



**Lower and lower Middle Jurassic foraminiferal assemblages
and calcareous algae from the southern margin
of the Central High Atlas, Morocco**

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Abstract: The Lower and lower Middle Jurassic carbonates from the southern margin of the Moroccan High Atlas yielded well-preserved foraminifers and calcareous algae. The identification of these microfossils, based on thin-section observations, allowed us to define seven successive micropaleontological assemblages with ages from the early Sinemurian to the early Bajocian. These micropaleontological assemblages, relatively well calibrated by ammonites and brachiopods, were compared with the larger foraminiferal biozonation of SEPTFONTAINE (1984) for the Moroccan Tethys domain. A new biozone with *Palaeodasycladus mediterraneus* is introduced to characterize the upper Pliensbachian (Algovianum Zone) to lower Toarcian interval.

Keywords:

- Lower Jurassic;
- large benthic foraminifers;
- algae;
- biostratigraphy;
- biozones;
- carbonate platform;
- High Atlas;
- Tethys domain;
- Morocco

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Résumé : *Les associations de foraminifères et d'algues calcaires du Jurassique inférieur et de la base du Jurassique moyen de la marge sud du Haut Atlas central, Maroc.*- Les carbonates du Jurassique inférieur et de la base du Jurassique Moyen de la marge méridionale du Haut Atlas marocain

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ont livré des algues calcaires et des foraminifères bien conservés. L'identification et l'inventaire de ces microfossiles, basés sur l'observation de lames minces, a permis de définir sept associations micropaléontologiques se succédant du Sinémurien inférieur au Bajocien inférieur. Ces associations micropaléontologiques, relativement bien calibrées par les ammonites et les brachiopodes, ont été comparées à la biozonation à base de foraminifères de SEPTFONTAINE (1984) pour le Domaine téthysien marocain. Nous proposons d'introduire une association à *Palaeodasycladus mediterraneus* pour caractériser l'intervalle Pliensbachien supérieur (Zone à Algovianum) - Toarcien inférieur.

Mots-clefs :

- Jurassique inférieur ;
- grands foraminifères benthiques ;
- algues calcaires ;
- biostratigraphie ;
- biozones ;
- plate-forme carbonatée ;
- Haut Atlas ;
- Domaine téthysien ;
- Maroc

1. Introduction

For recent depositional environments, foraminifers and calcareous algae are considered good paleontological and environmental bioindicators (HALLOCK & GLENN, 1986; KOOISTRA *et al.*, 2002). Fossil assemblages of larger benthic foraminifers (LBF) and calcareous algae are generally considered as indicators of paleoenvironments with a stratigraphical significance (SEPTFONTAINE, 1984, 1985, 2020; KABAL & TASLI, 2003; CLARK & BOUDAGHER-FADEL, 2004; VELIĆ, 2007; REOLID *et al.*, 2008; GALE, 2014; SEVILLANO *et al.*, 2020). In some cases, they can play a key role in age-calibrating and refining the biostratigraphic framework for correlation of sedimentary sequences.

The present work deals with biostratigraphic analyses based on the associations of Lower Jurassic calcareous algae and larger benthic foraminifers (LBF) from the southern margin of the Central High Atlas. Most of the previous biostratigraphical and paleontological studies (DUBAR, 1952; DRESNAY, 1977; DRESNAY *et al.*, 1978; SADKI, 1996; EL HARIRI, 1998; LACHKAR, 2000) have been devoted to the northern and the northeastern parts of the Central High Atlas, whereas our study area is located in the southern margin of the central High Atlas. If we exclude the biostratigraphic studies carried by SEPTFONTAINE (1984, revised 2020), ETTAKI *et al.* (2011) and those forming part of a PhD Thesis (ETTAKI, 2003), this region remains insufficiently studied from a micropaleontological point of view. The micropaleontological work developed by HOTTINGER (1967), SEPTFONTAINE (1984, 1985, 2020), and BASSOULLET (1997a, 1997b, in BASSOULLET *et al.*, 1999) have been supportive of the study herein.

An inventory of larger benthic foraminifers (LBF) and other microfossils was reported for the first time by ETTAKI (2003) in an unpublished PhD thesis. This inventory will be documented and detailed in this paper, providing insights into the proposed assemblages of Lower Jurassic foraminifers and calcareous algae. Furthermore, a biostratigraphic subdivision with high resolution is proposed, helping to trace the evolution of the micropaleontological assemblages from the southern margin of the Central High Atlas during the Lower Jurassic. This subdivision, based on LBF and calcareous algae, is compared to the reference biostratigraphic scheme developed by SEPTFONTAINE (1984, revised 2020). The stratigraphic position of some LBF biozones was precisely located from levels with ages constrained by ammonites and brachiopods collected from stratigraphical sections in the Todrha-Dades area.

2. Study area and methodology

This study was carried out in the Todrha-Dades area, located about 100 km NE of Ouarzazate city. This area, which is part of the southern edge of the Central High Atlas, is bordered by Wadi Dades to the west and Wadi Todrha to the east, and is limited to the south by the South Atlas Fault (P. & L. Russo, 1934) and to the north by the North Atlas Fault (ROCH, 1939) (Fig. 1). The structural fabric of the Todrha-Dades area is mainly a network of NE-SW and NNW-SSE faults, inherited from the Hercynian multi-stage orogeny.

For this work, seven stratigraphical sections were logged on the southern margin of the Moroccan High Atlas at localities within the Todrha-Dades area (Table 1):

Table 1: Names and geographical coordinates of the studied sections.

Locality	Latitude	Longitude
1. Todrha canyon	31°36'48.60"N	5°35'55.96"W
2. Tariah n'Dades	31°32'47.04"N	5°55'29.64"W
3. Jbel Akenzoud	31°37'39.72"N	5°54'15.48"W
4. Bou-Oumardoul	31°36'02.52"N	5°52'21.00"W
5. Jbel Agouni	31°31'41.16"N	5°59'16.80"W
6. Ikerzi ridge	31°44'42.36"N	5°50'29.76"W
7. Ouguerd Zegzaoune	31°45'16.92"N	5°39'44.28"W

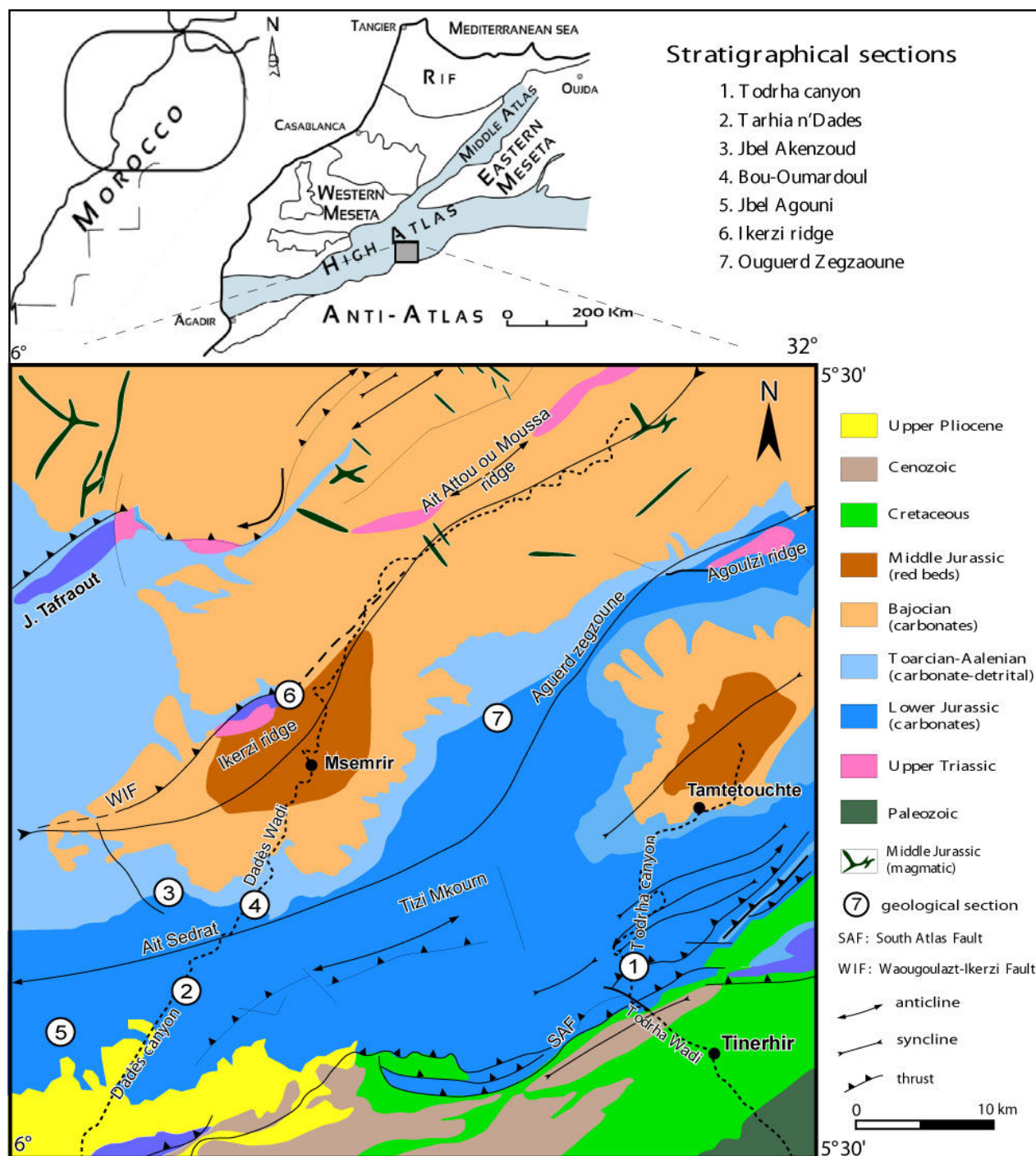


Figure 1: Geological map of the Toudrha-Dades High Atlas.

Selective sampling was guided in the field by an initial observation with magnifying hand lenses. Subsequently, the laboratory analysis of microfossils in thin sections allowed for the identification of foraminifers and calcareous algae, as well as the characterization of depositional paleoenvironments. The inventory of the different microfossils found in the Lower Jurassic was compared to previous work by HOTTINGER (1967), SEPTFONTAINE (1984), MILHI (1992, 1997), and ETTAKI (2003), carried out in the same area, and with stratigraphic work conducted in other High Atlas regions by BASSOULLET *et al.* (1976) and ETTAKI *et al.* (2000a, 2000b, 2011).

3. Stratigraphic framework

The Lower Jurassic Formations of the Toudrha-Dades High Atlas show a lithological heterogeneity (Fig. 2) related to active syn-sedimentary tectonics coupled with eustatic variations (ETTAKI, 2003; ETTAKI *et al.*, 2007a, 2007b, 2008). These sedimentary successions, often fossiliferous, have evolved in depositional environments ranging from coastal marginal marine to offshore deeper-water settings. The studied sedimentary successions consist of 500 to 800 m-thick carbonate and siliciclastic sediments, subdivided into eleven lithostratigraphic Formations. These have been

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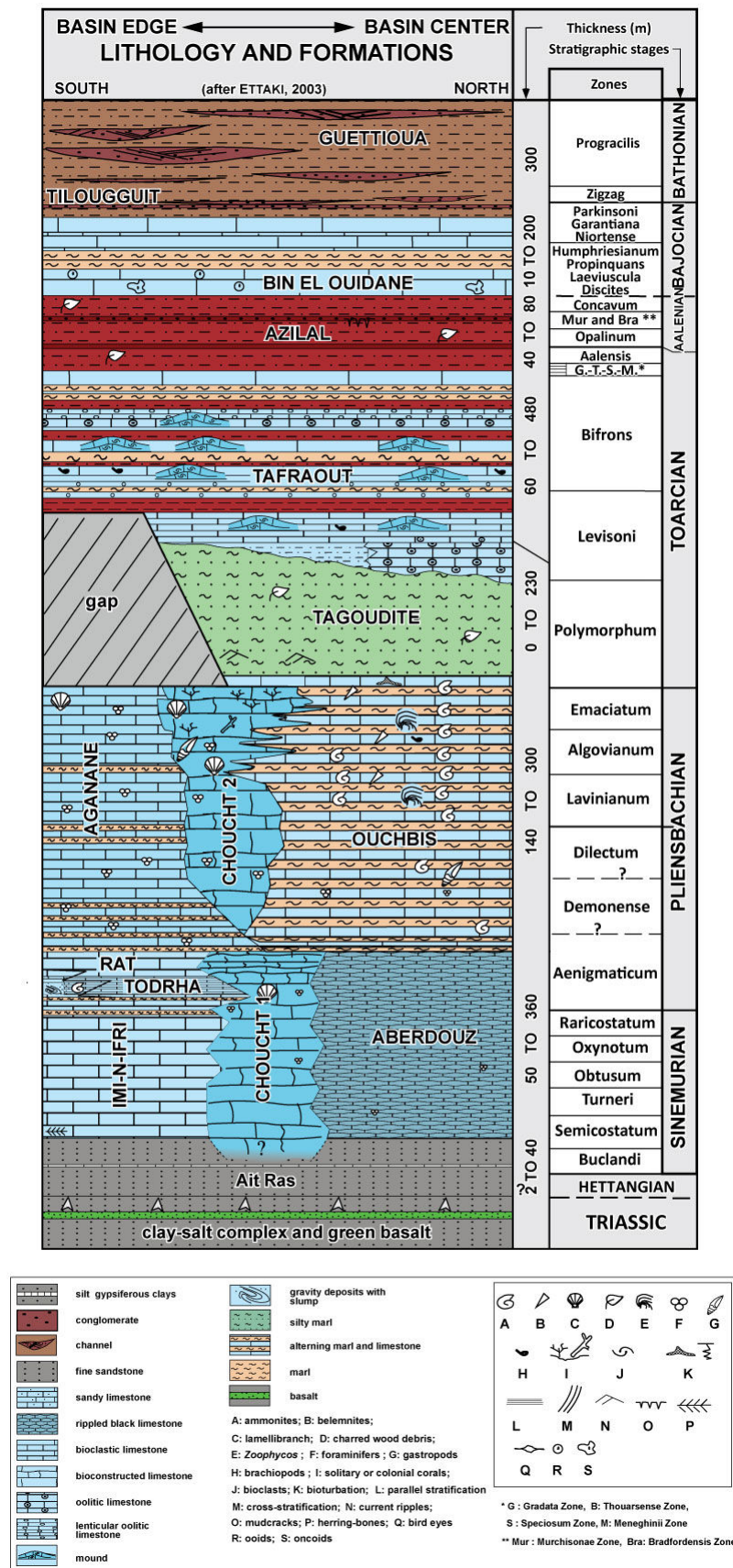
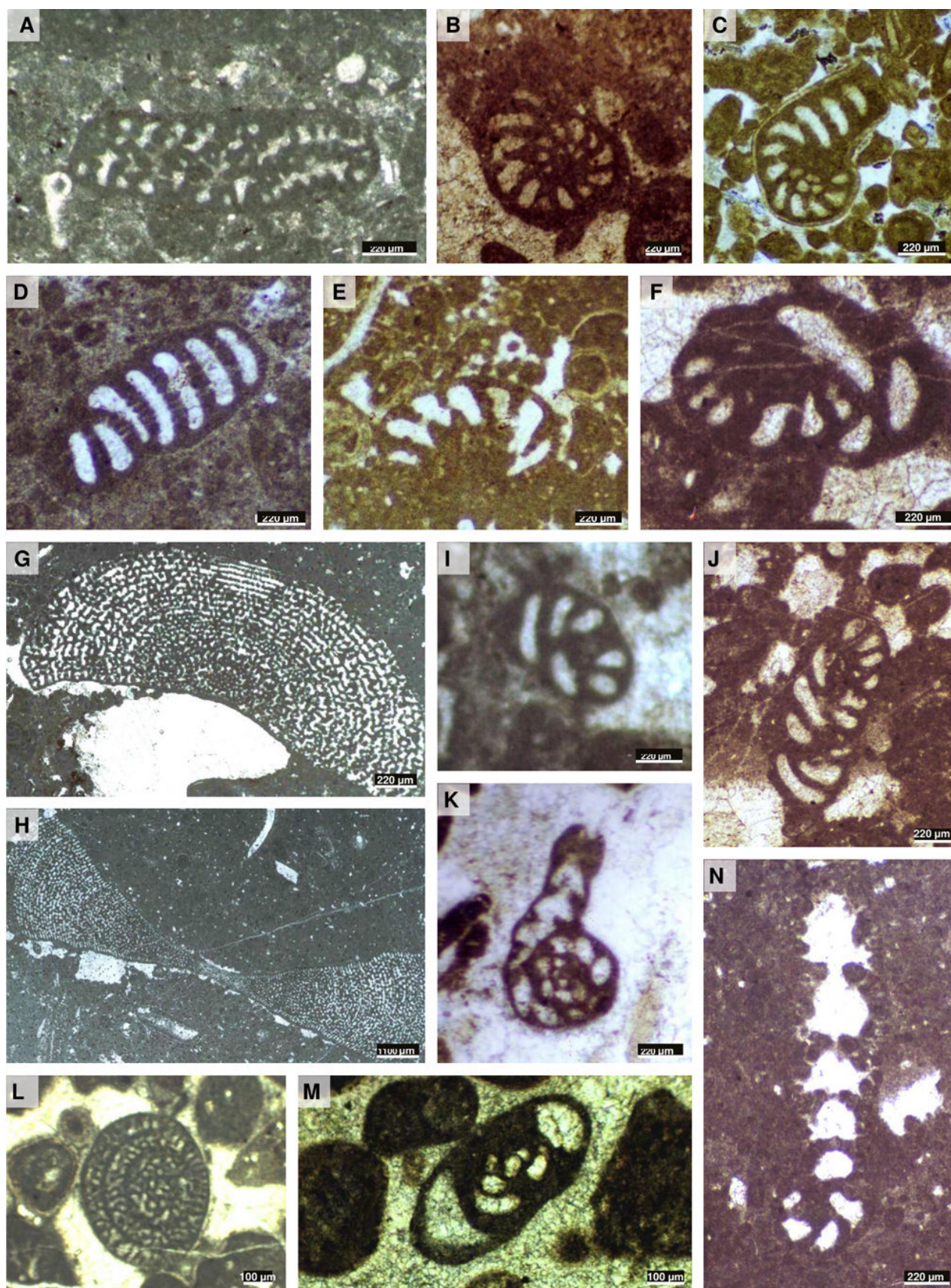


Figure 2: Lithostratigraphy of the Lower and Middle Jurassic in the Toudra-Dades High Atlas (after ETTAKI *et al.*, 1996, 2008; MILHI *et al.*, 2002; ETTAKI, 2003, compiled).

Figure 3: Examples of Lower Jurassic foraminifers from the southern margin of the Central High Atlas: **A)** *Lituo-septa recoarensis*, sub-axial section, thin section JR2, Toudra canyon (Akka n'Igoulzane), lower Pliensbachian (Aenigmaticum Zone). **B-E)** *Paleomayncina termieri*: B) Equatorial section, thin section N14, Toudra canyon, Sinemurian (biozone B); C) Equatorial section, thin section Aga19, Toudra canyon (Akka n'Igoulzane), lower Pliensbachian; D) Sub-axial section, thin section N17, Toudra canyon, upper Sinemurian - lower Pliensbachian (Aenigmaticum Zone) (biozone C1); E) Oblique/equatorial section, thin section Aga10, Toudra canyon (Akka n'Igoulzane), lower Pliensbachian. **F, I-J)** *Pseudopfenderina butterlini*: F) Sub-transverse section, thin section N17, Toudra canyon (biozone C1); I) Transverse section/oblique, thin section N7, Toudra canyon, Sinemurian; J) Axial section, thin section N17, Toudra canyon (biozone C1). **G-H)** *Orbitopsella praecursor*: **G)** Sub-equatorial section of microspheric form, thin section P20, Toudra canyon (Akka n'Igoulzane), lower Pliensbachian (biozone C2); **H)** Axial section of microspheric form preserved in a dark fine micrite, thin section F69, Tizgui locality, lower Pliensbachian (biozone C2). **K)** *Bosniella croatica*, equatorial section, thin section Rh9, Ilourhman locality, upper Pliensbachian. **L)** *Haurania deserta*, transverse section, thin section Ta45, Tarhia n'Dades, upper Pliensbachian Emaciatum Zone (biozone E). **M)** *Bosniella* sp., sub-axial section, thin section Rh3, Ilourhman locality, upper Pliensbachian. **N)** *Everticyclammina* sp., equatorial section, thin section N18, Toudra canyon (biozone C1).

tensively described in unpublished synthetic works elaborated for the whole central High Atlas by ETTAKI *et al.* (1996) and ETTAKI (2003), and are briefly summarized here:

3.1. The Ait Ras Formation (LE MARREC & JENNY, 1980). This Formation is represented by alternations of limestone, lithoclastic dolostone, flagstone dolostone, and sandy marlstone (50 to 60 m). The lithology of this Formation indicates that it was deposited in a marginal-littoral environment, and yielded only very rare, indeterminate foraminifers and ? Rivulariaceae. This Formation is of Hettangian? - early Sinemurian age (LE MARREC & JENNY, 1980).



3.2. The Imi-n-Ifri Formation (JENNY, 1988). This 102 m thick Formation consists of laminated limestone, oolitic limestone, lithoclastic limestone, and intraFormational breccia levels. This Forma-

tion, evolved from an intertidal to a supratidal environment, and based on its stratigraphic position is of Sinemurian age (ETTAKI, 2003).

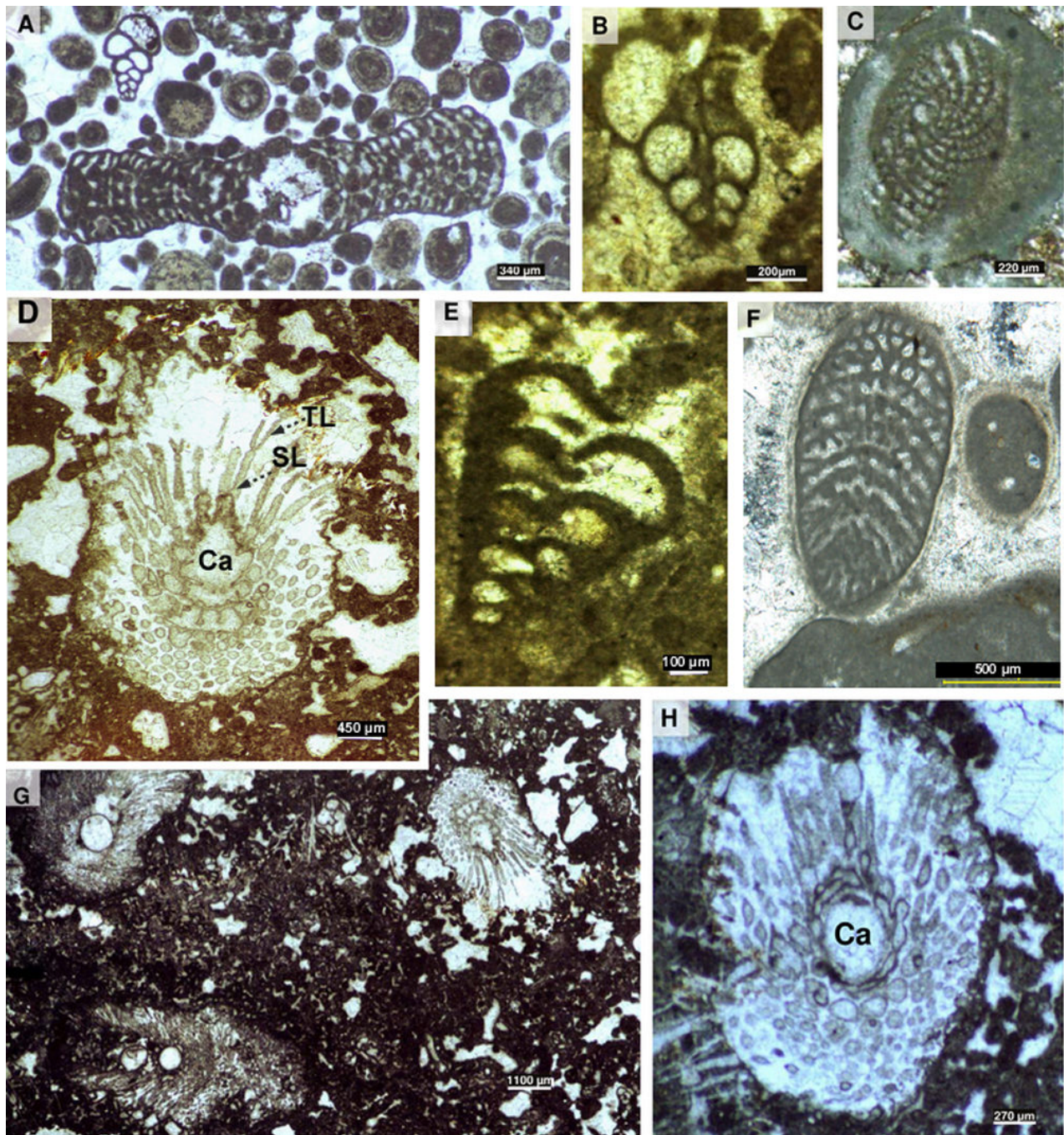


Figure 4: Examples of Lower Jurassic Algae and foraminifers from the southern margin of the Central High Atlas: **A)** *Orbitopsella praecursor*. Axial section of a macrospheric form associated to *Valvulina* sp., thin section Aga12, Todrha canyon (Akka n'Igoulzane). **B)** *Siphovalvulina* sp. Axial section, thin section GT5, Tarhia n'Dades, upper Pliensbachian (Emaciatum Zone, *Elisa* Subzone). **C)** *Timidonella sarda*. Sub-equatorial section, thin section Agz288, Ouguerd Zegzaoune locality, middle Aalenian - lower Bajocian. **D, G-H)** *Palaeodasycladus mediterraneus*: **D)** Oblique section (Ca: axial cavity, SL: secondary laterals, TL: tertiary laterals), thin section Ta44, Tarhia n'Dades, upper Pliensbachian (Emaciatum Zone, *Elisa* Subzone); **G)** Association of *Palaeodasycladus mediterraneus*, thin section Ta44, Tarhia n'Dades, upper Pliensbachian (Emaciatum Zone, *Elisa* Subzone); **H)** Oblique section, thin section Ta43, Tarhia n'Dades, upper Pliensbachian (Emaciatum Zone). **E)** *Valvulina* sp., Axial section, thin section N15, Todrha canyon, Sinemurian (biozone B). **F)** *Haurania deserta*. Axial section, thin section Aga36, Todrha canyon (Akka n'Igoulzane), upper Pliensbachian (Algovianum Zone).

3.3. The Choucht Formation (SEPTFONTAINE, 1985; JOSSEN, 1990). This unit corresponds to a set of gravelly, oolitic, and coralligenous sediments. This Formation developed within a carbonate platform and has been subdivided into two parts MILHI (1992, 1997):

- The lower part (Choucht 1), constituting the wall of the Todrha canyon, corresponds to approximately 360 m of massive limestone with cross-bedding and sponge-rich limestone containing: Lithistids (identified by Prof. BERNIER, Claude BERNARD Lyon 1 University), calcareous algae including *Palaeodasycladus* sp., *Tersella alpina*, and



Thaumtoporella parvovesiculifera, as well as larger benthic foraminifers (LBF), including *Amijiella amiji*, *Everticyclammina* sp., *Glomospira* sp., *Lituosepta recoarensis*, *Paleomayncina termieri*, *Pseudopfenderina butterlini*, *Redmondoides* sp., *Siphovalvulina* sp., *Spirillina* sp., *Verneuillinoidea mauritii*, and *Ophthalmidium martanum* (Fig. 3). Additionally, microproblematic fossils, such as *Bacinella* microstructures (SCHLAGINTWEIT *et al.*, 2011; GRANIER, 2021), *Cayeuxia* sp., *C. piaie*, *C. aff. kurdistanensis*, *C. cf. mediterranea*, and *Mitcheldeania* sp., are present. The association of algae and LBF indicates an age extending from the early Sinemurian to the early Pliensbachian (ETTAKI, 2003).

- The upper part (Choucht 2) is a 190 m thick peri-reef limestone constituting the dominant part of the Dades canyon wall (ETTAKI, 2003). The fossil content includes bivalve fragments, echinoid fragments and radioles, belemnites, brachiopods: *Lobothyris* sp., *Lobothyris subpunctata*, *Prionorhynchia canavarii*, and *Pr. gignouxii* (identified by Prof. ALMÉRAS), ammonites of the genus *Emaciatiticas* sp. (identified by Prof. DOMMERGUES), and foraminifers including *Amijiella amiji*, *Ammobaculites coprolithiformis*, *Bosniella* sp., *Epistomina* sp., *Everticyclammina* sp., *Glomospira* sp., *Glomospirella* sp., *Haplophragmoides* sp., *Haurania deserta*, *Involutina liassica*, *Lituosepta* cf. *compressa*, *Mesoendothyra* sp., *Nodosaria* sp., *Ophthalmidium martanum*, *Planisepta compressa*, *Pseudocyclammina* sp., *Redmondoides* sp., *R. cf. lugeoni*, *Siphovalvulina* sp., *Spirillina* sp., *Trochammina* sp., *Trocholina* sp., *Valvulina* sp., *Verneuillinoidea mauritii*, *Verneuillina* sp., and encrusting foraminifers such as *Coscinophragma* sp. The algae are represented by Dasycladales including *Chinianella ellebergeri*, *Otternstella* sp., *Palaeodasycladus* sp., *P. elongatus*, *P. mediterraneus* (Fig. 4.D, .G-H), *Uragiella liassica*, as well as Eliaellaceae, *Thaumtoporella parvovesiculifera*, and microproblematic organism such as *Cayeuxia piaie* and *Bacinella* microstructures.

This microfossil content indicates a late Pliensbachian (Algovianum Zone) to the earliest Toarcian age (ETTAKI, 2003). The presence of *Emaciatiticas* allowed the upper part of the Choucht 2 Formation to be attributed to the Emaciatum Zone, Elisa Subzone (ETTAKI, 2003).

3.4. The Todrha Formation (MILHI, 1992). It consists of 120 m of sediment gravity flow deposits. The limestone microfacies correspond to a biomicrite with lithoclasts, oncoids, bioclasts, and calcareous algae. The foraminiferal content includes *Ammobaculites coprolithiformis*, *Epistomina* sp., *Everticyclammina* sp., *Glomospira* sp., *Pseudopfenderina butterlini*, *Redmondoides* sp., *Siphovalvulina* sp., *Verneuillinoidea mauritii*, and other small foraminifers with a hyaline wall.

The Todrha Formation, which was attributed to the Sinemurian by MILHI (1992, 1997), yielded *Miltoceras taguendoufi* (EL HARIRI *et al.*, 1996), and *Metaderoceras* gr. *apertum* (EL HARIRI *et al.*, 1996) (identified by Prof. DOMMERGUES) in the Akka n'Igoulzane (Todrha Canyon) locality, which

made it possible to extend the age of this Formation to the Aenigmaticum Zone of the early Pliensbachian (ETTAKI, 2003; ETTAKI *et al.*, 2011).

3.5. The Jbel Rat Formation (JENNY, 1988). It is composed of a 0 to 60 m-thick sequence of limestones or dolostones with 'bird eyes', oncoids, oolitic limestones with cross-bedding, and dolostones with oncoids and tepee structures. The identified foraminifers are *Everticyclammina* sp., *Lituosepta recoarensis*, *Redmondoides* sp., *Siphovalvulina* sp., and *Verneuillinoidea mauritii*. The algae include Dasycladales and ? Rivulariaceae (*Cayeuxia* sp.). This Formation was deposited in an intertidal to supratidal environment (MILHI, 1992, 1997; ETTAKI, 2003) during the Aenigmaticum Zone of the early Pliensbachian (ETTAKI, 2003).

3.6. The Aganane Formation (JENNY, 1985, 1988; SEPTFONTAINE, 1985). This 160 m thick Formation is a rhythmic sedimentary succession, organized into cycles formed of limestones and dolostones, separated by varicolored marl layers. These facies were deposited in a temporary lagoonal environment within an inner platform (SEPTFONTAINE, 1985; MILHI, 1992, 1997; ETTAKI, 2003). The faunistic content includes in the lower part of this Formation the following benthic foraminifers and other microfossils forms: *Ammobaculites* sp., *Bosniella* aff. *croatica*, *Glomospira* sp., *Paleomayncina termieri*, *Pseudopfenderina butterlini*, *Siphovalvulina* sp., and archaic forms of Valvulinidae. The upper part contains: *Amijiella amiji*, *Bosniella* sp., *Orbitopsella praecursor*, and *Planisepta compressa*. The algae include *Cayeuxia* sp. These microfossils indicate the interval represented by the Demonense Zone to Lavinianum Zone, and corresponding to SEPTFONTAINE'S (1984) biozones C2 and D.

3.7. The Aberdouz Formation (STÜDER, 1980). This Formation consists of 30 to 140 m of black micritic limestones, locally associated with flint nodules. This open marine Formation includes bivalves, echinoderms, some algae such as *Thaumtoporella parvovesiculifera* and foraminifers including *Ammobaculites* gr. *coprolithiformis*, *Dentalina* sp., *Epistomina* sp., *Everticyclammina* sp., *Lenticulina* sp., *Nodosaria* sp., *Ophthalmidium martanum*, *Pseudopfenderina butterlini*, *Redmondoides* sp., *Spirillina* sp., and *Verneuillinoidea mauritii*. In some sections (e.g., the Bou-Oumardou locality), rare discoveries of *Liospiriferina* sp. (brachiopods, identified by Prof. ALMÉRAS) allow these layers with brachiopods to be assigned to the Algovianum Zone of the upper Pliensbachian (ETTAKI, 2003; ETTAKI *et al.*, 2008). The Aberdouz Formation extends from the Sinemurian to the Algovianum Zone of the upper Pliensbachian (ETTAKI *et al.*, 2011).



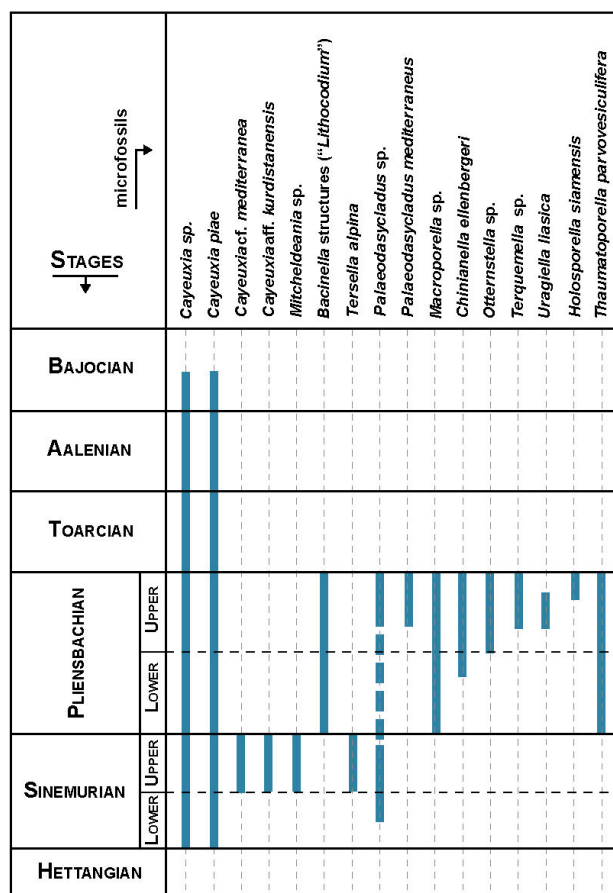


Figure 5: Stratigraphic distribution of some algal species in the Lower and Middle Jurassic limestones of the southern margin of the Central High Atlas.

3.8. The Ouchbis Formation (STÜDER, 1980). It consists of 140 to 300 m of limestone and marlstone alternations that were deposited in a subtidal to bathyal environment or even on a reef slope (EVANS & KENDALL, 1977; DRESNAY, 1971, 1979; STÜDER, 1980; BERNASCONI, 1983; MILHI, 1992, 1997; ETTAKI, 2003). The macrofauna includes ammonites, belemnites, and bivalves (*Bositra*). The micropaleontological association is composed of foraminifers: *Amijiella amiji*, *Ammobaculites* gr. *coprolithiformis*, *Everticyclammina* sp., *Paleomayncina* sp., *Pseudocyclammina* aff. *liasica*, *Pseudopfenderina butterlini*, aff. *Redmondoides lugeoni*, *Siphovalvulina* sp., and other taxa such as *Epistomina* sp., *Glomospirella* sp., *Glomospira* sp., *Haurania deserta*, *Lenticulina* sp., *Lingulina* gr. *tenera*, *Nodosaria* sp., *Ophthalmidium leischneri*, *O. martanum*, *Spirillina* sp., *Trochamminidae*, *Verneuilinoides mauritii*, and *Verneuilinoides* sp., as well as algae including *Elanelaceae* and *Thaumtoporella parvovesiculifera*. Additionally, microproblematic fossils, such as *Cayeuxia pia* and *Bacinella* nodules, are present. These microfossils are often reworked (ETTAKI, 2003). The ammonites collected by ETTAKI include several species of the genera *Metaderoceras*, *Lytoceras*, *Protogrammoceras*, *Fucineras*, *Arieticeiras*, *Reynesocoeloceras*, *Neolioceras*, *Emaciaticeiras*, *Canavaria*, *Tauromeniceras*, *Fontanelliceras*, and *Eodactylites*, that allow the Ouchbis Forma-

tion to be assigned to the interval from the lower Pliensbachian (Demonense Zone) to the lower Toarcian (Polymorphum Zone) (ETTAKI, 2003; ETTAKI *et al.*, 2011).

3.9. The Tagoudite Formation (STÜDER, 1980). It consists of up to 230 m of sandy marlstone and calcareous sandstone. These sediments correspond to turbidite facies that were deposited in a deep depocentre created by block tilting (ETTAKI, 2003; ETTAKI *et al.*, 2007a, 2008). This Formation, dated by stratigraphic framing, is attributed to the lower Toarcian (Polymorphum - Levisoni zones) (ETTAKI & CHELLAI, 2005).

3.10. The Taфраout Formation (MILHI, 1997). This Formation is composed of 60 to 400 m of siliciclastic sediments with oolitic and bioclastic limestone layers deposited on a proximal platform (MILHI, 1997). In some sections, the brachiopods collected include: *Homoeorhynchia meridionalis*, *H. batalleri*, *Telothyris jauberti* var. *depressa*, *T. arnaudi*, and juvenile forms of *Telothyris jauberti* (identified by Prof. OUAHHABI). This association indicates an interval within the Toarcian extending from the Serpentinus Zone to the base of the Bifrons Zone (Sublevisoni and probably Lusitanicum subzones) (ETTAKI *et al.*, 2011). The upper levels of this Formation yielded two poorly preserved ammonite molds corresponding to *Hildoceras* sp. (identified by Prof. OUAHHABI), indicating the middle Toarcian, Bifrons Zone (ETTAKI, 2003).

3.11. The Azilal Formation (JENNY, 1988). This is composed of siltstones, calcareous sandstones and dolostones. The faunistic content includes only rare bivalves, gastropods, brachiopods, and foraminifers. The Azilal Formation is stratigraphically located between the Taфраout Formation (middle Toarcian) and the Bin El Ouidane 1 Formation of a Bajocian age (MILHI *et al.*, 2002). The carbonate horizons at the top of the Azilal Formation yielded *Timidonella sarda*, indicating that this Formation belongs to the upper Toarcian - lower Bajocian interval.

4. Biostratigraphic analysis

Only some Lower Jurassic Formations of the Todrha-Dades area yielded a significant fauna of ammonites and/or brachiopods for high precision age-calibration. However, other carbonate-dominated Formations contain well-preserved foraminifers and calcareous algae (Fig. 5) allowing biostratigraphic interpretations. Thus, the Lower Jurassic micropaleontology can be described and a biostratigraphic subdivision proposed based on larger benthic foraminifers (LBF) and calcareous algae.

In the Todrha-Dades High Atlas, the most recent discoveries of brachiopods and ammonites (ETTAKI *et al.*, 2011) assisted with the age-calibration of micropaleontological assemblages and provided constraints regarding the stratigraphy of some biozones previously proposed for the Lower Jurassic of the High-Atlas in the Moroccan Tethys domain (SEPTFONTAINE, 1985). In horizons devoid of fossil markers, the age-calibration of micropaleontological assemblages is based on compari-



sons with the biostratigraphic scale proposed by SEPTFONTAINE (1984). The lower Sinemurian - lower Bajocian interval is characterized by seven microfossil assemblages presented here from base to top:

4.1. *Siphovalvulina* sp. and *Everticyclammina* sp. assemblage: Hettangian? - lower Sinemurian.

This assemblage characterizes the base of the Lower Jurassic series in the study area. It corresponds perfectly to SEPTFONTAINE'S (1984) biozone A (interval zone). The microfossils identified here are not age-characteristic since they occur in almost all of the overlying assemblages. The absence of typical markers belonging to the orbitopsellids generate a need for further investigations in the field. This assemblage is represented in the Todrha-Dades High Atlas only by *Everticyclammina* sp., *Siphovalvulina* sp., and rare ? Rivulariaceae.

4.2. *Lituosepta recoarensis* and *Pseudopfenderina butterlini* assemblage: upper Sinemurian.

From the late Sinemurian, new paleoecological conditions led to a flourishing of foraminifers, especially those with complex internal structure.

The base of this assemblage is defined by the appearance of *Pseudopfenderina butterlini*, whilst its top coincides with the disappearance of *Lituosepta recoarensis*. These two characteristic forms are associated with other microfossils, among which the most notable are *Amijiella amiji*, *Ammobaculites* gr. *coprolithiformis*, *Everticyclammina* sp., *Ophthalmidium martanum*, *Paleomayncina termieri*, *Pseudopfenderina* sp., *Siphovalvulina* sp., *Verneuilioides mauritii*, *Palaeodasycladus* sp., *Cayeuxia piae*, *C. cf. mediterranea*, *C. aff. kurdistanensis*, and *Thaumatoporella parvovesiculifera*.

This assemblage of late Sinemurian age corresponds to SEPTFONTAINE'S (1984) biozone B (lineage zone), defined by the appearance of *Lituosepta recoarensis*. In the Todrha-Dades High Atlas, *Pseudopfenderina butterlini* appears before *Lituosepta recoarensis*, and this disagrees with the data presented by SEPTFONTAINE (1984, 2020). This difference in the vertical distribution of taxa could be related to facies and paleoenvironmental conditions. It is likely that *Lituosepta* proliferated in lagoonal facies (Aganane Formation). In the Todrha canyon, the *L. recoarensis* and *Pseudopfenderina butterlini* assemblage was recognized within the deposits of the Choucht 1 Formation (Fig. 3.A). It should be noted that in the Todrha-Dades High Atlas, the occurrence of lagoonal facies starts within the Aenigmaticum Zone of the early Pliensbachian.

The chronostratigraphic position of this assemblage is based both on the interpretations of SEPTFONTAINE (1984, 2020) and on the occurrence of

ammonites (*Metaderoceras* gr. *apertum* and *Miltoceras taguendoufi*) of the lower Pliensbachian (Aenigmaticum Zone) in the overlying horizons (ETTAKI, 2003; ETTAKI *et al.*, 2011). These occurrences allow the *Lituosepta recoarensis* and *Pseudopfenderina butterlini* assemblage to be assigned to the upper Sinemurian.

4.3. *Paleomayncina termieri* and *Pseudopfenderina butterlini* assemblage: uppermost Sinemurian - lower Pliensbachian, Aenigmaticum Zone (interval zone).

This interval zone is characterized by the disappearance of *Lituosepta recoarensis* at its lower limit and by the appearance of *Orbitopsella praecursor* at its upper limit. This assemblage is based on the association of *Paleomayncina termieri* and *Pseudopfenderina butterlini*. The accompanying fauna consists of *Bosniella* gr. *croatica*, *Everticyclammina* sp., aff. *Redmondoides lugeoni*, and *Siphovalvulina* sp.. The algae include Dasycladales, *Thaumatoporella parvovesiculifera*, *Cayeuxia piae*, and *incertae sedis*. This association has been recognized within the Aganane and the Choucht 1 Formations in Todrha canyon, and within the Aberdouz Formation at Jbel Agouni. This assemblage can be correlated with SEPTFONTAINE'S (1984) biozone C1. According to this author, the index species of biozone C1 (lineage zone) is *Orbitopsella primaeva*. This index species has not been identified in the Todrha-Dades High Atlas.

The age of this assemblage is based on the ammonites of the early Pliensbachian (Aenigmaticum Zone): *Miltoceras taguendoufi* EL HARIRI *et al.*, 1996, and *Metaderoceras* gr. *apertum* EL HARIRI *et al.*, 1996 (ETTAKI, 2003; ETTAKI *et al.*, 2011). These species appear in association with *Paleomayncina termieri* and *Pseudopfenderina butterlini*. These biostratigraphic calibrations confirm and validate the indirect dating proposed by SEPTFONTAINE (1984, 2020) at the scale of the Moroccan Tethys domain.

4.4. *Orbitopsella praecursor* assemblage: lower Pliensbachian (Demonense and Dilectum zones).

The lower limit of this assemblage is characterized by the appearance of *Orbitopsella praecursor*. This index species is associated with *Paleomayncina termieri* and *Planisepta compressa*. The upper limit is marked by the abrupt disappearance of *Orbitopsella praecursor*. This is also confirmed in other regions of the Central High Atlas, particularly at its northern border (SOUHEL, 1996), and in the Middle Atlas (SEPTFONTAINE, 1984; BASSOULLET *et al.*, 1999). Other taxa, including *Ammobaculites* gr. *coprolithiformis*, *Bosniella* sp., and *Everticyclammina* sp., are associated with this assemblage, which corresponds perfectly to phylozone C2 of SEPTFONTAINE'S (1984) biozonation.

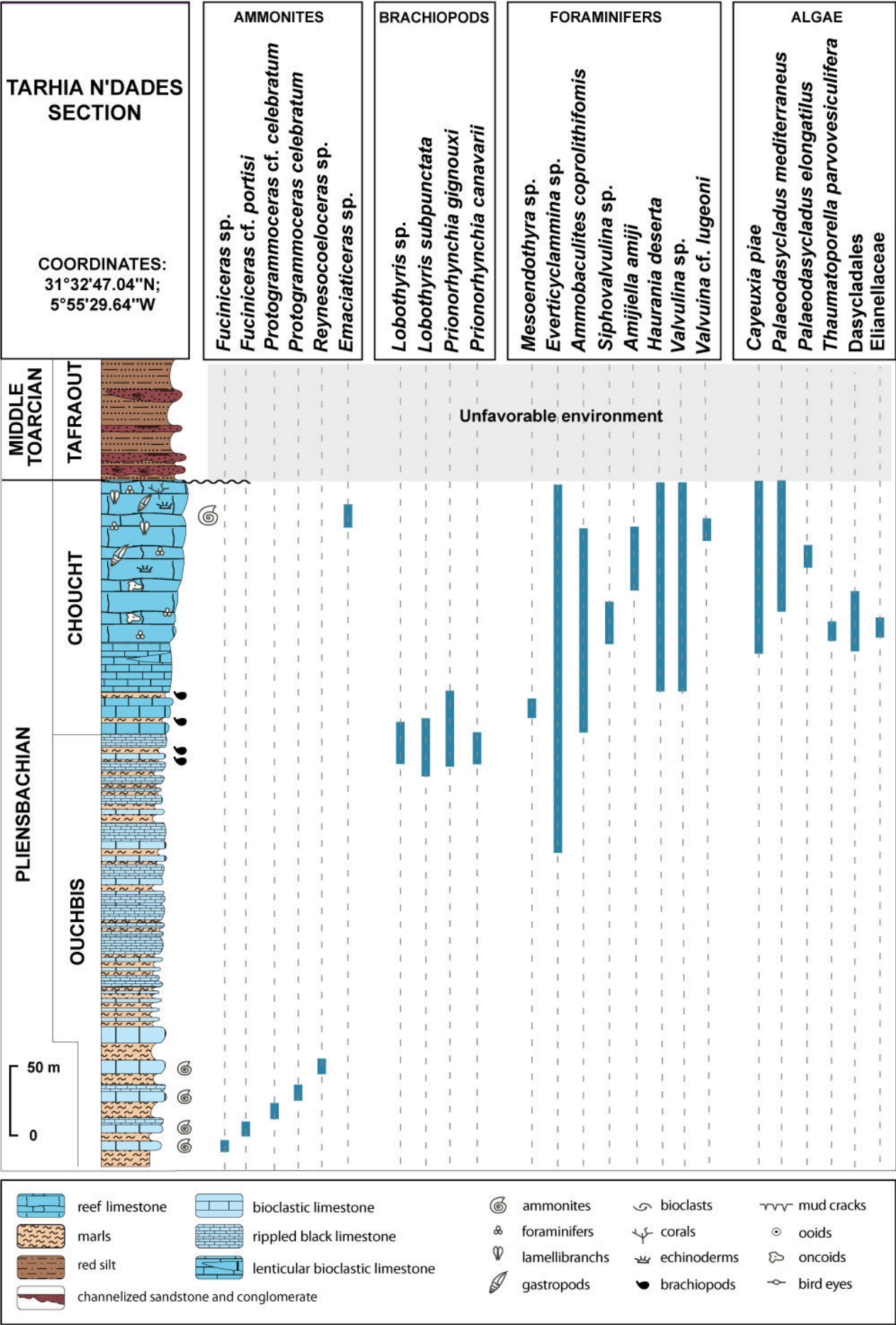


Figure 6: Distribution of fauna and algae in the Tarhia n'Dades section (after ETTAKI, 2003, compiled).



4.5. *Paleomayncina termieri* and *Planisepta compressa* assemblage: upper Pliensbachian (Lavinianum Zone).

This interval zone is mainly characterized by the association of *Paleomayncina termieri* and *Planisepta compressa*. These two species are very abundant and are associated with *Amijiella amiji*, *Bosniella croatica*, *Everticyclammina* sp., and *Haurania* aff. *deserta*. The recorded algae are *Cayeuxia* sp. and Dasycladales. This assemblage is found in the inner platform lagoon-type facies of the Aganane Formation and in the Choucht 2 Formation. The lower limit is denoted by the disappearance of *Orbitopsella praecursor*, while its upper limit coincides with the appearance of *Pseudocyclammina liasica*. This assemblage correlates precisely with SEPTFONTAINE'S (1984) biozone D and is assigned to the upper Pliensbachian (Lavinianum Zone).

4.6. *Pseudocyclammina liasica* assemblage or *Palaeodasycladus mediterraneus* assemblage: upper Pliensbachian (Algovianum Zone) - Toarcian

Within the upper Pliensbachian (Algovianum Zone) to Toarcian interval, two assemblages are defined according to facies type:

4.6.1. *Pseudocyclammina liasica* assemblage

According to SEPTFONTAINE (1984, 2020), this biozone is defined by the presence of *Pseudocyclammina liasica*. This index species often coexists with *Amijiella amiji* and *Haurania deserta*. In the study area, except in the inner platform facies, we noted the scarcity, or even the absence of *Pseudocyclammina liasica*. In the Todrha-Dades High Atlas, *P. liasica* is associated, in some sections, with an open sea fauna of the lower to middle Toarcian, allowing its biostratigraphic calibration. Thus, the brachiopods collected at the base are *Telothyris arnaudi* and many juvenile forms of *Telothyris jauberti* var. *depressa* of the lower Toarcian (Levisoni Zone? and base of the Bifrons Zone), while at the top, the taxa identified are *Homoeorhynchia batalleri* and juvenile forms of *Homoeorhynchia meridionalis* (identified by Prof. OUAHHABI) indicating the middle Toarcian (Bifrons Zone) (ETTAKI, 2003, p. 209-213; ETTAKI et al., 2008).

Elsewhere, at several localities of the Atlas domain and of the south Rifan ridges, SEPTFONTAINE'S (1984) biozone E (i.e., range zone of *Pseudocyclammina liasica*) belongs to the upper Pliensbachian (Algovianum Zone). However, in the Todrha-Dades High Atlas, the new biostratigraphic data allow us to reasonably place the upper limit of the biozone within the middle Toarcian (Bifrons Zone).

4.6.2. *Palaeodasycladus mediterraneus* assemblage

Palaeodasycladus mediterraneus was first described by PIA in 1920 and subsequently revised

by the same author in 1927. In 1967, PRATURLON introduced the new variety *P. mediterraneus* var. *elongatulus*. Later, DELOFFRE and LAADILA (1990) proposed an emended diagnosis for both the genus and its type species. Additionally, *P. elongatulus* was later validated in GRANIER and DELOFFRE (1993) under the name *P. gracilis*, which may in fact represent a junior synonym of *P. mediterraneus*. In their study, BARATTOLO et al. (1994) offered descriptions that diverged from PIA's original characterization of *P. mediterraneus*, providing a basis to critically assess the emendation proposed by DELOFFRE and LAADILA (1990). However, in 2003, GRANIER et al. reinterpreted the original specimens of DELOFFRE and LAADILA as *Petrascula iberica*, not as a species of *Palaeodasycladus*.

Other works on calcareous algae (Dasycladales) from the lower Lias, and more precisely from the Pliensbachian, particularly those referencing the genus *Palaeodasycladus* and its species, were published in the 2000s, notably by SOKAČ (2001) and BARATTOLO and ROMANO (2005). It is noteworthy that *P. mediterraneus* is widespread in the lower and middle Lower Jurassic of the Tethys domain.

In the Dades High Atlas, *P. mediterraneus* has been found in peri-reefal and reefal deposits of the Choucht 2 Formation (ETTAKI, 2003).

In the peri-reef and reef deposits (Choucht 2 Formation). These facies are characterized by a high abundance of *P. mediterraneus* (Fig. 4.G). This alga is often associated with *Haurania deserta* (in great abundance) and *Amijiella amiji*. Other foraminifers, including *Everticyclammina* sp., *Ophthalmidium leischneri*, and *O. martanum*, as well as algae such as *Cayeuxia piae*, and *incertae sedis*, are associated with this characteristic assemblage.

This assemblage is biostratigraphically calibrated by the occurrence of an ammonite and brachiopod fauna (ETTAKI et al., 2000a, 2000b; ETTAKI, 2003).

The lower horizons can be attributed to the upper Pliensbachian (Algovianum Zone) by the presence of the brachiopods: *Lobothyris* sp., *L. subpunctata*, and *Prionorhynchia gignouxii* (Fig. 6). The upper part of the *Palaeodasycladus mediterraneus* assemblage is attributed to upper Pliensbachian (Emaciatum Zone) due to the occurrence of *Emaciatoceras* (ETTAKI et al., 2000a, 2000b) (Figs. 7-8).

Consequently, at the Atlas domain scale, we propose to include the *Palaeodasycladus mediterraneus* assemblage, acme zone, in the reef facies to mark the upper Pliensbachian (Algovianum and Emaciatum zones). This *P. mediterraneus* assemblage can be correlated with the *Pseudocyclammina liasica* biozone of the reference biostratigraphic scheme developed by SEPTFONTAINE (1984, revised 2020), which seems characteristic of lagoonal facies.

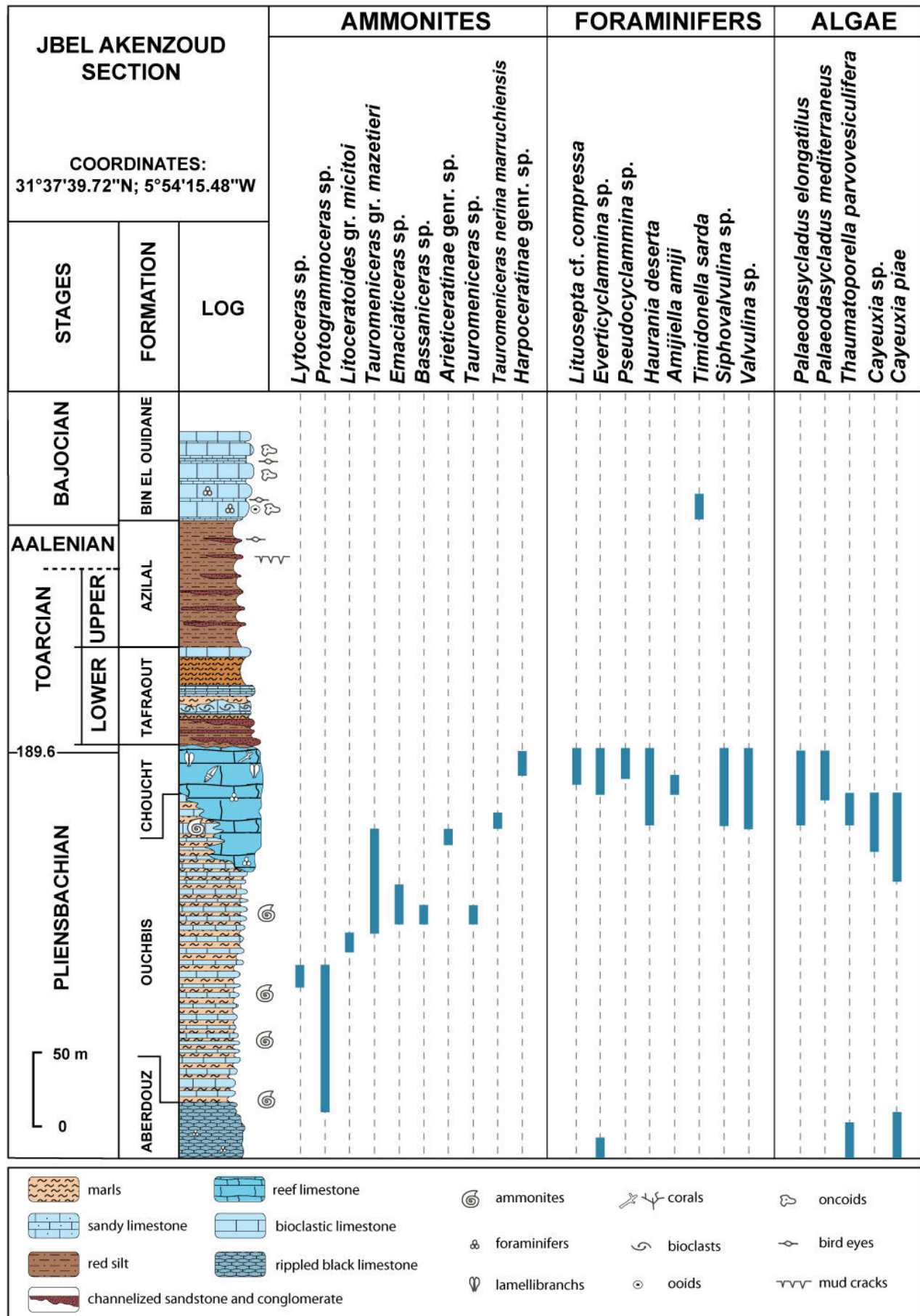


Figure 7: Distribution of fauna and algae in the Jbel Akenzoud section (after ETTAKI, 2003, compiled).

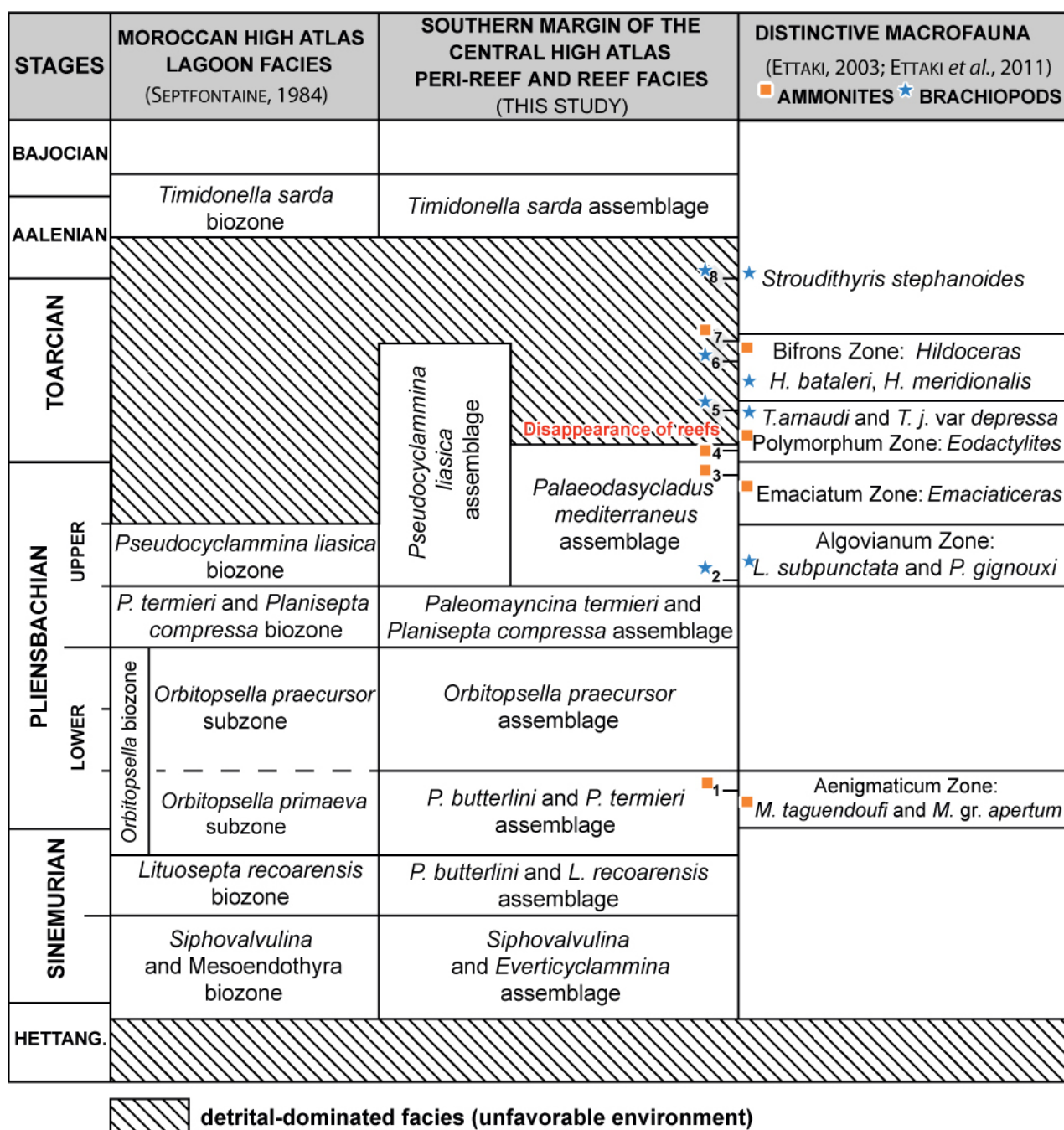


Figure 8: Micropaleontological assemblages based on foraminifers and the calcareous algae of the Lower and Middle Jurassic of the Central High Atlas. Numbers refer to Ammonites and Brachiopods recovered in the southern Central High Atlas (after ETTAKI, 2003, compiled): Ammonites, 1: *Mitoceras taguendoufi* and *Metaderoceras gr. apertum*; 3: *Emaciatoceras*; 4: *Eodactylites mirabilis*; 7: *Hildoceras*; Brachiopods, 5: *Telothyris arnaudi* and *Telothyris jauberti* var. *depressa*; 2: *Lobothyris subpunctata*, *Lobothyris* sp., and *Priorhynchia gignouxii*; 6: *Homeorhynchia batalleri* and juvenile forms of *Homeorhynchia meridionalis*; 8: *Stroudithyris stephanoides*.

4.7. *Timidonella sarda* assemblage

This assemblage is characterized by the occurrence of typical forms of *Timidonella sarda*. It corresponds to SEPTFONTAINE's (1984) biozone F. The earliest occurrences of *T. sarda* are found within the carbonate beds at the top of the siliclastic Azi-lal Formation. At Ikerzi, the lower part of this Formation yields narrow morphs of *Stroudithyris stephanoides* (identified by Prof. OUAHABI), indicating the Aalensis Zone and the transition to the Opalinum Zone (ETTAKI, 2003). *Timidonella sarda* has been found in other areas of the Central High

Atlas. It characterizes the middle Aalenian - lower Bajocian interval (JOSSEN *et al.*, 1987; SEPT-FONTAINE *et al.*, 1991). This is confirmed in several regions of the Tethys domain, where the stratigraphic distribution of *T. sarda* is observed within the Middle Jurassic (BASSOULLET *et al.*, 1976).

5. Conclusion

The biostratigraphic scheme proposed in this work results from the identification of larger benthic foraminifers, calcareous algae and their associations, as well as the stratigraphic context of



these microfossils. It is the result of a micropaleontological analysis of several stratigraphic sections studied on the southern margin of the Central High Atlas. Seven consecutive assemblages have been recognized based on the stratigraphic distribution of foraminifers and algae. The seven identified assemblages (Fig. 8) always occur in the same stratigraphic order. We partially recognize the different biozones defined in 1984 by SEPTFONTAINE and revised in 2020; we present observations and provide additional details regarding the stratigraphic age and succession of the assemblages. We propose to introduce a new biostratigraphic subdivision: a *Palaeodasycladus mediterraneus* assemblage, in the reef facies of the upper Pliensbachian (Algovianum and Emaciatum zones). This newly proposed assemblage can be correlated with the *Pseudocyclammia liasica* biozone of SEPTFONTAINE (1984, 2020), as defined within low energy lagoon-type facies.

It is noteworthy that *Palaeodasycladus mediterraneus* is a very common and widely distributed algal species. Its occurrence has been frequently documented in the literature within Jurassic carbonate facies. This species is widespread throughout the lower and middle Lower Jurassic of the Mesogean domain. Numerous studies have reported its presence in various regions, including Italy (CHIOCCHINI & MANCINELLI, 1978; CHIOCCHINI *et al.*, 1994, 2008; BARATTOLO *et al.*, 1994), Spain (SEVILLANO *et al.*, 2020), Croatia and Slovenia (SOKAČ, 2001), southern Iran (BASSOULLET *et al.*, 1978), as well as Algeria, Tunisia, Turkey, and Oman.

During the Pliensbachian, *P. mediterraneus* was a significant component of the algal biomass, thriving under favorable environmental conditions on carbonate platforms of the southern margin of the Tethys Ocean. The persistence of favorable environmental conditions sustained the presence of *P. mediterraneus* until the dislocation of carbonate platforms and the subsequent collapse of reef systems following the syn-Polymorphum crisis (ETTAKI, 2003; ETTAKI & CHELLAI, 2005). The disappearance of this microfossil reflects a shift in paleoenvironmental conditions, marking the transition from biostasis to rhexistasis, as observed in the Toarcian Stage (ETTAKI & CHELLAI, 2005; ETTAKI *et al.*, 2007a, 2008, 2011). *P. mediterraneus* appears to be absent in the lower Toarcian (Serpentinus Zone) as well as in the middle and upper Toarcian. The predominantly siliciclastic facies that were deposited following the syn-Polymorphum crisis likely contributed to the absence of *P. mediterraneus* and larger benthic foraminifera (LBF).

The correlation of certain biozones or assemblages, as well as some taxa, with the Jurassic stages has been calibrated either through the association of stratigraphic markers (such as ammonites and brachiopods) within the assemblages, or by their placement within well-dated paleontological layers (Fig. 8). This approach enabled us to determine the age of the *Palaeodasycladus mediterraneus* assemblage, as well as the

Paleomayncina termieri and *Pseudopfenderina butterlini* assemblage from SEPTFONTAINE's (1984) biozone C1, and subsequently to define the age of the *Pseudocyclammia liasica* biozone.

The biostratigraphic subdivisions proposed contribute to a better stratigraphic knowledge of the southern margin of the Central High Atlas. This publication contributes to the discussion on the spatio-temporal distribution of benthic foraminiferal assemblages and calcareous algal associations throughout the entire Jurassic system, with the aim of establishing a high-resolution regional stratigraphic scale based on microfossils and making correlations with other regions of the Atlas domain and the broader Mediterranean region.

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List of species

Microfossils

- *Amijiella amiji* (HENSON)
- *Ammobaculites coprolithiformis* (SCHWAGER)
- *Bosniella croatica* (GUŠIĆ)
- *Cayeuxia kurdistanensis* ELLIOTT
- *C. mediterranea* HERAK
- *C. pia* RECH-FROLLO
- *Chinianella ellembergeri* (LEBOUCHÉ & M. LEMOINE)
- *Haurania deserta* HENSON
- *Involutina liassica* (JONES)
- *Lingulina* gr. *tenera* BORNEMANN
- *Lituosepta* cf. *compressa* (HOTTINGER)
- *L. recoarensis* CATI
- *Ophthalmidium leischneri* (KRISTAN-TOLLMANN)
- *O. martanum* (FARINACCI)
- *Orbitopsella praecursor* (GÜMBEL)
- *O. primaeva* (HENSON)
- *Palaeodasycladus elongatus* PRATURLON
- *P. gracilis* CROS & M. LEMOINE
- *P. mediterraneus* (PIA)
- *P. mediterraneus* var. *elongatus* PRATURLON
- *Paleomayncina termieri* (HOTTINGER)

- *Petrascula iberica* (DRAGASTAN & TRAPPE, 1986)
- *Planisepta compressa* (HOTTINGER)
- *Pseudocyclamina liasica* (HOTTINGER)
- *Pseudopfenderina butterlini* (BRUN)
- *Redmondoides lugeoni* (SEPTFONTAINE)
- *Tersella alpina* CROS & LEMOINE
- *Thaumaporella parvovesiculifera* (RAINERI)
- *Timidonella sarda* BASSOULLET *et al.*
- *Uragiella liasica* (LEBOUCHÉ & M. LEMOINE)
- *Verneulinoides mauritii* (TERQUEM)

Ammonites

- *Metaderoceras* gr. *apertum* EL HARIRI *et al.*
- *Miltoceras taguendoufi* EL HARIRI *et al.*

Brachiopods

- *Homoeorhynchia batalleri* (DUBAR)
- *H. meridionalis* (DESLONGCHAMPS)
- *Lobothyris subpunctata* (DAVIDSON)
- *Prionorhynchia canavarii* (JIMÉNEZ de CISNEROS)
- *Pr. gignouxii* (JIMÉNEZ de CISNEROS)
- *Stroudithyris stephanoides* ALMÉRAS & MOULAN
- *Telothyris arnaudi* ALMÉRAS-MOULAN
- *T. jauberti* (DESLONGCHAMPS)
- *T. jauberti* var. *depressa* DUBAR