Revised planktic foraminiferal biostratigraphy of the early late Albian of northern Tunisia (southern Tethys)

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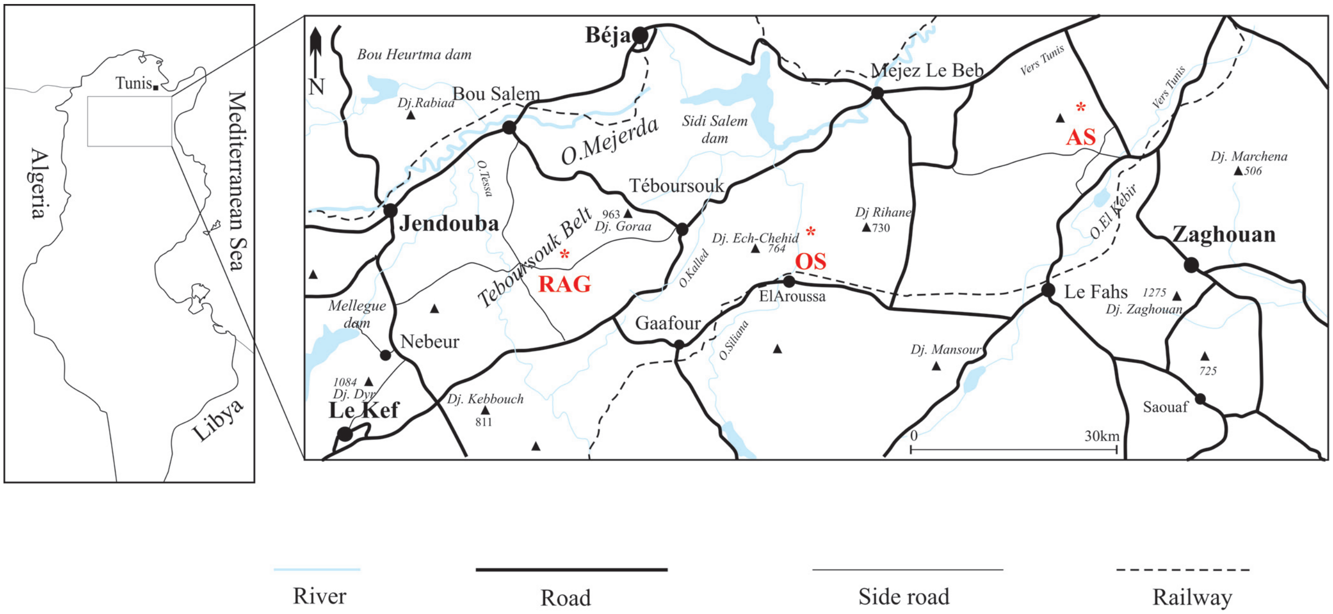
ABSTRACT: The upper Albian exposed near the Imbrication Zone of northern Tunisia is composed of a pelagic sequence that includes organic-rich beds. High-resolution biostratigraphy based on planktic foraminiferal bioevents across marker beds (i.e., organic-rich beds), allows revision of the lithostratigraphic subdivision and zonal scheme in comparison with late Albian time equivalents recorded in the northern Tethyan margins. In the present study, we proposed a new subdivision of the upper Albian lithostratigraphic section that now includes the Mellegue horizon as an equivalent of the Amadeus Segment rhythmic marl/limestone interval (central Italy). Three studied sections are subdivided into five biozones with the abundance and morphological trends of planktic foraminifera and inferred paleoenvironments: 1) The *Biticinella breggiensis* Total Range Zone is characterized by the appearance of ticinellids with pinched chambers (i,e., *Ticinella praeticinensis*) and is recorded a few meters above the first occurrence of *Biticinella breggiensis*. A gradual increase of trochospiral thick-walled (*B. breggiensis, T. roberti, T. raynaudi*) and *Globigerinelloides* taxa, reflecting mesotrophic conditions. 2) The *Pseudothalmanninella subticinensis* Interval Zone includes the first appearance of keeled forms (*Ps.subticinensis*), associated with abundant ticinellids with flattened chambers (*B.breggiensis*, *T. roberti*) below the base of the organic-rich Mellegue horizon, indicating an oligotrophic environment. 3) The *Pseudothalmanninella ticinensis* Interval Zone .The continuous occurrence of *T.primula* and the scarcity of *Globigerinelloides* throughout the lower part of this zone indicates an oligotrophic to weakly mesotrophic environment. The occurrences of radiolarian-rich horizons and abundant forms with elongated chambers (*T. raynaudi*) in the lower part of this zone indicate an abrupt shift to enhanced eutrophic and dysaerobic conditions. 4) The *Thalmanninella appenninica* Zone, which shows a decrease in abundance preceding the extinction of ticinellids, and a gradually increasing number of specialized keeled forms (i.e., *Th. appenninica*), indicates oligotrophic conditions. 5) The *Planomalina buxtorfi* Total Range Zone is characterized in its lower part by an increasing abundance of clavate forms with radially elongated chambers (i.e., *Clavihedbergella*) above the organic-rich bed of the Mouelha Member, indicating low-oxygen, oligotrophic to mesotrophic conditions.

Keywords: Northern Tunisia, late Albian, organic-rich beds, biostratigraphy, planktic foraminifera, bioevents

INTRODUCTION

The Albian was marked by an increased influx of terrigenous sediments into the oceans and a worldwide crisis on carbonate platforms which coincided with a global sea-level rise (Grötsch et al. 1993; Erbacher and Thurow 1997; Strasser et al. 2001; Bornemann et al. 2005; Follmi 2012; Peybernes et al. 2013; Haq et al. 2014). These events were punctuated by perturbations of the global carbon cycle, reorganization of the climate system, and productivity that resulted in significant changes in the marine biota, some of which were influenced by oceanic anoxic events (Coccioni and Galeotti1993; Weissert et al. 1998; Premoli Silva et al. 1999; Steuber 2002; Giraud et al. 2003; Herrle et al. 2003; Huber and Leckie 2011; Hu et al. 2014; Charbonnier et al. 2018; Friedrich et al. 2018; Ben Amara et al. 2020; Mansour et al. 2020).

During the late Albian, the northern Tunisian realm was characterized by the deposition of pelagic sequences composed of limestone and marl successions, attributed to the lower Fahdene Formation (Burollet 1956), which includes organic-rich beds that are recognized as a potential source rock of hydrocarbons (Saidi and Belayouni 1994; Ben Fadhel et al. 2011; Khalifa et al. 2018; Hallek et al. 2020). Several studies of Albian planktic foraminiferal biostratigraphy of pelagic sequences outcropping in northern Tunisia have provided various zonal schemes based on bioevents (Salaj 1980; Bellier 1985; Ben Haj Ali 1987; Touir et al. 1989; Ben Haj Ali and Ben Haj Ali 1996; Zghal et al. 1996; Ben Haj Ali 2005; Robaszynski et al. 2007; Ben Haj Ali 2008; Ben Haj Ali and Memmi 2014). However, some ambiguities surround the lithostratigraphic nomenclature and subdivision of upper Albian organic-rich beds. Most of the aforementioned previous studies carried out on Albian exposures in northern Tunisia stated that the upper Albian was represented by a single episode of black shale deposition without providing an accurate age constraint to establish a reliable regional chronostratigraphic correlation. Much of this confusion resulted from the lack of more detailed sampling, lithological descriptions, and integrated geochemical studies. Moreover, there is not a well-defined zonation for Albian pelagic successions, including well-preserved organic-rich sediments deposited in halokinesis-related half-grabens (Jaillard et al. 2017). The previous investigation carried on the upper Albian pelagic successions of northern Tunisia has revealed two distinct episodes of black shale deposition characterized by high total organic carbon (TOC) content that occurred



TEXT-FIGURE 1
Location map of the studied sections (in red asterisks). RAG: Ragoubet Lahneche, OS: Oued Siliana, AS: Ain Slim

in the upper part of the *Biticinella breggiensis* Zone and the lower part of the *Thalmanninella appenninica* Zone, respectively (Ben Fadhel et al. 2011).

A revision of the late Albian biostratigraphy requires high-resolution sampling of sections to ensure accurate species identification given that the upper Albian exposures are affected by hiatuses linked to erosion or tectonic complications associated with salt extrusion in northern Tunisia (Memmi 1999; Ben Slama et al. 2009; Masrouhi and Koyi. 2012).

Previous investigations by Ben Fadhel et al. (2010, 2011, 2014) of composite sections have subdivided the earliest late Albian interval using radiolarians and planktic foraminifera. For litho-biostratigraphic subdivision purposes, we take into consideration, in addition to the bioevents, the stratigraphic distribution of vertical lithofacies changes, radiolarian-rich horizons, and marker beds.

Two black shale horizons have been used as lithostratigraphic marker beds in this study: the Mouelha Member and the rhythmically-bedded Mellegue horizon (Ben Fadhel et al. 2016). A semi-quantitative analysis of the planktic foraminifera across organic-rich intervals has been conducted for each section to provide evidence about variations in paleoecological conditions and inferred biotic changes. The bioevents and zonal subdivisions were compared with the zonal schemes of time equivalent intervals identified in northern Tethyan outcrops.

GEOLOGICAL SETTING

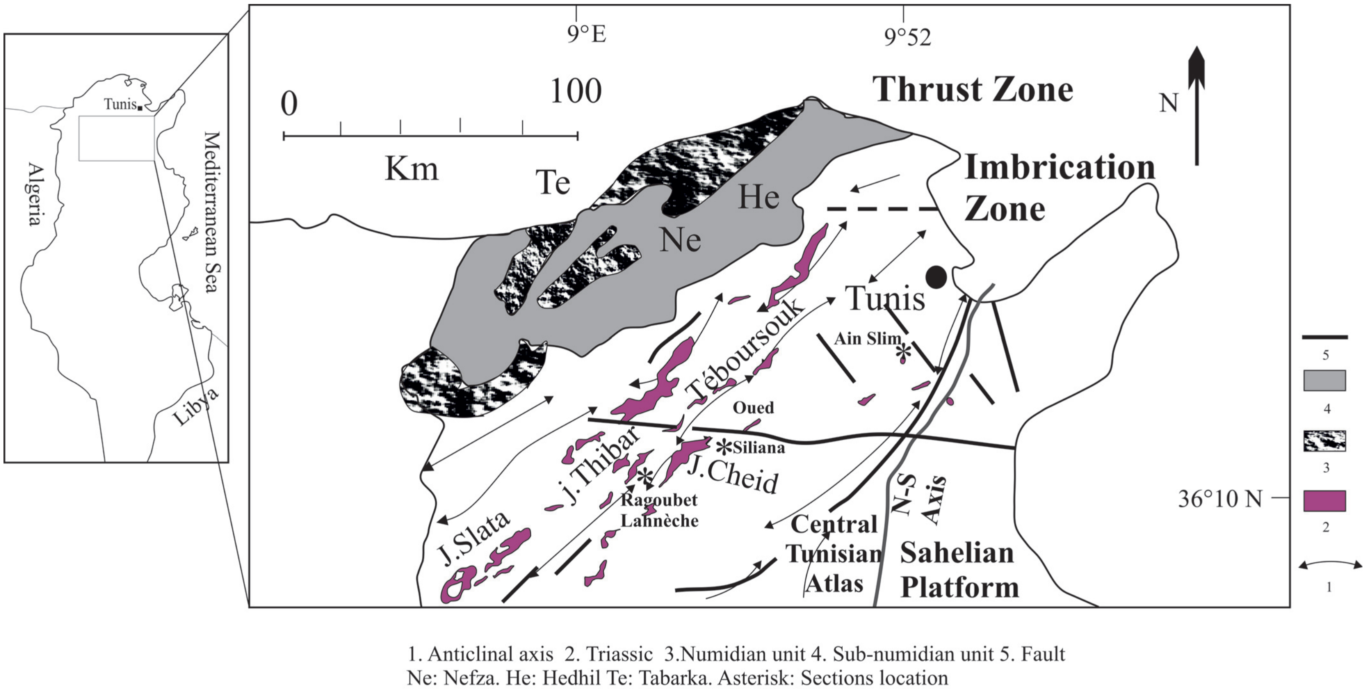
The study area, located in the central part of northern Tunisia, is bordered on the east by the Cap Bon Peninsula, the Pelagian block to the southeast, and by the Tunisian - Algerian border towards the southwest (text-figure 1). The Tunisian Trough or the Imbrication Zone, including Triassic piercing-salt domes, is bordered on the north by the Thrust Zone, on the south by the Central Tunisian Atlas, and on the east by the Sahel foreland and the eastern segment of the N-S axis (text-figure 2).

The subsurface structure of the Tunisian margin is the result of the geodynamic evolution of the Mediterranean Tethys induced by significant rifting events during the Early Cretaceous (Durand-Delga and Fontboté 1980; Souquet et al. 1997; Guiraud 1998; Guerrera and Martin-Martin 2014).

The opening of the Maghrebian Tethys and the subsequent Early - Middle Jurassic rifting event (Leprêtre et al. 2018) resulted in the injection of Triassic salts along normal faults (Vila et al. 2002). Triassic salt ascension induced the development of a tilted-block structure, resulting in hiatuses, facies and thickness variations, and extensional subsiding basins called the "Tunisian Trough" or "Sillon Tunisien", bounded by dextral strike-slip and normal faults (Chikhaoui et al. 1998; Memmi 1999; Zouari et al. 1999; Chikhaoui et al. 2002; Jallouli et al. 2005; Ben Chelbi et al. 2006; Ben Slama et al. 2009; Jaillard et al. 2013; Masrouhi et al. 2014; Jaillard et al. 2017).

During the Albian, radiolarian and foraminiferal-rich pelagic sequences were deposited in these subsiding basins, which have a paleodepth of approximately 1100 m (Ben Haj Ali 2005; Ben Fadhel et al. 2010; Chihaoui et al. 2010; Ben Fadhel et al. 2014; Harzali et al. 2019). These intervals include organic-rich beds or black shales that represent the Albian Oceanic Anoxic Events (OAE1b, c, and d) (Saïdi et Belayouni 1994; Ben Fadhel et al. 2011; Soua 2016; Khalifa et al. 2018).

These intervals are composed of stacked monotonous pelagic members of the lower Fahdene Formation (Burollet 1956) (text-fig. 3). Southward, the sedimentary pile displays several hiatuses in the lower and middle Albian intervals of the shelf edge (Bismuth et al. 1981; Zghal et al. 1996; Memmi 1999; Jaillard et al. 2013).



TEXT-FIGURE 2
Structural map of northern Tunisia (after Ghanmi et al., 1999; Ould Bagga et al., 2006; modified). 1. Anticlinal axis 2. Triassic 3. Numidian unit 4. Sub-Numidian unit 5. Fault Ne: Nefza. He: Hedhil Te: Tabarka. Asterisk: Sections localization.

The lower Fahdene Formation is composed of three members: 1) The lower shale or "Argiles Inférieures" Member; 2) the "Marnes Moyennes" Member; 3) the Mouelha Member; 4) the Defla Member.

Studies of the stratigraphic framework of upper Albian pelagic sequences identified distinctive facies successions characterized by a prominent, rhythmically thin-bedded black shale interval lying below the organic-rich Mouelha Member. This interval, which lies within the middle part of the *Biticinella breggiensis* Zone previously identified in Albian outcrops near El Kef (northwestern Tunisia), was correlated to the equivalent Amadeus Segment level that outcrops in Central Italy (Galeotti 1998; Luciani et al. 2004; Ben Fadhel et al. 2011). In this paper, we assign the name of 'Mellegue horizon" (text-figure 3) (Ben Fadhel et al. 2016), to the equivalent level exposed in northern Tunisia. This nomenclature is based on the work of Pimienta (1973), who was the first to define cyclic silicified limestone/marl couplets from Cretaceous exposures in the Mellegue area (northwestern Tunisia).

The studied sections belong to an area dominated by NNE-SSW oriented Triassic bodies, bordered to the southeast by the Zaghouan Fault and the north by the NE continuation of the main El Alia – Teboursouk Fault (Martinez and Truillet 1987).

Three sections have been selected for this study (text-figure 1 and 2) including 1) the Ain Slim (AS) section located in the Bir M' Cherga area southeast of Tunis and 9 km away from Ain Askar village. The base of the section is bordered by the Triassic diapir of Jebel Aouinet; 2) The Ragoubet Lahnech (RAG) section located in the western part of northern Tunisia, a few kilometers northeast of the town of Teboursouk; and 3) the Oued Siliana (OS) section located in the north-eastern anticline at the terminus of the Jebel Cheid Triassic extrusive structure.

STRATIGRAPHY OF FAHDENE FORMATION

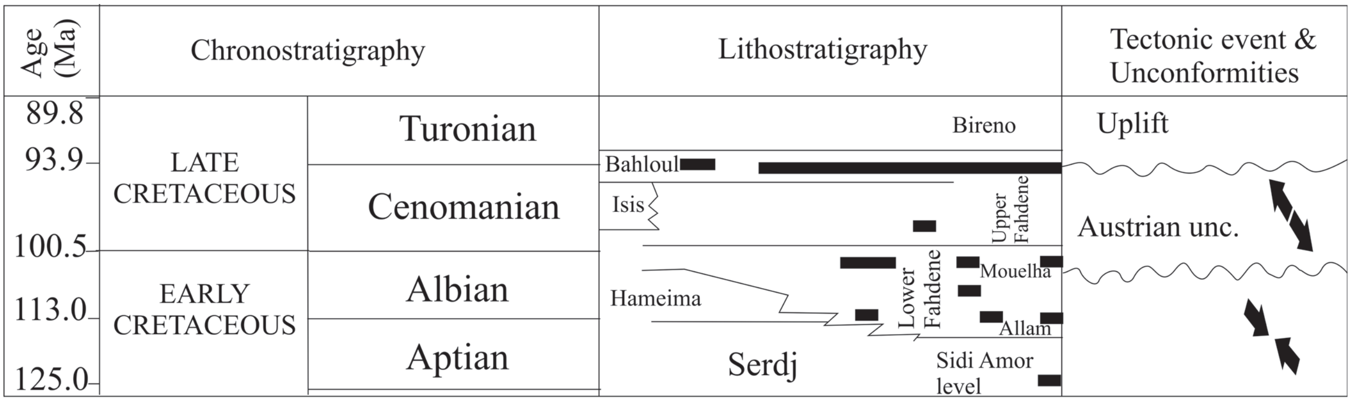
The Albian exposures of northern Tunisia consist of marl and limestone alternations that include organic-rich horizons confined to the lower part of the Fahdene Formation. The Fahdene Formation is overlain by the Hameima Formation, which is dated as earliest Albian (Chihaoui et al. 2010; Latil 2011) and is capped by the Bahloul Formation, which spans the Cenomanian – Turonian transition (Amédro et al. 2005)(text-figure 3).

Various nomenclature has been proposed to establish the stratigraphic framework of the Fahdene Formation (Burollet 1956; Salaj 1980; Robaszynski et al. 1993).

As defined by Burollet (1956), who proposed a stratotype section in the Tajerouine area, the Fahdene Formation is subdivided into five members: 1) the Lower Shales 2) the Allam 3) the Middle Shales 4) the Mouelha Member and 5) the Upper Shales.

Robaszynski et al. (1993) and Amédro (2008) subdivided the upper part of the Fahdene Formation into six members: 1) The Marnes Moyennes Member confined to the upper Albian s.s 2) the Mouelha Member and the Defla Member, both confined to the Vraconian (uppermost Albian) 3) the Kef Azreg Member, which spans the Albian – Cenomanian transition and 5) the lower to middle Cenomanian Touil Member and 6) the upper Cenomanian Dellel Member.

Based on ammonite biostratigraphy, Jaillard et al. (2013) stated that "The base of the Lower Shales ("Basal Shales") is still of earliest Albian age (*L. tardefurcata* Zone), while most of the unit is



TEXT-FIGURE 3
Mid-Cretaceous stratigraphic chart of northern Tunisia (After ETAP, 2001; modified). Bolded dashs correspond to black shale members. Numerical age scale is based on Gradestein et al (2012). Mid-Cretaceous lithostratigraphic subdivision is modified after Soua (2009; 2016); Ben Haj Ali and Memmi (2014); Chihaoui et al (2010), Ben Fadhel et al (2011; 2016) and Robascynski et al (1993); ElKhazri et al. (2013); Khaled et al. (2017).

of early Albian age (*D. mammillatum* superzone p.p.)". They also stated that the Allam Member may span the upper lower Albian – middle Albian interval.

MATERIALS AND METHODS

Three sections were studied and approximately 100 samples were collected. Dense sampling (0.5 to 1 m sample interval) was conducted across marker beds, member boundaries, and organic-rich intervals (black shales).

The microfauna was recovered using standard techniques. The indurated samples were soaked in a 10% hydrogen peroxide solution for 48 hours and then washed through a series of sieve meshes (500 ìm - 125 µm - 63 µm). The residue was then dried at 30°C. Picking and identification of all the specimens were carried out using a Heerbrugg binocular microscope at the Georessource Laboratory of the CERTE, Borj Cedria. Planktic foraminifera specimens are mounted on a slide, using double-faced adhesive tape, coated with silver, and photographed using a JEOL JSM 5400 scanning electron microscope at the ETAP Research and Development Center (RDC), Tunis. The semi-quantitative estimate of species abundance was made on > 63 µm fractions using an Otto microsplitter. For accurate paleoecological interpretation of planktic foraminifera, the estimated specimen number must be between 300 and 400 specimens. For estimation of preservation, relative abundance and species abundance counts of planktic foraminifera were made according to the chart discussed in Sliter (1999) and Huber and Leckie (2011). All the identified taxa are listed in the Appendix.

The lithostratigraphic subdivision is based on the nomenclature adopted by Burollet (1956) and Robaszynski et al. (1993).

LITHOSTRATIGRAPHY OF STUDIED SECTIONS

The middle to late Albian transition of the Ain Slim section, which lies within the lower part of the Fahdene Formation, is composed of 52-meter alternations (AS4 - 25) of thick gray and laminated limestone beds and marl alternations yielding quartz grains and abundant benthic foraminifera (text-figure 4).

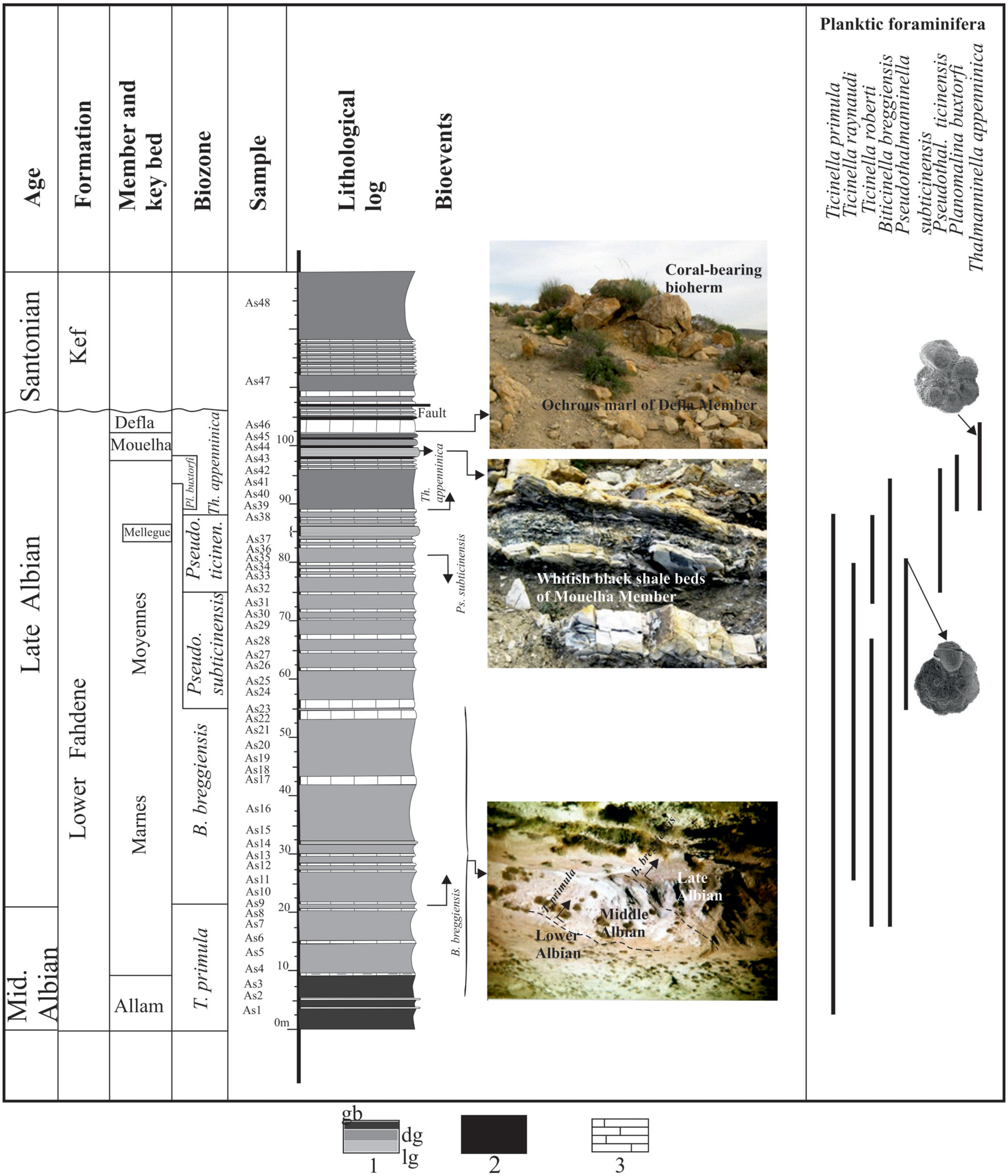
The marl and limestone beds grade upward into centimeter-thick schistose limestone beds, which then become massive at the top, and contain cross-cutting calcite veins and glauconite grains (AS22). These intervals provided discrete radiolarian microfauna. A 25 m thick alternation of whitish limestone and gray marl beds (AS26-32) passes upward into detrital quartz and glauconite-rich rhythmic bundles of thin laminated limestone and gray to whitish-colored marl couplets which represent the Mellegue horizon (AS33-35). The planktic foraminiferal content is moderately diverse and is associated with a discrete cryptocephalic radiolarian fauna.

The upper part of the section is composed of alternations of beige limestone beds and thick marly intervals displaying ammonite molds and moderately preserved and abundant planktic foraminifera (22 m thick). Upward, these alternations include organic-rich and micritic limestone beds attributed to the Mouelha Member (AS40). The limestone beds pass laterally into coral–bearing bioherms, displaying pale yellow veins (AS42) overlying the marls of the Defla Member. These successions are unconformably overlain by Santonian marls of the Kef Formation.

The Oued Siliana section is located westward of the Bir M'Cherga area (text-figure 5). It consists of a detrital-rich gray marl interval (OS1) that is overlain by an 8 m alternation of thick dark-gray splintery limestone and marl beds (OS2). They provide an assemblage composed of scarce, recrystallized radiolarian, and planktic and benthic foraminiferal tests. These beds are overlain by slumped gray-colored limestone and marl alternations containing small pyritized concretions (OS3).

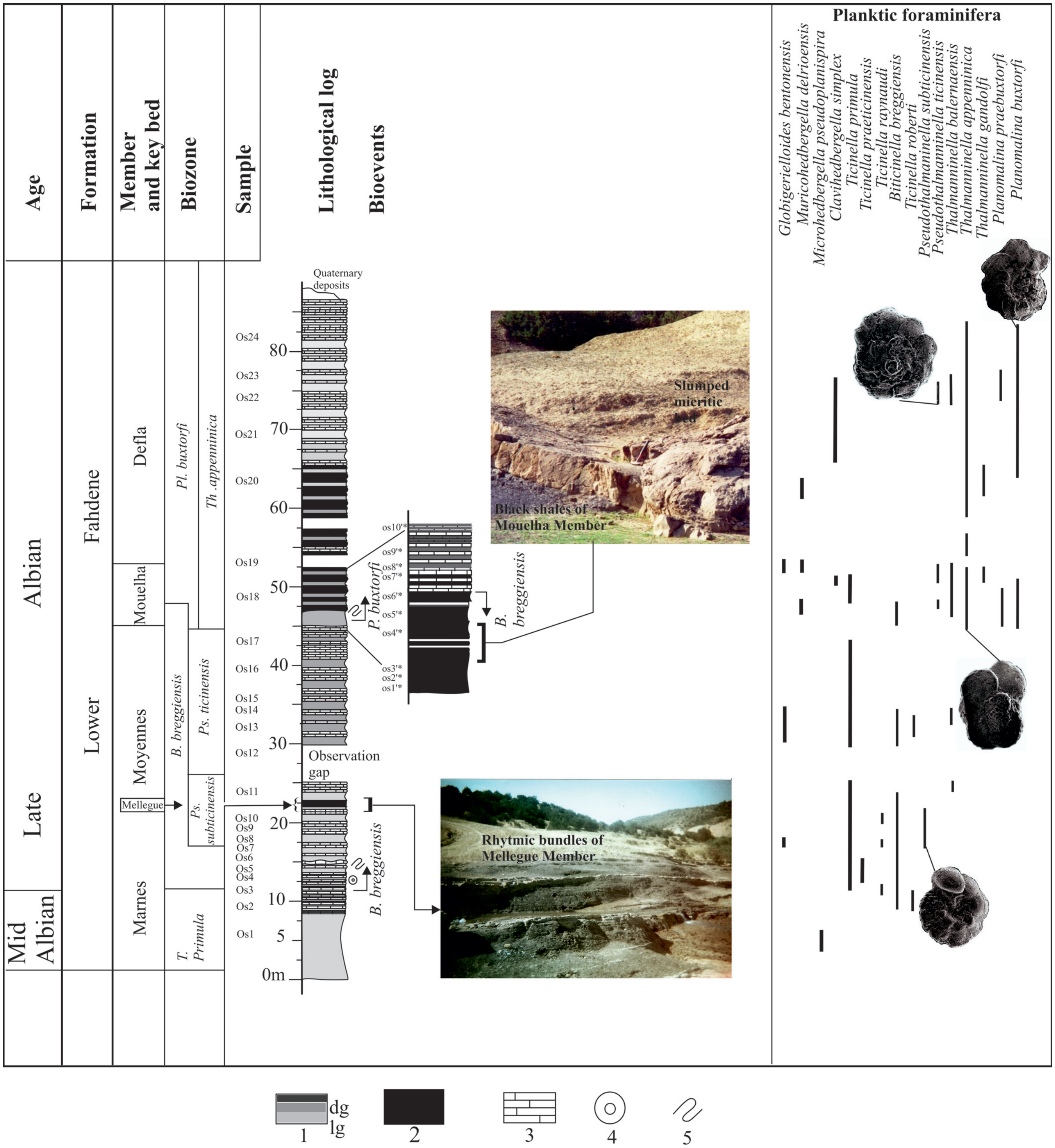
These intervals grade upward into darker thin limestone and marl beds, including rhythmic bundles of organic-rich limestone and marl couplets which correspond to the Mellegue horizon (OS10-11).

The upper part of the Oued Siliana section consists of an organic-rich dark bed of the Mouelha Member overlain by an oil-impregnated limestone bed cut across by calcite veins and displaying a southeast-trending flexural deformation (OS17-19). The organic-rich Mouelha Member consists of 5 m-thick bituminous, thin laminated limestone and marl alternations (OS1 – 6), providing abundant keeled planktic



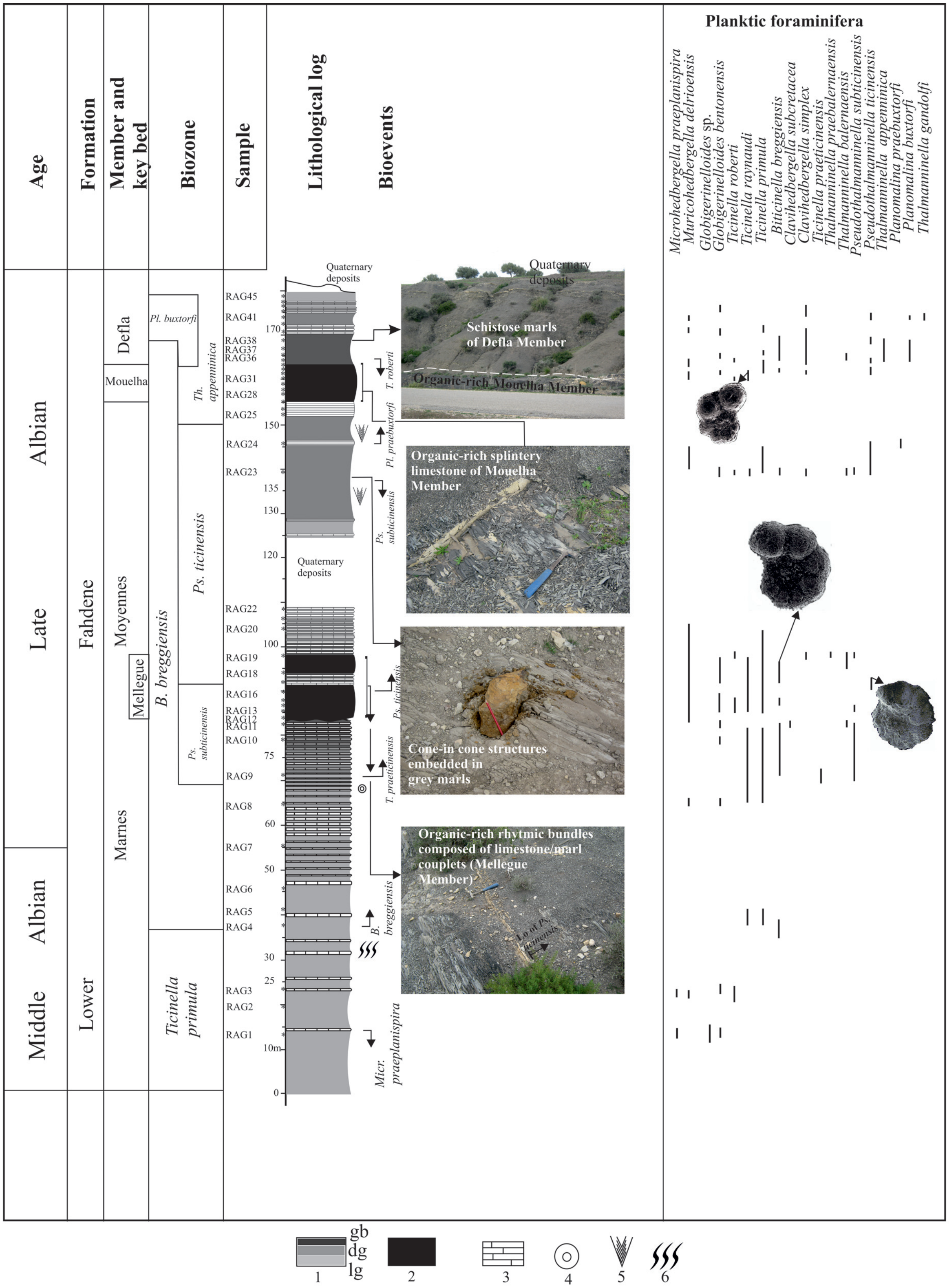
1. Marl (lg: light gray, dg: dark gray, gb:gray to black). 2 Blackshales. 3. Limestone

TEXT-FIGURE 4
Biostratigraphy of the Ain Slim section.



1. Marl (lg: light gray, dg: dark gray, gb:gray to black). 2 Blackshales. 3. Limestone. 4. Pyrite nodule. 5. Slumped bedding

TEXT-FIGURE 5
Biostratigraphy of the Oued Siliana section.



1- Marl (lg: light gray, dg: dark gray, gb:gray to black). 2- Blackshales. 3- Limestone. 4. Pyrite nodule. 5. Cone-in-cone structure. 6. Burrows

TEXT-FIGURE 6
Biostratigraphy of the Ragoubet Lahnech section.

foraminifera and scarce radiolarian microfauna. The next succession consists of ochreous laminated limestone and gray marl alternations corresponding to the Defla Member.

The Ragoubet Lahnech section (text-figure 6) shows the most continuous record of the upper Albian pelagic sequence in the study area. The sedimentary sequence is composed of gray marl and limestone beds grading upward into splintery and black shaly limestone beds (RAG1 – 5). The middle part of this unit contains limestone beds containing fractures filled with calcite and oxide crystals. The marly intervals provided small pyritized concretions and abundant detrital quartz crystals (RAG 1 - 6). They are overlain 36 m thick gray-colored limestone beds and equally thick gray marl intervals (RAG 7 - 11). The thickness of the marly interval decreases upward through this unit. In the middle part, between RAG6 and RAG7, the 50 cm-thick limestone beds are intensely bioturbated and affected by weathered veins. The detrital grain-rich marly interval (RAG7) provided scarce planktic foraminifera. The next sample (RAG8) is characterized by a diversified and abundant radiolarian microfauna.

A 16m-thick (RAG 11 to RAG 19) interval is composed of rhythmic, organic-rich laminated limestone and marl beds that are attributed to the Mellegue horizon. The organic-rich interval is subdivided into two sets separated by an alternation composed of 2 m-thick shaly laminated limestone and thin marly intercalations. The single bundles of black shales are composed of ten limestone/marl rhythmic couplets. The single couplet is composed of a 30-centimeter-thick marly interval overlain by an alternation of 10 cm thick limestone and marl beds.

The marly intervals contain, in places, small pyritized concretions, detrital material and pyrite crystals (RAG14). They also provided scarce benthic foraminifera and ostracods. At the base of this interval, the microfaunal content contains abundant cryptocephalic radiolaria and trochospiral planktic foraminifera (i.e. *Ticinella*).

These successions are overlain by a thickening-upward gray to black laminated limestone and marl alternation (RAG19 to RAG 26). Mineralized veins and fibrous calcite nodules ("cone-in-cone" structures) are present in the upper part. The planktic foraminiferal microfauna is scarce at the base and becomes very abundant toward the middle part of this interval (RAG24).

This unit is overlain by ten meters of black, laminated bituminous limestone bed (RAG27 to RAG 47), corresponding to the Mouelha Member. The microfaunal content is characterized by abundant, diverse, and small-sized planktic foraminifera, particularly in the middle part of this interval. The RAG35 bed yielded abundant trochospiral planktic foraminifera that increase in abundance upward, together with a decrease in the relative abundance of radiolaria. The next 16 m is composed of beige laminated limestone and dark to gray marl beds bearing septarian nodules (RAG37 - 45). The limestone beds have an average thickness of about 20 cm. This unit is overlain by a centimetric ochreous limestone bed.

PLANKTIC FORAMINIFERAL BIOSTRATIGRAPHY

The late Albian was characterized by major changes in planktic foraminiferal assemblages marked by a high rate of diversification and turnover events, in addition to the reappearance of keeled morphologies and the development of muricae on species such as *Muricohedbergella*, *Rotalipora, Praeglobotruncana,* and *Planomalina* (Premoli Silva and Sliter 1999; Leckie et al. 2002; Petrizzo and Huber 2006a). These events occurred after periods of extreme environmental stress affecting planktic foraminifera, characterized by dwarfism and extinction events across the Aptian/Albian boundary (Huber and Leckie 2011; Ferraro et al. 2020).

The biostratigraphic subdivision of the studied section is based mainly on bioevents, in addition to morphological changes, and the relative abundance of planktic foraminifera (Table1, 2, and 3) recognized across the organic-rich bed markers. The identification of biozone boundaries includes the involvement of taphonomic artifacts probably arising from the diagenetically-induced alteration of the sedimentary record. Here, we used the terminology of Huber and Leckie (2011) and Coccioni and Premoli Silva (2015), and biozones are based on the lowest occurrence (LO) and highest occurrence (HO) of the marker species. Species identification of the genus *Rotalipora* is based on morphological characteristics discussed by Gonzalez-Donozo et al. (2007) and Lipson-Benitah (2008).

Planktic foraminiferal zones and bioevents

The bioevents identified in the studied sections allowed us to establish a zonal scheme for the late Albian succession in the Tunisian Trough and to better constrain the age of organic-rich black shale members. A comparison with age equivalent sediments of the northern Tethyan allowed for the identification of five biozones (text-figure 7). The zonal boundaries are identified based on bioevents and biozone definitions established by Robaszynski and Caron (1995) and Petrizzo and Gilardoni (2020). The biozone definition depends on the reliability of bioevents throughout the studied sections. Because of their poor preservation and inconsistent distribution throughout the studied sections, the *Ticinella praeticinensis* bioevents was not used as a zonal marker.

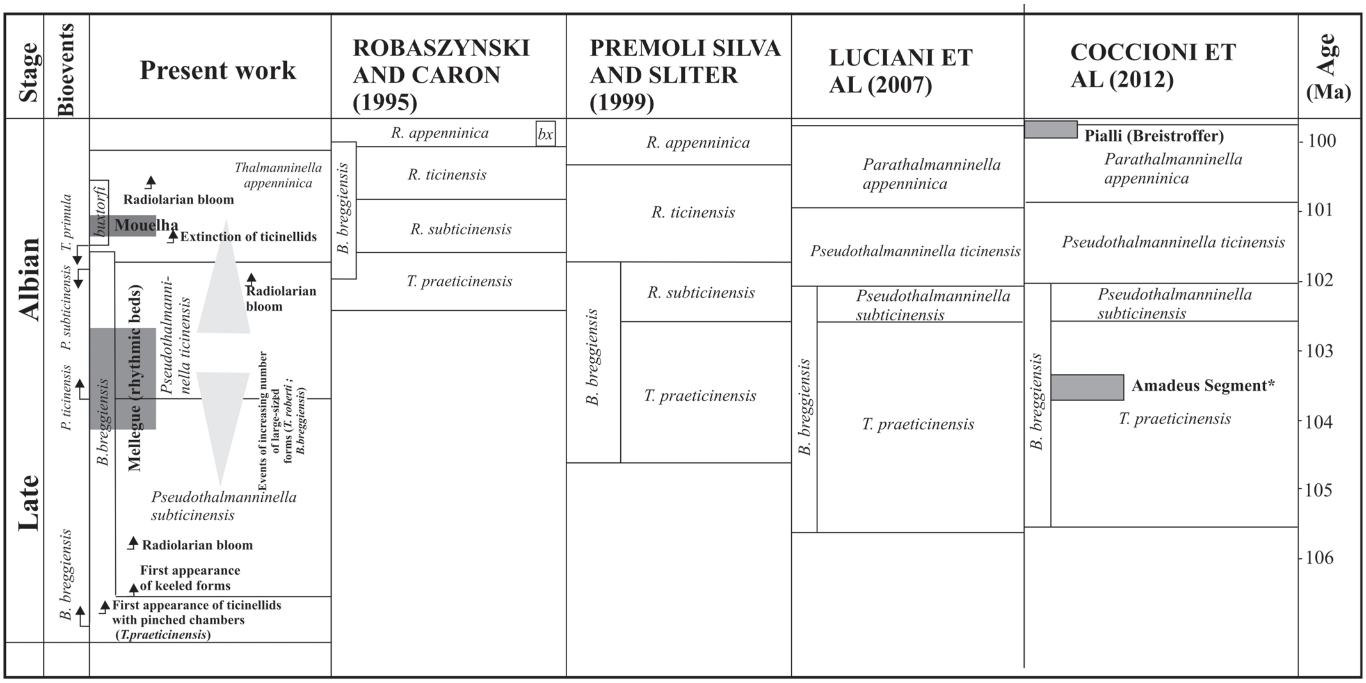
The *Biticinella breggiensis* Zone

Definition: total range zone from the LO of the nominal species to the HO of the nominal species.

Discussion: The *B. breggiensis* Zone is considered an interval zone by Lipson -Benitah (1980), Leckie et al. (1984), Tornaghi et al. (1989), Coccioni and Galeotti (1993), Sliter (1999), and later by Luciani et al. (2004; 2007). To refine the resolution of the mid-Cretaceous biostratigraphy, Lipson-Benitah (1991; 2009) reiterated the zonal scheme of Robaszynski and Caron (1995) and applied the "Retrozone" concept, based on the last occurrences of *T. praeticinensis* and *B. breggiensis*, respectively. This zone is defined as a total range zone by Robasynski and Caron (1995) and is considered as an interval range zone by Premoli Silva and Sliter (1999) and Luciani et al. (2007).

In the studied sections, the lowest occurrence (LO) of *Biticinella breggiensis* precedes the LO of *Ticinella praeticinensis.* The organic-rich beds of the Mellegue horizon and Mouelha Member occur in the middle and upper parts of this zone.

In the Umbria Marche of the Italian realm, the organic-rich Amadeus Segment horizon, identified as a possible equivalent to the rhythmically-bedded Mellegue horizon and oceanic anoxic event 1c (OAE1c) (Ben Fadhel et al. 2011), is confined to a few portions of the *B. breggiensis* Zone (Coccioni and Galeotti 1993; Luciani et al. 2004; 2007). The Mellegue horizon produced a depauperate planktic foraminifera assemblage rep-



TEXT-FIGURE 7
Comparison of Mediterranean Tethys zonal schemes with the present study. The gray rectangles correspond to organic-rich bed markers. Subdivisions of previous zonal schemes are calibrated with the geologic time scale of Gradstein et al (2012). *Amadeus Segment is a rhythmically bedded black shales interval exposed in northern Italy (Galeotti 1998; Galeotti et al. 2003).

resented by *T. primula*, *T. praeticinensis*, and *B. breggiensis*, similar to that recovered from the Amadeus Segment Horizon.

The LO of *Ticinella praeticinensis* was recorded at 12.46 m below the base of the organic-rich rhythmic bundle of the Mellegue horizon in the Ragoubet Lahneche section and lies in the pyrite concretions-rich marly interval. It is associated with *B. breggiensis*, *Globigerinelloides* [=*Laeviella* Huber, Petrizzo and Falzoni 2022] *bentonensis*, *Ticinella raynaudi*, and *T. primula*.

Given the poor preservation of specimens recovered from the pyritized concretions-rich marls, it may occur closer to the base of the *B. breggiensis* Zone. The highest occurrence of *T. praeticinensis* was recorded 10.24 m below the base of the rhythmic, organic-rich Mellegue horizon.

The *Pseudothalmanninella subticinensis* Zone

Definition: interval zone from the LO of the nominate species to the LO of *Pseudothalmanninella ticinensis*

Discussion: This zone is considered to be a subzone by Cobianchi et al. (1997), defined by the lowestoccurrence (LO) of the zonal marker to the LO of *R. ticinensis*. Parize et al. (1998) used the LO of *R. subticinensis* to subdivide the late Albian. He stated that bioevents correspond to the boundary between the "late Albian *s.s.*" and the "Vraconian".

This zone includes an assemblage of *Ticinella roberti*, *Muricohedbergella delrioensis, Globigerinelloides bentonensis,* and *Ticinella raynaudi.* The upper part of this zone records the first appearance of *Thalmanninella praebalernaensis* (Ben Fadhel et al. 2011), which belongs to the *appenninica* group that evolved from *Ticinella raynaudi* Sigal (Ando and Huber 2007; Petrizzo et al. 2015). A similar event has been identified from Albian exposures of the northern Tethyan margins, which consists of the co-occurrence of *Rotalipora praebalernaensis* (= *Thalmanninella praebalernaensis*) in the upper *Pseudothalmanninella subticinensis* Zone (Tornaghi et al. 1989; Gale et al. 2011).

The lowest occurrence of *Pseudothalmanninella subticinensis* was recorded 10.5 m below the organic-rich rhythmic first bed of the Mellegue horizon at the Ragoubet Lahnech section. At Oued Siliana and Ain Slim, the lowest occurrences of *Ps. subticinensis* are recorded at 2.6 m and 12.98 m, respectively, below the first bed of rhythmic bundles. This species is associated with *Globigerinelloides bentonensis, B.breggiensis, Ticinella raynaudi, Ticinella roberti*, and *Muricohedbergella delrioensis*. The extinction of *T. praeticinensis* was recorded 11.15 m below the base of the Mellegue horizon at the Ragoubet Lahnech section. At the Oued Siliana section, the highest occurrence of *T. praeticinensis* is recorded at 6.55 m below the top of the Mellegue horizon.

At the Ragoubet Lahnech section, the highest occurrence of *Ps. subticinensis* is recorded within the cone-in-cone rich marly interval, 16. 72 m below the organic-rich Mouelha Member. At the Oued Slim section, the highest occurrence of *Ps. subticinensis* was recorded at 9 m above the LO of *Ps. ticinensis.*

The *Pseudothalmanninella ticinensis* Zone

Definition: Partial Range Zone from the lowest occurrence of the index taxon to the lowest occurrence of *Thalmanninella appenninica*

TABLE 1
Relative abundance estimate for planktic foraminifera through the upper Albian samples from the Ain Slim section. Estimation of preservation and abundances of planktic foraminifera were made according to the chart discussed in Sliter (1999), Huber and Leckie (2011): A = abundant; C = common; F = few; R = rare; B = barren (no specimens in sample). Preservation ratings: G = good; M = moderate; P= poor.

Age	Sample	Thickness (m)	Preservation	*Ticinella primula*	*Ticinella raynaudi*	*Ticinella roberti*	*Biticinella breggiensis*	*Pseudo. subticinensis*	*Pseudothal. ticinensis*	*Planomalina buxtorfi*	*Thalmanninella appenninica*
late Albian	As45	101.25	M								
	As44	99.45	M								
	As43	97.36	M							C	F
	As42	95.94	M							C	F
	As41	93.94	M				R			C	C
	As40	91.23	M				R		F	C	C
	As39	89.34	M				R		F	C	C
	As38	87.02	G	R		R	R		F	A	C
	As37	84.74	G	C		F	F		F		
	As36	81.92	G	C		F	C		C		
	As35	80.20	M	C		C	C	F	C		
	As34	78.61	M	C	R	F	F	F	C		
	As33	77.18	M	A	F	F	F	C	A		
	As32	75.32	M	C	F	C	R	F	C		
	As31	72.85	P	C	F	C	R	F			
	As30	70.57	P	C	C		R	C			
	As29	68.94	P	A	F		R	C			
	As28	66.13	P	C	C	R	F				
	As27	64.28	P	A	A	F	F				
	As26	62.21	M	C	A	F	C				
	As25	59.72	M	C	A	C	C				
	As24	57.34	P	R	A	C	C	F			
	As23	54.78	P	R	A	F	C	F			
	As22	52.53	P	R	A	C	C				
	As21	50.28	G	A	C	C	C				
	As20	48.19	G	C	C	F	C				
	As19	45.97	M	A	C	R	C				
	As18	43.57	M	A	C	R	F				
	As17	42.90	M	C	C	F	F				
	As16	37.29	M	C	R	F	C				
	As15	34.32	M	C	R	A	C				
	As14	31.84	G	A	A	R	C				
	As13	29.88	M	R	R	A	A				
	As12	27.18	M	R	R	A	A				
	As11	25.36	M	F	C	C	A				
	As10	23.12	G	F		C	A				
	As9	21.07	P	F		F	A				
	As8	18.89	P	C		F					
	As7	16.37	M	C		F					
	As6	14.25	M	C		F					
	As5	12.14	M	A							
	As4	9.53	P	A							
Mid. Albian	As3	7.16	P	C							
	As2	5.32	P	C							
	As1	2.86	P	F							

TABLE 2
Relative abundance estimate for planktic foraminifera through the upper Albian samples from the studied Oued Siliana section. Estimation of preservation and abundances of planktic foraminifera were made according to the chart discussed in Sliter (1999), Huber and Leckie (2011): A = abundant; C = common; F = few; R = rare; B = barren (no specimens in sample). Preservation ratings: G = good; M = moderate; P= poor.

Age	Sample	Thickness (m)	Preservation	Abundance of planktic foraminifera relative to Benthic foraminifera (0–1)	*Murico. delrioensis*	*Ticinella primula*	*Ticinella raynaudi*	*Ticinella roberti*	*Gl. bentonensis*	*Biticinella breggiensis*	*Pseudo. subticinensis*	*Pseudothal. ticinensis*	*Thalmanninella balernaensis*	*Planomalina buxtorfi*	*Thalmanninella appenninica*
late Albian	Os24	82.21	M												C
	Os23	76.65	M											A	A
	Os22	74.83	M										R	A	F
	Os21	68.72	M									F		C	R
	Os20	63.76	P		F									F	C
	Os19	54.53	P		F				R						
	Os10'*	52.53	M										F		
	Os9'*	50.32	M											C	F
	Os8'*	50.58	M										F	A	C
	Os7'*	49.96	P										R	C	A
	Os6'*	49.37	P			R						C			R
	Os5'*	47.25	P			F						C		F	F
	Os4'*	46.72	P		C	F				R		A	F	A	C
	Os3'*	45.56	M		F									A	C
	Os2'*	45.48	M						C	C				C	C
	Os1'*	45.38	M							F				A	C
	Os17	42.17	M			C									
	Os16	39.32	P			F									
	Os15	35.70	P			R									
	Os14	34.47	P		F	R		R		R			R		
	Os13	32.15	P		R	F		R		R					
	Os12	28.75	M		R	F				F					
	Os11	23.82	P			R							R		
	Os10	20.33	P			R	R			F	F				
	Os9	19.42	M			C				C	F				
	Os8	17.50	M		F	A				A	F				
	Os7	17.36	M		R	C	R			A	C				
	Os6	15.00	G			C				A					
	Os5	13.75	G			A				A					
	Os4	13.01	P		C	F				F					
	Os3	11.74	M		A	F	A	C		C					
Mid. Albian	Os2	8.77	P												
	Os1	6.01	P												

Discussion: Ps. ticinensis differs from *Ps. subticinensis* by a decreased number of chambers in the last whorl and the acquisition of periumbilical ridges in the earlier chambers of the last whorl (Ando and Kakegawa 2007).

This zone is considered to be an interval zone by Bellanca et al. (1996). They stated that *T. primula* and *R. subticinensis* disappear in the lower half of the *Pseudothalmanninella ticinensis* Zone. Bellier and Moullade (2002) mentioned that the first occurrence of *P. praebuxtorfi* was recorded at the top of this zone.

The recovered planktic foraminiferal assemblage is composed of *B. breggiensis, Globigerinelloïdes bentonensis*, *Ticinella praeticinensis, Ps. ticinensis, Ps. subticinensis,* and *T. primula.* The *Ps. ticinensis* Zone includes dark marl intervals bearing cone-in-cone structures. These marls can be correlated with the *Thalmanninella ticinensis*-bearing marly interval overlying the iron-rich hardground surface southward in the Kasserine area (Bismuth et al. 1982). Eastward, the lower and upper parts of the *Ps. ticinensis* Zone encompasses the organic-rich Mellegue horizon.

The upper part of the *Ps. ticinensis* Zone is often characterized by the appearance of *Planomalina praebuxtorfi* and the disappearance of *Ps. subticinensis* just a few meters above the organic-rich beds of Mouelha Member.

At Ragoubet Lahnech, the LO of *Ps. ticinensis* is at 6.13 m above the base of the Mellegue horizon. At the Ain Slim section, the LO of *Ps. ticinensis* is recorded 8.77 m below the first bundles of organic-rich rhythmic beds of the Mellegue horizon. The LO of *Ps. ticinensis* is identified in the lower part of the organic-rich Mouelha Member at the Oued Siliana section. However, we found that the LO of *Ps. balernaensis* which should coincides with the LO of *Ps.ticinensis* according to the occurrence data in Mesozoic Planktonic Foraminifera - pforams@mikrotax (https://www.mikrotax.org/pforams/index.php?dir=pf_mesozoic), was identified at 25 m below the Mouelha Member. Therefore, we place the base of the *Ps. ticinensis* Zone at the LO of *Ps. balernaensis* at the Oued Siliana section.

The *Thalmanninella appenninica* Partial Range Zone

Definition: The interval zone from the LO of *Thalmanninella appenninica* to the LO of *Thalmanninella globotruncanoides*.

Discussion: Gale et al. (2011) suggested that the first and last occurrences of *P. buxtorfi* occur in the upper part of this zone. According to Petrizzo and Huber (2006a), the evolution from *P. praebuxtorfi* to *P. buxtorfi* takes place in the lower part of the *R. appenninica* Zone. Moreover, it has been suggested that *P. buxtorfi* disappears just before the top of this zone (Bellanca et al. 1996).

Erbacher and Thurow (1997) were the first to mention the existence of OAE1d in the *Rotalipora appenninica* Zone (=*Thalmanninella appenninica* Zone) corresponding to the rhythmically bedded organic-rich black shale of the Breistoffer event (Breheret, 1997) or Pialli Level (Coccioni 2001; Gambacorta et al. 2020).

According to Bellier and Moullade (2002), the *R. appenninica* Zone is characterized by the occurrence of the index species and the absence of *R. globotruncanoides.*

This zone is characterized by peaks of species diversity (Coccioni and Premoli Silva 2015), particularly in the proximal part of the Tunisian Trough (Oued Siliana area). This interval produced abundant radiolarians and keeled forms-dominating assemblages composed of *Thalmanninella appenninica, Planomalina buxtorfi, Planomalina praebuxtorfi, Pseudothalmanninella ticinensis, Ticinella primula, Biticinella breggiensis*, *G. bentonensis,* and *Clavihedbergella simplex*. The LO of *Th. appenninica* coincides with the gradual extinction of *Ticinella primula, Rotalipora ticinensis,* and *Biticinella breggiensis*.

The organic-rich Mouelha Member encompasses the lower part of this zone. At Jebel Mrhila and Kalaat Senan, southward of the study area, the first occurrence of *Rotalipora appenninica* (= *Thalmanninella appenninica*) was recorded higher above the Mouelha organic-rich black shales or its glauconite-rich equivalent (Zghal 1994; Amedro 2008).

The top of the *Th. appenninica* Zone, which coincides with the LO of *Thalmanninella globotruncanoides,* was not identified due to the slumping of overlying Quaternary deposits.

At the Ain Slim section, the lowest occurrence of *Thalmanninella appenninica* is found at 4.71 m below the organic-rich bed of the Mouelha Member and 11.03 m above the highest occurrence of *Ps. subticinensis*.

At the Oued Siliana section, the lowest occurrence of *Thalmanninella appenninica* is recorded just at the base of the Mouelha Member. At the Ragoubet Lahnech section, the lowest occurrence of *Thalmanninella appenninica* is recorded above the Mouelha Member, 5 m above its base. The LO of *Th. appenninica* might have occurred earlier, just a few meters above the HO of *Ps. subticinensis* and below the organic-rich Mouelha Member, taking into account the possible effects of selective dissolution on planktic foraminiferal tests attributed to shoaling of the carbonate compensation depth (CCD) during radiolarian bloom episodes (Ben Fadhel et al. 2011).

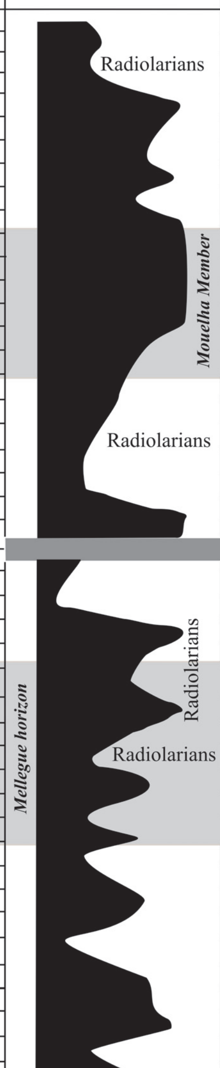
The *Planomalina buxtorfi* Total Range Zone

Definition: the total range zone (TRZ) from the LO to the HO of the nominal species.

Discussion: Leckie (1984) subdivided the latest Albian into the *Pl. praebuxtorfi* and *Pl. buxtorfi* Zones which were subdivided into two subzones (the *Pl. praebuxtorfi* and *Th. appenninica* subzones). Later, this zone was identified as an "interval range zone" in the Umbria Marche domain of Italy by Tornaghi et al. (1989) and Wonders (1992) identified a *Pl. buxtorfi* TRZ devoid of rotaloporids in the Austral Realm. According to Ando et al. (2015), the top of this zone corresponds to the Albian/Cenomanian boundary at which its typical assemblages, including *Pl. buxtorfi,* highly evolved forms of *Pseudothalmanninella ticinensis*, *Thalmanninella balernaensis*, and *Ticinella raynaudi*, are replaced by Cenomanian-specific taxa, including *Th. globotruncanoides* and *Rotalipora montsalvensis*. According to Robaszynski et al. (2007), the last occurrence of *Planomalina buxtorfi* has been identified in the early Cenomanian based on ammonite assemblages in the Kalaat Senan area, southwestward of our study sections.

At the Ain Slim section, the lowest occurrence of *Planomalina buxtorfi* is recorded at 6.6 m below the organic-rich bed of the Mouelha Member (text-fig. 4, sample AS 43, 97.36 m). The highest occurrence is recorded in the middle part of the same or-

TABLE 3
Relative abundance estimate for planktic foraminifera through the upper Albian samples from the Ragoubet Lahnech section. Estimation of preservation and abundances of planktic foraminifera were made according to the chart discussed in Sliter (1999), Huber and Leckie (2011): A = abundant; C = common; F = few; R = rare; B = barren (no specimens in sample). Preservation ratings: G = good; M = moderate; P= poor.



Age	Sample	Thickness (m)	Preservation	Abundance of foraminifera relative to Radiolarians (0–1)	*Microhedbergella praeplanispira*	*Murico. delrioensis*	*Ticinella primula*	*Ticinella raynaudi*	*Ticinella roberti*	*Clavihedbergella subcretacea*	*Clavihedbergella simplex*	*Gl. bentonensis*	*Biticinella breggiensis*	*Pseudo. subticinensis*	*Thalmanninella praebalernaensis*	*Thalmanninella balernaensis*	*Pseudothal. ticinensis*	*Planomalina praebuxtorfi*	*Planomalina buxtorfi*	*Thalmanninella appenninica*	*Thalmanninella gandolfi*
late Albian	RAG45	178.90	P																		
	RAG44	177.68	P																		
	RAG43	176.66	P																		
	RAG42	175.37	P			F					R	R									
	RAG41	173.95	M			A					F	C					R		F		R
	RAG40	172.39	P																		
	RAG39	170.67	P			F	F				F	A									
	RAG38	168.75	M								F		R				F		F	F	
	RAG37	166.80	M								F	F	R								
	RAG36	165.20	MP			F	C		R		R	A	F			R	R		R	F	
	RAG35	164.17	MP			C															
	RAG34	163.15	MP			C	C										F				
	RAG33	162.18	MP																		
	RAG32	161.30	MP			F	C	F	F		F	A	A				F				
	RAG31	160.16	P																		
	RAG30	159.07	P																		
	RAG29	157.56	P																		
	RAG28	156.78	P																		
	RAG27	155.15	P																		
	RAG26	153.42	P																		
	RAG25	152.37	P																		
	RAG24	145.74	M			C	C										C	F			
	RAG23	138.43	P			F	C	F	C		F	C	C	F		R	C				
				Observation gap																	
	RAG22	107.92	P																		
	RAG21	106.25	P																		
	RAG20	104.06	P			R	F														
	RAG19	97.78	M			A	F	A	R		F	A	A	R		F					
	RAG18	93.86	MP			A	A	C				C	F		F	F					
	RAG17	91.90	P			C	C	C				F	C				A				
	RAG16	89.95	P			F	R	F													
	RAG15	88.13	M			C	A	A	F			C	R								
	RAG14	86.91	M			F	C	A	F				F	F							
	RAG13	85.43	P			F	A	C				C		F							
	RAG12	83.82	P			R			R												
	RAG11	82.44	M				C	C		R		C	R	R		F	F				
	RAG10	78.96	M				F	R					F	R							
	RAG9	72.20	P				C	R					F	F							
	RAG8	64.82	P			A	C	C				C									
	RAG7	55.47	P																		
	RAG6	45.87	M																		
	RAG5	41.25	P				F	F													
	RAG4	37.62	M				F	C					F								
Mid. Albian	RAG3	23.43	P		F	F			F			C									
	RAG2	19.87	P																		
	RAG1	13.56	P		F							F									

ganic-rich bed. Westward at Oued Siliana, the LO of *Planomalina buxtorfi* coincides with the LO of *Thalmanninella appenninica* and a few specimens of *B. breggiensis*, just at the base of the Mouelha Member (sample OS1*, 45.38 m). The LO of *Planomalina buxtorfi* recorded at Ragoubet Lahnech is at 1.03 m above the top of Mouelha Member. The HO of *P. buxtorfi* could not be identified at Ragoubet Lahnech and Oued Siliana because the tops are covered by alluvial deposits.

Bioevents correlation and order of ticinellid extinctions across the organic-rich Mouelha Member

The sequence of ticinellid extinctions is identified by comparing the ranges of bioevents in the studied sections. The highest occurrence of *Ticinella raynaudi* (sample AS 34, 78.61 m) precedes the HOs of *Ticinella primula* (sample AS38, 87.02 m), *Ticinella roberti* (sample AS38, 87.02 m), and finally, *B. breggiensis* (sample AS41, 93.94 m) at the Ain Slim section.

At Oued Siliana, the HO of *T. raynaudi* (sample OS10 – 20.33 m) precedes the HOs of *T. roberti* (sample OS14 – 34.47 m), *B. breggiensis* (OS4* - 46.72 m), followed by the HO of *T. primula* (sample OS6* - 49.37 m). The sequence of extinction is almost the same, farther west, at the Ragoubet Lahnech section.

At the Ain Slim section, the HO of *B.breggiensis* occurs 6.92 m below the lowest occurrence (LO) of *P. buxtorfi* and *Th. appenninica*. At the Oued Siliana section, the LOs of *P. buxtorfi* and *Th. appenninica* fall 1.34 m below the HO occurrence of *B. breggiensis*. The latter occurs 17.04 m below the LO of *Th. gandolfi*. At the Ragoubet Lahnech section, the LO of *Th. appenninica* occurs 1.34 m below the HO of *B. breggiensis*.

All ticinellid extinction events, including those of large-size species (*B.breggiensis* and *T.roberti*), take place within the lower part of *Th. appenninica* Zone and a few meters below the organic-rich black shales of the Mouelha Member. Our findings are in agreement with the interpretations documented by Petrizzo and Huber (2006b) and Petrizzo et al. (2008), who suggested that the extinction and appearance events occurring between the LO and HO of *P.buxtorfi* indicate a major change in the planktonic foraminiferal composition.

Based on these bioevents, it appears that the organic-rich beds of the Mouelha Member are confined to the *Th. appenninica* Zone, more precisely the lower part of the *Pl. buxtorfi* Zone. The previous geochemical investigations on these beds document high total organic carbon content in this portion of the biozone, ranging between 1.7 and 3.5 wt% in northwestern Tunisia (Ben Fadhel et al. 2011; Khalifa et al. 2018).

Several authors have attempted to constrain the age of the time-equivalent black shale horizons and related late Albian oceanic anoxic event 1d (OAE1d) using an integrated approach based on stable isotopes and planktic foraminiferal biostratigraphy. According to Bornemann et al. (2005), the deposition of the Breistroffer time-equivalent black shale horizon, which falls within the *buxtorfi* range, is associated with higher δ^{13}C values. Other authors place the onset of OAE1d just above the last occurrence of *Thalmanninella subticinensis* (Kennedy et al. 2004; Ghanem et al. 2012). The onset of the latest Albian black shale deposition is confined to the upper part of the *Pl. buxtorfi* Zone, based on the stable isotope record characterized by steadily increasing δ^{13}C values during the last phase of deposition in the Mediterranean Tethys and Atlantic realms (Petrizzo et al. 2008).

Despite the minor diachroneity, which may be linked to paleogeographic factors or different surface water conditions (Bralower et al. 1995; Petrizzo and Huber 2006b), the Mouelha black shale correlates well with the Breistroffer organic-rich beds exposed in the Vocontian Basin (text-fig. 7) (Bréhéret 1988; Bréheret 1997; Giraud et al. 2003; Bornemann et al. 2005; Petrizzo et al. 2008).

It is also correlative with other radiolarian and organic-rich beds confined to the *Pl. buxtorfi* Zone and associated with high TOC content, including the Pialli level in the Italian Appennine (text-fig. 7) (Coccioni 2001), in the Blake Nose and DSDP site 547 of the Atlantic Domain (Erbacher et al. 1996; Petrizzo and Huber 2006b, text-fig. 2; Petrizzo et al., 2008; text-fig. 6) and the La Grita Member in southwestern Venezuela (Rodriguez-Cuicas et al. 2019).

Planktic foraminiferal abundance, size and morphologic trends – Paleoecological implications

The low planktic/benthic ratios recorded in the proximal part of the Tunisian Trough (Oued Siliana and Ain Slim) (Table 1 and 2), suggest mesotrophic and neritic environments (Erbacher et al. 1998; Huber and Leckie 2011) prevailed during the early late and latest Albian. These time intervals are characterized by an increasing abundance of r/K-strategists and mesotrophic deeper-dwelling *Globigerinolloides bentonensis* at the Ragoubet Lahnech section (Coccioni and Luciani, 2004; Rückheim et al. 2006; Huber and Leckie 2011) (Table 3).

The transition between the *primula* and *breggiensis* Zones identified in the studied section is characterized by the gradual diversification of many trochospiral and thick-walled forms, particularly the ticinellids (*B. breggiensis, T. roberti, T. raynaudi*), including large-sized planktic foraminifera and transitional forms of *B. subbreggiensis*. The increasing abundance of *Ticinella roberti*, *Ticinella raynaudi,* and transitional forms of *B. subbreggiensis* represent a global biological event also characterized by increasing shell diameter and high rates of diversity (Huber and Leckie 2011). It also indicates that these taxa could have inhabited warm waters during their growth (Norris and Wilson 1998). The scarcity of planktic foraminifera across the *primula – breggiensis* zonal transition at the Ragoubet Lahnech section (Table 3) may be attributed to dissolution and mechanical destruction caused by intense bioturbation (Martin 1999) that characterizes this interval (text-figure 6).

The planktic foraminiferal assemblages recovered from the base of the upper Albian beds show significant morphological changes in some ticinellid taxa, characterized by pinched chambers (i.e., *Ticinella praeticinensis*) in the last whorl. The development of such morphology coincides with an increase in calcification associated with sea-level rise and global warming episodes through the late Albian (Leckie et al. 2002). In the distal part of the Tunisian Trough (Ragoubet Lahnech area), the first two meters above the lowest occurrence of *T. praeticinensis* are characterized by the gradual diversity and abundance increase of deeper-dwelling planktic foraminifera (*T. primula*, *G. bentonensis*) and could be explained by deepening of the basin in response to sea-level rise (Leckie et al. 2002; Huber and Leckie 2011). These events coincide with a gradual increase in the relative abundance of radiolarians. The radiolarian-rich horizon has been documented throughout the late Albian pelagic

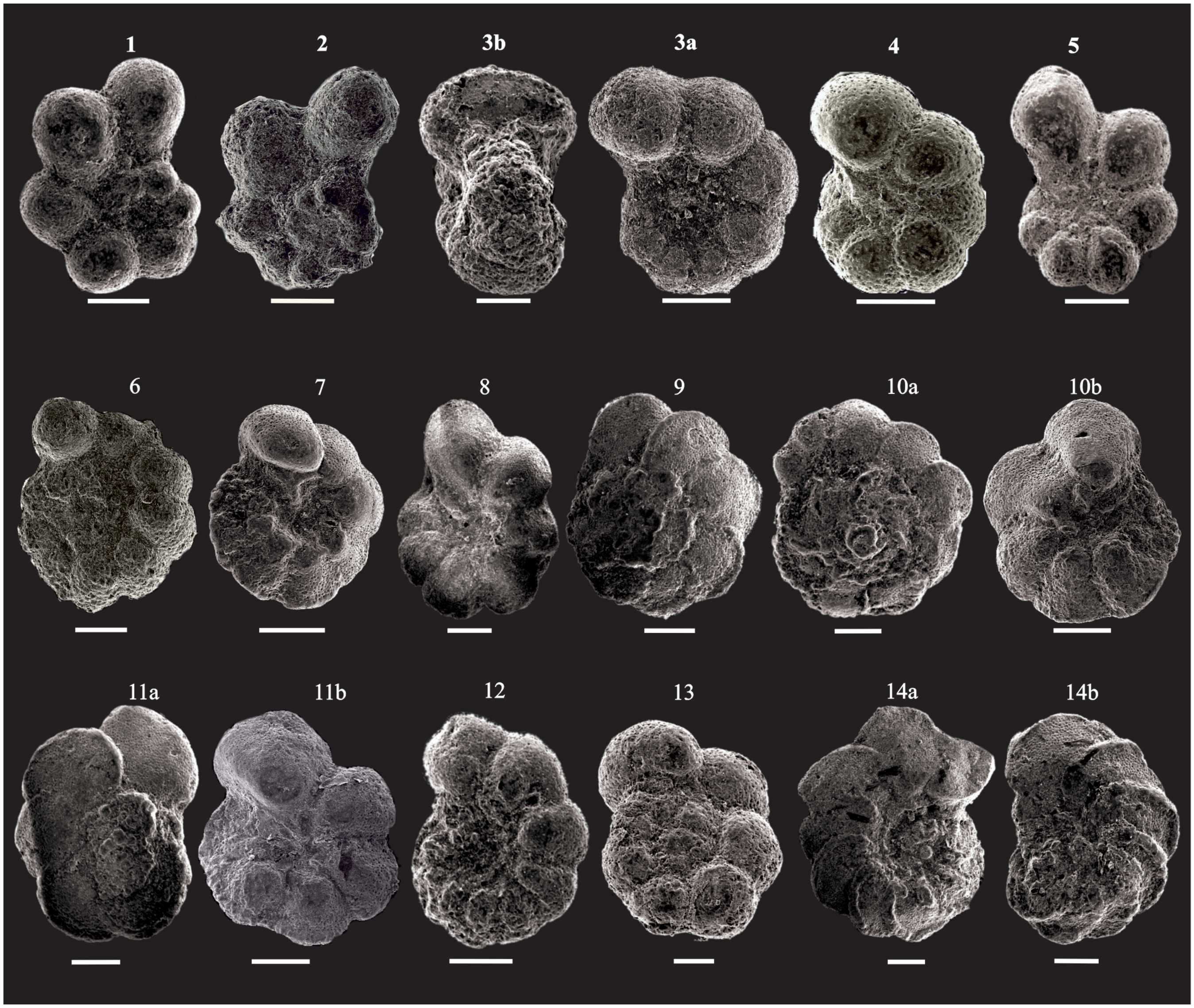


PLATE 1
Scale bar = 100 µm

1 *Ticinella primula,* Ain Slim section, *Bi. breggiensis* Zone.

2 *Ticinella primula*. Ragoubet Lahnech section, the upper part of *Ps. ticinensis* Zone.

3a, b *Biticinella breggiensis*. Ragoubet Lahneche section, the upper part of *Bi. breggiensis* Zone.

4 *Ticinella raynaudi*. Ain Slim section, *Ps. subticinensis* Zone

5 *Ticinella raynaudi digitalis*. Ragoubet Lahneche section, *Ps. ticinensis* Zone.

6 *Ticinella praeticinensis*. Oued Siliana section, *Ps. subticinensis* Zone.

7 *Pseudothalmanninella subticinensis*. Oued Siliana section, *Ps. subticinensis* Zone.

8 *Thalmanninella praebalernaensis*. Oued Siliana section, *Th. appenninica* Zone.

9 *Thalmanninella balernaensis*. Oued Siliana, *Th. appenninica* Zone.

10a, b *Pseudothalmaninella ticinensis*. Oued Siliana, *Th. appenninica* Zone.

11a, b *Thalmanninella appenninica*. Oued Siliana, *Th. appenninica* Zone.

12 *Planomalina praebuxtorfi*. Oued Siliana, *Th. appenninica* Zone.

13 *Globigerinelloides bentonensis*. Oued Siliana section, *Ps. ticinensis* zone.

14a, b *Planomalina buxtorfi*. Oued Siliana, *Th. appenninica* Zone.

successions, representing a marker bed in the Tunisian Trough realm (Ben Haj Ali 2005; Ben Fadhel et al. 2010; 2011).

The increasing abundance of ticinellids with flattened chambers (i.e., *Ticinella roberti, Biticinella breggiensis*) recorded a few meters below the organic-rich beds of Mellegue (Table 1 and 2) in the Ain Slim and Oued Siliana areas indicates a trend toward oligotrophic, deeper environments close to the thermocline and more stable stratified conditions (Leckie 1987; Premoli-Silva and Sliter 1999, Wilson and Norris 2001; Bornemann et al. 2005). The fluctuation and scarcity of flattened chamber taxa in the Ragoubet Lahnech area (Table 3) could be linked to an unstable, eutrophic environment that prevented these taxa from thriving.

The consistent occurrence of planktic foraminiferal clavate forms (i.e., *Clavihedbergella*) with radially and elongated chambers, recorded above the organic-rich beds of the Mouelha Member (Table 3), suggests a deep, oligotrophic to mesotrophic, and oxygen-depleted environment (Coccioni et al. 2006; Rückheim et al. 2006; Friedrich et al. 2018). Abundant ticinellid morphotypes with radially elongated chambers (*Ticinella raynaudi*) associated with radiolarian and recorded across the Mellegue horizon (Table 3), may indicate an adaptative response to change toward enhanced mesotropic/ eutrophic and dysaerobic environments. The development of elongated chambers reflects a feeding adaptation characterized by the increase of the surface/volume ratio of the test to facilitate the oxygen uptake for the metabolic needs under dysaerobic conditions (Coccioni and Luciani 2004; Coccioni et al. 2006; Coxall et al. 2007; Coccioni et al. 2014)

The continuous distribution of *T.primula*, associated with sporadic occurrences of *Globigerinelloides,* recorded across the organic-rich Mellegue horizon exposed at the Ragoubet Lahnech section (Table 3), suggests oligotrophic to weakly mesotrophic conditions (Galeotti 1998; Friedrich et al. 2018). The radiolarian-rich horizons included in the Mellegue black shales exposed at the Ragoubet Lahnech section indicate that these nutrient-poor conditions were interrupted by enhanced eutrophication episodes, triggered by increased nutrient supply related to halokinetic-induced hydrothermalism (Ben Fadhel et al. 2010).

The first occurrence of single-keeled *Pseudothalmanninella subticinensis* coincides with gradual increases in abundance of large-sized forms (i.e., *B. breggiensis*) below the organic-rich Mellegue horizon at Ain Slim and Oued Siliana sections (Table 1 and 2). These trends indicate a deep, oligotrophic environment close to the thermocline, dominated by large-sized and specialized deep-dwelling taxa (K-strategists). Another factor that could be responsible for the appearance of keeled forms is related to an increased rate of calcification (Leckie et al. 2002). The scarcity of *Ps. subticinensis* across the Mellegue horizon (Table 3) at the Ragoubet Lahnech section may be attributed to selective dissolution linked to very high fertility (Coccioni and Luciani 2004).

The continuous occurrence of specialized keeled forms (i.e., *Thalmanninella appenninica*) throughout the organic-rich Mouelha Member at the Oued Siliana section (Table 2), suggests that black shales were deposited in an oligotrophic environment. However, it appears that increased concentration of CO^2-interstitial bottom waters due to enhanced accumulation of organic matter (Leckie et al. 1987), or a sudden shift from oligotrophic to eutrophic conditions due to change in the upwelling regime or nutrient flux (Ferraro 2018), prevented not only *Th.appenninica* but other keeled forms from thriving at Ragoubet Lahnech (Table 3). In the absence of these keeled specialized K-strategist taxa, the upwelling–dominated and eutrophic environments were inhabited by opportunistic r-strategists including radiolarians and hedbergellids (i.e., *Muricohedbergella delrioensis*) (Table 3).

An impoverished assemblage devoid of keeled forms recovered from the base of the Mouelha Member shows instead dwarf trochospiral specimens (Table 3; Rag 29 to Rag 32) at the Ragoubet Lahnech section. This microfaunal content reflects an unstable environment characterized by high surface productivity associated with oxygen deficiency. The resulting increase in nutrient supply might have favored a high reproduction rate and, consequently, size reduction (Coccioni and Luciani 2004). This life strategy constitutes an ecological response to environmental stress that might represent pre-extinction dwarfism (Ferraro et al. 2020) of some trochospiral taxa (i.e., *T. primula*).

CONCLUSION

A detailed biostratigraphic study of late Albian exposures in the Dome Belt domain of northern Tunisia allows for revision of the lithostratigraphy and the associated zonal scheme using planktic foraminiferal bioevents. In this study, we used the lithostratigraphic marker beds in conjunction with bioevents recorded across time equivalents in adjacent basins of the Mediterranean Tethys. Based on the results, it appears that proximal sections of the Tunisian Trough (northeastern Tunisia), provided rich and well-to -moderately preserved age – diagnostic assemblages of planktic foraminifera, allowing us to define the zonal scheme of the late Albian in the African margins of the western Tethyan realm. These sections could also be the subject of future studies on the Albian/Cenomanian boundary and evolutionary trends, considering the occurrence of diversified keeled planktic foraminifera.

We have concluded that the organic-rich horizons are confined to the late Albian and can be subdivided into two members: the Mellegue marl/limestone rhythmites and the well-known Mouelha black whitish limestone bed, which is confined to the *subticinensis – ticinensis* transition and the base of the *Thalmanninella appenninica* Zones respectively. Despite slightly diachronous boundaries linked to the local geodynamic settings and preservation of index markers, the biostratigraphic positions of the studied black shale beds are identical to those of the Amadeus Segment and Breistroffer levels exposed in the Italian Apennines and Vocontian Basin in southern France.

The semi-quantitative analysis of planktic foraminifera of the upper Albian successions has shown the following:

-A gradual diversification of many trochospiral and thick-walled forms, particularly the ticinellids (*B. breggiensis*, *T. roberti*, *T. raynaudi*), under mesotrophic and neritic conditions confined to the lower part of the breggiensis Zone and the entire *buxtorfi* Subzone in the proximal part of the Tunisian Trough (Ain Slim and Oued Siliana areas). In the distal part (Ragoubet Lahnech area), the r/K-strategist *Globigerinelloides bentonensis* inhabited and proliferated in deep, mesotrophic waters.

-The increasing abundance of ticinellids with flattened chambers (i.e., *Ticinella roberti, Biticinella breggiensis*) together with single-keeled forms (*Ps. subticinensis*), recorded a few meters below the organic-rich beds of Mellegue exposed in Ain Slim and Oued Siliana areas indicates a trend toward more stable, stratified, oligotrophic conditions and a deeper environment close to the thermocline. The scarcity of flattened chamber taxa, observed at the same level in the Ragoubet Lahnech area, could be attributed to an unstable, eutrophic condition characterized by radiolarian bloom, which has prevented these taxa from thriving.

The oligotrophic to weakly mesotrophic conditions that prevailed during the deposition of the organic-rich Mellegue horizon were interrupted by an abrupt increase of nutrients marked by the bloom of eutrophic indicators (radiolarians), preventing deep-dwelling, less tolerant *Globigerinelloides* to proliferate in the distal part of the Tunisian Trough (Ragoubet Lahnech area).

The increasing abundance of clavate forms of planktic foraminifera (*Clavihedbergella*) and ticinellid taxa with elongated chambers (*T.raynaudi*) recorded above the Mouelha (upper part of *buxtorfi* Subzone) and throughout the Mellegue horizon (middle part of *breggiensis* Zone) respectively, indicate episodes of adaptative response toward enhanced mesotropic/eutrophic and dysaerobic environments in the distal part of the Tunisian Trough (Ragoubet Lahnech section).

The organic-rich Mouelha Member was deposited under oligotrophic conditions in the proximal part of the Tunisian Trough (Ain Slim and Oued Siliana areas) as suggested by the bloom of specialized keeled forms (i.e., *Th. appenninica*). In the distal part (Ragoubet Lahnech area), these keeled specialized k-selected strategists were unable to thrive.

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APPENDIX 1
List of planktic foraminifera taxa

Biticinella breggiensis (Gandolfi 1942) = *Anomalina breggiensis* Gandolfi 1942
Clavihedbergella simplex (Morrow 1934) = *Hastigerinella simplex* Morrow 1934

Clavihedbergella simplex (Tappan 1943) = *Hastigerinella subcretacea* Tappan 1943
Globigerinelloides sp.
Globigerinelloides bentonensis (Morrow 1934) = *Anomalina bentonensis* Morrow 1934. Type species of the genus *Laevilla* Huber, Petrizzo and Falzoni 2022.
Microhedbergella praeplanispira Huber and Leckie 2011
Microhedbergella pseudodelrioensis Huber and Leckie 2011
Muricohedbergella delrioensis (Carsey 1926) = *Globigerina cretacea delrioensis* Carsey 1926
Planomalina praebuxtorfi Wonders 1975
Planomalina buxtorfi (Gandolfi 1942) = *Planulina buxtorfi* Gandolfi 1942
Pseudothalmanninella subticinensis (Gandolfi 1957) = *Globotruncana (Thalmanninella) ticinensis subticinensis* Gandolfi 1957
Pseudothalmanninella ticinensis (Gandolfi 1942) = *Globotruncana ticinensis* Gandolfi 1942
Thalmanninella appenninica (Renz 1936) = *Globotruncana appenninica* Renz 1936
Thalmanninella balernaensis (Gandolfi 1957) = *Globotruncana (Rotalipora) appenninica* subsp. *balernaensis* Gandolfi 1957
Thalmanninella gandolfii (Luterbacher and Premoli Silva 1962) = *Rotalipora appenninica gandolfii* Luterbacher and Premoli Silva 1962
Thalmanninella praebalernaensis (Sigal 1969) = *Rotalipora praebalernaensis* Sigal 1969
Ticinella praeticinensis Sigal 1966
Ticinella primula Luterbacher 1963
Ticinella raynaudi Sigal 1966
Ticinella raynaudi digitalis Sigal 1966
Ticinella roberti (Gandolfi 1942) = *Anomalina roberti* Gandolfi 1942