**The Tellian units, the Sellaoua window and the High Medjerda foreland in the Souk Ahras area, NE Algeria**

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**Abstract:** In northeastern Algeria and south of Annaba city, the Souk Ahras region forms the southern Tellian external domain. It exhibits a complex structure characterized by the stacking of Tellian thrust sheets. These units are thrust above the Sellaoua and High Medjerda foreland, and are overthust by the Numidian thrust sheet. The overall structure is complicated by the presence of Triassic evaporitic bodies, which occur in various positions in the stratigraphic pile. This area has been deformed by several tectonic phases in the Cenozoic.

In this work we have updated the stratigraphy and integrated it with geometric, structural and tectonic surface data to characterize the structural style of the Tellian thrust sheets and their relationship with the surrounding units. The Paleocene to Eocene of the Tellian thrust sheets encompasses two main facies: deep marine globiberinid facies to the north (Oued Driss Sector), and shallow marine nummulitid facies to the south (Boukebch and Dekma areas), both have been unconformably covered by the Miocene.

The Tellian thrust sheets of the Souk Ahras region exhibits a duplex geometry in the northern sector and an imbricate fan of thrusts to the south. These units are thrust over the Sellaoua and High Medjerda parautochthonous foreland with a basal decollement located in the Paleocene series. The tectonics wedge involves also the Sellaoua and High Medjerda foreland strata, leading to a classic fold-and-thrust belt structure.

**1. Introduction**

The Tellian thrust sheets are part of the Magrebides thrust belt that extends through the western Mediterranean region from the Betic Cordilleras in Spain, along the North African margin (Morocco, Algeria and Tunisia), extending eastwards to Sicily and the southern Apennines (Fig. 1; Durand Delga, 1969, 1980, Wezel, 1970, Vila, 1980, Hoyez, 1989, Wildi, 1983, Bouillin , 1986, Chouabi, 1997, Guerrera et al., 1993, Frizon de Lamotte et al., 2000, 2006 and 2009, Bracène, 2001, Khomsi et al., 2009, 2016, 2019 and 2021, Roure et al., 2012, Leprêtre, 2018 and references therein).

Fig. 1: framework of the different paleogeographic domains of the Maghrebides thrust belt showing the studied area.

In order to better understand the stratigraphy, the architecture of the Tellian thrust sheets and its relationship with their neighboring units (Sellaoua and High Medjerda parautochthous foreland units); a detailed interdisciplinary study has been undertaken, integrating biostratigraphy, petrography and structural geology. This study focuses on the Tellian formation of the southern part of the Maghrebides belt in northeastern Algeria between Djebel M’Cid and Djebel Graout in the Souk Ahras region (Fig.3). This study aims to: (1) review the stratigraphy of the main of Tellian outcrops within the Ouled Driss and Boukebch Dekma sectors using planktonic and benthic foraminifera, (2) document the specific petrographic characteristics, their depositional environments and the current architecture of this segment of the Maghrebides fold-and thrust belt.

**2. Geological setting**

According to numerous studies (Durand-Delga, 1969, 1980) Auzende, 1978, Vila,1980, Wildi, 1983, Bouillin, 1986, Frizon de Lamotte et *al*., 2000, Bracène, 2001; Bracène et *al*., 2002, Roure et *al.*, 2012, Bouyahiaoui, 2014, Bouyahiaoui et *al*., 2015, Leprêtre, 2018, Khomsi et al., 2019 and 2021) the Maghrebides fold-and-thrust belt, can be divided into three major domains, i.e., an internal domain, the Flyschs domain, and the external domain (fig.1, 2a and 2b).

(1) The internal domain is considered of European origin and corresponds to the former northern margin of an Alpine Tethys (Frizon de Lamote et al., 2009). In Algeria the internal domain are the lesser Kabylia and the greater Kabylia (so-called Kabylides, Raymond, 1976), which comprise the Kabylides and the “Dorsale calcaire” units (fig. 2a).

(a) The Kabylides massifs are mainly made up of crystalline Hercynian basement, with erosional remnants of Triassic continental red beds Jurassic to Eocene, marine to shallow marine series (Djelit, 1980, Roure et al., 2012). It comprises greenschist facies phyllites of Paleozoic age resting on amphibolitic facies rocks constituting the Kabylian basement. Most authors have considered this basement as rigid blocks weakly deformed during Alpine orogeny (Gélard, 1979, Benaouali-Mebarek et a., 2006). The Kabylides massifs are covered by Chattian to Middle Burdigalian molassic deposits, so-called ‘Oligo-Miocene Kabyle’, tectonically overlain by various Flysch units. Finally, the molasses and allochthonous thrusts sheets are overlain by marine sediments of Langhian-Early Serravallian age (Benaouali-Mebarek et al., 2006). The Kabylides massifs are thrust on top of the “Dorsale calcaire” in the south (fig. 2b).

(b) The “Dorsale calcaire” is considered as the former northern passive margin of a Maghrebian Tethys (Bouillin 1986, Benaouali–Mebarek et al., 2006, Roure et al., 2012, Frizon de Lamotte et al., 2009). It is a thick Lower Jurassic carbonate platform (Khelil et al., 2021) resting on detrital sediments of Upper Paleozoic and Triassic ages and supporting a thin cover of Jurassic–Cretaceous pelagic and Cenozoic siliciclastic sediments (Benaouali et al., 2006).

Fig. 2 (a) Paleogeographic reconstruction of the main domains of the Maghrebides belt during the Lower Cretaceous (Bouillin, 1986), (b) synthetic cross section showing the structure of the Maghrebides thrust belt on its Algerian eastern part (after Peybernès et al., 2002). Legend. a. Kabylides massif, b. ”Dorsale calcaire”, c. Mauritanian and Massylian flysch, d. Numidian flysch, e. Tellian thrust sheets, f. Constantinois thrust sheets, g. Sellaoua foreland, h. Pre-Atlasic foreland domain and (High Medjerda and Mellegues).

(2) The Flysch domain is sandwiched between the nortern Kabylides and the southern external domain (fig. 2a). This domain is commonly defined as the former cover of a Maghrebian Tethys separating Europe and Iberia from the African plate from Jurassic to Miocene (Bouillin et al., 1986, Durand- Delga, 1969, 1986, and Leprêtre et al., 2018). The flyschs are made up of deep water turbiditic deposits containing radiolarians and are divided into three units (fig.2a): the Mauritanian flysch were deposited in the northern part of the deep basin and are made up of immature turbiditic sandstones derived from the European margin. Its stratigraphic ages span from Jurassic to Miocene (Raoult, 1974). The Massylian flyschs were deposited at the base of slope of the African margin which fed it with well sorted sandstone, being coeval in age with the Mauritanian flyschs (Bracène, 2001, Vila, 1980). Between these two domains, mixed flysch units show both Mauritanian and Massylian characters. The Numidian flysch unit is considered as an allochton unit detached above the ductile “Argiles Sous-Numidienne”. These allochthonous flysch units have been interpreted as thrust over the Kabylian internal zones to the north and over the Tellian external area to the south (fig.2b, Vila et al., 1995). These units extent eastwards to the Tunisian Kroumirie (Rouvier, 1977; Talbi et al., 2008, Riahi et al., 2010), Sicily and the southern Apennines (Guerrera et al., 1993). The flysch deposits are mostly made up of a thick series of alternating sandstone and sandy limestone (>1200m thick), Aquitanian in age, resting on a green mudstone of Oligocene age (120m thick), topped by a clay and sandstone series of Aquitanian to Burdigalian age (Lahondère et al., 1979; Feinberg et al., 1981; Riahi et al., 2010).

(3) The external domain: this domain is well exposed in Algeria. It has been studied by Leikine (1971), Vila (1980), Obert (1981), Chouabbi (1987) and Chabbi (2017). It represents the former African paleo-margin (Leprêtre, 2018, Khomsi et al., 2019 and 2021) (fig. 2a), and is composed of a fan of thrust sheets staked on top of the foreland domain (Sellaoua and High Medjerda domains) in the study area (Chabbi et al., 2019). In eastern Algeria, the external domain comprises the Ultra-Tellian thrust sheets of Medjez Sfa (marly and limestone Barremian to Ypresian series) (Chouabbi, 1987, Lahondère, 1987) and the Tellian thrusts sheets of the Souk Ahras region. They have been thrust towards the south on top of the Sellaoua foreland domain (Voüte, 1967) and of the adjacent Pre-Atlasic foreland domain (High Medjerda – Mellegue). The Tellian thrusts sheets of the Souk Ahras region are the focus of the present study (fig. 2.b).

Following Marmi and Guiraud (2006) and Chadi (1991), the Constantinois foreland, between Nador and Debagh cities, includes many allochthonous units amongst which the principal, in a lower position, corresponds to a carbonate unit represented by marine platform carbonates, extending from Jurassic to Turonian. These series are unconformably overlain by marl-carbonate marine formations of Late Senonian to Middle Miocene age, in which unconformity surfaces and/or sedimentary lacuna were observed. The Constantinois foreland is mainly characterized by thrust sheets verging southward owing to Cenozoic contractional tectonic setting.

The Sellaoua foreland mainly involves a succession of dolomitic-limestone of Jurassic age, marls of Cretaceous to Paleocene ages and detrital sequences of Miocene age which rest unconformably on the older series. The NE–SW trending Chebka Sellaoua unit is characterized by thrust imbricates and very narrow folds, giving a particular structural pattern to this belt (Voüte, 1967).

The Pre-Atlasic domain gathers the High Medjerda and the Mellegues domains. It involves a marine succession represented by marl, limestone, and sandstone formations of lower Cretaceous age, marl and limestone of Upper Cretaceous to Lutetian age. The Miocene cover, represented by marine detrital deposits, unconformably overlies older formations. The Plio-Quaternary series made up lagoon or continental deposits, rest unconformably over the previous series. This domain is less deformed, with south-verging folds (fig. 2b).

**3. Material and methods**

The study area is situated in northeastern Algeria and represents the southern part of the external domain of the Maghrebides. It extends between Djebel M’Cid in the north and Taoura city in the south (fig. 3). The studied area displays a complex structural architecture. Its north and north-western part constitutes an allochthonous domain, and includes the Numidian and the Tellian thrust sheets and the Sellaoua parautochthonous foreland. Its south and south-eastern part is a para/ or -autochthonous domain, including the High Medjerda foreland, dominated by Cretaceous and Paleocene to Lutetian carbonate deposits unconformably covered by Miocene to Quaternary siliciclastic deposits.

The Triassic lagoon and continental formations made up of gypsum, clays, conglomerates …etc, crop out at the front of the main thrust sheets and between the tectonic units, mainly along the tectonic contacts (fig. 3).

Fig. 3 : simplified structural map showing the mains structural units of the study area.

The present work is based on the detailed geological cartography, supported by field work, carried out on the Tellian outcrops of the Souk Ahras region. We also carefully examined the basic documents available, in particular the geological maps and Master/PhD theses, which cover or touch part of the study area (i.e., David, 1956, Vila, 1978, Rudis, 1985, Kriviakine et al., 1989, Chabbi et al., 2016 and 2019, Chabbi, 2017).

The aims of fieldwork were to collect the maximum of data on lithology, stratigraphy, bedding attitude and overall tectonic architecture of Tellian outcrops and surrounding units. Data were mainly collected from three sectors, including, from the north to the south and from the east to the west, the Ouled Driss, Dj. Boukebch and Dekma sectors. Several samples of marl and limestone were taken from different sectors and treated for biostratigraphic and petrographic analyses. The biostratigraphic determinations were carried out by M. Benyoussef and A. Chermiti in the Water Research and Technology Laboratory in Tunisia, with reference to the results published on the Mediterranean and other regions by Blow (1969), Aubert et al. (1977), Bolli et al. (1985), Bellier et al. (1995, 2010).

**4. Stratigraphic results**

**4.1. Ouled Driss sector**

The results of the various studies carried out in the sector of Ouled Driss located in the north of the region are projected and synthesized in the Ouled Driss cross-section (fig.3).

This section was measured in the west part of Ouled Driss sector, between Oued Maaden in the south and Dj. M’Cid in the north. The section exhibits a repetition of marls and limestone bars resting tectonically on top of the Ouled Driss Sellaoua foreland unit and Triassic formations, and supporting the Numidian thrust sheets of Dj. M’Cid (fig.3). From bottom to top we can distinguish (fig. 4):

**Dj. Hammam Tellian unit**: this unit is composed of three members; blackish marls at the base, limestone bar in the middle and blackish marl rich in yellow balls at the top.

- The first member consists of 160 m thick black marl series, which are rich in organic matter and contain rare marl-limestone beds (fig.5a). Biostratigraphic analysis (Fig.4) indicates that samples S1 and S2 are rich in a diverse planktonic foraminiferal assemblage including; *Morozovella pseudobulloides, M. praecursoria, M. angulata, M. pusilla,*  *Acarinina primitiva, Planorotalites chapmani*. These species correspond to Globigerina sellii zone (P3 zone) of early to Middle Paleocene age.

A few tens meters higher, samples S3 includes *Globigerinoides triloculinoides, Planorotalites pseudomenardii, Morozovella velascoensis, M. aequa*. These species correspond to *Planorotalites pseudomenardii* zone (P4 zone) of Late Paleocene age. Sample S4 contains in addition foraminifers of the previous levels: *Morozovella uncinata, M. velascoensis, M. conicotruncana, Planorotalites pseudomenardii*. This level is attributed to *M. velascoensis* zone (P5) characterizing the Late Paleocene (Thanetian) age.

**Fig.** 4: figure showing the stratigraphy of the different units of the Tellian thrust sheets cuts in Ouled Driss section, showing the main species of benthic and planktonic foraminifers used in biostratigraphic analysis.

**Legend:** (1) marl, (2) marly-limestone, (3) limestone, (4) phosphatic limestone, (5) phosphatic level, (6) glauconitic sandstone level, (7) yellow balls, (8) biozone species, (9) samples number, (10) Blow biozone, (1) tectonic contact.

We note that except the base of Middle Paleocene which is rich in benthic foraminifera *(Gyroidinoides, Lenticulina, Dentalina, Nodosaria, Tritaxia midwayensis, Ammodiscus, Anomalinoides, Gavelinella danica)*, the other levels are poor in benthic foraminifera.

**Fig. 5**: Paleocene marl (a) and Ypresian limestone bar (b) of Dj. Hammam showing the position of the samples (T1 to T6) used for thin sections.

- The middle part is made up of a thick limestone bar (140 m), which begins with an alternation of mar-limestone and marl beds. Samples S5 and S6 contain *M. aequa, Globigerina linaperta, M. subbotinae, M. aragonensis and Globigerina inaequispira*. This assemblage is attributed to *M. subbotinae* zone (P6) characterizing the Ypresian age. On this alternation a Globigerinous black limestone bar exhibits decimetric beds rich in silex and phosphate (fig. 4).

Petrographic analysis supported by thin sections made from six (06) samples of rock taken from the different levels of this bar (T1 to T6 from the bottom to the top of the limestone bar) (fig. 5b), shows a wakstone (biomicrite) rich in organic matter and planktonic foraminifera (*Globigerina* and *Morozovella*) and rare benthics (*Bolivina, bullimuna*), phosphatic clasts and ostracods debris (fig.6). We note the presence of shark teethes (fig.6, T6) and coprolites. This facies characterizes a deep marine depositional environment of distal platform.

The detail and description of the photographic samples are presented in table1.

Fig. 6 : Pictures of thin sections made in the limestone bar of Dj. Hammam

Tab. 1: description and interpretation of thin sections made in the limestone bar of Dj. Hammam (Ouled Driss).

|  |  |  |
| --- | --- | --- |
| **Thin section number** | **Description** | **Interpretation** |
| T1 | Wackestone: biomicrite including pyrite pigment, rich in *Morozovelles, Globigerines* and organic matter. | Black shale facies of distal platform. |
| T2, T3 | Wackestone: biomicrite containing *Morozovella, Globigerina* species and radiolarians, rich in organic matter. | Facies of distal platform. |
| T4 | Wackestone: biomicrite rich in organic matter, planktonic foraminifera and rare *Bolivina* | Facies of distal platform. |
| T5 | Wackestone: Phosphatic biomicrite containing species of *Globigerina*, Bolivina, Bulimina and radiolarians. | Facies of distal platform. |
| T6 | Wackestone: biomicrite very rich in phosphates, phosphatic clasts, ostracods debris. Only *Globigerines* species are present with some shark teeths and coprolites | Deep marine facies « bathyal domain » |

- The upper part of the Dj. Hammam Tellian unit is characterized by a series (240 m thick) of black marl rich in yellow balls and containing a decimetric layer of sandstone at the base. Biostratigraphic analysis (fig. 4) shows that samples S8 and S7 contain plancktonic foraminiferal assemblages (*Morozovella subbotinae, M. aragonensis, and Acarinina bullbrooki*) associated with benthic foraminifera (*Lenticulina, bulimina and Uvegerina*), outlining a Late Lutetian age.

**Aïn Ghorab Tellian unit**: above a tectonic contact, this unit starts with about ten (10m) meters of black marl where biostratigraphic analyses (fig. 4) indicate that samples S11 and S12 are rich in planktonic foraminiferal assemblages including *Globigerinoides triloculinoides*, *Globigerina velascoensis, Planorothalites chapmani, P. pseudomenardii, Acarinina primitiva, Morozovella angulata, M. subbotinae, M. aequa, M. velascoensis* and *M. acuta*. These species correspond to *M. velascoensis* zone (P5 zone) characterizing the Late Paleocene (Thanetian) age.

On these Paleocene (Thanetian) marls comes the Ypresian limestone bar (140m thick) similar to the Dj. Hammam bar described previously. At the top of this bar the phosphatic (fig. 7a) and silex levels are well exposed (fig.7b).

Fig. 7 : phosphatic and silex levels of the Ypresian limestone of the Aïn Ghorab Tellian unit

Above this bar the black marl rich in yellow balls spreads out over approximately 120 m in thickness. The base of this level contains a decimetric sandstone bed. Samples taken from these marls (S13 and S14) include *Morozovella aragonensis, Acarinina pentacamerata, A. bullbrooki and Globigerina inaequispira* associated with benthic foraminifera (*Lenticulina and Bolivina antegrissa*), outlining a Lutetian age (fig. 4). Samples S15-S17 and S18 (fig. 4) contain only benthic foraminifera (*Lenticulina and Bolivina antegrissa*).

**Ras El Oued Tellian unit** (fig. 4): this unit starts by Late Paleocene (Thanetian) marls and Ypresian limestones similar to the previous unit, overlain by thick series of marl rich in yellow balls, but thicker than in the previous units and containing a glauconitic sandstone levels in the upper part (580m thick). Biostratigraphic analysis shows that samples S19, S20, S21 and S22 contain only benthic foraminiferal assemblages such *Bulimina* and *Bolivina antegrissa*. Sample S23 includes *Globigerina linaperta*, associated with benthics (*Annomalina, Nonion, Bolivina antegrissa* and *Uvegerina marginolopsis*). Few meters beneath the first glauconitic level, samples S25 and S26 contain *Acarinina bullbrooki*, *Globigerina eocaena* and *Truncanorotaloides topilensis*. These assemblages provide a Late Lutetian age.

In the upper part of marl series which exhibit a glauconitic level, sample 9/6 displays a planktonic foraminiferal association comprising *Acarinina bullbrooki, Globigerina eocaena* and *Turborotalia cerroazulensis*. The assemblage also identified in S27 to S30 samples is characterized by the presence of *Hantkenina alabamensis* outlining a *Bartonian* age. These marls are rich in benthic foraminiferal assemblage such *Lenticulina, Bulimina, Bolivina antegrissa* and *Uvegerina marginolopsis*.

**Douar Nouail Tellian unit** (fig. 4): this section begins with Thanetian marls which are overlain by the Ypresian limestone bar, which is only 30 meters thick here. At the base of the black marl rich in yellow balls (360 m thick), sample S31 provided *Morozovella subbotinae, Acarinina broedermanni and Globigerina inaequispira,* thus dating the early Lutetian. Benthic foraminifera such *Lenticulina, Bulimina, Bolivina antegrissa* and *Uvegerina marginolopsis* are also present. Samples S32, S33, S34 and S35 contain planktonic foraminiferal assemblages dating the Lutetian. The planktonic foraminiferal assemblages defined from samples S36, S37, S38 and S39 collected from the base of the glauconitic level are characterized by the presence of *Acarinina bullbrooki, Globigerina eocaena, Turborotalia cerroazulensis, Truncanorotaloides topilensis, T. libyaensis, Hantkenina demblei,* and *Globigerinatheka suconglobata* dating the Bartonian age. In the uppermost part, samples S40, S41, S42 and S43 contain *Truncanorotaloides hayanensis* and *Glaubigerinatheka Mexicana*, indicating a Bartonian-Priabonian age. We note that the Bartonian to Priabonian series are 220 m thick and rich in benthic foraminiferal assemblages.

**4.2. Boukebch - Dekma sector:**

This sector is situated in the south of Ouled Driss region (fig.3). It includes the outcrops of Dj. Boukebch in the east and Dj. Dekma in the west. The outcrops of this sector are been well studied by Blayac (1902 and 1912), David (1956). In the present study, we covered some gaps in relation to the petrography and the structure. The Tellian outcrops of this sector are rich in nummulites, bivales, gastropods and lumachelles with oysters. The stratigraphic results obtained from our field observations, and previous results published by the authors cited above are synthesized as follows (fig.8):

The base the Dekma Tellian unit exhibits a deformed, brownish to black marl mostly covered by recent formations. Their thickness estimated by David (1956) is 100m. At Dj. Boukebch, these marls do not exceed 10m in thickness. They are in tectonic contact with the Triassic material.

Biostratigraphic analysis of sample (b1) taken from this marl provided a rich benthic foraminiferal assemblage (*Tritaxia midwayensis, Ammodiscus glabrata, Trochammina abrupta, Trochamina budashvaella)* indicating a Paleocene age*.* On top of these marls a thick nummulitic limestone bar develops and is subdivided as follows from bottom to top (fig.8): 70m thick of red massif limestone very rich in nummulites (fig.9), overlain by (20m thick) of brown limestone rich in nummulites, lumachelles and bivalves. These layers are dated as Ypresian in age by David (1956).

The limestone bar grades upwards into white limestone (70 m thick) rich in large nummulites (fig.10e) such as (*Nummilite irregularis, N. subirregularis, N. globulus, N. atacicus, N. subatacicus, N. gizehensis),* dating the Late Lutetian age (David 1956).

The nummulitic limestone bar is covered by brownish sandy and marl series (180 m thick) containing some fossiliferous limestone beds (3 – 5 m thick) in the middle and lithoclastic limestone beds at the top (fig.10c, 10d, 10g). Marl levels are rich in gastropods (*Phasianella sp. fig.).* Biostratigraphic analysis of samples (b2 and b3) taken from these marls provided *Lenticulines,* rare *Morozovelles, Globigerines* and Ostracods (*Loculocyteretta*) dating the Lutetian age. The fossiliferous limestone beds in the middle of marl series are rich in gastropods (*Turritella carinifera, Phasianella sp.*), lumachelle and clams (fig. 10a, 10b).

The Dekma series are mostly similar to the Boukebch series, but are richer in Oysters fossils, the Paleocene marl being also thicker than in the Boukebch section.

Fig. 8: Stratigraphic column of the Tellian thrust sheet of Boukebch-Dekma sector.

Legend: 1. Limestone, 2. Marl and clay, 3. Lithoclastic limestone, 4. Phosphatic layer, 5. Nummulites, 6. Bivalves, 7. Marl samples l, 8. Rock sample.

Fig. 9: Picture of red limestones very rich in Nummulites of Ypresian bar of Dj. Boukebch (Tb1), (a) microscopic observation from thin section.

The Tellian thrust sheets of Dj. Boukebch - Dj. Dekma sector are unconformably covered by late Burdigalian-Langhian siliciclastic formations and late Miocene series, similar to the Neogene series exposed in underlaing thrust sheets farther to the south. Notice that Dekma Miocene series are better conserved than the Boukebch Miocene series, the later being mostly eroded and preserved in only small outcrops resting directly on top of the Lutetian series.

Fig. 10: Picture of Lutetian facies of Dj. Boukebch – Dj. Dekma sector; ( Macroscopic) a*. Gastropods phasianella sp*., b. *Gastropods turritella carinifera* , c. fossiliferous limestone, d. lithoclastic limestone, (Microscopic) e. brown limestone rich in nummulites, bivalves and lumachelle taken from Tb2, f. taken from fossiliferous limestone Tb4, g. lithoclastic limestone Tb5.

**4.3. Interpretation and correlation of stratigraphic results**

Stratigraphic results show that the Tellian thrust sheets of the Souk Ahras region are Paleocene to Priabonien in age. Two facies types are documented: globigerinous facies in the north and nummulitic facies in the south.

**The globigerinous facies** is recognized at Ouled Driss sector in the northeast of the study area and extends westwards to Djebel Alia. This facies is characterized by (1) black Paleocene marl, (2) black Ypresian limestone rich in silex and phosphate layers, (3) Lutetian marl rich in yellow balls and (4) Bartonian – Priabonian marl rich in glauconite.

Most part of the Paleocene and Ypresian series of this facies displays a diverse planktonic foraminiferal assemblage indicating a deep marine depositional environment. The occurrence of benthic foraminifera associated with a planktonic foraminifera assemblage at the base of Paleocene marls, indicates that the water level was shallower during the early Paleocene and began to deepen during the lower Paleocene, reaching its maximum depth dating the Ypresian stage when only the Globigerina were present (fig.5, tab.1). The Lutetian marls containing yellow balls indicate an unstable depositional environment, like a slope. The Lutetian to Priabonian series are rich in benthic foraminiferal assemblages with rare planktonic foraminifera, thus indicating a shallow marine depositional environment.

Nummulitic facies is mapped south of the Medjerda River at Djebel Boukebch and Djebel Dekma.   
This facies indicates a shallow marine depositional environment. This facies is represented by (1) Paleocene marl, (2) Ypresian – early Lutetian nummulitic limestone and (3) marl and limestone rich in nummulites, gastropod, lummachelle and bivalves. We note that the formations of this facies are thinner than the globigerinous facies series (fig. 11).

These two facies are correlated with those situated in the west of the study area between Guelma and Sedrata city and in the Setif region, as described by Chouabbi (1987) and Vila (1980). According to previous descriptions made by Ben Ismail-Latrech (2000) and Mesrouhi (2006), the Paleocene and Eocene Tellian series of Tunisia at the Anssarine Plateau, Dj. Meftah and Matter look different (both from their thicknesses and structural position) from our Algerian sections, despite the occurrence of the same two facies, i. e. the deep water globigerina and shallower water nummilitic facies.

Fig. 11. Stratigraphic correlations between the different Tellian thrust sheets

**5. Surface structural data**

Due to lack of subsurface data (geophysics and wells), we have based our work only on surface data. They were obtained from geological maps (Souk Ahras, Oued Mougras and M’daourouche maps at 1/50000 scale) published by the national geological map agency of Algeria (ASGA), both published and unpublished theses and also from several field surveys carried out in (2012-2016 and 2019-2020) in this area.

Here the orogen contains a stack of northeast- southwest-trending thrust sheets imbricating the Cenozoic carbonate strata in a fold-and-thrust domain called the Sellaoua and High Medjerda foreland. The architecture and tectonic style of the Tellian thrust sheets are summarized in the following two sectors: Ouled Driss sector in the north and Boukebch – Dekma sector in the south.

**5.1. Ouled Driss sector**

The Ouled Driss sector exhibits a stack of Tellian thrust sheets resting tectonically on top of the Sellaoua foreland unit and Triassic salt, and below the Numidian thrust sheet (fig.12 and fig. 13). This sector is dominated by duplex structures with a roof thrust located in the Oligocene mudstone at the base of the Numidian thrust sheet and a sole thrust in the Paleocene black shale. Ouled Driss Tellian thrust sheets have a diamond shape, being 15 kilometer wide, with a maximum elevation reaching 1200m.

The western part of the sector shows a hinterland dipping duplex structure, made up of four NE-SW trending thrust sheets. From the base to the top, they comprise :( fig. 12, fig 14):

Fig. 12. Structural map of Ouled Driss sector

Fig.13. Picture of the southern Ouled Driss Tellian thrust front, looking northward.

- **Dj. El Hammam Tellian thrust sheet** exhibits Paleocene-Lutetian marls and limestone strata (550 m thick), dipping 20°- 40° towards the north above Ouled Driss Sellaoua foreland, the later involving upper Maastrichtian strata dipping 20° - 60° towards the south.

- Above this unit, the **Aïn Ghorab Tellian thrust sheet** also exhibits Thanetian-Lutetian marls and limestone strata with 310 m thickness, dipping 45°-70° towards the north.

- **Ras el Oued Tellian thrust sheet** has an arcuate shape and shows similar series as in the Aïn Ghrab unit. The Lutetian marls are thicker here than in the previous units and contain Bartonian -Priabonian series. The thickness of this thrust unit reaches up to 730m. The limestone bar is dipping 70° - 80° towards the northwest.

- **Hdeb – M’Cid Tellian thrust sheet** is the higher Tellian unit, directly belowthe Numidian thrust sheet/ It shows similar series as in the Ras el Oued thrust sheet. In this unit however, the Ypresian limestone bar is thinner, being only 30 m thick. The total thickness of this thrust sheet reaches 590m.

The eastern part of Ouled Driss sector exhibits a foreland dipping duplex formed by two to four thrust sheets involving Paleocene to Lutetian carbonate strata (fig. 14) dipping 40° - 60° towards the south. These Tellian units are tectonically overlain by the Numidian thrust sheet in the north. The base of this duplex is dominated by the Triassic salt.

Fig. 14. Structural cross sections from Ouled Driss sector.

**Legend:** 1. Pliocene, 2. Oligo-Miocene, 3. Oligocene, 4. Bartonian-Priabonian, 5. Lutetian, 6. Ypresian, 7. Paleocene, 8. Maastrichtian, 9. Triassic, 10. Conglomerates, 11. Sandstone, 12. Mudstone, 13. Limestone, 14. Yellow balls, 15. Thrust contact, 16. Tectonic contact, 17. Stratigraphic limit.

**5.2. Boukebch – Dekma sector**

The Boukebch-Dekma Nummulitic thrust sheets are situated to the south of the Globigerinous Tellian thrust sheets, south of the Medjerda River. Two thrust sheets are well exposed, i.e. the Boukebch Nummulitic Tellian thrust sheet in the east and the Dekma Nummulitic thrust sheet in the west.

**5.2.1. Boukebch Nummulitic Tellian thrust sheet**

The Boukebch thrust sheet is exposed in the south of Souk Ahras city, and has a circular shape of about five kilometers large with a maximum elevation reaching 850m (fig. 15). Most part of this thrust sheet is surrounded by Triassic salt. To the south, the Boukebch thrust sheet is thrust over the Dj. Graout foreland of the High Medjerda, resting tectonically on top of the Miocene (Serravallian) siliciclastic series covering the northern flank of the Graout anticline. To the north, this unit is in turn under thrust below the Bouallegue Sellaoua foreland unit. The Boukebch Tellian thrust sheet involves Paleocene-Lutetian nummulitic carbonate strata dipping towards the north (fig. 15).

Fig. 15. A) Geologic map of the Boukebch Nummulitic Tellian thrust sheet indicating the location of the cross section. B) NW-SE geologic cross section (a-b) across the Boukebch thrust sheet.

**5.2.2. Dekma Tellian thrust sheet**

In the southwest of the study area the SW-NE trending Dekma Tellian thrust sheetextends over a surface which is 4 km wide and 8 km long with a maximum elevation reaching 1050m (fig.16a).The structural map (fig.16a) and the two geologic cross sections (fig.16b, 16c) show that the Dekma Tellian thrust sheet is thrust over early to middle Miocene series covering the Sellaoua Foreland and Triassic salt of Argoub El Djemel in the east. In the south, the nummulitic Tellian series forms with the Cretaceous series the anticline of Dj. Serrou, which involves Campanian to Maastrichtian and Paleocene carbonate strata unconformably covered by early-middle Miocene detrital series. The Dekma thrust sheet unit involves Paleocene to Lutetian carbonate strata rich in nummulites and oysters. These series are also unconformably covered by Miocene strata dipping northwestwards. The Dekma Tellian thrust sheet and the Serrou anticline are thrust towards the south on top of the Miocene along a decollement level located within the Campanian-Santonian series. In the north in contrast, these units are undertrusted beneath the Mechta Ech Cheurfa Sellaoua foreland unit (Campanian-Santonian). The ductile Triassic series, made up of clays, breccias and gypsum, is always present at the front of this thrust sheet. This thrust unit shows a main decollement level within the Paleocene and Santonian marls.

Fig. 16. Structural map of Dj. Dekma Tellian thrust sheet (a) and schematic geological cross sections (b and c) cross sections located on the map

**6. Discussion**

Stratigraphic results and structural diagrams (maps and geological sections) lead us to discuss the following points:

Stratigraphic analyses allow us to distinguish two very distinctive facies within the Paleocene- Priabonian carbonate series: (1) a northern facies rich in globigerina, of deep marine origin and (2) a southern facies with nummulites and oysters, of shallow marine origin. Currently, the Ouled Driss Tellian thrust sheets (deep marine facies), which were deposited further north and in a deeper marine domain, are at the same elevation (1200 m) or topographically higher than the southern Dj. Boukebch and Dekma Tellian thrust sheet (1050 m) which display nummulitic facies. This accounts for a thrust wedge involving ramps and flats (Boyer et al. 1982), with distinct decollement levels, i.e. in the Paleocene marls for the so-called Tellian thrust sheets and in Santonian series for the so-called parautochthonous units. These thrusts result from Alpine compressional phases inducing the tectonic inversion of the former North African passive margin of the Tethys during long-lasting episodes of convergence between Eurasian and African plates (Bracène et al. 2002, Khomsi et al., 2006, Frizon De Lamote et al. 2009, Roure et al. 2012 and Leprêtre et al. 2018).

Two thrust systems are recognized in the Souk Ahras region: the upper thrust system involves the Tellian units and the lower system involves the Sellaoua and High Medjerda parautochthonous units. The upper thrust system made up of the Tellian thrust sheets rides over the Sellaoua parautochthon domain , with the coeval formation of duplex structures in the northern part of the study area (Ouled Driss sector and large thrust sheets in the south (Boukebch – Dekma sector). The lower thrust system involves the parautochthonous foreland strata, and lead to a fold-and-thrust structure (Serrou anticline).

The northern Tellian thrust sheets of Ouled Driss are made up of Paleocene to Priabonian imbricated series and are in tectonic contact with the Numidian thrust sheet of Dj. M’Cid while the southern Tellian thrust sheets of Dj. Boukebch and Dekma are unconformably overlain by Miocene series. This stratigraphic architecture indicates that: (1) the Tellian domain began to accreted in the tectonic wedge from the late Priabonian onward. This event corresponds to the Atlassic phase which is recognized in the entire Maghrebides domain (Guiraud 1975, Vila 1980, Bracène 2000, Khomsi et al. 2006, Frizon de La Motte et al., 2009). (2) During the Miocene the return of the sea is recorded in certain areas of the Tell domain and its foreland (already folded). The Miocene deposits on the Tellian formations are older (Burdigalian) than in the parautochthonous foreland (late Burdigalian – early Langhian). Therefore the Miocene sea returned first on the Tellian domain then on the foreland but the withdrawal of the Miocene sea occurred earlier in the northern Tellian area. The sea remained in the southern Tellian area during the thrust emplacement and probably until the Tortonian when the Sea ultimately retired permanently.

The Miocene series stacked between the Tellian thrust sheets and the foreland are Burdigalian – Langhian (-20.4 MA to -13.8 MA) in age, while the Miocene strata below the Sellaoua parautochthonous foreland units are Upper Miocene in age (Tortonian -11.6 MA to -7.2 MA). These allow us to put the chronology of the thrusts setting. The Tellian thrust sheets were first detached from their Cretaceous series along the Paleocene marls, being the thrust over the Sellaoua parautochthonous foreland during the Langhian, then the entire bloc (Tellian thrust sheets and Sellaoua parautochthonous foreland units) were thrust on top of the High Medjerda foreland using Santonian and Campanian marls as the main decollement level during the Tortonian.

**7. Conclusion**

Surface data together with the biostratigraphic analysis and construction of geological cross sections have been integrated to study the stratigraphy and structural architecture of Souk Ahras Tellian thrust sheets and their relationship with the Sellaoua and High Medjerda parautochthonous foreland units. The main conclusions are as follows.

The Tellian thrust sheets of Souk Ahras area are made up of Paleocene to Priabonian carbonate series divided into two facies, i.e. a globigerinian facies of deep marine depositional environment in the north (Ouled Driss sector) and a nummulitic facies of shallow marine depositional environment in the south (Boukebch - Dekma sector). The southern facies is covered unconformably by the Miocene series indicating Atlassic tectonic events. They are in tectonic contact with both the underlying Sellaoua and high Medjerda parautochthonous foreland units, and overlying Numidian thrust sheets.

The northern part (Ouled Driss sector) is characterized by a duplex structure involving four thrust sheets with a roof thrust in the Numidian mudstone, and a sole thrust in the Paleocene marls. In the southern part (Boukebch – Dekma sector), the Nummulitic Tellian thrust sheets are thrust directly on top of the Sellaoua and High Medjerda parautochthonous foreland units along a Paleocene decollement.

Two contractional systems are recognized in the Souk Ahras region (fig. 17). The Northern thrust system displays an imbricate fan of thrusts involving local and infraformational décollement driven by the specific mechanical stratigraphy. Large Triassic bodies cannot be geometrically linked to this thrust system and should rather the record of previous salt tectonics (diapirism, canopies…). The southern inversion structures are probably basement-involved pop-up. The leading fault corresponds to inverted north-facing normal fault, which controlled the sedimentation during Jurassic and Lower Cretaceous times as the southern Tethys margins developed. Salt tectonic is also associated with such extensional settings. In the Northern thrust systems, break-forward thrust propagation can be considered as a rule, even if synchronous or out-of-sequence thrusting cannot be excluded. As in many orogens, it probable that inversion occurred early in the evolution as soon as the geodynamic setting switched from extensional to contractional.

**Fig. 17.** Regional interpretative cross section showing the tow contractional systems recognized in the Souk Ahras region.

**8. Acknowledgments**

Dr Khomsi is warmly acknowledged for his editorial effort. The paper benefited from the reviews of Dr. Roure. Petex provided their MOVE suite software to the University Paul Sabatier, Toulouse 3.

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