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Investigation of paleoenvironmental evolution and ichnofacies diversity in the Aptian-Albian section of the Amizmiz Region, Western High Atlas, Morocco

Mohcine Jdaba[1*], Ahmed Algouti[1], Abdellah Algouti[1], Naji Jdaba[2], Fatiha Hadach[2], Imane El Kihal[1], Hafssa Naciri[1]

[1] Laboratory Sedimentary Basins Geology of Morocco, "2GRNT" Geology Department, Faculty of Science Semlalia, University Cadi Ayyad, BP 2390, 40000, Marrakech, Morocco
[2] Department of Geology, Faculty of Sciences, Ibn Zohr University, 80000, Agadir, Morocco
* Corresponding author's e-mail: mohcinejdaba@gmail.com

ABSTRACT

This study aims to reconstruct the paleoenvironmental evolution of the Amizmiz region (Western High Atlas, Morocco) during the Aptian-Albian transition, characterizing the substrate conditions that accompanied the collapse of the Urgonian carbonate platform. The research employed a comprehensive field investigation involving detailed lithostratigraphic logging, sedimentological facies analysis, and in situ ichnological documentation. The study utilized trace fossils (*Thalassinoïdes*, *Spongeliomorpha*, *Arenicolites*) and macrofossils (ammonites, rudists) as high-resolution proxies for oxygenation, hydrodynamic energy, and substrate consistency. The analysis revealed a stratigraphic succession transitioning from a shallow subtidal carbonate platform to a deepening basin, culminating in an intertidal environment. A key finding is the identification of a Spongeliomorpha-dominated firmground (*Glossifungites* ichnofacies) marking a major erosional discontinuity and platform drowning event. The study documents the replacement of the *Pseudotoucasia*-dominated benthic community by ammonite-rich condensation levels (*Nolaniceras*, *Hypacanthoplites*) indicating stratigraphic starvation. The study is limited to the outcrop scale of the Amizmiz section; however, the consequences imply a broader regional applicability for interpreting sedimentary hiatuses using ichnology. This research establishes a predictive model for using firmground ichnofacies to locate sequence boundaries and erosional surfaces in the High Atlas, aiding in regional stratigraphic correlations. This is the first study in the Amizmiz region to explicitly link the mechanical properties of the substrate (via *Spongeliomorpha* bioglyphs) to the specific timeline of the Aptian-Albian anoxic events, providing a novel dataset for the Atlasic Gulf paleo-ecosystem.

Keywords: Morocco, High Atlas, paleoenvironment, ichnofacies, Aptian-Albian.

INTRODUCTION

The geological history of the Western High Atlas (WHA) during the Mesozoic Era is a testament to the dynamic tectonic processes that shaped the northwest African margin. Following the breakup of Pangea and the opening of the Central Atlantic Ocean in the Triassic and Jurassic, the Atlas domain evolved as an intra-continental rift system subject to varying regimes of extension and thermal subsidence (Choubert and FaureMuret, 1962). By the Early Cretaceous, this region had developed into a complex configuration of subsiding basins and uplifted highs, forming a broad seaway known as the "Atlasic Gulf" (Choubert and Salvan, 1950). This gulf opened westward towards the young Atlantic Ocean and maintained intermittent connections with the Tethys Ocean to the northeast, creating a unique biogeographic and sedimentological corridor.

The Amizmiz region, situated on the northern flank of the WHA, represents a key segment of this sedimentary system, within its stratigraphic context, the Cretaceous interval of Amizmiz yields a rich fossiliferous and ichnological assemblage that provides essential insights into benthic behaviour, substrate conditions, and paleoenvironmental gradients. Fossils such as Ammonites, Lamellibranchs and Rudists and trace fossils such as *Thalassinoïdes*, *Arenicolites* and *Spongeliomorpha* occur in varying abundances and morphologies, reflecting shifts in energy levels, oxygenation, sedimentation rates, and bioturbation intensity. These ichnofossil communities, combined with associated macrofossil and sedimentological evidence, serve as robust proxies for distinguishing between shallow-marine, proximal shoreface, and more restricted environments along the Cretaceous epoch (Algouti et al., 2022).

Despite the extensive stratigraphical studies on the Western High Atlas, there remains a lack in understanding the precise ethological response of benthic communities to the Aptian-Albian platform drowning event in the Amizmiz sector. Previous works have largely focused on lithostratigraphy, often overlooking the high-resolution environmental data preserved in the trace fossil record. Specifically, the relationship between substrate consistency and the faunal turnover during this critical interval has not been fully reconstructed.

The primary objective of this investigation is to fill this gap by characterizing and interpreting the lithological, paleontological, and ichnological records of the Aptian-Albian in the Amizmiz region. The hypothesis shows that the transition from *Thalassinoïdes* to *Spongeliomorpha* traces is not random but represents a direct biological response to the substrate hardening associated with the platform's demise, thereby providing a new tool for identifying cryptic sequence boundaries.

Geological setting

The Western High Atlas is an intracontinental fold-and-thrust belt that resulted from the Cenozoic inversion of a Mesozoic rift basin. The structural grain of the region is defined by the interplay between the inherited Paleozoic basement structures and the Mesozoic extensional faults, which were subsequently reactivated as thrusts during the Atlasic orogeny (Choubert and FaureMuret, 1962).

The Amizmiz Basin is situated on the northern flank of the ancient massif of the Central Western High Atlas, it falls within the Marrakesh-Safi administrative region, specifically in the Al Haouz province, approximately 55 km southwest of Marrakesh. (Figure 1)

Geologically, it lies at the interface between the stable Meseta domain to the north and the mobile Atlas belt to the south. This boundary is often defined by major fault zones that accommodated significant vertical displacement during both the rifting and inversion phases. The basin itself is oriented southwest-northeast, reflecting the dominant structural trend of the Atlas system (Algouti et al., 2015). Geomorphologically, the region is characterized by rugged terrain, marked by steep hills, escarpments, and deeply incised river gorges.

The stratigraphic column in Amizmiz rests on a Paleozoic basement consisting of deformed Cambrian and Carboniferous sedimentary rocks, metamorphosed during the Hercynian orogeny. The Mesozoic cover begins with Triassic red beds and basalts, followed by a thick Jurassic carbonate sequence. The Cretaceous interval, which is the focus of this study, overlies the Jurassic or older Cretaceous units, reflecting significant hiatuses and erosional events driven by halokinesis and block tilting (Algouti et al., 2022).

The Lower Cretaceous formations are organized into six primary depositional sequences. These sequences record major geodynamic pulses, including a Late Berriasian distensive phase and a significant intra-Aptian tectonic event. This intra-Aptian event is of particular importance as it restructured the basin geometry immediately prior to the deposition of the studied succession, creating the accommodation space necessary for the accumulation of the Aptian-Albian sediments (Rey et al., 1988).

Materials and methods

The reconstruction of the paleogeography of the Aptian epoch located in the Western High Atlas, was made with the conduction of several field missions. The analysis of different Sedimentological facies was thoroughly realized in the field by examining various outcrops and beds,

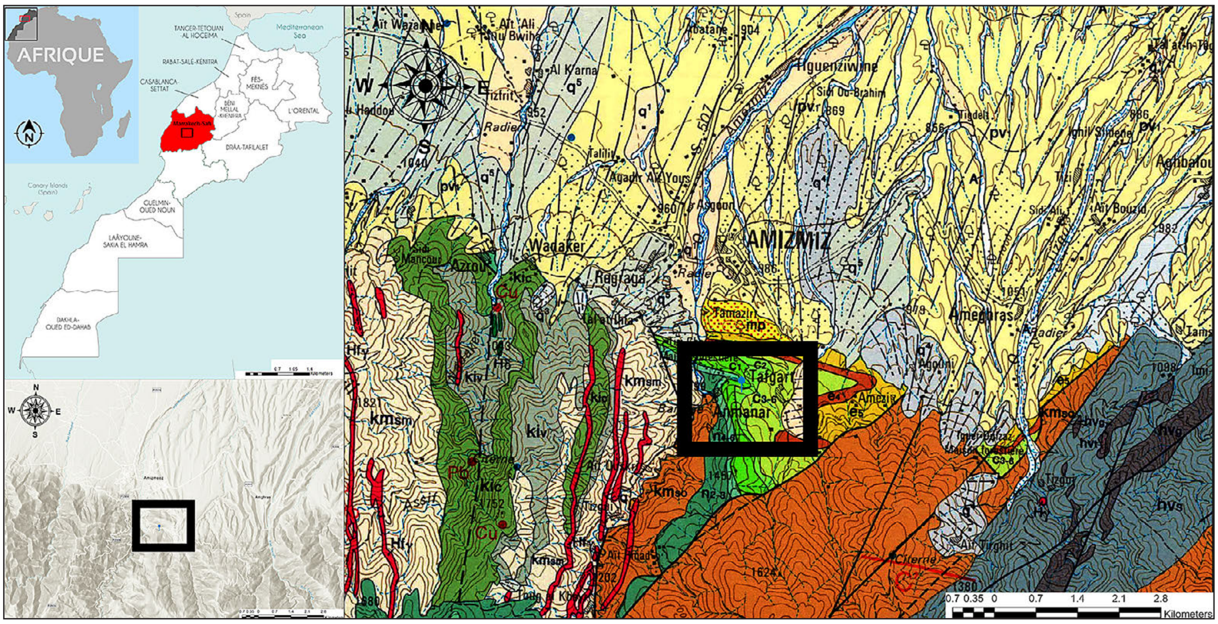

Figure 1. Geological and geographical location map of the Amizmiz region

and comparing them with similar facies in other regions with the aim of identifying the depositional environments. The field research concentrated on the identification of sedimentary structures, with focused lithological observations conducted throughout the section. This investigation entailed the examination and registration of both Paleontological fossils and Ichnological traces exposed in the rock formations. Significant specimens were photographed, and their paleoecological context was deduced regarding the surrounding sedimentary facies.

The production of visual data, including geographic maps, geological profiles, figures and specimen plates, was executed using tools such as: *Adobe Photoshop*, *Adobe Illustrator*, *Photofiltre*, and *Inkscape*.

RESULTS

The Amizmiz Aptian section

The Aptian-Albian stratigraphic succession that overlies the Jurassic (Figure 3, A) in the Amizmiz region provides a particularly rich sedimentary record, allowing a detailed reconstruction of marine environmental evolution during the Early Cretaceous (Figure 2). This sequence documents a gradual transition into predominantly subtidal depositional settings characterized by fine, stable sedimentation sensitive to sea-level fluctuations. At the base, the presence of marly limestone followed by alternating limestone and clay beds indicates a shallow subtidal marine environment affected by variations in terrigenous input, likely controlled by minor oscillations in relative sea level.

Higher in the succession, the predominance of yellowish marls and red to yellow clays reflects a phase of quiet-water sedimentation with variable oxidation conditions. The occurrence of reddish clays suggests temporary continental influence or a moderate regressive episode. The subsequent return to yellowish and then greenish marls toward the top marks a shift back to more reduced conditions, pointing to renewed marine influence.

Above this interval, the alternation of marls and fossiliferous lenticular limestone beds (Figure 3, B), containing bivalves and trace fossils such as *Thalassinoïdes* that indicates a well-oxygenated, marine inner-platform environment characterized by active bioturbation, is followed by a south-eastward progradation (Figure 3, C), reflecting the landward advance of marine sedimentation. Finally, the succession culminates in marls that progressively become more carbonate-rich, overlain by sandy limestone beds alternating with marly levels, representing a new phase of sedimentary stabilization in an intertidal setting with increasing detrital influence.

Overall, this stratigraphic architecture highlights a complex paleoenvironmental dynamic shaped by eustatic variability, fluctuating detrital inputs, and changing oxygenation conditions. It

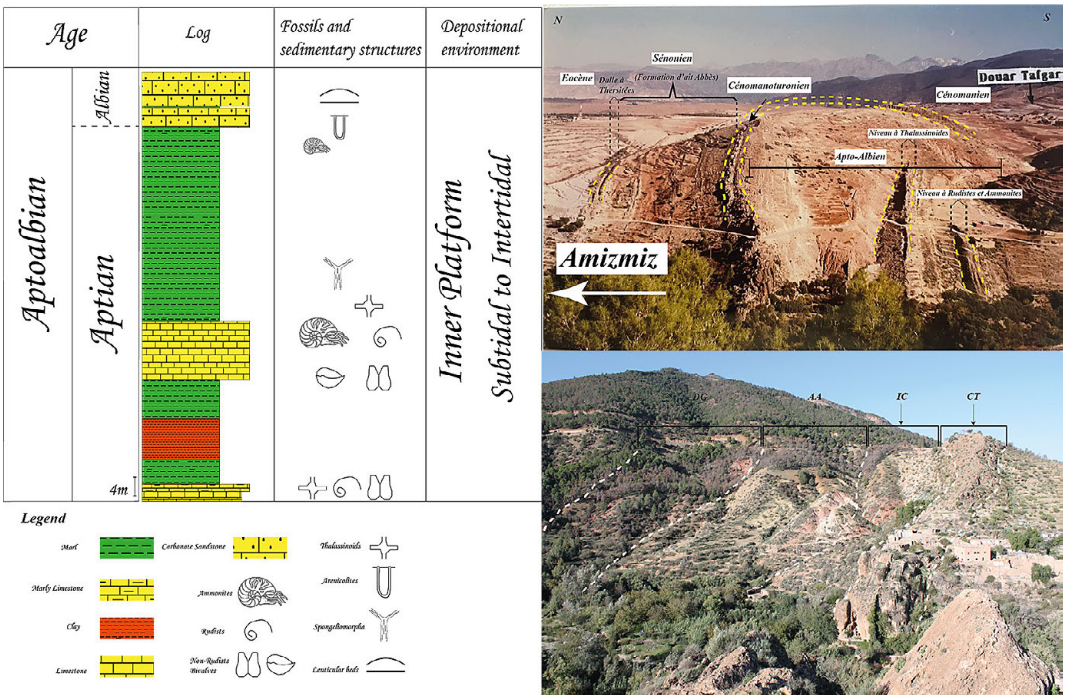

Figure 2. Lithostratigraphic log of the Aptian-Albian of the Amizmiz section with two panoramic views showing the different ages

also provides the framework for interpreting the distribution of fossils and trace fossils. The diversity of biogenic structures, benthic communities, and macrofossil assemblages will be presented in the following sections, offering insights into the ecological conditions, colonization patterns, and ichnofacies characteristics of the Aptian-Albian marine environments of the Amizmiz area.

Ichnological analysis of the Amizmiz section

Trace fossils serve as invaluable recorders of paleoenvironmental conditions, capturing the behavioral responses of benthic organisms to stress factors such as oxygenation, salinity, and substrate consistency. The Aptian-Albian deposits of Amizmiz yield a diverse and well-preserved ichnoassemblage. This study focuses on three diagnostic ichnogenera: *Thalassinoïdes*, *Spongeliomorpha*, and *Arenicolites.*

Thalassinoïdes

Within the Amizmiz section, the ichnogenus *Thalassinoïdes* (Figure 4) is recorded as extensive, three-dimensional boxwork systems characterized by cylindrical to sub-cylindrical tunnels with diagnostic Y- or T-shaped branchings enlarged at junction points. Preserved primarily in endogenic full relief within marly limestones and dolomites, these structures exhibit passive infill often composed of coarser bioclastic material distinct from the fine-grained host rock, indicating that the tunnels remained open at the sediment-water interface prior to gravitational infiltration. The smooth, unlined walls of these *domichnia*/*fodinichnia* structures suggest construction by decapod crustaceans (Rodríguez-Tovar et al., 2009), likely thalassinidean shrimp, within a stable, cohesive substrate. The proliferation of these burrows, which frequently results in the homogenization of the sedimentary fabric, is consistent with the *Cruziana* ichnofacies (Figure 5f) and indicates a well-oxygenated, nutrient-rich sub-littoral environment situated between fair-weather and storm wave bases, where high burrow densities imply intervals of low sedimentation rates (Frey and Pemberton, 1984).

Spongeliomorpha

In the Amizmiz outcrops, the ichnogenus *Spongeliomorpha* (Figure 5a–b) is distinguished from the pervasive *Thalassinoïdes* systems by the presence of diagnostic bioglyphs or scratch marks (D'Alessandro and Bromley, 1995; Muñiz and Mayoral, 2001) on the burrow walls (Figure 5e). These surficial features manifest as a reticulate pattern of intersecting ridges and grooves, interpreted as scratch marks left by crustacean

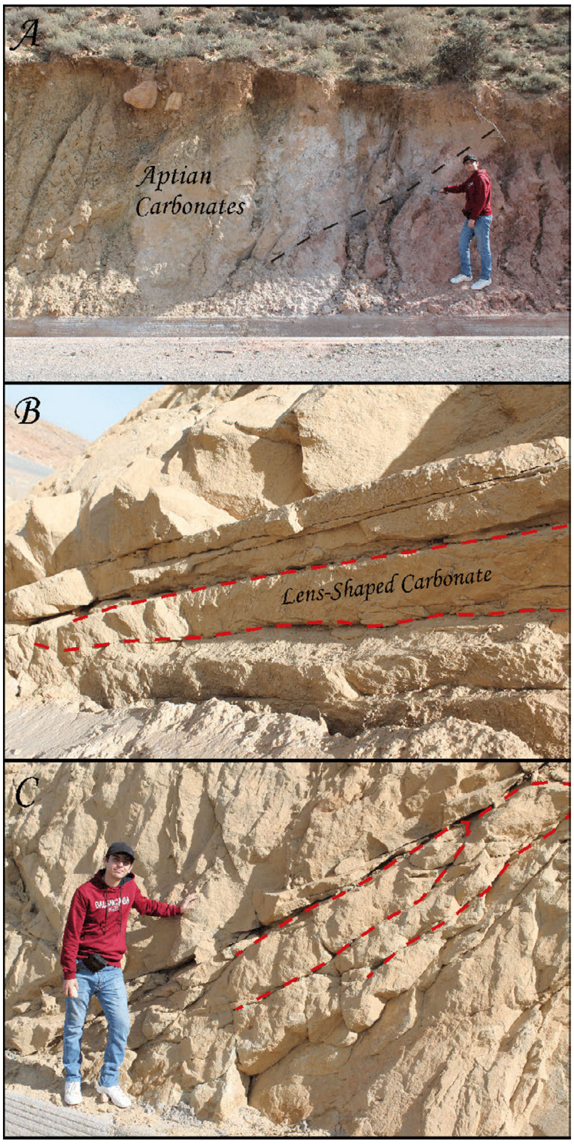

Figure 3. The different sedimentary structures found throughout the Aptian of the Amizmiz section. A: the boundary between the Jurassic (reddish) and Aptian (yellowish) of the Amizmiz section. B: Lenticular carbonate beds found in the study section. C: Progradation sedimentary structure found in the carbonates of the Aptian

pereiopods or chelae within a stable, dewatered substrate (Bromley and Frey, 1974; Frey et al., 1978). This preservation style indicates colonization of a firmground, thereby assigning these horizons to the *Glossifungites* ichnofacies (Figure 5f). Stratigraphically, these occurrences mark significant erosional discontinuities or surfaces of non-deposition associated with sequence boundaries (Gibert and Robles, 2005). The burrows typically exhibit passive infill by coarser sediment deposited during the subsequent middle Aptian transgression, preserving the bioglyphs as natural casts in hyporelief or as exhumed full reliefs atop the Aptian limestones.

Arenicolites

Within the sandy dolomitic intervals at the start of the Albian, *Arenicolites* (Figure 5c–d) are recorded as simple, vertical U-shaped burrows distinct from *Diplocraterion* traces, due to the absence of spreiten structures. These traces consist of two parallel to sub-parallel vertical shafts connected by a basal curve, featuring tube diameters of 2–5 mm and limb spacing of 1–4 cm. The smooth-walled morphology is interpreted as the *domichnia* of suspension-feeding organisms, such as *polychaetes* or small crustaceans (Häntzschel, 1975; Jensen, 1997; Gingras et al., 1999; Dashtgard, 2011), which utilized the U-shape to facilitate unidirectional current flow for filtration. Characteristic of the *Skolithos* ichnofacies (Figure 5f), the presence of *Arenicolites* indicates deposition in high-energy environments influenced by tides or storms (Figure 6).

Paleoenvironmental implications

The trace fossil assemblages of the Amizmiz Aptian-Albian section reflect a dynamic depositional system governed by fluctuating hydrodynamic energy and substrate consolidation. The widespread occurrence of *Thalassinoïdes* (*Cruziana* ichnofacies) characterizes a stable, oxygenated sublittoral setting with moderate sedimentation rates, typical of a healthy carbonate platform below the fair-weather wave base. In contrast, the presence of *Arenicolites* (*Skolithos* ichnofacies) signals episodic high-energy events, suggesting periods of increased wave or tidal action that favored suspension feeders within sandy intervals (Hofmann et al., 2012). Furthermore, the identification of *Spongeliomorpha* is stratigraphically significant, as it highlights firmground development and omission surfaces (*Glossifungites* ichnofacies) linked to erosional discontinuities and sequence boundaries. Collectively, the vertical stacking of these distinct ethological behaviours allows for a high-resolution reconstruction of the sequence stratigraphic evolution within the Western High Atlas.

Paleontological analysis of the Amizmiz section

The body fossil assemblages of the Amizmiz region are essential for establishing the

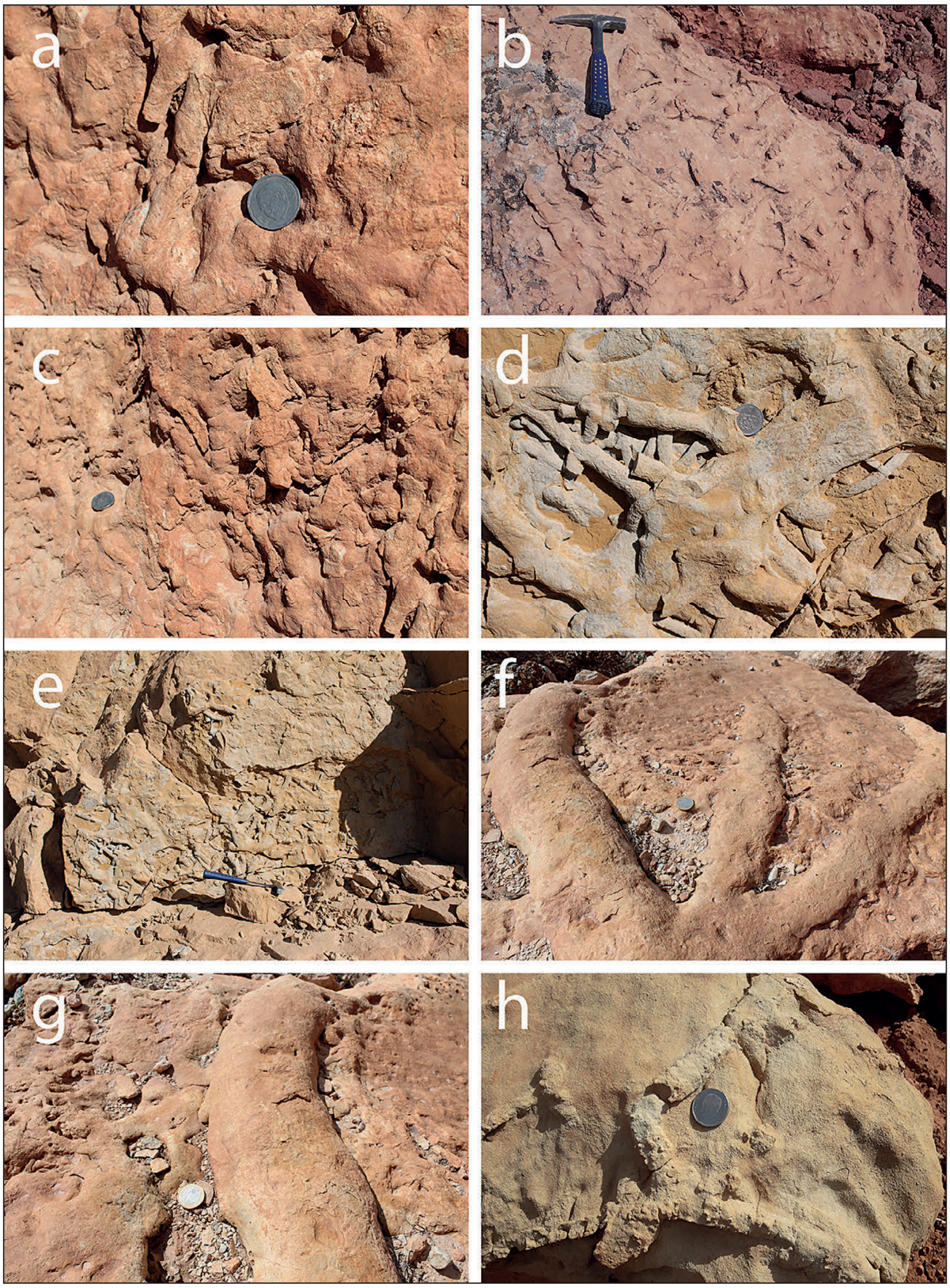

Figure 4. The various Thalassinoïdes trace fossils found throughout the Amizmiz section. a to e: Thalassinoïdes found in the base of the Aptian section. F to h: Thalassinoïdes found in the Middle of the Aptian section showing a bigger size than the ones seen before

chronostratigraphic framework and for reconstructing the trophic structures of the Cretaceous marine ecosystems. The fauna is divisible into three major groups: the nektonic ammonites, the epibenthic bivalves (oysters and rudists).

Ammonites

Ammonites provide the chronostratigraphic backbone for the study (Rey et al., 1988). Their absence at the base of the Aptian section platform and sudden abundance in its middle precisely dates the drowning event.

The middle of the Aptian section yields a rich fauna concentrated in "condensation levels" These beds, representing slow sedimentation rates, contain key index fossils:

- *Nolaniceras* spp.: including *N. gr. nolani* and *N. aff. uhligi*. These are quintessential markers for the Aptian Tethyan province;

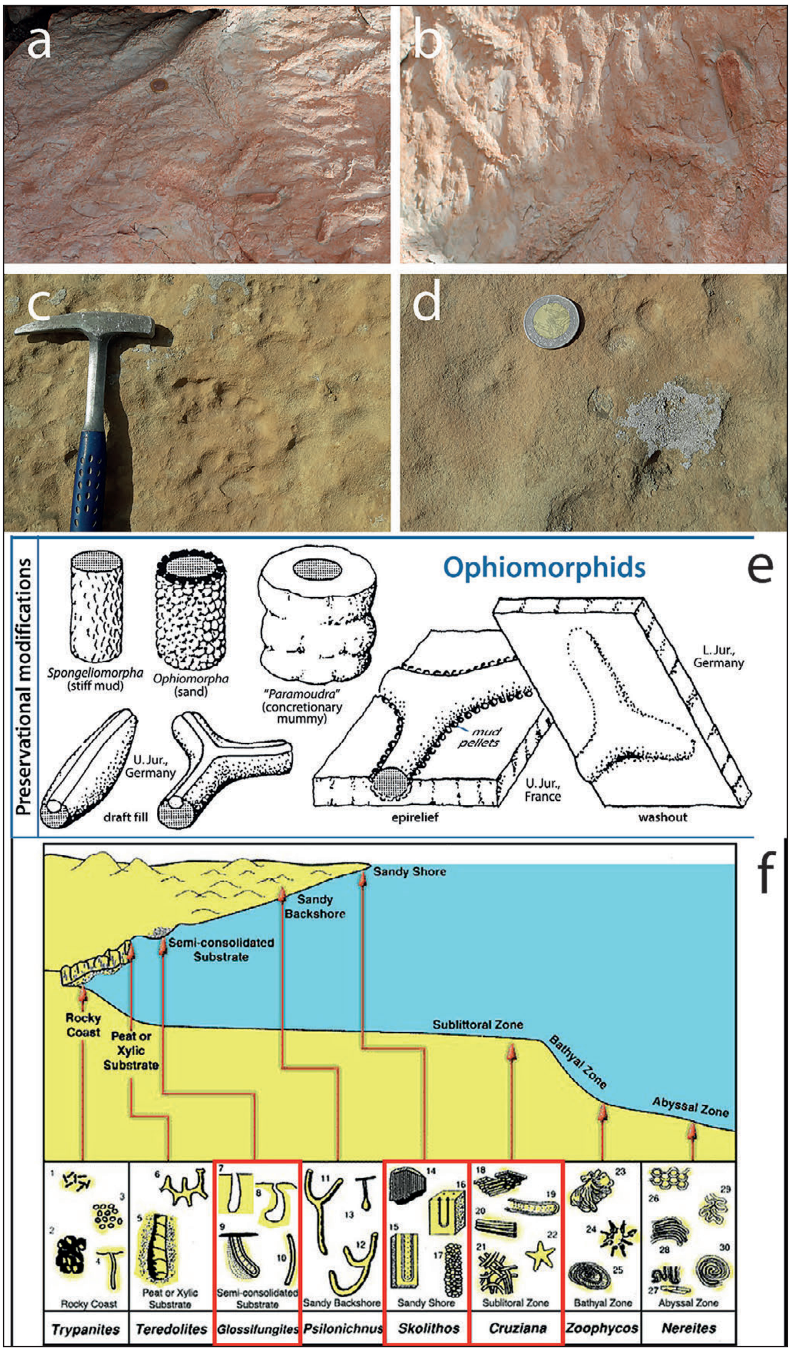

Figure 5. The different Ichnofossils found in the Amizmiz section. a and b: Spongeliomorpha trace fossils found in the Summit of the Aptian section. c and d: Arenicolites trace fossils found in the base of the Albian. e: The morphology of the different Preservational modifications made by the Ophiomorphids (Spongeliomorpha). f: Distribution of the different marine Ichnofacies

- *Acanthohoplites* and *Hypacanthoplites*: Taxa such as *A. bigoureti* and *H. jacobi-plesiotypicus* indicate marine shelf environments and define the terminal Aptian zones;
- the summit of the Aptian Transition Fauna: The summit of the Aptian section is marked by small ammonites such as *Beudanticeras dupinianum* var. *africana*. In lateral equivalents, *Douvilleiceras* confirms the Early Albian age (Rey et al., 1988).

Rudists

The platforms at the base of the Aptian section, were dominated by rudist bivalves, representing the final pulse of the "Urgonian" ecosystem in North Africa. *Pseudotoucasia catalaunica*:

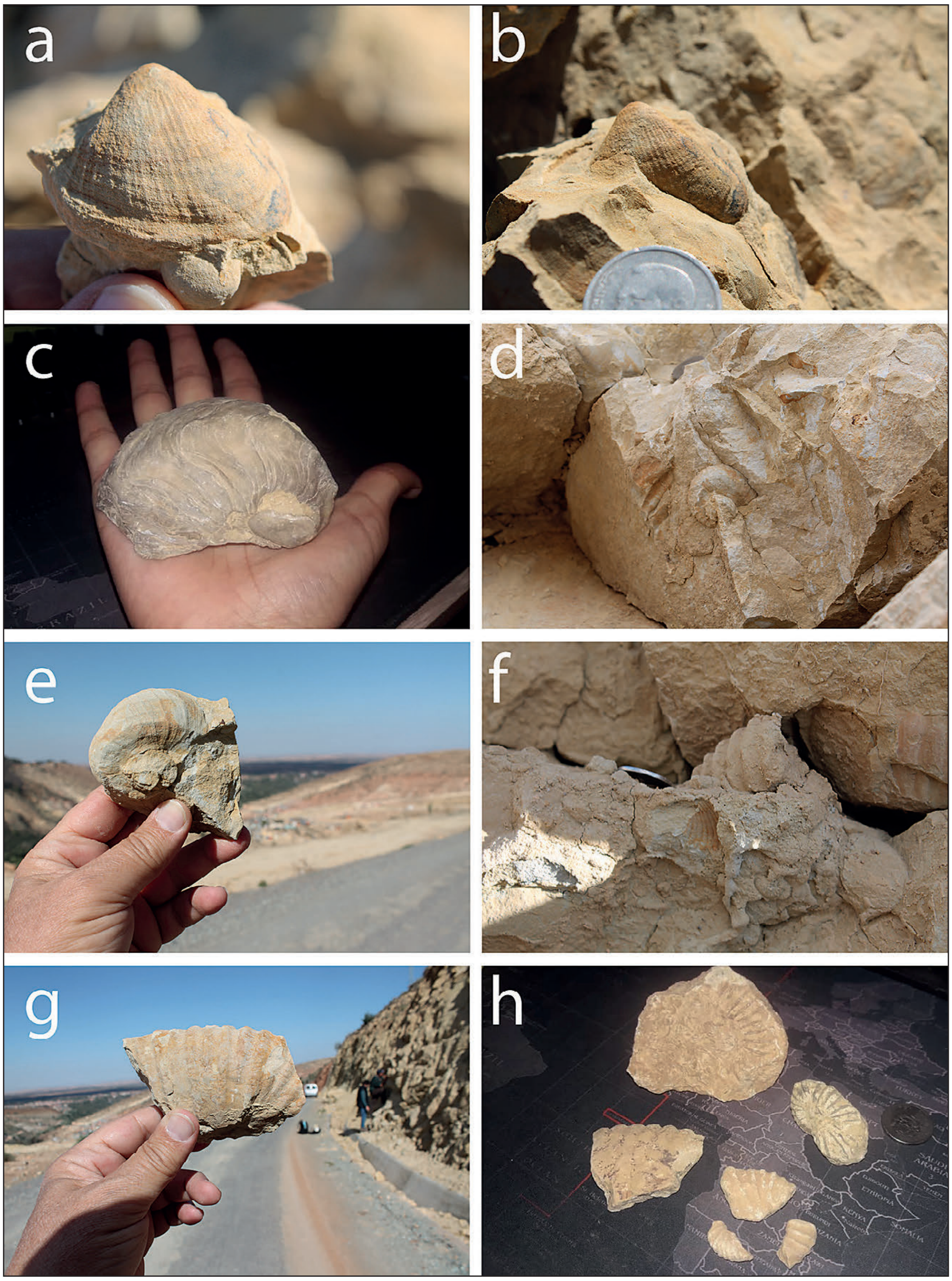

Figure 6. The various macrofossils found throughout the Amizmiz Aptian-Albian section. a and b: example of the Bivalves or Lamellibranchs found in the Aptian section. c: an example of Ceratostreon Bivalves found in the study region. d and e: Rudists found in Limestone beds. f to h: an example of the Ammonites found in the Aptian carbonates of the Amizmiz section

This requieniid rudist is the most significant taxon identified in the Aptian of Amizmiz (Masse et al., 2018). It is characterized by a spiral, attached left valve and a smaller opercular right valve.

Unlike the massive reef-building rudists of the earlier Cretaceous, *Pseudotoucasia* likely formed extensive, low-relief biostromes or banks in the shallow, restricted waters of the platform. Their morphology was adapted for stability in soft carbonate muds. The abrupt disappearance of *Pseudotoucasia* at the middle of the Aptian section coincides with the *Spongeliomorpha* surface. It is a local extinction which is part of the global demise of Urgonian platforms, linked to the environmental stress of the Aptian-Albian boundary (eutrophication, anoxia).

Benthic community structure

The non-rudist benthic fauna also records the environmental shift (Rey et al., 1986).

- Oysters (*Ceratostreon*): Abundant at the base of the Aptian, *Ceratostreon tuberculifera* formed clusters in high-energy zones. Their thick shells indicate adaptation to predation and wave action.
- Pectinids (*Plicatula*): In the marls found in the middle of the Aptian section, the fauna shifts to small, cementing bivalves like *Plicatula placunea*. These organisms colonized secondary hard substrates (shell debris) in the soft, muddy bottoms of the deepening shelf.

DISCUSSION

Dynamics of the Urgonian ecosystem collapse

The biotic turnover recorded in the Amizmiz section represents a localized manifestation of the global decline of Urgonian carbonate platforms during the Aptian-Albian transition (Masse et al., 2018). The benthic community at the base of the Aptian, dominated by the requieniid rudist *Pseudotoucasia catalaunica* and *Ceratostreon* oysters, reflects a "climax community" adapted to stable, shallow-water carbonate production. The morphology of *Pseudotoucasia*, specifically its adaptation to soft carbonate muds through automimicry, suggests a substrate-dependent ecosystem that was highly vulnerable to rapid environmental changes.

The abrupt disappearance of these rudist biostromes is not merely a biostratigraphic boundary but an ecological collapse signal. The transition from these autochthonous benthic assemblages to the allochthonous, pelagic-dominated assemblages of the Aptian section (ammonites) indicates a rapid deepening event (Rey et al., 1988). The replacement of heavy-shelled oysters by small, cementing Pectinids like *Plicatula* further corroborates this bathymetric deepening, as the latter exploited secondary hard substrates in an increasingly muddy, lower-energy environment.

Ichnological signatures of substrate rheology and hydrodynamics

The trace fossil record provides a high-resolution log of the physical properties of the substrate and the hydraulic energy at the sediment-water interface. The progression from *Thalassinoïdes* to *Spongeliomorpha* and *Arenicolites* illustrates a dynamic interaction between sedimentation rates and consolidation. The pervasive *Thalassinoïdes* networks in the Aptian section indicate periods of environmental stability where the substrate was cohesive yet soft enough to support extensive 3D burrowing by thalassinidean shrimp (Frey and Pemberton, 1984). This bioturbation window suggests well-oxygenated bottom waters and a thriving endobenthic community capable of homogenizing the sediment. However, the stratigraphic juxtaposition of *Spongeliomorpha* offers a critical contrast. The specific preservation of bioglyphs necessitates a firmground substrate (Gibert and Robles, 2005), which is a sediment that has been dewatered and compacted. Consequently, the identification of *Spongeliomorpha* allows for the reconstruction of erosional phases where the soft upper sediment layers were stripped away, exposing the stiff subsurface clays (Howard, 1978). This identifies hidden time gaps in the sedimentary record that traditional lithostratigraphy might miss. Conversely, the presence of *Arenicolites* in sandy dolomitic intervals signals pulses of high hydraulic energy (storms or tidal currents), serving as a proxy for the shifting wave base relative to the platform position (Häntzschel, 1975; Jensen, 1997).

Taphonomy and sediment preservation as paleoenvironmental archives

A critical aspect of reconstructing these ancient ecosystems lies in the specific preservation modes of the fossil assemblage. The physical and chemical state of the fossils and the enclosing sediment act as a primary sensor for ancient environmental chemistry and physics.

Condensation levels as indicators of starvation

The "condensation levels" observed in the middle of the Aptian section, rich in *Nolaniceras* and *Hypacanthoplites*, reveal specific sedimentation dynamics (Rey et al., 1988). These layers represent intervals of minimal net deposition (stratigraphic starvation) associated with maximum flooding surfaces. The soil here did not accumulate; instead, shells from successive generations piled up on a stable surface. This preservation style is diagnostic of a basin where sediment supply was cut off, likely due to coastline transgression trapping clastics near the shore.

Therefore, the sediment preservation itself tells us that the water column had become stratified and the bottom waters dysoxic. This aligns with global anoxic events often associated with the Aptian-Albian boundary. The preservation of the trace fossils and body fossils thus serves as an integrated environmental monitoring system:

- mechanical properties – bioglyphs in *Spongeliomorpha* reveal sediment shear strength and erosion.
- biological properties – The shift from *Thalassinoïdes* (crustaceans) to *Arenicolites* (worms) reveals energy regimes.

In conclusion, the detailed analysis of substrate preservation allows for a precise reconstruction of the paleo-ecosystem's response to sea-level rise, transitioning from a subtidal to an intertidal environment, offering a methodology applicable to understanding both ancient and modern sedimentary responses to environmental stress.

CONCLUSIONS

The primary goal of this study which is reconstructing the paleoenvironmental dynamics of the Amizmiz Aptian-Albian section has been reached, by presenting new evidence identifying the *Spongeliomorpha* firmground surface as the precise marker of the Urgonian platform's drowning, a correlation previously undocumented in this specific sector. Unlike previous lithological descriptions, this research confirmed that the extinction of the rudist *Pseudotoucasia* coincides exactly with this substrate induration event.

The identification and in situ documentation of key ichnotaxa *Thalassinoïdes*, *Spongeliomorpha*, and *Arenicolites* alongside a succession of rudist (*Pseudotoucasia*) and ammonite faunas, represent a novel contribution to the mid-Cretaceous record of Morocco alongside those mentioned in the Maastrichtian phosphate series of the Western High Atlas (Jdaba et al., 2025). The detailed analysis of their distribution within a rigorous stratigraphic framework provides new insights into paleoecological conditions, specifically revealing fluctuations in substrate consistency, oxygenation levels, and hydraulic energy regimes. Notably, the stratigraphic juxtaposition of *Thalassinoïdes* (softground) and *Spongeliomorpha* (firmground) highlights critical intervals of substrate stabilization and erosional discontinuity, supporting a refined interpretation of the omission surfaces that characterize the drowning of the platform (Howard, 1978). The study also identifies clear vertical variations in sediment preservation, marking a key advancement in understanding the sequence stratigraphy of the area. This variation reflects the influence of rapid eustatic sea-level rise, shifting from the rudist-dominated highstand to the starved, ammonite-rich condensation levels of the Aptian transgression, and finally to the environments of the Albian epoch showing the *Arenicolites* trace fossils. The study filled the existing lack of ichnological data in Amizmiz by establishing a direct link between the preservation of bioglyphs and the regional sequence stratigraphy. The prospect of these findings allows for a more accurate detection of sedimentary hiatuses in the broader Atlasic Gulf using trace fossils as a primary diagnostic tool.

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