

Research Article

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Aptian–Albian deposits of the Ait Ourir basin (High Atlas, Morocco): New additional data on their paleoenvironment, sedimentology, and palaeogeography<https://doi.org/10.1515/geo-2020-0214>

received November 12, 2019; accepted November 10, 2020

Abstract: This sedimentological and palaeontological analysis of the Aptian–Albian sedimentary succession of the Ait Ourir basin in the High Atlas Mountains of Marrakesh in Morocco provides new data from a previously poorly understood basin. The palaeoenvironmental evolution is deduced based on a facies analysis allowing the restoring of depositional environments and their stratigraphic architecture. Within the Aptian–Albian succession, we distinguish two sedimentary sequences separated by a major discontinuity. The first sequence is composed of calcareous and dolomitic marls with the rudist *Pseudotoucasia catalaunica* of the Tadhart formation (upper Aptian in age) and of strongly dolomitized limestones with corals (*Eugyra* sp., *Thalamocaeniopsis* sp., and *Holocystis* sp.) of the Lemgo formation (uppermost Aptian in age). These two formations were formed in an internal carbonate platform (the intertidal zone to the subtidal zone). The second sequence, Albian in age, is composed of sandy limestones of the Oued Tidzi formation and is represented by sediments showing terrigenous influence, with deposits of silt, sandstone, dolomitic sandstone, and limestone.

Keywords: carbonate platform, ichnofacies, rudists, corals, Aptian, Albian, High Atlas, Morocco

1 Introduction

The Lower Cretaceous of the Western High Atlas (WHA) Mountains is subdivided into several formations, originally dated by micro- and macropalaeontological data [1]. This subdivision was later revised by a number of other authors to delve further into the geological history during the Early Cretaceous [2,3]. In this study of the Aptian–Albian sedimentary succession of the north side of the High Atlas Mountains of Marrakesh, we adopt the method used by [2] based on the eastern area close to our sector of study. Thus, three distinct formations are highlighted. The objectives of this work are to characterize (i) the lithostratigraphic formations; (ii) these sedimentary and biotic structures; and (iii) an interpretation of the sedimentary environments in the studied area during the Aptian–Albian succession.

2 Geographical, geological, and stratigraphic settings of the Ait Ourir basin

The Ait Ourir basin, which is the subject of this study, belongs to the WHA region of Morocco. More precisely, it is part of the Northern Sub-Atlas zone of the Marrakesh High Atlas [4]. It is demarcated to the north by the plain of Haouz, to the south by the zone of the high plateaus, and to the east by the Oued R'dat (Figure 1).

The Ait Ourir basin has a Mesozoic cover that was folded during the Atlasic orogeny. It is characterized by broad, flat-bottomed, and sub-horizontal synclines that are separated by upright and acute anticlines [2–7].

In this area, marine or marginal-marine Aptian–Albian deposits overcome continental clastics of the Middle Jurassic Age. The Aptian–Albian succession comprises, from top to base, a total of three formations, such as Tadhart, Lemgo, and Oued Tidzi [1–3] (Figure 2). These formations were brought into existence because of the cumulative changes effected by a multitude of ages.

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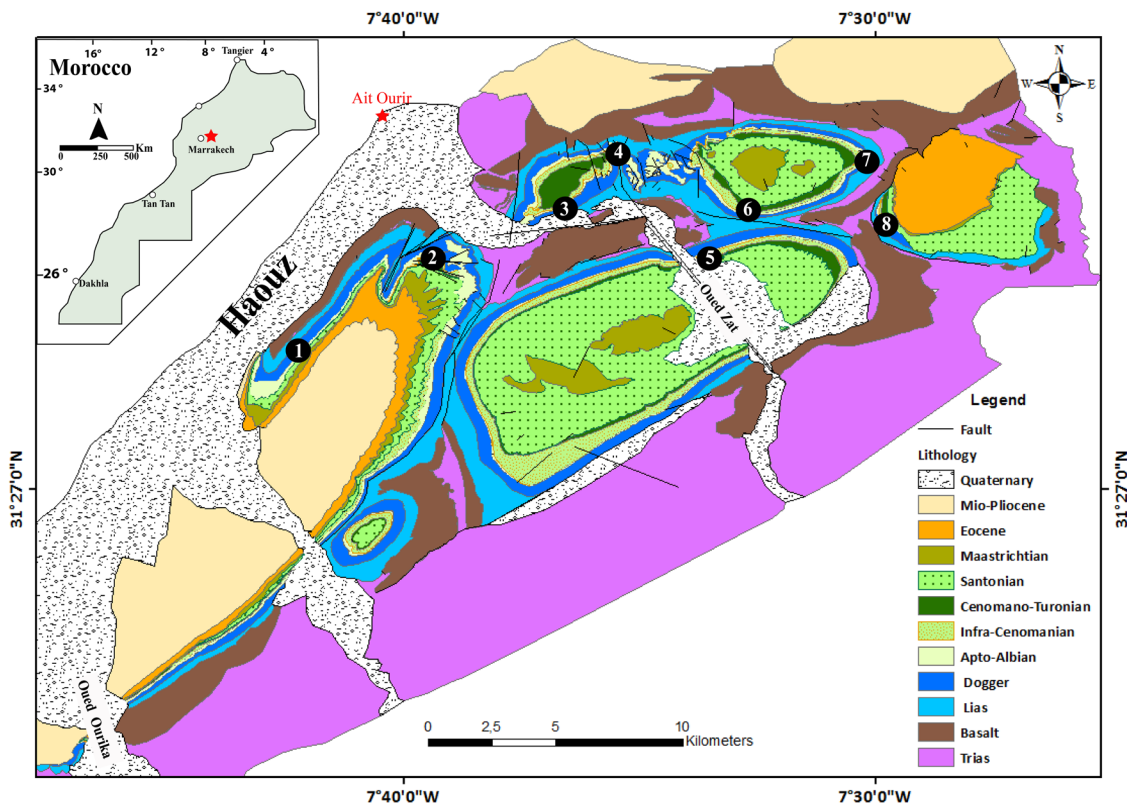


Figure 1: Geological map 1:10,000 of the Ait Ourir basin showing the locations of the sections studied. 1: Zaouiat Sidi Driss; 2: Wanina East; 3: Tasghimout N-1; 4: Tasghimout N-2; 5: Tighadouine; 6: Tafelt West; 7: Tafelt East; 8: Jbel Sour.

However, on the basis of the detailed regional study of stratigraphic ammonites' sections, the latest review by ref. [8] posits that the Tadhart formation is a time-equivalent of the Tamzergout formation's uppermost section and is restricted to the east and to the more proximal parts of the basin. The age of the formation in question corresponds to the *Elsaisabiella Tiskanitensis* Zone. This ammonite is associated, in the Mrammer section, with *Diadochoceras gr. nodosocostatum* of the late Aptian Age (pro Clansayesian). In the same vein, [2] also situates the Lemgo formation in the "Clansayesian" Age. They advance this view by virtue of the fact that ammonites were found near Imi N°Tanout and Amizmiz. For ref. [8], the Lemgo formation belongs to the *Elsaisabiella Tiskanitensis* Zone, but its uppermost part yields an early Albian marker: *Mellegueiceras chihaouiae*. This stance matches the stratigraphic framework drawn up by ref. [9,10] based on planktonic foraminifera.

3 Materials and methods

Several field missions were conducted to create a 1:10,000 map of the Ait Ourir basin. The observed lithological characteristics allow us to distinguish several types of facies. The

superficial altered horizon was removed to about 30 cm deep. After washing the marl, silt, and sandstone samples on 315, 400, and 500 μm sieves, they were studied at the Scanning Electron Microscope Laboratory of Cadi Ayyad University, Marrakesh, and the consolidated rock samples were transferred to the thin section laboratory at the Faculty of Sciences Semlalia of Marrakesh.

4 Lithologic description

4.1 Tadhart formation

The Tadhart formation, 7–26 m thick (Figure 3), overlies the Middle Jurassic detrital red deposits [11]. These deposits are separated by a discontinuity surface (D1) characterized by terrigenous ferruginous crusts, with evidence of emersion indicated by calcretes and root traces (Figure 4).

The formation is represented by an alternation of azoic marls and carbonated layers, often with a lenticular-shaped form and erosive bases with the presence of cross-bedding, indicating a predominant palaeocurrent from the south-east toward the north-west. Locally, hummocky cross-stratification (HCS) could be recognized.

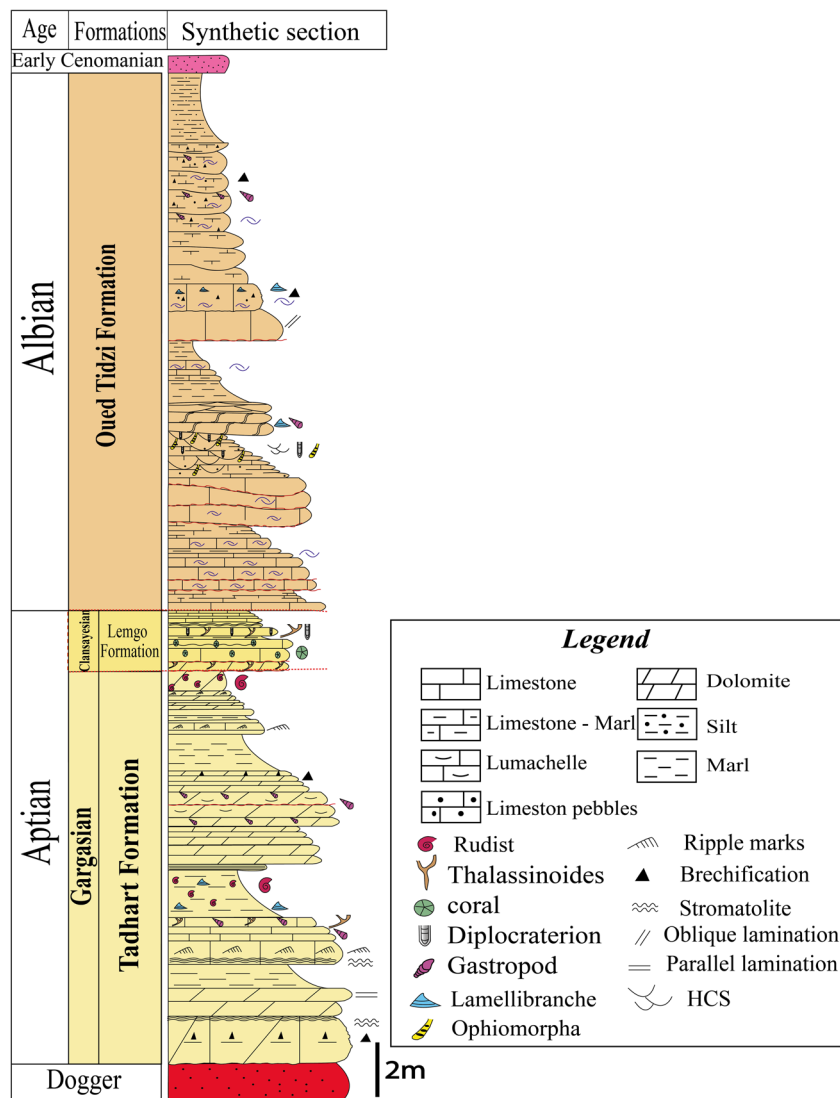


Figure 2: Lithostratigraphic log of the basin area of Ait Ourir (Tasghimout North Basin).

A network of T- or Y-shaped horizontal, cylindrical, and not aligned burrows commonly occur in these deposits. The traces in the sediments form branchy networks with connections open to the top of the beds. The axes of the branches can be vertical or tilted referred to the *Thalassinoides* ichnogenus (Figure 5a and b). This branchy ichnofossil is like “crossing form facies” [12]. *Thalassinoides* represent the activity of small shellfish decapods [13], detritus feeders, and/or suspension feeders [14]. These are generally stabilized in substrates at the beginning of consolidation [15] and provide evidence of a sea bottom with normal oxygenation and receiving significant nutritive matter flow [16].

Associated with these *Thalassinoides* are *Nerineid* and *Itieriid* gastropods in the middle part of the formation. In some places at the center of the Tadhart formation,

there are centimetric structures of subspherical form. In the cross section they show irregular and discontinuous concentric algal micritic sedimentary laminations. They have a thickness of up to 6 cm at mudcracks and surround a nucleus of silty mudstone of dolomicrite nature (Figure 6).

At the top of the formation are stromatolites with slightly undulating to parallel laminations, sometimes forming small domes. In addition to these stromatolites, there are brecciated dolomitic layers, in some cases laminated with the presence of asymmetric ripples (Figure 7).

The most relevant feature of this formation is the presence of two carbonate levels with rudists. The first is located at the middle part of the Tadhart formation, with completely altered specimens. The second level is located at the top of the formation, some of which are

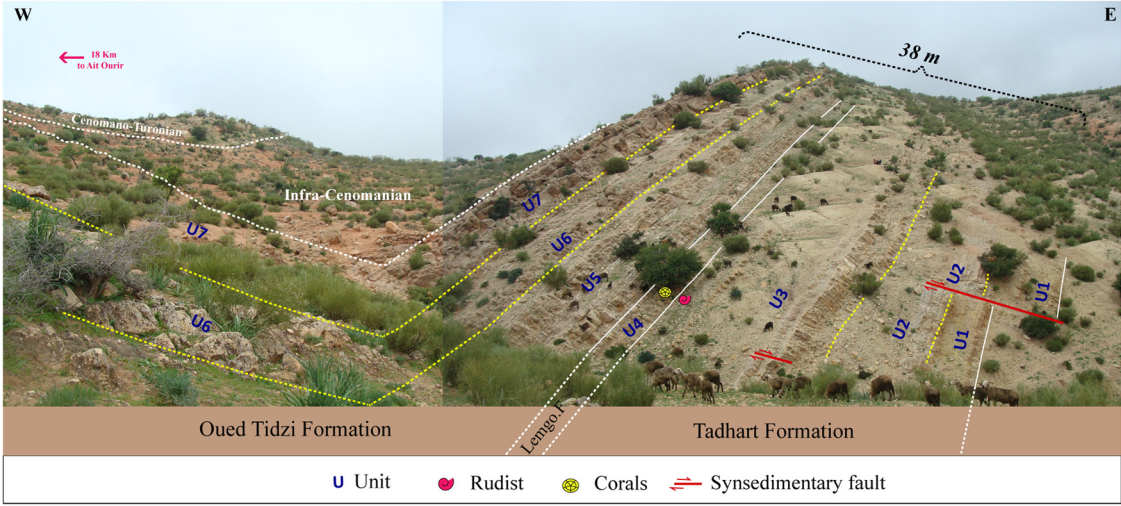


Figure 3: Panoramic view of Tasghimout North showing the Aptian–Albian succession.

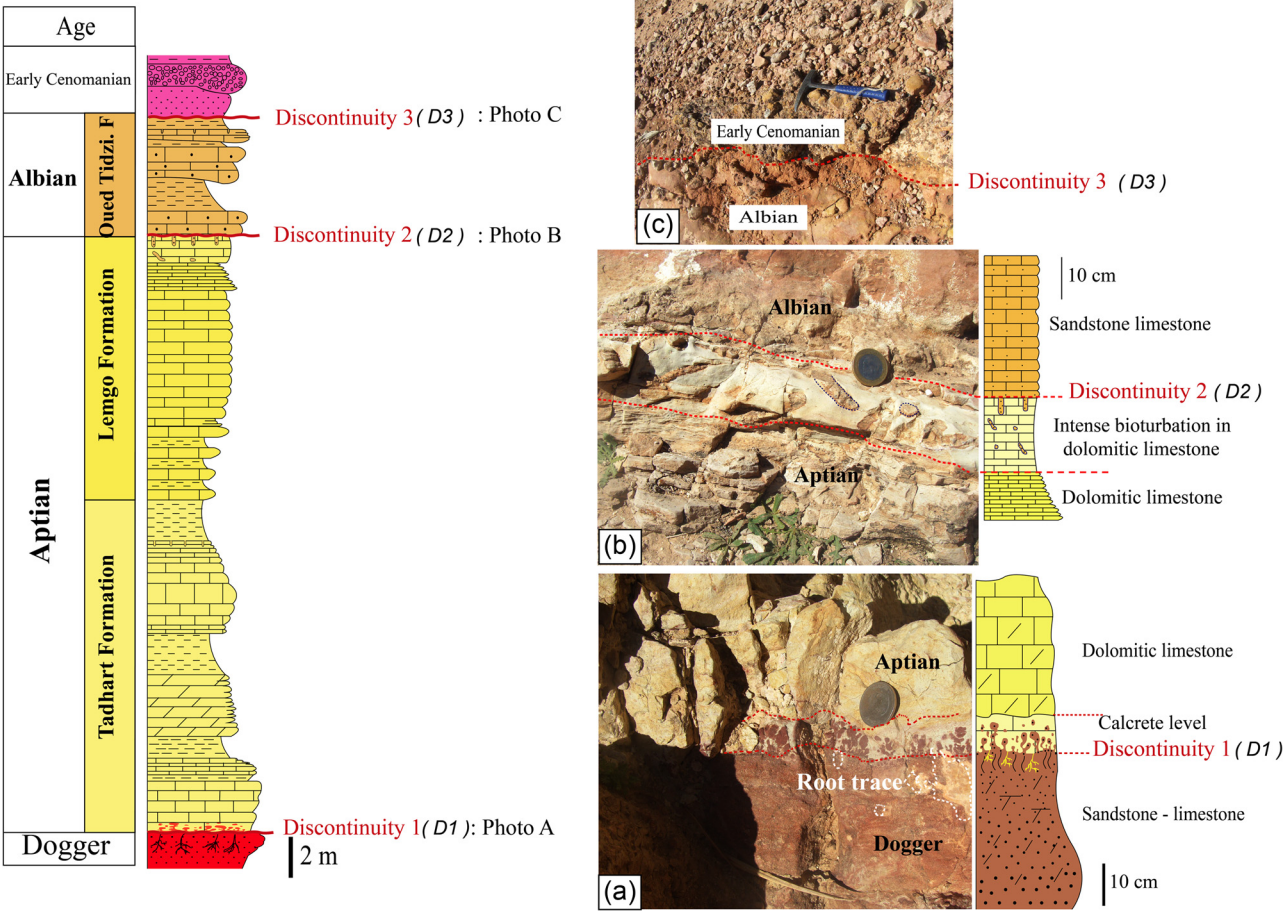


Figure 4: Wanina East section. (a) Discontinuity (D1) separating the Middle Jurassic detritic deposits from the carbonate of the Aptian–Albian succession, revealing ferruginization and pushed crusting. (b) Discontinuity (D2) separating the Lemgo formation and the Oued Tidzi formation, materialized by an intense perforation. (c) Discontinuity (D3) separating the Oued Tidzi formation (carbonate) and the late Cenomanian red fluvial conglomerates.

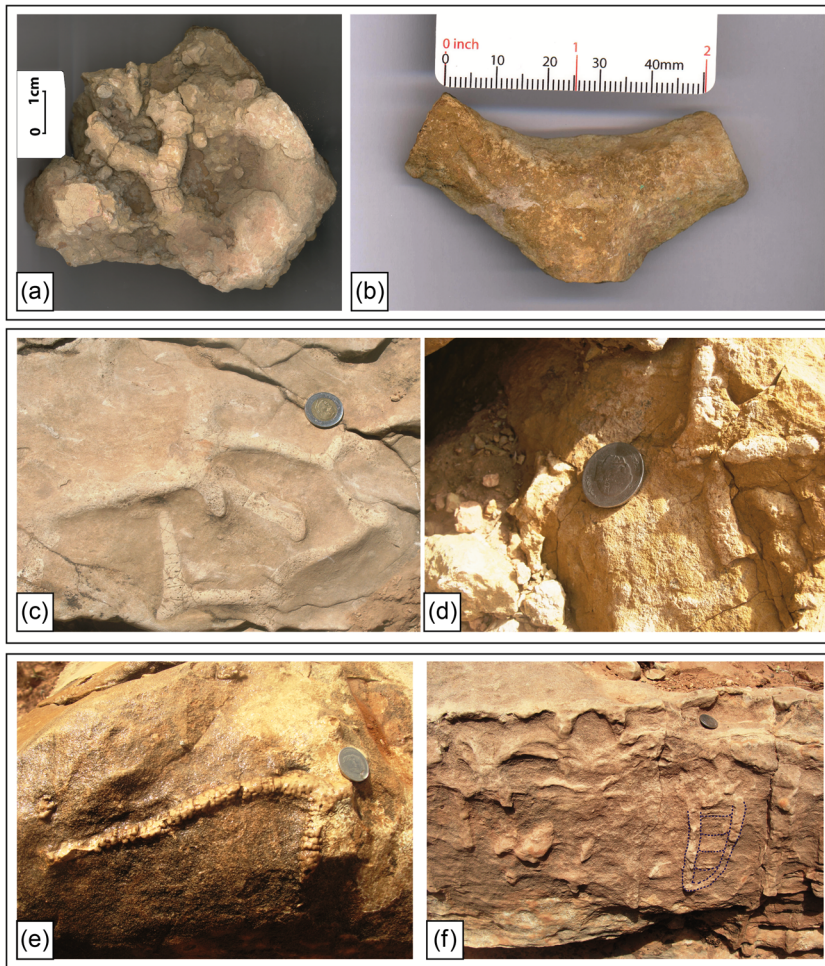


Figure 5: (a and b) *Thalassinoides*-type burrows observed at the Tadhart formation. (c and d) *Thalassinoid* burrows found in a level of the Lemgo formation. (e) *Ophiomorpha*-type and (f) *Diplocraterion*-type burrows in the Oued Tidzi formation.

well preserved. This is the first time that this species *Pseudotoucasia catalaunica* has been described in Morocco in the Ait Ourir basin (Figure 8).

4.2 Lemgo formation

A relatively reduced Lemgo formation compared to other cuts overlies the Tadhart formation through an erosional surface. This is characterized by the presence of strongly dolomitized limestones with corals. Small colonies of *hydorphoroid Eugyra* sp. (the dominant coral), *cerioid Thalamocaeniopsis* sp., *plocoid Holocystis* sp., and undermined branching corals form small patch reefs up to 1.20 m thick (Figure 9). Owing to considerable dolomitization, other biotic components, with the exception of rare bryozoans, were not recognized.

Associated with these reef deposits, we found U-shaped tubes of *Diplocraterion*-type burrows, whereas *Thalassinoides*-

type bioturbations are less abundant compared to the previous formation (Figure 5c and d). Thin-bedded limestone occurs at the top of the formation. This formation ends with a discontinuity marked by firm ground, which has been interpreted as related to a brief pause in sedimentation and an intense perforation (Figure 4).

4.3 Oued Tidzi formation

The Oued Tidzi formation consists of fossiliferous dolomitized limestone levels, often of lenticular shape with a cross-stratified lumachelle (Figure 10(1 and 2)) showing a huge accumulation of lamellibranchs. These carbonate levels also manifest structures of HCS, megaripples, and ripples, indicating an east–west current, sometimes with a migration direction toward the north–north–west (Figures 10[3] and 11).

This formation often contains *Ophiomorpha*-type burrows. Locally, the *Diplocraterion*-type (Figure 5e and f)

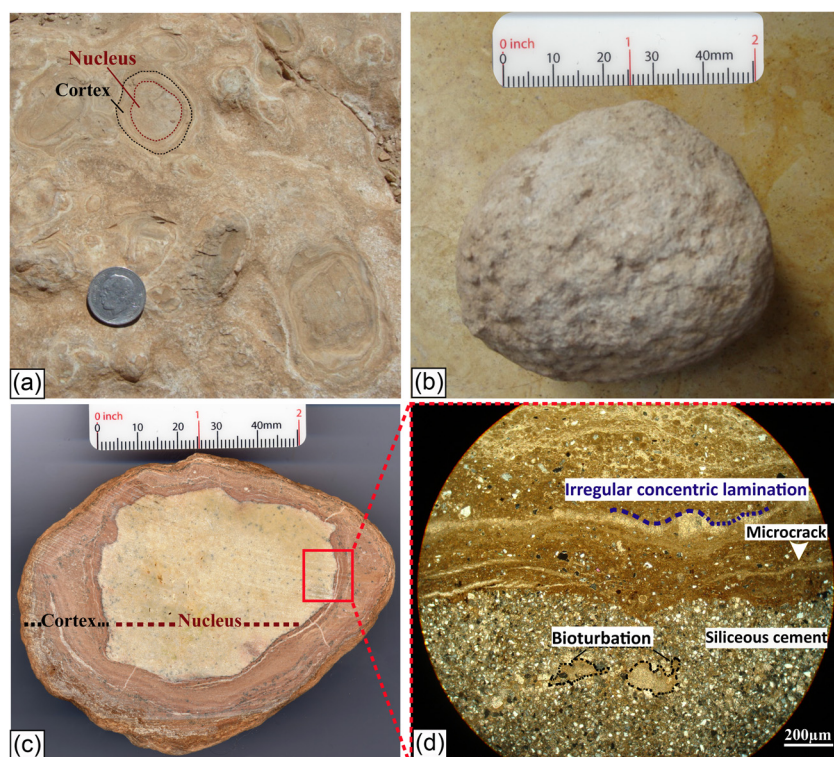


Figure 6: (a and b) Oncooids from the middle part of the Tadhart formation (U2), Wanina East section. (c and d) Centimetric structures of subspherical shape, with concentric, irregular, and discontinuous algal micritic laminations. Thickness can achieve 6 cm with mudcracks surrounding a nucleus of silty dolomicrite mudstone.

or *Arenicolites*-type burrows form a dense network of circular or U-shaped structures. Locally, at the top of the formation, there are mudcracks, oxidation surfaces, and escape structures. The most marked structures at the top of the Oued Tidzi formation are irregular dissymmetric pockets filled by the overlying coarse sediment. This indicates a progressive karstification going to the uppermost Albian (Figure 12).

The Oued Tidzi formation ends with increased siliclastic input in the form of clays and red sandstones (south-east to north-west), being overlain by conglomerates of Late Cenomanian age (D3) [17,18] (Figure 4).

5 Interpretation

5.1 Tadhart formation

Fossil traces can provide good indications of the sedimentary setting and specifically the environmental conditions of the environment in which they were formed.

Thalassinoides characterizes tropical environments of very low depth (only a few meters) until emergence [19,20]. Moreover, ref. [21] has shown that the maximum development of *Thalassinoides* occurs in littoral environments. Carbonate levels with *Thalassinoides* burrows indicate an environment of littoral accumulation. The installation of this last sedimentary environment can be related to a shallowing-upward trend and final emergence. The organisms responsible support variable conditions of oxygenation but never live in environments that are low in oxygen [22,23].

Stromatolites with slightly undulatory to parallel lamination indicate an upper to supratidal intertidal environment [24], with phases of emergence in a hot and arid climate and a slightly low level of hydrodynamism. The stromatolitic structures present in the top-most carbonate levels recall those of the laterally linked hemispheroids (LLH) type classified by ref. [25] and more precisely the structures of the *Collenia* type. These are small, closely linked centimetric domes. According to ref. [25,26], the algal mats are located in the superior part of the mediolittoral zone and the supralittoral zone. On modern carbonate platforms, algal mats are located

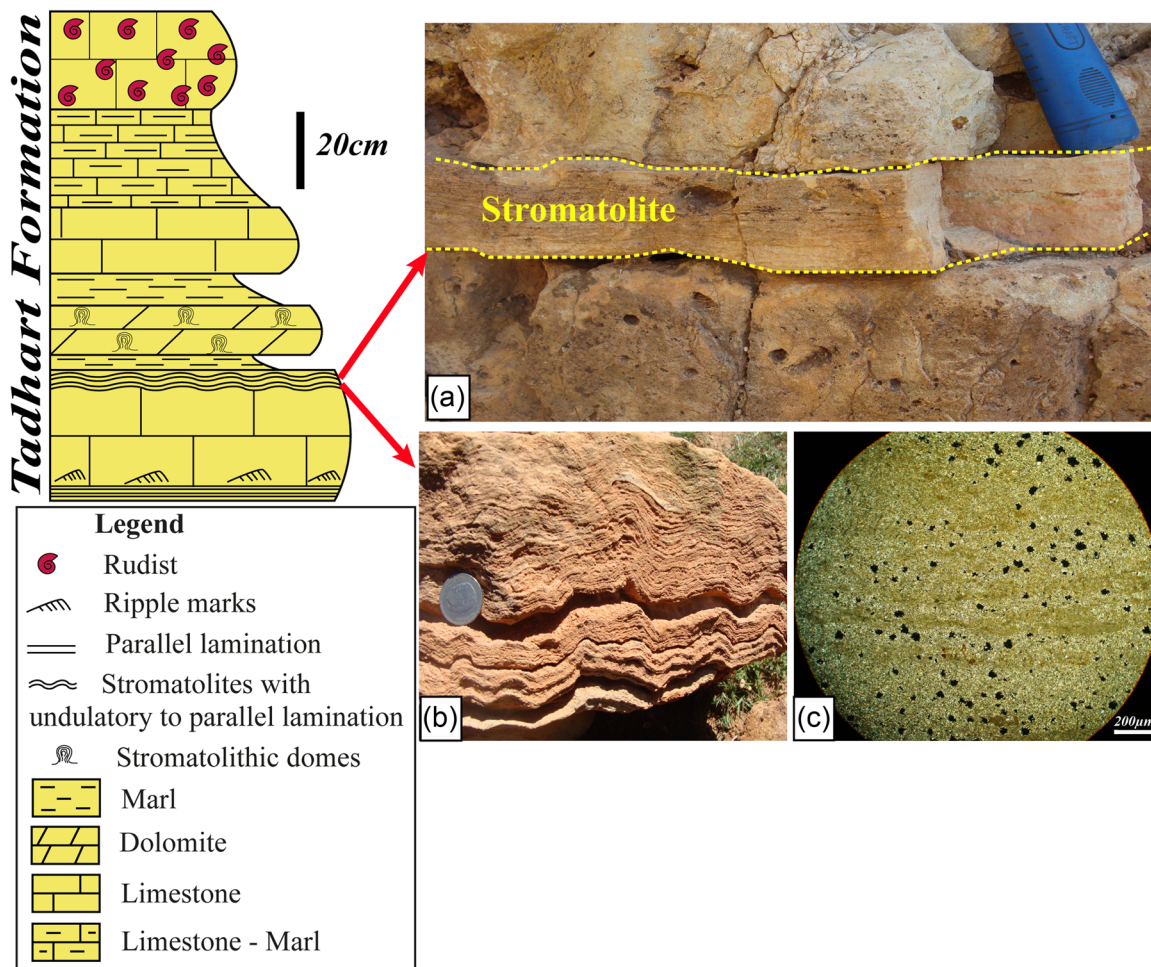


Figure 7: Stromatolites with wavy laminations from the Tadhart formation, Tasghimout N-2 section. (a and b) Stromatolites with undulatory to parallel laminations; (c) microfacies of stromatolites showing alternating somber micritic zones and silty microsparitic clear zones.

primarily in the mediolittoral zone [27,28]; this is the case in the Persian Gulf or when the development of the algae does not exceed the higher mediolittoral [24–29]. In our case, the association of these stromatolites with fenestral structures and mudstone matrices (with vacuoles of dissolution) suggests a marine environment that is calm in a higher mediolittoral zone.

The nerineid gastropods present in the Tadhart formation generally characterize the area wedged between the reef and the lagoon [30]. They suggest a subtidal environment with a lower intertidal zone. However, their abundance and good preservation suggest an environment with weak hydrodynamic energy [31].

The oncoliths found characterize a calm mediolittoral environment. The cores of the oncoids are large but poorly abraded, indicating a rapid encrusting of the clast by microbial mats after the destruction of the

substrate. The settlements with rudists in particular indicate a depth of life that does not seem to exceed the lower limit of the infralittoral zone. These biological data are the main characteristics of a presumed internal platform [32].

5.2 Lemgo formation

The bioturbation of the *Diplocraterion* type underlines the succession of the periods of deposit and erosion [33] in an infralittoral [34] and under conditions of moderate energy [35,36].

The low diversity of the corals and the small size of the patch reefs suggest that these have developed in an inner platform environment [37].

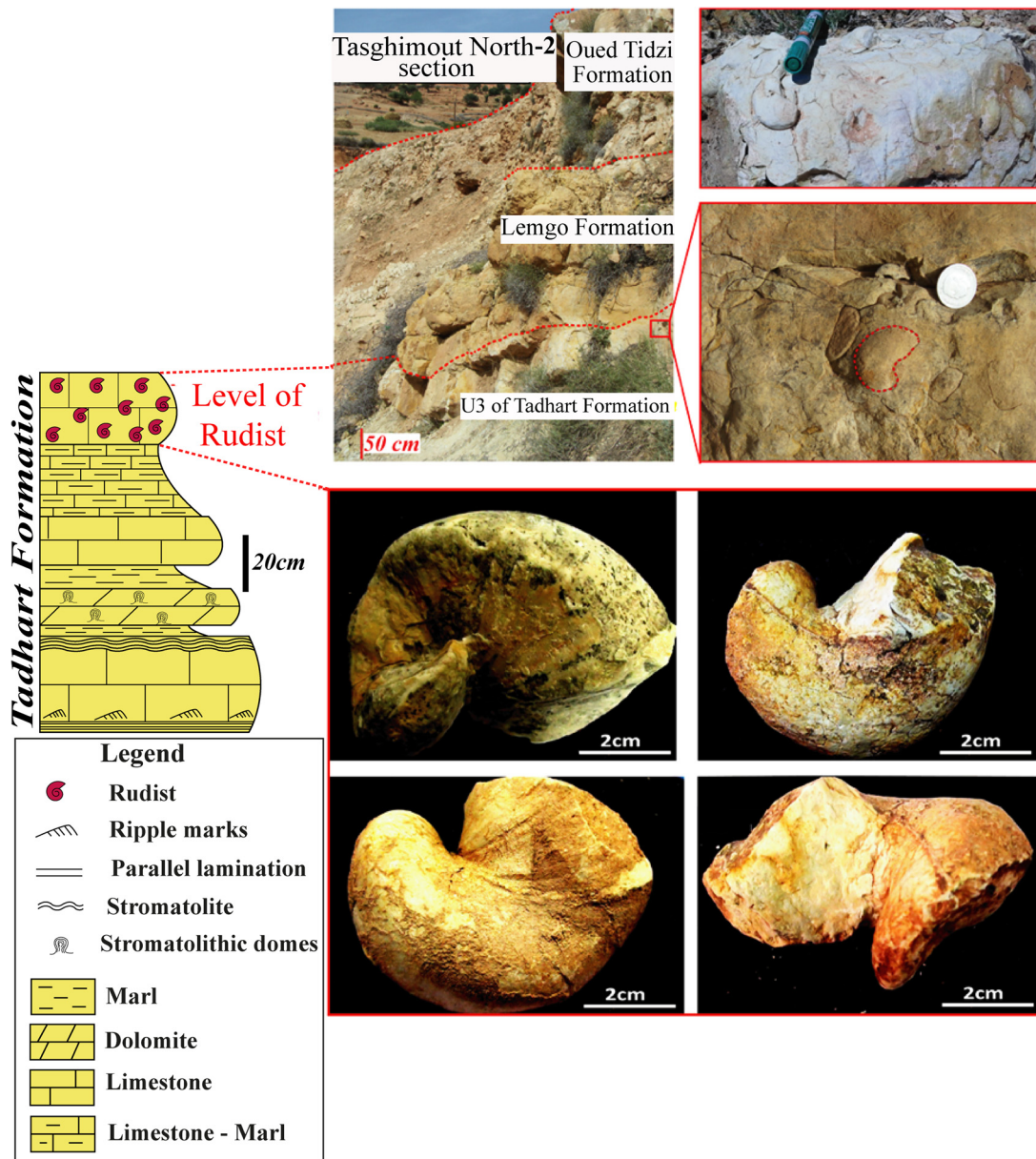


Figure 8: Rudist *Pseudotoucasia catalaunica* from the top of the Tadhart formation, Tasghimout N-2 section.

5.3 Oued Tidzi formation

The presence of the HCS indicates sedimentary structures that are most characteristic of the deposits of storms transferring sediments from the shoreface to offshore under the traction of combined flows [38–41].

The coquina levels are generally gravel-bearing, indicating an important siliciclastic influence and high energy.

The ichnogenus *Ophiomorpha* [42] characterizes the carbonate deposits of this formation. It is rather common in many high-energy marine palaeoenvironments [43,44].

The ichnogenous *Arenicolites* indicates shallow and marginal marine environments with moderate or high hydrodynamic energy [45–47].

The top of this formation outlines emersion or the occurrence of mudcracks, karstic dissolution, and subaerial detrital deposits.

The exoscopic study allows us to determine several interpretations according to the characteristics of the quartz grains, based on the work of ref. [48,49]. The grains of quartz are sub-rounded and show a fluvial heritage, with less significant marine action, and the

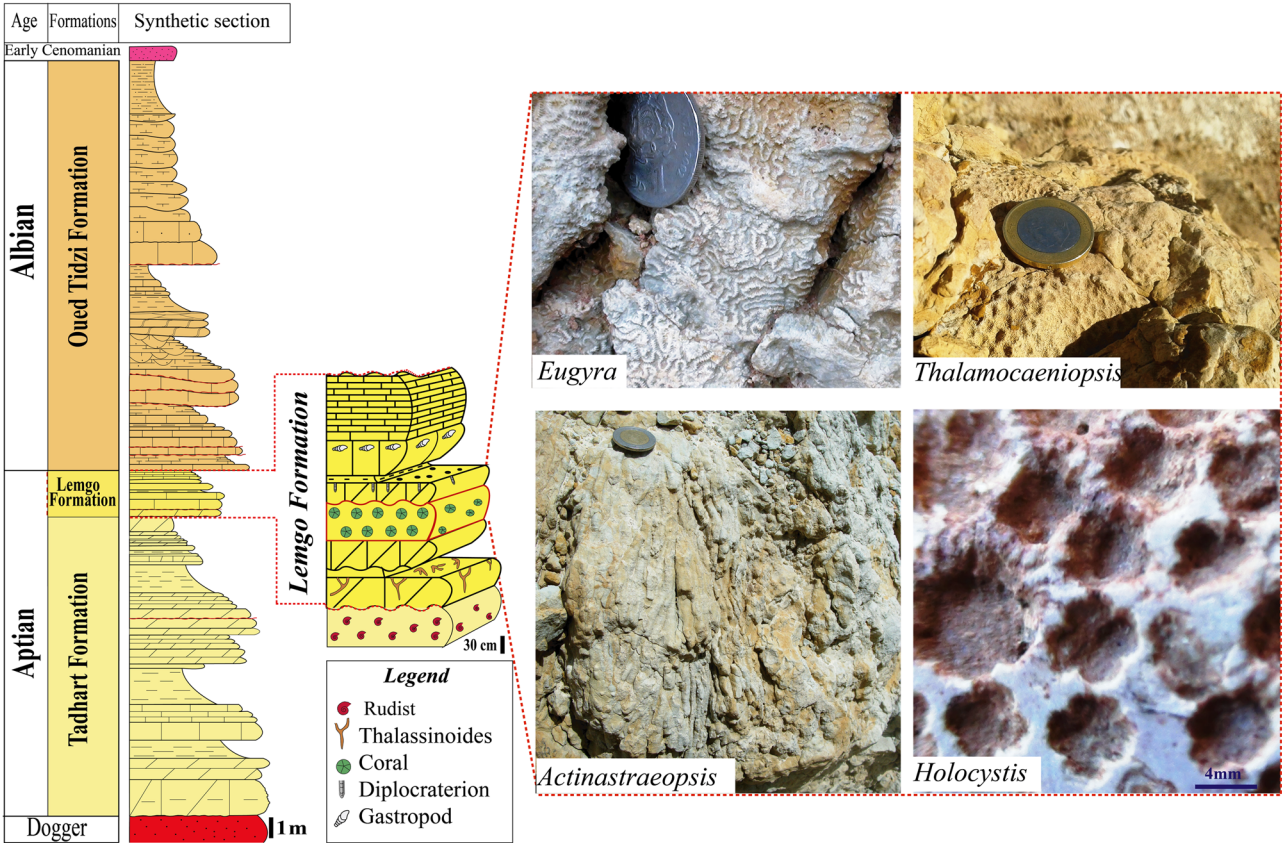


Figure 9: Different species of corals from the Lemgo formation; Tasghimout N-2 section.

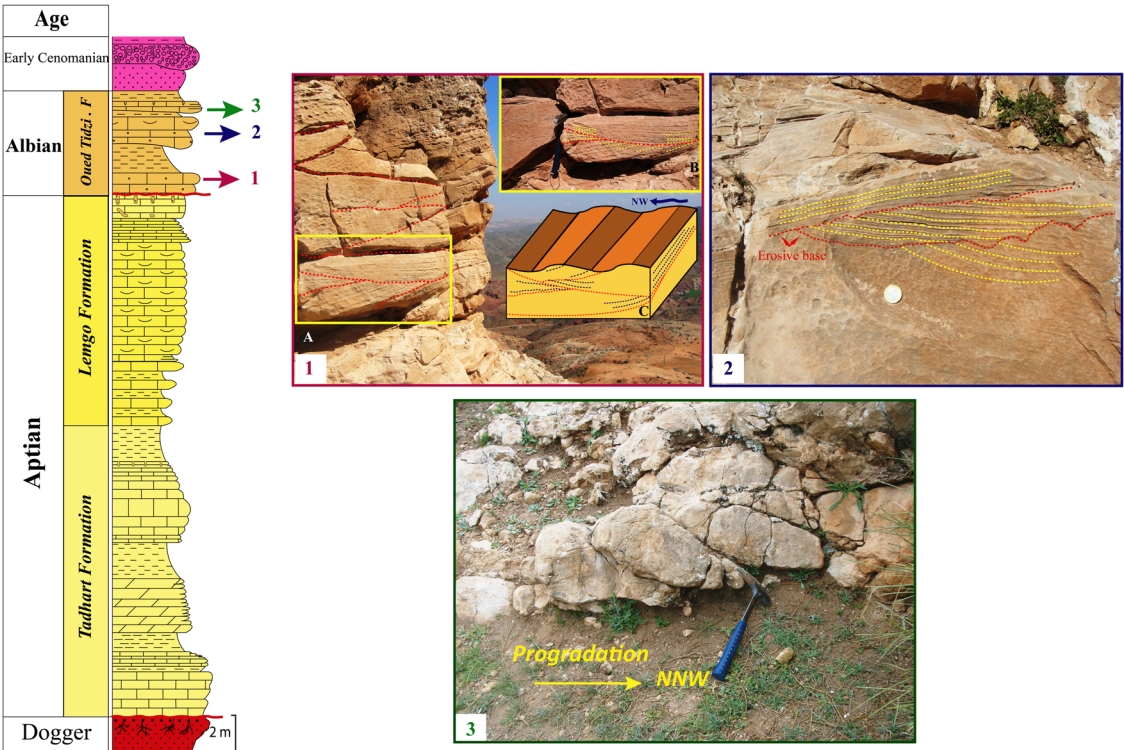


Figure 10: Deposit of the Oued Tidzi formation in the Wanina East section; (1 and 2) Coquina deposits with lenticular-shaped tidal channels showing through cross-stratifications and ripple marks; (3) carbonated lumachellic lenticular deposit showing a progradation from south-south-east to north-north-west.

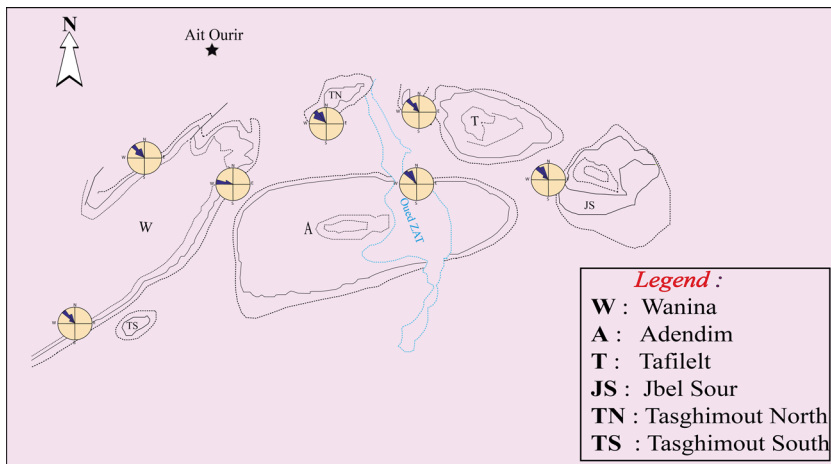


Figure 11: Carte with rose diagrams show the direction of paleocurrent flow at the top of the Oued Tidzi formation.

presence of silica flowers reflects a long period of exposure to the air in a confined supra-medium. In this regard, the large breaks are very old and indicate a heritage resulting from the transport of fluvatile. The v-shaped percussion cracks without polishing are typically aeolian [48]. Indeed, the quartz grain has an abraded surface with irregular pits and cavities, indicating a closed environment with a significant aeolian action. The cracks at the grain's surfaces have been exploited by intense and deep dissolution. These observations indicate an

emersion event, well-marked at the end of the Albian, related to a continental detrital influence (Figure 13).

6 Facies correlation and paleogeography

To deduce the palaeogeography, we have characterized the different sedimentary facies, their interpretation in

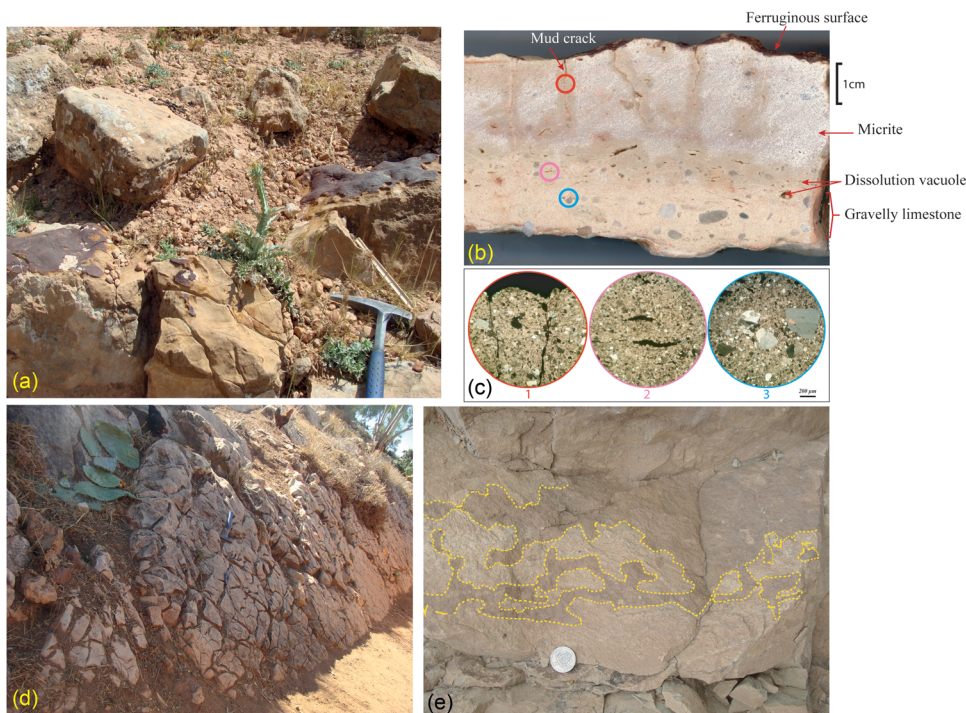


Figure 12: The top of the Oued Tidzi formation showing several structures indicating an emersion event: (a) ferruginous surface; (b and c) limestone showing detrital gravel at the base and at the top a micrite with vacuoles of dissolution; (d) mudcracks; (e) karstification.

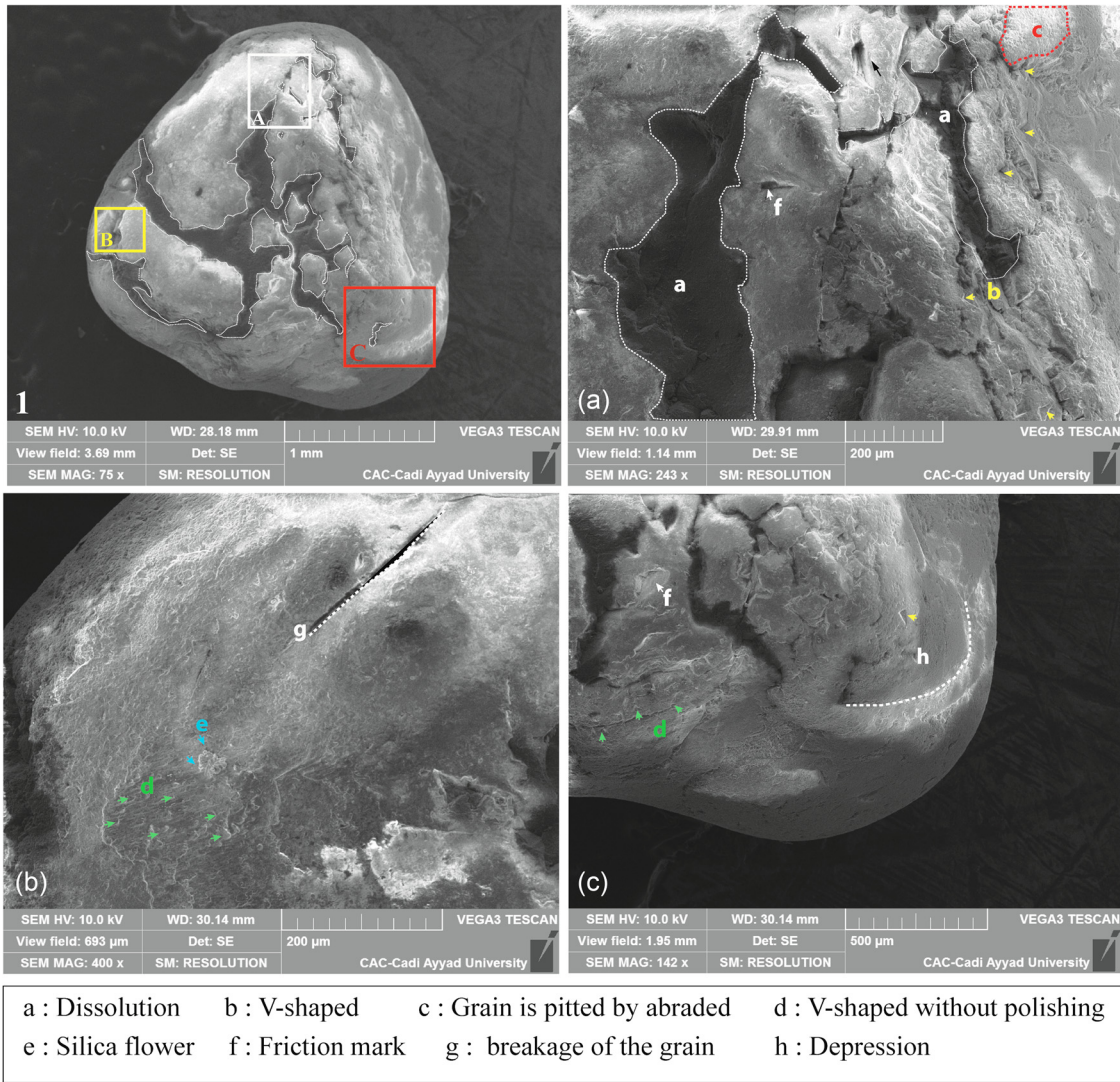


Figure 13: Exoscopy of a quartz grain; Oued Tidzi formation, Zaouiat Sidi Driss section. (a) General view of the quartz grain. (b and c) Views showing the grain surface detail.

terms of depositional environments, and their integration into a facies model. From the detailed analysis of eight main sections covering the Aptian–Albian interval in the Ait Ourir basin area, we have grouped five (05) facies associations from A to E. Table 1 presents the synthesis of the sedimentary systems and the facies associations defined by ref. [50,51].

The vertical distribution of facies associations reveals a transgressive tendency for the first two Aptian formations (Tadhart formation and Lemgo formation). Association C is found at the base. It is surmounted by association B, which ends with association A. This succession characterizes a shallow marine environment from the intertidal to the subtidal zone. The Oued Tidzi formation exhibits association

D at the base surmounted by association E. This reflects a regressive trend in a coastal environment subject to continental influences.

The lithostratigraphic correlation (Figure 14) of the different sections at the level of the Aptian–Albian series coupled with the evolution of the facies associations revealed the following:

The western part of the Tadhart formation study area shows the presence of association B, characterizing an internal platform in a littoral zone of a relatively closed tidal type. The eastern part is characterized by association C, depositing in an upper intertidal to supratidal zone in a hot and arid climate with a slightly weak level of hydrodynamism (Figure 15).

Table 1: Environment of the facies association

F	Facies	Facies environment	Environment of the facies association
F1	Coral limestone	Shallow marine environment, relatively open to the basin. Intertidal to subtidal zone	Patch reef developed on the edge of an internal carbonated platform as a shallow ramp connecting with the open sea A
F2	Madreporaria limestone	Inter-subtidal zone	
F3	Bryozoan limestone	Shallow marine, inter-subtidal zone	
F4	Limestone with <i>Thalassinoidea</i>	Tidal zone	
F5	Gastropod limestone (<i>Nerineidae</i>)	Inner reef to lagoonal depositional environment (from subtidal to intertidal) with low hydrodynamic energy	Inner platform in a littoral zone. Relatively confined B
F6	Limestone with <i>diplocraterion</i>	Infra-littoral environment, moderate to relatively high energy	
F7	Rudist limestone	Intertidal to lower intertidal	
F8	Oomicrite	Intertidal zone, calm depositional environment	
F9	Stromatolitic limestone	Upper intertidal to supratidal environment in a hot and arid climate with a slightly low amount of hydrodynamism. The association with fenestrae and mudstone textures with dissolution vacuoles suggests a calm marine environment in a vadose zone	Inner-platform with supratidal zone with low hydrodynamic energy C
F10	Azoic marl	Supratidal	
F11	Limestone with HCS	Storm deposits, from shoreline to upper offshore zone	
F12	Limestone with <i>Ophiomorpha</i>	Marginal marine palaeoenvironment with high energy	
F13	Limestone with <i>Arenicolites</i>	Shallow marine environment and marginal with moderate to high hydrodynamic energy	Shallow inner platform with tidal channels with hydrodynamic energy D
F14	Lumachellic limestone with pebbles	Intertidal environment with high energy	
F15	Lenticular coarse-grained limestone with erosive surface	Channels in intertidal environment	
F16	Limestone with mudcracks	Supratidal	
F17	Karstified dolomitic limestone	Inter-supratidal zone affected by emersion and characterized by intense dissolution	Upper intertidal to supratidal zone affected by repeated emersion with a continental/clastic influence E
F18	Azoic red silt	Zone with continental influence	

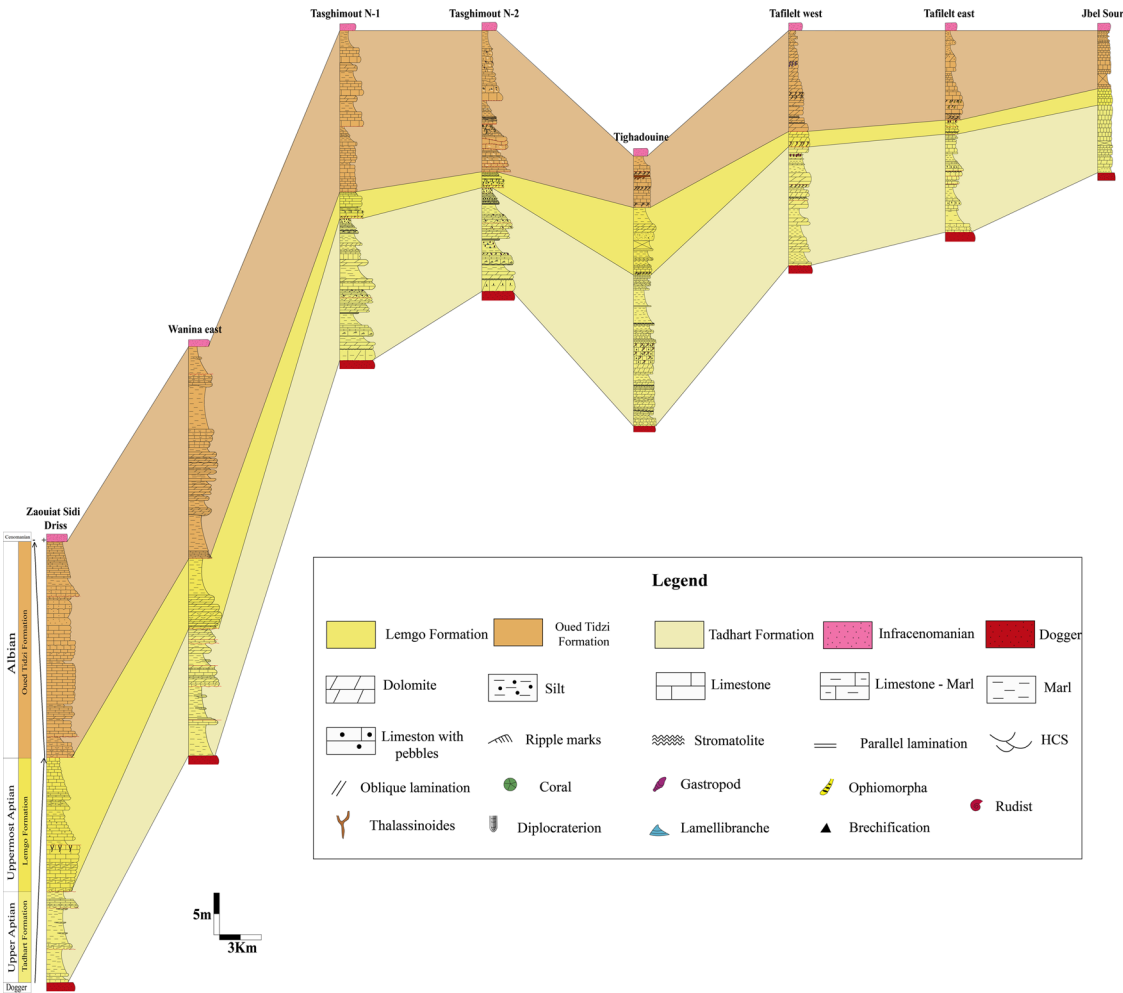


Figure 14: Lithostratigraphic correlation of sections of the Ait Ourir basin.

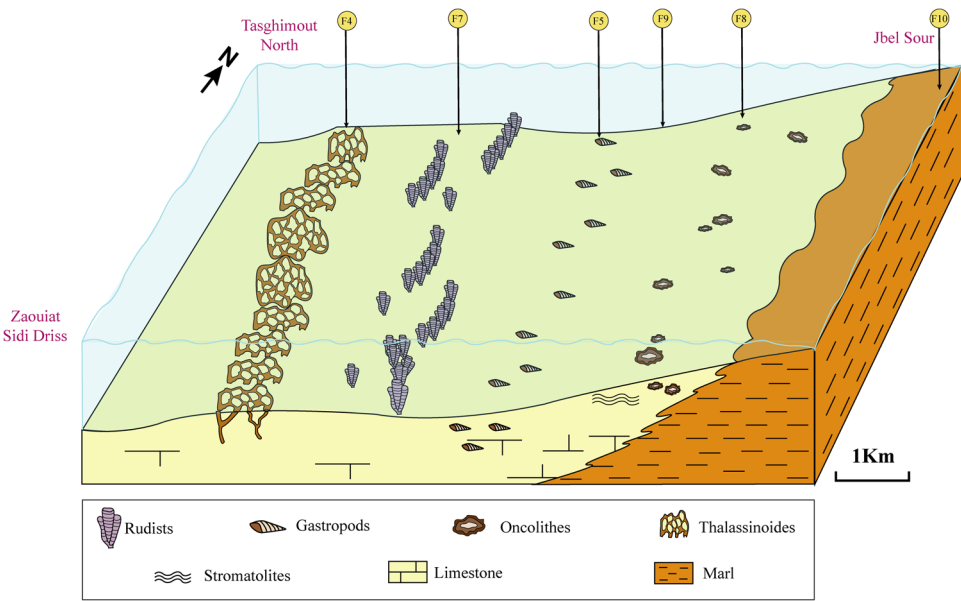


Figure 15: The palaeogeographic history of the Tadhart formation.

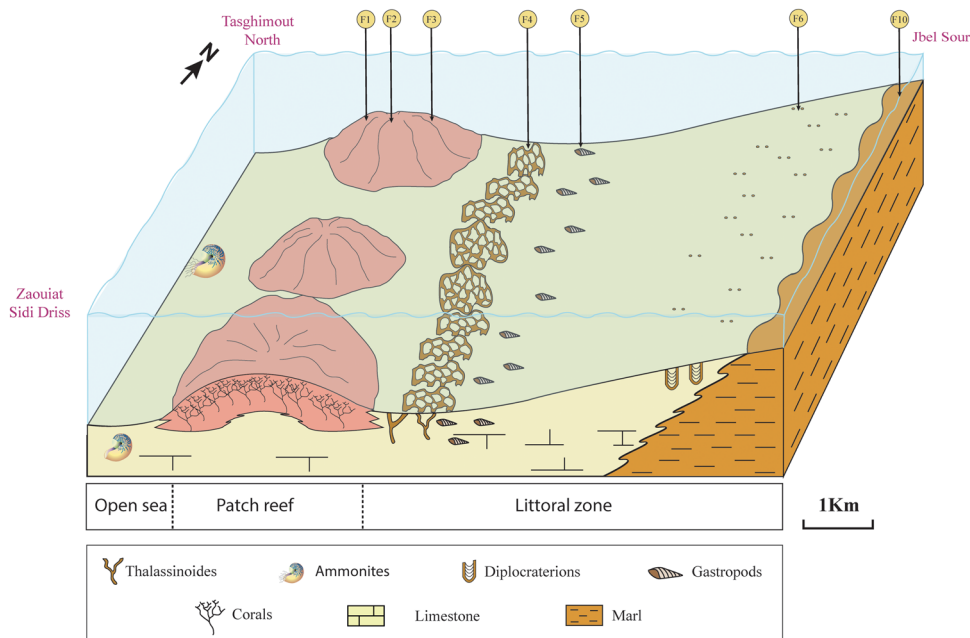


Figure 16: The palaeogeographic history of the Lemgo formation.

The Lemgo formation manifests the presence of association A in the western side, revealing a patch reef environment. It has been developed on the edge of an internal carbonated platform as a shallow ramp connecting with the open sea. The eastern part shows association B, characterizing an internal platform in a relatively closed littoral zone (Figure 16).

The Tidzi formation presents association D in the western part, showing a shallow internal platform with tidal channels under strong hydrodynamic energy. The eastern part reflects the installation of association E, deposited in an upper intertidal to supratidal zone affected by repeated emersions with a detrital continental influence (Figure 17).

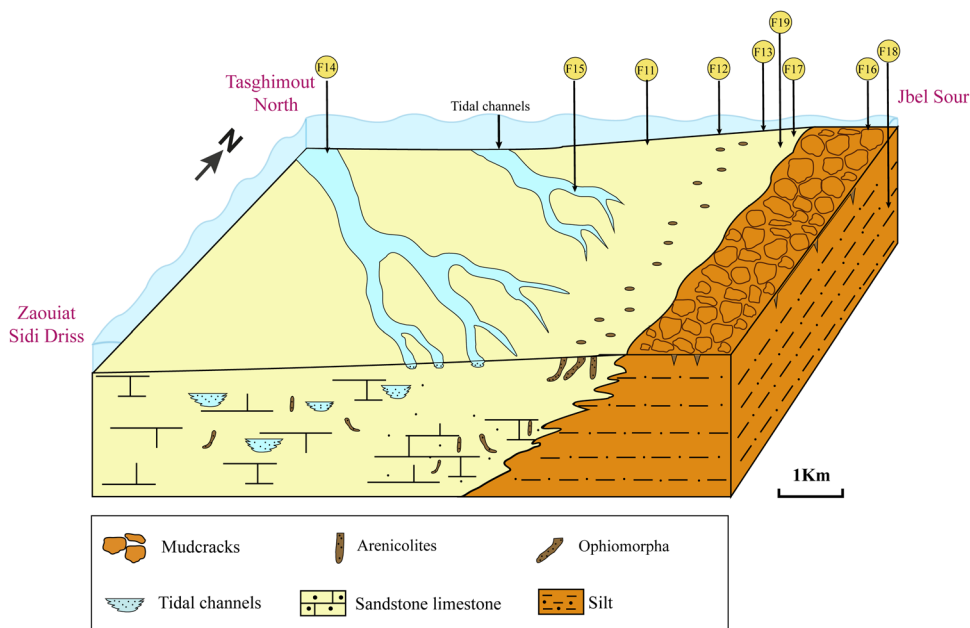


Figure 17: The palaeogeographic history of the Oued Tidzi formation.

Table 2: The credit based on the impact factor, which is 0.89 (2019–2020) for open geoscience

Author	SDC	EC	FLAE	PCI	Contribution (%) for PCI	Traditional credit
FH	0.89	0.22	0.89	0.53	60	0.89
AA	0.44	0.22	0.22	0.22	25	0.89
ABA	0.30	0.22	0.22	0.09	10	0.89
ZM	0.22	0.22	0.44	0.04	5	0.89
Sum	1.86	0.88	1.77	0.88	100	3.56

SDC: sequence-determines-credit; EC: equal contribution; FLAE; first-last-author-emphasis; PCI; percent-contribution-indicated.

7 Conclusion

This study of the Aptian–Albian deposits of the High Atlas Mountains of Marrakesh in the zone of the Ait Ourir basin has allowed us to obtain new sedimentological, biostratigraphic, and paleogeographic data. The Tadhart formation, Lemgo formation, and Oued Tidzi formation have been described and interpreted here in terms of their sedimentary environments. Palaeontological study of Aptian–Albian has been mainly oriented toward the determination of corals, while also taking into consideration data on rudists recently studied by ref. [52]. Thus, we have been able to identify numerous species that are cited for the first time in this field of study. The rudist *P. catalaunica*, recently identified in the Tadhart formation, indicates its late Aptian age.

The authors applied the SDC approach for the sequence of authors (Table 2).

Acknowledgments: The authors express their gratitude to Professors Hannes Löser and Jean-Pierre Masse for their determination of corals and rudists, respectively. The authors thank Professor Boguslaw Kołodziej for providing constructive remarks. The authors also thank the editor and the anonymous reviewer for their review and suggestions.

Author contributions: FH carried out the sedimentological and stratigraphic study from the fieldwork and prepared the manuscript. AA realized the exoscopic of the quartz grain in the scanning electron microscope and collaborated to conduct the stratigraphic division. ABA developed a 1:10,000 geological map of the study area. ZM participated in the microscopic study of the thin sections.

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