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Abstract:

New stratigraphic data, lithostratigraphic correlations and fault kinematic analysis are used to discuss the basin geometry and sedimentation patterns of the northeastern Tunisia during Cretaceous times. Significant facies and thickness variations are deduced along the northeastern Atlas of Tunisia. The NW-SE 80 km-long regional correlation suggests a high sedimentation rates associated with irregular sea floor. The fault kinematic analysis highlights N-S to NE-SW tectonic extension during early Cretaceous. During Aptian-Albian times, an extensional regime is recognized with NE-SW tectonic extension. The Cenomanian-Turonian fault populations highlight a WNW-ESE to NW-SE extension, and, Campanian-Maastrichtian faults illustrate NW-SE extension. The normal faulting is associated to repetitive local depocenters with a high rate of sedimentation as well as abundant syntectonic conglomeratic horizons, slump folds and halokinetic structures. The sequences correlation shows repetitive local depocenters characterizing the basin during early Cretaceous times. All the above arguments are in favor of basin configuration with tilted blocks geometry. This geometry is shaped by major synsedimentary intra-basin listric normal faults, themselves related to the extensional setting of the southern Tethyan paleomargin, which persisted into the Campanian-Maastrichtian times. The results support a predominant relationship between tilted blocks geometry and sedimentation rather than E-W "Tunisian Through" as it was previously accepted.

Keywords: Cretaceous, tilted blocks, stratigraphic consideration, fault kinematic, Tunisia.

Introduction

The present-day structure of the Northern African margin in Tunisia results from a complex tectonic evolution that operated since late Permian with the beginning of the breakup of Pangea and ended with the Cenozoic Alpine orogeny of the Maghrebide chain. The geodynamic evolution of the northern margin of Africa has been characterized by extension, crustal stretching and thinning, as well as subsidence during the Mesozoic Tethyan rifting (Boughdiri et al., 2007; Gharbi et al., 2013; El Amari et al., 2016; Soussi et al. 2017, Naji et al., 2018). The Mesozoic passive margin, where rifting occurred, was followed by subsequent inversion during Late Cretaceous-Cenozoic subduction and ended by Alpine collisional process (De Lamotte et al., 2009; Khomsi et al., 2016). 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 normal faults, tilted blocks and Halokinetic and volcanic activity (Mattoussi Kort et al., 2009; Masrouhi et al., 2014a; Dhahri and Boukadi, 2017). The Tunisian Atlas has particularly recorded the effect of Tethyan rifting as revealed by considerable facies and thickness variations within the Mesozoic sequences (Ben Ferjani et al., 1990; Masrouhi and koyi, 2012; Gharbi et al., 2015; El Amari et al., 2016).The complex structural pattern of Tunisia is mainly a consequence of the polyphased Cenozoic reactivation of inherited extensional faults systems which controlled fault-related folds (Masrouhi et al., 2008; Dhahri and Boukadi, 2010; Gharbi et al., 2015; Khomsi et al., 2016).

The present study focuses on the basin geometry and sedimentation patterns of northeastern Tunisia during Cretaceous times. In this study, new sedimentologic, stratigraphic, paleontologic and structural data are reported to understand the basin configuration of the southern Tethyan paleomargin in northern Tunisia. This work aims to contribute to the debate about the basin paleogeography during Mesozoic times on the basis of structural field data, stratigraphic precisions, lithostratigraphic correlations and fault kinematic analysis.

1. Geologic setting

The northern Tunisian belt forms the northeastern edge of the African plate and set the eastern limits of the Atlas System. Except its northerly range which corresponds to the Numidian thrusted Range, the Northern Tunisian Atlas is classically subdivided into two distinguished structural units (Fig. 1a): The first unit corresponds to the southeastward major thrusted unit called the Teboursouk thrust unit which represents the front of the Alpine Range. This area shows thick Aptian–Albian sequences and exhibits frequent outcropping salt structures belonging to the northeastern Maghreb salt province (Masrouhi et al, 2013; Jaillard et al., 2017). The second one called the Zaghouan-Ressas unit corresponds to the front of the northern Tunisian Alpine Range. During Mesozoic times, the present Zaghouan Thrust Fault corresponds to a paleogeographic line between a relatively shallow platform to the south, with a condensed Aptian section from a deep basin to the north with a thick Aptian–Albian section (Morgan et al., 1998; Chihaoui et al., 2010; Soua, 2016).

The Meso–Cenozoic geological evolution of the northern African margin can be summarized in two main periods. The first period, from the late Permien? To the early Cretaceous, of the Mesozoic rifting is related to the Tethyan and Atlantic Oceans opening (Guiraud, 1998). Recent works demonstrate that the opening of Central Atlantic operates during Jurassic and early Cretaceous (Souquet et al., 1997; Boughdiri et al., 2007; Masrouhi and Koyi, 2012; Naji et al., 2018). Furthermore, related Cretaceous salt movement confirms a hyperactive extension, thick and/or thin-skinned tectonic extension (Masrouhi et al., 2014b). In addition, frequent synsedimentary normal faults are recognized to produce a general tilted-blocks geometry. During this period, the Aptian–Albian ages are described to have developed syndepositional facies and thickness heterogeneities of the south Tethyan margin in north Tunisia (Souquet et al., 1997; Gharbi et al., 2013; Masrouhi et al., 2014b; Naji et al., 2018). Commonly, the Cretaceous sequences, outcropping in northern Tunisia, display significant thickness and/or facies variations with abundant soft-sediment deformations and syntectonic growth strata (Gharbi et al., 2013; Naji et al., 2018).

The second main period, started since Late Cretaceous (at Campanian-Maastrichtian transition), causes a basin positive inversion related to the African and Eurasian plate convergence (Guiraud and Bosworth, 1997; Khomsi et al., 2009; Gharbi et al., 2015; El Amari et al., 2016).

2. Lithostratigraphy of early Cretaceous successions

2.1. Jebel Sidi Salem section

The Sidi Salem–Messella is a NE-trending structure located along the Zaghouan–Ressas thrust system (Fig. 1b). The early Cretaceous outcropping in this structure includes sequences ranged from Neocomian to Albian (Fig. 2). The outcropping Cretaceous sequences are subdivided as follows:

a- A first unit consists of marls –to- marly limestone succession, which are attributed to the Neocomian without additional precision (Fig. 2). These units, include pelagic and benthic fauna, indicate deposit of a marine environment.

b- The Neocomian deposits are covered by gray marls interbedded with quartzitic and clayey limestone beds with ammonites at the base and topped by dark marls. This ~150 m-thick unit of clayey facies delivered a faunal assemblage dominated by benthic foraminifera *Lenticulina, Nodosaria* and *Dentalina* (Elkhazri et al., 2009; confirmed by M. Ben Youssef) which indicated the Barremian age.

c- Green to Gray laminated marls intercalated with sandstones and gray nodular limestone beds showing in outcrop abundant Belemnites and Ammonites macrofauna. The common presence of bi-pyramidal quartz indicates halokinesis activity during this period. This ~300 m thick unit is dated as Aptian. Nagazi (2016), with an extensive biostratigraphic analysis, shows that the Jebel Sidi Salem's Aptian sequences are subdivided as follow:

- Early Aptian (Bedoulian) is dominated by a planktonic association which contains: *Gorbachikella grandiapertura Hedbergella sigali, Schackoïna cabri, Lenticulina bizonae* and *L. protuberans* associated with Benthic foraminifera: *Lenticulina ouachensis, Gavelinella barremiana, Nodosaria paupercula* and *Gavelinella* sp.
- Middle Aptian (Gargasian) is identified by micropalentological association with: *Globigerinoïdes barri, Globigerinoïdes ferreolensis, Leupoldina protuberans, Globigerinelloides algerianus, Globigerinelloides ferreolensis, Hedbergella trocoïda.*
- Uppermost Aptian (Clansayesian) is marked by the appearance of *Hedbergella trochoïda (*Gandolfi*), Pseudoplanomalina cheniourensis (*Sigal*)* and *Hedbergella palanispira* associated to benthic foraminifera such as *Gavelinella* sp.*, Ammodiscus tennuissimus, Trochammina* sp.
- Aptian sequences are covered by gray to black marls succession with thin beds of nodular and quartzitic limestone. According to the biostratigraphic analysis of Nagazi (2016), this unit contain the following planktonic foraminifers' assemblage: *Ticinella primula*, *Ticinella bejaouansis, Rotalipora ticinensis, Hedbergella trocoïda, Ticinella roberti* and *Rotalipora subticinensis*, which indicate a middle Albian age. The top of the unit is made of marls sequences with platy limestone succession beds which are attributed to the uppermost Albian (Vraconian in literature) on the basis of the following micropaleontological association: *Planomalina buxtorfi, Biticinella breggiensis*, *Rotalipora appenninica, Dentalina guttifera* and *Praedorothia hechti, subticinensis R.,* and *B. ticinensis breggeinsis.* The 180 m-thick Albian sequences contain abundant black shale levels, testifying for deep sea environment deposition. The Albian strata are characterized by abundant slumps and carbonate nodules symptomatic of contemporaneous sub-marine slope.

d- 120 m-thick series made of nodular limestone interbedded by marls dated as early Cenomanian. The top of these monotone sequences is marked by thinly laminated, dark-grey limestone and marl of the uppermost Cenomanian-early Turonian-aged Bahloul Member.

e- Coniacian–Santonian-aged sequences of the Aleg Formation conformably overlie the previous Cenomanian-Turonian series. They are defined by thick sequences of limestone interbedded with marl layers at the base and thick marly sequences at the top. The Coniacian–Santonian series can reach a maximum ~450 m in thickness in the northern flank of Sidi Salem anticline. These sequences are topped by the Campanian-Maastrichtian Abiod Formation with three well-known terms.

2.2. Jebel Oust type-section

The Jebel Oust is a 15 km-large N40°E-trending anticline structure exposes series ranging from Jurassic sequences in the core and Campanian–Maastrichtian outcrops in the limbs. In this locality, which is considered in northern Tunisia as the type-section of lower Cretaceous (Ben Ferjani et al., 1990; Souquet et al., 1997), 2600 m-thick siliciclastic and marly sequences (Fig. 3) have been deposited (Fig. 3). According to Souquet et al. (1997), this "reference section" is made of:

a- 90 m of debris flow deposits and marl calpionellid bearing mudstone parasequences which correspond to the Tithonian-Berriasian transition followed by mud-flow and debris flow deposits of 40 m-thick which marked the early Berriasian. The Berriasian *p.p* is made of ~160 m of greenish muds with thin bedded sandstones and siltstones. The following micropaleontological association was described by Maamouri and Salaj (1978): *Tintinopsella carpathica, Spirillina neocomiana, Trocholina infragranulata* North, *Trocholina vasserodi* Guillaume, *Trocholina molesta* Gorbastschek, *Trocholina burlini* Gorbastschek, *Spirillina neocomiana* Moullade and *Spirillina minimina* Schacko. These units are covered by a 160 m carbonate dominated sequences which are attributed by souquet al. (1997) to the uppermost Berriasian–early Valanginian.

b- A large 900 m-thick unit consists of siliciclastic turbidites with pelites, thin-bedded sandstones, slumped quartzites bed and sometimes sliding blocks which corresponds to Valanginian deposits. This unit is covered by 120 m-thick rich Ammonites mudstones marked by *Castellensis* zone which indicates the lower Hauterivian (Souquet et al., 1997) followed by aggrading marls-mudstone parasequences. To the top, a ~280 m-thick siliciclastic and carbonate storm with marls succession is attributed to the late Hauterivian.

c- The Barremian is made up of siliciclastic tempestites and slumped sandstone beds (Fig. 3) followed by thick nodular limestone bar, siliciclastic storm topped by black-shales. This ~600 m-thick unit delivered to Maamouri and Salaj (1978) *Anomila (Gavelinella) sigmoicosta barremiana, Epistomina (Brotzenia) hechti* which indicates the early Barremian. The top of sequences delivered: *Conorotalites bartensteini bartensteini, Glavihedbergella subcretacea* and *Schackoina pustulans* which indicates the late Barremian.

d- The Aptian is marked by offshore muds with siliciclastic turbidites (Fig. 3).

e- The Jebel Oust late Cretaceous series were studied by Turki (1975) in eastern section of the structure. This section shows that Albian series begins by 60 m thick marly sequences, topped by 180 m platy limestone of uppermost Albian.

f- The thinly laminated organic rich 100 m -thick limestones of Bahloul Formation. These series are covered by 450 m-thick of Coniacian Santonian limestone-marls successions topped by 150 m-thick Campanian–Maastrichtian Abiod sequences.

2.3. Jebel Kechtilou section

The Jebel Kechtilou is a NE-trending faulted anticline. It corresponds to one of numerous structures disturbed during Cretaceous rifting by halokinetic intrusion. Active extensional tectonics have been recorded along the Jebel Kechtilou particularly within Aptian-Albian deposits (Haggui, 2012). The Aptian-Cenomanian series display numerous metric 'olistostromes' associated to frequent reworked blocks, slumps, and nodules; all are interpreted as deriving from submarine gravity sliding (Naji et al, 2018). The Upper Cretaceous sequences of Jebel Kechtilou have been well described by El Ouardi (1996) and revised in this work (Fig. 4). From the bottom to the top, outcropping Cretaceous series are made of:

a- A thick series of ~160 m yellow and yellow-green marls with decametric to metric limestone bed successions. Polygenic conglomerates mark the top of these series, themselves covered by ~120 m of silty green marls topped by 40 cm of breccia layer. These series delivered to Haggui (2012) *Leupoldina pustulans, Hastigerinella bizonae Chevalier, Ticinella Roberti* (Gandolfi), *Ticinella bejaouensis, Ticinella roberti* indicating Aptian age.

b- ~120 m bar composed of gray platy limestone beds with ammonites, which were dated as early Albian. This unit is covered by 80 m-thick middle to late Albian deposits consisting of dark gray marls interbedded by gray clayey limestones. They contains an assemblage with *Rotalipora ticinensis, Hedbergella breggiensis*. At the top, ~120 m-thick platy limestone bar of was attributed to the uppermost Albian on the basis of *Planomalina buxtorfi* microfauna's occurrence in thin section (Haggui, 2012).

c- Cenomanian sequences show, at the bottom, ~120 m-thick gray limestone bar. The base of sequences contains: *Rotalipora cushmani, Rotalipora greenhornensis, Hedbergella simplex, Hedbergella* sp., *Lenticulina* sp. (Det. Maamouri in El Ouardi, 1996) which indicates the late Cenomanian. The top, of this middle sequences, contains *Whiteinella archaeocretacea*, *Helvetoglobotruncana helvetica*, *Ammodiscus cretaceus*, *Heterohelix* sp. indicating early to middle Turonian age. These series are covered by ~90 m gray marls with gray decametric to metric limestone succession beds which was dated as late Turonian based on microfaunal association with *Marginotruncana schneegansi, Marginotruncana pseudolinneiana, Hedbergella flandrini.*

d- ~180 m-thick series made of monotone marl-limestone successions topped by metric rich-Inocerames limestone beds. The samples collected from the upper part of this series delivered a Coniacian association consisting of *Dicarinella primitiva, Dicarinella concavata, Marginotruncana schneegansi, Marginotruncana praeconcavata, Hedbergella flandrini, Lenticulina rotulata.*

e- ~900 m-thick gray flaky marls with a micropaleontological association including *Sigalia carpatica* (Det. Zaghbib-Turki and Rami in El Ouardi, 1996) attesting a Santonian age. The Santonian marls are covered by ~220 m gray marls with white to gray clayey limestone beds, dated as early Campanian with *Globotruncana elevata* fauna. The Campanian sequences are followed by ~140 m white limestone beds alternated with marly joints, dated as middle to upper Campanian containing *Globotruncana ventricosa* and *Globotruncanita stuartiformis*.

2.4. Jebel Rihane section

The Jebel Rihane corresponds to a WNW-to NW-trending syncline (Ben Yagoub, 1978). It is located eastern of Jebel Oust structure and it is mainly made up of Upper Cretaceous deposits. This structure exposes Cretaceous series ranging from Aptian to Maastrichtian. Ages are deduced from Floridia (1963) and Ben Yagoub (1978) works, which they indicate that the Jebel Kechtilou section shows reduced thickness with a comparable microfaunal assemblage. The Jebel Rihane clearly exposes considerable thickness variation of Aptian-Albian sequences suggesting a local basin configuration. This configuration reflects a tilted blocks geometry produced by the reactivation of inherited faults (Naji et al., 2018).

2.5. Medjez-El-Bab sections

The Medjez-El-Bab area exposes early Cretaceous sequences in the Jebel El Mourra, Jebel Bou Rahal and Sidi Mohamed Akermi localities with significant thicknesses changes ranging from tens meters to hundreds of meters (Fig. 5).

2.5.1. Jebel El Mourra

The Jebel El Mourra is a NE-trending anticline structure consists by Triassic and reduced early Cretaceous series. It was subject to various interpretations as a salt dome structure by El Ouardi (1996) or as a single salt sheet extruded during the Cretaceous forming a submarine salt glacier by Masrouhi and Koyi (2012). The Cretaceous series plunging above Triassic rocks are as follow:

a- 20 m of decametric platy limestones beds separated by marly joints. This first unit delivered: *Planomalina buxtorfi* GANDOLFI, *Rotlipora appenninica* MORROW, *Hedbergella planispira* TAPPAN, *H. delrioensis* CARSEY (Det. Zaghbib-Turki and Rami in El Ouardi, 1996) which allow to attribute it to the uppermost Albian. This latter is covered by an observation gap of 15 m-thick.

b- Marls alternated with metric to decametric limestone beds topped by gray marls. This 55 m-thick unit is covered by Plio-Quaternary conglomeratic deposits. Marls delivered to El Ouardi

(1996) the following micro-fauna association *Dicarinella concavata* BROTZEN, *D. primitiva* DALBIEZ, *Marginotruncana undulate* LEHMANN, *M. sinuosa* PORTHAULT , *M. tarfayaensis* LEHMANN, *M. pseudolinneiana* PESSAGNO, *Hedbergella flandrini* PORTHAULT, *Lenticulina rotulata* LAMARCK, *Dorothia oxycona* REUSS indicating late Coniacian age. The upper marls delivered *Marginotruncana pseudolinneiana* PESSAGNO, *M. undulate* LEHMANN, *M. tarfayaensis* LEHMANN indicative of Santonian age.

Masrouhi and Koyi (2012) described a coral algal reef on the upper Albian marls dated by *Planomalina buxtorfi*. The Cenomanian sequences were characterized by the occurrence of *Globotrancana appenenica*, and, the Turonian limestones by the presence of *helvetoglobotruncana Helvetica*. The Coniacian–Santonian delivered *Globotruncana coronata* and *Dicarinella concavata* in the bottom and *Dicarinella concavata assymetrica* in the top.

2.5.2. Jebel Bou Rahal section

Jebel Bou Rahal is a NE-trending south-East dip limb of Medjez-El-Bab anticline structure and shows an interbedded Triassic salt sheet with early Cretaceous sequences. According to El Ouardi, (1996) Cretaceous series (Fig. 5) shows from the bottom to the top:

a- A first unit is formed by ~160 m green clays with limestone and sandstone beds successions in which limestone beds predominate to the top. This unit is attributed to upper Barremian-Aptian age by correlation of lithological units of nearby sections.

b- A second unit showing at the base ~80 m green marls and scarce gray decametric clayey limestone beds, followed by ~40 m-thick gray limestone bar, itself covered by 35 m-thick marls with ammonites-rich flaky limestones sequences. This unit is topped by ~25 m-thick gray platy limestone bar covered by ~25 cm-thick yellow siltstone sequences. The platy limestone unit contains: *Planomalinan buxtorfi, Hedbergella simplex, Hedebergella planispira, Hedebergella delrioensis, Rotalipora appenninica* (Det. Zaghbib-Turki and Rami in El Ouardi, 1996), characterizing the uppermost Albian. The Lower part of this series delivered *Tincinella roberti, Tincinella bejaouaensis*, *Hedebergella infracretacea, Nodosaria prismatica, Nodosaria nuda, Ramulina* sp.*, Dentalina linearis, Lenticulina muensteri* (Det. Salaj in El Ouardi, 1996) which attest the early Albian. The middle bar of flaky limestone delivered to El Ouardi (1996) the following association *Tincinella bejaouaensis, Tincinella roberti, Dentalina* sp.*, Lenticulina* sp. which indicates early to middle Albian age.

c- The platy limestones unit is covered by ~4 m-thick bar consists of limestone breccia that resides monogenic conglomerates. This unit is attributed to Cenomanian-Turonian age.

d- Marls with Metric to decametric limestone beds successions. Marls delivered *Dicarinella concavata, Dicarinella primitiva, Marginotruncana sinuosa, Marginotruncana pseudolinneina,* *Globotruncana angusticarinata* (Det. Salaj and Rami in El Ouardi, 1996) which attests the late Coniacian age.

e- The last unit is covered by an observation gap of 250 m-thick then an outcrop of ~120 m-thick gray marls topped by Nummulitic limestone beds of the early Eocene. These marls delivered *Dicarinella asymetrica, Dicarinella concavata, Marginotruncana tarfayaensis, Marginotruncana sinuosa, Sigalia carpatica* and *Dorothia oxycona* (Det. Zaghbib-Turki and Rami in El Ouardi, 1996) which indicate the Santonian.

2.5.3. Jebel Bou Rahal to Sidi Mohamed Akermi section

The Jebel Bou Rahal locality exhibits thick Cretaceous sequences ranging in age from Barremian to Coniacian (Fig. 5). According to El Ouardi (1996), from the base to the top, this section exposes:

a- ~80 m of gray to dark marls with thin-bedded sandstone layers and gray bioclastic limestone beds intercalations. These successions are covered by ~60 m-thick carbonate unit made of three limestone bars topped by platy gray to black limestone beds with Ammonites. The first bar exposes reworking blocks with the same facies. The top of this first unit is formed by ~40 m of silt and sandy marls with gray sandy limestone layers. This fist unit was dated as late Barremian age, on the basis of rich microfauna association (El Ouardi, 1996).

b- ~120 m-thick green marls sequences containing iron and celesto-barite nodules with metric and decimetric gray limestone beds characterized by belemnites and breccia. This series are covered by 50 cm-thick polygenic conglomerate unit. these were dated as Bedoulian-Gargasian on the basis of the following association: *Lingulogavenillela sigmoicosta barremiana, Epistomina carpeuleri, Hedbergella infracreteceas, Hedbergella tuschepsensis, Hedbergella bolli, Hedbergella* sp.*, Leupoldina pustulans, Leupoldina protuberans, Dentalina nana, Dentalina* sp.*, Lenticulina roemeri, Lenticulina* sp.*, Ortokarstenia senestralis, Ammodiscus tenuissimus, Vaginulina Arguta, Nodosaria* sp. (El Ouardi, 1996). This sequences are covered by 75 m-thick gray flaky marls, themselves topped by 40 cm-thick breccia beds. These marls delivered *Planomalina chiniourensis* which mark the late Aptian.

c- ~200 m-thick green marls with numerous gray decimetric limestone beds successions characterized by slump folds and septaria (Masrouhi and Koyi, 2012) followed by an observation gap of 60 m , and then 120 m-thick gray platy limestone bar. These rich ammonite limestone beds are surmounted by 170 m-thick marls with limestone intercalations. The lower successions part and the lower part of platy limestone bar delivered to El Ouardi, 1996 a rich microfauna association including *Tincinella roberti*, *Tincinella bejaouaensis*, *Haplophragmoides concavus*, *Haplophragmoides nonioninoides*, *Textularia* sp., which indicates the early Albian. The upper marl-limestone alternations indicated a middle

Albian age attested by *Ticinella primula* (El Ouardi, 1996). These sequences are covered by 100 m-thick gray rich- ammonites and rudists hard limestone with marls and slumped platy limestones. This level is dated as uppermost Albian with *planomalina buxtorfi* fauna.

d- ~120 m-thick bar consisting of dark gray laminated limestone beds with abundant ammonites. These beds show repetitive clayey joints. It was dated as by El Ouardi (1996) on the basis of the following assemblage: *Rotalipora cushmani, Rotalipora greenhornensis, Hedbergella simplex, Wheiteinella archaeocretacea, Helvetoglobotruncana helvitica, Ammodiscus cretaceus* which attests the late Cenomanian-early Turonian age. These series are topped by 90 m marl-limestone alternations. Micropaleontological analysis indicates an late Turonian age attested by *Helvetoglobotruncana helvetica* disappearance and the appearance of *Margcinotruncana shneegansi* (Det. Zaghbib-Turki and Rami in El Ouardi, 1996).

e- Large monotone limestone-marl successions dating Coniacian-Santonian age on the base of the following microfauna association *Globotruncana coronata* and *Dicarinella concavata* at its bottom and *Pseudolinneiana* sp., *Dicarinella asymetrica* and *D. concavata* at its top (Masrouhi and Koyi, 2012).

2.6. Jebel Bechtab section

The Jebel Bechtab, located in southwestern part of the Lansarine belt, is a NNE-trending faulted anticline, crossed by Triassic evaporitic bodies. This structure is made of Hauterivian-Barremian to Oligo- Miocene sequences (Masrouhi et al., 2013). The Glib Abiod locality situated in the south-east of Bechtab structure exposes a reduced late Cretaceous series described by Masrouhi et al. (2013) as follow:

a- ~40 m unit formed by dark gray marls with successions of gray platy limestone including ammonites. This unit delivered *Rotalipora subticinensis, R. ticinensis, Ticinella breggiensis, Ticinella primula* which indicates the late Albian-to uppermost Albian.

b- ~120 m-thick deposits made up of schistose marls with successions of platy limestone on the base and metric limestone beds to the top. Middle limestone beds delivered to Masrouhi et al. (2013): *Rotalipora greenhorensis*, *Rotalipora cushmani*, *Rotalipora reicheli*, and rare *hedbergellae* which attest the middle to late Cenomanian. The following sequences delivered rich-filaments and globigerina microfacies with *Roralipora reichelli, Rotalipora cushmani, Dicarinlla imbricate, Whithenella* sp. which indicates the late Cenomanian-lower Turonian.

c- ~120 m-thick sequences of black schistose and marl-limestone successions. The middle part of this series delivered *Dicarinella concavata, Dicarinella assymetrica, Sigalia carpatica* which attest the Santonian age.

d- ~60 m-thick chalky limestones sequences of the Campanian–Maastrichtian Abiod Formation.

2.7. Oued Tazega section

Two kilometers to the south, the Cretaceous outcrop of Oued Tazega shows the following litho-stratigraphic succession (Fig. 6):

a- ~70 m-thick gray marl with siliciclastic intercalations with the following assamblege (Solignac, 1927): *Puzosia ligaata d'orb., Holcostephanus astieianus d'orb., Holcosdiscus aff. Incertys d'orb., Phylloceras infundibulum d'orb., Duvalia dilatata BLV, Belemnopsis pistilliformis* of Valanginien p.p-Hauterivien age. This age attribution was confirmed by Peybernès et al. (1996) as lateral equivalent of the Valanginian-p.p Hauterivian Seroula Formation.

b- ~150 m thick sequences made of shale, gray marl and limestone alternations. To the top the marly series shows sandstone successions. This unit is dated as Barremian age by its position.

c- ~200 m-thick sequences of gray marls, alternating with gray limestone beds with clear patina, which delivered rare microfauna i.e. lenticulina and could be attributed to Aptian.

2.8. Jebel Boulahouadjeb section

Jebel Boulahouajeb is a NNE-trending anticline located in the northwestern of Tebourba region. It is part of the large salt structure of Lansarine-Baouala. It exposes thick early Cretaceous sequences as previously described (Solignac, 1927; Zargouni, 1975; Masrouhi et al., 2013) and revised by the present work. This section shows the following lithological succession (Fig. 6):

a- ~400 m-thick pelitic sequences characterized by the stacking of lenticular sandstone deposit of variable size (from cubic centimeters to blocks of a few cubic meters). The top of this first unit is marked by schistose gray-blue marls, alternating with thin marly limestone beds. These series are attributed to Valanginian-aged Seroula Formation (Khessibi, 1967, Peybernes et al., 1996). The Valanginian-Hauterivian boundary is located in the upper marls-limestone sequences.

b- ~600 m thick sequences made of schistose gray marl showing intercalations of marly limestones with pyritic Ammonites and Aptychus (Solignac, 1927). The following microfauna association was decsribed: Lissocers grasianum d'orb., Phylloceras infundibulum d'orb., Phylloceras semisulcatum d'orb., Holodiscus incertus d'orb.. Limestone beds provided Calpionella tintacica, Calpionella carpatica with rare Hedbergellas and Lagenidae allowing to attribute the base of this set to the Early Hauterivian (dét. Raoult; in Zargouni, 1975). The upper part of these sequences delivered: *Epistomina eichenbergi*, *Spirillina neocomiana*, *Lenticulina ouachensis*, *Dorothia hauterivica*, *Lenticulina gaultina*. Above, studied samples delivered *Epistomina eichenbergi*, *Trochamina sp.*, *Hedbergella planispira*, *Gavelinella sp.*, *Lenticulina ouachensis*, *Dorothia hauterivica*, *Lenticulina eichenbergi*, *Vaginulina sp.* attributed to Hauterivian-Barremian age.

c- ~100 m-thick hard nodular gray limestones, usually as great benches or platy alternating with schistose gray marl layers containing: *Silisites seranonis d'orb.*, *Paranophites angulicostatus d'orb.*, *Crioceras angulicostatus* Wolam., *Crioceras barremense* Kil., which allow to attribute Barremian age (Solignac, 1927). In thin-section this level shows a micrite with Radiolaire and Hedbergelles. The gray schistose marls enclosing some intercalations of centimetric beds of brown quartzites. These sequences are covered by green pelites with sandstone blocks of varied size and rare carbonate intercalations.

d- ~400 m-thick sequences delivered spicules of echinoderms associated to *Lenticulina eichenbergi*, *Ammobaculites cretaceus*, *Gavelinella barremiana*, *Conorotalites bartensteini-intercedens-aptiensis*, *Epistomina ornata*, *Epistomina eichenbergi*, *Trochamina* sp., of the Upper Barremian.

e- ~250 m-thick sequence mainly formed by gray schistose marl alternations with marly limestones rich in organic matter beds. This interval constitutes an important reference level for correlating the subsidence of deposit areas on the Barremian-Aptian boundary.

f- ~120 m-thick sequences of gray marls covered by the quaternary plain of Oued Et tine containing *Lenticulina gaultina*, *Conorotalites aptensis*, *Valvulina* sp., *Ammobaculites*, *Dorothia oxycona*, *Dorothia trochus* which indicates Aptian age.

3. Lithostratigraphic correlation

In the Northern Tunisia, the early Cretaceous sequences has been described as “flyschoid deposits” (Memmi, 1981, 1989; Souquet et al., 1997). The Jebel Oust is considered in northern Tunisia as the type-section of lower Cretaceous. On the basis of Souquet et al. (1997), two 2nd order phases of sequence stacking are distinguished: (1) syn-rift prograding phase controlled essentially by tectonic subsidence and sedimentary infilling extending from late Tithonian to Hauterivian, and, (2) post-rift retrograding/prograding phase driven by transgressive-regressive processes extending from Barremian to Albian.

The Correlation of early Cretaceous measured sections, from northeastern Tunisia, shows a significant facies and thicknesses changes ranging from tens meters to hundreds of meters (Fig. 7). The Sidi-Salem locality situated in the Southeast of the study area exposes a reduced early Cretaceous series (Berriasian-Barremian) compared to Jebel Oust “reference section” where Early Cretaceous series reaches 2000 m of thickness. This variation attests an inconstant sedimentation rate along north Tunisia during early Cretaceous. This local distribution sedimentation was qualified by previous work as the result of the so-called “Zaghouan flexure” (or Zaghouan fault) separating subsiding Jebel Oust area from other edge with reduced thickness (Jebel Sidi-Salem). Apparently, no significant flexure has worked at the base of the current Zaghouan fault during the Barremian, but it is possible to envisage a synsedimentary fault or set of faults further west separating subsiding areas of the Tunisian trough (Jebel Oust) from other sections with reduced thickness (Turki, 1988; El Khazri et al., 2013). Further north, in the Medjez-el-Bab area, the Barremian is the old Cretaceous deposits in outcrop. In this area, Barremian sequences of Jebel Bou Rahal do not exceed 100 m, however 4 km to the north, the section of Sidi Mohamed Akermi exposes 180 m-thick Barremian deposits (Fig. 5). To the northwest, in the west of the Lansarine structure, Oued Tazega locality exposes 220 m-thick Valanginian-Barremian deposits, while the Jebel Boulahouadjeb -which is located two kilometers to the north- exposes 1500 m-thick sequences for the same period. Consequently, Jebel Boulahouadjeb is qualified as a significant depocenter with a very high rate of sedimentation. Taking in account the inherited fault systems controlled this structure, the Boulahouadjed depocenter is created in response to an active listric deep normal fault growth and associated to halokinetic movement. The Cretaceous series of Jebel Boulahouadjeb, reviewed in the present study, reveals strong facies and thickness similarities with the Jebel Oust "reference" section (Fig. 3). Similarly, Early Cretaceous series exposes frequent siliciclastic turbidite and reworking metric sandstone blocks of varied size comparable to those described by Souquet et al. (1997) in Jebel Oust.

The compilation of the early Cretaceous sequences data conduct to a number of paleogeographic concerns. The lower Cretaceous sequences, of northeastern Tunisia, show thickness and facies considerable variation reflecting an irregular sea floor (Fig. 7). The Jebel Boulahouadjeb thick section, 50 km to the northwest of Oust locality, shows strong facies and thickness similarities of Jebel Oust “type-section”. These two sections reflect an active subsidence, which suggest basement faults activity (probably Zaghouan and Teboursouk faults) under an extensional to transtensional tectonic regime. Between these two localities, further sections show reduced early Cretaceous sequences. In details, the 80 Km-long correlation clearly reflects basin infilling very similar to others Tethyan provinces that are controlled by tilted blocks geometry. In addition, this correlation revealed for the early Cretaceous, a repetitive depocenters limited and shaped by major synsedimentary listric normal fault systems.

The Aptian–Albian ages are perceived to have deposited the thick and rapid sediments rates. The Aptian-Albian epoch was also characterized by previous studies as the most extreme extensional period of the south Tethyan margin in North Tunisia (Souquet et al., 1997; Masrouhi et al., 2014b; Naji et al., 2018).

After Aptian period, the sandstone deposition is more limited in space, and sedimentation becomes uniform with homogeneous facies mainly composed of marls and fine-grained limestones. During

Albian, a mudstone limestone platform is installed overall the basin. Furthermore, Aptian-Albian sediment shows considerable thickness variation but no significant facies variation (sequences are of pelagic to hemi-pelagic facies). During this period, Jebel Oust remain a subsident area with a high rate of sedimentation. To the West, Jebel Rihane and Jebel Kechtilou structures show also a significant thick Aptian-Albian series with thickness that differs from one section to another (Ben Yagoub, 1978; El Ouardi, 1996; Haggui, 2012;). In these two localities, numerous Aptian-Albian slump folds are associated to further instability features. Sequences are qualified to contain numerous features of soft-sediment deformation correlated to the tectonic extension (Naji et al., 2018). From Jebel El Mourra to Jebel Bou Rahal (Medjez-El-Bab area) Aptian-Albian series range from 20 m to 225 m. 4 km to the north, Sidi Mohamed Akermi area exposes 785 m-thick Aptian-Albian deposits. This area exposes specifically significant thickness variation of Aptian-Albian sequences (Fig. 5) associated to numerous slumps folds, calcareous nodules, breccia and conglomerates which indicates a sedimentation operated above an irregular sea floor. Consequently, the distribution of sediments was clearly to have been operated under tilted-block geometry tectonic control. The correlation highlights also a repetitive high sedimentation rates depocenters separated by area with less rates (Fig. 5). Few kilometers southwest of Oued Tazega, a reduced Aptian-Albian sequences are found in the Jebel Bechtab structure. In Oued Tazega and Boulahouadjeb structures, only Aptian series are correlated, for which thickness strongly varies from ~200 m in Oued Tazega and ~1400 m in Jebel Boulahoudjeb, and with abundant synsedimentary features such as slumps folds (Figs. 8, 9), sealed normal faults, “olistolith” blocks and breccia (Masrouhi et al., 2013; Naji et al., 2018).

The Correlation of late Cretaceous series shows the same configuration with considerable thickness variations, but without facies change (Fig. 8). Since the Cenomanian, the facies heterogeneity decreases and all sequences are of pelagic to hemi-pelagic facies. A significant thickening is attested in Jebel Oust, Jebel Rihane, Jebel Kechtilou and Sidi Mohamed Akermi which reflects a persisted tilted blocks geometry, revealed for the Late Cretaceous, and possibly shaped by major synsedimentary normal fault systems (Fig. 9). Coniacian–Santonian deposits seem to seal all the above mentioned differentiation and described as post-rift marl-rich sequences (Naji et al., 2018).

4. Fault kinematic analysis

The paleostress regimes are reconstructed based on the analysis of fault slip data populations measured in the field at several sites. Brittle deformation is frequently quantified using fault kinematic analysis methods. These methods are based on measurements of mesoscale faults and associated striation. Sometimes, the observed fault planes have more than one set of striation. Distinct families of striae has been separated on the basis of geological field data using relative chronology of the striations (crosscutting relationships) and their relations with regional Known tectonic events. Fault kinematic analysis commonly determines the reduced stress tensor, i.e. the directions of principal stresses ($\sigma_1>\sigma_2>\sigma_3$), and the stress ratio R = (σ_2-σ_3/σ_1-σ_3). Therefore, to support our structural interpretation, more numerous striated fault planes ranging from early to late Cretaceous series are measured and computed. The fault kinematic analysis of mesoscale faults documents a quantitative reconstruction of paleostresses. These paleostresses provide useful information on the compressional, extensional or strike-slip origin of larger structures.

4.1. Early Cretaceous faults

Early Cretaceous sequences display abundant conglomeratic horizons and slumping, in addition to significant thickness changes (Masrouhi et al., 2013, Gharbi et al., 2015; Naji et al., 2018). The early Cretaceous sequences studied in this work show abundant ~NW, ~NE and ~E-trending centimetric, metric to decametric-scale sealed normal faults. Faults data collected from Early Cretaceous of Jebel Oust and Jebel Sidi-Salem structures are rotated, using fault diagram, to their original orientation to restore their initial tectonic extension. The back-tilted fault diagrams typify a NNW-SSE to NE-SE extensional tectonic regime. Locally, E-trending extension is highlighted.

The first three sites show homogenous NNW-trending extensional regime. In details, the first stereoplot (Fig. 10, F13) shows extensional stress regime with a NNW-SSE minimum stress axis (σ_3). These measurements have been done in the Valanginian series of the Jebel Oust's northern limb. The second site is located in Oued Tazega locality. These measurements have been done in the Barremian strata. The stereoplot shows (Fig. 10, F24) typical extensional paleostress regime with NNW-SSE minimum stress axis. The Other fault kinematic data (stereoplot F6 in Fig. 10) collected from Sidi-Salem-Messella structure highlight normal fault populations. This stereoplot provides similar state of paleostress with NNW-SSE local minimum stress axis (σ_3).

One stereoplot (Fig. 10, F17) typifies ~N-trending extentional tectonic regime. This latter is calculated from Barremian fault population collected in the same region. Similarly, another stereoplot (Fig. 10, F12) collected from Valanginian sequences of Jebel Oust provides a local NE-trending extensional paleostress tensor.

Four back-tilted fault diagrams (F6', F15, F18 and F21, Fig. 10) show a general E-trending extensional tectonic regime with local perturbed direction of σ_3 axis. In details, two measurements (Fig. 10, F6' and F21) have been done in Barremian age strata of Jebel Messella structure and provide E-trending minimum stress axis (σ_3). This different local state of stress could be explained probably by its particular structural setting at the junction of Sidi-Salem-Messella major fault systems. The Third computed paleostress field (Fig.10, F15) shows a pattern of WNW-ESE minimum stress axis (σ_3). These measurements have been done in Hauterivian sequences of Jebel Oust. The back-tilted fault diagrams deduced from fault data collected in Barremian sequences of Jebel Bouala (Fig.10, F18) highlights E-W extensional tectonic regime.

4.2. Aptian-Albian faults

An Aptian-Albian unconformity is reported in the whole of Tunisia. The origin of the associated deformations is still debated. Several authors assign this unconformity as the result of an extensional origin created progressive unconformities of the sedimentary basin-fills (Turki, 1985; Masrouhi and Koyi, 2012; Masrouhi et al., 2013). Numerous Aptian-Albian faults are collected from the northeastern Tunisian domain. The Aptian Albian deposits seem to be controlled by NW to NE-trending major fault systems. The back-tilted Albian fault diagram shows an extensional tectonic regime with general NE-SW tectonic extension. This state is significantly homogenous in the entire region (Fig. 11).

The first paleostress tensor collected from fault populations measured in the Albian sequences of Jebel Kechtilou (Fig. 11, F23) typify permanently N-S extensional tectonic regime, which appears that prevailed during the entire Albian time. The computed stress tensors belonging to the paleostress state of Jebel Sidi-Salem during Aptian-Albian times reveals again a relatively homogenous stress field. Two sites (Fig.11, F1 and F16) collected from Albian series provide a tectonic regime with a NE-SW tectonic extension. The last site (Fig. 11, F7) situated in Lella Sellalia located in the north-east of Lansarine structure shows also a local pattern highlighting a NE-SW minimum stress axis during Aptian-Albian period.

4.3. Cenomanian-Turonian faults

The most Cenomanian-Turonian striated fault planes indicate that the dominant stress regime in the northeastern Tunisia is a WNW-ESE to NW-SE extensional tectonic regime (Fig. 12a). The directions of extension computed from fault-slip data sets give a remarkably Cenomanian-Turonian homogeneous state of stress in all sites from northeastern Tunisia.

The first paleostress tensor is calculated from Cenomanian-Turonian faults of Jebel Kechtilou structure. The stereoplot of this first site (Fig.12a, F19) highlights WNW-ESE extensional tectonic regime. The second fault kinematics data (Fig. 12a, F3) collected from Sidi-Salem-Messella structure highlight normal fault populations. The stereoplot F3 provides a local NW-SE minimum stress axis (σ_3), which confirms the regional paleostress state and permit to relate the regional scale deformation to this dated stress regime.

The Jebel Bechteb structure (Glib El Abiod area) offers also Cenomanian-Turonian faults populations. Most of them are sealed faults and the calculated paleostress tensor is characterized by NW-SE minimum stress axis (Fig.12a, F9').

4.4. Campanian-Maastrichtian faults

During Campanian-early Maastrichtian times, a regional NNW-SSE to NW-SE extension is documented by the synsedimentary fault populations associated to these sequences (Fig. 12b). This extension is calculated from NNW- and NNE-trending conjugate normal fault systems that cut the Campanian-Maastrichtian carbonates of the Abiod Formation in two localities from northeastern Tunisia, and, all of them are sealed normal faults. The first site is collected from the Abiod Formation of Dar Zoufira locality. The corresponding fault kinematic diagram (Fig.12b, F27) provides a NE-SW extensional tectonic regime. Two additional sites (Fig. 12b, F28 and F29) collected from the lower member of the Abiod Formation of Oued Zitoun locality (northwestern part of Mateur region) show opposite extensional regime. The stereoplots F28 (Fig. 12b) provides NW-SE minimum axis and the stereoplot F29 (Fig. 12b) gives NE-SE minimum axis. This local stress axis perturbation confirms the regional paleostress state and permit to relate the regional scale deformation to this dated stress regime. This later began to change from pure extension to transtensional regime related to the African plate trajectory.

5. Present-day regional geometry of north Tunisia

Since the 1980^s, the main crustal structures of North Africa are interpreted as the result of distinguished crustal blocks, which were converged and collided during Alpine Cenozoic period. In that model, different domains are identified on the basis of their lithologic, chronologic and structural affinities (Guiraud, 1998; Roure et al., 2012). In the Atlas region of Tunisia, the belt is classically divided into six major domain i.e. the northern allochthonous Numidian Domain, the northern Atlassic domain, the central Atlassic domain, the southern Atlassic domain, the Saharan platform and the Eastern Sahel and Pelagian domain. Whether the geodynamic interpretation of northern Atlassic domain, authors widely accepted two major fault systems i.e. the Teboursouk thrust fault and the Zaghouan-Ressas thrust fault (Jauzein, 1967; Morgan et al., 1998; De Lamotte et al., 2009; Khomsi et al., 2016). The structural style and the kinematic interpretation suffer from little or non-quantitative documentation on a large scale. Only few works attempt to solve the geometrical reassembly by retracing long structural transects (Rouvier, 1977; Ben Ferjani et al., 1990; Morgan et al., 1998, Khomsi et al., 2009, 2016)

In the study area, the Zaghouan-Ressas belt thrust contact is the major northeast-trending fault system, which constitutes the southern edge of a major domain called the Zaghouan unit. This later was defined as T2 by Jauzein, 1967 in its major fault systems enumeration in Tunisia, which was defined 6 major lines numbered from T1 to T6). In the Zaghouna area, this system shows the Jurassic platform limestones thrusted over the Cenozoic sequences (Turki et al., 1988; Khomsi et al., 2016). Jurassic sequences are now at 1300 m of elevation, and thus it is believed that they have elevated up at least 2.5 km above their original position. This structural setting is well defined on the basis of lithostratigraphic and structural affinities. Previous studies outlines the implication of the Triassic evaporites in the main thrust fault (Turki, 1980; Turki et al., 1988; Khomsi et al., 2016). This fact is favor to admit that Triassic evaporites are previously concerned by earlier tectonics. It is also clear that thickness and facies variations characterize the Jurassic and cretaceous sequences early controlled by active extensional setting (Souquet et al., 1997; Morgan et al., 1998). In thin-skinned model of deformation, previous studies highlight that such variation guides the style and the position of the major subsequent thrusting (Turki et al., 1988; Souquet et al., 1997; Morgan et al., 1998). However, Khomsi et al. (2016) have distinguished two main detachment level: Triassic evaporites and late Eocene shales. In addition, this work imply the role of reverse basement fault at depth of 2 Km. This major tectonic unit shows numerous normal faults that are preserved on the major thrust system. All the above mentioned features are in favor of a system of fault inversion model for the development of the major Zaghouan thrust system. The Zaghouan unit is limited to the North by thrusted unit called the Teboursouk thrust unit. This front is early defined as major fault system in north Tunisia (defined as T4 by Jauzein, 1967). This area is characterized by thick Aptian–Albian sequences and exhibits frequent outcropping salt structures belonging to the northeastern Maghreb salt province (Masrouhi et al, 2013; Jaillard et al., 2017). In addition, the front of this unit is scattered by dispersal Jurassic outcropping assigned to upper Tithonian–Berriasian sequences (Peybernes et al., 1996. Curiously, these sequences are usually inverted when outcrop. Previous studies have been demonstrated that these series are the deepest deposits of the lower Cretaceous rift (Peybernes et al., 1996). These pre-configurations are inverted by subsequent shortening events and incorporated in cleaved zone of folding and thrusting. The present-day configuration highlight at least two major events of folding. Triassic evaporites are associated to the shortening and the growth of the structures.

Cenozoic contractional events resulted in the reactivation of earlier inherited structures, the development of new faults, and the development of major thrust zones are also well identified in the far west Algerian basins illustrating equivalent geological field and events, i.e. the Hodna basin and the Chelif basin (Roure et al., 2012) and Sellaoua basin (for more details see Herkat and Guiraud, 2006). Geologic data document the pre-Neogene inversion of former depocenters in the Saharan Atlas in Algeria (Roure et al., 2012). Previous studies documented some of the Mesozoic normal faults directly extend into the crystalline basement, whereas others become listric at depth and root along Triassic evaporites. Many of them have been reactivated as reverse faults, or passively rotated in fold and thrust structures during subsequent compression. In Algerian basins, lateral thickness variations within the Jurassic and Cretaceous series are shown, which reflect the south Tethyan passive margin basins developed during Mesozoic times.

Field relationships between units and the present distribution of faults and folds clearly involve the role of the inherited structures in the growth and the style of north Tunisia fold-and-thrust belt. Halokinetic structures developed during Mesozoic rifting, led to the implication of the Triassic evaporites in major thrust systems.

6. Discussion

During Mesozoic times, the North African domain pertain to the Southern Tethyan rifted continental margin. The rift stage, started during Permian (?)–Triassic, is followed during Jurassic and Cretaceous times by passive margin basin's style (Tlig, 2015; Martín-Martín et al., 2017; Moragas et al., 2017). The correlation of 10 sections studied from the northeastern Tunisia, on the base of new stratigraphic precisions together with existent data from previous works, shows a considerable thickness and facies variations of Cretaceous series reflecting clear tilted-blocks geometry. The early Cretaceous series in northern Tunisia, showing significant thicknesses variation, reflecting that they were deposited above an irregular sea floor. The abundant synsedimentary features (slumps, sealed normal faults, syntectonics conglomerates, lenticular sandstone blocks…) testify for Mesozoic extensional tectonic regime and display character of related growth strata (Masrouhi et al., 2013, 2014a; Naji et al., 2018). Based on this study and previous paleogeographic reconstruction's data (e.g. Souquet et al., 1997; Soua, 2016), the early Cretaceous sequences of the Tunisian Atlas can be subdivided into four second order cycles. The first two cycles extending from late Tithonian to Hauterivian are included within the rifting phase where basement block-faulting predominates (creating regional tilted blocks geometry). Third and fourth cycles extend from the Barremian to Albian can be integrated within a geological setting related to the intra-basin growth faulting. The Jebel Oust Section is considered as the type-section of lower Cretaceous in northern Tunisia (Ben Ferjani et al., 1990; Souquet et al., 1997), where 2600 m-thick siliciclastic and marly sequences have been deposited. The present study demonstrates that an equivalent to this "reference" section is even found 50 km to the north. Therefore, taking in account the current stratigraphic precisions, the 1700 m-thick Jebel Boulahouadjeb section may be also undertaken as a representative section equivalent to "reference" section in northern Tunisia where the early Cretaceous is thick and fossiliferous (Fig. 3). Moreover, during early Cretaceous times, these two localities (Jebel Boulahouadjeb and Jebel Oust) seem to be two significant subsident depocenters with a high rate of sedimentation, created in response to active normal faulting. Similarly, the reworked blocks and soft-sediment deformations observed until late Barremian determines the existence of listric active faults controlling the Cretaceous sedimentation of northeastern Tunisia domain. The fault kinematic analysis highlights a NNW to NE extensional regime during early Cretaceous, showing local E-W extensional regime.

The Aptian–Albian ages are perceived to have the most extreme extensional related-structures time of the south Tethyan edge in North Tunisia (Souquet et al., 1997; Masrouhi et al., 2014b). These data are well correlated on regional scale in term of subsidence, for which recent studies were established subsidence curves from the central high Atlas of Morocco to eastern Tunisia (Moragas et al., 2018). The lower cretaceous period is recognized as the period of rapid subsidence in northern Tunisia and accompanied by active salt movement. The studied sections show significant thickness variation of Aptian-Albian deposits accompanied with numerous slump folds (Masrouhi et al., 2013; Naji et al., 2018) which indicates clearly a contemporaneous submarine slope in the regional context of the Southern Tethyan rifted continental margin that operates in an extensional regime with tilted blocks geometry. This instability indicates a synsedimentary listric normal fault systems activity in a context of an extensional paleomargin.

Since the Cenomanian, the facies heterogeneity decreases. The homogeneity of the late Cretaceous facies reflects a basin post-rifting subsidence history. The back-tilted fault diagrams show WNW to NW-trending extension during Cenomanian time. Coniacian–Santonian deposits seem to seal all the aforementioned differentiation and can be qualified as post-rift marl-rich sequences followed by limestone and marl sequences approximately homogeneous in the entire basin (Fig. 13). During Campanian-Maastrichtian times, a regional NW-trending extension is documented, in which Upper Cretaceous tectonic was related to a general North Africa extensional paleomargin, at least until earliest Maastrichtian time (Masrouhi et al., 2008; Gharbi et al., 2013).

In addition to the above-mentioned criteria, the normal faulting at depth actively controls Triassic salt movements. The Aptian-Albian times were reported as the maximum period of salt structure growth in northern Tunisia (Masrouhi et al, 2013; Jaillard et al., 2017). The evolution of salt structures are related to fault-controlled depocenters that occur and were observed along all the Atlassic margin from Morocco (Moragas et al., 2018) to Tunisia (Jaillard et al., 2017). The tilted block systems is associated to salt evacuation and then the creation of mini-basins in local fault blocks (Fig. 13).

7. Conclusion

Detailed lithostratigraphic surveys, long sequence correlations, faults kinematic analysis together with existent data of relationship tectonic-sedimentation allow us to constrain the structural architecture and the deformational style of the Cretaceous basin in northern Tunisia as basin with a sedimentation patterns preferentially guided by tilted blocks geometry. The main conclusions are as follows:

- Significant facies and thickness variations are deduced along the northeastern Atlas of Tunisia,

- N-S to NE-SW extensional tectonic regime prevailed during early Cretaceous, and, WNW-ESE to NW-SE extension during late Cretaceous,
- The normal faulting is associated to repetitive local depocenters with a high rate of sedimentation as well as abundant syntectonic conglomeratic horizons and slump folds, and
- The tilted block system is associated to salt evacuation and then the creation of mini-basins in local fault blocks.

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Figures captions

Figure 1. Simplified geologic map of northern Tunisia (modified from Bel Haj Ali et al., 1984) with location of the studied sections in northeastern Tunisia. The inset on the top left shows the location of Tunisia in North Africa.

Figure 2. Detailed lithostratigraphic subdivision of Cretaceous sequences in Jebel Sidi-Salem.

Figure 3: NE-SW lithostratigraphic correlation of Early Cretaceous series of Jebel Oust and Jebel Boulahouadjeb sections.

Figure 4. Detailed lithostratigraphic subdivision of Cretaceous sequences in Jebel Kechtilou.

Figure 5. NW-SE lithostratigraphic correlation of Cretaceous sequences in Medjez El Beb area (Jebel El Mourra, Jebel Bou Rahal and Sidi Mohamed Akermi).

Figure 6. Detailed lithostratigraphic section of early Cretaceous series in Oued Tazega and the Jebel Boulahoudjeb. (a), (b) and (c) correspond to lithological units, for detailed description, see in the text.

Figure 7. Lithostratigraphic correlation of Cretaceous sequences in Northeastern Tunisia from the Jebel Sidi Salem (south) to Jebel Boulahouadjeb (north) including the Jebel Oust type-section.

Figure 8. Photographic plate illustrating some important tectono-sedimentary features in the study area: A) Panoramic view looking to the northwest of the Boulahouadjeb showing thick lower Cretaceous series. B) Panoramic view showing the contact between Triassic strata of Lansarine structure and the early Cretaceous sequences in Oued Tazega. C) Panoramic view illustrating Tempestite deposits in early Cretaceous series of Jebel sidi-Salem structure. D) Detailed photographic plate of (C). E) Field photo looking to the North-East showing nodular limestone of the uppermost Albian outcropping in the northern limb of Jebel Sidi-Salem testifying to a synsedimentary paleoslope. F) Field photo of sealed synsedimentary early Cretaceous normal fault in the Jebel Sidi-Salem area. G) Detailed view of photo (F) showing the fault plane. H) and (I) Field photos showing nodular Aptian-Albian limestone sedimentation (septaria) (black arrows) testifying to a synsedimentary submarine slope.

Figure 9. Photographic plate illustrating some important tectono-sedimentary features in the study area: A) Panoramic view looking to the north-east showing Cenomanian-Eocene series of Jebel Bechtab structure. B) Panoramic view looking to the north showing the thick early Cretaceous series of Jebel Oust. C) Field photo showing Barremian sandstone slump folds of northern limb of Jebel Oust testifying sedimentation above an irregular sea floor. D) Syn-tectonic conglomeratic redeposits in the Albian sequences of Medjez El Beb area. E) Field photo showing slump structures between two parallel layers (Medjez El Beb structure) testifying to a sedimentation above an irregular sea floor. F) Small-scale extensive deformation preserved showing a sealed normal fault in the Aptian sequences

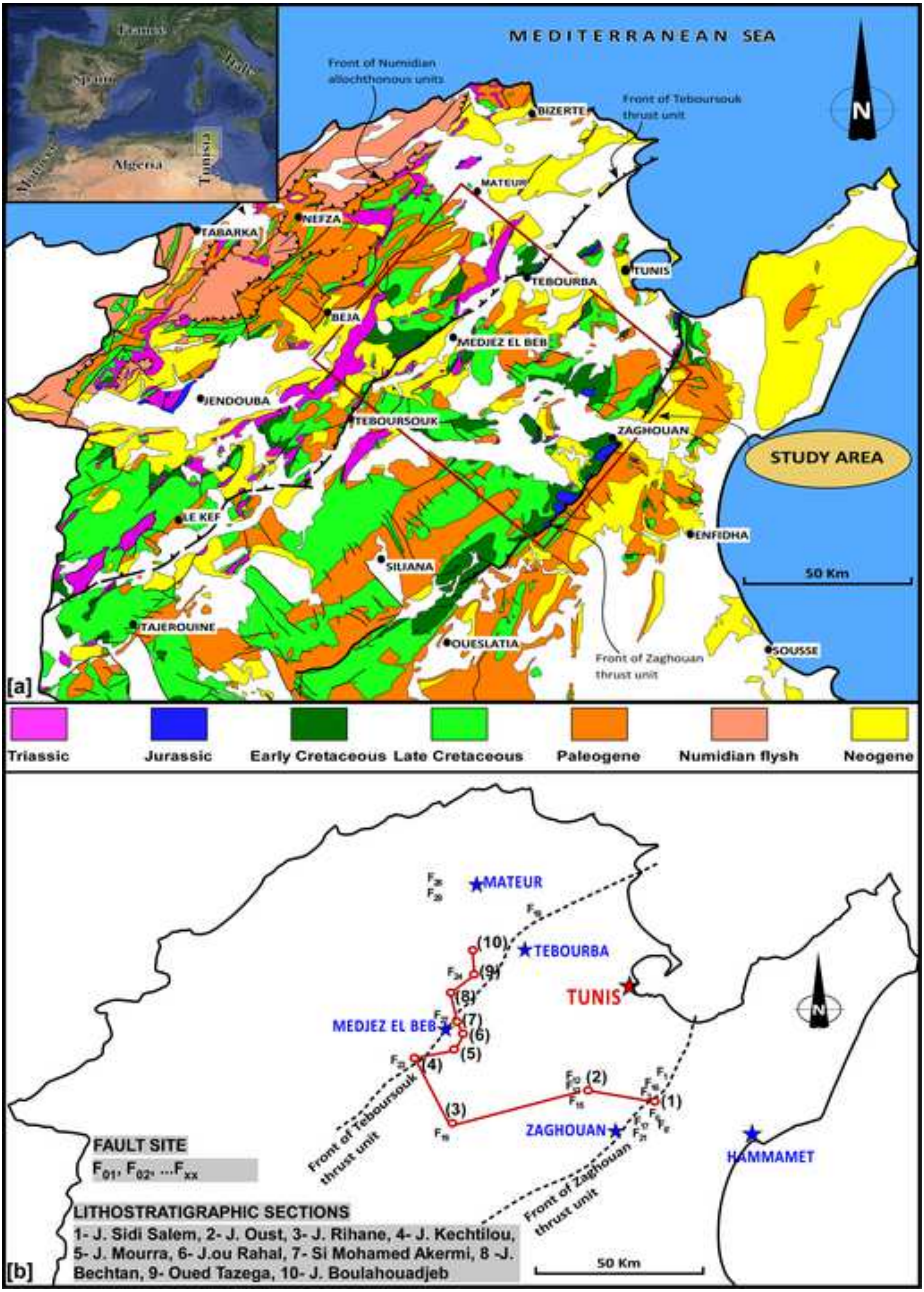
of Jebel Oust. G) Syn-sedimentary sealed normal fault in the Cenomanian sequences of the southern limb of Glib El Abiod structure. H) Small-scale sealed normal fault in the Aptian deposits (M'Cherga formation) of Jebel Oust.

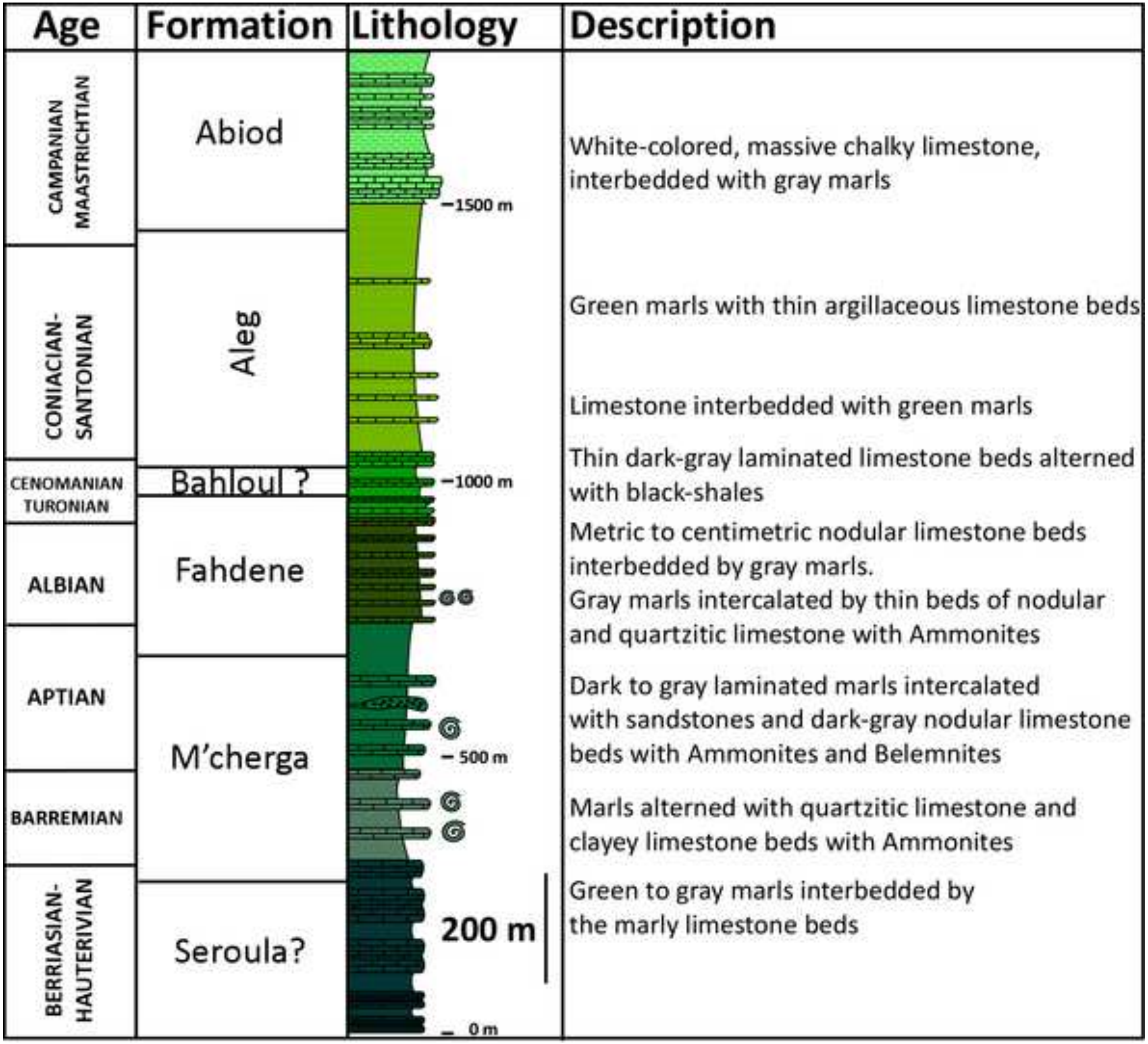
Figure 10. Fault kinematic analysis of the synsedimentary early Cretaceous normal faults with lower hemisphere stereograms projection of back-tilted data.

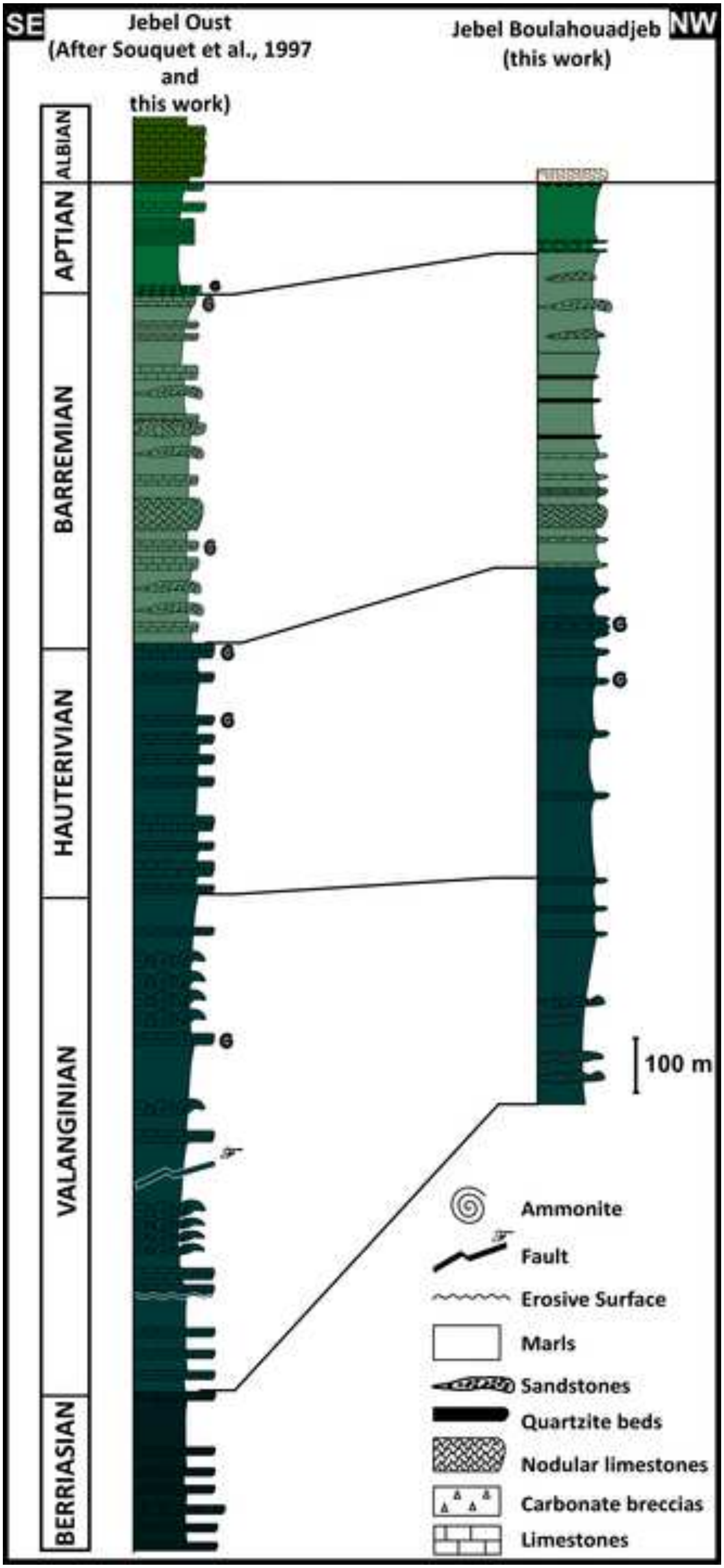
Figure 11. Fault kinematic analysis of the synsedimentary Aptian-Albian normal faults with lower hemisphere stereograms projection of back-tilted data.

Figure 12. Fault kinematic analysis of the synsedimentary late Cretaceous normal faults with lower hemisphere stereograms projection of back-tilted data: (a) During Cenomanian-Turonian times. (b) During Campanian-Maastrichtian times.

Figure 13. Simplified reconstructed schematic cross-section (not to scale, in detail this section do not attempt to model the entirely basin's elements) of Northern Tunisia during Cretaceous showing the general structural configuration of the basin (based on Masrouhi et al., 2013, 2014a; Naji et al., 2018).

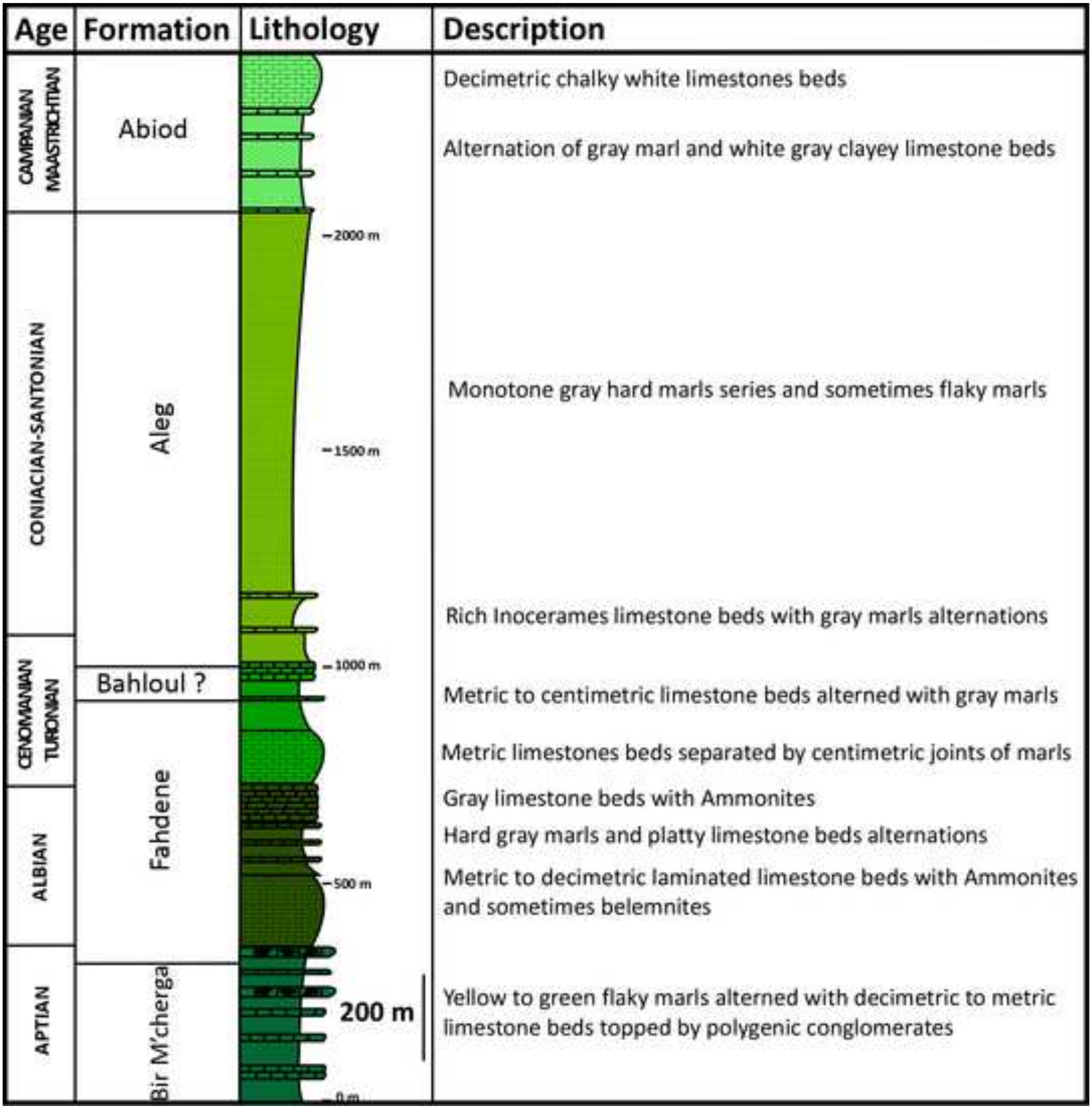

France
Italy
Spain
Morocco
Algeria
Tunisia
MEDITERRANEAN SEA
N
Front of Numidian allochthonous units
Front of Teboursouk thrust unit
BIZERTE
MATEUR
NEFZA
TABARKA
TUNIS
TEBOURBA
BEJA
MEDJEZ EL BEB
JENDOUBA
TEBOURSOUK
ZAGHOUAN
STUDY AREA
LE KEF
ENFIDHA
SILIANA
50 Km
TAJEROUINE
OUESLATIA
SOUSSE
Front of Zaghouan thrust unit
[a]
Triassic
Jurassic
Early Cretaceous
Late Cretaceous
Paleogene
Numidian flysh
Neogene
MATEUR
TEBOURBA
TUNIS
MEDJEZ EL BEB
ZAGHOUAN
HAMMAMET
(10)
(9)
(8)
(7)
(6)
(5)
(4)
(3)
(2)
(1)
Front of Teboursouk thrust unit
Front of Zaghouan thrust unit
FAULT SITE
F01, F02, ...Fxx
LITHOSTRATIGRAPHIC SECTIONS
1- J. Sidi Salem, 2- J. Oust, 3- J. Rihane, 4- J. Kechtilou, 5- J. Mourra, 6- J.ou Rahal, 7- Si Mohamed Akermi, 8 -J. Bechtan, 9- Oued Tazega, 10- J. Boulahouadjeb
50 Km
[b]


Age
Formation
Lithology
Description
CAMPANIAN MAASTRICHTIAN
Abiod
1500 m
White-colored, massive chalky limestone, interbedded with gray marls
CONIACIAN-SANTONIAN
Aleg
Green marls with thin argillaceous limestone beds
Limestone interbedded with green marls
CENOMANIAN TURONIAN
Bahloul ?
1000 m
Thin dark-gray laminated limestone beds alterned with black-shales
ALBIAN
Fahdene
Metric to centimetric nodular limestone beds interbedded by gray marls.
Gray marls intercalated by thin beds of nodular and quartzitic limestone with Ammonites
APTIAN
M'cherga
500 m
Dark to gray laminated marls intercalated with sandstones and dark-gray nodular limestone beds with Ammonites and Belemnites
BARREMIAN
Marls alterned with quartzitic limestone and clayey limestone beds with Ammonites
BERRIASIAN-HAUTERIVIAN
Seroula?
200 m
0 m
Green to gray marls interbedded by the marly limestone beds


SE
Jebel Oust
(After Souquet et al., 1997
and
this work)
Jebel Boulahouadjeb
(this work)
NW
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
100 m
Ammonite
Fault
Erosive Surface
Marls
Sandstones
Quartzite beds
Nodular limestones
Carbonate breccias
Limestones

Figure

Click here to access/download;Figure;Fig. 4.tif



Figure

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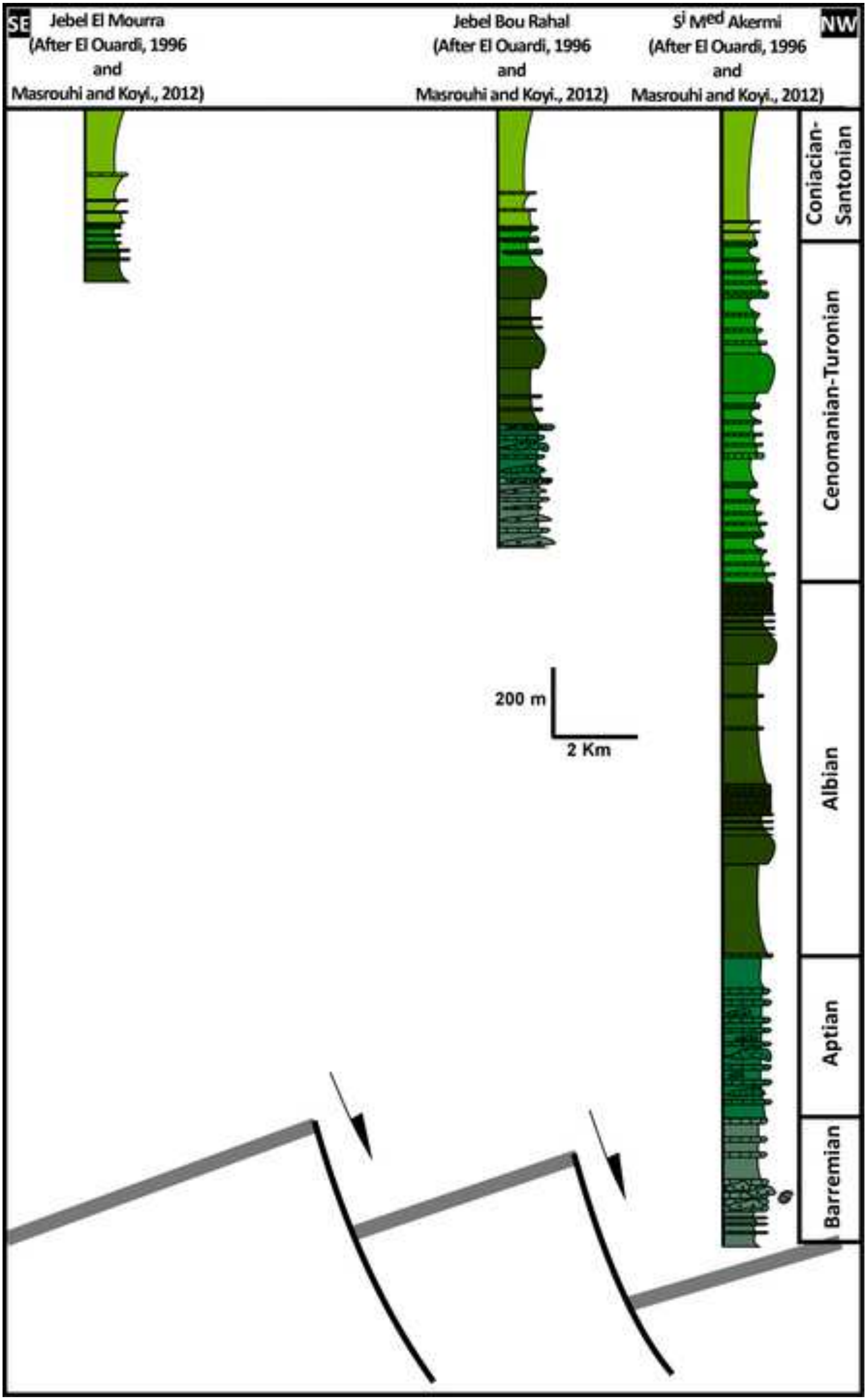

Figure

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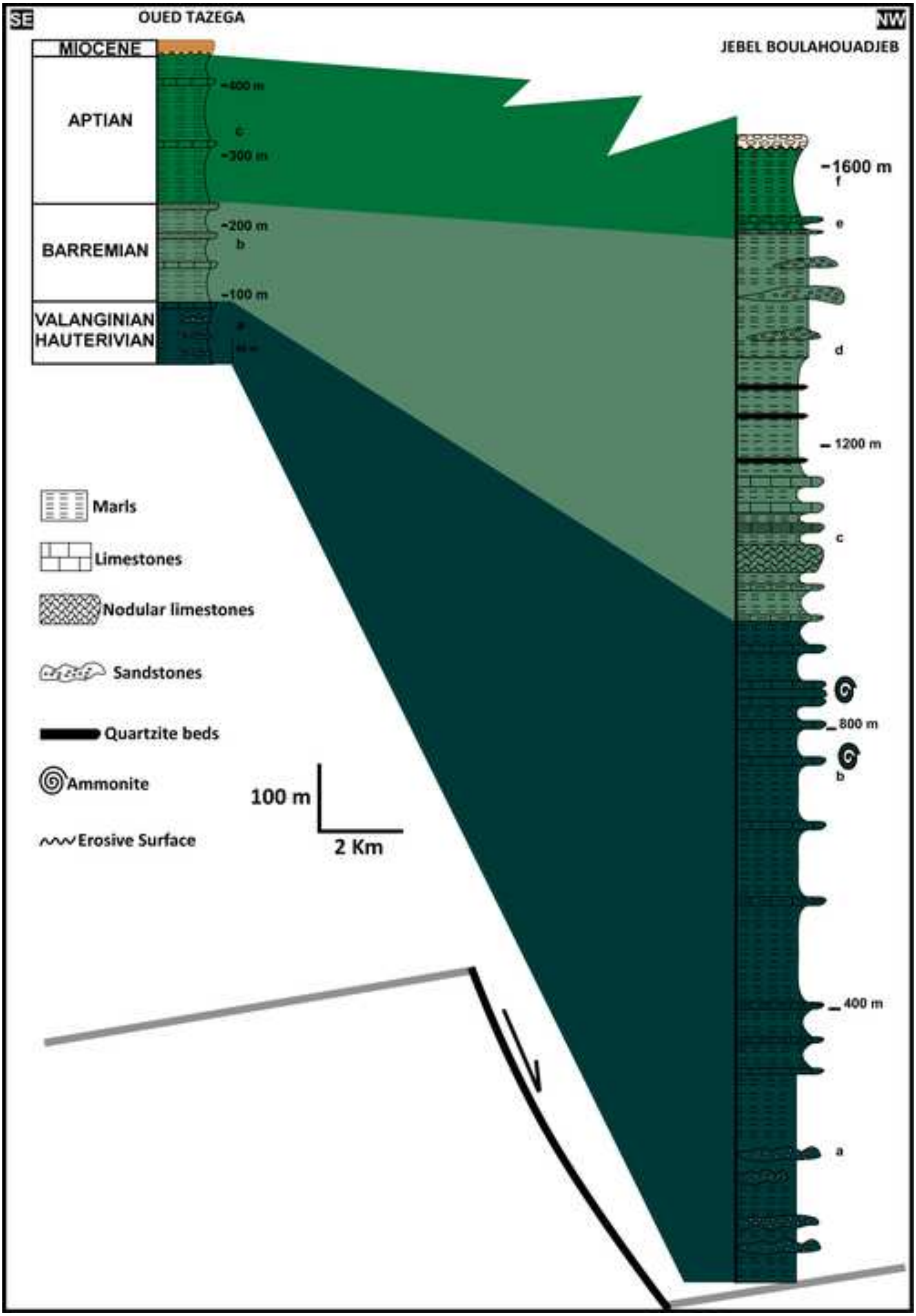

Figure

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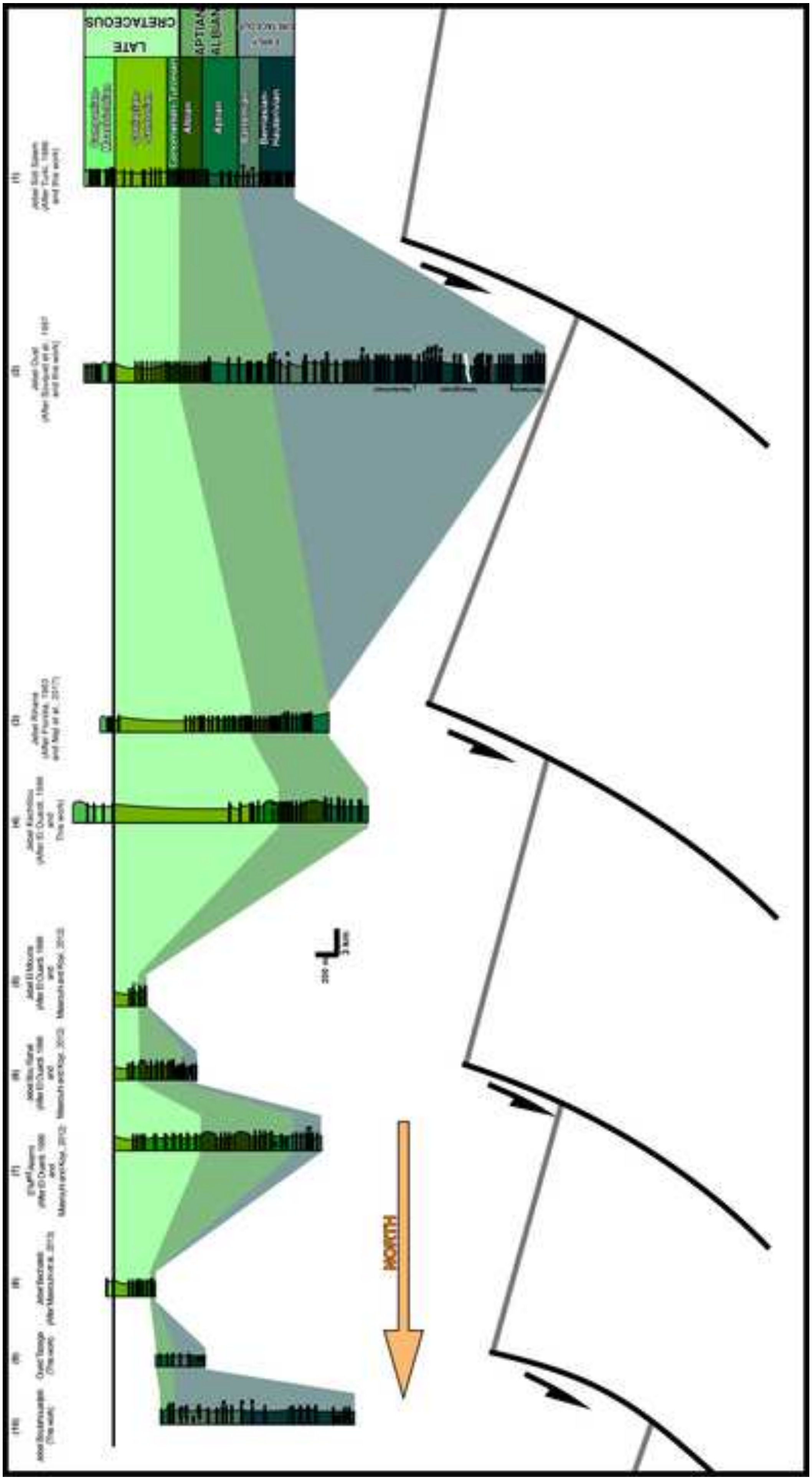

Figure

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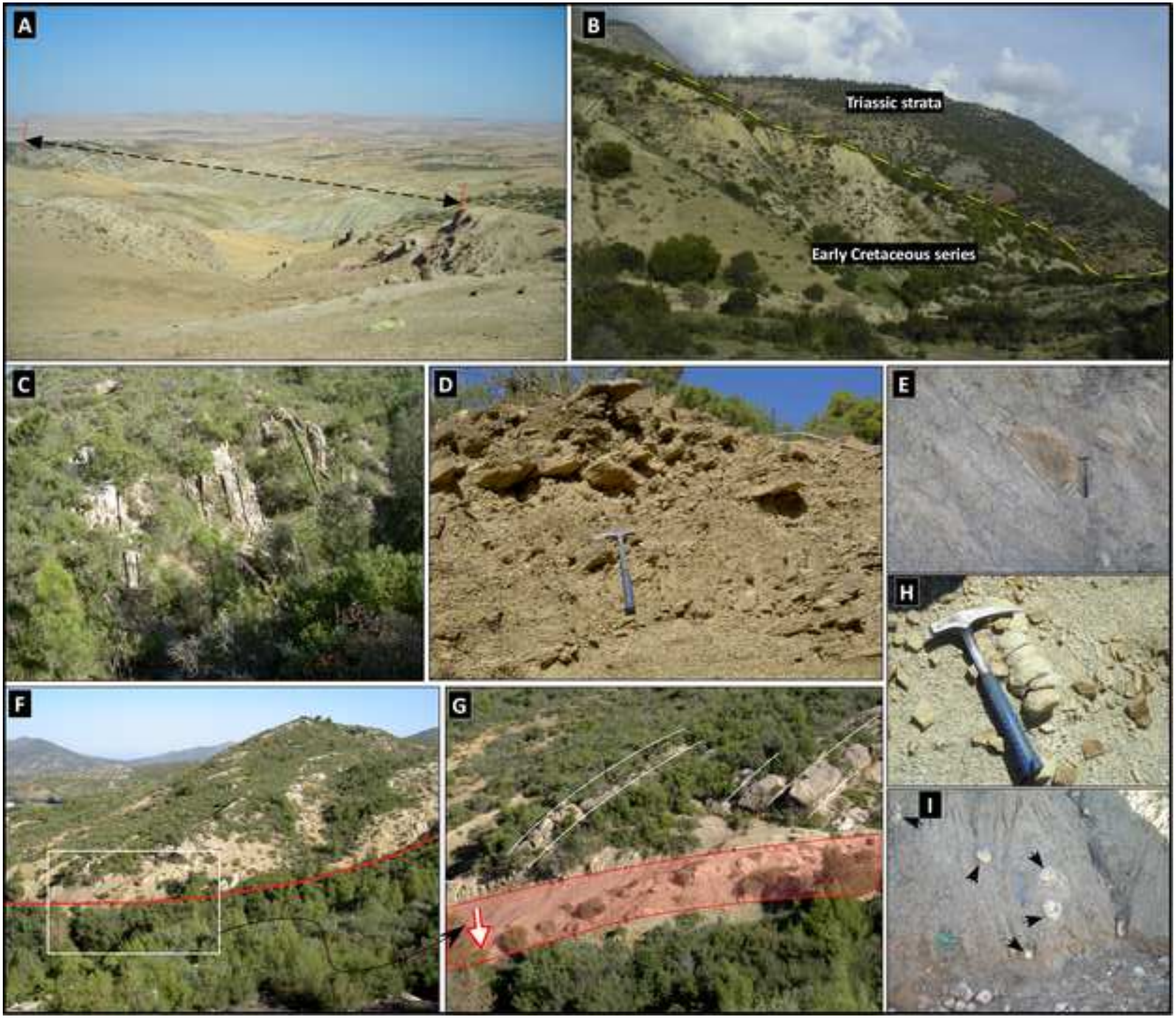
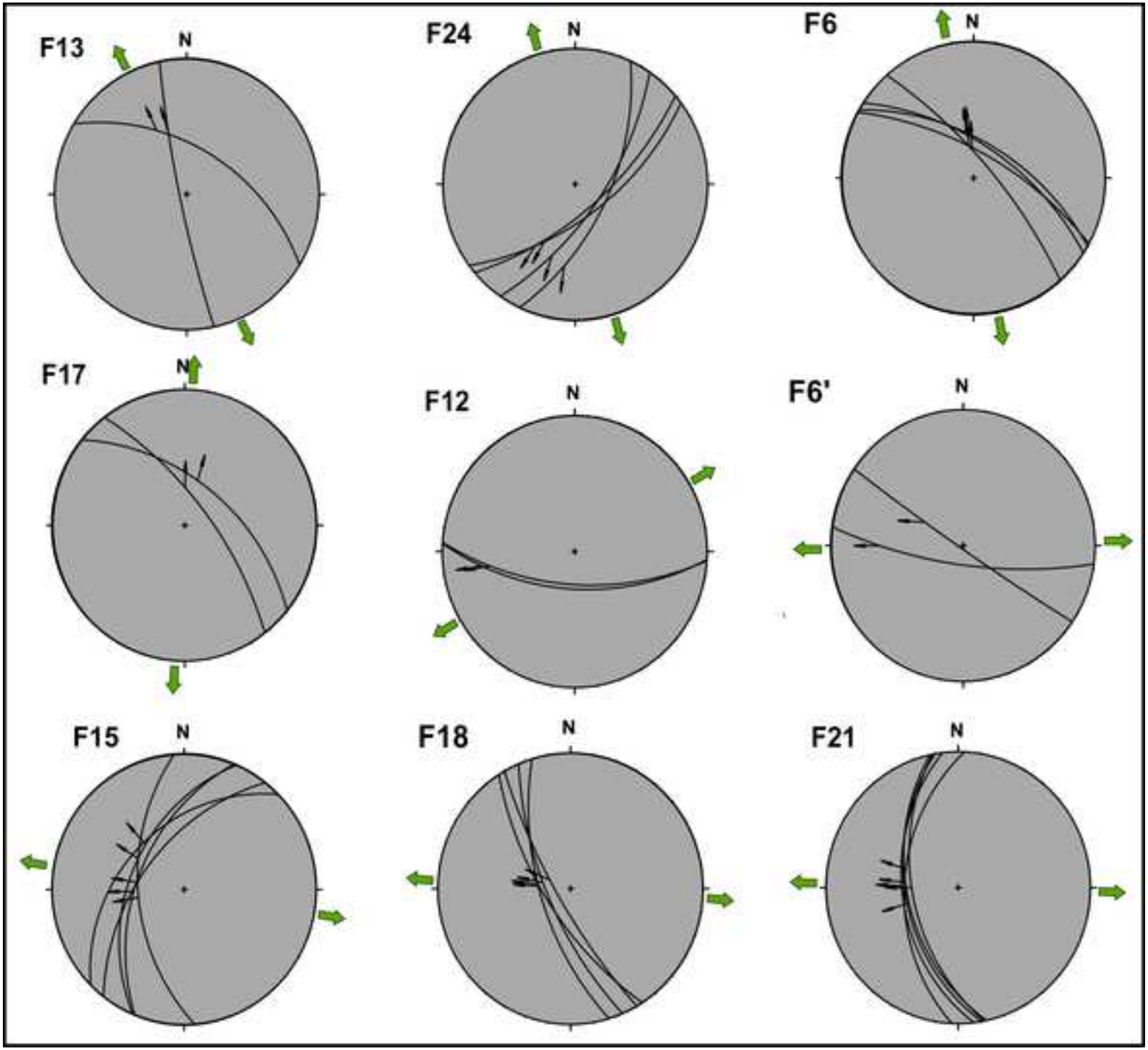
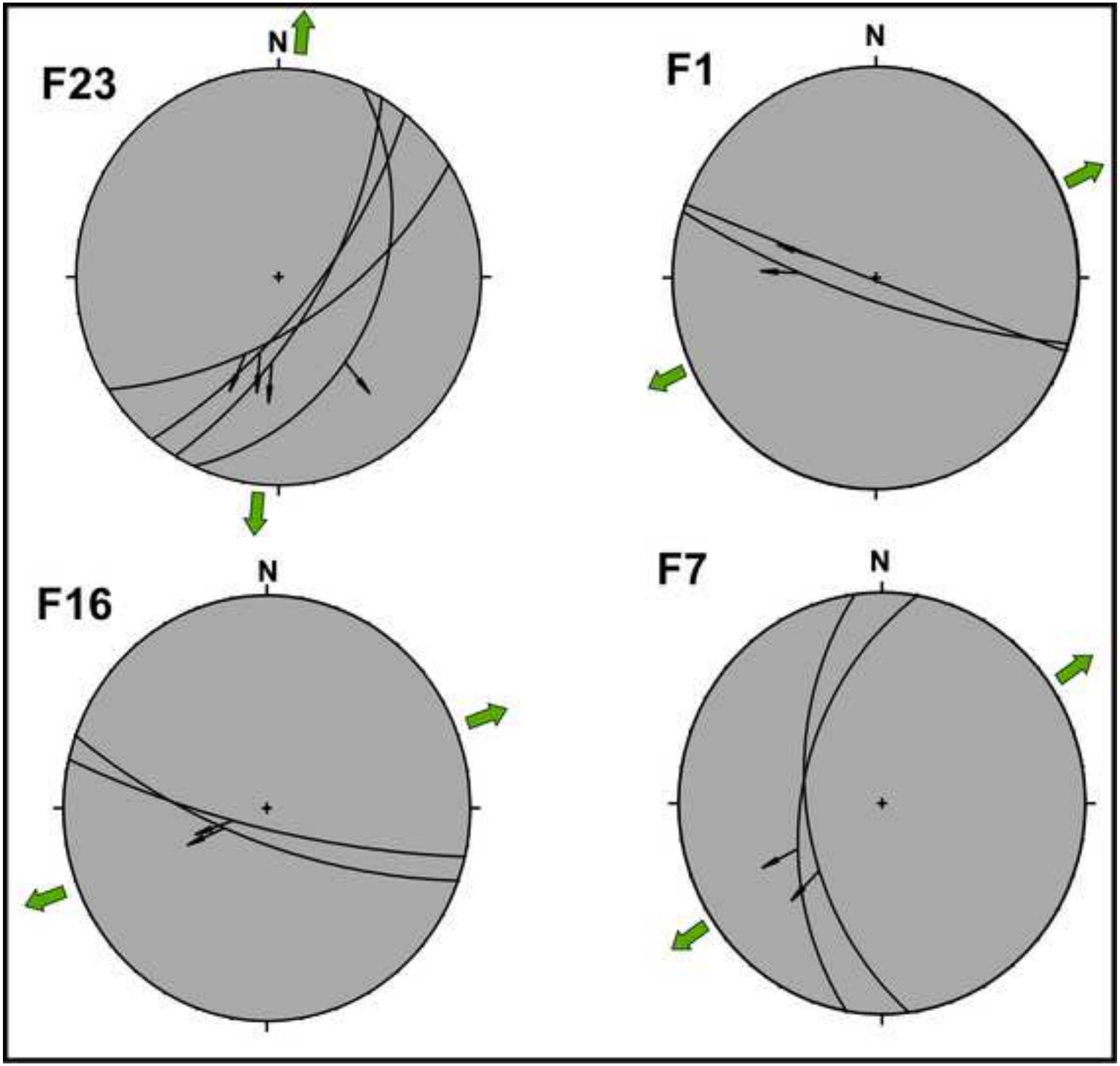



A
Eocene strata
Ablod formation
Coniacian-Santonian
Cenomanian-Turonian
B
C
D
E
F
G
H


F13
N
F24
N
F6
N
F17
N
F12
N
F6'
N
F15
N
F18
N
F21
N

Figure

Click here to access/download;Figure;Fig. 11.tif



Figure

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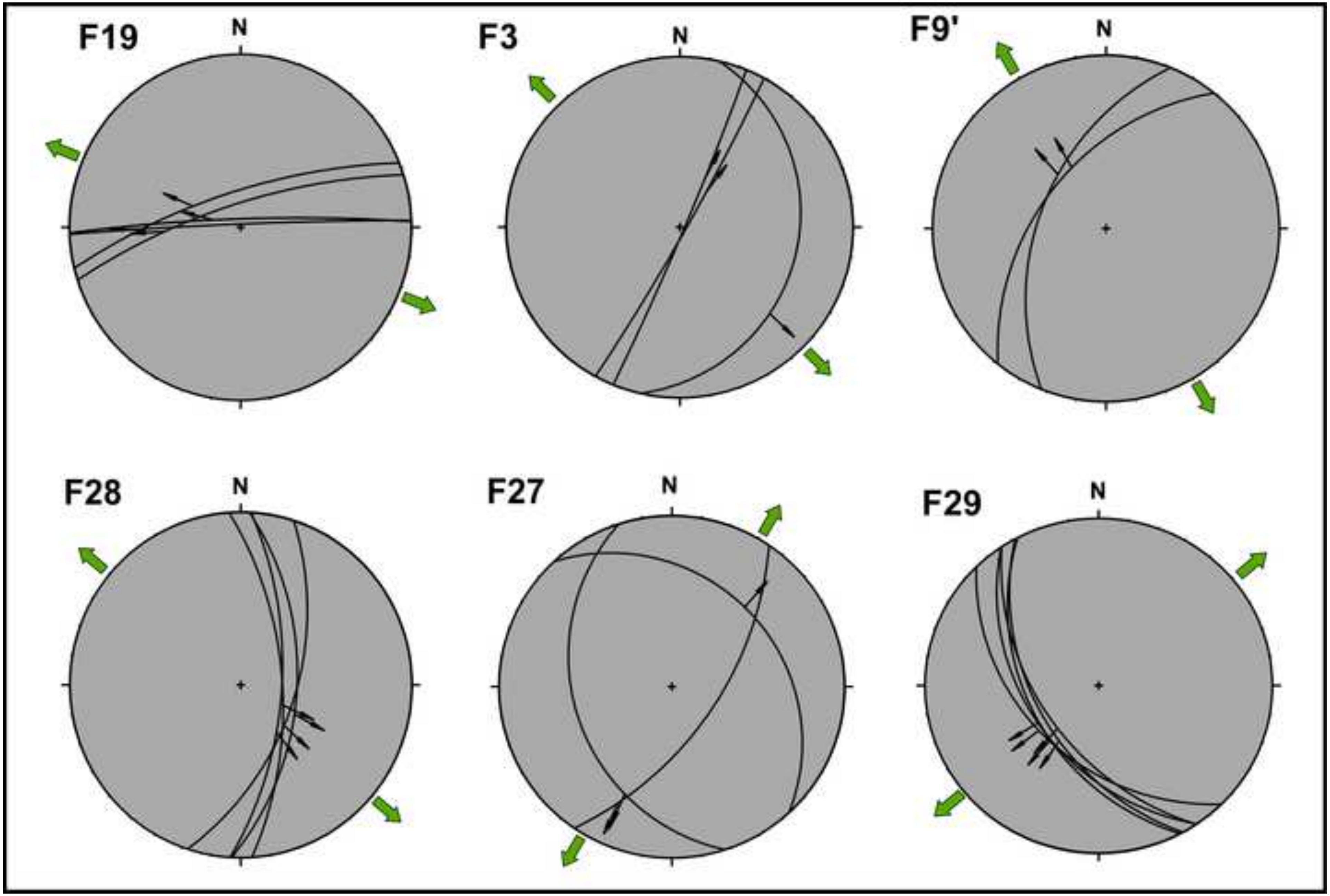

Figure

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