Sedimentology and ichnology of the mid-Cretaceous succession of the Ouled Nail Mounts (Eastern Saharan Atlas, Algeria)

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Abstract
Shallow marine deposits characterize the upper Albian – lower Cenomanian deposits of Northern Algeria. In Djebel Azzeddine (Ouled Nail Mounts), the corresponding sediments have been subdivided into three distinctive units A to C. The first discovered ammonite fauna from the Bou Saada area allowed the attribution of a part of the mid-Cretaceous post-Continental Intercalaire deposits to the upper Albian. The ammonite-bearing level indicates a maximum flooding surface and could be correlated with similar levels from Northern Algeria. The studied succession is characterized by a low ichnodiversity containing eight ichnotaxa with abundant Thalassinoides, common Skolithos, and rare Gyrolithes, Oichnus, Planolites and cf. Tisoa. This ichnoassemble is dominated by domicnichnion, fodinichnion and praedichinon trace fossils, and is attributed to the Skolithos and Glossifungites ichnofacies. These traces are produced mainly by decapod crustaceans, polychaetes and naticid gastropods. The sedimentological and ichnological data suggest shoreface to backshore environments with mixed tide/storm energy, and long subaerial exposures indicated by Lofer cyclothems in the lowermost part and dinosaur footprints in the upper part of the section.

Keywords: Trace fossils, Transgression, Albian – Cenomanian, Ouled Nail Mounts, Algeria

1. INTRODUCTION
The Cretaceous deposits are widely distributed in the Algerian Saharan Atlas. In the last few years, several sedimentological, bio-lithostratigraphic and palaeontological studies were focused on the mid-Cretaceous strata of the western (Ksour Mounts) and central Saharan Atlas (Djebel Amour Mounts) (MEBARKI et al., 2016; BENYOUCEF et al., 2017; FERRÉ et al., 2017; MENNAD et al., 2020; SALHI et al., 2020; ÖZER & BENYOUCEF, 2021). In the Ouled Nail Mounts (eastern part of the Saharan Atlas), the corresponding deposits are represented by a succession made of marly-limestone/dolostone alternations which display a rich macrofauna (bivalves, gastropods, ammonites), as well as trace fossils. The best exposures of this interval crop out in the Djebel Azzeddine, Djebel Amrane and Djebel Tsegna, and were first investigated since the late mid 20th century (EMBERGER, 1960; RITTER (1902). The studied interval has been mapped and investigated by BROSSARD (1866), PÉRON (1883) and GUIRAUD, 1973; HERKAT, 1999). Unfortunately, with the exception of the previously cited works, no comprehensive revision of the upper Albian–lower Cenomanian succession has been carried out in recent years. The last Albian (Vraconnian) – lower Cenomanian interval is thereby considered as an important eustatic event, corresponding to the global and greatest mid-Cretaceous transgression (HANCOCK & KAUFFMAN, 1979; AMEDRO, 2008).

This paper aims to provide the first sedimentological and ichnological study of the upper-Albian transgressive marine deposits exposed in Djebel Azzeddine (Ouled Nail Mounts). Our contribution provides the first ammonite-bearing level, ichnotaxa inventory, detailed facies analysis and new dinosaur footprint record that facilitates identification of the depositional environment and the palaeobiogeography in the Saharan Atlas during the mid-Cretaceous.

2. GEOLOGICAL SETTING
The Algerian Atlasic system consists of the Saharan Atlas to the west, and the Aures, Nementcha, Negrine and Tebessa Mountains to the east (e.g., DJEBBAR, 2000). Their equivalents are the High and Middle Atlas in Morocco, and the Tunisian Atlas in Tunisia, forming, together with the Tell-Rif System to the North, the Atlas Mountains belts sensu lato of northwestern Africa (HALAMSKI & CHERIF, 2017), considered as part of the west Mediterranean alpine system (Fig. 1A).

The Ouled Nail Mounts represent the eastern part of the Saharan Atlas (Fig. 1B), which corresponds to an intracratonic autochthonous chain located in northern Algeria, belonging to the Atlasic system (DJEBBAR, 2000; NAIMI & CHERIF, 2021a; NAIMI et al., 2021a). The Algerian Saharan Atlas extends SW-NE over about 650 km in length and 90 to 140 km wide between the Moroccan High-Atlas and the Zibane Mountains (or Biskra promontory) (GUIRAUD, 1973). This chain was developed in a subsiding intra-plate asymmetric basin, in existence since the Triassic, located between two stable domains, the Oran Meseta (High Plateaus) in the North, and the Saharan Platform in the South, from which it is respectively isolated, by the South Meseta and the South Atlasic Faults (KAZI-TANI, 1986).

The stratigraphic series (Fig. 1C) of the study area (the northeastern part of the Ouled Nail Mounts) begins with Triassic strata cropping out in diapirs (Kerdada and Ain Ograb), represented by purplish clays, gypsum, dolostones and doleritic ophiolites. The Triassic rocks are overlain by a 6000 m-thick Cretaceous (Valanginian to Maastrichtian) succession. The Cenozoic (Paleogene to Quaternary) continental deposits unconformably overlies the Mesozoic sediments (EMBERGER, 1960).

The mid-Cretaceous sedimentary succession cropping out in the investigated area is characterized by lower Albian continental sandstones of the Continental Intercalaire, rich in the re-
mains of vegetation (EMBERGER, 1960), overlain by shallow marine carbonate platform deposits. The lower part (300–400 m) of this sequence is dated as upper Albian, consisting of marly-dolostone alternations rich in fragments of oyster shells. The palaeontological content of these facies suggests a very shallow marine environment under rough-water conditions (NAIMI et al., 2021b).

The lower part of the overlying 460–735 m-thick Cenomanian strata is characterized by shallow-water marlstone-limestones. They are similar to the underlying upper Albian deposits,
Figure 2. The main lithostratigraphic characteristics of the upper Albian – lower Cenomanian of Djebel Azzeddine. (A) Lithostratigraphic column of the Djebel Azzeddine section; (B) Field photography of the studied succession: 1, dolomitic limestones of the lowermost part of the section; 2, Thalassinoides-rich beds; 3, algal limestones of the uppermost part of Unit A (black arrow shows the chert level); 4, micritic limestones of Unit B; 5, gastropod-rich limestones; 6, the lowermost part of Unit C (white arrow indicate ammonites-bearing limestones; black arrow indicate dinosaur tracks-bearing dolostones); 7, dinosaur tracks-bearing surface; 8, marls-shelly limestones alternation from the uppermost part of the section.
rich in oysters and echinoderms, and overlain by lagoonal marlstone-dolostone alternations and thick gypsum beds with subordinate limestone interlayers rich in foraminifera (EMBERGER, 1960). The uppermost part of the Cenomanian beds consists of massive mudstones, nodular and bioclastic limestones and black shales (GROSHENY et al., 2008).

3. MATERIAL AND METHODS

Two field expeditions (December 2019 and March 2020) were conducted. During these missions the mid-Cretaceous succession cropping out in Djebel Azzeddine near the city of Bou Saada was sampled and described bed-by-bed for lithological changes, colour, composition, geometry, sedimentary structures and palaeontological content. The fossils (bivalves, gastropods, ammonites and brachiopods) as well as trace fossils were photographed in situ, collected and stored in the Géologie du Sahara laboratory (Kasdi Merbah University) to be identified and investigated for their palaeoenvironmental interest.

A new dinosaur tracksite was discovered in the studied succession. However, further studies on these footprints are required.

4. LITHOSTRATIGRAPHIC FRAMEWORK AND PALAEOENVIRONMENT

The Upper Albian – Lower Cenomanian deposits of Djebel Azzeddine were framed as Vraconnian – Cenomanian, corresponding to a megasequence, divided into two fourth-order sequences (HERKAT, 1999). In the present work, the studied interval has been subdivided into three informal units (Fig. 2).

4.1. Unit A: Marlstone-algal bioturbated limestones unit (upper Albian)

This 52 m-thick unit constitutes the base of the marine mid-Cretaceous deposits outcropping near the city of Bou Saada. Its lower limit has been hidden due to recent urbanization. EMBERGER (1960) indicates that Djebel Azzeddine marine carbonates overlie Albian sandstones of the Continental Intercalaire. The dominant stacking pattern of this unit is represented by an obvious rhythmicity expressed by discrete bed packages (0.6 – 6 m thick) of limestones and dolomitic limestones intercalated with greenish to grayish soft, occasionally foliated, fossiliferous marlstones (0.6 – 3 m) (Fig. 2). The limestones are hard, highly burrowed with large Thalassinoides isp. (Fig. 7A) and organized in shallowing-upwards wackestone to packstone. They are massive, sub-nodular (Fig. 3A), rarely laminated, yellow to dark brown in colour when weathered, white to light gray in cross-section and mostly with sharp erosive bases. The fossil components are dominated by oysters, gastropods and echinoids. These dolomitic limestones show a red loferitic breccia, mud cracks, parallel laminations, micro-HCS (hummocky-cross stratifications), stromatolitic laminae, silex layers, paleosol, teepee structures and shrinkage pores (Fig. 3B, D and E). The upper contact of this unit

Figure 3. Field photographs of Unit A. (A) Pseudo-nodular limestones; (B) Intertidal to supratidal limestones with algal laminae, paleosol, shrinkage pores (black arrow), and loferitic breccia (white arrow); (C) Subtidal limestones with in-situ slumped breccia; (D) Stromatolitic limestone; (E) Dolomitic limestone showing algal laminae including chert nodules; (F) Top surface of dolomitic limestone showing hardground with abundant Acteonella delgadoi.
corresponds to a hardground with oxidized dolomudstones characterized by condensed gastropod levels dominated by the species *Actonella delgadoi*, as well as vertical borings (Fig. 3F).

### 4.2. Unit B: Lower marlstone-shelly limestone unit (upper Albian)

This 22.5 m-thick unit comprises white and green marls (0.2 – 2.5 m) alternating with grayish to yellowish massive, shelly and sandy limestones. The limestone beds are 0.05 to 2.5 m thick, broadly pseudo-nodular to nodular, bioturbated, channelized, white to dark gray weathering coloured, gray to yellowish in cross-section, showing noteworthy densely packed thin bioclasts of benthic fauna, organized in packstone to grainstone textures (Fig. 4A). The middle part of this unit exhibits many subordinate shell beds (0.2 – 2.5 m thick), thinning upwards, amalgamated and wave rippled, showing a rapid transition into an overlying marly lithofacies, namely: *Cucullaea*-rich limestones corresponding to bioturbated limestone, composed of monotaxic bivalves (*Cucullaea sp.*) (Fig. 4B), and polytaxic gastropod-rich limestones with fragmented and randomly oriented shells (Fig. 4C). A scarce brachiopod fauna is also present.

Internally, the limestone beds of this unit contain small scale hummocky-cross stratifications, lenticular, flaser to wavy bedding, internal mud drapes, tidal rhythms, unidirectional, linguoid, wavy ripple marks and mega ripples (Fig. 4D-E). The ichnotaxa of this unit are represented by *Gyrolites* isp. (Fig. 6A), *Oichnus* isp. (Fig. 6B) and cf. *Tisoa siphonalis* (Fig. 7E).

Figure 4. Field photographs of Unit B. (A) Micritic limestone bed; (B) *Cucullaea*-rich limestones; (C) Gastropod-rich limestones, with sharp erosive base and ripple-mark in top surface; (D) Small-scale hummocky-cross stratification in fine limestone bed at the top of the unit, with light micritic laminae and dark sandy-micritic laminae; (E) Tidal rhythms from the top of the unit; (F) Limestone bed with robust bioclasts of oysters and wavy rippled upper surface; (G-H) Large size Mortoni-ceracidae of the ammonites-bearing bed.
The uppermost part of this unit is represented by a concentration of large-sized ammonites *Mortoniceras* sp. and *Pervinquiera* sp., arranged in single post-mortem disposition (Fig. 4G-H), and small fragments of *Engonoceras* sp. which co-occur with bivalves and gastropods.

4.3. Unit C: Upper marlstone-shelly limestone unit (upper Albian – lower Cenomanian)

The lower part of this 18 m-thick unit is composed of an alternation of white marls (2 – 3 m) and whitish massive limestones with sporadic, thin, bivalve shell beds of *Cucullaea* sp. These limestone beds are hard, display yellow-red sandy inclined burrows as *Planolites* isp. (Fig. 6C), hummocky-cross stratifications (HCS), swaley-cross stratifications (SCS) and parallel and cross laminations (Fig. 5A-B).

The 2 – 3 m-thick dolomite in the middle part of this unit is characterized by dinosaur footprints (Figs. 8 and 9) associated with vertical burrows attributed to *Skolithos* (Fig. 6D), as well as a rich assemblage of worn and recrystallized molds of bivalves and gastropods. The uppermost part of the studied succession consists of regular alternations of light green to white soft marls (Fig. 5E-F) and mollusk rich limestones, composed of abundant disarticulated and fragmented (Fig. 5C) or whole mollusk shells including bivalves and gastropods (Fig. 5D).

4.4. Facies analysis

On the basis of sedimentological and palaeontological characteristics such as lithology, sedimentary structures, fossils and/or trace fossils, bed thickness and taphonomy of shell beds, fifteen distinctive sedimentary facies types (FT1 to FT15) have been identified, described, interpreted and presented in Table 1 and Figures 3–5.

4.5. Age of the succession

Despite the extension of the mid-Cretaceous succession of the Ouled Nail Mounts, no detailed bio- and lithostratigraphic investigations have been previously carried out on these deposits. EM-BERGER (1960), based only on lithological criteria, such as the occurrence of rich oyster shell fragment-limestones, assigned a latest Albian (Vraconnian) and early Cenomanian age to the mid-Cretaceous marine sediments of the Djebel Azzeddine section. Furthermore, HERKAT (1999) assigned the same deposits to a whole Vraconnian-Cenomanian mega-sequence encompassing three successive sequences.

Our new findings indicate a late Albian-lower Cenomanian age for the mid-Cretaceous deposits of the Ouled Nail Mounts. No biostratigraphic fossils have been recorded in the lowermost part of the analyzed succession. The last bed of the first unit contains a condensed gastropod shell-bearing level of *Acteonella*

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**Figure 5.** Field photographs of Unit C. (A) Limestone bed with low-angle cross lamination; (B) Limestone bed showing hummocky cross-stratification (HCS) and swaley-cross stratification (SCS); (C) Oyster-rich bioclastic limestone (black arrows indicate echinoid spines); (D) Limestone bed rich in gastropod and pectinid shells; (E) Greenish marls interlayered with limestone beds; (F) Uppermost part of the succession showing rhythmic whitish marls-dolomitic limestones alternations.
Table 1. Description and sedimentological attributes of facies identified in the upper Albian–lower Cenomanian deposits of Ouled Azzedine (Ouled Nail Mounts, Algeria).

| Facies type (FT) | Description and range | Interpretation and environmental significance |
|-----------------|-----------------------|---------------------------------------------|
| FT1. Marlstone-algal bioturbated limestones unit | They consist of yellowish to brownish, hard, massive or scarcely laminated, poorly fossiliferous, 0.6 to 2 m thick, fine-grained dolomitic limestones. The main textural components are gastropods, echinoids, and highly fragmented, fragmental, and disarticulated shells, which are oriented horizontally to the bedding. The biological component and ichnological association of this facies supports middle shoreface environment (e.g., HOWARD & FREY, 1984; NAIMI et al., 2020)). | The presence of algal molds, Thalassinoides, and burrowing structures indicates a middle shoreface environment with high energy conditions. |
| FT2. Loberites | Sub-nodular dolomitic limestones, similar to that of the FT1, but with well-developed erosional surface, lateral facies variations, and irregular thickness (Fig. 6A). The gypsum crystals grew displacively as lenticular crystals within the algal mats. Furthermore, the bioclastic content consists of fragments of monospecific oyster shells fragments randomly oriented, moderately to highly fragmented, abraded and relatively poorly sorted, embedded in a packstone to grainstone cement. | The presence of gypsum and algal molds indicates a shallow marine setting with restricted circulation. |
| FT3. Lower marlstone-shelly limestones unit | This facies consists of white to greenish fine-grained, micritic massive, sub-nodular and tabular micritic limestones (Fig. 6B). In thin sections, the micritic limestones facies shows benthic and planktonic foraminifera embedded in a mudstone-wackestone texture. | This facies was deposited in an open marine setting, under low energy conditions, below storm wave base. |
| FT4. Acrostronic-rich bed | Acrostronic-rich bed. Many of the acrostronic mounds are situated on a prominent bed. In the upper parts, the mounds are up to 1 m thick, well-rounded, and composed of a mixture of calcylus brachiopods, articulated foraminifera, and calcareous algae. | The presence of acrostronic mounds suggests a low energy environment (MÁNGANO & BUATOIS, 1991). |
| FT5. Lower marlstone-shelly limestones unit | Lower marlstone-shelly limestones unit (Fig. 7A). | The presence of bioclasts suggests a shelf environment. |
| FT6. Upper marlstone-shelly limestones unit | Upper marlstone-shelly limestones unit (Fig. 7B). | The presence of bioclasts suggests a shelf environment. |
Table 1. Continued

| Facies type (FT) | Description and range | Interpretation and environmental significance |
|-----------------|------------------------|-----------------------------------------------|
| FT8. Gastropod-rich limestones | Lower marlstone-shelly limestones unit | This facies corresponds to grayish amalgamated limestone beds, 0.2 – 0.5 m thick, showing sharp erosive bases, composed mainly of abundant polytaxic gastropods. They are densely packed, randomly oriented, highly fragmented and flattened by compaction, and exhibit signs of abrasion (Fig. 4C). The top of the beds show wave ripples and scarce trace fossils. The characteristics of this facies as well as the sharp erosive base, the high degree of fragmentation and dense packing of bioclasts indicate storm-induced currents transporting gastropod. The sedimentological and taphonomic data suggest wave to storm dominated platform, above the fair-weather wave base (shoreface). |
| FT9. Laminated limestones | Lower marlstone-shelly limestones unit | The laminated limestones are whitish to yellowish beds, 0.1 – 0.6 m thick, containing small scale HCS (hummocky cross stratifications), lenticular, as far as wavy bedding, internal mud drapes, and vertically stacked bundles of alternating sandstone/mudstone parallel laminations (tidal ripples) (Fig. 4D-E). The top surfaces of the beds are commonly characterized by unidirectional, linguoidal and wavy ripple marks and megaripples. This facies can also contain abundant disarticulated and fractured or whole mollusk shells (thick-shelled oysters) (Fig. 4F), and spiral burrows perpendicular to the bedding, assigned to the ichnogenus *Gyrolithes* isp. (Fig. 6A). The recorded sedimentary features of this facies suggest a tidal flat environment, characterized by an alternation of low and high energy periodic tidal flat deposits (CHERIF et al., 2018). The presence of the trace fossil *Gyrolithes* indicates a shallow marine environment (intertidal zone), with stiff and/or firm substrates (NETTO et al., 2007). The intense fragmented bioclasts and hummocky-cross stratifications provide evidence of periodic storm events and deposition in a wave/tide-dominated zone (lower foreshore to upper shoreface environment). |
| FT10. Ammonites-bearing limestones | Lower marlstone-shelly limestones unit | FT10 consists of condensed ammonite bed, formed by fine-grained yellowish to grayish sandy and glauconitic limestones, 0.8 cm thick, rich in Mortoniceratidae and Engonoceratidae, arranged in single post-mortem disposition, associated with abundant bivalves *Cucullaea* sp., oysters, rare inoceramids and gastropods. It constitutes the only facies containing ammonite fauna along the section. The ammonites belong to *Mortoniceras* sp., *Pervinqueria* sp. and *Engonoceras* sp. *Pervinqueria* sp. specimens are abundant on the top of the bed, and they are characterized by their large diameter often about 25 cm (Fig. 4G-H). The microfacies, the distribution of molluscan shells as well as the sedimentological features indicate tempestite related to two processes: (i) the slight reworking of autochthonous elements such as oyster shells; or (ii) the sedimentation of transported bioclasts from proximal areas. Thus, FT14 reflects a shoreface environment, under storm influence. |
| FT11. Structureless limestones | Upper marlstone-shelly limestones unit | This facies is composed of hard limestone beds, whitish weathering color-grayish in fresh, 0.2 – 0.3 m thick, displaying strong concretionary vertical burrows filled with yellow-red coarser-gained sandy material, associated with *Planolites* isp. (Fig. 6C). The internal face of the limestone beds includes HCS, SCS and parallel and low-angle cross laminations. The trace fossil *Planolites* characterizes all aquatic environments (KNAUST, 2017). The hummocky cross stratifications indicate storm wave action dominated platform and the presence of low-angle cross bedding suggests wave swash zone (BENVYUCEF et al., 2017), reflecting an upper shoreface depositional environment. |
| FT12. Dinosaur tracks-bearing dolostones | Upper marlstone-shelly limestones unit | The FT12 corresponds to hard brownish to reddish dolostone beds, 2 m-thick, including small-sized tridactyl dinosaur footprints, which comprise traces of digits II, III and IV, preserved in concave epirelief. Some vugs are present on the track-bearing surface and they are mineralized with calcite. The track-bearing surface contains *Skolithos* isp. burrows (Fig. 6D) associated with scarce *Thalassinoideas* (Fig. 7B). These footprints are very poorly preserved due to weathering processes and they are associated with oyster and gastropod remains. The track fossils *Skolithos* and *Thalassinoideas* co-occur in very shallow marine environments, influenced by tides and storms (BENVYUCEF et al., 2014). A subaerial exposure is evidenced by the presence of dissolution-vugs, red detrital material, and oxidized dolostone. The co-occurrence of marine bivalve and gastropod fauna with dinosaurs suggests its marginal-littoral environment. The sedimentological analysis together with palaeontological and taphonomical data indicate an intertidal environment with periodic storm-generated episodes. |
| FT13. Shelly limestones | Upper marlstone-shelly limestones unit | FT13 is represented by biotidal and amalgam mulluscan packstone-wackestone beds, 0.15 to 0.8 cm-thick, whitish, composed of complete or fragmentary bivalves (pectinids and oysters) and gastropods shells, randomly oriented parallel to bedding (Fig. 5C-D). The sedimentary structures are represented by rare hummocky- (HCS) and wavy/cross stratifications (SCS) (Fig. 5A-B). The microfacies, the distribution of mulluscan shells as well as the sedimentological features indicate tempestite deposits referred to a lower shoreface environment, between fair weather wave and storm wave basis. |
| FT14. Greenish marls | Marlstone-algal bioturbated limestones unit, Lower marlstone-shelly limestones unit and Upper marlstone-shelly limestones unit | Marlstone-algal bioturbated limestones unit, Lower marlstone-shelly limestones unit and Upper marlstone-shelly limestones unit. These facies corresponds to glauconitic greenish to grayish, soft, and occasionally foliated, 0.6 – 7 m-thick marlstones (Fig. 5E), including rich foraminifera, abundant oyster and gastropod bioclasts. In this mafy facies, no sedimentary events have been recorded, but the presence of reworked bioclasts could be related to two processes: (i) the slight reworking of autochthonous elements such as oyster shells; or (ii) the sedimentation of transported bioclasts from proximal areas. Thus, FT14 reflects a shoreface environment, under storm influence. |
| FT15. Whitish marls | Lower marlstone-shelly limestones unit and Upper marlstone-shelly limestones unit | The FT15 consists of whitish to light gray, soft marls, 0.2 – 2.5 m-thick (Fig. 5F). The main components of this facies are bioclasts, gastropods and rare small brachiopods. Based on the lithological and fossil content, this facies is attributed to an open marine setting, with low energetic conditions (BENVYUCEF et al., 2017). |
delgadoi (Fig. 3F). The studied specimens are considered to constitute the first record from Algeria. This Acteonellid gastropod is a widespread middle to upper Albian taxon, recorded from Egypt, France, Morocco and Portugal (SOHL & KOLLMANN, 1985). A. delgadoi occurs in the Diploceras (D.) cristatum and Mortoniceras (M.) inflatum Interval Zones (EL QOT, 2018).

In the uppermost part of the second unit, an ammonite-bearing level has been discovered for the first time in this part of Ouled Nail Mounts, including Mortoniceras sp., Pervinquieria sp. and Engonoceras sp. (Fig. G-H). Mortoniceras and Pervinquieria species indicate the upper Albian sensu lato, and co-occur in the M. (Mortoniceras) pricei, M. (Mortoniceras) inflatum and M. (Mortoniceras) fallax Zones (MONOD ET AL., 2000; KENNEDY ET AL., 2008; GALE & KENNEDY, 2020). On the basis of this association (Acteonella delgadoi, Mortoniceras sp. and Pervinquieria sp.), a part of the mid-Cretaceous post-Continental Intercalaire marine deposits should correspond to the late Albian.

A similar ammonite-bearing bed has been documented in the late Albian of the Frenda-Tiaret Mounts (BOUALEM, 2018), 300 km to the northwest of the Djebel Azzedine section. The ammonite fauna which yielded this level indicates the M. (Mortoniceras) pricei and M. (Mortoniceras) fallax Zones, named the Mortoniceras event. The same glauconitic ammonite-bearing level was recorded in the Hodna (to the east of our study area), including Hysteroceras orbignyi, Pervinquieria perinflata var. crassissima, Scaphites hugarianus, Stoliczkaia dovesdensis st. notha and Turrilites tuberculatum, and indicating a late Albian age (M. (Mortoniceras) inflatum Zone) (KIEKEN, 1974).

Consequently, the maximum flooding surface related to the mid-Cretaceous transgression in northern Algeria (Frenda-Tiaret, Ouled Nail and Hodna basins) is characterized by condensed Mortoniceratinae-beds, which are diachronous, pointing to a late Albian age sensu lato.

5. INVERTEBRATE TRACE FOSSILS

The mid-Cretaceous succession of the Djebel Azzeddine section records a low diversity assemblage of trace fossils. Six ichnogenera were recognized with abundant Thalassinoides, common Skolithos, and rare Gyrolithes, Oichnus, Planolites and Tisoa. Except for Thalassinoides and Tisoa, it was impossible to identify specimens in the ichnospecies level.

5.1. Gyrolithes isp. (Fig. 6A)

Description: Bioturbation structures described herein consist of vertical, sinistrally or dextrally spiraled burrows, corkscrew-shaped, preserved as epichnial. These burrows are smooth and filled by dark and fine sediment in comparison with the host sediment. They are perpendicular to the bedding. Coil diameter is 40 – 50 mm, and shaft diameter is 5 – 8 mm.
Occurrence: Lower marlstone-shelly limestones unit.
Remarks: The ichnogenus Gyrolithes constitutes a domichnion trace fossil produced by crustaceans in intertidal and shallow subtidal environments (GERNANT, 1972; DWORSCHAK & RODRIGUES, 1997; NETTO et al., 2007). It can also be produced by capitellid polychaetes (POWELL, 1977). Gyrolithes occurs from the Ediacaran – Cambrian boundary (LAING et al., 2018) to the Holocene (WETZEL et al., 2010), and indicates a marginal marine environment (GERNANT, 1972; POWELL, 1977; WETZEL et al., 2010). This trace fossil is attributed to the Skolithos and Cruziana ichnofacies (PEMBERTON et al., 2001). Morphological features of the studied burrows resemble that of the ichnospecies G. lorcaensis UCHMAN & HANKEN (2013) and G. polonicus FEDONKIN (1981).

5.2. Oichnus isp. (Fig. 6B)
Description: Circular, sub-circular, oval to weakly elliptical, millimetre-sized borings in the tests of undetermined bivalves. They are perpendicular to the surface of the substrate, and shallower than wide. These borings are over 2 mm in maximum diameter.
Occurrence: Lower marlstone-shelly limestone unit.
Remarks: Bioerosion structures or borings occur in shallow marine biogenic substrates such as bivalve, brachiopod and echi- noid shells (e.g., NAIMI et al., 2021c; VINK et al., 2021a). Many small round holes (or drill holes) in shells are assigned to the ichnogenus Oichnus which is produced essentially by predatory gastropods (MÜLLER, 1969), known from the Cambrian (VINK et al., 2021b) to the Holocene (NIELSEN & NIELSEN, 2001), and belonging to the ichnofamily Oichnidae (WISSHAK et al., 2019). Oichnus is interpreted as an example of Preadichnium (predation traces) with or without signs of attachment (WISSHAK et al., 2015; VALLON et al., 2016).

5.3. Planolites isp. (Fig. 6C)
Description: Epichnial burrows preserved in positive epirelief and oriented more or less parallel to the bedding. They consist of simple, unlined, straight, unbranched, slightly inclined burrows, 6 mm wide and 35 mm long. Planolites isp. burrows are filled with yellow-red coarser-grained sandy material different from that of the host rock, which is finer and lighter, and co-occur with strong concretionary vertical undetermined burrows characterized by a similar fill.
Occurrence: Upper marlstone-shelly limestones unit.
Remarks: The post-depositional trace fossil Planolitisis interpreted as a feeding trace of vermiform deposit-feeders (UCHMAN, 1995), arthropods and bivalves (KNAUST, 2017). It is considered as a cosmopolitan trace fossil known from the Ediacaran, occurring in different aquatic environments in softgrounds (e.g., UCHMAN, 1995; KNAUST, 2017; BELAID et al., 2020). In a shallow marine setting, Planolites commonly occurs in the Cruziana ichnofacies (BUATOIS & MANGANO, 2011).

5.4. Skolithos isp. (Fig. 6D)
Description: Vertical to subvertical, unbranched, cylindrical and tabular burrows, preserved as endichnia. The burrow apertures at the bedding plane surface are circular to slightly oval. Skolithos isp. burrows usually completely penetrate the rock and are filled with a brownish sandy material with small recrystallized bioclasts. They are 2–13 mm in diameter, with a maximum length of about 120 mm. Skolithos isp. co-occurs with Thalassinoides isp. and dinosaur footprints.
Occurrence: Upper marlstone-shelly limestones unit.
Remarks: The ichnogenus Skolithos characterizes the littoral to shallow sublittoral Skolithos ichnofacies (SEILACHER, 1967). It is created by suspension-feeding organisms such as anthozoans, crustaceans, holothurians, phoridons, polychaetes and priapulids for dwelling (domicnia) (KNAUST, 2017; KNAUST et al., 2018). Skolithos burrows are generally associated with high hydrodynamic energy within shallow water environments (VINN & WILSON, 2013). This trace fossil is known from the Ediacaran (MCCALL, 2006) through to the Holocene (DASHTGARD & GINGRAS, 2012).

5.5. Thalassinoides isp. (Fig. 7A and B)
Description: Systems of burrows consisting of horizontal tunnels and vertical or inclined cylindrical shafts. Diameters of tunnels and shafts range from 10 to 30 mm. Thalassinoides isp. burrows show Y- and T-shapes, and are filled with a brownish detrital material.
Occurrence: Marlstone-algal bioturbated limestones unit and Lower marlstone-shelly limestones unit.
Remarks: Thalassinoides burrows occur in a shallow marine setting and represent a common constituent of the Cruziana ichnofacies (BENYoucef et al., 2012, 2019; CHERIF et al., 2015, 2018; BELAID et al., 2020). They are known from the Ordovician (EKDALE & BROMLEY, 2003) to the Holocene (NICKELL & ATKINSON, 1995), and seem to be abundant within Mesozoic and Cenozoic strata (EL-SABBAGH et al., 2017). Thalassinoides is considered as a fodinichnion-domicnich trace fossil produced by decapod crustaceans (FREY et al., 1984). Furthermore, Palaeozoic Thalassinoides may be produced by non-crustacean trace-makers (CARMONA et al., 2004).

5.6. T. paradoxicus WOODWARD, 1830 (Fig. 7C)
Description: T. paradoxicus is recorded for the first time from Algeria. It is preserved in positive epichnia and hypichnia, mostly as hypichnia on the sole of the beds. T. paradoxicus is densely branched, subcylindrical to cylindrical burrows, highly irregular in size and morphology. The burrow system is multidirectional and oriented at various angles with respect to bedding, 20 – 80 mm in diameter, occurring as contorted nodules. The tunnels are horizontal, straight to slightly curved, whereas the bifurcations consist mostly of T-shaped intersections than Y-shaped. The burrow filling is similar to that of the host material.
Occurrence: Marlstone-algal bioturbated limestones unit.
Remarks: T. paradoxicus differs from the recorded T. suevicus by its complex irregularly branching system, as well as the predominance of T-branches rather than Y-shaped bifurcations. The studied T. paradoxicus branched system resembles that described in the middle Miocene of Egypt (EL-SABBAGH et al., 2017). It occurs in shallow siliciclastic deposits (KNAUST, 2020), especially in the middle shoreface (HOWARD & FREY, 1984) to foreshore (CHRZASTEK et al., 2018), and suggests a low energy environment (MANGANO & BUATOIS, 1991). T. paradoxicus burrows are domicnich, documented in firmgrounds characterizing the Glossifungites ichnofacies. They probably required firm, at least semi-consolidated substrates to prevent burrow collapse (MYROW, 1995).

5.7. T. suevicus RIETH, 1932 (Fig. 7D)
Description: The studied Thalassinoides suevicus are preserved in epichnia and endichnia, characterized by their complex irreg-
ularly branching system. Tunnels and shaft diameters vary from 5 to 24 mm, filled with a fine brown sandy material. Thereby, dichotomous bifurcations are more common than T-shaped branches.

**Occurrence:** Marlstone-algal bioturbated limestones unit.

**Remarks:** *Thalassinoides suevicus* burrows support a subtidal environment (middle shoreface) (e.g., HOWARD & FREY, 1984). They characterize the soft grounds (MYROW, 1995), within a shallow marine setting, with well-oxygenated water above the sea floor (NAIMI et al., 2020; NAIMI & CHERIF, 2021b).

### 5.8. cf. *Tisoa siphonalis* DE SERRES, 1840 (Fig. 7E)

**Description:** It consists of a cylindrical, vertical U-shaped burrow, showing laminations within the passive burrow fill, the tube is filled by micritic material. The remaining portion of the well-preserved tube is 30 mm long and 6 mm wide, constituting the long axis of a cylindrical calcareous concretion.

**Occurrence:** Lower marlstone-shelly limestones unit.

**Remarks:** The difference between *Arenicolites* and *Tisoa* was discussed by KNAUST (2019). Despite the close affinity between these trace fossils, the studied burrow has been attributed to cf. *T. siphonalis* due to the high length-width ratio and the presence of the calcareous concretion. The studied cf. *Tisoa siphonalis* resembles the trace fossil *Annerepichnites walakhavasensis* (sensu KULKARNI & GHARE, 1991), recorded from shallow marine Bathonian – Kimmeridgian sediments from India, and which has been recently attributed to *Tisoa siphonalis* (KNAUST, 2019). The key feature of this trace is the presence of a laminated fill, which has been observed in the studied burrow. *Tisoa siphonalis* occurs in shallow to deep marine environments (KNAUST, 2017, 2019; CHERIF et al., 2021a, b), from the lower Ordovician (PICKERILL & KEPPIE, 1981) to the Holocene (BADVE & GHARE, 1984). ++ is interpreted as the result of dwelling activity (domichnion) of polychaetes (KNAUST, 2017), related to widespread authigenic seep carbonate formation (VAN DE
SCHOOTBRUGGE et al., 2010), and it is common in quasi-anoxic organic-rich and in cold seep deposits (KNAUST, 2019). In Algeria, this ichnospecies has been reported from the lower Miocene Tiaret Marl Formation (CHERIF et al., 2021a) and the early Cretaceous of the Ouarsenis Range (CHERIF et al., 2021b).

6. DISCUSSION

6.1. Ichnological analysis

The ichnoassemblage of the studied succession is composed of horizontal, vertical and inclined trace fossils constituting an impoverished example of the Skolithos – Glossifungites ichnofacies. It is dominated by domicinion, fodinichnion and praedichnion trace fossils produced mainly by worms, decapods and naticid gastropods.

Trace fossils of the lower part of the section correspond to a firmground suite of the Glossifungites ichnofacies and they are represented essentially by Thalassinoides paradoxicus. The T. paradoxicus rich bed (unit A) is characterized by low ichnodiversity, high abundance, and intense bioturbation which destroyed the primary sedimentary structures and the presence of branched burrow systems. These characteristics are typical of the substrate-controlled Glossifungites ichnofacies (BUATOIS & MÁNGANO, 2011). However, firmground burrowers may produce Tisoa (KNAUST, 2017) and Gyrolites (NETTO et al., 2007). The typical examples of the Glossifungites ichnofacies (archetypal Glossifungites ichnofacies) are recorded in shallow-to marginal marine environments; furthermore, surfaces containing this ichnofacies indicate transgressive events (BUATOIS & MÁNGANO, 2011). The Glossifungites ichnofacies occurs as a result of intense erosion in the zone of maximum wave energy of wave-dominated tidal flats (YANG et al., 2009).

The Skolithos ichnofacies is well represented in the upper part of the section, mainly dominated by vertical, cylindrical, simple dwelling burrows of suspension-feeders, and characterized by the abundance of three-dimensional burrow systems dominated by vertical components, the absence of horizontal trace fossils produced by a mobile fauna, low ichnodiversity and variable abundance. Skolithos constitutes the most common ichnogenus of the Skolithos ichnofacies, well-known in nearshore settings. The dominance of vertical dwelling structures of infaunal suspension-feeders such as Skolithos isp. indicates the high abundance of organic particles that are kept in suspension in the oxygenated water column by currents and waves (BUATOIS & MÁNGANO, 2011). The predominance of vertical components over horizontal components indicates relatively high wave energy (HOWARD & FREY, 1984) related to stressful conditions. Such situations can be indicated by the low ichnodiversity and the nonspecific occurrences of Skolithos isp. (MÁNGANO & BUATOIS, 2004). In shallow marine water, the Skolithos ichnofacies is typical of foreshore to upper- and middle-shoreface environments, and it occurs in lower-intertidal flats depending on the tidal regime (BUATOIS & MÁNGANO, 2011).

Several dinosaur footprints have been recorded in a similar setting. Marginal marine carbonate sediments of a large inner-shelf environment, characterized by dolomitic sedimentation related to a warm and dry climate yielded theropod and ornithopod footprints from the Barremian of Portugal (SANTOS et al., 2013). Furthermore, tridactyl footprints which co-occur with bivalves and gastropods have been documented in dolomitic facies from the early Jurassic of France (MOREAU et al., 2018). These tracks are associated with desiccation cracks and they indicate deposition within a periodically emergent environment. The invertebrate trace fossils and mud volcanoes recorded from these deposits allowed attribution of these track-bearing deposits to a subtidal to inter-supratidal flat marsh. In northern Africa, a similar ichnoassemblage including Skolithos and dinosaur footprints (theropod, sauropod and ornithischian), reported to represent a tidal flat, has been described from the mid-Cretaceous of Morocco (IBRAHIM et al., 2014). Such a vertebrate-invertebrate ichnoassemblage has also been documented in a shallow-marine carbonate setting in the middle Jurassic of Wyoming (KVALE et al., 2001). Invertebrate trace fossils are dominated by vertical and cylindrical burrows attributed to the ichnogenus Skolithos, indicating a soft-ground typical of an intertidal onshore facies persistent during formation of the dinosaur trackway. In the lower Cretaceous of Texas, dinosaur footprints are associated with a shallow invertebrate ichnofauna, suggesting a supratidal to shallow subtidal environment (FARLOW et al., 2012).

6.2. The mid-Cretaceous transgression and palaeogeography

The Djebel Azzedine mid-Cretaceous series could be correlated with the upper unit of the Rhelida Formation, which crops out in the Ksour and Djebel Amour Mountains, respectively in the western and central parts of the Algerian Saharan Atlas. The Rhelida Formation transgressive deposits directly overlay the Continental Intercalaire and have been attributed firstly to the Vraconnian (uppermost Albian) (BASSOULLET, 1973). On the basis of new biostratigraphic data, as well as vertebrate remains from the Rhelida Formation equivalents in Morocco (e.g., CAVIN et al., 2010), Egypt (e.g., LE LOEUFF et al., 2012), and the Guir basin (southwestern Algeria) (BENYOUCEF et al., 2014, 2015, 2016), this Formation has now been dated as lower – middle Cenomanian (BENYOUCEF et al., 2017). Further north of the Saharan Atlas in the Fenda-Tiaret Mounts (northern border of High Plateaus), similar deposits defined as the Mcharref Formation dated as upper Albian (BOUALEM & BENHAMOU, 2017) overlie the Sidi Ouadah Formation, considered as the equivalent of the Continental Intercalaire (PEYBERNÉS et al., 1986). The condensed ammonite bed [Mortoniceras event sensu BOUALEM (2018)] indicates a maximum flooding surface related to the late Albian transgression (NAGM & BOUALEM, 2019). Further west, in the Daïa Mounts, the equivalent of the Albian Continental Intercalaire consists of the Grès de Bossuet Formation (AUCLAIR & BIEHLER, 1967). These fluvi-deltaic sediments are overlain by the late Albian – Cenomanian Djebel Tenfeld carbonate Formation (AUCLAIR & BIEHLER, 1967; CISZAK, 1993), which yielded new ostracod species (DAMOTTE, 1984). The Albian – lower Cenomanian strata of the Tellian Atlas (northernwestern Algeria) are represented by turbidite-deposits and deep marl-limestone alternations (e.g., CISZAK, 1993). It is concluded that the mid-Cretaceous transgression is diachronous across northern Algeria. It is precocious (late Albian) in the eastern part of the Saharan Atlas (Ouled Nail basin) and the northern border of the Oran High Plateaus (Daïa and Fenda-Tiaret basins), and more recent in the central and western parts of the Saharan Atlas (Djebel Amour and Ksour basins).

7. CONCLUSIONS

New insights on the lithostratigraphy and the palaeoenvironment have been provided from the upper Albian – lower Cenomanian marine succession overlying the Continental Intercalaire in the eastern part of the Ouled Nail Mounts (eastern Algerian Saharan
Atlas). The studied succession has been subdivided into three distinctive units: The Marlstone-algal bioturbated limestones (unit A), lower marlstone-shelly limestones (unit B) and upper marlstone-shelly limestones (unit C). Units A and B have been attributed to the upper Albian on the basis of new recorded fossils. A typical Lofer cyclothem with in situ slumped brecciation has been observed from the lowermost part of the section, reflecting local collapses of the carbonate platform. An ammonite-rich bed, discovered at the uppermost part of unit B including morganoceratids and engonoceratids belonging to Mortoniceras sp., Pervinquieria sp. and Engonoceras sp. has been recorded for the first time in the Bou Saada area. These ammonites indicate a maximum flooding surface of the mid-Cretaceous transgression and could be correlated with similar levels from other Algerian basins such as the Frenda-Tiaret and the Hodna basins. Unit C is barren of any biostratigraphic fauna, but has been assigned to the uppermost part of unit B including morganoceratids and engonoceratids belonging to Mortoniceras sp., Pervinquieria sp. and Engonoceras sp. has been recorded for the first time in the Bou Saada area. These ammonites indicate a maximum flooding surface of the mid-Cretaceous transgression and could be correlated with similar levels from other Algerian basins such as the Frenda-Tiaret and the Hodna basins. Unit C is barren of any biostratigraphic fauna, but has been assigned to the uppermost part of unit B including morganoceratids and engonoceratids belonging to Mortoniceras sp., Pervinquieria sp. and Engonoceras sp. has been recorded for the first time in the Bou Saada area. These ammonites indicate a maximum flooding surface of the mid-Cretaceous transgression and could be correlated with similar levels from other Algerian basins such as the Frenda-Tiaret and the Hodna basins. Unit C is barren of any biostratigraphic fauna, but has been assigned to the uppermost part of unit B including morganoceratids and engonoceratids belonging to Mortoniceras sp., Pervinquieria sp. and Engonoceras sp.

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REFERENCES
AMÉDRO, F. (2008): Support for a Vracconnian Stage between the Albian sensus stricto and the Cenomanian (Cretaceous System).— Carnets de Géologie, 2008/02, 1–83.
AUCLAIR, D. & BIEHLER, J. (1967): Etude géologique des Hautes Plaines oranaises entre Tlemcen et Saida.— Publications du Service de la Carte géologique de l’Algérie, 34, 3–45.
BADVE, R.M. & GHARE, M.A. (1984): Holocene trace fossils from beach rock of Ve- las coast, Raigad District, Maharashtra.— Biovignyam, 10, 165–172.
BASSOULLET, J.P. (1973): Contribution à l’étude stratigraphique du Mésozoïque de l’Atlas saharien occidental (Algérie). Thèse de Doctorat d’État, Université de Pa- ris VI, France, 497 p.
BELAID, M., CHERIF, A., VINN, O. & NAIMI, M.N. (2020): First record of trace fos- sils from the Oxfordian Argiles rouges de Khemeg Formation (Tiarat, northwestern Algeria).— Geologia Croatica, 73, 85–94.
BENYOUCEF, M., MEISTER, C., BENSALAH, M. & MALTI, F.Z. (2012): La plate- forme préalpine (Cénomanien supérieur – Turonien inférieur) dans la région de Béchar (Algérie): stratigraphie, paléoenvironnements et signification paléobio- géographiques.— Revue de Paléobiologie, 31, 205–218.
