Journal of African Earth Sciences 135 (2017) 220–234

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Albian salt-tectonics in Central Tunisia: Evidences for an Atlantic-type passive margin

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ARTICLE INFO

Article history:
Available online 8 September 2017

Keywords:
Albian
Central Tunisia
Salt tectonics
Passive margin

ABSTRACT

Tunisia is part of the south-Tethyan margin, which comprises Triassic evaporites and a thick series of Jurassic and Cretaceous, mainly marine deposits, related to the Tethyan rifting evolution. A survey of various Cretaceous outcrops of central Tunisia (Kasserine-El Kef area), combined with literature descriptions, shows that the style of Albian deformation changes from the proximal (South) to the distal part (North) of the margin. The southern part is dominated by tilted blocks and growth faults, which evolve to the north to turtle-back and roll-over structures. Farther North, deformation is dominated by the extrusion of diapirs and salt walls. Such a distribution of deformation strongly suggests that the whole sedimentary cover glided northward on the Triassic evaporites during Albian times, as described for the Atlantic passive margin or for the Gulf of Mexico. Subsequently, these halokinetic structures have been folded during Alpine compressional tectonics.

1. Introduction

Regions characterized by halokinetic deformations commonly present stratigraphic or structural traps for oil, that make them interesting targets for hydrocarbon exploration, as exemplified by the Gulf of Mexico (Peel et al., 1995), or the Iranian Zagros (Jackson et al., 1990). This triggered intensive studies on salt tectonics and halokinetic deformation mechanics (e.g. Cobbold and Szatmari, 1991; Vendeville and Jackson, 1992a, 1992b; Jackson, 1995; Fort et al., 2004a,b; Brun and Fort, 2004; Hudec and Jackson, 2007), and intensive exploration of salt-bearing passive margins (Mohriak et al., 1995; Hudec and Jackson, 2002; Fort et al., 2004a,b). Most of the well documented margins affected by salt tectonics are known through subsurface imaging (e.g. Brazil: Modica and Brush, 2004; Angola: Spathopoulos, 1996; Marton et al., 2000; Fort et al., 2004a,b; Morocco: Davison, 2005; Hafid et al., 2000, 2008; North Sea: Mohr et al., 2005).

Our recent stratigraphic, sedimentological, and structural observations in Central Tunisia (Dumont et al., 2005; Chihaoui, 2009; Chihaoui et al., 2010; Latil, 2011; Jaillard et al., 2013) indicate that the nature, chronology and spatial distribution of the Cretaceous deformations resemble those observed on present-day Atlantic-type margins. In such margins, synsedimentary deformation is controlled both by gliding of the sedimentary cover upon the basal evaporite layer décollement, and by the related mobilization of the evaporites, which gives rise to tilted blocks, rafts, "turtle back" structures or diapirs (e.g. Spathopoulos, 1996; Brun and Fort, 2011). These observations led us to propose new interpretations of the Cretaceous synsedimentary deformation observed in Tunisia.

2. Geological setting

Tunisia is part of the southern Tethyan passive margin, which is marked by a Triassic-Early Jurassic rifting, a middle Cretaceous extensional tectonic event, and by compressional tectonic events from the Late Cretaceous onwards, that culminated with Tertiary compressional phases related to the Alpine orogeny (Burollet, 1956; Bishop, 1975; Masse et al., 1995; Souquet et al., 1997; Klett, 2001; Bouaziz et al., 2002; Frizon de Lamotte et al., 2011; Ghanmi et al., 2016).

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http://dx.doi.org/10.1016/j.jafrearsci.2017.09.009
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During the Cretaceous, the passive margin of Tunisia is classically divided into three main paleogeographic zones (Fournié and Pacaud, 1973; Zghal and Arnaud-Vanneau, 2005; Soua, 2015) (Fig. 1).

– To the South, the stable, Saharan epicratonic platform was covered by thin, mainly clastic, continental to shallow marine deposits, which are virtually undeformed.
– The Central Tunisian platform was marked by shallow marine, siliciclastic then calcareous deposits. It was bounded to the north by the north Tunisian Basin, and to the South by the Chott depression, which separated the Saharan and Central Tunisian platforms.
– The North Tunisian basin received thick marly deposits during most of the Cretaceous, and is presently folded to form the Tunisian Tell, marked by numerous NE-SW trending folds and thrusts, and by pinched diapirs (Fig. 1).

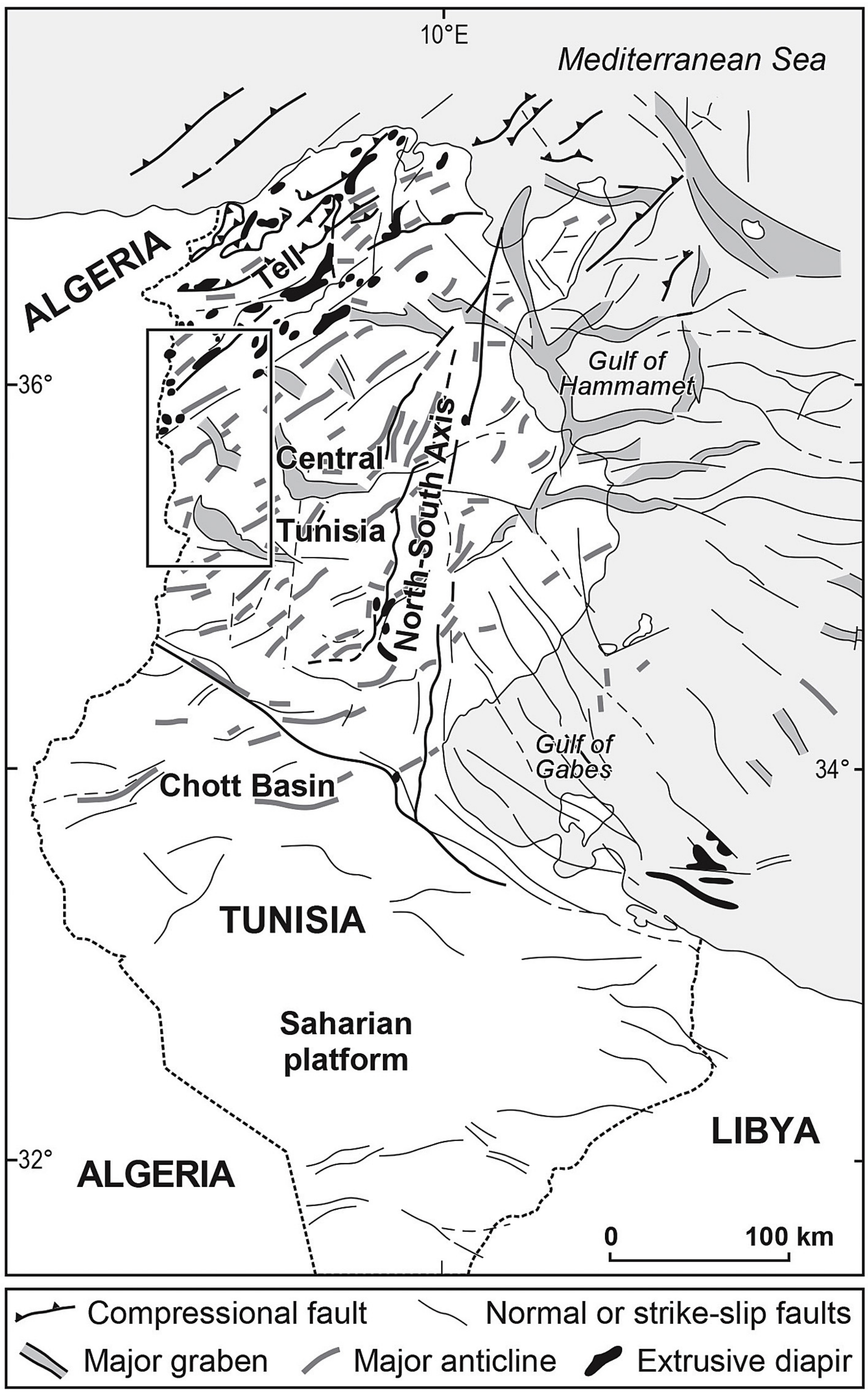

Fig. 1. Structural sketch of Tunisia (from Klett, 2001).

The “Albian tectonic crisis” is a classical feature of the geological evolution of Central Tunisia (e.g. Soyer and Tricart, 1987; Piqué et al., 1998; Zouaghi et al., 2011; Jaillard et al., 2013), which provoked the demise of the carbonate shelf sedimentation, the emergence of Central Tunisia, and the regional unconformity of Late Albian beds upon Jurassic to Early Albian deposits (Burollet, 1956).

Although halokinetic deformations have been described for a long time in Tunisia, and gave way to different interpretations, sometimes controversial (e.g. Perthuisot et al., 1988, 1998; Smati, 1986; Vila et al., 1994, 1995b, 1998, 1996), most of the published papers are mainly based on field work at a local scale (Smati, 1986; Perthuisot et al., 1988, 1998; Vila et al., 1995a,b, 1996, 1998, 1999a; Chikhaoui et al., 1998, 2001, 2002; Ghanmi et al., 2001, 2006; Gharbi et al., 2005, 2013; Masrouhi and Koyi, 2012; Masrouhi et al., 2013, 2014; Zouaghi et al., 2013; Ayed-Khaled et al., 2015). Some papers, however, attempt to synthetize the location and chronology of diapir ascents, mainly based on subsurface data (e.g. Burollet, 1973; Boukadi and Bedir, 1996; Hlaiem, 1999; Zouaghi et al., 2005, 2009). According to the latter, diapir movements were associated with extensional regimes from Late Triassic to Early Cretaceous times, and with compressional phases during the Eocene, and Miocene to Quaternary periods. However, poor chronological data usually make the results of these analyses inaccurate. According to some authors, halokinetic deformation is responsible for most of the structures presently observed in these areas, and diapirs would have cropped out as early as the Aptian. For other workers, the observed evaporite-related structures result from polyphased deformations, which include Mesozoic extensional tectonics, and superimposed contractional Tertiary deformations (Perthuisot et al., 1988, 1999; Chikhaoui et al., 2002; Ghanmi et al., 2016).

Here, we present the Middle Cretaceous deformational history and structure of several massifs that we studied (El Hamra, Bou el Haneche, Slata, Hameima), as well as some relevant areas studied by other authors (Mrhila, Sidi Embarka, Nebeur, Fig. 2), defining a grossly South-North transect of the Cretaceous South Tethyan passive margin at the platform to basin transition.

3. Stratigraphic outline

The Aptian-Albian stratigraphic nomenclature of Central Tunisia has been established by Burollet (1956) and refined by more recent workers (Bismuth, 1973; Bismuth et al., 1981, 1982; M'Rabet, 1981; M'Rabet et al., 1995; Zghal, 1994; Zghal et al., 1997; Jaillard et al., 2005; Robaszynski et al., 2008; Chihaoui et al., 2010; Latil, 2011; Soua, 2015). According to these works, the following nomenclature will be adopted.

The Late Aptian Serdj Formation is composed of massive limestones and dolostones. Where present, the marls, limestones and sandstones of the Hameima Formation overly the Serdj Formation, usually in conformable contact. The recorded ammonite fauna indicates an earliest Albian age for the Hameima Formation (Latil, 2011).

The Fahdene Formation is mostly made of shaly marls. It can be divided, from base to top (Burollet, 1956), into the Lower Shales, the Allam Limestones, the Middle Shales, the Mouelha Limestones, and the Upper Shales (Fig. 3). According to Chihaoui et al. (2010) and Latil (2011), the Early Albian Allam Limestones and the Late Albian Middle Shales are separated by a long-lasting hiatus that spend the Middle Albian and part of the Late Albian.

Farther South, in jebel El Hamra, El Euchi (1993) defined an “intermediate series”, which overlies the Serdj Formation and is overlain by the Fahdene Formation (Fig. 3). The “intermediate series” can be divided into 5 sedimentary sequences (Chihaoui, 2009), which can be precisely correlated with the series of the Tajerouine area (Latil, 2011). It is separated from the Late Albian Fahdene Formation by a major hiatus that encompasses the Middle Albian and part of the Late Albian (Fig. 3).

These biostratigraphic studies made possible the statement of a detailed chronology of the synsedimentary deformations observed in Central Tunisia (Jaillard et al., 2013).

4. Structure of some outcrops of Central Tunisia

4.1. Jebel El Hamra (Fig. 4 et 5)

The Jebel El Hamra has been studied by El Euchi (1993), Vila et al. (2001), Dumont et al. (2005), Chihaoui (2009), and Bejaoui et al. (2013), and is made of Aptian dolomites (Serdj Fm), overlain by Albian-Cenomanian limestone and shales. It is a NNE-trending anticline, the axis of which shows a plunge to the SSW (Fig. 4). A few kilometers to the NNW, a diapir of Triassic evaporites (Hir Adjerat Souda) intrudes Albian-Turonian deposits and is unconformably overlain by Miocene deposits (Vila et al., 2001). Jebel El Hamra is divided into three blocks by E-W to WNW-trending, normal faults (Fig. 4), probably related to the growth of the aforementioned diapir.

Detailed study of the Jebel Hamra anticline shows that NNW-trending normal faults crosscut the Aptian dolomites, creating half-grabens where Early Albian deposits are preserved (Intermediate Unit of El Euchi, 1993), and are sealed by the Late Albian shales (Fahdene Fm, Dumont et al., 2005; Jaillard et al., 2013). These Early Albian faults express a NE-SW to ENE-WSW extensional strain (Dumont et al., 2005, Fig. 5), which is responsible for hectometer scale tilted blocks. Although difficult to demonstrate, these faults may be coeval with an early stage of halokinetic activity (Vila et al., 2001).

4.2. Jebels Mrhila and Douleb (Figs. 6 and 7)

The Jebel Mrhila is a large, NE-to NNE-trending anticline that crops out Northeast of Sbeitla (Figs. 2 and 6). It has been studied by Zghal (1994), Zghal et al. (1996, 1998), Touir et al. (1989), Touir and Zaghbib-Turki (2004) and partly by Soua (2015). West of the Jebel Mrhila, the jebels Douleb and Tioucha are ENE-trending anticlines (Figs. 2 and 6). The Jebel Semmama is a classical section of the Early to Mid-Cretaceous succession of Central Tunisia (Bismuth, 1973; Bismuth et al., 1981, 1982), while the coeval series of the Jebel Douleb - Tioucha is only known through well log samples (DL 101 in Figs. 6 and 7) (Burollet, 1956; Zghal, 1994; Zouaghi et al., 2011). Another well log has been drilled and studied (Zghal, 1994) at Bled el Gouna, between Jebel Tioucha and Jebel Mrhila (BEG 1, Fig. 6).

Comparisons of these sections unravel important thickness variations. The northern tip of the Jebel Mrhila is marked by an E-W trending normal fault that separates a 1500 m thick Albian series to the North, from a reduced, 30 m thick, coeval series to the South (Fig. 7). Zghal et al. (1998) demonstrated that the kilometer-scale offset of this fault is mostly of Early to Middle Albian age, and is sealed by the Late Albian *p.p.* Such an important thickness variation in such a short distance has been interpreted as the result of the offset of a major extensional fault active during most of the Albian (Zghal et al., 1998, Fig. 7). Similar thickness variations have been observed between wells DL 101 and BEG 1, separated from each other by about 20 km (Figs. 6 and 7).

Very few breccias, erosional structures or gravity slidings have been reported (Zghal et al., 1996, 1998), thus suggesting that the offset of this fault was smooth, slow and progressive. This is consistent with a thin-skinned deformation, continuously accommodated downward along a flat décollement level. Therefore, we propose that, rather than a simple normal fault, this structure is

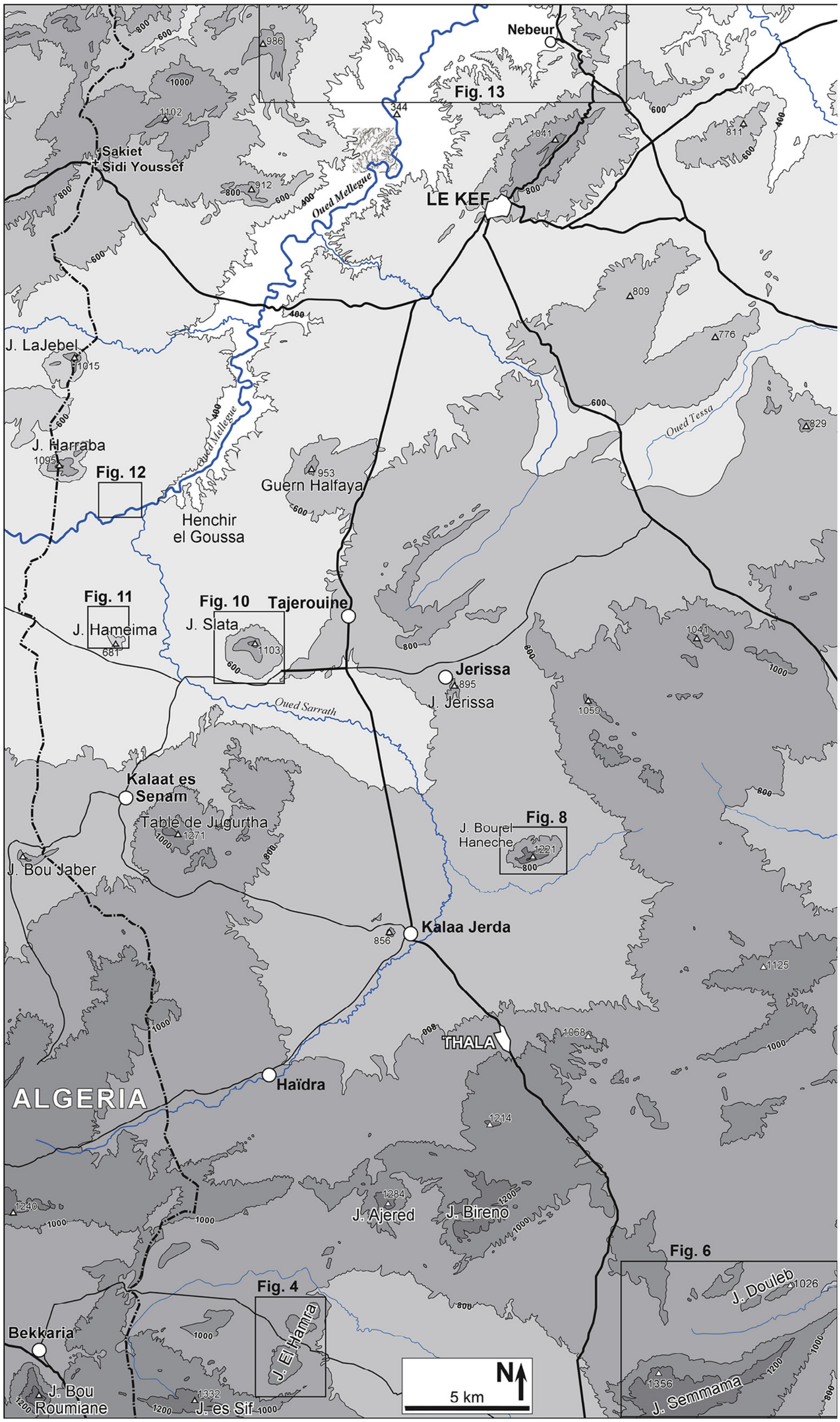

Fig. 2. Location map of the studied areas. Location on Fig. 1.

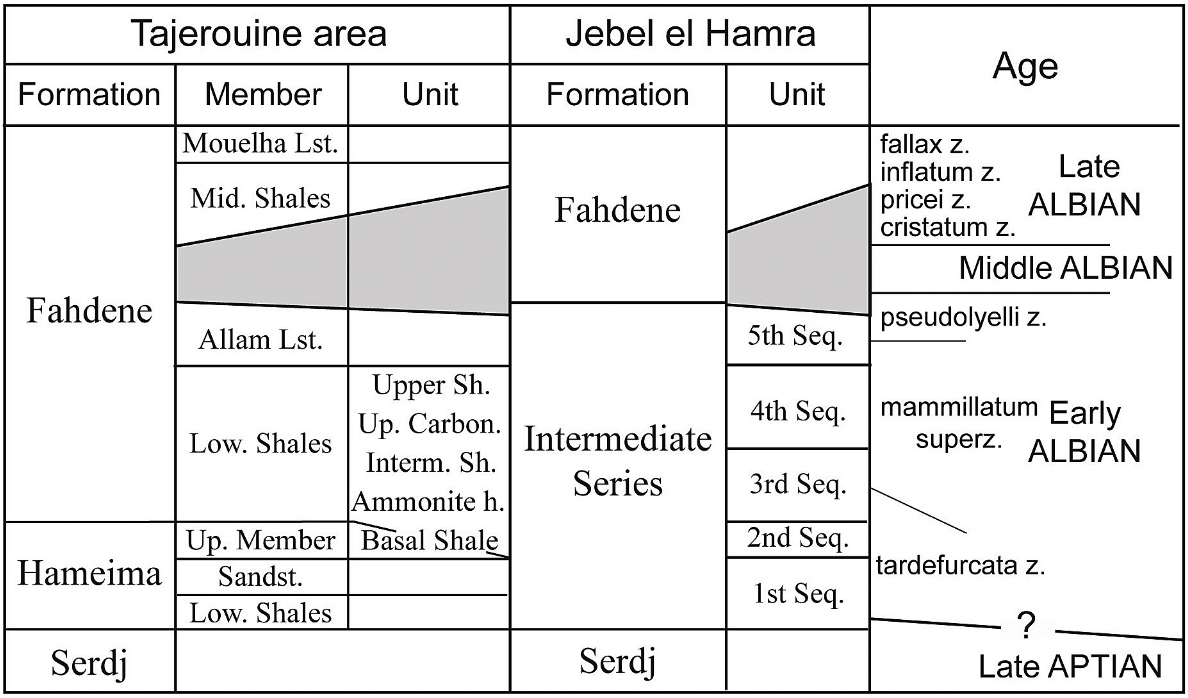

Fig. 3. Stratigraphy of the Tajerouine area (Chihaoui et al., 2010; Latil, 2011).

related to the “raft tectonics”, as described by Burollet (1975) on the Angola margin, on top of a salt layer (see also Jackson, 1995; Rouby et al., 2002; Brun and Mauduit, 2008). In this interpretation, the sliding of the fragmented cover (rafts) on a ductile evaporite layer creates extensional grabens or half-grabens, within which thick sedimentary piles can accumulate (BEG 1, Koudiat el Beida, Fig. 7), while the shoulders of the graben receive much thinner deposits (DL 101, Sidi Sifi, in Fig. 7).

4.3. Jebel Bou el Haneche (Fig. 8)

Jebel Bou el Haneche is located SE of Tajerouine. It resembles a half dome, limited to the South by a major, E-W trending normal fault (Figs. 2 and 8). The core of the dome is made of Aptian limestones and dolomites (Serdj Fm), while the upper surface of the dome is constituted by marls, limestones and sandstones of earliest Albian age (Hameima Fm). Early and Late Albian marls and shales (Fahden Fm) crop out around this structure (see Chihaoui et al., 2010; Latil, 2011 for stratigraphic details).

The half dome is crosscut by NW-SE trending normal faults. To the South, these faults bound a NNW trending graben (Jaillard et al., 2013). Farther North, the eastern fault vanishes, whereas the western, major fault separates a north-eastern domain with thick sedimentation, from a southwestern compartment with much thinner deposits. Since the thickness of both the Early and Late Albian deposits are different on either sides of the fault, the latter must have been active since the beginning of the Early Albian, although the Late Albian deposits show the maximum thickness difference. The NW-trend of this fault supports the occurrence of a NE-SW extensional regime during Albian times (Soyer and Tricart, 1987; Bouaziz et al., 2002; Ouali, 2007; Jaillard et al., 2013). Because this main fault crosscut the Late Albian strata, it either was active until Late Albian or younger times, or has been reactivated during subsequent deformations, as suggested by the opposite offset of Early and Late Albian strata (Fig. 8). This cartographic pattern is very similar to cross sections of roll over structures known on evaporite floored passive margins, and illustrated by numerous authors (Burollet, 1975; Rouby et al., 2002; Hudec and Jackson, 2004; Brun and Mauduit, 2008). Therefore, as for the faults of jebels Mrhila and Douleb, this structure is interpreted as a rollover structure related to the gliding, during the Albian, of the Cretaceous sedimentary cover on an evaporite layer.

4.4. Jebel Slata (Figs. 9 and 10)

Jebel Slata is located west of the village of Tajerouine, and exhibits a triangular shape, with two arms, of E-W and N-S direction, respectively (Figs. 2 and 10). It has been extensively studied and gave way to contradictory interpretations. Smati (1986), Perthuisot et al. (1988, 1998a,b), Rouvier et al. (1998) and Inoubli et al. (2006) proposed that the present structure is mainly inherited from an original “shirt collar”-shaped fold created in Mid Cretaceous times by the extrusion of a Triassic diapir located SW of the Jebel Slata (Fig. 9). In this interpretation, the tips of the western and southern arms are made of inverted series.

Conversely, Vila et al. (1994, 1995a, 1996, 1999a,b) and Ghanmi et al. (2001) proposed that most of the diapiric structures of the Tajerouine area represent salt glaciers, extruded on the sea floor during the Albian, and that no inverted series are visible in Jebel Slata. However, all these workers agree that the Late Albian marls were deposited in strong angular unconformity on Early Albian to Late Aptian rocks.

Using the stratigraphic framework of Chihaoui et al. (2010), we drew a new geological map of the structure (Fig. 10). This survey allowed us to find various identifiable ammonites, which demonstrated that the southern limb of Jebel Slata is constituted by a West-dipping inverted series, so that the Late Aptian Serdj Formation rests upon the earliest Albian Hameima Formation. Similarly, the western arm of the Jebel Slata is made of a Northeast trending fold, the upper limb of which is a South-dipping, inverted series of Late Aptian and earliest Albian age. These observations confirm the interpretation of Perthuisot et al. (1988, 1998a,b).

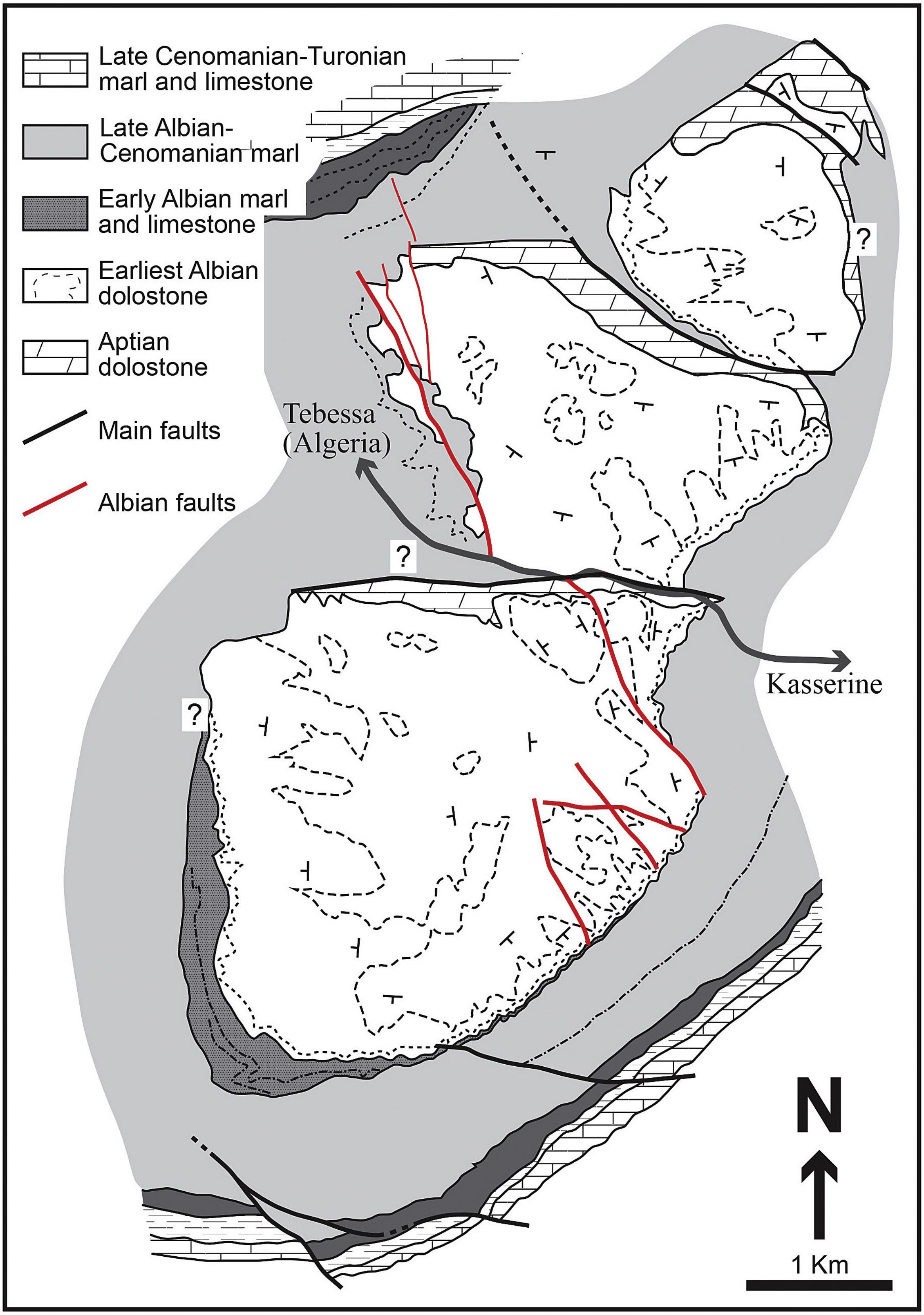

Fig. 4. Geological map of Jebel El Hamra (after Vila et al., 2001; Dumont et al., 2005; simplified).

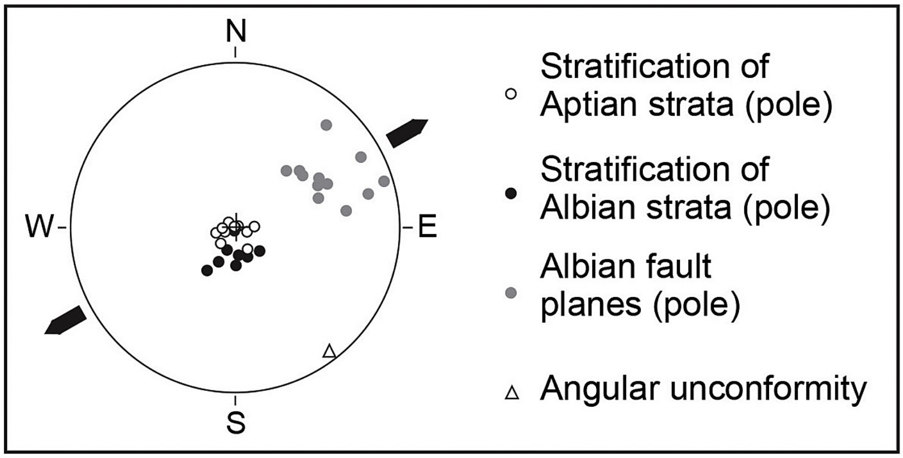

Fig. 5. Structural data for the Early Albian deformation in Jebel El Hamra (after Dumont et al., 2005).

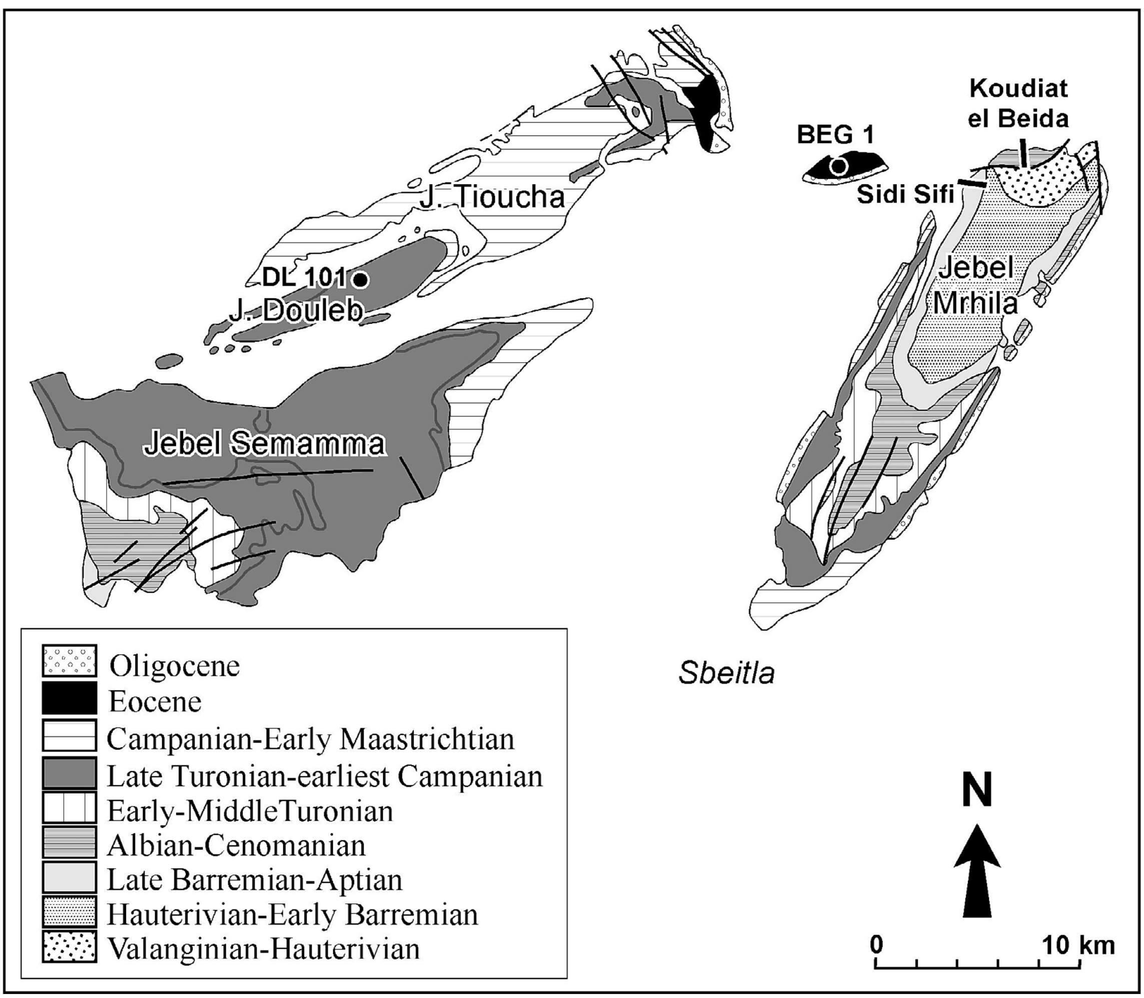

Fig. 6. Simplified geological maps of jebels Semmama, Douleb-Tioucha and Mrhila (Zghal et al., 1998). DL 101: Douleb 101 well, BEG 1: Bled el Gouna 1 well.

Because only mild tectonic deformation have been observed in the Early Albian succession (Jaillard et al., 2013), and because the structure is postdated by Late Albian deposits, the extrusion of the diapir must have occurred during the Middle Albian. This interpretation is further supported by the local occurrence of reworked dolomitic clasts, of probable Triassic age, at the base of the Late Albian, unconformable transgressive beds.

The shape of the basal surface of the Late Albian deposits is a well-defined, Northeast trending and Northeast-ward plunging anticline, which is, therefore, of post-Albian age. According to Smati (1986) this fold is of Miocene to Late Quaternary age (Atlasic folding phase). The restoration of a subhorizontal Late Albian basal surface

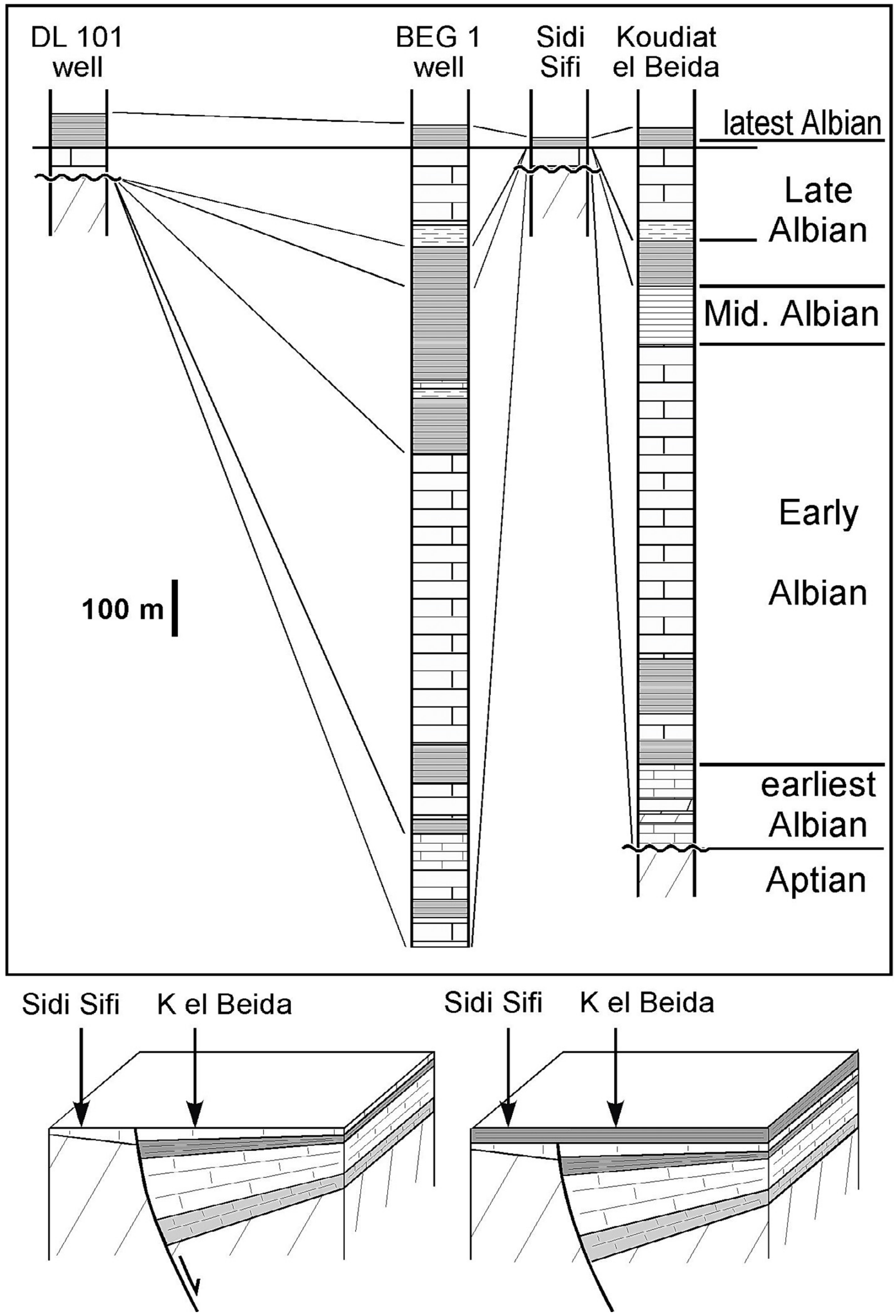

Fig. 7. Stratigraphic sections and wells of the jebels Douleb and Mrhila (adapted from Zghal et al., 1998). Location on Fig. 6.

evidences that the original fold related to the extrusion of the diapir was grossly orientated NW-SE, thus defining a "salt wall", and that the subsequent Atlasic folding gave its present-day structure to Jebel Slata. In this interpretation, the original fold axis related to the diapir intrusion was orientated NW-SE and was subsequently deformed by the NE-trending Atlasic fold. The present-day structure of Jebel Slata results, therefore, from a polyphased tectonic history.

4.5. *Jebel Hameima (Fig. 11)*

The Hameima Massif constitutes the base of the classical section of the Albian Hameima and Fahdene formations (Pervinquière, 1907; Dubourdieu, 1956; Burollet, 1956; Zghal, 1994; Zghal et al., 1997; Chihaoui et al., 2010; Latil, 2011). Like Jebel Slata, it belongs to the NE trending Atlasic fold system (Inoubli et al., 2006) (Fig. 2). It is crosscut by NW trending faults, and is marked by spectacular mineralised veins and karstic caves (Pb, Zn, Fe) that have been formerly exploited on a small scale.

According to Dumont et al. (2005), the NW trending normal faults that crosscut the Aptian carbonates of the Hameima Jebel are of Late Aptian age (Serdj Fm), provoked the karstification of the Serdj Formation, and defined tilted blocks sealed by the Early Albian Hameima Formation. However, our recent observations show that the stratal deep of the Aptian deposits are not significantly different from those of the Albian strata (Fig. 11). Therefore,

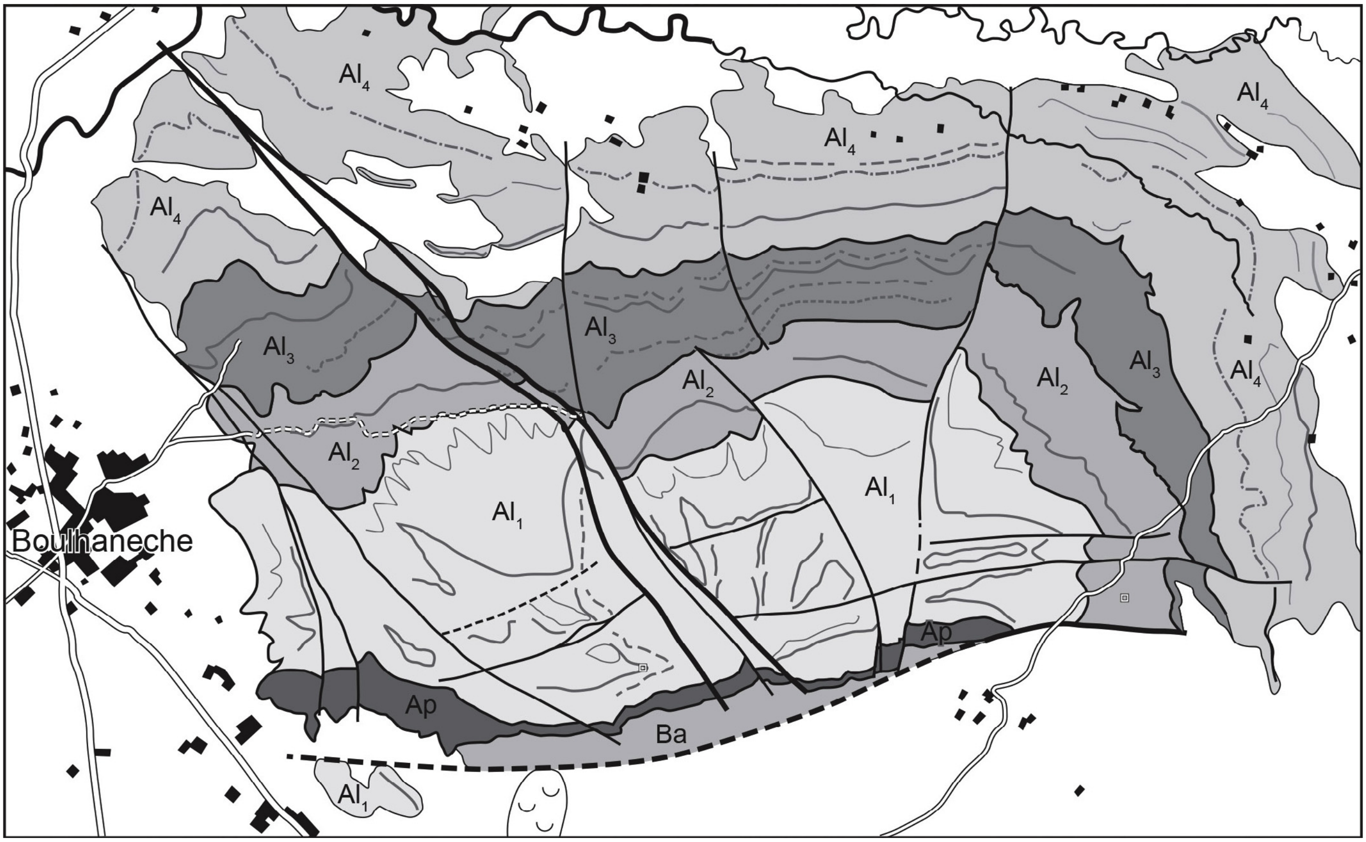

Fig. 8. Simplified geological map of Jebel Boulhaneche. Ba: Barremian, Ap: Aptian; Al_1: Earliest Albian (Hameima Fm), Al_2: Early Albian (Fahdene Fm, Lower Shales), Al_3: Early to Middle Albian (Fahdene Fm, Allam unit), Al_4: Late Albian (Fahdene Fm, Middle Shales).

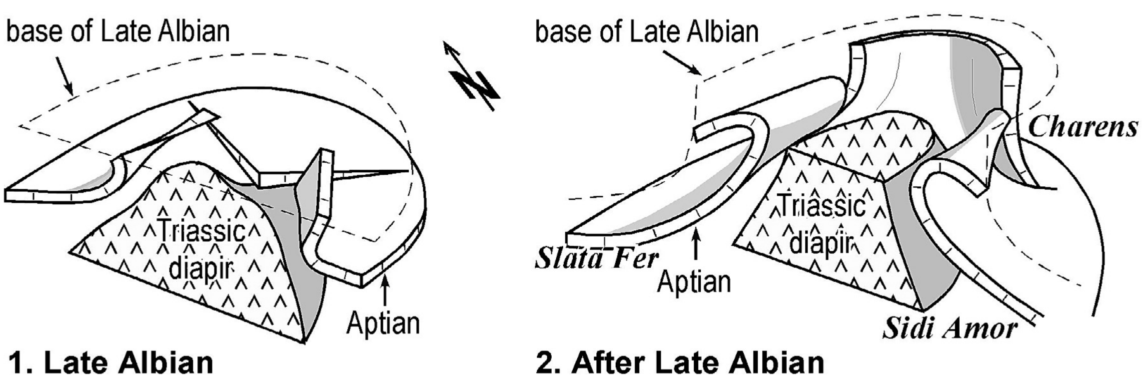

Fig. 9. Structural evolution of the Jebel Slata, according to Perthuisot et al. (1988).

no Albian unconformity is evidenced. Moreover, as already noted by Dubourdieu (1956), the main normal fault crosscuts the Early Albian strata, and probably the overlying Early to Late Albian deposits (Fig. 11). Finally, the mineralised veins are mostly vertical, and thus, are subsequent to the tilting of the Hameima massif. Therefore, the main offset of this fault is clearly of post-Early Albian age.

4.6. *Sidi Embarka area (Fig. 12)*

The Sidi Embarka area (Figs. 2 and 12) has been described by Dubourdieu (1956), Vila et al. (1996) and Jaillard et al. (2013). There, earliest Albian deposits are slightly unconformable on the Aptian dolomites, and Early Albian strata are deformed by the intrusion of Triassic evaporites, whereas Late Albian sediments seal this halokinetic deformation.

4.7. *Henchir el Goussa and Guern Halfaya areas*

In the Henchir El Goussa area (Fig. 2) earliest Albian times are marked by metric to pluridecametric slumps, which induce local, progressive unconformities. No exotic reworked blocks are observed. Conversely, in the Guern Halfaya area, olistoliths of earliest Albian age are redeposited in late Early Albian strata, and demonstrate that more than 300 m of sediments were locally removed (Jaillard et al., 2013). This observation suggests that

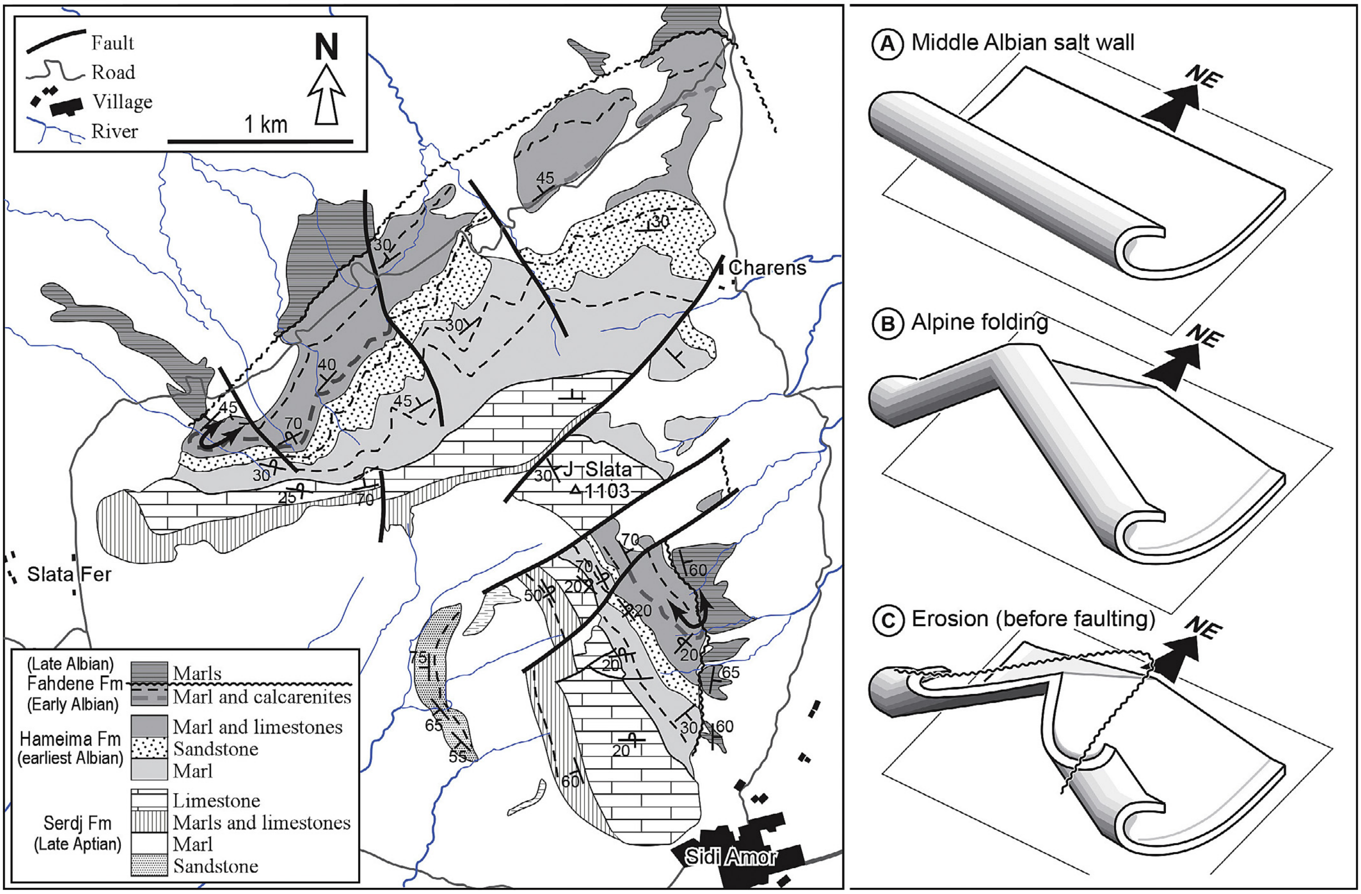

Fig. 10. Simplified geological map of the Jebel Slata (left), and proposed structural interpretation (right).

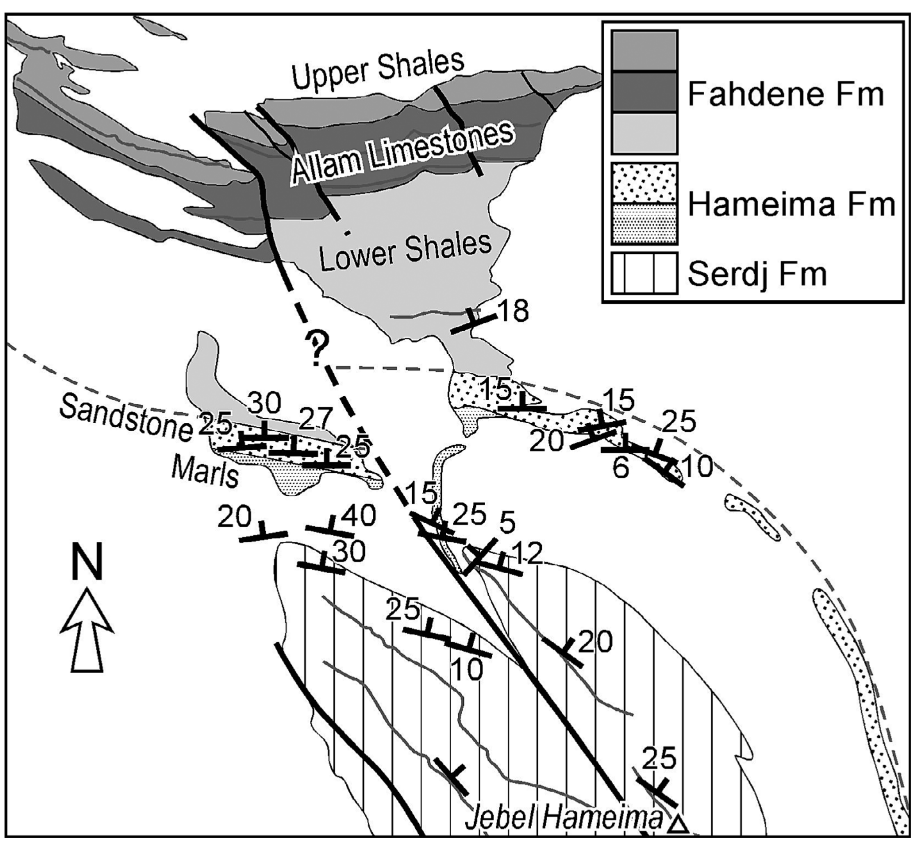

Fig. 11. Simplified geological map of Jebel Hameima (location on Fig. 2).

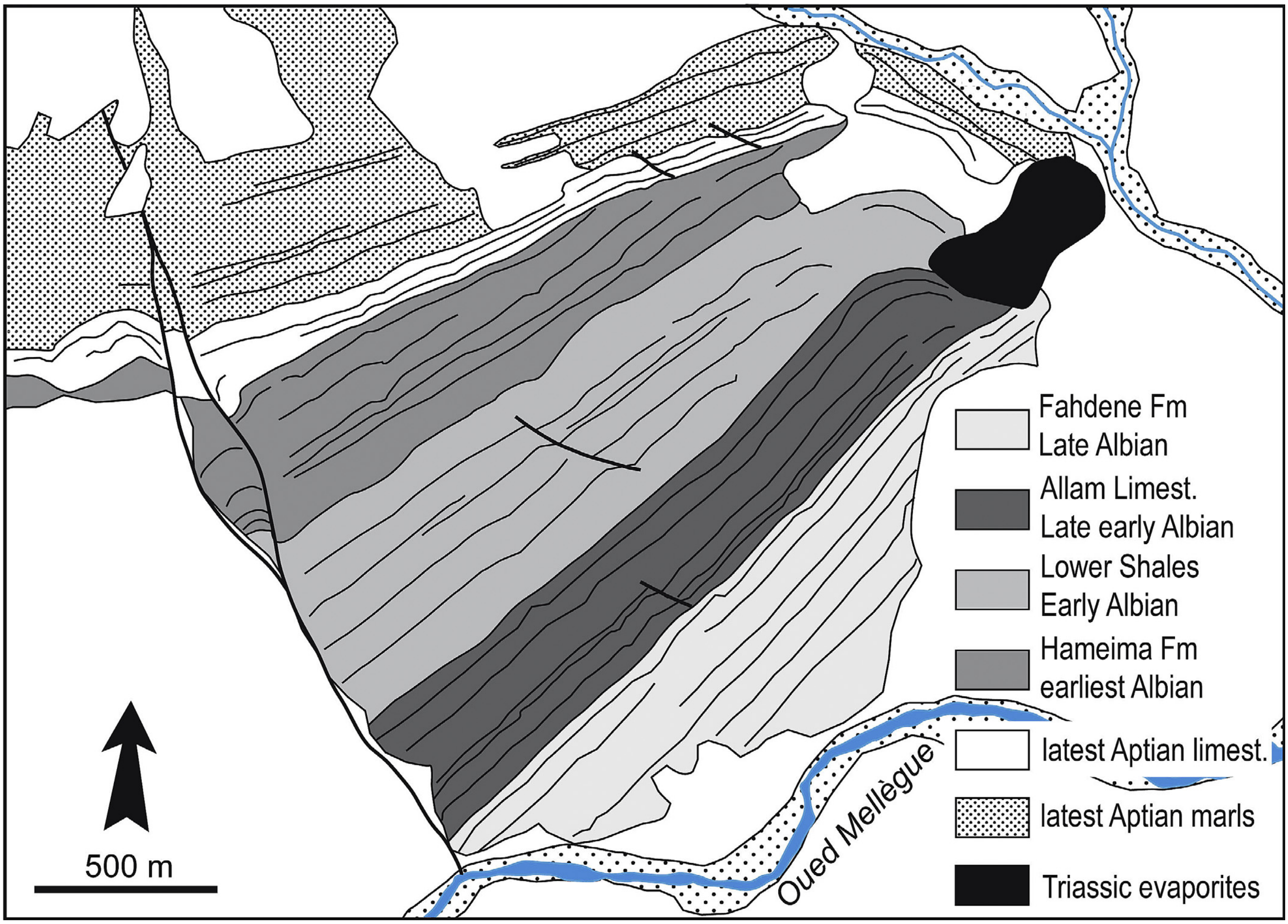

Fig. 12. Geological map of the Sidi Embarka area (modified from Dubourdieu, 1956) (location on Fig. 2).

significant vertical uplift occurred as early as the late Early Albian. Note that in this area, Vila (1998) interpreted the evaporite outcrops as a salt glacier.

4.8. Nebeur area (Fig. 13)

The Nebeur locality is located 25 km North of Le Kef (Figs. 2 and 13). This area has been studied by Martinez et al. (1991), Chikhaoui et al. (1991), Ghanmi et al. (2006) and Masrouhi et al. (2014). Reconstructing Cretaceous geometries and environments, these authors described a « Nebeur swell » located immediately Northwest of the Nebeur village, created by the uplift of a diapir made of Triassic evaporites. The diapir uprise provoked the thinning out of sedimentary strata of Aptian-Albian age against the salt dome (Fig. 13). Triassic material reworked in, and slope-related deformations recorded by, Albian strata indicate that the diapir rised during the Albian, and then expanded as a submarine salt glacier. At the top of these structures, unconformable shales of Late Albian age, emphasized by a basal conglomerate, rest directly upon the Triassic evaporites (Chikhaoui et al., 1991; Ghanmi et al., 2006). Therefore, as in Jebel Slata, the diapir extrusion and the salt glacier were sealed by the unconformable Late Albian shales, but as in the El Goussa and Guern Halfaya area, the diapir ascent may have begun earlier (Aptian-Albian *s.l.*) (see Fig. 13).

5. Synthesis and discussion

The observations mentioned in the former sections show that the nature and intensity of deformations vary in time and space. Synsedimentary deformations increased throughout the Early Albian and culminated in the Middle Albian (Jaillard et al., 2013). At Jebel El Hamra for instance, the first normal faults, of earliest Albian age, present meter-scale offsets, while late Early Albian to Middle Albian faults (M'rich half-graben) exhibit 30 m offsets, and the regional tilt of the whole massif occurred before the Late Albian. The same observations can be made in Jebel Slata, where low-angle progressive unconformities of earliest Albian age (Jaillard et al., 2013) are followed by the extrusion of a salt wall during Middle Albian times. Therefore, the Albian "tectonic crisis" must be considered a period of progressively increasing deformation, which culminated in Middle Albian times (Jaillard et al., 2013).

In the South of the studied area (El Hamra, Boulhaneche, Mrhila), dominant deformation was normal faulting, whereas slope creation, expressed by slumpings and olistolith emplacements, and diapirism prevailed in the North of the area (Slata, El Goussa, Guern Halfaya, Harraba, Nebeur). On one hand, these observations indicate that an extensional regime prevailed during the whole Early Albian, and probably during the Middle Albian. The orientation of the measured normal faults supports the NE-SW extensional strain regime assumed for the Aptian-Albian period (Fig. 5; Barrier et al.,

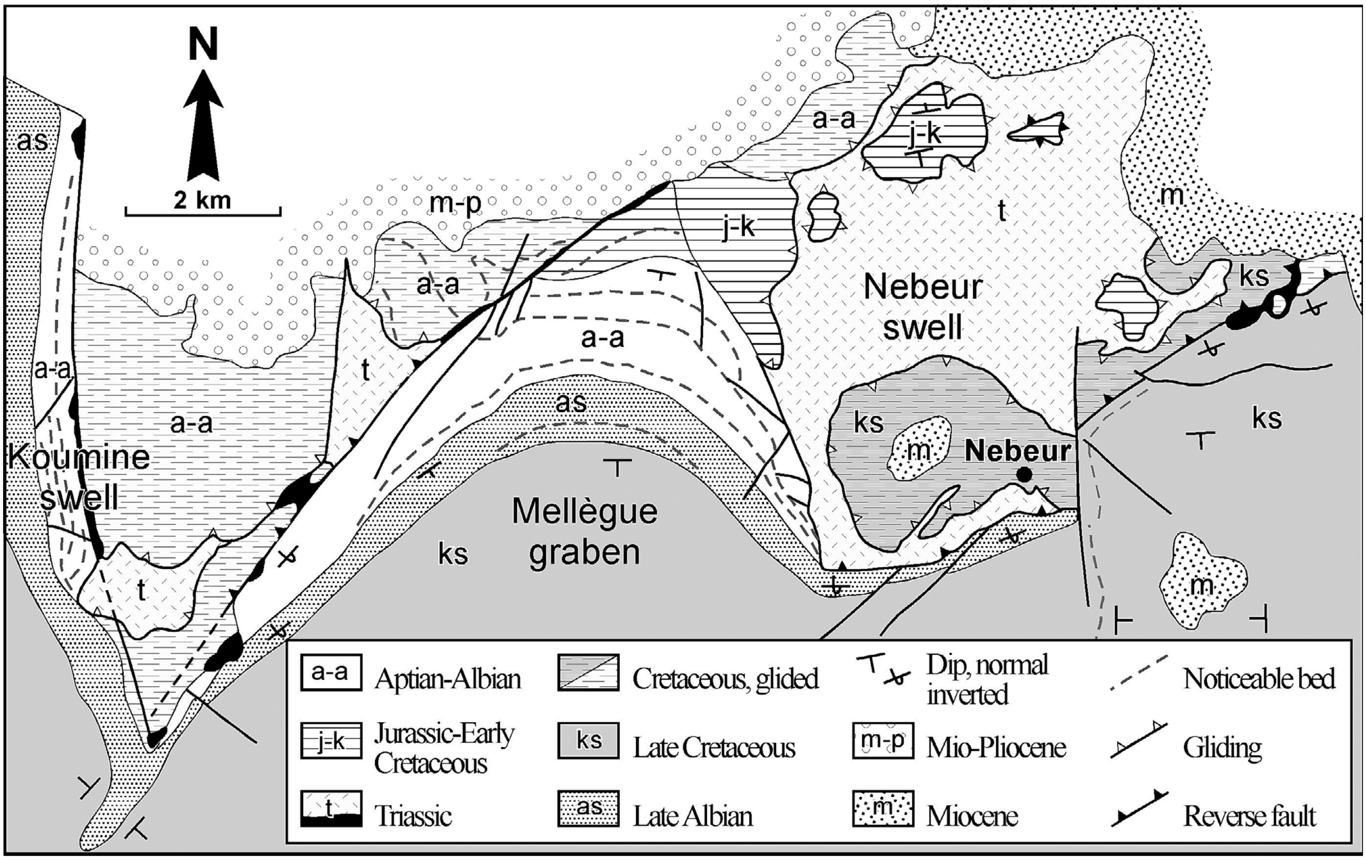

Fig. 13. Geological map of the Nebeur area, after Martinez et al. (1991) and Chikhaoui et al. (1991).

1993; Bouaziz et al., 2002; Ouali, 2007). On the other hand, the occurrence of dominant normal faults in the proximal, southern parts of the Tunisian passive margin, and the prevailing slope creations and diapir ascents in the distal, northern part of this margin suggest that the Tunisian passive margin behaved during the Albian as an evaporite floored margin, comparable to the Angolan (Fort et al., 2004a,b; Hudec and Jackson, 2007), Brazilian (Aptian evaporites) or Moroccan margins (Triassic evaporites, Zühlke et al., 2004; Davison, 2005; Hafid et al., 2008).

In the latter margins, due to thermal subsidence and/or overloading by the sedimentary prism, the post-salt sedimentary cover glided toward the toe of the passive margin, upon the evaporite layer, which acted as a décollement surface. This movement provoked the thickening of the evaporite layer beneath the distal lower part of the margin, which is marked by contractional structures, and the thinning of the salt bed in the proximal upper parts of the margin, characterized by extensional deformations (e.g. Spathopoulos, 1996; Marton et al., 2000; Fort et al., 2004a,b; Brun and Fort, 2004). Comparisons between natural examples and analog modelling, led Fort et al. (2004a,b) to propose that the proximal, upper part of such a margin is marked by extensional normal faults giving way to tilted blocks, which grade downsolpe to growth faults and rollover structures. The latter originate rafts (Burollet, 1975), half-grabens, "rollover" (Brun and Mauduit, 2008) and "turtle-back" structures (Vendeville and Jackson, 1992a; Mauduit et al., 1997), responsible for important and rapid thickness variations in the syntectonic deposits. On the other hand, the distal, lower part of the margin is characterized by the development of a compressional fold and thrust belt, intruded by compressional diapirs, locally coalescent, and forming salt canopies. Between these zones, a "neutral" area is translated downward through time upon the salt layer, and is dominated by rising diapirs delimiting synsedimentary synclines ("pillows" of Marton et al., 2000).

Analyzing the South-North distribution of the observed structures in Tunisia, we propose that Central Tunisia can be divided into four structural zones (Fig. 14). To the South, Jebel El Hamra belongs, during the Albian, to the normal fault and tilted blocks area. In Jebel Semmama and farther south, the dominant observed deformations are also brittle, extensional structures, such as normal faults indicating a NE-SW extension (Ouali et al., 1986; Abbes and Tlig, 1991; Martinez et al., 1991; Ladeb et al., 1995; Zouari et al., 1999). In this area, diapirs will be active in the Late Cretaceous and during the Tertiary.

Farther North, between Thala and Tajerouine, jebels Boulahneche, Mrhila and Douleb belong to the "rollover" zone of a passive, Atlantic-type margin. As a matter of fact, the important and quick thickness variations observed in Mrhila and Douleb (Zghal et al., 1998) are better explained by the movement of a listric fault generating rafts and rollover structures. A similar structure can be interpreted from Jebel Bou el Haneche, even though the age of the movement of the normal faults related to the rollover structure is not accurately constrained.

Between Tajerouine and Le Kef, some diapirs cropped out during the Albian, as exemplified by the Jebel Slata and Sidi Embarka areas, and described by other authors (e.g. Vila et al., 1996). This zone would correlate with the "neutral" zone of Fort et al. (2004a,b), marked by ascending passive diapirs. This area is also marked by slumps, deep erosions and olistoliths in the Henchir El Goussa and Guern Halfaya areas (Jaillard et al., 2013), which suggest vertical

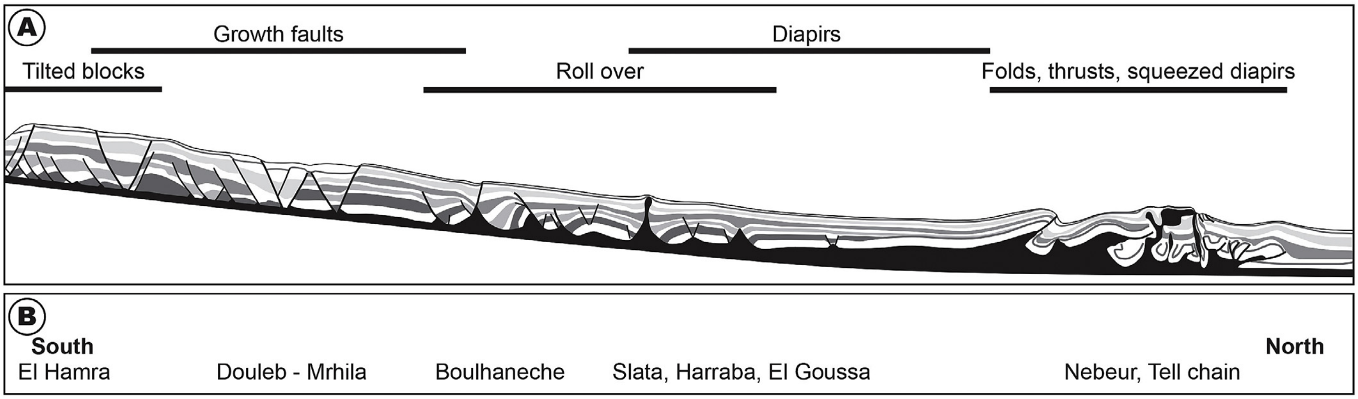

Fig. 14. Interpretative model of the Tunisian margin. A: Model of an evaporite-floored margin showing deformation style, according to analogic models (simplified from Fort et al., 2004a,b). B. North-South distribution of the studied Tunisian outcrops, showing a good correspondence between deformation style and location along the margin.

movements related to diapir ascent at depth during the Early Albian. This latter area, which constitutes the basinal part of the Cretaceous margin, is also marked by a predominantly argillaceous lithology. The weak rheology of shales may partly account for both the style of deformation, and the earlier age of deformation of this area, since the uprise of diapirs would be easier.

In our interpretation, the present-day north Tunisian Tellian area, which exhibit numerous diapirs, salt glaciers and canopies (e.g. Vila et al., 1995a, 1996; Masrouhi et al., 2013) subsequently squeezed during Alpine compression (Fig. 1), would represent the distal part of the system, exemplified by the Nebeur area, and supposedly characterized by Albian North-verging compressional structures (Fig. 14). In this area, however, significant Tertiary deformations, marked by Southward-verging folds and nappes, obscured the early structures, and more work is required to refine this interpretation. In our view, the studied area of Central Tunisia would represent an onshore example of an evaporite-floored passive margin, as known offshore for instance on the Atlantic margins. Central Tunisia thus gives a noteworthy opportunity to study the evolution, deformation and sedimentary response to this kind of gravity tectonics.

6. Summary and conclusion

The main results of this study are as follows:

- Important deformation of the sedimentary cover of the Tunisian margin took place in the Early to Middle Albian.
- This deformation consists of normal faults and block tilting in the southern part (El Hamra, Semmama), roll over and turtle-back structures farther north (Bou el Haneche, Douleb-Mrihla), and diapir or salt wall intrusions to the North (Slata, Harraba, Nebeur), thus suggesting that the whole Mesozoic sedimentary cover of the Tunisian margin underwent a gliding toward the North on the Triassic evaporite décollement level, as recorded in Atlantic-type passive margins.
- Subsequently, the Alpine orogeny provoked the folding of tilted blocks and fault planes, the formation of NE-to ENE-trending folds superimposed to former halokinetic deformation to the north, squeezing of most pre-existing diapir structures, and final intrusions of numerous diapirs in the whole area, thus obscuring the nature, intensity and geometry of Albian deformation.
- In this interpretation, Central Tunisia would represent an onshore example of large-scale gliding of a sedimentary cover on an evaporitic décollement level, and offers good opportunities to study the evolution and consequences of such gravity tectonics.

Acknowledgements

This work has been carried out in the framework of a scientific collaborative agreement between the universities of Grenoble and Sfax, and the Ecole National d'Ingénieurs de Sfax, sponsored by the Ministries of Foreign Affairs of France and Tunisia, project Utique - 07G1008. The French Institut de Recherche pour le Développement (IRD) and the ISTerre laboratory (Grenoble) financially supported field work and analysis. Thanks are due to A. and H. Arnaud, I. Zghal and J. Touir for fruitfull discussions. A. Masrouhi and M. Soua are thanked for helpful reviews.

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