New tectono-sedimentary evidences for Aptian to Santonian extension of the Cretaceous rifting in the Northern Chotts range (Southern Tunisia)

Mohamed Gharbi, Amara Masrouhi, Nicolas Espurt, Olivier Bellier, El Amjed Amari, Mohamed Ben Youssef, Mohamed Ghanmi

Accepted Manuscript

New tectono-sedimentary evidences for Aptian to Santonian extension of the Cretaceous rifting in the Northern Chotts range (Southern Tunisia)

Mohamed Gharbi, Amara Masrouhi, Nicolas Espurt, Olivier Bellier, El Amjed Amari, Mohamed Ben Youssef, Mohamed Ghanmi

PII:	S1464-343X(12)00202-6
DOI:	http://dx.doi.org/10.1016/j.jafrearsci.2012.09.017
Reference:	AES 1804

To appear in: *African Earth Sciences*

Received Date:	18 April 2012
Revised Date:	21 September 2012
Accepted Date:	30 September 2012

Please cite this article as: Gharbi, M., Masrouhi, A., Espurt, N., Bellier, O., Amari, E.A., Youssef, M.B., Ghanmi, M., New tectono-sedimentary evidences for Aptian to Santonian extension of the Cretaceous rifting in the Northern Chotts range (Southern Tunisia), *African Earth Sciences* (2012), doi: http://dx.doi.org/10.1016/j.jafrearsci.2012.09.017

New tectono-sedimentary evidences for Aptian to Santonian extension of the Cretaceous rifting in the Northern Chotts range (Southern Tunisia)

Mohamed Gharbi[a,b*], Amara Masrouhi [a,b], Nicolas Espurt[b], Olivier Bellier[b], El Amjed Amari[a], Mohamed Ben Youssef[c] and Mohamed Ghanmi[d].

[a] Département des Sciences de la Terre, Faculté des Sciences de Gabès, Université de Gabès, Cité Erriadh, 6072 Gabès, Tunisia

[b] Aix-Marseille Université, Institut Pytheas, CNRS, CEREGE UMR 7330 , Aix-en-Provence, France

[c] Centre de Recherches et Technologies des Eaux, BP 273, 8020 Soliman, Tunisia

[d] Département de Géologie, Faculté des Sciences de Tunis, 1060 Tunis, Tunisia

[*]*corresponding author; gharbim.mohamed@gmail.com phone: +216 75 392600; fax: +216 75 392421*

Abstract

Based on new structural, sedimentary, stratigraphic and seismic reflection data from Cretaceous sequences of the Zemlet el Beidha anticline of the northern Chotts range (South Tunisia), this study yields fresh insights into the geodynamic evolution of the South Tethyan margin. The rifting of the margin started in the Triassic-Jurassic and continued during the Aptian-Albian. In this last period N to NE trending extension was associated with WNW and NW trending normal faults, bounding the developing horsts and grabens structures. This tectonic framework is highlighted by strong thickness and facies changes in the Aptian-Albian series associated with slumps and syntectonic conglomerates. During the Coniacian to Santonian times, the study area was characterized by continued subsidence. Consequently, the Coniacian-Santonian series are represented by sedimentary infilling consisting of post-rift marl-rich sequences followed by limestone and marl sequences.

Folds geometry and associated faults system and tectonics analysis, confirm the role of the Aptian-Albian rifting inheritance faulting in the structuring and the development of the folds and thrusts belts of the southern Tunisian Atlas during the Cenozoic inversion, in particular in the development of the ENE striking structures such as the Zemlet el Beidha anticline.

Keywords:

South Tethyan margin, Rifting, Aptian-Santonian, Southern Atlassic domain, Tunisia, Chotts range, Zemlet el Beidha anticline

1. Introduction

The geodynamic evolution of the northern margin of Africa has been studied by many authors (Dercourt et al., 1986; Philip et al., 1986; Dewey et al., 1986; Soyer and Tricart, 1987; Guiraud and Maurin, 1991; 1992; Martinez et al., 1991; Piqué et al., 2002; Bouaziz et al., 2002; Burnet and Cloetingh, 2003), observing, that this margin was characterized by (1) the extension, crustal stretching and thinning, as well as subsidence during the Mesozoic Tethyan rifting (Bouaziz et al., 2002; Piqué et al., 2002; Bumby and Guiraud, 2005), and (2) the occurrence of subsequent inversion during Late Cretaceous-Cenozoic subduction and collision (Guiraud et al., 1991; Guiraud and Bosworth, 1997; Guiraud, 1998; Laville et al., 2004; Abrajevitch et al., 2005; Bumby and Guiraud, 2005; Dhari and Boukadi, 2010).

Along the northern margin of Africa, the rifting began during the Late Permian-Middle Triassic period (Raulin et al., 2011), and culminated at the transition between the Triassic and Jurassic. The Early Mesozoic transgressions are characterized by a heterogeneous sedimentary cover (Piqué et al., 2002; Courel et al., 2003; Guiraud et al., 2005). During this sedimentation cycle an extensional tectonic context predominated, as indicated by numerous synsedimentary normal faults systems. During the Jurassic time, a regional extensional tectonic regime produced the dislocation of the existing continental platform, which is related to the opening of the Central Atlantic and led to the development of "*en échelon*" normal faults, tilted blocks and volcanic activity (Laridhi Ouazaa and Bédir, 2004). The distribution of the sedimentary facies has taken place along the WSW trending Atlassic range from Morocco to northern Tunisia during the Late Liassic-Early Cretaceous period (Piqué et al., 2002; Guiraud et al., 2005).

In southern Tunisia, the rifting has been associated with the development of WNW to NW trending half grabens related to high rate subsidence, especially during Neocomian and Barremian (Piqué et al., 1998; Bouaziz et al., 2002; Guiraud et al, 2005; Herkat et al., 2006). The rifting led to presence of unconformities within many basins in the Early Aptian (Guiraud and Maurin, 1991; 1992; Zouaghi et al., 2005b; Bodin et al., 2010) and continued during the Aptian-Albian creating N to NE trending regional extension (Zghal et al., 1998; Rigane et al., 2010). The Early Aptian unconformities mentioned above are associated with the lower Cretaceous rifting stage. On the contrary, these later are related by some authors to the compressional regime (Austrian Event; Ben Ayed, 1993; Bedir et al., 2001; Zouaghi, al., 2005; Lazez et al., 2008) and/or halokinetic movements (Rigane et al., 2010; Zouaghi, al., 2011).

Along the southern margin of Tunisia, the rifting has been associated with volcanism in the Pelagian block (Fig. 1A; Ouazaa and Bédir, 2004). Extensional structures have been recognized by surface and subsurface data in the Northern African margin (Piqué et al., 2002; Bumby and Guiraud, 2005; Guiraud et al., 2005). The Cretaceous evolution of this margin was associated with thickness and facies variations of the sedimentary sequences (Ben Youssef et al., 1985; Ben Ferjani et al., 1990; Delteil et al., 1991; Abdallah et al., 1995; Souquet et al., 1997; Bédir et al., 2001; Patriat et al., 2003; Zouaghi et al., 2005). This tectonic regime involved the reactivation of pre-existing (Early Cretaceous) passive margin structures, with a maximum extension occurring during Albian times. Early Cretaceous extensional structures have been sealed by Senonian post-rift series with reefal buildings along uplifted ridges (Negra et al., 1995). Thereafter, during Late Cretaceous and Cenozoic times, tectonic inversion occurred as a result of convergence between Africa and Eurasian plate. The North African margin was characterized by the reactivation of pre-existing extensional faults systems which controlled fault-related folds (Zargouni, 1985; Ben Ayed, 1986; Catalano et al., 1996; Doglioni et al., 1999; Vergés and Sabat, 1999; Frizon de Lamotte et al., 2006; Masrouhi et al., 2007; Dhahri and Boukadi, 2010).

This study focuses on the structure of the Zemlet el Beidha anticline in the eastern part of the northern Chotts range, which belongs to the southern Atlassic front of Tunisia. In this area, the tectono-sedimentary framework displays evidence for the southernmost Cretaceous rifting. Our study provides new structural elements, new detailed geologic mapping, sedimentologic, palaeontologic and new interpretation of geophysical data to understand the Cretaceous passive margin evolution.

2. Geological setting

2.1. Structural features of the study area

The Atlas orogen forms a part of the present-day North African margin and is the result of the collision between the African and the European plates. The development of the southern Tunisian Atlas fold-and-thrust belt is related to this tectonic convergence occurred during Tertiary times. This domain is characterized by E-W to NE-SW and NW-SE anticlines separated by synclines filled with Neogene and Quaternary series (Fig. 1B; Zargouni, 1985; Abdeljaoued and Zargouni, 1981; Burollet, 1991; Bédir et al.; 2001, Hlaiem, 1999; Bouaziz et al, 2002).

The southern Tunisian Atlas fold-and-thrust belt is limited westward by major NW trending strike-slip fault systems (Gafsa and Negrine-Tozeur fault systems; Fig. 1A, B). The

Gafsa fault system (Zargouni, 1984; Burollet, 1991; Haleim, 1999) is a N120° E trending dextral strike-slip system (Zargouni et al., 1985; Abbès and Zargouni, 1986; Abbès et al., 1994; Boutib and Zargouni, 1998) and cuts the Bou Ramli, Ben Younes and Orbata anticlines in the north and the Zemlet el Beidha and Koudiat Hammamet anticlines in the south (Fig. 1B, C). Another prominent northwest striking strike-slip fault is the Negrine-Tozeur fault (Fig. 1B), which borders the west of the Gafsa-Metlaoui basin and parallel to the Gafsa fault. It extends from the Negrine (Algeria) through the Tunisian Atlas Mountains (Zargouni, 1984; Zargouni et al., 1985). The Sehib, Berda, Chemsi and Belkheir folds separate the wide Gafsa-Metlaoui basin to the northern Chotts range towards the south.

The Chotts depression corresponds to foredeep depozone (according to the nomenclature of DeCelles and Giles, 1996). This foredeep depozone is formed by two connected depression: the Chott El-Jérid to the west and the Chott El-Fejej to the east (Fig. 1B, C). The Chott El-Fejej occupies the core of a mega-anticline called “Fejej dome” whose southern limb corresponds to Jebel Tebaga and northern limb is formed by the northern Chotts range (Fig. 1B, C).

The eastern part of the northern Chotts range fold belt is affected by several faults that’s the most significant is the Bir Oum Ali and Fejej faults system (Fig. 1B). The northern Chotts range (E-W trend) changes direction to a NE-SW in its eastern part that corresponds to the Zemlet el Beidha anticline. The Zemlet el Beidha anticline limits the Sidi Mansour basin in the north and the Chotts Fejej basin in the south (Fig. 1C). The Zemlet el Beidha anticline (Fig. 2) belongs to the southern Atlassic front of Tunisia in the eastern part of the northern Chotts range (Fig. 1B). It is located between an intensely deformed domain, the southern Atlassic fold-and-thrust belt, in the north, and a less deformed domain, the Saharan Platform, in the south (Fig. 1A, B), (Zargouni, 1984; Ben Ferjani et al., 1990; Burollet, 1991; Haleim, 1999; Bouaziz et al., 2002).

2.2. General stratigraphy

The stratigraphy (Fig. 3) of the Zemlet el Beidha region is derived from micropaleontology analysis (Table. 1) and from boreholes which were drilled close to the anticline (wells 1, 2, 3 and 4, Fig. 1 C). The sedimentary series outcropping in the study area are Cretaceous to Quaternary in age (Fig. 1C, 2 and 3). The core of the Zemlet el Beidha anticline (Fig. 2) is formed by Hauterivian-Barremian marls, alternating with anhydrites, limestones and claystones of the Bouhedma Formation (Abdejaouad and Zargouni, 1981; Lazez and Ben Youssef, 2008). The Bouhedma Formation is overlain by shale-rich sands and ferruginous sandstones of the Sidi Aïch Formation, for which a Barremian (pro parte) age is deduced from its stratigraphic position. The Sidi Aich Formation is overlain by the dolomitic bank of the Lower Aptian Orbata Formation (Ben Youssef and Peybernes, 1986; Chaabani and Razgallah, 2006), which is topped by a rich-Orbitolinidae hardground, showing some Ammonites (Gharbi, 2008). This massive dolomitic bank is a common feature all over the area and forms the flanks of folded structures. The Upper Albian deposits correspond to the lower member of the Zebbag Formation. This formation, which rarely outcrops in the study area, is dominated by dolomitic sandstones, marls, limestones and argillaceous limestones. The upper member of Zebbag Formation (Upper Cenomanian-Turonian) is characterized by the flint dolomitic bank of the Guettar member. This sequence is only deposited at Jebel Jerouala (Fig. 2). The Coniacian-Santonian series of the Aleg Formation unconformably overlie the previous series. They are defined by thick sequences of dolomitic sandstones at the base and interbedded green marls and bioclastic limestones at the top. The fauna of this formation is distinguished (Fig. 3 and Table. 1) by the ammonites in the Khanguet Aïcha River, planktonic foraminiferas in the Gouada plain and the Rudistes in the Khanguet Telmem (Abbès and Tlig, 1991; Louhaïchi and Tlig, 1993; Gharbi, 2008). The Abiod Formation conformably overlies the Aleg Formation and consists of limestone banks with intercalations of thin clay layers. These intercalations are enriched by phosphatic debris and glauconite grains. The associated fauna suggests a deep marine environment, similar to the central and northern Tunisian domain (Abdeljaouad and Zargouni, 1981). According to facies (Louhaïchi and Tlig, 1993) and microfauna data (Gharbi, 2008), the Abiod Formation is Upper Campanian to Maastrichtian in age (Fig. 3 and Table. 1).

The Cenozoic series of the study area are composed by thin Paleocene marine marls covered by Paleogene and Neogene continental sediments. The Early Tertiary comprises green clays of the El Haria Formation. The clays show a Maastrichtian to Paleocene marine fauna (Gharbi, 2008). The Bouloufa Formation is dated to the Middle Eocene by Abdeljaouad (1987) and overlies unconformably (U1) the clays of the El Haria Formation. It is formed by red gypsum clay and encrusted limestone with Bulimes fauna. At the end of Eocene period, south and central Tunisia emerged and compressional deformations took place (Masrouhi et al., 2008; Frizon de Lamotte et al., 2009). As a result, intense erosion in the Atlassic fold-and-thrust belt zone caused the deposition of thick syntectonic series of silt and molasse basins during the Neogene and Quaternary. Miocene sands of the Beglia Formation unconformably overlie (U2) the Bouloufa Formation. Finally, the Segui Formation, which crops out on the southern flank of the Zemlet el Beidha anticline, consists of coarse alluvial conglomerate deposits. The Segui Formation unconformably overlies (U3) the Beglia Formation and record the growth of the Zemlet el Beidha anticline.

3. Zemlet el Beidha Cretaceous structures

3.1. Structures

The Zemlet el Beidha structure corresponds to a south-verging asymmetric thrust-related anticline with a curved axis that changes from an E strike to NE strike from west to east (Fig. 2). The Zemlet el Beidha anticline has a single periclinal closure in the east. As shown in geologic map of Figure 2, the core of the Zemlet el Beidha consists of Coniacian-Santonian outcrops in the Jebel Romana and Gouada plain (NE part of Zemlet el Beidha). Westward, the anticline of Jebel Haidoudi is occupied by the Coniacian-Santonian deposits. In the central part, the core of the anticline is formed by the Hauterivian-Barremian series.

The geometry of the Zemlet el Beidha anticline is illustrated by the two cross sections of Figure 4. The section A-A' crosses the eastern part of the anticline (Fig. 2 and 4). In the Tebaga Fatnassa region, the fold corresponds to a gently deformed anticline of Cretaceous strata unconformably overlain by Late Miocene (U2) and Late Pliocene to Quaternary series (U3). The northern backlimb is formed by ~10° N-dipping thin layers of marls (Fig. 4A), alternating with anhydrites, limestones and claystones of the Bouhedma Formation. The series are also deformed by the N-dipping normal faults. The southern forelimb is formed by Coniacian-Santonian series of the Aleg Formation and dips ~20°southeastward. The central part, the Khanguet Aïcha and Khanguet Amor region, exposes a forelimb formed by ~ almost 45° S-dipping layer (Fig. 2 and 5). The southern flank of the Zemlet el Beidha anticline also shows subvertical faults, previously interpreted by several authors as strike-slip faults (Abdeljaouad and Zargouni, 1981; Zargouni et al., 1985; Abbès and Zargouni, 1986; Abbès et al., 1986).

Along the cross section B-B' (Fig. 4), the northern limb of the anticline exhibits 5-10° N-dipping Hauterivian-Barremian series. The cross section B-B' shows a Cretaceous series from the Hauterivian to Late Maastrichtian unconformably overlain by Middle Eocene, Late Miocene and Late Pliocene to Quaternary (U1, 2, 3) series on the Jebel Jerouala and Jebel Haidoudi (Figs. 2 and 4).The western part of the Zemlet el Beidha anticline is characterized by a 70°-80° S-dipping forelimb intensively deformed by the S-vergent faults acting now as right-lateral oblique-slip of the Fejej coridor (Fig. 2).

3.2. Fault kinematics analysis

The Zemlet el Beidha area has undergone a complex tectonic evolution related to its geometric position in relation to the whole northern Chotts range. To support our structural interpretation we measured and analyzed striated fault planes within Aptian-Albian series. Such a fault kinematics analysis of mesoscale faults permits a quantitative reconstruction of paleostresses that can be related to the chronological sequence and orientations of larger-scale structures. These paleostresses thus provide useful information not only on the compressional, extensional or strike-slip origin of larger structures, but also on their kinematics and orientation relative to the stress field (oblique or normal).

The western part of the Zemlet El Beidha anticline (Jebel Haidoudi, Jebel Fejej and Jebel Jerouala) is characterized by a major NW to WNW-trending fault Fejej system (Abdeljaouad and Zargouni, 1981; Zargouni et al., 1985; Abbès and Tlig, 1991; Louhaïchi and Tlig, 1993). This fault system, acting now with a right-strike-slip component, may correspond to inherited Cretaceous normal faults (Gharbi, 2008). The detailed geologic mapping (1:25 000) of the Khanguet Aïcha area (central part of Zemlet el Beidha, Fig. 2) combined with the SPOT images (Fig. 5A, B) also show numerous N100-110° E apparent trending strike-slip faults. These faults are well expressed in the southern flank of the Zemlet el Beidha anticline. The Khanguet Aïcha and the Khanguet Amor faults appear on map as strike-slip faults. They affect the Hauterivian to Albian series and are sealed by Coniacian-Santonian deposits (Fig. 5B, C) with no evidence of recent displacement (Fig. 5 and 6). Fault kinematics analysis performed along the Khanguet Aïcha and Khanguet Amor faults (Fig. 5D) shows oblique strike-slip faulting component. The normal faulting generates the sedimentary reworking of the Aptian dolomitic bank in the Khanguet Aïcha and Khanguet Amor. The syntectonic Aptian conglomerates (Fig. 7 A, B, C and D) observed in the downdropping normal fault of Khanguet Aïcha and Khanguet Amor (Fig. 6) indicated tilted block geometry. In addition, the eastern part of Tebaga Fatnassa (Fig. 2) exposes growth strata in the hanging-wall of the ancient normal fault testifying the Albian extensional regime (Fig. 8).

Using the fault diagram, we rotated the fault data to restore the bedding plane to its horizontal orientation. The resulting back-tilted fault diagram shows that these faults were normal faults before Cenozoic tilting (Fig. 5D). This pre-tilting normal faulting shows a ~NE trending extension (Fig. 5D). The reactivation of this normal fault is attested by reverse sense of movement (Fig. 8) and shows thrust reactivation and the shortcut geometry affecting the Bouhedma Formation in the core of the Zemlet el Beidha anticline (Fig. 9).

3.3. Tectono-sedimentary data

Along-strike correlation of the sedimentary sequences of the Zemlet el Beidha region allows us to characterize at least four periods of tectono-sedimentary evolution related to the Cretaceous rifting (Fig. 10A) i.e. Neocomian, Aptian-Albian, Coniacian-Santonian and Campanian-Maastrichtian tectono-sedimentary sequences.

During the Neocomian, a sporadic clastic sedimentation testifies two periods of marine regression. The sequences correspond essentially to continental sediment including sands, clays, silts, lacustrine dolomites and gypsum deposits. The Early Albian tectonic extensional episode is recorded by N100-110° E trending faults related to a regional N to NE trending extension. This tectonic episode may be associated with the general uplift and erosion (ds1) of the Zemlet el Beidha zone (Fig. 10A) and continued to Early Albian times. The subsidence in the northern Chotts range area began during the Hauterivian-Barremian. Sedimentary features such as small slumps (Fig. 11 A), turbidites, mudflows (Fig. 11 B), and several meter scale olistoliths (included within the Barremian anhydrites, limestones and claystones) indicate basin instabilities. The Early Aptian dolomitic series include rare orbitolines and ammonites (Fig. 11 C; Abdeljaouad and Zargouni, 1981; Ben Youssef and Peybernès, 1986; Chaabani and Razgallah, 2006; Lazez et al., 2008; Gharbi, 2008) give evidence for a hard ground surface. In the Khanguet Aïcha, this dolomitic bank is also affected by the N110°E trending faults. This faulting is associated with thickness and facies variations of the Barremian series (Fig. 5C) as well as the occurrence of Aptian conglomerates within the hanging-walls of the Kanguet Aïcha and Kanguet Amor faults (Figs. 5 and 6). These conglomerates probably attest to syntectonic sedimentation during normal faulting. Moreover, the stratigraphic correlation of Fig. 10A shows usually lateral thickness changes from the Khanguet Amor (log 7) to the Kanguet Aïcha (log 8) areas that appear to be correlated with the normal faults. The Early Aptian tectonic extensional episode is well known in the northern Chotts range and south Atlassic domain. It is characterized by a tilted block system associated with horsts and grabens. In fact, this structural frame is responsible for the distribution of the Albian sequences in the northern Chotts range and the regional unconformity deposits which are defined by the absence of the deposits of Late Aptian and of the Early and Middle Albian age (Abdeljaouad and Zargouni, 1981; Ben Youssef et al., 1984; Lazez et al., 2008).

In this area, the irregular distribution of these series is also expressed within deposits around the uplifted zone of the present-day Zemlet el Beidha fold (Fig. 10B). In this region, the series distribution is related to a tilted bloc geometry, which has been dated to the Neocomian-Early Albian. Faulting produced differential uplift and high subsidence rates in the northeastern Chotts range (Fig. 10B).

The transgressive Cenomanian and Turonian period is well known across the northern African plate. Despite this transgression (Guiraud et al., 2005), the tectonic activity induced differential subsidence; the Zemlet el Beidha formed an uplift zone during this period of high sea level. The Jebel Jerouala is the unique locality (log 3 in Fig. 10A) where Turonian sediments were deposited. In this zone we note the presence of red flint dolomite limited by the Fejej normal fault systems. The thickness variations and the main tectonic elements suggest that the Turonian sedimentation was controlled by WNW to NW trending faults.

The Coniacian-Santonian sedimentation is characterized by a subtle onlap pattern and facies changes. These sediments consist of marl-rich limestones and clays enriched by benthic and pelagic foraminifera and ostrea, indicating a deepening basin. On the northern side and southern flank of the Zemlet el Beidha anticline, the strong thickness of the Coniacian-Santonian series is related to the reactivation of NW trending faults that delimited the Zemlet el Beidha horst (Fig. 2 and 10A). Eastward, the region of Gouada plain (Fig. 2) is characterized by pelagic facies (Fig. 10A) while westward, at Jebel Haidoudi, the deposits are characterized by benthic facies. In the Khanguet Telmem (Fig. 2 and log 5 and 6 in Fig. 10A), a lens of reef-building rudist colonies (Fig. 11D) has been observed, which recorded and developed due to the Zemlet el Beidha uplift. The rudist coral limestones preferentially developed on the horst of Zemlet el Beidha. During the Coniacian-Santonian stage, the paleostructure of the Zemlet el Beidha limits SW and NE marginal zones with basin sedimentation. In particular, the eastern Tebaga Fatnassa-Gouada plain and the western Jebel Fejej-Haidoudi area are characterized by strong subsidence during the Coniacian-Santonian (log 1, 2, 9, 10 in Fig. 10A). This subsidence is consistent with the previous tectonic context described above.

During the Campanian, the western part of the Zemlet el Beidha domain is characterized by marine transgression, recorded by the occurrence of deepwater limestones and clays, and pelagic facies in the Late Campanian. West of the Zemlet el Beidha area, just at the south of Jebel Fejej (Fig. 2 and Fig. 10 log 1, 2 and 3) and on the Jebel Haidoudi, these series are transgressive, and a significant increase in thickness subsidence rate is recorded by the Late Maastrichtian series. In the Fejej graben, the structural evolution during the Campanian and Late Maastrichtian led to a significant subsidence increase as a consequence of the transtensional (Guiraud et Bosworth, 1997; Zouari et al., 1999) displacement of the Fejej fault.

4. Discussion: Geodynamic evolution of the southern Atlassic margin

4. 1. Cretaceous rifting inheritances

4.1.1. Aptian-Albian syn-rift

The northern Chotts range was dominated by regional normal faulting. The WNW and NW trending faults were mainly inherited from the Jurassic and reactivated during the Early Cretaceous-Albian times (Gharbi, 2008). Seismic reflection profiles of Figure 12 illustrate the structural architecture of the southern Tethyan margin in the northern Chotts range. Analysis of the seismic profiles EL05 and EL07 crossing the Sidi Mansour Basin (Fig. 1C) permits to identify faults with normal components bounding the subsiding domains (Fig. 12). These faults are associated with other synthetic faults that have contributed to the formation of a major graben systems. The study area is marked by thick Hauterivian-Barremian and Albian deposits, which are progressively thickening, associated with listric faults (Fig. 12). The geometry and the thickness variations are interpreted to be related to the regional extensional strain during the Aptian-Albian. The evolution proposed in Fig.13 shows a possible tectonic scenario for the Zemlet el Beidha zone during Aptian-Albian faulting. The reactivation of the Khanguet Aïcha fault is associated with syntectonic conglomerates and leads to produce an unconformity at the base of the Upper Aptian series (Fig. 3, log 5, 8 in Fig. 10A and B, Fig. 13). Our observations suggest that this unconformity is associated with normal faults and an extensional tectonic regime. Such as the Jebel Chemsi, Jebel Bir Oum Ali at west of Zemlet el Beidha, Jebel Tebaga of Kebili (Fig. 14 a, b and c), the fault kinematics deduced from the study of striated fault planes display evidence for the tectonic regime which is extensional during the Aptian-Albian period. Geologic and geophysic data were integrated to confirm that the syn-rift tectonic in the northern Chotts range is still related to the Early Albian. This rifting has been accompanied by an episode of volcanism which is testified by basalt flows observed in the pelagian blocks of eastern Tunisia (Fig. 1B; Ellouz et al., 2003; Ouazaa and Bédir, 2004).

Many interpretations have been proposed to explain the Upper Aptian-Lower Albian regional unconformity. Several authors interpret this unconformity as the result of a major compressional event during the Aptian-Albian time (the Austrian Phase, Ben Ayed, 1993; Bédir et al., 2000; Bouaziz et al., 2002; Zouaghi et al., 2005). Other authors plead for an extensional event (normal faulting regime) (Martinez et al., 1991; Guiraud, 1998; Zghal et al., 1998; Zouari et al., 1999; Guiraud et al., 2005; Bodin et al., 2010; Rigane et al., 2010). Our observations yield fresh data to support an Aptian-Albian extensional deformation of the south Tethyan margin. This rifting episode ended with a regional unconformity identified by a hard ground surface, and halokinetic movements (Bédir et al., 2001; Rigane et al., 2010; Zouaghi et al., 2011). Thus, the Upper Aptian-Lower Albian unconformity can be related to intraplate extensional deformation linked to the opening of the central segment of the South

Atlantic while the northward movement of part of the African Plate was accompanied by N trending extension registered in the central African basins (Martinez et al., 1991; Guiraud and Maurin, 1991; Guiraud et al., 2005) and northeastward movement of the Arabian–Nubian block during the Aptian–Albian transition (Bodin et al., 2010).

4.1.2. Coniacian-Santonian post-rift

The Coniacian-Santonian stage is attested by thick deposits of pelagic and benthic facies (Fig. 10A). These deposits are characterized by thickness and facies variations and by reefal carbonates on horst structures (log; 5, Fig. 10A). In Sidi Mansour Basin, the Coniacian-Santonian sequence observed in seismic profile (EL-05, Fig. 12) shows along-strike changed in term of thickness which does not follow the usual hierarchies of the Early Cretaceous sequences. The ancient normal fault systems controlled the distribution of the Coniacian–Santonian deposits that are marked by a significant thickness and facies variations from northwest to southeast (Fig. 12). The Coniacian–Santonian distribution of the sedimentary deposits testifies for a post rift stage with major transgression (Abdallah and Rat, 1987; Herkat and Guiraud, 2006).

During the Coniacian-Santonian, the Maghreb area was covered by an important transgression leading to a very extensive marine incursion covering the northern platforms of the Sahara domain corresponding to shallow sea characterized by the deposition of a homogeneous carbonate platform (Zouaghi et al., 2005; Herkat and Guiraud, 2006; Frizon de Lamotte et al., 2009). A subsiding deep-marine basin has been developed in the Aurès (Herkat and Guiraud, 2006) that allows the deposition of black deep-marine shales in the Tunisian Atlas, which is one of the most important hydrocarbon-source rocks of the Atlas system (Bédir et al., 2001; Zouaghi el al., 2005; Frizon de Lamotte et al., 2009).

4.1.3. Campanian-Maastrichian tectonic reactivation

Several authors have suggested tectonic inversion in the Tunisia Atlas since the Campanian (Guiraud and Bosworth, 1997; Guiraud et al., 2005; Herkat and Guiraud, 2006; Masrouhi et al., 2008; Frizon de Lamote et al., 2009; Masrouhi and Koyi, 2012). Zouari et al. (1999) defined that the inversion occurred between middle Turonian and the Late Maastrichtian. In our study area, Late Campanian to Paleocene series are absent in the eastern Zemlet el Beidha region. However, these series develops westward in the Fejej corridor (Fig. 2 and Fig. 10A). We propose that fault reactivation occurred during Late Campanian to Paleocene, producing the westward migration of the subsidence from the Gouada plain to the Fejej corridor (Fig. 10A). This tectonic event may be related to N trending compression which reactivated the major inherited fault. This stage corresponds to southwestward migration of the subsidence in the southern Atlasic domain, especially in the Gafsa Basin (Zouari et al., 1999).

4.2. Implications for Cenozoic tectonic evolution

In this study, field data show evidences for unconformities and syntectonic deposits recording several periods of shortening during the Cenozoic. We present here the sedimentary signatures of the different pulses of shortening associated with the development of the Zemlet el Beidha fold.

According to the cross section A-A' (Fig. 4), the unconformity angle between the Coniacian-Santonian and the erosional Late Miocene surface is 10° while between Coniacian-Santonian and Late Pliocene-Quaternary is about 20°. Locally south of the Jebel Jerouala, we observed that the Late Middle Eocene unconformably overlie the Late Maastrichtian-Palaeocene series (cross section B-B', Fig. 4). This unconformity confirms that the Zemlet el Beidha Cretaceous basin was inverted during the Cenozoic. During the compressional deformations, some extensional structures were not reactivated (Fig. 2 and Fig 4) while others were reactivated and evolved to strike-slip faults, such as the apparent Khanguet Aïcha and Khanguet Amor strike-slip faults (Fig. 5 and Fig. 6) and reverse faults (Fig. 8).

In addition, some Atlassic folds are related to the early halokinesis during Jurassic and Early Cretaceous associated with the synsedimentary activity of some normal faults (Rigane et al., 2010). The seismic lines interpreted by several authors (e.g., Hlaiem, 1999; Frizon de Lamotte et al., 2000; 2009) show that the fold structures are associated with reverse deep-seated faults rooting at depth within the Triassic levels. The position and orientation of pre-existing structures would be related to the position of ancient normal faults which may be probably linked to structural inheritance due to the Triassic-Jurassic to Aptian-Albian rift (Guiraud, 1998; Guiraud et al., 2005). In our study area, the Upper Aptian-Albian normal faulting also played a major role during Cenozoic compressions in controlling the structural architecture of the Zemlet el Beidha anticline and probably, of others structures of the Chott range.

5. Conclusion

The structural and tectono-sedimentary study of Jebel Zemlet el Beidha underlines the predominant role of inherited structures acquired during the evolution of the southern Tethyan margin, and their influence of the present-day geometry of the Atlassic fold belt. The geodynamic history of the Tethyan margin during the Cretaceous in the northern Chotts range can be divided into three different tectonic events. The first syn-rift Aptian-Albian period shows a general episode of variable depositional thickness and facies variations. It is dominated by an extensional stress regime. The onset of the tilted blocks along the N100-110°E trending normal fault was associated with Upper Aptian syn-depositional conglomerates. This extensional tectonics was also accompanied, in several regions of the Atlas, by volcanic activity and halokinetic movement. The second Coniacian-Santonian period corresponds to a post-rift stage with major marine transgression. The Coniacian-Santonian extensional faulting is recognized in the southern Tunisian Atlassic domain. In contrats, in Algeria and Morocco, the Coniacian-Santonian is characterized by the first period of inversion tectonics (Herkat and Guiraud, 2006; Frizon de Lamotte et al., 2009). In our study area, we propose that fault reactivation occurred during Late Campanian to Paleocene, producing the westward migration of the subsidence. This tectonic event can be correlated with the onset of the Africa-Eurasia convergence (Guiraud and Bosworth, 1997; Zouaghi et al. 2005; Frizon de Lamotte et al., 2009). Major structural inversion of the Upper Aptian-Albian normal faults occurred during successive Cenozoic compressions. This Cretaceous inheritance controlled the structural architecture of the Zemlet el Beidha anticline and probably of others structures of the Chott range.

Acknowledgments

This work is based on M. Gharbi’s Masters at "Faculté des Sciences de Tunis" (Tunisia) and PhD research at "University of Sfax", "Unité de Recherche Hydrosciences Appliquées à Gabés (06/UR/10-03)" (Tunisia) and at CEREGE (Université Paul Cézanne Aix-Marseille (UPCAM), France). M. Gharbi benefits of a Foreign Affair Ministry (Ministère des Affaires Etrangères) grant through French Embassy in Tunisia and a complement support through the "Cotutelle de thèse" program (F2IR program - UPCAM). Field has benefited from financial support under UPCAM RFQ's International Relations. SPOT images were provided thanks to the ISIS program (©CNES, distribution SPOT images S.A.). The Tunisian Enterprise for Petroleum Activities (ETAP) and particularly A. Amri and Y. Bouazizi are thanked for providing access to the seismic lines. We are indebted to Nick Marriner and Rita Katharina Kraus for comments and English language corrections. We are grateful to Dr. W. Bosworth and the anonymous reviewer for providing constructive reviews that significantly improved this article.

References

Abbès, A. et Tlig, S., 1991. Tectonique précoce et sédimentation de la série Crétacée dans le bassin des Chotts (Tunisie du sud) Géologie Méditerranéenne. Tome XVIII, n° 3. pp, 149-161.

Abbès, C et Zargouni, F., 1986. Anatomie d'un couloir de décrochements: le couloir de Hadifa (Chaîne Nord des Chotts-Tunisie). Rev. Sc. de la Terre, Vol. 4, Tunisie.

Abbès, C., Abdeljaouad, S. et Ben Ouezdou, H. 1986. Carte Geologique d'El Hamma au 1/100.000, feuille n°74. Institut National de recherche Scientifique de Tunisie et Service Geologique Nationale d'Office Nationale de Mines, Tunisie.

Abdallah, H. et Rat, P., 1987. Le rôle de la faille de Gafsa dans le jeu transgressif et régressif au Crétacé supérieur de la chaîne nord des Chotts (Tunisie). In Colloque: Transgressions et régressions au Crétacé (France et régions voisines), Dijon, 1985 (ed. Saloman, J.), Mémoires Géologiques de l'Université de Dijon 11. pp, 232–242

Abdallah, H., Memmi L., Damotte, R., Rat, P. and Magniez, Jannin F., 1995. Le Crétacé supérieur de la chaîne Nord des Chotts (Tunisie du centre-sud): Biostratigraphie et comparaison avec les régions voisines. Cretacrous Research, 16. P,487-538.

Abdeljaouad, S et Zargouni, F., 1981**.** Mise en évidence d'une tectonique intracrétacé dans le secteur de J. Zemlet El Beïda (chaîne des Chotts). Acte de 1er Congr. Nat. Sc. Terre, Tunis, t. I, p, 285.

Abdeljaouad, S., 1987. Sur l'âge Paléocène supérieur-Miocène des dépôts continentaux à calcrètes ou dolocrètes de la Formation Bouloufa en Tunisie méridionale. Conséquences paléogéographiques. Bull. Soc. Géol. Fr, (8), t, III, n°4. pp, 777-781.

Abrajevitch, A.V., Jason, R.A., Aitchison, J.C., Badengzhu, Davis, A.M., Jianbing Liu, J., and Ziabrev, S.V., 2005. Neotethys and the India–Asia collision: insights from a palaeomagnetic study of the Dazhuqu ophiolite, southern Tibet. Earth and Planetary Science Letters 233. pp, 87-102.

Aris, Y., Coiffait, P.E., Guiraud, M., 1998. Characterization of Mesozoic–Cenozoic deformations and paleostress fields in the Central Constantinois, northeast Algeria. Tectonophysics. 290. pp, 59-85.

Bédir, M., Boukadi, N., Tlig, S., Ben Timzal, F., Zitouni, L., Alouani, R. Slimane, F., Bobier, C., and Zargouni, F., 2001. Subsurface Mesozoic basins in the central Atlas of Tunisia, tectonics, sequence deposit distribution and hydrocarbon potential, AAPG Bull. 85, 5. pp, 885-907.

Ben Ayed, N., 1986. Evolution tectonique de l'avant-pays de la chaîne alpine de la Tunisie du début du Mésozo à l'Actuel. Thesis es-sciences, Univ. Paris Sud, Orsay, 347 p.

Ben Ferjani, A., Burollet, P., F. and Mejri, F. 1990. Petroleum geology of Tunisia. Entreprise Tunisienne d'activités pétrolières, 194p.

Ben Youssef, M., Biely, A., et Memmi, L., 1985. La Formation Orbata (Aptien) en Tunisie méridionale précisions biostratigraphiques nouvelles. Notes service géologique de Tunisie, n°51. pp, 105-120.

Ben Youssef. M et Peybernes. B., 1986. Données micropaléontologiques et biostratigraphiques nouvelles sur le Crétacé inférieur marin du Sud tunisien, J. Afr. Earth Sci. 5. pp, 217-231.

Bodin. S., Petitpierre. L., Wood. J., Elkanouni. I., and Redfern. J., 2010. Timing of early to mid-cretaceous tectonic phases along North Africa: New insights from the Jeffara escarpment (Libya–Tunisia). J. Afr. Earth Sci. 46, pp, 346-370.

Brunet. M., and Cloetingh. S., 2003. Integrated Peri-tethyan Basins studies (PeriTethys Programme). Sedimentary Geology 156. pp 1-10.

Bumby, A. J., and Guiraud, R., 2005. The geodynamic setting of the Phanerozoic basins of Africa J. Afr. Earth Sci. 43. pp, 1-12.

Burollet. P. F., 1991. Structures and tectonics of Tunisia. Tectonophysics 195.P, 359-369.

Catalano, R., Di stefano, P., Sulli, A., and Vitale, F.P., 1996. Paleogeography and structure of the central Mediterranean: sicily and its offshore area. Tectonophysics 260. pp, 291-323.

Chaabani, F., and Razgallah, S., 2006. Aptian sedimentation: an example of interaction between tectonics and eustatics in Central Tunisia. Geological Society, London, Special Publications, 262. pp, 55-74.

Courel, L., Aït Salem, H., Benaouiss, N., Et-Touhami, M., Fekirine, B. Oujidi, M., Soussi, M., and Tourani, A., 2003. Mid-Triassic to Early Liassic clastic/evaporitic deposits over the Maghreb Platform. Palaeogeogr. Palaeoclimatol. Palaeoecol. 196, 157–176.

DeCelles, P. G., and K. N. Giles (1996), Foreland basin systems, Basin Res., 8, 105–123, doi:10.1046/j.1365-2117.1996.01491.x.

Dercourt, J., Zonenshain, L.P., Ricou, L.P., Kazmin, V.G., Le Pichon, X., Knipper, A.L., Laurier, J.P., Bashenov, M.L., Boulin, J., Pechersky, D.H., Biju Duval, B., Savostin, L.A., Lepvrier, C., and Geyssant, J., 1986. Geological evolution of the Tethys belt from the atlantic to the pamirs since the LIAS. Tectonophysics 123 (1-4), 241-315. 15

Deteil. J., Zouari. H., Chikhaoui. M., Creuzot. G., Ouali. J, Turki M. M., Yaïch. C et Zargouni. F. 1991. Relation entre ouvertures téthysienne et mésogéenne en Tunisie. Bull. Soc.Géol. France, t. 162, n°6 .p1173-1181.

Dewey, J.F., Hempton, M. R., Kidd, W. S. F., Saroglu, F., and Segnör, A. M. C., 1986. Shortening of continental lithosphere: The neotectonics of eastern Anatolia.Special Publications Geological Society London 19, pp 3-36.

Dhahri, F., and Boukadi, N., 2010. The evolution of pre- existing structures during the tectonic inversion process of the Atlas chain of Tunisia. J. Afr. Earth Sci. 56. pp 139–149.

Doglioni, C., Fernandez, M., Gueguen E and Sabat, F., 1999. On the interference between the early Apennines–Maghrebides back arc extension and the Alps-betics orogen in the Neogene geodynamics of the Western Mediterranean. Bol. Soc. Geol. Ital.118, pp 75– 89.

Ellouz, N., Patriat, M., Gaulier, J.M., Bouatmani, R., and Sabounji, S., 2003. From rifting to Alpine inversion: Mesozoic and Cenozoic subsidence history of some Moroccan basins. Sedimentary Geology. 156, pp 185-212.

Frizon de Lamotte, D., Leturmy, P.,Missenard, Y., Khomsi, S., Ruiz, G., Saddiqi, O., Guillocheau, F., and Michard, A., 2009. Mesozoic and Cenozoic vertical movements in the Atlas system (Algeria,Morocco, Tunisia): an overview. Tectonophysics. 475. pp, 9-28.

Frizon de Lamotte, D., Michard, A., and Saddiqi, O., 2006. Some recent developments on the geodynamics of the Maghreb. C. R. Geosciences, v. 338, 1-10 n°1-2.

Gharbi, M., 2008. Etude Tectonique de la région de Zemlet El Beidha (Chaîne Nord des Chotts) : Structuration Crétacée et Evolution Tertiaire. Mastère Fac Sci. of TunisUniversity Tunis-El-Manar. 86p.

Guiraud, R., 1998. Mesozoic rifting and basin inversion along the northern African Tethyan margin: an overview. In: MacGregor, D.S., Moody, R.T.J., Clark-Lowes, D.D. (Eds.), Petroleum Geology of North Africa. Geological Society, London, Special Publication 133, pp. 217-229.

Guiraud, R., and Bosworth, W., 1997. Senonian basin inversion and rejuvenation of rifting in Africa and Arabia: synthesis and implications to plate-scale tectonics. Tectonophysics 282, pp 39-82.

Guiraud, R., and Bosworth, W., 1999. Phanerozoic geodynamic evolution of northeastern Africa and the northwestern Arabian platform. Tectonophysics. 315, pp 73-108.

Guiraud, R., et Maurin, J.C., 1991. Le rifting en Afrique au Crétacé inférieur: synthèse structurale, mise en évidence de deux étapes dans la genèse des bassins, relations avec les ouvertures océaniques périafricaines. Bull. Soc. Géol. France 162, pp 811-823.

Guiraud, R., and Maurin, J.C., 1992. Early Cretaceous Rifts of Western and Central Africa. An overview. Tectonophysics 213, pp 153-168.

Guiraud. R., and Bosworth, W., Thierry, J and Delplanque, A., 2005. Phanerozoic geological evolution of Northern and Central Africa: An overview J. Afr. Earth Sci. 43, pp 83-143.

Herkat, M., and Guiraud, R., 2006. The relationships between tectonics and sedimentation in the Late Cretaceous series of the Eastern Atlasic Domain (Algeria). J. Afr. Earth Sci. 46, pp 346-370.

Hlaiem, A. 1999. Halokinisis and structural evolution of the major features in eastern and southern Tunisian Atlas. Tectonophysics 306, pp. 79-95.

Laridhi-Ouazaa, N., and Bédir, M., 2004. Les migrations tectono-magmatiques du Trias au Miocène sur la marge orientale de la Tunisie. Africa Geosciences Review, Vol. II, n°3, pp179-196.

Laville, E., Pique, A., Amrhar, M., and Charroud, M., 2004. A restatement of the Mesozoic Atlasic Rifting (Morocco). J. Afr. Earth Sci. 38, pp 145-153.

Lazzez, M., and Ben Youssef, M., 2008. Relative Sea-level Changes of the Lower Cretaceous Deposits in the Chotts Area of Southern Tunisia. Turkish J. Earth Sci., 17,pp 835–845.

Lazzez, M., Zouaghi, T., and Ben Youssef, M., 2008. Austrian phase on the northern African margin inferred from sequence stratigraphy and sedimentary records in southern Tunisia (Chotts and Djeffara areas). C. R. Geosciences, v. 340. Issue 8, pp 543-555 C.

Louhaïchi, M. A., et Tlig, S., 1993. Tectonique synsédimentaire des séries post-Barrémiennes au Nord-Est de la chaîne Nord des Chotts (Tunisie méridionale). Géologie méditerranéenne. XX, n°1, pp 53-74.

Marmi, R., and Guiraud, R., 2006. End Cretaceous to recent polyphased compressive tectonics along the “Mole Constantinois” and foreland (NE Algeria). J. Afr. Earth Sci. 45, pp 123–136.

Martinez, C., Chikhaoui, M., Truillet, R., Ouali, J., and Creuzot, G., 1991. Le contexte géodynamique de la distension albo-aptienne en Tunisie septentrionale et centrale: structuration éocrétacée de l’Atlas tunisien. Eclogae Geologicae Helvetiae 84, pp 61-82.

Masrouhi, A. and Koyi. H., 2012. Submarine “salt glacier” kinematics of Northern Tunisia, a case of Triassic salt mobility in North African Cretaceous passive margin. Alsop, G. I., Archer, S. G., Hartley, A., Grant, N. T and Hodgkinson, R. J. Geol. R. (eds) 2012. Salt Tectonics, Sediments and Prospectivity. Geological Society, London, Special Publications, 363, pp 579–593. http://dx.doi.org/10.1144/SP363.29.

Masrouhi, A., Ghanmi, M., Ben Slama, M.-M., Ben Youssef, M., Vila, J.-M, and Zargouni, F., 2008. New tectono-sedimentary evidence constraining the timing of the positive tectonic inversion and the Eocene Atlasic phase in northern Tunisia: Implication for the North African paleo-margin evolution. C. R. Geosciences, 340. pp 771-778.

Masrouhi, A., Ghanmi, M., Youssef, M.B., Vila, J.M., and Zargouni, F., 2007, Mise en évidence d’une nappe de charriage à deux unités paléogènes au plateau de Lansarine (Tunisie du Nord): Définition d’un nouvel élément structural de l’Atlas Tunisien et réévaluation du calendrier des serrages tertiaires: C. R. Geosciences, v. 339, p. 441–448.

Patriat, M., Ellouz N., Dey Z., Gaulier J. M., and Ben Kilani H., 2003. The Hammamet, Gabes and Chotts basins (Tunisia) a review of the subsidence history. Sedimentary geology 156, pp 241-262.

Negra, M. H., Purser, B. H., M'rabet, A. 1995. Sedimentation, diagenesis and syntectonic erosion of Upper Cretaceous rudist mounds in central Tunisia. Carbonate mud-mounds: their origin and evolution, pp. 401-419.

Philip, H., Andrieux, J., Dlala, M., Chihi, L., and Ben Ayed, N., 1986. Evolution tectonique moi- plio-quaternaire du fossée de Kasserine (Tunisie centrale): implications sur l’évolution géodynamique récente de la Tunisie. Bull. Soc. Géol. France, 8 t. II, 4, 559-568.

Piqué, A., A Brahim., L., Ait Ouali, R., Amrhar, M., Charroud, M., Gourmelen, C., Laville, E., Rekhiss, F., and Tricart, P., 1998. Evolution structurale des domaines atlasiques du Maghreb au Méso-Cénozoïque; le rôle des structures héritées dans la déformation du domaine atlasique de l’Afrique du Nord. Bull. Soc. Géol. France, 6 t. 169, 797-810. pp.217-231.

Piqué, A., Tricart, P., Guiraud, R., Laville, E., Bouaziz, S., Amrhar, M., and Ait Ouali, R., 2002. The Mesozoic-Cenozoic Atlas belt (North Africa): an overview. Geodinamica Acta 15, pp185-208.

Raulin, C., Lamotte, D.F.D., Bouaziz, S., Khomsi, S., Mouchot, N., Ruiz, G., Guillocheau, F. 2011. Late Triassic-early Jurassic block tilting along E-W faults, in southern Tunisia: New interpretation of the Tebaga of Medenine. Journal of African Earth Sciences 61, pp. 94-104

Rigane, A., Feki, M., Gourmelen, C., and Montacer, M., 2010. The “Aptian Crisis” of the South-Tethyan margin: New tectonic data in Tunisia. J. Afr. Earth Sci. 57. pp. 360–366.

Souquet, P., Peybernès, B., Saadi, J., BenYoussef, M., Ghanmi, M., Zarbout, M., Chikhaoui, M., and Kamoun, F., 1997. Séquences et cycles d’ordre 2 en régime extensif et transtensif: exemple du Crétacé inférieur de l’Atlas tunisien, Bull. Soc. geol. France 168, pp. 373-386.

Soyer, C. and Tricart, P., 1987. La crise aptienne en Tunisie centrale : approche paléostructurale aux confins de l’Atlas et l’Axe Nord-Sud. C.R. Acad. Sci. Paris. t. 305 (Serie II), pp. 301–305.

Vergès, J. and Sabàt, F., 1999. Constraints on the western Mediterranean kinematics evolution along a 1000 km transect from Iberia to Africa. In: Durand, B. (Ed.). The Mediterranean Basins: Tertiary Extension within the Alpine Orogen, vol. 156. Geol. Soc. Spec. Publ., London, pp. 63–80.

Vially, R.; Letouzey, J.; Bernard, F.; Haddadi, N.; Desforges, G.; Askri, H.and Boudjema, A., 1994 . Basin inversion along the northern African margin: the Saharan Atlas (Algeria). In: Peri-Tethyan Platforms, F. Roure (Ed.), pp. 79-118, Edition Technip, Paris.

Zargouni, F., 1984. Style et chronologie des déformations des structures de l’Atlas tunisien méridional. Évolution récente de l’accident Sud-atlasique. C.R. Acad Sc.Paris, t.299, Série II, n°2. pp.179-196.

Zargouni, F., 1985. Tectonique de l'Atlas méridional de Tunisie, évolution géométrique et cinématique des structures en zone de cisaillement. Thèse d'Etat, Univ. Louis Pasteur, Strasbourg-Paris.

Zargouni, F., Rabiaa, M.C., et Abbés, C., 1985. Rôle des couloirs de cisaillement de Gafsa et de Négrine-Tozeur dans la structuration du faisceau des plis des Chotts, éléments de l'accident sud-atlasique. C.R. Acad Sc.Paris, t 301. 11, pp. 831-883.

Zghal. I, Ouali. J, et Bismuth, H. 1998. Syn-sedimentary tectonics in central Tunisia (Jebel Mrhila area) during the Aptian-Albian. C.R. Acad Sc Paris, V 326, 3, pp 187-192.

Zouaghi, T., Bédir, M., and Inoubli, M, H., 2005. 2 D Seismic interpretation of strike-slip faulting, salt tectonics, and Cretaceous unconformities, Atlas Mountains, central Tunisia. J. Afr. Earth Sci. pp. Vol. 43, pp 464-486.

Zouaghi, T.; Ferhi, I.; Bédir, M.; Ben Youssef, M.; Gasmi, M. and Inoubli, M.H., 2011. Analysis of Cretaceous (Aptian) strata in central Tunisia, using 2D seismic data and well logs. . Afr. Earth Sci. Vol. 61, pp. 38-61.

Zouari, H., Turki, M.M., Delteil, J., et Stephan, J.-F., 1999. Tectonique transtensive de la paléomarge tunisienne au cours de l'Aptien-Campanien. Bull. Soc. Géol. France 170 (3), pp. 295–301.

Figure captions

Figure 1: Structural map of the northern African margin. B. Tectonic background of the southern Atlas of Tunisia is mapped based on satellite images analysis and field investigations (The base map is produced using elevation data from NASA SRTM Gtopo 30). C. Geological map of the North Chotts range with the location of Zemlet el Beidha.

Figure 2: Detailed geologic map of the Zemlet el Beidha anticline. Location of Fig. 5 is shown. The cross sections A-A' and B-B' are located in Fig. 4.

Figure 3: Stratigraphic column of the Mesozoic and Cenozoic series in the Zemlet el Beidha region. Only the outcropping series are shown.

Figure 4: Surface cross sections (For location, see Fig. 2) across the Zemlet El Beidha anticline. Section A-A' demonstrates the reactivation of the normal fault as reverse fault in the east of Tebaga Fatnassa structure. Section (B-B') shows the role of the NW-SE strike slip fault of the Fejej system (Fig. 2) affecting the southwestern part of Zemlet el Beidha.

Figure 5: A: The SPOT image of the Khanguet Aïcha area; B: Interpretative geological and structural map of Khanguet Aïcha area; C: The correlation of Barremian deposits with the normal fault of Khanguet Aïcha; D: Lower hemisphere stereographic projection of planes and striations of the Khanguet Aïcha and Khanguet Amor faults. The back-tilting shows the existent N100-110° E trending normal fault of Khanguet Aïcha and Khanguet Amor.

Figure 6: A: Panoramic view of the tilted synsedimentary Khanguet Aicha normal fault. This fault affects the Sidi Aïch and Orbata Formations and is sealed by the Coniacian-Santonian strata. B: Photograph of the tilted Khanguet Amor normal fault associated with syntectonic conglomerates of the Orbata Formation.

Figure 7: Details of the Aptian syn-tectonic conglomerates of the Orbata Formation.

A: The Aptian conglomerate; B: The metric bed of Aptian conglomerates located in the Khanguet Amor (See fig. 2); C and D: Small conglomerates resedimented in the Khanguet Aicha and Khanguet Amor.

Figure 8: Panoramic view, looking ENE, of a preserved Early Cretaceous normal fault. For location, see Fig. 2 Growth strata located in the hanging-wall indicate that this normal fault was active at least during the Albian.

Figure 9: Shortcut inverted normal fault with hangingwall shortcut deformation in the Bouhedma Formation.

Figure 10: A: NE-SW correlations of Cretaceous sedimentary log in the Zemlet el Beidha This correlation shows evidence of a central horst (Zemlet el Beidha) and lateral grabens (Fejej and Romana). Note the major thickening of the Cretaceous sediments toward the major faults. B: Block diagram showing tilted half graben systems of the Zemlet el Beidha as a result of a N to NE extension during Aptian-Albian(see Fig.5 D).

Figure 11: Photographs showing the principal features of the extensional Cretaceous along the Zemlet el Beidha structure. (A) The olistholites within the Bouhedma Formation indicate the depositional syn-rift. (B) Conglomerate interstratified in the Bouhedma Formation. (C) Ammonite Aptian in the Orabata Formation. (D) Rudist fossils (arrows) within the Aleg Formation (Coniacian-Santonian).

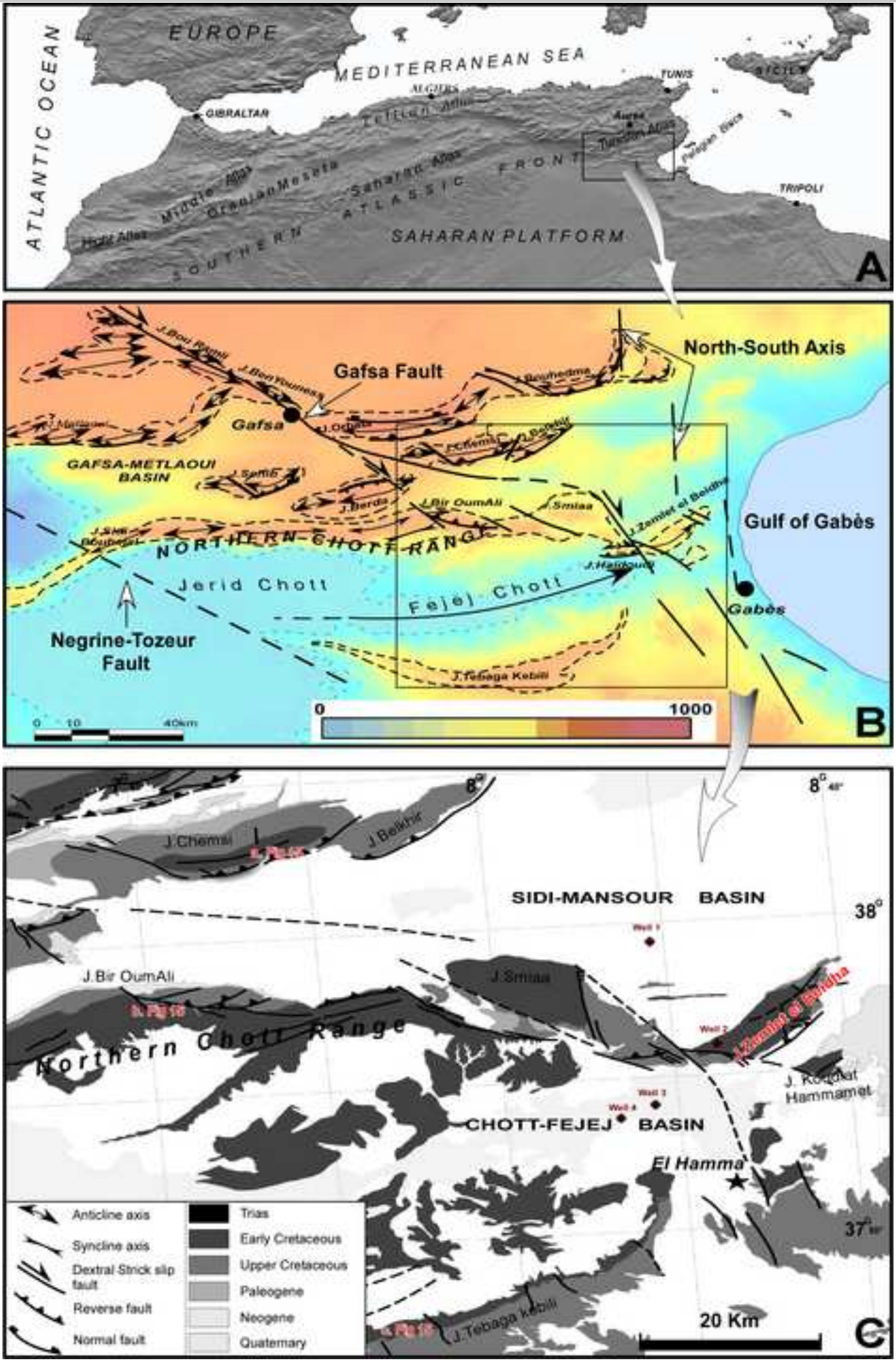
Figure 12: Seismic reflexion profiles EL05 and EL07 across the Sidi Mansour Basin, showing horst and graben systems trending NNE–SSW related to the extension of the

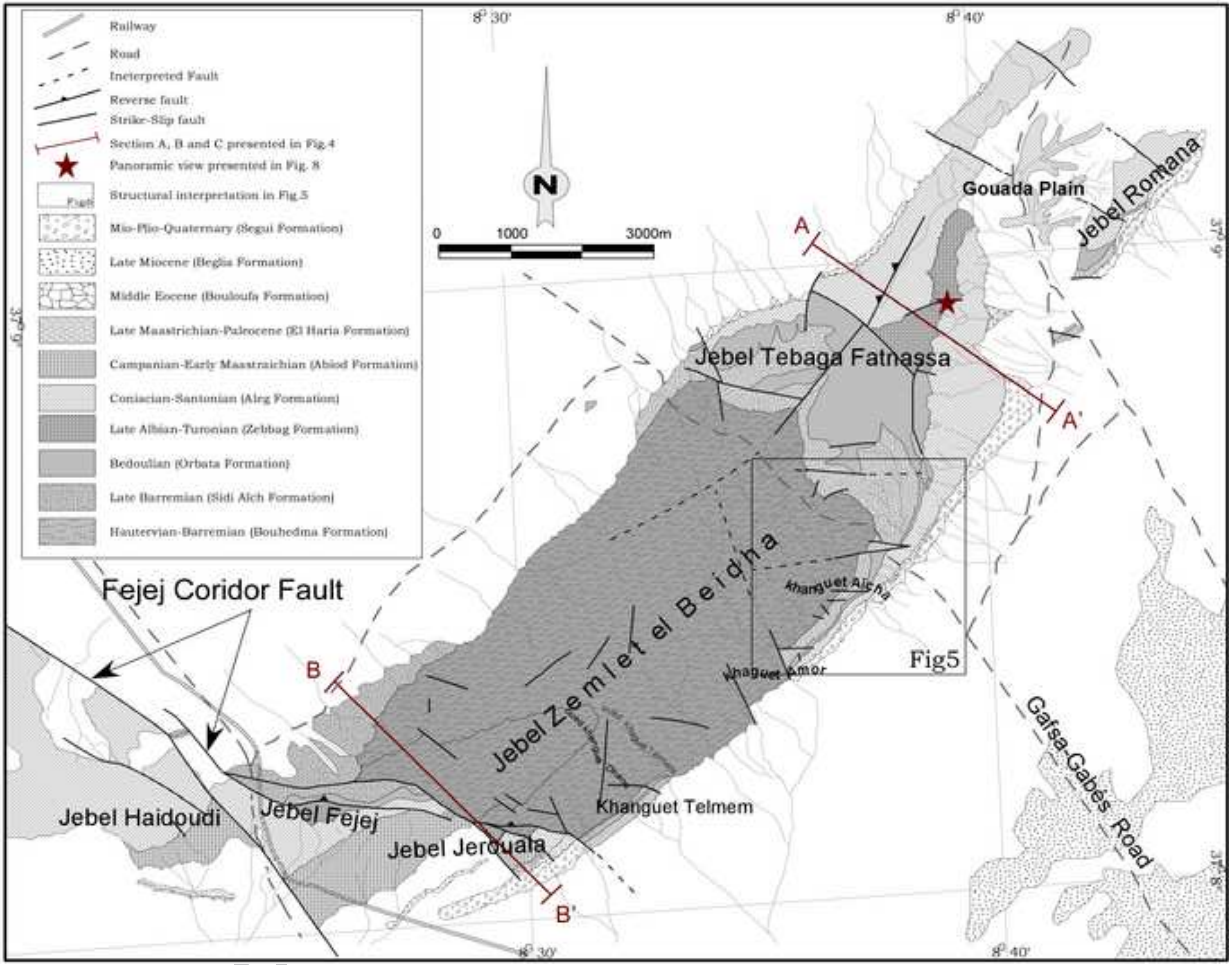
Tethyan margin. The base map is produced using elevation data from NASA SRTM Gtopo 30shows the position of seismic sections and the locations of petroleum wells used in this study.

Figure 13: Interpretative model of Khanguet Aicha fault: genetic mechanism explaining the presence of sedimentary discontinuity ds1 and ds2 of the upper Aptian and Early Albian deposit related to extensional tectonic. See details in the text.

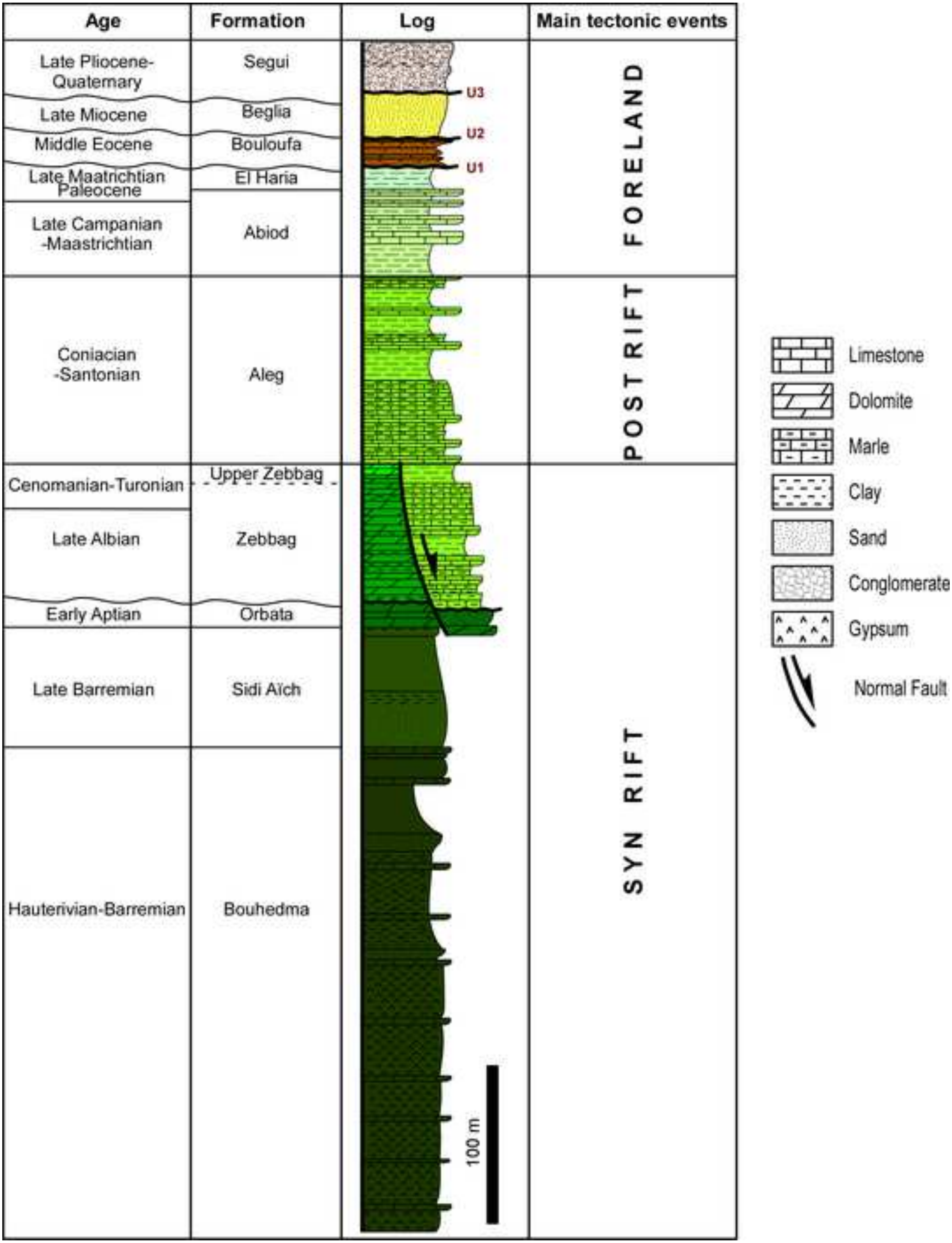
Figure 14: Similar Aptian-Albian extensional structures observed in the southern Atlas of Tunisia. A: The core of the Chemsi anticline shows, still preserved, a normal fault affecting the Albian series; B: Graben in the Aptian series; C: Map view (Google Earth image) of the Jebel Tebaga of Kebili. The geological interpretation shows that the Orbata Formation is affected by the normal fault, sealed by the Zebbag Formation.

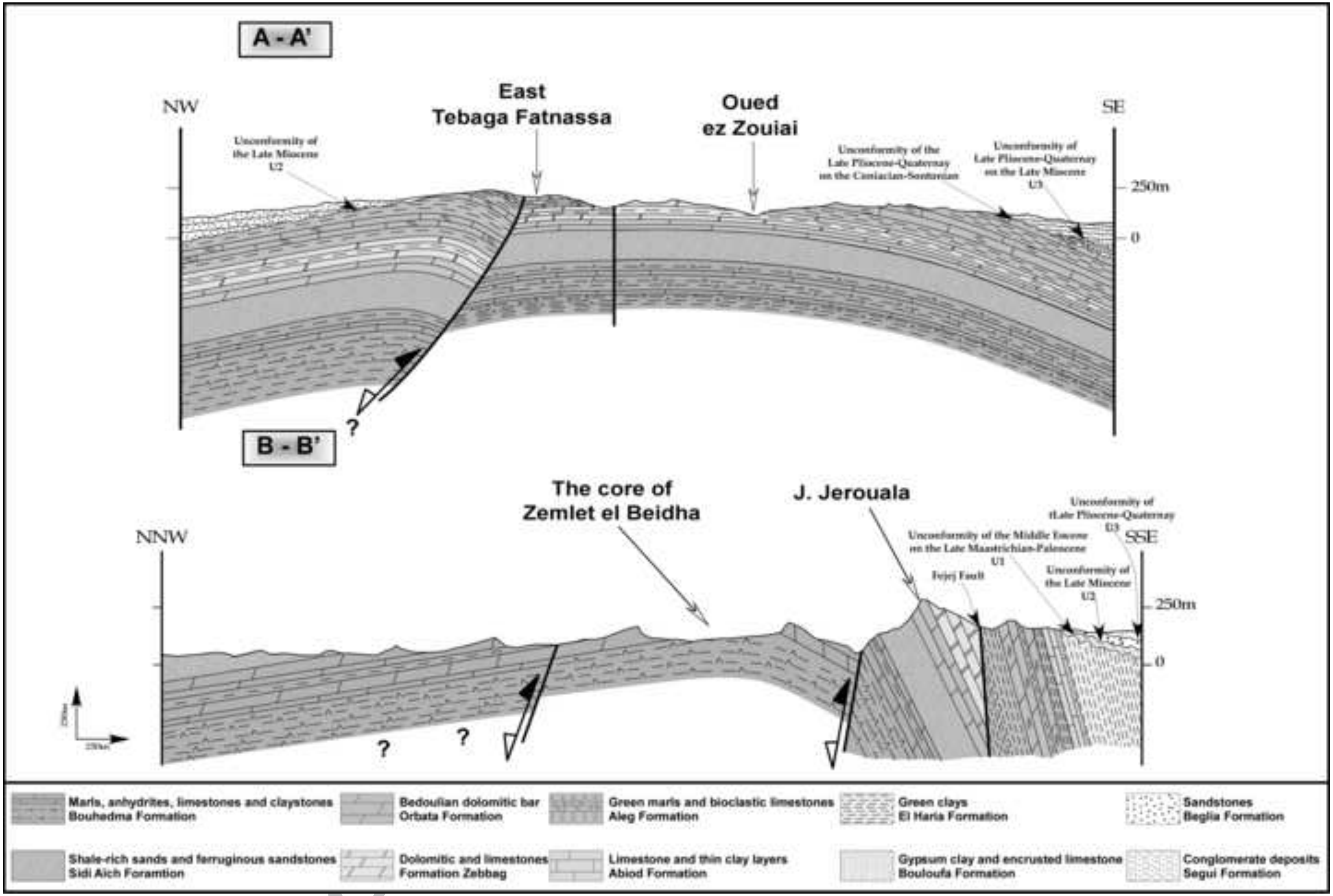
Table 1: Biostratigraphic data from the Zemlet el Beidha. Location of sample are in meter (UTM system). Microfauna and corresponding age of samples are also shown.


EUROPE
MEDITERRANEAN SEA
ATLANTIC OCEAN
GIBRALTAR
ALGIERS
TUNIS
SICILY
TRIPOLI
SAHARAN PLATFORM
SOUTHERN ATLASSIC FRONT
A
North-South Axis
Gafsa Fault
Gafsa
GAFSA-METLAOUI BASIN
NORTHERN CHOTT RANGE
Jerid Chott
Fejej Chott
Gulf of Gabès
Gabès
Negrine-Tozeur Fault
J.Tebaga Kebili
0
1000
B
J.Chemsi
J.Belkhir
SIDI-MANSOUR BASIN
J.Bir OumAli
J.Smiaa
Northern Chott Range
CHOTT-FEJEJ BASIN
El Hamma
J.Tebaga kebili
20 Km
Anticline axis
Syncline axis
Dextral Strick slip fault
Reverse fault
Normal fault
Trias
Early Cretaceous
Upper Cretaceous
Paleogene
Neogene
Quaternary
C

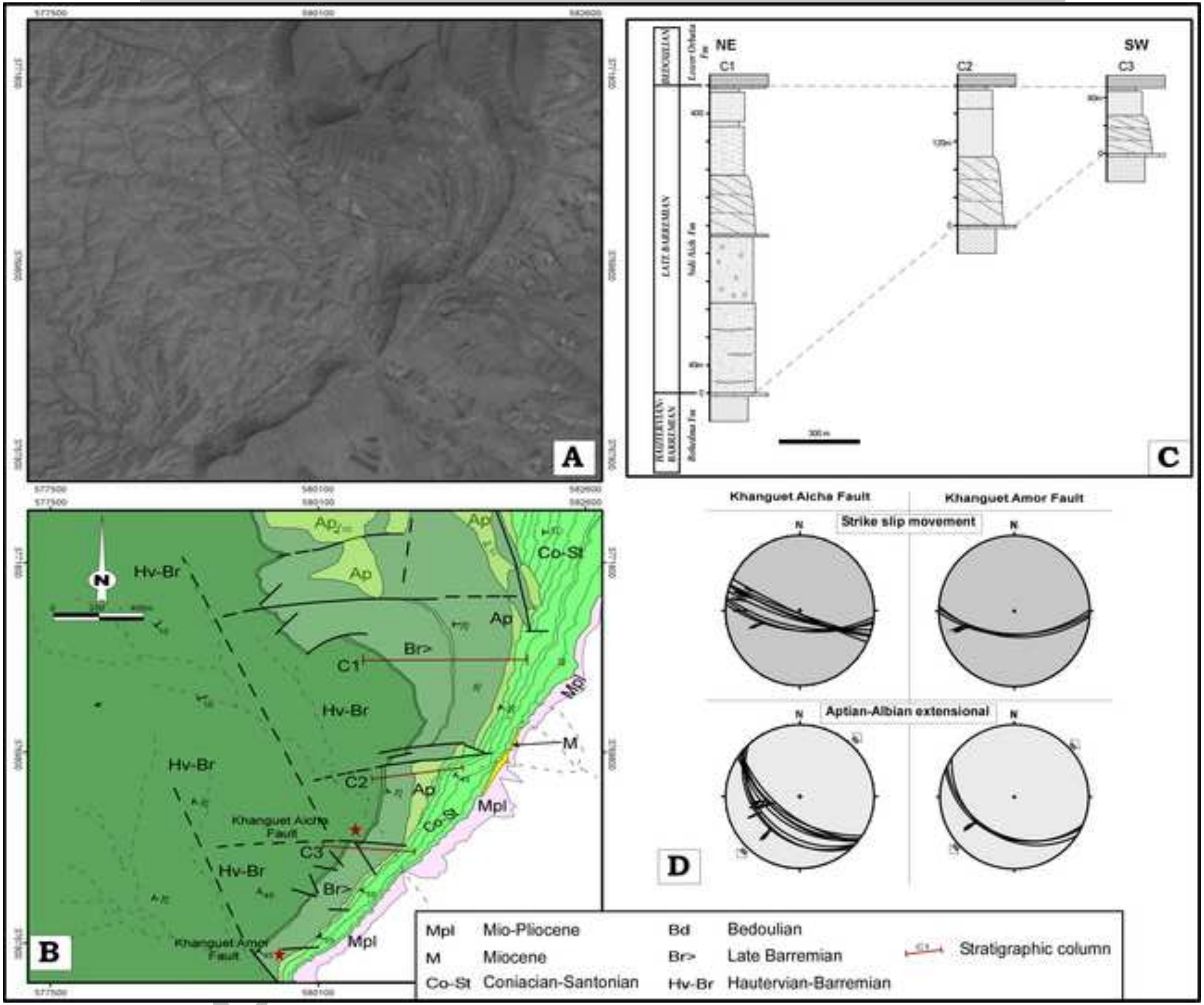


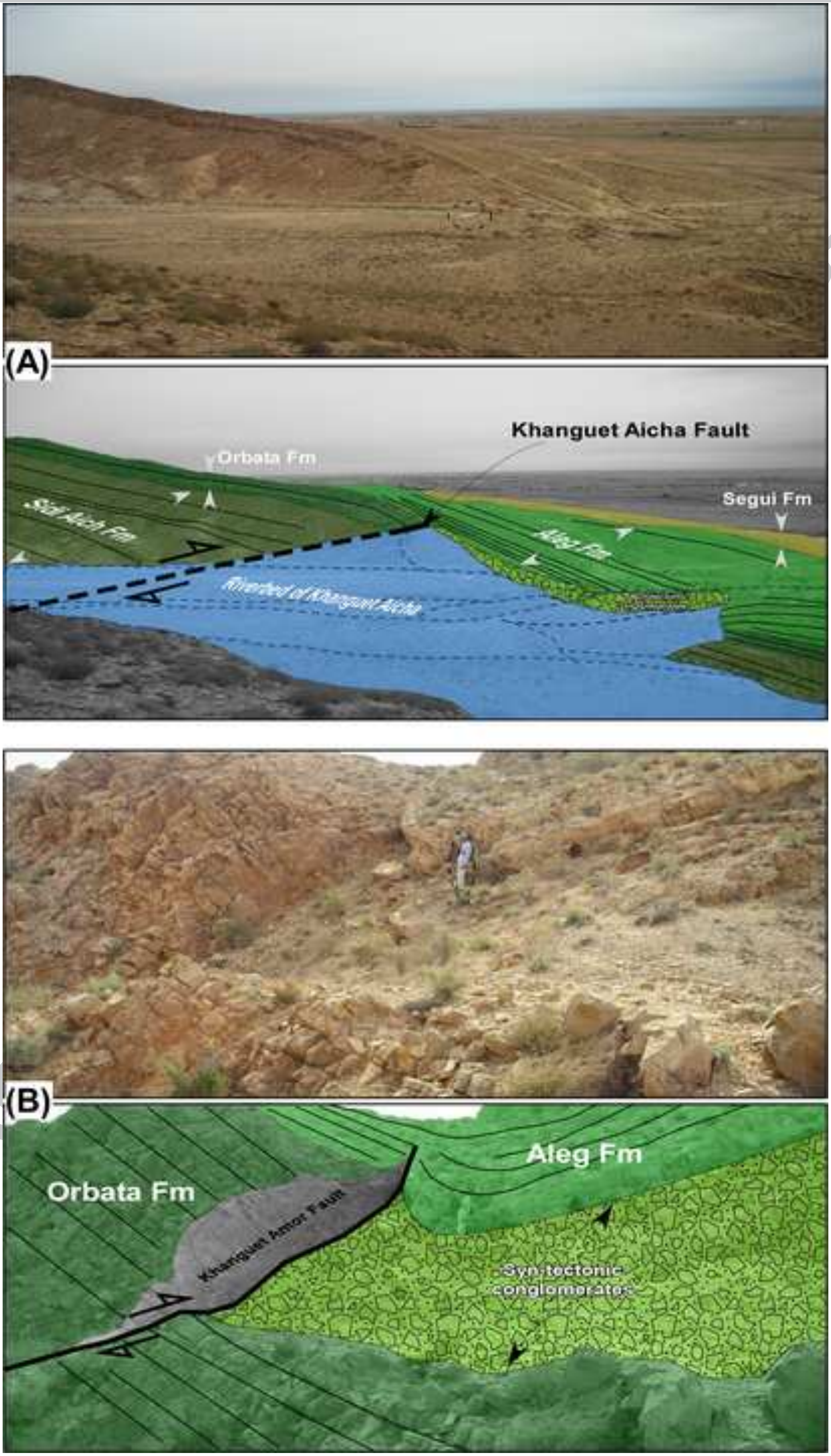
Railway
Road
Interpreted Fault
Reverse fault
Strike-Slip fault
Section A, B and C presented in Fig.4
Panoramic view presented in Fig. 8
Structural interpertation in Fig.5
Mio-Plio-Quaternary (Segui Formation)
Late Miocene (Beglia Formation)
Middle Eocene (Bouloufa Formation)
Late Maastrichian-Paleocene (El Haria Formation)
Campanian-Early Maastraichian (Abiod Formation)
Coniacian-Santonian (Aleg Formation)
Late Albian-Turonian (Zebbag Formation)
Bedoulian (Orbata Formation)
Late Barremian (Sidi Aich Formation)
Hautervian-Barremian (Bouhedma Formation)
8° 30'
8° 40'
0
1000
3000m
N
Gouada Plain
Jebel Romana
A
A'
Jebel Tebaga Fatnassa
Jebel Zemlet el Beidha
khanguet Aicha
Khanguet Amor
Fig5
Fejej Coridor Fault
B
B'
Jebel Haidoudi
Jebel Fejej
Jebel Jerouala
Khanguet Telmem
Gafsa-Gabès Road


Age
Formation
Log
Main tectonic events
Late Pliocene-Quaternary
Segui
Late Miocene
Beglia
Middle Eocene
Bouloufa
Late Maatrichtian Paleocene
El Haria
Late Campanian -Maastrichtian
Abiod
Coniacian -Santonian
Aleg
Cenomanian-Turonian
Upper Zebbag
Late Albian
Zebbag
Early Aptian
Orbata
Late Barremian
Sidi Aïch
Hauterivian-Barremian
Bouhedma
U3
U2
U1
100 m
FORELAND
POST RIFT
SYN RIFT
Limestone
Dolomite
Marle
Clay
Sand
Conglomerate
Gypsum
Normal Fault

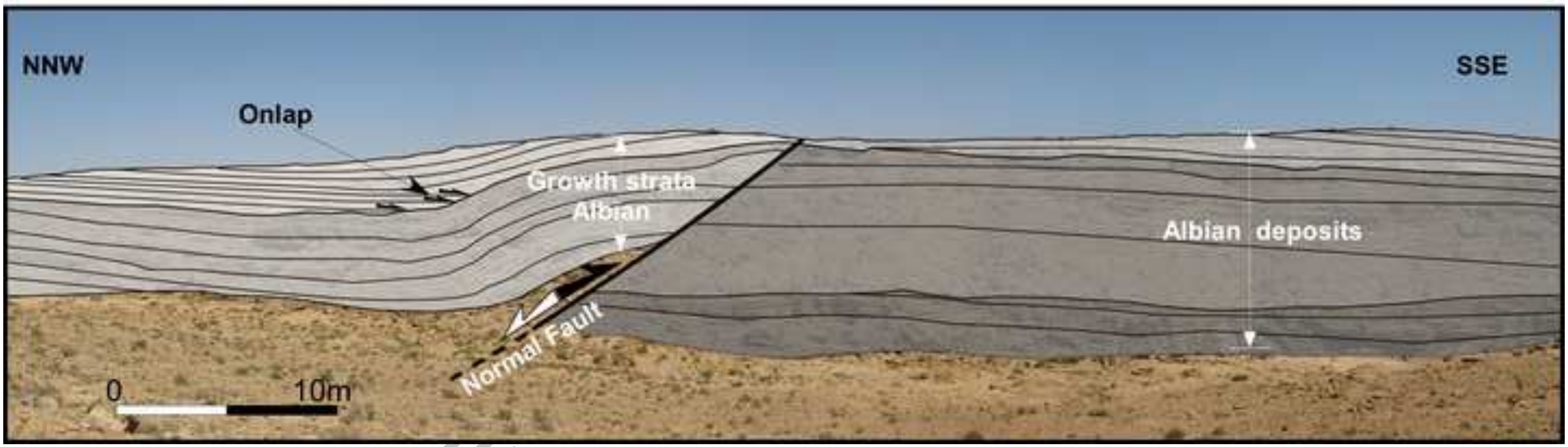


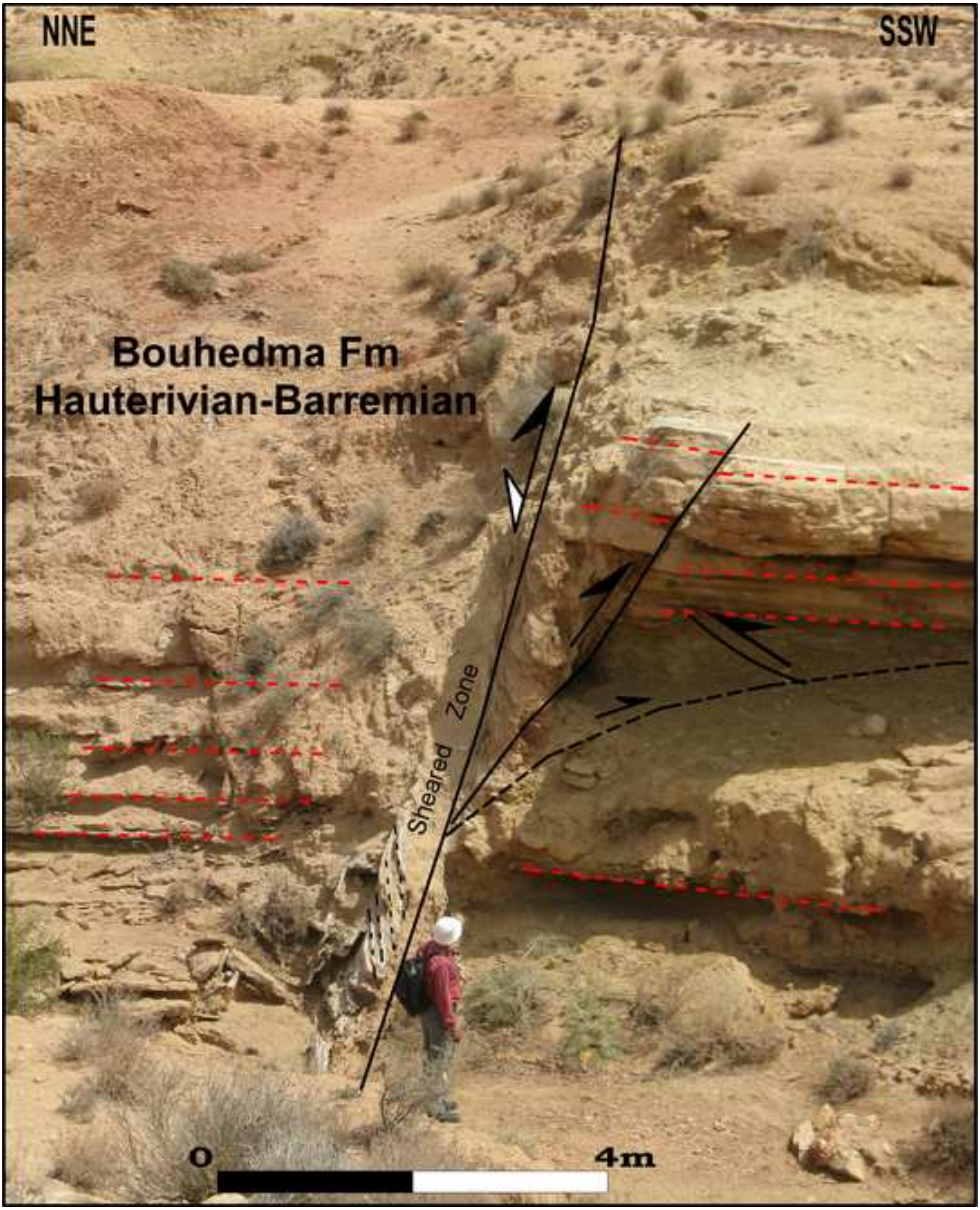
A - A'
NW
SE
East
Tebaga Fatnassa
Oued
ez Zouiai
Unconformity of
the Late Miocene
U2
Unconformity of the
Late Pliocene-Quaternay
on the Coniacian-Santonian
Unconformity of
Late Pliocene-Quaternay
on the Late Miocene
U3
250m
0
?
B - B'
NNW
SSE
The core of
Zemlet el Beidha
J. Jerouala
Unconformity of
tLate Pliocene-Quaternay
U3
Unconformity of the Middle Eocene
on the Late Maastrichian-Paleocene
U1
Fejej Fault
Unconformity of
the Late Miocene
U2
250m
0
?
?
Marls, anhydrites, limestones and claystones
Bouhedma Formation
Bedoulian dolomitic bar
Orbata Formation
Green marls and bioclastic limestones
Aleg Formation
Green clays
El Haria Formation
Sandstones
Beglia Formation
Shale-rich sands and ferruginous sandstones
Sidi Aich Foramtion
Dolomitic and limestones
Formation Zebbag
Limestone and thin clay layers
Abiod Formation
Gypsum clay and encrusted limestone
Bouloufa Formation
Conglomerate deposits
Segui Formation

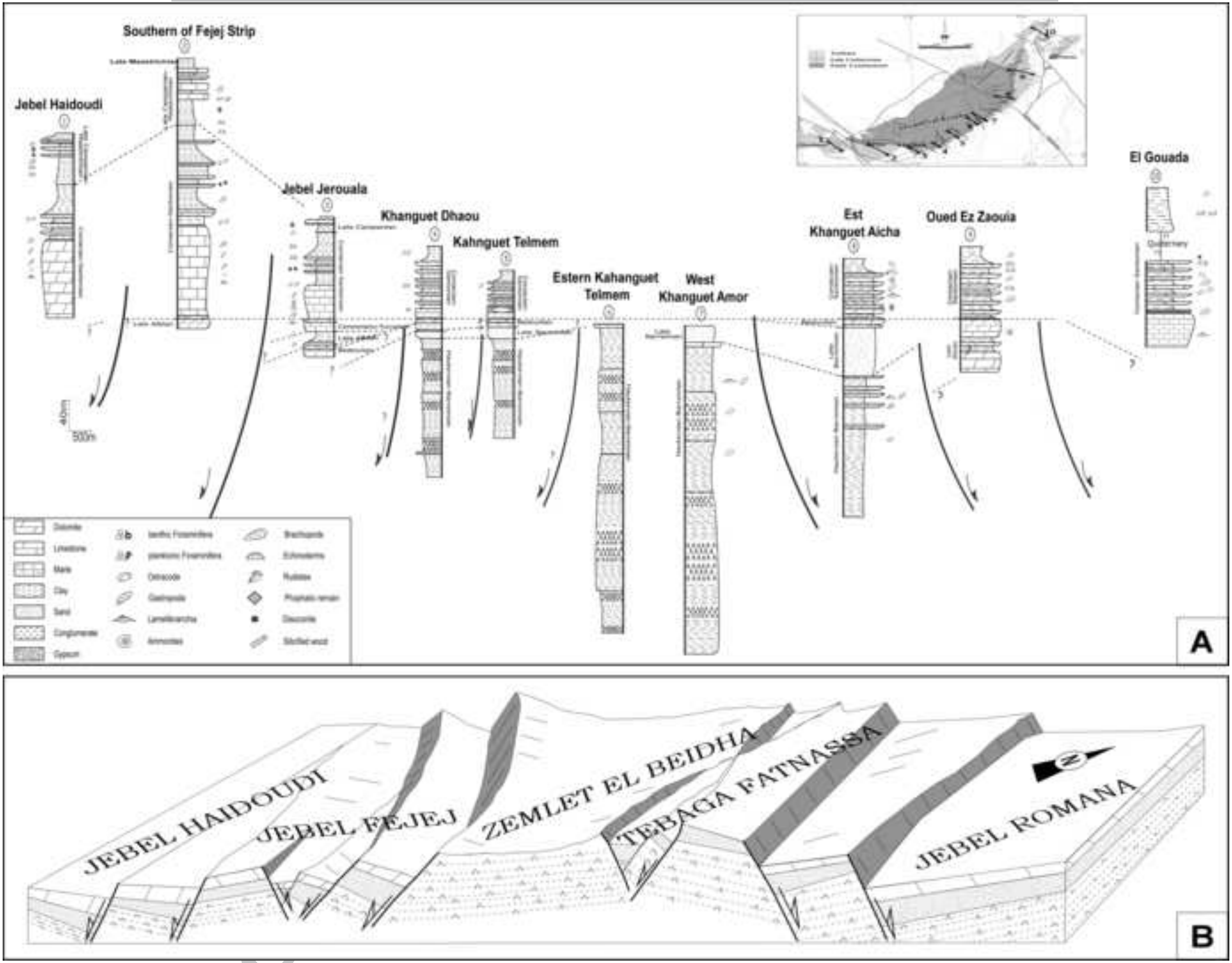

A
B
C
D
NE
SW
C1
C2
C3
Hv-Br
Ap
Br>
Co-St
Mpl
M
Khanguet Aicha Fault
Khanguet Amor Fault
Strike slip movement
Aptian-Albian extensional
N
Mpl Mio-Pliocene
M Miocene
Co-St Coniacian-Santonian
Bd Bedoulian
Br> Late Barremian
Hv-Br Hautervian-Barremian
Stratigraphic column

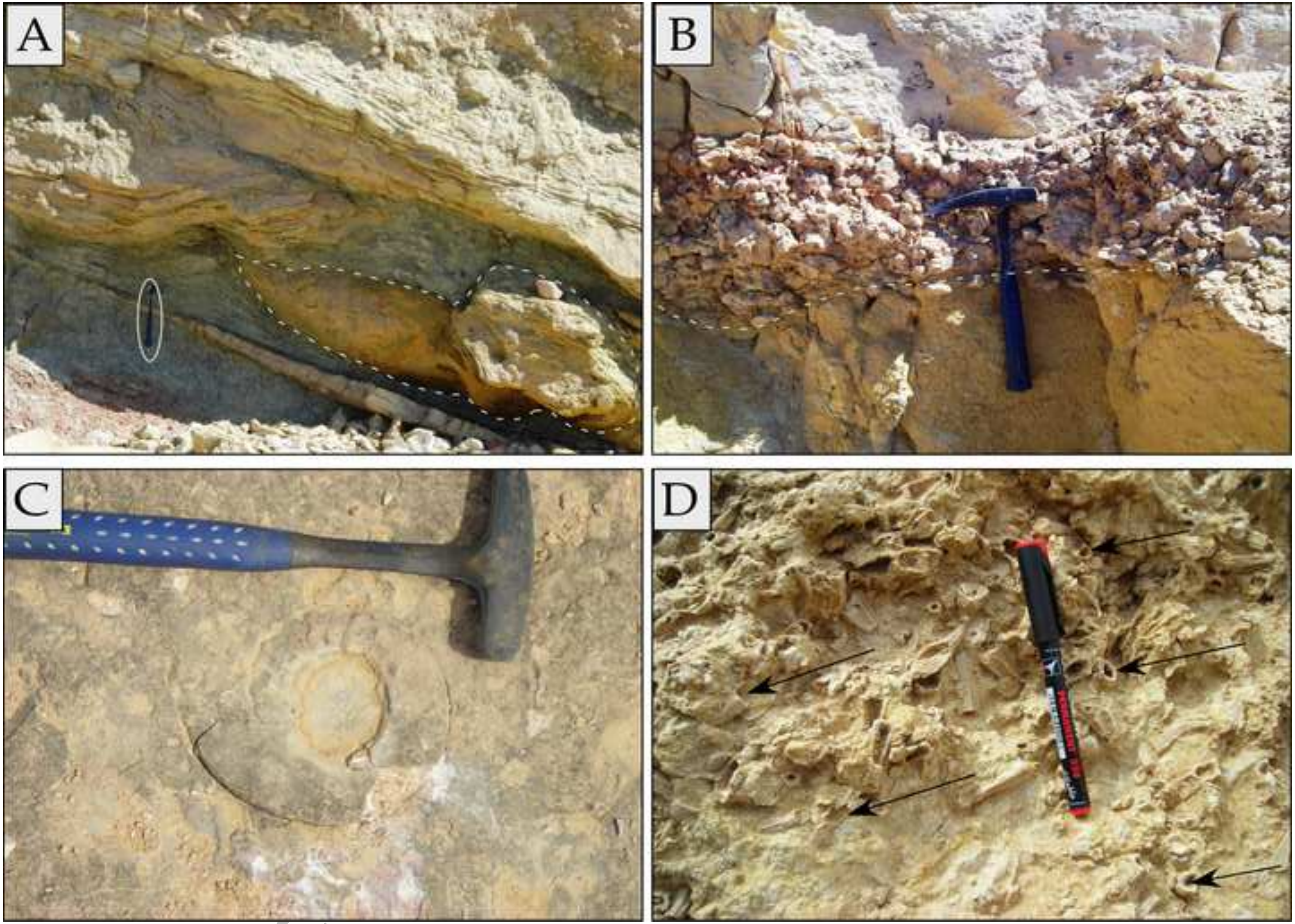

(A)
Khanguet Aicha Fault
Orbata Fm
Sidi Aich Fm
Segui Fm
Aleg Fm
Riverbed of Khanguet Aicha
(B)
Orbata Fm
Aleg Fm
Khanguet Amor Fault
Syn-tectonic conglomerates

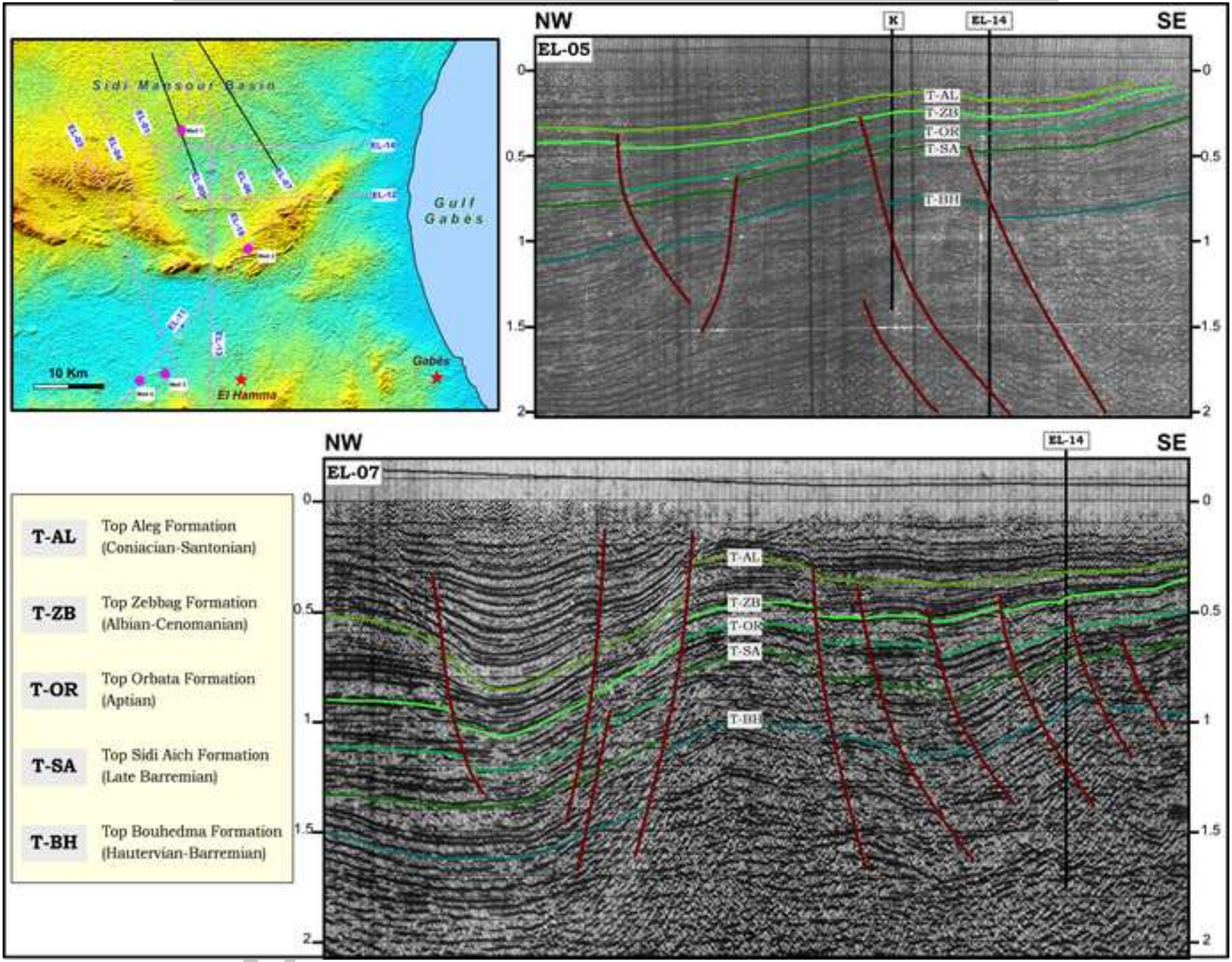

A
B
C
D


NNW
SSE
Onlap
Growth strata
Albian
Albian deposits
Normal Fault
0
10m

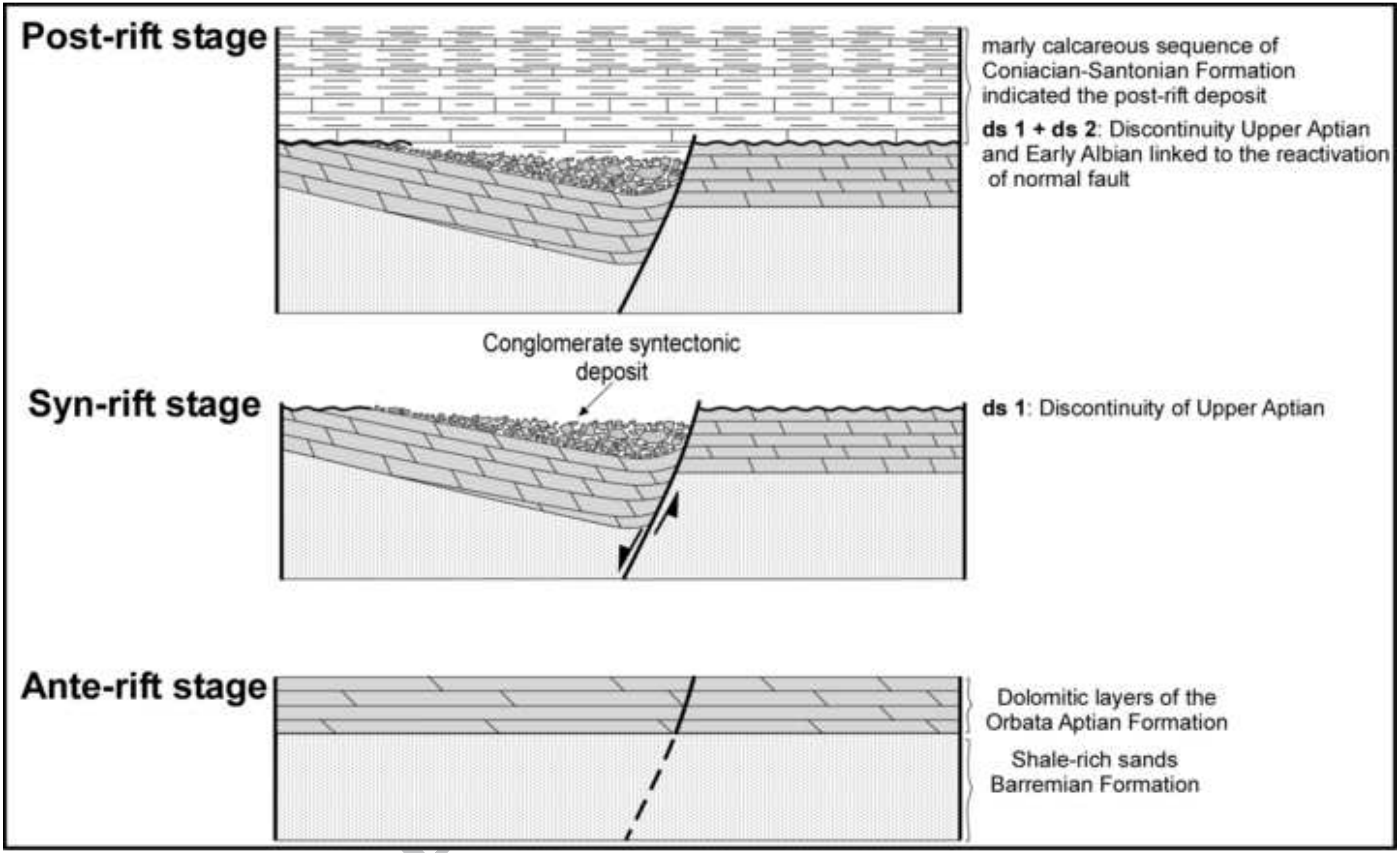

NNE
SSW
Bouhedma Fm
Hauterivian-Barremian
Sheared Zone
0
4m


Southern of Fejej Strip
Jebel Haidoudi
Jebel Jerouala
Khanguet Dhaou
Kahnguet Telmem
Estern Kahanguet Telmem
West Khanguet Amor
Est Khanguet Aicha
Oued Ez Zaouia
El Gouada
A
JEBEL HAIDOUDI
JEBEL FEJEJ
ZEMLET EL BEIDHA
TEBAGA FATNASSA
JEBEL ROMANA
B

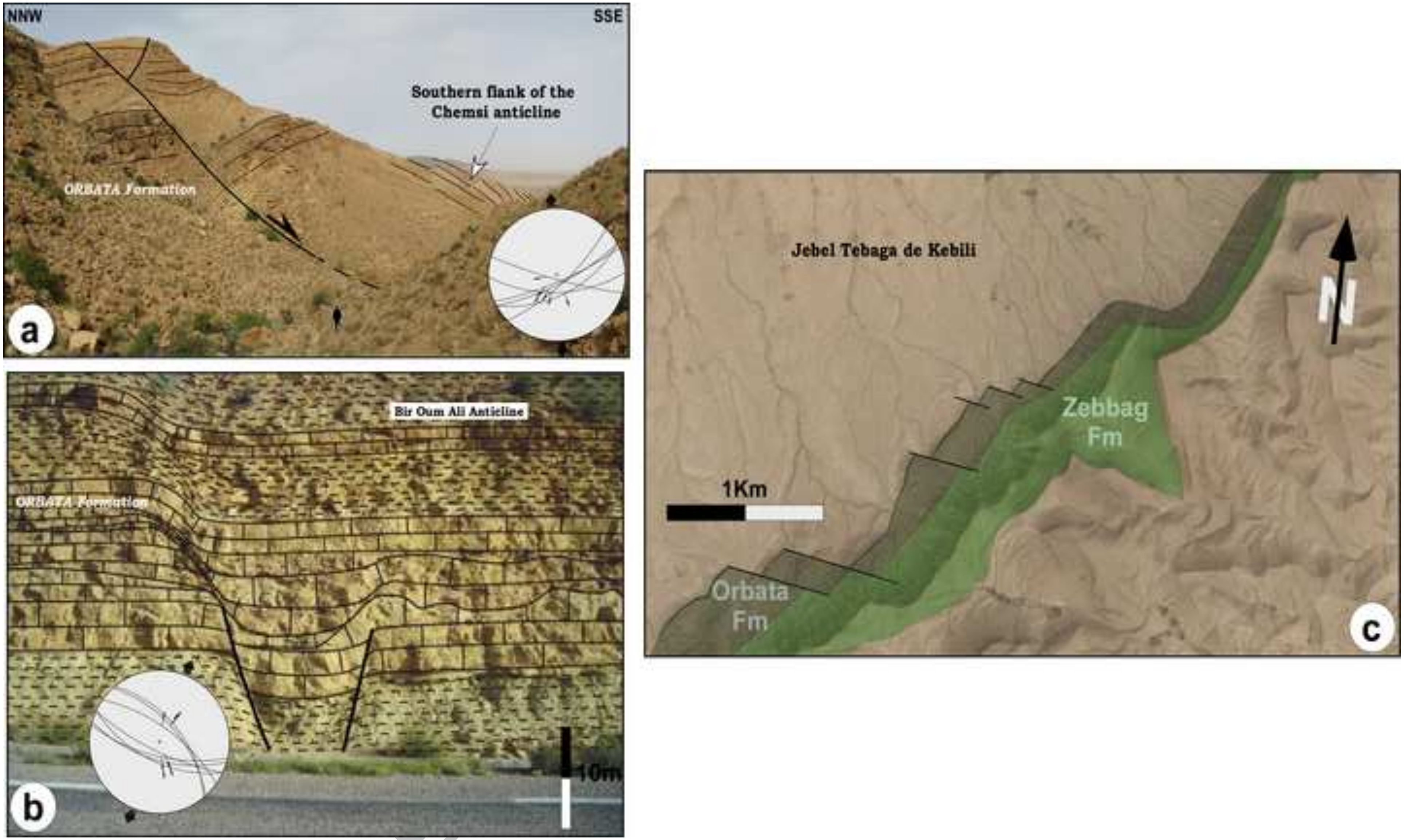

A
B
C
D



NW
SE
K
EL-14
EL-05
T-AL
T-ZB
T-OR
T-SA
T-BH
Sidi Mansour Basin
Gulf Gabès
10 Km
Gabès
El Hamma
EL-07
T-AL Top Aleg Formation (Coniacian-Santonian)
T-ZB Top Zebbag Formation (Albian-Cenomanian)
T-OR Top Orbata Formation (Aptian)
T-SA Top Sidi Aich Formation (Late Barremian)
T-BH Top Bouhedma Formation (Hautervian-Barremian)



Post-rift stage
marly calcareous sequence of Coniacian-Santonian Formation indicated the post-rift deposit
ds 1 + ds 2: Discontinuity Upper Aptian and Early Albian linked to the reactivation of normal fault
Conglomerate syntectonic deposit
Syn-rift stage
ds 1: Discontinuity of Upper Aptian
Ante-rift stage
Dolomitic layers of the Orbata Aptian Formation
Shale-rich sands Barremian Formation


NNW
SSE
Southern flank of the Chemsi anticline
ORBATA Formation
a
Bir Oum Ali Anticline
ORBATA Formation
10m
b
Jebel Tebaga de Kebili
Zebbag Fm
1Km
Orbata Fm
N
c

Locality	Nb	X	Y	Fauna	Age
Jebel Romana-Gouada plain	EH 152	585047	3,775,657	*Echinoderme, Cytherella sp, Cythereis sp, Brachycythere*	Coniacian-Santonian
	EH 153	585000	3,775,593	*Radiole, Cytherella sp, Bairdia sp*	Coniacian-Santonian
	EH 155	584483	3,775,204	*Rotallia, Gavelinella sp, Lenticulina sp.*	Coniacian-Santonian
	EH 156	582497	3,775,659	*Rotallia, Gavelinella sp*	Coniacian-Santonian
	EH 220	584,262	3,774,591	*Brachycythere, Globotruncana fornicata, Bairdia sp.*	Coniacian-Santonian
	EH 221	584,257	3,774,589	*Globotruncana fornicata,Globigerinelloides aspera, Lenticulina.*	Coniacian-Santonian
Tebaga Fatnassa-Oued ez Zouaia	EH 118	580,635	3,774,718	*Ammonites, Cytherella sp, Bairdia sp,*	Coniacian-Santonian
	EH 124	581,839	3,773,088	*Ammonites, Brachycythere, Bairdia sp,*	Coniacian-Santonian
	EH 125	581,752	3,773,090	*Ammonites, Echinodermes, Ostreas, Cytherella sp.*	Coniacian-Santonian
	EH 128	581,199	3,773,404	*Dawinula sp, Cythereis sp*	Late Albian
	EH 130	578,345	3,773,830	*Radiole, Ammonites, Brachycythere.*	
Khanguet Aicha-khanguet Amor	EH 113	579,411	3,770,340	*Cypridea, Cytherella, Choffatella decipiens*	Barremian
	EH 131	577,676	3,768,980	*Fabanella, Cypridea, Choffatella decipiens, Fabenella sp, Perissocytheridea*	Barremian
	EH 173	580,877	3,769,897	*Cythertlia dextrocepematta, Numidica, Cytherella*	Coniacian
	EH 176	580,934	3,769,897	*Echinoderme, Cytherella sp, Cythereis sp, Brachycythere*	Coniacian-Santonian
Jebel Jerouala Khanguet Telmem-khanguet Dhaou	EH 142	571,821	3,766,103	*Rotalia, Protobontomia numidica,Gavelinella sp, Globotruncana lapparenti.*	Coniacian-Santonian
	EH 143	571,841	3,766,101	*Brachycythere, Cytherella.*	Coniacian-Santonian
	EH 145	572,474	3,765,998	*Knemiceras, Darwinula sp, pracypris sp*	Late Albian
	EH 183	573,864	3,765,434	*Cythereis sp, Spiroplectamira sp, Lenticulina sp, Globotruncana arca, Orbitoides.*	Late Campanian
	EH 184	573,956	3,765,399	*Hedbergella sp, Nodosaria sp, Globotruncana fornicata, Pseudotextularia nutalli.*	Late Campanian-Maastrichian
	EH 185	574,019	3,765,358	*Protobontonia sp, Hedbergella, Textularia.*	Coniacian
	EH 226	575,959	3,765,811	*Rudiste.*	Turonian
	EH 196	574,228	3,765,587	*Cytherelle, Radiole, Ostriea*	Coniacian
Jebel Fejej	EH 104	567,146	3,768,270	*Echinoderme, Ammonites*	Coniacian
	EH 107	568,910	3,765,986	*Vaginulopsis sp, Globotruncana arca,*	Late Campanian
	EH 109	568,457	3,766,134	*Globotruncana rugosa, Macrocypris sp, Globotruncana fornicata.*	
	EH 140	570,900	3,765,808	*Echinoderme, Cytherella sp, Cythereis sp, Brachycythere*	Late Campanian-Maastrichian
	EH 142	570,926	3,765,758	*Globotruncana fournicata,Globigerinelloides aspera, Lenticulina.*	
	EH 143	570,999	3,765,737	*Rotallia, Gavelinella sp, Lenticulina sp, Brachycythere.*	Coniacian-Santonian
South Jebel Haidoudi	EH 200	568,491	3,765,622	*Globotruncana, Lenticulina*	Coniacian-Santonian
	EH 201	568,431	3,765,659	*Echinoderme, Cytherella sp, Cythereis sp, Brachycythere*	
	EH 202	568,484	3,765,108	*Hedbergella sp, Globotruncana fornicata, Pseudotextularia nutalli, Vaginulopsis sp.*	Late Campanian-Maastrichian
	EH 207	568,356	3,764,916	*Subbotina triloculinoides, Gavelinella danica, Bairdia sp, Globotruncana fornicata.*	Paleocene?

Highlights:

►We used new data to examine inheritance Cretaceous structure pattern of Atlassic front.

►Most faults were active during Aptian Albian times of rifting stage.

►Lower Cretaceous rifting structure are sealed by Coniacian Santonian post-rift deposits.