.53
60–160 m
Marine limestones and claystones presented by two carbonate members
Coniacian-Santonian
2.52
350–900 m
Thick sequences of marls-limestone with marls dominance
Turonian
2.54
60–200 m
Marls and limostones alternation
Cenomanian
Aptian- Albian
2.63
100–1000 m
Black limestones and green black marls
Black to green marls with calcareous layers
2.63
Barremian
450–700 m
Marls and dark nodular limestones alternations
Hauterivian-Valanginian
2.62
130–800 m
Marls with limestones and frequents sandstones alternations
Berriasian
60 m
Greenish muds and thin bedded sandstones and siltstones
Jurassic
2.58
40–440 m
Carbonates composited of calcites and dolomites
Dark carbonates with marble aspect and red to dark brown pelites with siliceous limestones beds
Triassic
2.17
150–1000 m
Thick continental evaporitic salt (halite-gypsum), clays and dolomites
ALPINE COMPRESSIONS
OLIGO-MIOCENE EXTENSION
ATLASSIC COMPRESSION
POST RIFTING
SYN RIFTING
ATLANTIC OPENING
TETHAN EXTENSION

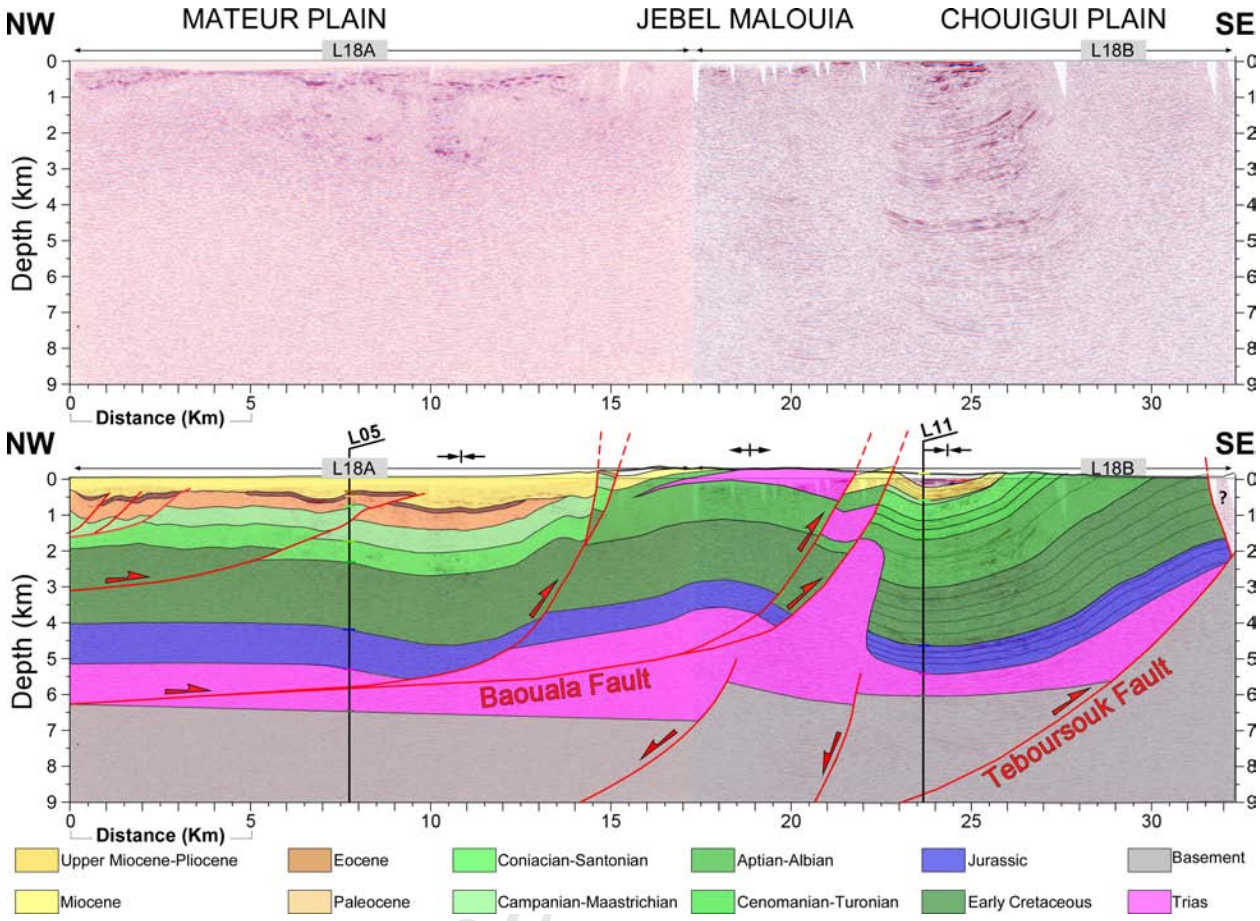

9°33'E
9°39'E
9°45'E
9°51'E
37°06'N
37°02'N
36°58'N
36°54'N
36°50'N
36°46'N
N
S
W
E
J. Ichkeul
Henchir Bel Khamsa
J. ech Cheggaga
Henchir Sabaa Aouinet
J. el Mallaha
W-1
W-2
W-3
L18A
L05
L11
L18B
J. Ras el Ain
Mateur
Henchir Bech Hanba
J.Mourra
Ain Ghelal
Henchir el Kraeucha
Henchir Borej Et Taleb
Henchir Beni Mris
J. Guenndoul
J. Ben Yakoub
J. El Hefira
Henchir Tachegga
J. Essakak
J. Bou Rekouba
Tell El Hallouf
J. Sennhaji
J. ed Ksour
Argoub Errais
J. el Arid
Lella Sellila
J. Maloula
Gouss el Bay
J.Bou Djebah
Baouala Thrust Fault
Chouigui
J. Bouala
Sidi Salem et Tebai
J. el Annz
J. Sidi Meftah
Fig. 4
Kef Ed Debba
Eddekhila
J. Neggala
Ain Kerma
J. Saroula
Hameda
J. Maiana
J. Lansarine
Aroussia
J. Boulahouajeb
Fig. 5
J. Djedaria
Sidi Barka
Teboursouk Thrust Fault
J. Ain el Krima
0 2.5 5 10 km
J. Bou Hamra
Ragoubet el Halfa
J. Bechtab
J. Ahmera
Wadi El Bachar
Coniacian - Santonian
Cenomanian - Turonian
Aptian - Albian
Hauterivian - Barremian
Jurassic
Triassic
Upper Miocene-Pliocene
Miocene
Oligocene -Lower Miocene
Eocene
Paleocene
Quaternary
Campanian - Maastrichtian
Reverse Fault
Observed Fault
Interpreted Fault
Seismic Line
W-2 Well

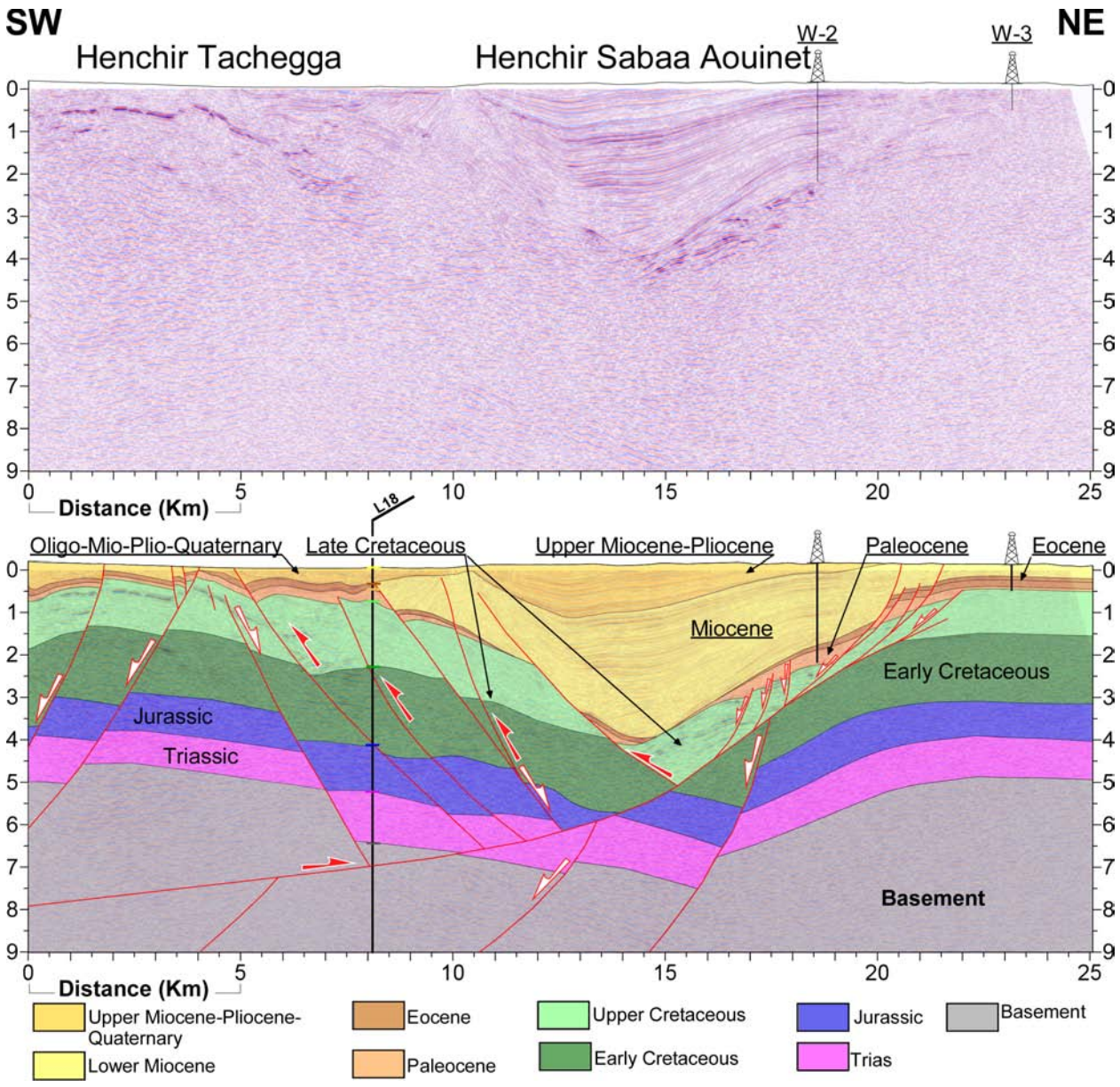

A
Quaternary
Miocene Pliocene
Oligocene
Eocene
Paleocene
Campanian-
Maastrich.
Coniacian-
Santonian
Turonian
Cenomanian
Aptian- Albian
Barremian
Hauterivian-
Valanginian
Berriasian
Triassic
B
9°45'E
36°58'N
36°54'N
JEBEL MALOUIA
JEBEL BAOUALA
1 km
N
fs_1
fs_2
fs_3
C
D
LELLA SELILIA
JEBEL BOU DJEBAH
WADI MAIOU
2 km
LELLA SELILIA
WADI EL AHMER
WADI EL MARIR
SEBAA REGOUD
2 km
W
E
Triassic salt
Quaternary
Aptian
Triassic salt
100 m
Approximate Scale
E
W
E
Aptian
Triassic salt
100 m
Approximate Scale
F






9°39'N
9°45'N
9°51'N
37°02N
36°58'N
36°54'N
36°50'N
36°46'N
MATEUR
J. Ben Yakoub
J. El Arid
Lella Selilia
J. Kef Eddeba
Eddekhila
J. Lansarine
J. Boulahouadjeb
J. Bechtab
J. Ahmera
J. Djedaria
J. Baouala
CHOUIGUI
Ain el Karma
Sebaa Regoud
J. Essakak
1
2
3
4
5
6
N
W
E
S
5 km
[1]
[2]
[3]
[4]
[5]
[6]


NW
MATEUR PLAIN
JEBEL MALOUIA
CHOUIGUI PLAIN
SE
L18A
L18B
Depth (km)
Distance (Km)
L05
L11
?
Baouala Fault
Teboursouk Fault
Upper Miocene-Pliocene
Miocene
Eocene
Paleocene
Coniacian-Santonian
Campanian-Maastrichian
Aptian-Albian
Cenomanian-Turonian
Jurassic
Early Cretaceous
Basement
Trias


SW
NE
Henchir Tachegga
Henchir Sabaa Aouinet
W-2
W-3
Distance (Km)
L18
Oligo-Mio-Plio-Quaternary
Late Cretaceous
Upper Miocene-Pliocene
Paleocene
Eocene
Miocene
Early Cretaceous
Jurassic
Triassic
Basement
Upper Miocene-Pliocene-Quaternary
Lower Miocene
Eocene
Paleocene
Upper Cretaceous
Early Cretaceous
Jurassic
Trias
Basement

Highlights

Active Salt diapir developed during Tethyan Mesozoic extension in Northern Tunisia

Significance of allochthonous salt sheets spreading laterally from the diapir stem

During subsequent compressional stage diapir is squeezed and passively transported above major thrust