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The Toarcian (top of the *Polymorphum Zone–Bonarelli Zone*) in the Amellagou area (Central Moroccan High Atlas): Palynostratigraphy and Palaeoenvironments

Le Toarcien (sommet de la Zone à Polymorphum–Zone à Bonarelli) d'Amellagou (Haut Atlas Central, Maroc) : Palynostratigraphie et Paléoenvironnements

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Abstract. The palynological analysis of the Toarcian succession from the Amellagou region in the Central High Atlas (Morocco) yielded a moderately preserved assemblage, dominated by pollen grains and shows diversified spores content but scarce dinoflagellate cysts, acritarchs, chitinous foraminiferal test linings, and prasinophytes. Dinoflagellate cysts are rare, but their presence is significant in terms of biostratigraphic and palaeobiogeographic interest. Based on the recovered palynoflora, we identified two palynological assemblages. The first assemblage is of an early Toarcian age (ammonite *Polymorphum* Zone–*Levisoni* Zone) with the spore *Kraeuselisporites reissingeri* and dinoflagellate cysts *Luehndea spinosa* and *Luehndea cirilliae*. The second assemblage is assigned to the mid/late Toarcian (ammonite *Bifrons* Zone–*Bonarelli* Zone) with a more diversified continental fraction such as *Classopollis* spp., *Kraeuselisporites reissingeri*, *Neoraistrickia* sp., *Ischyosporites variegatus* and *Zonalapollenites* sp.

During the middle Toarcian to late Toarcian, we recorded an increase in dinoflagellate cyst taxa, manifested with the first occurrences of *Kallosphaeridium* sp., *Wallodinium* cf. *cylindricum*, *Moesidinium* sp., *Phallocysta* sp. and *Mendicodinium microscabratum*, and common presence of *Mancodinium semitabulatum*.

Quantitative composition of the palynofacies reflects a proximal continental shelf palaeoenvironment during the early Toarcian (top of the *Polymorphum* Zone-*Levisoni* Zone), fluctuating to more marginal palaeoenvironment under anoxic-dysoxic conditions in the *Bifrons* Zone.

Keywords: Biostratigraphy, Palynology, Dinoflagellate cysts, Toarcian, Central High-Atlas, Morocco.

Résumé. Ce travail palynologique concerne la série Toarcienne de la région d'Amellagou (Haut Atlas marocain). Il s'agit d'une série caractérisée surtout par les dépôts marneux qui dépassent 400 m d'épaisseur. Les résidus organiques obtenus sont dominés par les phytoclastes, la matière organique amorphe est rare. Pour les microfossiles organiques, ce sont les spores et grains de pollen, qui dominent sur la fraction d'origine marine, représentée par quelques acritarches, des foraminifères chitineux, des kystes de dinoflagellés et surtout les prasinophytes. Malgré la rareté des kystes de dinoflagellés, leur présence est significative vus leurs intérêts biostratigraphiques et paléobiogéographiques.

Deux assemblages palynologiques se distinguent : i) le premier d'âge Toarcien inférieur (Zone à *Polymorphum*-Zone à *Levisoni*), riche en spores ornementées avec l'espèce type *Kraeuselisporites reissingeri* et deux espèces de kystes de dinoflagellés marqueurs : *Luehndea spinosa* et *Luehndea cirilliae*. ii) Le deuxième assemblage correspond au Toarcien moyen/supérieur (Zone à *Bifrons*- zone à *Bonarelli*) avec une fraction continentale plus diversifiée (*Classopollis* spp., *Kraeuselisporites reissingeri*, *Neoraistrickia* sp., *Ischyosporites variegatus* et *Zonalapollenites* sp.).

Au cours du Toarcien moyen-Toarcien supérieur, nous avons enregistré une augmentation des taxons des kystes de dinoflagellés, qui s'est manifestée par les premières apparitions de *Kallosphaeridium* sp., *Wallodinium* cf. *cylindricum*, *Moesidinium* sp., *Phallocysta* spp. and *Mendicodinium microscabratum*, et la présence commune de *Mancodinium semitabulatum*.

L'analyse quantitative et qualitative du palynofaciès a révélé un paléoenvironnement de plateau continental proximal pendant le Toarcien inférieur (sommet de la Zone *à Polymorphum*-Zone à *Levisini*), qui va évoluer en un paléoenvironnement de bassin marginal dans des conditions anoxique-dysoxique à partir de la Zone à *Bifrons*.

Mot-clés : Biostratigraphie, Palynologie, Kyste de dinoflagellate, Toarcien, Haut-Atlas central, Maroc.

INTRODUCTION

The Lower Jurassic, especially the Pliensbachian–Toarcian interval, is a very important epoch in the geological history of the globe. This period was marked by remarkable paleoceanographic and palaeoenvironmental events: sea level variations, increased clay sedimentation, marine biosphere crisis, geochemical perturbations in isotopic sequences, and anoxic events (T-OAE) (Bodin *et al*. 2016, Haq *et al*. 1988, Jenkyns & Clayton 1997, Jenkyns *et al*. 2001, Van de Schootbrugge *et al*. 2013). This period corresponds to a great development of dinoflagellates, and it was a real evolutionary event, such as the Pliensbachian radiation (Fensome *et al*. 1999).

Lower Jurassic research based on palynology have largely been studied particularly in northwest Europe (Bjaerke 1980, Bucefalo-Palliani & Riding 1997, 2003, Davies 1983, 1985, Davey & Riley 1978, Feist-Burkhardt & Wille 1992, Koppelhus & Hansen 2003, Morbey 1978, Poulsen & Riding 2003, Riding 1984a, 1984b, Riding & Ioannides 1996, Wille & Gocht 1979, Williams & Bujak 1985, Woollam & Riding 1983). In this region, the Jurassic dinoflagellate cyst zonation is well known in comparison to the same period in Morocco. The most significant works on Toarcian dinoflagellate cysts is that of Bassoullet *et al*. (1991) who documented the dinoflagellate cyst record in well-dated sections in the Middle Atlas and the South-Rifan Ridge. In the latter locality, the contribution of Chahidi *et al*. (2016) is dedicated also to dinoflagellate cysts from two sections dated from upper Pliensbachian to lower Toarcian. The study of Bodin *et al*. (2016) have examined calcareous nannofossils and ammonites from the late Pliensbachian–early Toarcian of the Central High Atlas Basin. The authors documented the carbonate and organic matter carbon isotope of three sections including the Amellagou section to detect environmental perturbations recorded in the Pliensbachian–Toarcian boundary event.

The present work concerns a palynological study of the Toarcian of the Amellagou section (Central High Atlas). It is a continuation of the previous study undertaken by Bodin *et al*. (2016) carried out in the same area of Amellagou on the upper Pliensbachian–lower Toarcian interval. It aims to 1) use organic microfossils (dinoflagellate cysts, spores, and pollen) to give detailed ages, 2) provide a detailed palynostratigraphic account of the section to correlate between our palynological assemblages (dinoflagellate cysts, spores and pollen…) and those of other contemporary palaeogeographic domains, also with ammonite zones, and 3) provide palaeoenvironmental reconstructions of the Toarcian succession in the marly deposits of the Amellagou section.

GEOLOGICAL SETTING

The High Atlas is an intracontinental mountain belt that belongs to the Atlas system and represents an advanced component of the Alpine orogeny in Morocco (Blomeier & Reijmer 1999, Frizon de Lamotte *et al*. 2008, Mattauer *et al*. 1977). It extends from the Atlantic coast of Morocco to the Mediterranean coast of Tunisia. The High Atlas of Morocco is 100 km wide and 700 km long. It is limited to the south by South Atlas Fault, which separates it from the Anti-Atlas and the West African Craton, and to the north by the front of the Rif Chain. The Atlas Mountains were formed by the convergence of Africa and Eurasia as a result of rifting in the Mesozoic. The Atlas rift systems were formed as a consequence of a regional extension from the Carnian to the Early Jurassic, followed by a second extension phase from the Toarcian, leading to the establishment of the fault-bounded Middle and High Atlas troughs (Laville & Piqué 2004). The High Atlas is the result of the inversion of a system of Triassic-Liassic rifts that appeared on the edge of the African plate, below the South Tethyan margin (Dewey *et al*. 1989, Gomez *et al*. 2000, Lachkar *et al*. 2009, Moragas *et al*. 2018, Teixell *et al*. 2007, Wilmsen & Neuweiler 2008).

The High Atlas is subdivided into three domains: the Western, Central and Eastern High Atlas (Michard 1976). The Central High Atlas, where the studied section is located, is limited to the west by the Tizi N'Tichka valley and to the east by the Ziz valley. It is bordered to the south by the Paleozoic sedimentary rocks of the Anti-Atlas (Michard 1976) and to the north by the Mesetian domain (Laville *et al*. 1995).

The Central High Atlas, or "High Atlas limestone" is characterized by a large stratigraphic sequence dominated by shallow marine carbonate deposits of Jurassic age (Aït Addi 1998, 2000, Amour *et al*. 2013, Bodin *et al*. 2016, 2017, Brame *et al*. 2019, Danisch *et al*. 2021, Christ *et al*. 2011, Krencker *et al*. 2014, 2020, Wilmsen & Neuweiler 2008). This sequence is often deposited, in concordance, with the Triassic deposits in the synclinal basins in the center of the domain (Charrière *et al*. 2005, Charrière & Haddoumi 2016, Jenny *et al*. 1981, Laville *et al*. 1991, Haddoumi *et al*. 2010, Laville & Piqué 1992, Michard 1976, Souhel 1996). The studied area is located in the eastern part of the Central High Atlas and corresponds to the NE-SW depression that extends between the Amellagou and Agoudim villages. The following is an abridged description of the main lithostratigraphic formations of the Toarcian series (Fig. 1).

Tagoudite Formation: It consists of green marly sandstones in intercalation with lenticular beds of sandy limestones; it was originally described at the village of Tagoudite in the northern part of the domain (Studer 1980). To the west, this formation disappears and corresponds to a sedimentary hiatus or erosion period during the lower and middle Toarcian (Bodin *et al*. 2016, Ettaki 2003; Ettaki & Chellai 2005). In some localities, these deposits are characterized by the presence of Triassic basalts (Ibouh *et al*. 2001). The Tagoudite Formation is rich in ammonites of the lower to middle Toarcian (Bernasconi 1983, Bodin *et al*. 2016, Brechbühler 1984, Ettaki & Chellai 2005, Krencker *et al*. 2014, 2020, Lachkar 2000).

Agoudim Formation: Studer (1980) defined this formation in the Agoudim region southwest of the Er-Rich village. This author with Bernasconi (1983) and Ibouh (2004) subdivided this formation into two members (lower and upper). Brechbühler (1984) subdivided it into three members and Aït Addi (2002) suggested four members. The lower member is formed by a monotonous alternation of gray marls and rare centimetric limestone beds. The upper part of the formation is characterized by the presence of biodetritic and organogenic limestones, containing Zoophycus (Bernasconi 1983).

MATERIALS AND METHODS

The studied section (geographical coordinates: 31°58'15" North and 5° 4'11" West) is located near the village of Amellagou, about 110 km west of Errachidia city, at the foot of the Jebel Bou-Iflyou. This section is about 410 m thick (Fig. 2A). It can be subdivided into three main units:

The first unit, 26 m thick, begins at its base with an alternation of limestones (1 cm to 7 cm thick) and laminated marly beds (10 cm thick) (Fig. 2B). The upper part of the unit is characterized by the presence of more limestone beds

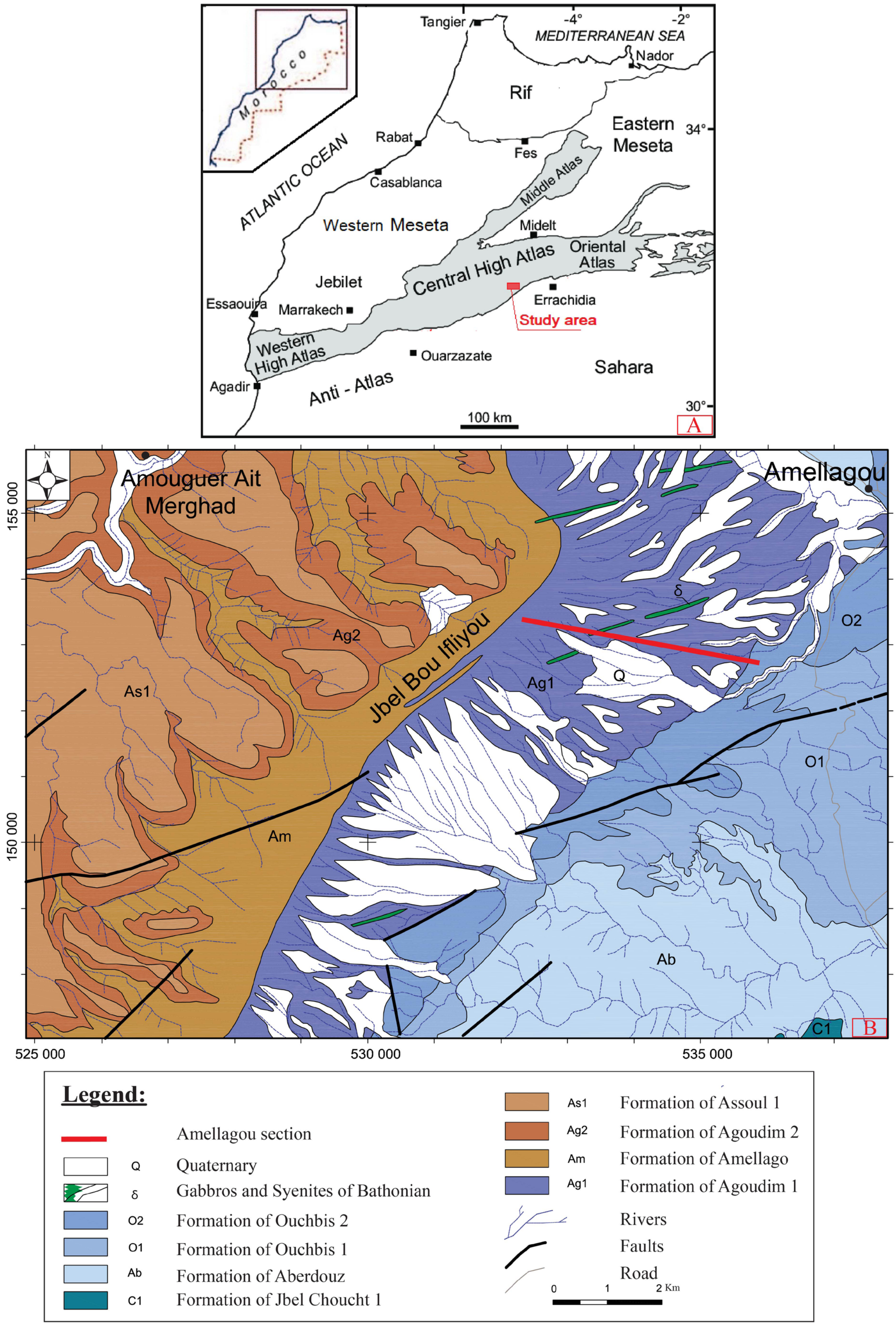


Figure 1. A: Different structural provinces of Morocco. B: Geological map of the study area in the Central High Atlas showing the location of the Amellagou section.

(Fig. 2C). The second unit (175 m thick) is marked by the dominance of black to green marls and interbedded limestone and sandstone interval (4 cm to 8 cm thick). It contains ammonites (Fig. 2E–F), brachiopods (Fig. 2G) and some bivalves (Fig. 2H). The third unit (209 m thick) consists of black marls with intercalations of marly limestone beds (4 cm thick) (Fig. 2I). At the top of this unit, these marly limestones show separate small nodules and their thickness decreases sharply. The last two units constitute the Agoudim Formation of Toarcian age (Pierre *et al*. 2005).

Thirty-three samples were collected from the Amellagou section between the *Polymorphum* and *Gradata* zones. They were processed according to the standard palynological procedure (Wood *et al*. 1996).

Fifty grams of each sample were washed, dried, crashed and then placed in labelled plastic beakers. Samples were initially treated with hydrochloric acid (HCl) (10%) to remove the carbonate fraction, followed by hydrofluoric acid (HF) attack (40%) to dissolve the silicates. The silicofluorides were removed by boiling the samples in hydrochloric acid (20%). Samples were rinsed several times with distilled water after each acid treatment. The residue was sieved using a nylon mesh screen 15 µm to concentrate the organic matter, and mounted on microscopic slides using glycerol gelatin. Two microscope slides were prepared for each sample for palynological analysis.

For each sample, 250 particles of organic matter were counted. The organic matter is grouped into: i) a continental fraction including phytoclasts (opaque and translucent), pollen, and spores; ii) a marine fraction composed of organic-walled dinoflagellate cysts, foraminiferal linings, prasinophytes, and acritarchs; and iii) amorphous organic matter (AOM).

Palynological slides are stored in the Palynology Laboratory, Faculty of Sciences Ben M'sik at the Hassan II University of Casablanca, Morocco. Slides were observed under a transmitted light microscope (Leica) equipped with a digital camera Leica DFC450C. The taxonomy of the dinoflagellate cysts is based on Dinoflaj3 (Fensome *et al*. 2008; Williams *et al*. 2017). All dinoflagellate cysts, spores and pollen taxa identified during this study are listed alphabetically in Table 1.

RESULTS AND DISCUSSION

Palynostratigraphy

Thirty-three samples from the Amellagou section (Fig.2) were processed and analyzed. The organic content of all samples is dominated by phytoclasts (61.2% to 91.6%), followed by palynomorphs (5% to 22.5%) and amorphous organic matter (1.1% to 22.22%).

The palynomorph assemblages are dominated by pollen, reaching 60.95–82.9% of total palynomorphs. Other continental palynomorphs, such as ornamented spores are also common (22.8%), except for the upper part of the section where they are rare to absent (5.2%).

The marine palynomorphs (foraminiferal wall linings, dinoflagellate cysts, acritarchs and algae) are generally few to rare (1.75–25.4%). We recognized four spore and four pollen *Classopoli*s sp. species and nine dinoflagellate cyst species of which two are good Pliensbachian–Toarcian markers. The biostratigraphic subdivision of the Amellagou section is based primarily on ranges of pollen and spores and partly on dinoflagellate cysts. We used the well-known Pliensbachian-Toarcian First Occurrence (FO) and Last Occurrence (LO) datums, as well as the global acmes of palynomorphs.

Lower Toarcian: Polymorphum Zone–Levisoni Zone

The interval spanning 90 m from sample AMG 1 to sample AMG 10 is of lower Toarcian age (Fig.3). This interval is numerically dominated by *Classopollis* sp., which usually accounts for more than 60.95% of the palynomorphs present. Our recognition of the age is based on several global pollen, spores and dinoflagellate cyst events. *Kraeuselisporites reissingeri* characterizes the Late Triassic-Early Jurassic interval (Batten *et al.* 1996, Correia *et al.* 2018). Its appearance (FO) is in the Hettangian (Pedersen & Lund 1980, Schuurman 1977), and its LO is in the early Aalenian (Portugal, Correia *et al.* 2019). If the Hettangian was the time of its apogee (Adloff & Doubinger 1982, Boutet, 1981, Bujak & Williams 1977), its presence is also significant in the Toarcian of NW Europe (in Portugal, Davies 1985; in England, Warrington 1983 and Riding 1987 and in France, Boutet 1981). In Morocco, the acme of *Kraeuselisporites reissingeri* was reported in the upper Pliensbachian in the Southern Rifan Ridges (Chahidi *et al*. 2016). In the Amellagou section, this species occurs between samples AMG 1 and AMG 16.

The FO of *Ischyosporites variegatus* is also another marker event of the Pliensbachian–Toarcian age. It characterizes the upper Pliensbachian of northwest Europe (Batten *et al*. 1996, Schulz 1967, Smith 1978) and the Toarcian in the Tethyan domain such as in Spain (Cresta *et al*. 2001, Martinez *et al*. 1996), Italy (Bucefalo-Palliani & Riding 1999) and Morocco (Bassoullet *et al*. 1991, Baudin *et al.* 1990, Chahidi *et al*. 2016).

Sample AMG 5 witnessed appearance of early Jurassic bisaccate pollen, *Alisporites* sp. and *Quadraeculina* sp. These two species first occur at the Hettangian in northern Europe and its acmes were reported in the lower Pliensbachian (Morbey 1975). According to Batten & Kopelhus (1996), these two genera have been recorded between the upper Sinemurian and the Pliensbachian in the northwest of Europe. In Morocco, they are faintly present in the upper Pliensbachian and the lower Toarcian assemblages of the South Rifan Ridges (Chahidi *et al*. 2016), similarly, the interval between AMG 5 and AMG 12 of the Amellagou section show minor ocurrences of these bisaccate pollen grains. This interval recorded also the appearance of the genus *Callialasporites,* which is a worldwide event characterizing the Lower Jurassic-Middle Jurassic boundary in several regions such as in Greenland (Pederson & Lund 1980) and in France (Schmitt 1987). This taxon was described for the first time in the Upper Triassic and its acme was reported in the Middle Jurassic (Batten & Koppelhus 1996, Koppelhus *et al*. 1996, Smith 1978). In the marine fraction, prasinophytes dominate, with an average rate of 12.3% (a few fragments of Botryococcus were recognized, particularly in sample AMG9 (Plate IV/6). These prasinophytes are represented by the Tasmanaceae (Plate IV/4, 9a–b), with the genus Tasmanites sp. (Newton 1875), which occur either isolated (Plate IV/9a, b) or in clusters. They are circular to subcircular, sometimes with an opening (the pylome) and no ornamentation. Their size ranges between 30 µm and 600 µm (Maithy 1973). The rather poor state of preservation makes specific identification very difficult.

During our previous study on the ammonites of the Amellagou section, we identified the following species in the *Polymorphum* Zone-*Levisoni* Zone (Benzaggagh *et al*. 2022): *Dactylioceras* (*Eodactylites*) *mirabile*, *D.* (*E.*) *pseudocommune*, *Dactylioceras* (*Orthodactylites*) aff. *Crosbeyi*, *Neolioceratoides* aff. *Hoffmanni*, *Calliphylloceras nilssoni*, *Dactylioceras* (*Orthodactylites*) cf. *semiannulatum*,

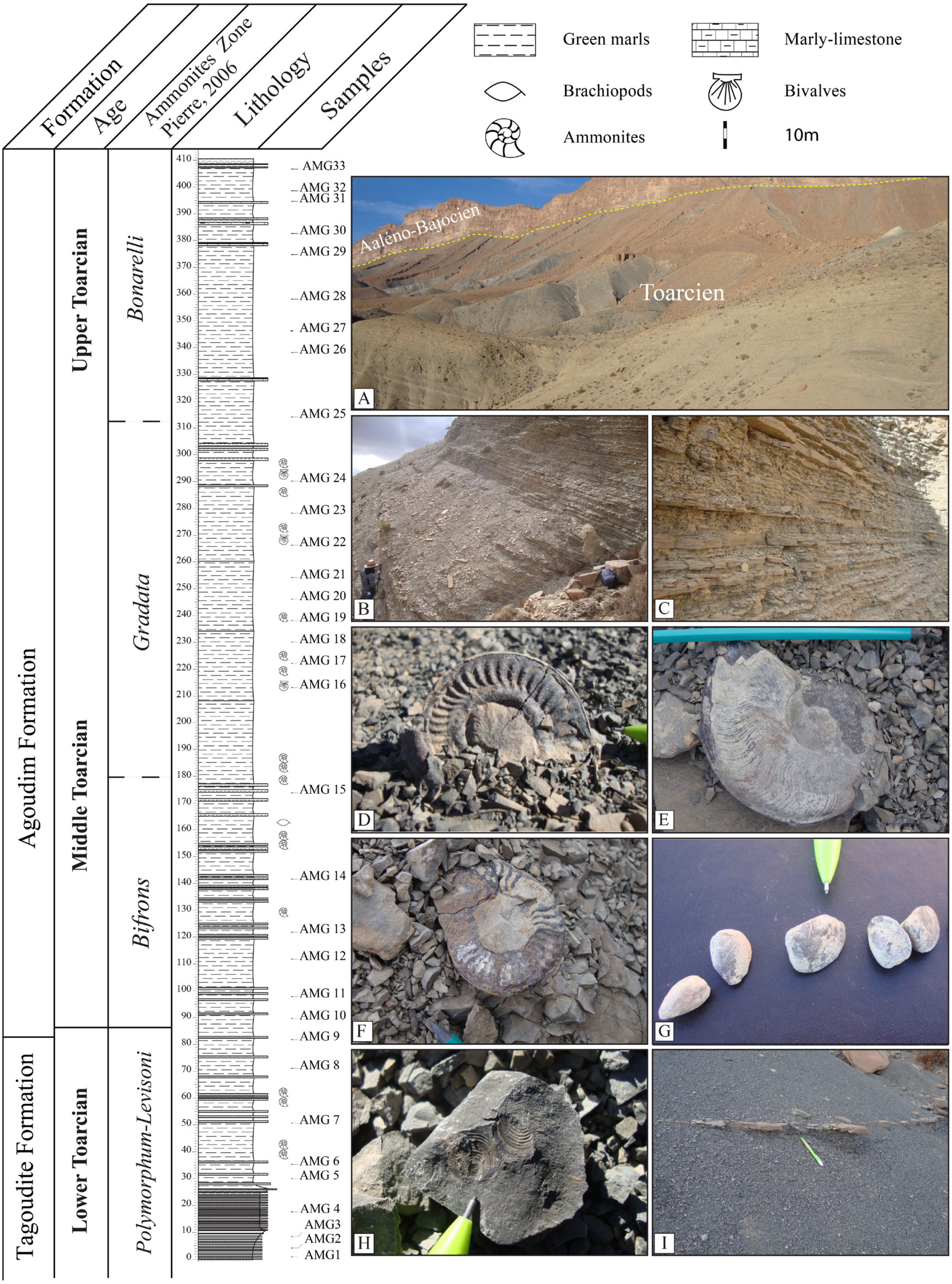


Figure 2. Lithostratigraphy, sampling points and field photograph of key intervals in the Toarcian interval of Amellagou section, Central High Atlas, Morocco. (A) Panoramic view of the studied series; (B, C) The lower part of the section showing alternation of limestone and marl beds; (D, E, F,) Ammonites observed at 60, 130 and 180m; (G, H) Brachiopods found in the marls and marly limestones at 160 m; (I) Example of two marly levels separated by limestone bed.

Table 1. List of dinoflagellate cysts, spores and pollen identified during this study.

Dinoflagellate cysts	Spores and Pollen
Kallosphaeridium sp., Coninck, 1969. *Luehndea cirilliae,* Bucefalo Palliani *et al*., 1997b. *Luehndea spinosa*, Morgenroth, 1970. *Mancodinium semitabulatum,* Morgenroth, 1970. *Moesiodinium* sp., Antonesçu, 1974. *Phallocysta* sp., Dörhöfer and Davies, 1980. *Wallodinium* cf. *cylindricum,* Habib, 1970; Duxbury, 1983. *Mendicodinium microscabratum* Bucefalo Palliani *et al.*, 1997a. *Mendicodinium* sp 1.	*Alisporites* spp., Daugherty, 1941. *Callialasporites* spp., Sukh Dev, 1961. *Classopollis* Pflug 1953. *Cyathidites* spp., Couper, 1953. *Deltoidospora* spp., Miner, 1935. *Ischosporites varegatus,* Couper, 1958; Schulz, 1967. *Kraeuselisporites reissingeri,* Morbey, 1975; Lund, 1980. *Neoraistrickia* spp., Potonié, 1956. *Quadraeculina* spp., Maliavkina, 1949. *Zonalapollenites* spp., Segmentatus Balme, 1957; Dudgeon, 1982.

Eleganticeras exaratum, *Harpoceras falciferum*, *Harpoceras pseudoserpentinum*, *Harpoceras serpentinum*, *Harpoceras subplanatum*, *Hildaites* cf. *forte*, *Hildaites levisoni*, *Hildaites* cf. *serpentiniformis*, *Hildaites* cf. *subserpentinus*, *Hildaites striatus*, *Hildaites wrighti*, *L. siemensi*, *Lytoceras* sp., *Maconiceras soloniacense*, *Phylloceras* sp., *Polyplectus pluricostatum* and *Polyplectus* sp.

These ammonite species were recorded in association with dinoflagellate cysts. The latter are represented by *Mancodinium semitabulatum* (Plate I/6), *Luehndea spinosa* (Plate I/1a, 1b and 1c) and *Luehndea cirilliae* (Plate I/3a, 3b and 3c). *Luehndea spinosa* constitutes an excellent marker of the Pliensbachian–Toarcian interval. It characterizes the lower Toarcian of England (Riding & Thomas 1992) and it does not exceed the *Tenuicostatum* Zone in the northwest of Scotland (Riding *et al*. 1991). The species is considered as a good indicator of the upper Pliensbachian–lower Toarcian interval that marks the *Margaritatus*–*Tenuicostatum* ammonite zones (Riding & Thomas 1992). It characterizes the *Luehndea spinosa* Zone (DSJ7 Zone) corresponding to the lowermost Toarcian (*Tenuicostatum* Zone) (Poulsen & Riding 2003). In northern Morocco, *Luehndea spinosa* was recorded in the lower Toarcian sediments of the South Rifan Ridges (Chahidi *et al*. 2016). This species is present in sample AMG 1 from the Amellagou section (Central High Atlas Basin) and disappear in sample AMG 2. The dinoflagellate cyst *Luehndea cirilliae*, which was described by Bucefalo-Palliani *et al*. (1997, 1999, 2002) and Chahidi *et al*. (2016) from the Pliensbachian–Toarcian in the Tethyan realm, also occurs in the interval. This species has never been found in the Boreal domain.

In association with this marker, we find the species: *Luehndea cirilliae* (Plate I/3a, b, c), *Mancodinium semitabulatum* (Plate I/8) and *Mendicodinium microscabratum* (Plate I/5–6). The first has never been found in the Boreal domain, its known to range within the Pliensbachian–Toarcian interval in the Tethyan realm (Bucefallo-Palliani *et al.* 1997, 1999, 2002, Chahidi *et al.* 2016); the second is distributed between the early Pliensbachian (Feist-Burkhardt & Wille 1992; Poulsen 1996), and the Bajocian, (Bucefallo-Palliani & Riding 2003) and it also characterizes the late Pliensbachian–early Toarcian interval with a large geographical distribution: Boreal, Sub-Boreal, transitional (Boreal/Tethyan) and Tethyan (Brideaux *et al.* 1975, Helden 1977, Bucefallo-Palliani *et al.* 2002, Prauss 1996, Woollau & Riding 1983, Correia *et al.* 2018). It is known to be a Tethyan species, whether in the northern Tethys (Greece, Bucefallo Palliani *et al.* 1999) or in the southern Tethys (Morocco, Chahidi *et al.* 2016 and the present study); this species is recorded from the early Toarcian. *Mendicodinium microscabratum* was first described by Bucefallo-Palliani *et al.* (1997) from the early Toarcian in central Italy. They have been recorded in France, Greece, Hungary, and Portugal by Bucefallo Palliani *et al.* (1995), Bucefallo-Palliani (1996), Bucefallo-Palliani & Riding (1998). This species is rare, only two specimens have been found (sample AMG5). This is in agreement with Bucefallo-Palliani & Mattioli (1998), who also reported its rarity in the early Toarcian of central Italy. In the present work, three specimens were also recorded in sample AMG18 and AMG24 (Bifrons Zone), which implies its presence beyond the early Toarcian, in agreement with Bucefallo-Palliani *et al.* (1998), who reported its presence in the late Toarcian.

Middle Toarcian-Upper Toarcian: Bifrons Zone–Bonarelli Zone

Middle to upper Toarcian interval, 300 m thick, is recognized from sample AMG 10 to sample AMG 33. This interval is collected in the alternation of marls and limestones. It is characterized by the high dominance of pollen grains represented mainly by *Classopollis* sp. (82.9%) in association with ornamented spores. The latter are completely absent at the top of the section. Marine palynomorphs ranges between 16% and 17.1%. They are represented by Tasmanaceae (8.3%), rare acritarchs and foraminiferal test linings (2%), while low percentages of dinoflagellate cysts are the most significant component of the palynomorphs (6% to 6.8%).

Diverse ammonite fauna was documented in the *Bifrons* Zone from the Amellagou section, comprising 8 species (Fig. 3): Eleganticeras sp., *Harpoceras subplanatum*?, *Hildoceras bifrons*, *Hildoceras lusitanicum*, *Hildoceras semipolitum*, *Hildoceras sublevisoni*, *Hildoceras* sp. and *Porpoceras* gr. *Vortex-verticosum*. The dinoflagellate cyst assemblage in this zone is represented by *Mancodinium semitabulatum, Kallosphaeridium* sp. and *Phallocysta* spp. This last genus first appears in the *Bifrons* Zone. It ranges between samples AMG 10 and AMG 33. Its earliest occurrence has been recorded in the Toarcian and its acme has been recognized in the Toarcian–Aalenian interval (Riding 1984a, Below 1987, Riding & Thomas 1992, Feist-Burkhardt 1995).

The ammonite zones *Gradata* and *Bonarelli* (Pierre 2006) are represented by four other dinoflagellate cyst assemblage *Wallodinium* cf. *cylindricum* and *Moesiodinium* sp., *Mendicodinium microscabratum, Mendicodinium* sp1., in addition to the three taxa recorded in the Bifrons Zone.

The lower Toarcian, middle and upper Toarcian assemblages recognized in the Amellagou section are comparable with those recorded in the Sub-Boreal (Riding & Thomas 1992, Feist-Burkhardt & Wille 1992) and the Tethyan realms (Bucefalo-Palliani *et al*. 1997, 1999, 2002, 2003).

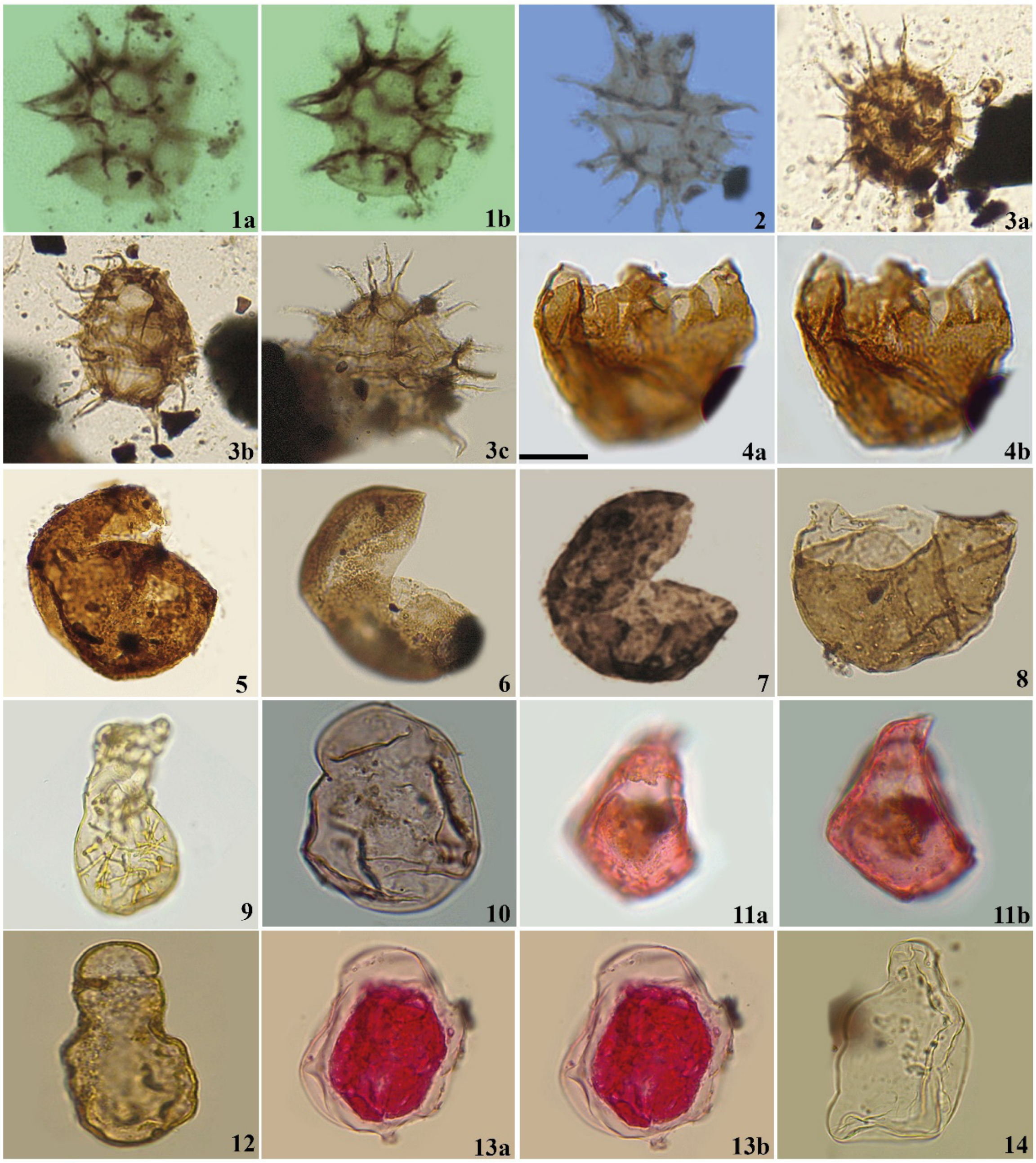
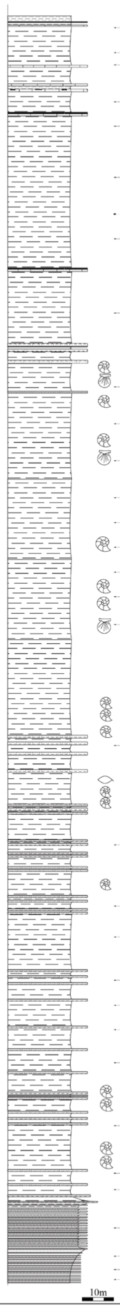


Plate I. Photomicrographs of dinoflagellate cysts from the upper Pliensbachian–lower Toarcian in the Amellagou section, Central High Atlas, Morocco. Each specimen identified by sample, slide number and England finder coordinates. (Magnification 100). Scale bar in Fig. 4a represents 20 µm for all specimens (1-14). 1- 2. *Luehndea spinosa* Morgenroth, 1970: 1a-b, Sample AMG 1, slide a, O39/1. 2, Sample AMG 2, slide a, H12. (Autophragm: Smooth and processes Homomorphic, gonal, solid, straight, conical, distally acuminate). 3. *Luehndea cirilliae* Bucefalo-Palliani *et al.*, 1997: 3a: Sample AMG 3, slide b, N55; 3b: Sample AMG 2, slide b, H12; 3c: AMG 2, slide a, T34/2. (Autophragm microscabrate, with processes Homomorphic, gonal, sinuous and distally acuminate). 4. *Kallosphaeridium* sp. of De Coninck, 1969. 4: Sample AMG 19, slide a, S14. 4a: Focus on the archeopyle. 5-6. *Mendicodinium microscabratum* Bucefalo Palliani *et al.*, 1997a. 5: Sample AMG 5, Slide a, F33; 6: Sample AMG24, T37/4. 7. *Mendicodinium* sp1., Sample AMG18, Slide a, S21. (The archeopyle is epicystal, and the paratabulation is discernable by the archeopyle and sulcus. A few small processes, straight or sinuous, are visible all over the wall). 8. *Mancodinium semitabulatum* Morgenroth, 1970: Sample AMG 8, slide a, U15. (Hypocyst only). 9-10. Phallocysta spp. of Dörhöfer & Davies, 1980: 9: Sample AMG 32, slide a, L51. 10: Sample AMG 33, slide a, I5/1. 11. *Phallocysta eumekes* Dörhöfer & Davies, 1980. Sample AMG 33, Slide a, H12. (11a: focus on the archeopyle, 11b: focus on the corne). 12. *Wallodinium* cf. *cylindricum* Habib, 1970, Duxbury, 1983. Sample AMG 30, slide a, V41/2. (Archaeopyl apical, with a wall not-rectilinear, sinuous). 13. *Moesiodinium* sp. of Antonesçu, 1974. 13(a-b): Sample AMG 31, slide a, T10. (13a-b: the same specimen, presence of the intercalary archeopyle). 14. Dinoflagellate Indet. Sample AMG 31, Slide a, F23.



Stage	Ammonite Zone (Benzaggagh et al.,2022)	Samples	Ornamented Spores: *Kraeuselisporites reissingeri*	Ornamented Spores: *Ischyosporites variegatus*	Ornamented Spores: *Neoraistrickia* sp.	Smooth Spores: *Cyathidites minor*	Pollen: *Classopollis* spp.	Pollen: *Alisporites* sp.	Pollen: *Quadraeculina* sp.	Pollen: *Callialasporites trilobatus*	Dinoflagellate cysts: *Luehndea spinosa*	Dinoflagellate cysts: *Luehndea cirilliae*	Dinoflagellate cysts: *Mancodinium semitabulatum*	Dinoflagellate cysts: *Mendicodinium microscabratum*	Dinoflagellate cysts: *Kallosphaeridium* sp.	Dinoflagellate cysts: *Phallocysta* spp.	Dinoflagellate cysts: *Mendicodinium* sp1	Dinoflagellate cysts: *Wallodinium cf. cylindricum*	Dinoflagellate cysts: *Moesiodinium* sp.	Prasinophytes: *Tasmanites*	Acritachs: *Micrhystridium*	Ammonite Zone (Pierre, 2006)
Middle Toarcian-Upper Toarcian		AMG 33					99						3		1	5				8		*Bonarelli*
		AMG 32					96			28			1		1	4		2	2	10		
		AMG 31					102			22			4					4	2	11		
		AMG 30				8	50						1		1	1		1		5	2	
		AMG 29					82								6					7		
		AMG 28					116															
		AMG 27					99								6	3				9		
		AMG 26																				
		AMG 25																				*Gradata*
		AMG 24					124						8	2						11		
		AMG 23					82						6							7		
		AMG 22					82						7							7		
		AMG 21					33								3					3		
		AMG 20					165								9	4				14		
		AMG 19					207								11	6				16		
		AMG 18		29		10	126						12				1			12	2	
		AMG 17					124						4		3	4				10		
		AMG 16	20				62								6					7		
	Bifrons	AMG 15																				*Bifrons*
		AMG 14					82								6					6		
		AMG 13					107								6	4				9		
		AMG 12		10	9	5	100	8					9		2					12	1	
		AMG 11		33	10		122						13							20	1	
Lower Toarcian	*Polymorphum-Levisoni*	AMG 10	20		10		82						2		1	1				16	2	*Polymorphum-Levisoni*
		AMG 9	18				48						2							8	1	
		AMG 8	15				42													6		
		AMG 7	22				60													10		
		AMG 6	57				100	19	20											20	3	
		AMG 5	42	3		8	98	5	10				3	2						15	1	
		AMG 4	45				121													15	1	
		AMG3	40	6			121					5								15	1	
		AMG2	57				152				3	2								20	2	
		AMG1	45				121				3		1							15	1	

Green marls | Marly-limestone | Ammonites | Bivalves | Brachiopods

Figure 3. Distribution table of palynomorphs identified in the Amellagou section.

Biostratigraphic discussion

Quantitative and qualitative analysis of 33 samples from the Amellagou section of lower Toarcian (*polymorphorum* Zone–*Levisoni* Zone) – middle Toarcian / upper Toarcian (*Bifrons* Zone–*Bonarelli* Zone) age shows the dominance of the continental fraction (spores and pollen grains) over the marine fraction. There is a significant similarity between our associations and those defined in the Sub-Boreal and North Tethyan domains (Davies 1985, Koppelhus & Dam 2003, De Oliveira *et al*. 2007), characterized mainly by the acme of *Classopollis*.

The presence of ornamented spores with cones, spines or bacules in the lower Toarcian is a phenomenon already reported in other regions from the Sub-Boreal domain, such as in northwest Europe (Herngreen & Boer 1974, Smith 1978, Boutet 1981) and the South Tethyan domain, such as in Morocco (Chahidi *et al*. 2016). This could be considered as a characteristic event of the Upper Pliensbachian–Lower Toarcian interval, associated with the climatic conditions (see sub-chapter «Paleoclimatic reconstruction» in this paper). The presence and the high dominance of *Classopollis* sp. in the Amellagou section has also been documented by some authors in other localities, such as in Poland (Muir-Marjorie 1967) and in southern England (Smith 1978). For the Lower Jurassic, the gymnosperm pollen *Classopollis* is quantitatively the most important and the most significant component of the sporomorphs in the Mesozoic with a worldwide scale. It corresponds to a fossil family of conifera that differs from all living families (Reyre 1973).

The other taxa *Ischyosporites variegatus* and *Callialasporites turbatus* are cosmopolitan. They mark the Toarcian of the Tethyan domain and particularly the northwest of Europe (Saad 1963, Morbey 1978, Smith 1978, Srivastava 1987, Bassoullet *et al*. 1991, Batten & Koppelhus 1996). *Ischyosporites variegatus* characterizes the Lower Jurassic; its first occurrence has been recorded in the Hettangian (Adloff *et al*. 1974, Guy-Ohlson 1986, Batten & Koppelhus 1996). The genus *Callialasporites* was considered as worldwide event of the Early Jurassic-Middle Jurassic transition (Smith 1978). The first appearances of this genus were noticed in the upper Toarcian and its abundance spike was recorded during the Middle Jurassic. This is in perfect agreement with our results. It was recorded at the top of the section between samples AMG 31 and AMG 32, characterizing the upper Toarcian age. Dinoflagellate cyst assemblages are poor, their low diversity show only seven species. The scarcity of dinoflagellate cysts in the Toarcian is a typical phenomenon in the Tethyan realm (Buceffalo-Pallian *et al*. 2002). Despite the limited number of dinoflagellate cyst studies in this domain on the Lower Jurassic, particularly the Toarcian, the associations cited by Smith (1978), Dodekova (1990), Bucefalo-Palliani & Mattioli (1998), Bucefalo-Palliani *et al*. (2002) and Dino et al. (2007) are similar to those of the Toarcian in Southern Rifan Ridges of Morocco and in the Amellagou section. However, in the Sub-Boreal domain especially in England from the northwest of Europe (Riding *et al*. 1991 and Riding & Thomas 1992) note a high richness and diversity in the *Bifrons* Zone.

Despite the poverty of dinoflagellate cysts in the samples, the result is significant since the species *Luehndea spinosa*, a marker of high importance has been recorded in the lower Toarcian in the Southern Rifan Ridges (Chahidi *et al*. 2016) as well as in the lower Toarcian of the High Atlas of Amellagou (present study). This could qualify the species *Luehndea spinosa* as a marker of the lower Toarcian of the Southern Tethys.

Several authors (Buceffalo-Palliani & Riding 1997, 1999, 2003, Buceffalo-Pallian *et al*. 2002) thought that the species *Luehndea spinosa* had a Tethyan origin before migrating to the Boreal Province, where it reached its greatest abundance in the Toarcian. However, this taxon has also been recorded in the Pliensbachian of NW Europe (Germany and England) and the Artic (Van de Schootbrugge *et al*. 2019), which makes it cosmopolitan.

Like *Luehndea spinosa*, the taxon *Nannoceratopsis* sp., was at first considered to be originally from the Tethyan realm (Buceffalo-Pallian & Riding 1999), as its abundance in the boreal realm is evidenced by its constant presence in the Toarcian of NW Europe (Buceffalo-Pallian & Riding 1999, Baranyi *et al*. 2016). This taxon is rare to absent in the Southern Tethys (Mediterranean province or bioprovince; Buceffalo-Palliani & Riding 1997b, 1999, 2003), in the Sud Rifan Ridges (Chahidi *et al*. 2015) and in the Central High Atlas, Amellagou (Present study). However, it has recently been recorded in the Moroccan Middle Atlas (*Polymorphum* Zone) (Rodrigues *et al*. 2020). In agreement with Riding (1983), the rarity or absence of these taxa may be related to the ecological conditions of the environment and not to the palaeolatitudinal distribution of dinoflagellate cysts.

Palynofacies and paleoclimatic reconstruction

Palynofacies analysis

The palaeoenvironmental reconstruction, based on quantitative analyses of organic matter components, allows the recognition of the sedimentary depositional environments, the characterization of organic matter types and the type of produced hydrocarbons depending on thermal maturation level. In the present study, Tyson's (1993, 1995) method is used. For each sample, a total of 250 palynomorph and palynodebris grains were included in the palynofacies count. The amorphous organic matter – phytoclast - palynomorphs ternary kerogen plot of Tyson (1993, 1995) enabled us to determine the distribution and organization of each identified palynofacies giving in turn an indication about the kerogen quality. Thus, in addition to determining the oxic-anoxic conditions of the basin, the three parameters, amorphous organic matter, phytoclasts, and palynomorphs, can be placed in one of the four-kerogen types: Type I, Type II, Type III or Type IV (Harwood 1977, Tissot & Welte 1984, Tyson 1995).

Quantitative and qualitative analysis of all organic residues from the Amellagou section samples revealed palynofacies rich in phytoclasts ranging from 61.2% to 91.6% (Fig. 4). Spores and pollen grains dominate the palynomorphs, reaching 80% in the *Bifrons* Zone. Amorphous organic matter (AOM) is relatively rare between samples AMG 1 and AMG 7, its relative abundance rarely exceed 3%, whereas it occurred in all the sediments of middle-upper Toarcian age where it reaches 25% in sample AMG 21.

The ternary diagram of Tyson (1993, 1995) shows that the samples belong to fields I, II, and IV (Fig. 4). These fields point to a proximal environment (field I) fluctuating to a marginal basin (field II) under anoxic-dysoxic conditions. Field IV represents a transitional environment between fields I and II or between fields II and III. The type of kerogen would be type III, with immature organic matter.

The reconstruction of the palaeoenvironment depend on quantitative and qualitative palynofacies characteristics. To assess the evolution of the palaeoenvironment, we have subdivided the Amellagou section into three distinct intervals:

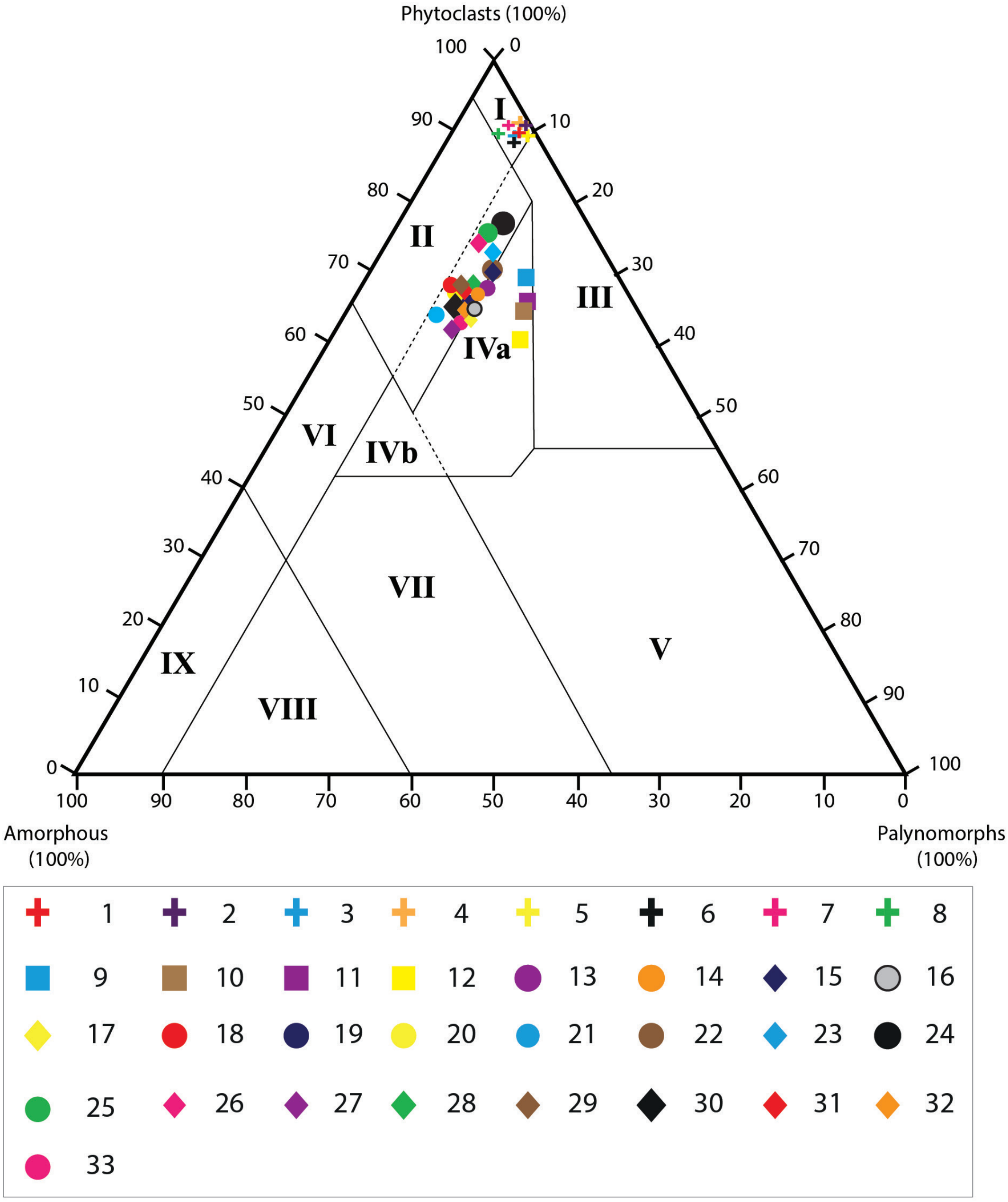


Figure 4. Ternary MOA-Phytoclasts-Palynomorphs plot of the Amellagou section (Tyson, 1993). Palynomorphs = spores + pollen + foraminifera + dinoflagellate cysts + Acritarchs + other marine algae; MOA = amorphous organic matter. Field I = type III kerogen, Field II = type III kerogen; Field III = type III or IV kerogen; Field IV = type III or II kerogen; Field V = type III or IV kerogen; Field VI = type II kerogen; Field VII = type II kerogen; Field VIII = type II or I kerogen; Field IX = type II or I kerogen.

Interval A (AMG 1–AMG 8 (*Polymorphum* Zone–*Levisoni* Zone)). In this interval, phytoclasts, spores and pollen grains dominate the organic residue (up to 90%). Samples are plotted in palynofacies field I, which corresponds, according to Tyson (1995), to a proximal continental shelf environment (Figs. 4–5). The continental influence and proximity to the terrestrial organic matter sources are indicated by large wood debris of different sizes, opaque particles and ornamented spores. These dense particles show low transport efficiency whose distribution is controlled by hydrodynamic equivalence Reyre (1973). The presence of *Tasmanites* (prasinophytes) indicates fresh or brackish water inputs in the depositional environment (Guy-olhlson 1986, Van de Schootbrugge *et al*. 2005).

Thus, the presence of ornamented spores (Fig. 6), in association with abundant black, opaque phytoclasts of various sizes, *Classopollis* pollen, and prasinophytes indicates that the sediments in interval A were deposited in a proximal marine environment.

Interval B (AMG 9–AMG 33 (*Bifrons* Zone–*Bonarelli* Zone)). This interval of middle-upper Toarcian age extends from sample AMG 9 to sample AMG 33. It is generally characterized by the dominance of phytoclasts, reaching 62–77% of total organic matter (Fig. 6). This interval shows a significant increase in the relative abundance of amorphous organic matter (10–25%). The MOA-Phytoclasts-Palynomorphs diagram of Tyson (1993 and 1995) shows two

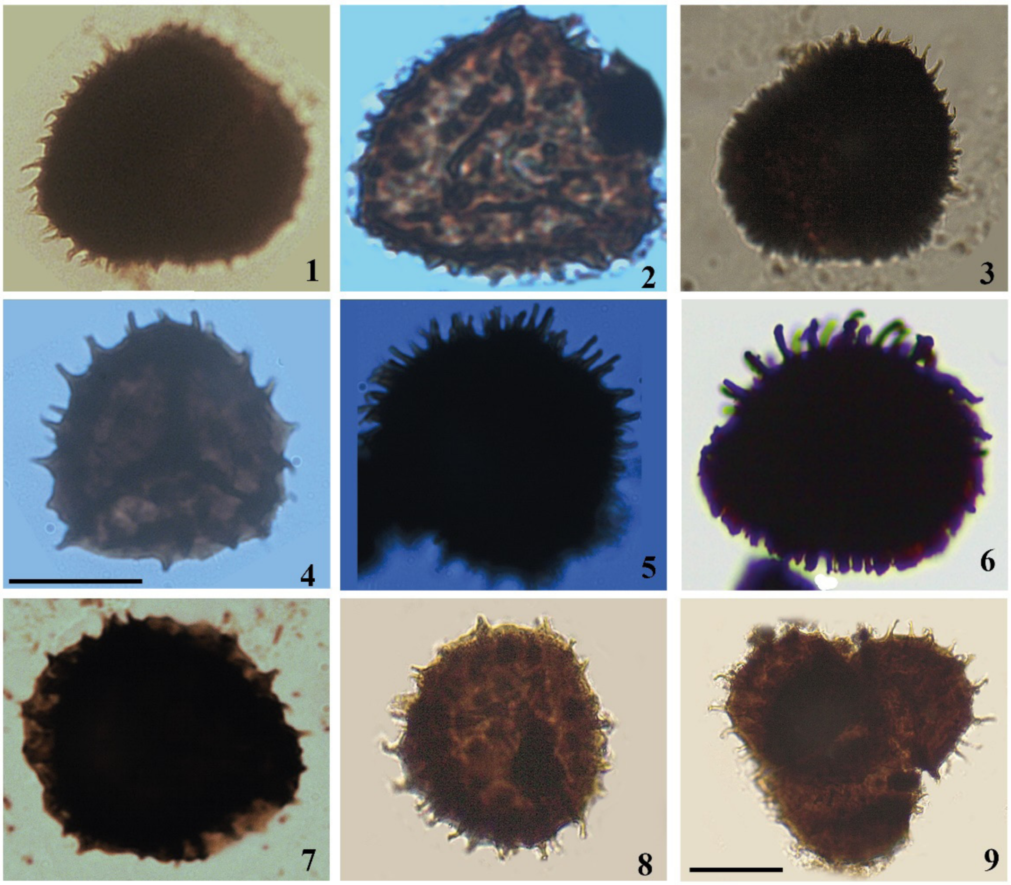


Plate II. Photomicrographs of ornamented spores from the upper Pliensbachian–lower Toarcian in the Amellagou section, Central High Atlas, Morocco. Each specimen identified by sample, slide number and England finder coordinates. Scale bars in Fig. 5; 9 represent 20 µm for all specimens (1-9). 1-2-3-4. *Kraeuselisporites reissingeri*, Group (Harris) Morbey 1975. 1: Sample AMG 1, Slide a, D24, 2: Sample AMG 10, Slide a, N27/2, 3: Sample AMG 5, Slide b, G34/2, 4: 4: Sample AMG 11, Slide a, Q32. 5-6. *Neoraistrickia*? spp., Potonié, 1956. Sample AMG1. 5: Sample AMG 8, Slide a, H13/2, 6: Sample AMG 7, Slide a, F23. 7-8. *Kraeuselisporites reissingeri*, (Harris) Morbey, 1975. 7: Sample AMG 16, Slide a, D43, 8: Sample AMG 4, Slide b, G14/2. 9. Tetrad *Kraeuselisporites reissingeri*, (Harris) Morbey, 1975. Sample AMG 4, Slide a, G34.

types of palaeoenvironments allowing us to subdivide the interval B into two sub-intervals:

1) Sub-interval **B1** (AMG 9–AMG 12 (top of the *Levisoni* Zone–base of the *Bifrons* Zone)). In this sub-interval, all samples belong to field IV in the ternary diagram of Tyson (1995). According to this author, the field IV represents the transition from a proximal continental shelf environment to marginal basin settings under anoxic-dysoxic conditions.

2) Sub-interval **B2** (AMG 13–AMG 32 (*Bifrons* Zone–*Bonarelli* Zone)). The 19 samples of this interval, of middle–upper Toarcian, belong to field II in the ternary diagram of Tyson (1995). This field corresponds to marginal basin environment under anoxic-dysoxic conditions. This is reflected by the dominance of the terrigenous material (spores, pollen and phytoclasts). The anoxic-dysoxic conditions are reflected by the presence of opaque particles with elongate and equidimensional shapes (Tyson 1993). These woody phytoclasts are comparable to detritus particles, whose spatial distribution depends mainly on hydrodynamics (Tyson 1995). The morphology of these particles, long like needles, witnesses long periods of floating in relatively significant water depth (Courtinat 2000).

Therefore, the previous findings suggest that the middle Toarcian-upper Toarcian (*Bifrons* Zone–*Bonarelli* Zone) records a marginal basin environment under dysoxic anoxic conditions (Fig. 5).

Palynofacies discussion

In the Central High Atlas, the continental organic matter, especially opaque, translucent phytoclasts and sporomorphs, dominates the sedimentary organic matter as previously reported by Bodin *et al*. 2010.

The palynofacies analysis indicates that the palaeoenvironment of the lower Toarcian (*Polymorphum* Zone–*Levisoni* Zone), recognized in the Amellagou section, may be of proximal continental shelf with a high terrestrial input as manifested by phytoclasts, spores, pollen and prasinophytes. The latter reflects the presence of fresh or brackish water in the depositional environment (Guy-olhlson 1986, Van de Schootbrugge *et al*. 2005).

The middle–upper Toarcian recorded an increase of the relative abundance of palynomorphs and amorphous organic matter. This could be related to the increased paleo-productivity. Bodin *et al.* (2016) have documented this event through carbon isotope analysis obtained from the Amellagou section. According to these authors, changes in carbon and phosphorus isotope content recorded in the Amellagou section show a pronounced positive isotope shift during the

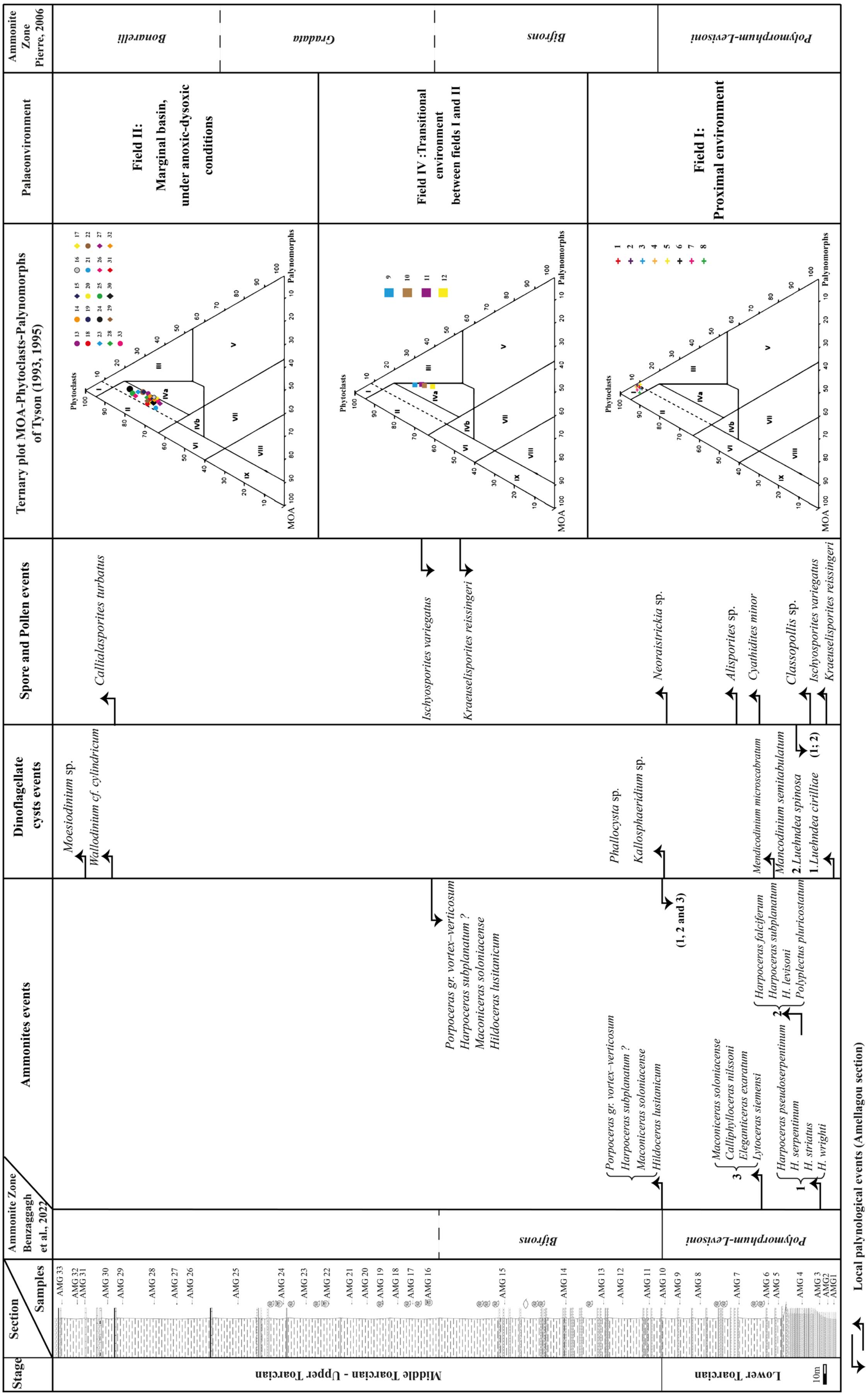


Figure 5. Biostratigraphic and palaeoenvironmental evolution during the lower Toarcian, middle-upper Toarcian in the Amellagou section.

Bifrons Zone, followed by a second less significant shift in the *Gradata* Zone. Positive changes in carbon isotope values are generally interpreted as reflecting enhanced primary productivity and preserved organic matter (Broecker & Peng 1982, Arthur *et al*. 1987, Weissert 1989, Weissert *et al*. 1996, Bodin *et al*. 2016).

The presence of Tasmanaceae indicates particular palaeoenvironmental conditions. Their spatial distribution depends on the physicochemical conditions of the photic zone, sea level and climate as suggested by Prauss & Riegel (1989) and Bucefalo-Palliani *et al*. (2002). According to the latter authors, green algae (*Prasinophyceae*), which use reduced nitrates, seem to be the best adapted and proliferate in oxygen-deficient environments, unlike other algae types. Bucefalo-Palliani *et al*. (2002) interpret the presence of *Tasmanites* and the scarcity of dinoflagellate cysts in marine sediments by a decrease in water salinity in the photic zone and prevailing anoxic conditions.

According to Rohl *et al*. 2001, the decrease in salinity could be explained by freshwater input resulting from intense summer monsoon with high freshwater runoff within the Tethys. This low salinity in the depositional environment could explain the absence of some euryhaline taxa, such as the genus *Nannoceratopsis*. In agreement with Riding (1983), the absence of this taxon in the Tethyan domain is related to ecological conditions and not to the latitudinal distribution of dinoflagellate cysts. These confined conditions during the Toarcian in the High Atlas Basin explain the constant and continuous occurrence of opportunist cysts such as *Phallocysta* spp. unlike other anoxic intolerant taxa with episodic presence.

Paleoclimatic reconstruction

A warm climate was prevailing during the Jurassic Smith (1978), with high stands of global sea level as a response to the glaciers melt at the poles (Arkell 1956, Bowen 1967, Smith 1978).

The aridity of the climate recorded in the Upper Triassic was confirmed by the abundance of the pollen *Cheirolepidiaceae* (*Classopollis*; Vakhrameev 1981). Furthermore, the

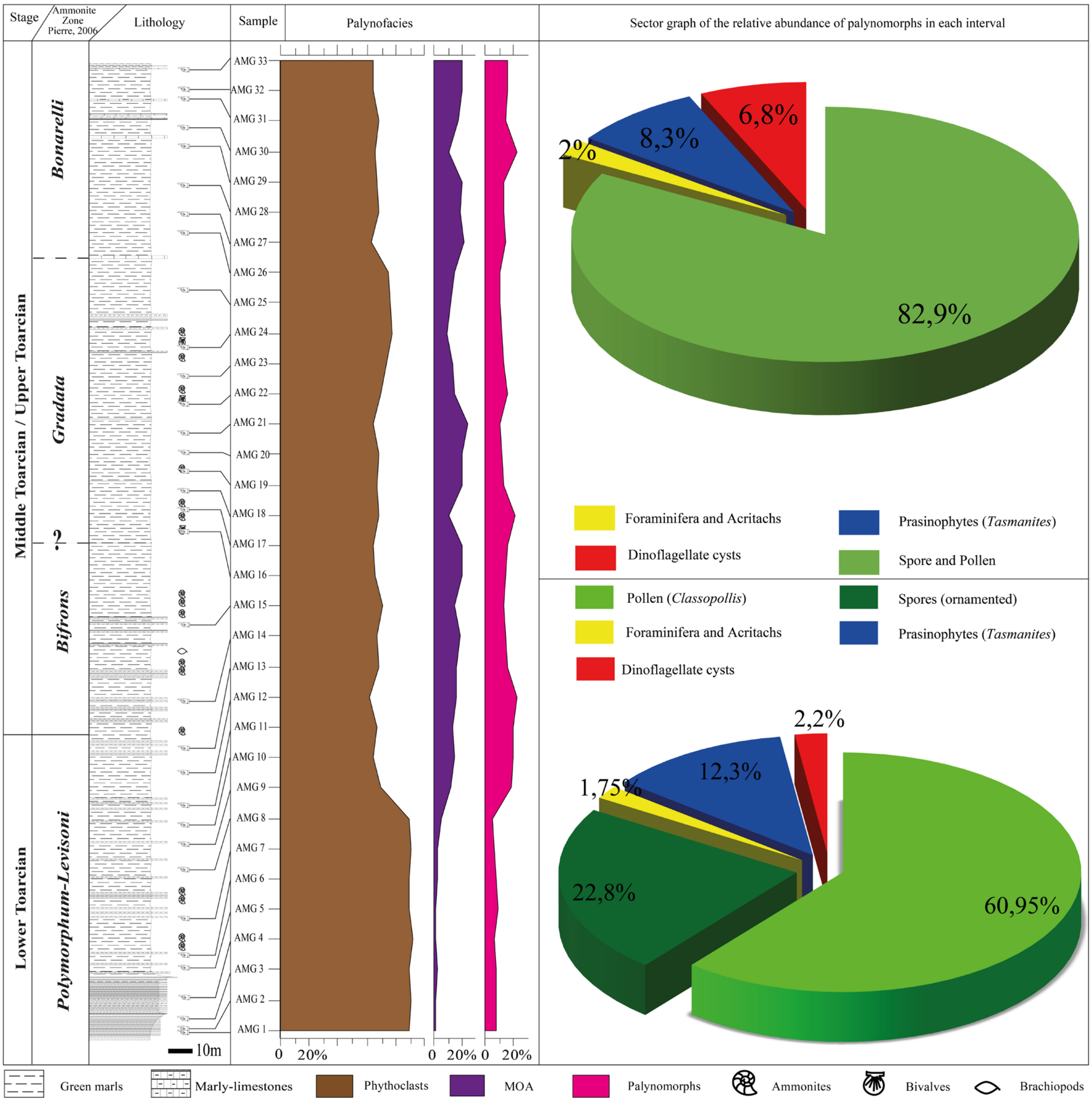


Figure 6. Relative abundance of organic matter components and palynomorphs in the Amellagou section.

opening of the Neotethys at the Upper Triassic (Vozenin-Serra & Taugourdeau-Lantz 1985) and the global marine transgression recorded during the Early Jurassic (Vail *et al*. 1977) have caused conditions of increasing humidity, which affected the flora distribution. Humid conditions have been recorded in the sediments through hygrophilic taxa, as for the species *Kraeuselisporites reissingeri*, whose relatively high abundances constitute an acme zone recorded during the Hettangian. Arid conditions reappeared at the Pliensbachian–Toarcian transition, and then the climate changed from semi-arid to humid with an increased fluvial-deltaic terrigenous material input (Wilmsen & Neuweiler 2008). Flora has been renewed by the increase of hygrophilic species in response to the climatic changes, and then conifers have shown their dominance pointing out a new arid climatic conditions phase (Davies 1985). This is supported by the dominance of *Classopollis* spp., belonging to the family *Cheirolepidiaceae* that produces large quantities of pollen grains (Jarzen & Nichols 1996). This climatic cyclicity could be related to the lithological cyclicity of the Lower Jurassic facies in our region (marl-limestone alternation). Indeed, Delfaud's (1994) sedimentological data show the existence of variations in the latitudinal zonation of the facies during the Jurassic. According to this author, this zonation is linked to eustatic pulsations and climatic variations. The depositional environment would correspond to a marginal, anoxic-dysoxic (confined) basin environment. This is recorded in the studied sediments through quantitative and qualitative palynological analysis. The significant relative abundance of phytoclasts (91.6%) coupled with that of spores and pollen (82%) confers to our samples the character of "marginal".

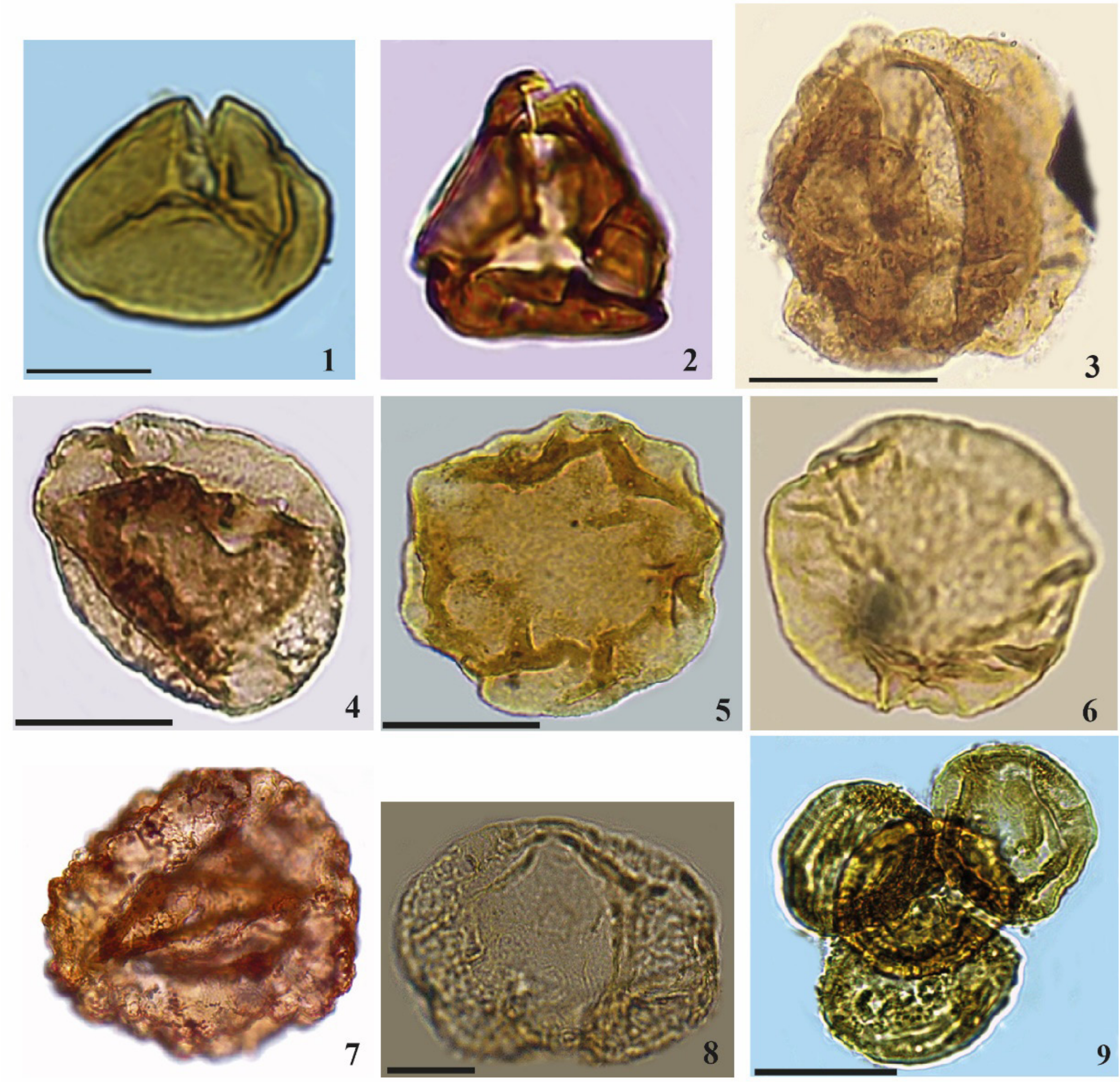


Plate III. Photomicrographs of spores from the upper Pliensbachian-lower Toarcian in the Amellagou section, Central High Atlas, Morocco. Each specimen identified by sample, slide number and England finder coordinates. Scale bar in Figs. 1, 3, 4, 5, 8 and 9 represents 20 µm for all specimens. 1. *Cyathidites* sp. Couper, 1953. Sample AMG 12, Slide a, S20/1. 2. *Cyathidites australis* Couper, 1953. Sample AMG 18, Slide b, G7. 3. *Quadraeculina* sp. Maliavkina, 1949. Sample AMG 6, Slide a, D12. 4. *Callialasporites turbatus* Schulz, 1967. 4: Sample AMG 10, Slide a, H46. 5: Sample AMG 12, Slide a, S12/3. 5-6-7. *Callialasporites* spp. Dev, 1961. 5: Sample AMG 12, Slide a, S12/3, 6: Sample AMG 12, Slide a, R3, 7: Sample AMG 7, Slide b, G32. 8. *Alisporites robustus* Nilsson, 1958. Sample AMG 6, Slide a, S39. 9. Tetrad *Classopollis* sp. Pflug, 1953. Sample AMG 7, Slide a, N54.

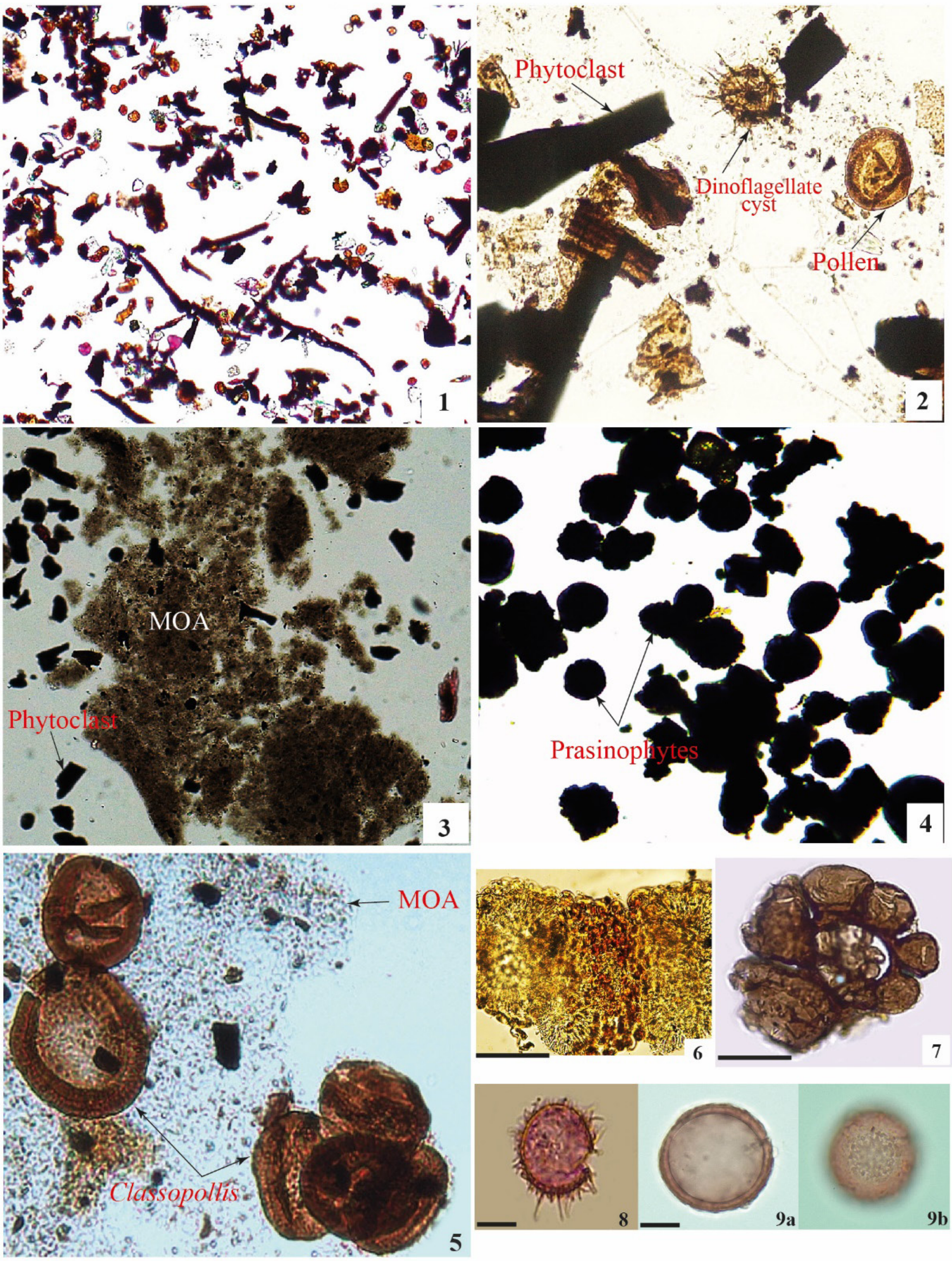


Plate IV. Photomicrographs of palynofacies from the upper Pliensbachian-lower Toarcian in the Amellagou (AMG) section, Central High Atlas, Morocco. Each specimen identified by sample, slide number and England finder coordinates. Scale bar is 20 µm in figures 1 to 5 and 100 µm in figures 6 to 10. 1. Palynofacies (palynomorphs, phytoclasts). Sample AMG 4, Slide a, D13. (Magnification *20). 2. MOA, phytoclasts and palynomorphs (pollen grains and dinoflagellate cysts). Sample AMG11, Slide a, S33. (Magnification *40). 3. Oxidized phytoclasts and MOA. AMG 21, Slide b, V26. (Magnification *40). 4. Oxidized prasinophytes. Sample AMG 4, Slide a, H8. 5. *Classopollis* and MOA. AMG 20, Slide a, G25. 6. *Botryococcus* (Algae). Sample AMG 9, Slide a, L40. 7. Foraminiferal test lining. Sample AMG 13, Slide a, O17. 8. Acritarch. Sample AMG 10, Slide b, L3. 9. *Tasmanites* (prasinophytes). 9a-b: Sample AMG 5, Slide a, S13.

CONCLUSION

The present palynological study on the Toarcian successions (top of the *Polymorphum* Zone–*Bonarelli* Zone) revealed valuable information despite the quality of preservation of the marine palynomorphs and their low relative abundance compared to phytoclasts. We assigned the lower part of the section to the lower Toarcian and its upper part to the middle–upper Toarcian. The presence of marker taxa in our sediments allowed us to correlate with associations from other contemporary paleogeographic domains.

Palynological data refined the assessment of depositional palaeoenvironments through quantitative and qualitative analysis of the organic matter. The Pliensbachian–Toarcian transition (base of the Amellagou section) recorded a wet phase indicated by hygrophilic taxa (ornamented spores). The wet conditions are followed by an episode of arid climate indicated by an abundance of *Classopollis* recorded during the lower Toarcian (top of the *Polymorphum* Zone–*Levisoni* Zone) with deposition in a proximal continental shelf palaeoenvironment. This episode is directly followed by anoxic-dysoxic conditions in the marginal basin during the middle–upper Toarcian (*Bifrons* Zone–*Bonarelli* Zone), denoted by the high relative abundance of black and needle-like phytoclasts. Amorphous organic matter (MOA) is found in this interval with variable proportions as well as palynomorphs, which are highly dominated by *Classopollis*.

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REFERENCES

Adloff M.C., Doubinger J. & Geisler D. 1982. Étude palynologique et sédimentologique dans le Muschelkalk moyen de Lorraine. *Sciences de la Terre*, 25(2), 91–104.

Adloff M.C., Doubinger J. & Palain G. 1974. Contribution à la palynologie du Trias et du Lias inférieur du Portugal. « Grès de Silves » du Nord du Tage. *Commission du service géologique. Portugal,* 58, 91–144.

Aït Addi A. 1998. Nouvelles données sédimentologiques et géodynamiques sur les faciès de l'Aalénien-Bajocien inférieur du Haut Atlas marocain (Nord d'Errachidia). *Comptes Rendus de l'Académie des Sciences - Series IIA - Earth and Planetary Science (Paris)*, 326, 193–200.

Aït Addi A. 2000. Les séries du Dogger moyen du Haut Atlas au Nord d'Errachidia (Maroc) : Lithostratigraphie et sédimentologie d'une nouvelle formation, la formation Tazigzaout. *Géologie Méditerranéenne*, 27(1–2), 57–69.

Aït Addi A. 2002. *Les séries du Dogger du Haut Atlas marocain (Nord d'Errachidia-Boudenib) : Lithostratigraphie, sédimentologie, stratigraphie séquentielle, cyclostratigraphie et évolution géodynamique*. PhD. Thesis, University Ibn Tofail, Kénitra (Maroc), 242 p.

Amour F., Mutti N., Christ N. *et al*. 2013. Outcrop analog for an oolitic carbonate ramp reservoir : A scale-dependent geologic modeling approach based on stratigraphic hierarchy. *The American Association of Petroleum Geologists*, 97, 845–871.

Antonesçu E. 1974. Un nouveau genre de dinoflagellé dans le Jurassique moyen de Roumanie. *Revue de micropaléontologie*, 17, 61–65.

Arkell W.J. 1956. Jurassic Geology of the World. Oliver and Boyd, Edinburgh. *Geological Magazine*, 94(4), 340.

Arthur M.A., Schlanger S.O. & Jenkyns H.C. 1987. The Cenomanian-Turonian Anoxic Event, II Paleoceanographic Controls on Organic Matter Production and Preservation. In J. Brooks and A. Fleet (eds.), *Marine Petroleum Source Rocks, Geological Society Special Publication,* 26, 401–420.

Baranyi V., Pálfy J., Görög Á. e*t al*. 2016. Multiphase response of palynomorphs to the Toarcian oceanic anoxic event (Early Jurassic) in the Réka Valley section, Hungary. *Review of Palaeobotany and Palynology*, 235, 51–70.

Bassoullet J.P., Lachkar G., Baudin F. *et al*. 1991. Global stratigraphy in the Moroccan Toarcian (South-Rifan Ridge and Middle Atlas) [Stratigraphie integree dans le Toarcien du Maroc (Rides Sud Rifaines et Moyen Atlas)]. *Bulletin de la Société Géologique de France*, 162(5), 825–839.

Batten D.J. & Koppelhus E.B. 1996. Chapter 20D. Biostratigraphic significance of upper-most Trias and Jurassic miospores in Northwest Europe. In: Jansonius, J., McGregor, D.C. (Eds.), Palynology: principles and applications. *American Association of Stratigraphic Palynologists Foundation*, 2, 795–806.

Baudin F., Herbin J.P., Bassoullet J.P. *et al*. 1990. Distribution of Organic Matter during the Toarcian in the Mediterranean Tethys and Middle East. In A.Y. Huc (Ed.): Deposition of Organic Facies. *American Association Petroleum. Geol. Studies in Geology*, 30, 73–91.

Below R. 1987. Evolution and systematics of dinoflagellate cysts from the Peridiniale order. II. Cladopyxiaceae and Valvaeodiniaceae [Evolution und Systematik von Dinoflagellaten-Zysten aus der Ordnung Peridiniales. II. Cladopyxiaceae und Valvaeodiniaceae.] *Paleontographica Abteilung,* 206 (1), 1–115.

Benzaggagh M., Khaffou H., Salamon M.A. *et al*. 2022. Toarcian ammonites from the central High Atlas (Morocco). *Annals of Paleontology*, 120(2), 102540.

Bernasconi R. 1983. *Géologie du Haut Atlas de Rich (Maroc).* Doctorat Thesis, University Neuchâtel, 107.

Bjaerke T. 1980. Mezosoic palynology of Svalbard IV. Toarcian dinoflagellate from Spitsbergen. *Palynology,* 4, 57–77.

Blomeier D.P.G. & Reijmer J.J.G. 1999. Drowning of a lower Jurassic carbonate platform: Jbel bou Dahar, high atlas, Morocco. *Facies*, 41, 81–110.

Bodin S., Hönig M.R. Krencker F.N. *et al*. 2017. Neritic carbonate crisis during the Early Bajocian: Divergent responses to a global environmental perturbation. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 468, 184–199.

Bodin S., Krencker F.N., Kothe T. *et al*. 2016. Perturbation of the carbon cycle during the late Pliensbachian–early Toarcian: New insight from high-resolution carbon isotope records in Morocco. *Journal of African Earth Sciences*, 116, 89–104.

Bodin S., Mattioli E., Fröhlich S. *et al*. 2010. Toarcian carbon isotope shifts and nutrient changes from the Northern margin of Gondwana (High Atlas, Morocco, Jurassic): Palaeoenvironmental implications. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 297, 377–390.

Boutet C. 1981. Etude palynoplanctologique du Trias et du Jurassique inférieur et moyen de Grésigne-Sud Quercy. *Travaux des Laboratoires de Géologie Méditerranéenne Associé au C.N.R. S*, 1–161.

Bowen F.E. 1967. Early Pleistocene glacial and associated deposits of the West Coast of the South Island, New Zealand. *New Zealand Journal of Geology and Geophysics*, 10(1), 164–181.

Brame H.M. R., Martindale R.C., Ettinger N.E. *et al.* 2019. Stratigraphic distribution and paleoecological significance of Early Jurassic (Pliensbachian–Toarcian) lithiotid-coral reefal deposits from the Central High Atlas of Morocco. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 514, 813–837.

Brechbühler Y.A. 1984. *Étude structurale et géologique du Haut-Atlas calcaire entre Jbel Ayachi et Rich (Maroc)*. Doctorat Thesis, University Neuchâtel, 128.

Brideaux W.W., Chamney T.P., Dunay R.E. *et al.* 1975. Biostratigraphic determinations of fossils from the subsurface of the Districts of Franklin and MacKenzie. *Geological Survey of Canada, Paper*, 74(39), 1–19.

Broecker W.S. & Peng T.H. 1982. Tracers in the Sea. Lamont-Doherty Geological Observatory. *Columbia University, Palisades, New York*, 690.

Bucefalo-Palliani R., Riding J.B. & Torricelli S. 1997. The dinoflagellate cyst Luehndea Morgenroth, 1970, emend. from the upper Pliensbachian (Lower Jurassic) of Hungary. *Review of Palaeobotany and Palynology,* 96, 113–120.

Bucefalo-Palliani R., Mattioli E. 1998. High resolution integrated microbiostratigraphy of the Lower Jurassic (late Pliensbachian-early Toarcian) of central Italy. *Journal Micropalaeontology,* 17, 153–172.

Bucefalo-Palliani R., Mattioli E. & Riding J.B. 2002. The response of marine phytoplankton and sedimentary and organic matter to the Early Toarcian (Lower Jurassic) oceanic event in northern England. *Marine Micropaleontology,* 46, 223–245.

Bucefalo-Palliani R. & Riding J.B. 1999. Relationships between the early Toarcian anoxic event and organic-walled phytoplankton in Central Italy. *Marine Micropaleontology*, 37(2), 101–116.

Bucefalo-Palliani R. & Riding J.B. 2003. Biostratigraphy, provincialism and evolution of European Early Jurassic (Pliensbachian to early Toarcian) dinoflagellate cysts. *Palynology*, 27, 179–214.

Bucefalo Palliani R., & Riding J.B. 1997. The influence of palaeoenvironment change of dinoflagellate cyst distribution; an example from the Lower and Middle Jurassic of Quercy, Southwest France. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, 21(1), 107–123.

Bujak J.P. & Williams G.L. 1977. Jurassic palynostratigraphy of offshore Eastern Canada. In: Swain, F.M. (Ed.) Stratigraphic micropaleontology of Atlantic basin and borderlands. *Elsevier, Amsterdam*, 321–39.

Chahidi S., Hssaida T., Benzaggagh M. *et al.* 2016. Palynostratigraphy and paleoenvironment of the South Rifian Ridges (Morocco) Upper Domerian-Lower Toarcian sequences : A transitional domain between the Proto-Atlantic and the Tethys. *Boletín Geológico y Minero,* 127 (2/3), 375–388.

Charrière A. & Haddoumi H. 2016. Les « Couches rouges » continentales jurassico crétacées des Atlas marocains (Moyen Atlas, Haut Atlas central et oriental) : bilan stratigraphique, paléogéographies successives et cadre géodynamique. *Boletín Geológico y Minero*, 127 (2/3), 407–430.

Charrière A., Haddoumi H. & Mojon P.O. 2005. Découverte du Jurassique supérieur et d'un niveau marin du Barrémien dans les « Couches rouges » continentales du Haut Atlas central marocain : implications paléogéographiques et structurales. *Comptes Rendus Palevol,* 4, 385–394.

Correia V.F., Riding J.B., Henriques M.H. *et al.* 2019. The middle Jurassic palynostratigraphy of the northern Lusitanian Basin, Portugal. *Newsletters on Stratigraphy*, 52(1), 73–96.

Correia V.F., Riding J.B., Duarte L.V. *et al.* 2018. The Early Jurassic palynostratigraphy of the Lusitanian Basin, western Portugal. *Geobios*, 51(6), 537–557.

Christ N., Immenhauser A., Amour F. *et al.* 2011. Characterization and interpretation of discontinuity surfaces in a Jurassic ramp setting (High Atlas, Morocco). *Sedimentology*, 59, 249–290.

Coninck J. 1969. Dinophyceae et Acritarcha de l'Yprésien du sondage de Kallo. *Mémoires de l'Institut royal des sciences naturelles de Belgique,* 161, 1–67.

Courtinat B. 2000. La matière organique sédimentaire en environnement de dépôt marginal. Exemple de la plaine deltaïque hypersaline du Ladinien de la bordure est du Massif central. *Géologie de la France*, 1, 35–45.

Cresta S., Goy A., Ureta S. *et al*. 2001. The Global Boundary Stratotype Section and Point (GSSP) of the Toarcian-Aalenian Boundary (Lower-Middle Jurassic*). Episodes Journal of International Geoscience*, 24(3), 166–175.

Danisch J., Krencker F.N., Mau M. *et al*. 2021. Tracking a drowning unconformity up to the peritidal zone: proximal expression of the early Bajocian carbonate crisis in Morocco. *Journal of African Earth Science*, 182, 104300.

De Oliveira L.C.V., Duarte L.V. & Perilli N. 2007. Calcareous Nannofossils and palynomorphs from Pliensbachian-Toarcian Boundary in Lusitanian Basin, Portugal. *Revista Brasileira Paleontologia*, 10 (1), 5–16.

Davey R.J. & Riley L.A. 1978. Late and Middle Jurassic dinoflagellate cysts. In: Thusu, B. (Ed.), Distribution of biostratigraphically diagnostic dinoflagellate cysts and miospores from the Northwest European continental shelf and adjacent areas. *Continental ShelfInstitute, Trondheim, Publication,* 100, 31–45.

Davies E.H. 1983. The dinoflagellate oppel zonation of the Jurassic-Lower Cretaceous sequences in the Sverdrup Basin. *Arctic Canada Geological Survey of Canada Bulletin*, 359, 59–91.

Davies E.H. 1985. The miospore and dinoflagellate cyst oppel-zonation of the Lias of Portugal. *Palynology*, 9, 105–132.

Dev S. 1961. The fossil flora of the Jabalpur Series. 3. Spores and pollen grains. *The Palaeobotanist*, 8(1), 43–56.

Dewey J.F., Helman M.L., Turco E. *et al*. 1989. Kinematics of the western Mediterranean. In: Coward, M.P., Dietrich, D., Park, R.G. (Eds.), Alpine Tectonics. *Special Publications, Geological Society, London,* 45, 265–283.

Dodekova L. 1990. Dinoflagellate cysts from the Bathonian-Tithonian (Jurassic) of North Bulgaria. I. Taxonomy of Bathonian and Callovian dinoflagellate cysts. *Geologica Balcanica*, 20, 3–45.

Dörhöfer G. & Davies E.H. 1980. Evolution of archeopyle and tabulation in rhaetogonyaulacinean dinoflagellate cysts. *Miscellaneous Publication 91; Royal Ontario Museum, Life Sciences Division, Toronto, Canada*.

Duxbury S. 1983. A study of dinoflagellate cysts and acritarchs from the Lower Greensand (Aptian to Lower Albian) of the Isle of Wight, southern England. *Palaeontographica, Abteilung* B 186 (1–3), 18–80.

Ettaki M. 2003. *Etude sédimentologique et stratigraphique du Lias début du Dogger de la région de Todrha-Dadès (Versant sud du Haut Atlas central, Maroc) : Implications géodynamiques*. Doctorat Thesis, University Cadi Ayyad, Marrakech, 429 p.

Ettaki M. & Chellaï E.H. 2005. Le Toarcien inférieur du Haut Atlas de Todrha–Dadès (Maroc) : sédimentologie et lithostratigraphie. *Comptes Rendus Geoscience*, 337(9), 814–823.

Feist-Burkhardt S. & Wille W. 1992. Jurassic palynology in southwest Germany- state of art. *Cahiers de Micropaleontology,* 7, 141–156.

Feist-Burkhardt S. 1995. *Weiachia fenestrata* gen. et sp., nov., a new phallocystean dinoflagellate cyst from the lower Jurassic of Switzerland. *Palynology,* 19(1), 211–219.

Fensome R.A., MacRae R.A. & Williams G.L. 2008. DINOFLAJ2, Version 1. American Association of Stratigraphic Palynologists, Data Series no. 1. http://dinoflaj.smu.ca/wiki/Main.

Fensome R.A., Saldarriaga J.F. & Taylor M.F. 1999. Dinoflagellate phylogeny revisited: reconciling morphological and molecular based phylogenies. *Grana,* 38, 66–80.

Frizon de Lamotte D., Zizi M., Missenard Y. *et al*. 2008. The Atlas System. In: *Lecture Notes in Earth Sciences*, 133–202.

Gomez F., Beauchamp W. & Baranzangi M. 2000. Role of Atlas Mountains (northwest Africa) within the African–Eurasian plate-boundary zone*. Geology*, 28, 775–778.

Guy-Ohlson D. 1986. Jurassic palynology of the Vilhelmsfalt Bore No. I, Scania, Sweden. Toarcian-Aalenian. *Section of Palaeobotany, Swedish Museum of Natural History, Stockholm*, 127.

Habib D. 1970. Middle Cretaceous palynomorph assemblages from clays near the Horizon Beta deep-sea outcrop. *Micropaleontology,* 16(3), 345–379.

Haddoumi H., Charrière A. & Mojon P.O. 2010. Stratigraphie et sédimentologie des «Couches rouges» continentales du Jurassique-Crétacé du Haut Atlas central (Maroc) : implications paléogéographiques et géodynamiques, *Geobios*, 43(4), 433–451.

Haq B.U., Hardenbol J. & Vail P.R. 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change: *Society of Economic Paleontologists and Mineralogists Special Publication,* 42, 71–108.

Harwood R.J. 1977. Oil and Gas Generation by Laboratory Pyrolysis of Kerogen. *AAPG Bulletin*, 61(12), 2082–2102.

Herngreen G.F.W. & De Boer K.F. 1974. Palynology of Rhaetian, Liassic and Dogger strata in the eastern Netherlands. *Geol. Mijnbouw*, 53, 343–368.

Ibouh H. 2004. *Du rift avorté au bassin sur décrochement, contrôles tectonique et sédimentaire pendant le Jurassique (Haut Atlas central, Maroc)*. PhD. Thesis, University Cady Ayad Marrakech, Maroc, 224 p.

Ibouh H., El Bchari F., Bouabdelli M. *et al.* 2001. L'accident tizal-azourki haut atlas central du maroc : déformations synsedimentaires liasiques en extension et conséquences du serrage atlasique. *Estudios Geológicos,* 57(1–2), 15–30.

Jarzen D.M. & Nichols D.J. 1996. Pollen in jansonius, J. et McGregar, D.C. (ed). Palynology: principles and Applications; A.A.S.P. *Fondation*, 1, 262–291.

Jenkyns H.C. & Clayton C.J. 1997. Lower Jurassic epicontinental carbonates and mudstones from England and Wales: chemostratigraphic signals and the early Toarcian anoxic event. *Sedimentology*, 44, 687–706.

Jenkyns H.C., Grocke D.R. & Hesselbo S.P. 2001. Nitrogen isotope evidence for water mass denitrification during the early Toarcian (Jurassic) oceanic anoxic event. *Paleoceanography,* 16, 593–603.

Jenny J., Lemarrec A. & Monbaron M. 1981. Les couches rouges du jurassique moyen du Haut Atlas central (Maroc) : corrélations lithostratigraphique, éléments de datation et cadre tectono-sédimentaire. *Bulletin de la Société géologique de France*, 7(6), 627–640.

Koppelhus E.B. & Hansen C. 2003. Palynostratigraphy and palaeoenvironment of the Middle Jurassic Sortehat Formation (Neill Klinter Group), Jameson Land, East Greenland. *GEUS Bulletin*, 1, 777–811.

Koppelhus E.B. & Dam G. 2003. Palynostratigraphy and palaeoenvironments of the Rævekløft, Gule Horn and Ostreaelv Formations (Lower–Middle Jurassic), Neill Klinter Group, Jameson Land, East Greenland. In: The Jurassic of Denmanrk and Greenland, *GEUS Bulletin*, 1, 723–775.

Koppelhus E.B. & Batten D.J. 1996. Applicaton of a palynomorph zonation to a series of short borehole sections, Lower to Middle Jurassic, Oresund, Denmark. *American Association of Stratigraphic Palynologists,* 2, 779–793.

Krencker F.N., Bodin S., Hoffmann R. *et al*. 2014. The middle Toarcian cold snap: trigger of mass extinction and carbonate factory demise. *Global and Planetary Change*, 117, 64–78.

Krencker F.N., Fantasia A., Danisch J. *et al*. 2020. Two-phased collapse of the shallow-water carbonate factory during the late Pliensbachian-Toarcian driven by changing climate and enhanced continental weathering in the Northwestern Gondwana Margin. *Earth-Science Reviews*, 103254.

Lachkar N. 2000. *Dynamique sédimentaire d'un bassin extensif situe´ sur la marge sud-téthysienne : Le Lias du Haut-Atlas de Rich (Maroc)*. PhD. Thesis, Université de Bourgogne.

Lachkar N., Guiraud M., Harfi A.E. *et al*. 2009. Early Jurassic normal faulting in a carbonate extensional basin : characterization of tectonically driven platform drowning (High Atlas rift, Morocco). *Journal of the Geological Society,* 166(3), 413–430.

Laville E., Charroud A. Fedan B. *et al.* 1995. Inversion négative et rifting atlasique : l'exemple du bassin triasique de Kérrouchéne (Maroc). *Bulletin de la Société Géologique de France*, 166, 365–374.

Laville E., Fedan B. & Piqué A. 1991. Déformation synschisteuse jurassique, orogenèse cénozoïque : deux étapes de la structuration du Haut Atlas (Maroc). *Comptes* *rendus de l'Académie des sciences. Série 2, Mécanique, Physique, Chimie, Sciences de l'univers, Sciences de la Terre*, 312, 1205–1211

Laville E. & Piqué A. 1992. Jurassic penetrative deformation and Cenozoic uplift in the central High Atlas (Morocco): a tectonic model. Structural and orogenic inversions. *Geologische Rundschau,* 81, 157–170.

Laville E., Piqué A., Amrhar M. *et al*. 2004. A restatement of the Mesozoic Atlasic Rifting (Morocco). *Journal of African Earth Sciences,* 38, 145–153.

Maithy P.K. 1973. Micro-organisms from the Bushimay System (late Precambrian) of Kanshi, Zaire. *Journal of Palaeosciences*, 22(1–3), 133–149.

Malyavkina V.S. 1949. Determination key of spores and pollen, Jurassic-Cretaceous [Opredelitel spori Pyltsy; Yura-Mel]. *Trudy Vsesoyuznogo Neftyanogo Naucho-Issledovatel Skogo Geologo-Razvedochnogo Instituta, Trudy, (VNIGRI*), 33, 1–137.

Martínez M., García V. & Quattrocchio M. 1996. Análisis de componentes principales aplicado al estudio palinológico del Jurásico medio de Cuenca Neuquina, Argentina. 12º Congreso Geológico Argentino y 3º Congreso de Exploración de Hidrocarburos, Actas 5, 171–179.

Mattauer M., Tapponier P. & Proust F. 1977. Sur les mécanismes de formation des chaînes intracontinentales, exemple des chaînes atlasiques du Maroc. *Bulletin de la Société Géologique de France*, 19, 521–526.

Michard A., 1976. Eléments de géologie marocaine. Notes et Mémoires de Service Géologique de Maroc 252, 422.

Miner E.L. 1935. Paleobotanical examinations of Cretaceous and Tertiary Coals.1. Cretaceous Coals from Greenland. 2. Cretaceous and Tertiary Oals from Montana. *American Midland Naturalist,* 16(4), 585–625.

Moragas M., Vergés J., Saura E. *et al*. 2018. Jurassic rifting to post-rift subsidence analysis in the central High Atlas and its relation to salt diapirism. *Basin Research,* 30, 336–362.

Morbey S.J. 1975. The palynostratigraphy of the Rhaetian stage, Upper Triassic in the Kendelbachgraben, Austria. P*alaeontographica*, B 152(1–3), 1–75.

Morbey S.J. 1978. Late Triassic and Early Jurassic subsurface palynostratigraphy in northwestern Europe. *Palinologia número extraordinario*, 1, 355–365.

Morgenroth P. 1970. Dinoflagellate cysts from the Lias Delta of Lühnde/Germany. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen,* 136(3), 345–359.

Muir-Marjorie D. 1967. Reworking in Jurassic and Cretaceous spore assemblages. *Review of Palaeobotany and Palynology,* 5(1–4), 145–154.

Newton E.T. 1875. On "Tasmanite" and Australian "White Coal." *Geological Magazine*, 2(08), 337.

Pedersen K.R. & Lund J.J. 1980. Palynology of the Plant-Bearing Rhaetian to Hetrangian Kap Stewart Formation, Scoresby Sund, East Greenland. *Review of Palaeobotany and Palynology,* 31, 1–69.

Pierre A., Durlet C., Chellaï E.H. *et al.* 2005. Spatial and temporal evolution of storm deposits within genetic sequences in an oolitic ramp (example from the Lias-Dogger transition, High Atlas, Morocco). *In: 24th IAS Meeting of Sedimentology. 124 IAS, Muscat, Oman*, pp. 192.

Pierre A. 2006. *Un exemple de référence pour les systèmes de rampes oolitiques. Un affleurement continu de 37 km de long (falaises jurassiques d'Amellago, Haut Atlas, Maroc)*. Ph.D. Thesis, University Bourgogne, Dijon, France. 242 p.

Potonié R. 1956. Synopsis of the genera of the sporae dispersae. Part 1 [Synopsis der gattungen der sporae Dispersae. Teil 1]. *Beihefte zum Geologischen Jahrbuch,* 23, 1–103.

Poulsen N.E. 1996. Dinoflagellate cysts from marine Jurassic deposits of Denmark and Poland. *American Association of Stratigraphic Palynologists, Contributions Series,* 31, 1–227.

Poulsen N.E. & Riding J.B. 2003. The Jurassic dinoflagellate cyst zonation of Subboreal north-west Europe. With a supplement by B. Buchardt: oxygen isotope palaeotemperatures from the Jurassic in Northwest Europe. In J. Ineson and F. Surlyk, Eds. *The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin*, 1, 115–144.

Prauss M. 1996. The Lower Toarcian Posidonia Shale of Grimmen, Northeast Germany implications from the palynological analysis of a Near-Shore section. *Neues Jahrbuch fmr Geologie and Paleontologie. Abhandlungen*, 200(1), 107–132.

Prauss M. & Riegel W. 1989. Evidence from phytoplankton associations for causes of black shale formation in epicontinental seas. *Neues Jahrbuch für Geologie und Paläontologie- Monatshefte Jg. 1989 Heft,* 11, 671–682.

Reyre Y. 1973. Palynologie du Mésozoïque Saharien. Traitement des données par l'Informatique et applications à la Stratigraphie et à la Sédimentologie. *Mémoires du Muséum d'Histoire Naturelle, Paris*, C, XXVII, 284.

Riding J.B. 1983. *Gonyaulacysta centriconnata* sp. nov., a dinoflagellate cyst from the late Callovian and early Oxfordian of eastern England. *Palynology*, 7, 197–204.

Riding J.B. 1984a. A palynological investigation of Toarcian to early Aalenian strata from the Blea Wyke area, Ravenscar, North Yorkshire. *Proceedings of the Yorkshire Geological Society,* 45(1–2), 109–122.

Riding J.B. 1984b. Dinoflagellate cyst range top biostratigraphy of the uppermost Triassic to lowermost Cretaceous of Northwest Europe. *Palynology,* 8, 195–210.

Riding J.B. 1987. Dinoflagellate cyst stratigraphy of the Nettleton Bottom Borehole (Jurassic: Hettangian to Kimmeridgian), Lincolnshire, England. *Proceedings of the Yorkshire Geological Society,* 46, 231–66.

Riding J.B. & Ioannides N.S. 1996. A review of Jurassic dinoflagellate cyst biostratigraphy and global provincialism. *Bulletin de la Société géologique de France*, 167, 3–14.

Riding J.B. & Thomas J.E. 1992. Dinoflagellate cysts of the Jurassic System. In: A Stratigraphic index of dinoflagellate cysts. *Edited by A.J. Powell. Chapman ang Hall, London*, 7–98.

Riding J.B., Walton W. & Shaw D. 1991. Toarcian to Bathonian (Jurassic) palynology of the Inner Hebrides, northwest Scotland. *Palynology,* 15, 115–179.

Rodrigues B., Silva R.L., Mendonca Filho J. G. *et al.* 2020. Late Pliensbachian–Early Toarcian palaeoenvironmental dynamics and the Pliensbachian–Toarcian Event in the

Middle Atlas Basin (Morocco). *International Journal of Coal Geology*, 217, 103339.

Röhl H.J., Schmid-Röhl A., Oschmann W. *et al.* 2001. The Posidonia Shale (Lower Toarcian) of SW-Germany: an oxygen-depleted ecosystem controlled by sea level and palaeoclimate. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 165(1–2), 27–52.

Saad S.I., 1963. Pollen and spores recently discovered in the coals of Sinai region, 1. Euone Moussa district. *Palaeontograpkica*, B, 113, 126–134.

Schmitt J.P., 1987. *Stratigraphic and paleogeographic interpretation of the Jurassic microfloral of Alsace, France [Les microflores du Jurassique Interets stratigraphiques, Paleogeographiques du Jurassique en Alsace]*. PhD. Thesis, U.E.R. des Sciences de la Vie et de la Terre, Institute de Géologie, Strasbourg, 1–189.

Schulz E. 1967. Study of fossil spores from Rhaetian-Liassic Layers in the central part of the German Basin. [Sporen palaontologische un tersuchungen Ratoliassischer Schichten im Zentralteil des Germanischen Beckens. Palaeontographica Abteilung B. *Palaobotanik* 2(3), 543–644.

Schuurman W.M.L. 1977. Aspect of late Triassic palynology. 2. Palynology of the «Grès et Schiste à Avicula contorta » and Argiles de Levallois » (Rhaetian) of northeastern France and Southern Luxemburg. *Review of Palaeobotany and Palynololgy*, 23, 159–253.

Smith P.H. 1978. Fungal spores of the genus Ctenosporites from the early Tertiary of southern England, *Palaeontology,* 21(3), 717–722.

Souhel A. 1996. Le Mésozoïque dans Haut Atlas de Beni-Mellal (Maroc). Stratigraphie, sédimentologie et évolution géodynamique. *Strata, Série* 2, 27, 249.

Srivastava S.C. 1987. Palynoligical correlations of coal seams in Godavari, India. *Palaeobotanist*, 35, 281–296.

Studer M. 1980. *Tectonique et pétrographie des roches sédimentaires, éruptives et métamorphiques de Tounfite, Tirrhist (Haut Atlas, Maroc).* University of Neuchâtel, 102.

Teixell A., Ayarza P., Tesón E. *et al*. 2007. Geodinámica de las cordilleras del Alto y Medio Atlas : Síntesis de los conocimientos actuales. *Revista de la Sociedad Geológica de España,* 20, 119–135.

Tissot B.P. & Welte D.H. 1984. From Kerogen to Petroleum. In: Petroleum Formation and Occurrence. Springer, Berlin, Heidelberg, 131–159.

Tyson R.V. 1993. Palynofacies analysis. In: Applied Micropaleontology, Jenkins, D.G. (Ed.), Kluwer Academic Publishers. *The Netherlands, Amsterdam*, 153–191.

Tyson R.V. 1995. Sedimentary Organic Matter: Organic facies and palynofacies. *Chapman and Hall, London*, 615.

Vail P.R., Todd R.G. & Sangree J.B. 1977. Seismic Stratigraphy and Global Changes of Sea Level: Part 5. Chronostratigraphic Significance of Seismic Reflections: Section 2. Application of Seismic Reflection Configuration to Stratigraphic Interpretation, 99–116.

Vakhrameev. 1981. Pollen classopolis: indicator of Jurassic and cretaceous climates. *The paleobotanist*, 28(29), 301–307.

Van de Schootbrugge B., Houben A. J.P., Ercan F.E.Z. *et al.* 2019. Enhanced arctic-tethys connectivity ended the toarcian oceanic anoxic event in NW Europe. *Geological Magazine,* 157(10), 1593–1611.

Van de Schootbrugge B., Bachan A., Suan G. *et al*. 2013. Microbes, mud and methane: cause and consequence of recurrent Early Jurassic anoxia following the end-Triassic mass extinction, *Palaeontology*, 56, 685–709.

Van de Schootbrugge B., Bailey T.R., Rosenthal Y. *et al*. 2005. Early Jurassic climate change and the radiation of organic-walled phytoplankton in the Tethys Ocean. *Paleobiology,* 31, 73–97.

Van Helden B.G.T. 1977. Jurassic palynostratigraphy of Sverdrup Basin, Canadian Arctic. (In: Report of activities of the Canadian Society of Petroleum Geologists, Paleontology Division 1975/1976). *Bulletin of Canadian Petroleum Geology,* 25(6), 1261–1262.

Vozenin-Serra C. & Taugourdeau-Lantz J. 1985. La flore de la Formation Shemshak (Rhétien à Bajocien; Iran): rapports avec les contemporaines. Implications Paléogéographiques. *Bulletin de la Société Géologique de France,* 5, 663–678.

Warrington G. 1983. Appendix 4. (In: Geology of the Country around Weston Super-Mare. A. Whittaker and G.W. Green, authors). *Memoir of the Geological Survey of Great Britain*, 131–132.

Weissert H. 1989. C-Isotope stratigraphy, a monitor of paleoenvironmental change: A case study from the early cretaceous. *Surveys in Geophysics*, 10, 1–61.

Weissert H. & Mohr H. 1996. Late Jurassic climate and its impact on carbon cycling. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 122, 27–43.

Wille W. & Gocht H. 1979. Dinoflagellaten aus dem Lias Südwest deutschlands. Dinoflagellates from the Lias of SW Germany. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen,* 158, 221–258.

Williams G.L., Fensome R.A. & MacRae R.A. 2017. The Lentin and Williams index of fossil dinoflagellates 2017 edition. *American Association of Stratigraphic Palynologists Contributions Series*, no. 48.

Williams G.L. & Bujak J.P. 1985. Mesozoic and Cenozoic dinoflagellates. In: Bolli, H.M., Saunders, J.B., Perch-Nielsen K. (Eds.), Plankton Stratigraphy. *Cambridge University Press, Cambridge,* 847–965.

Wilmsen M. & Neuweiler F. 2008. Bio-sedimentology of the Early Jurassic post-extinction carbonate depositional system, Central High Atlas rift basin, Morocco. *Sedimentology,* 55, 773–807.

Wood G., Gabriel A. & Lawson J. 1996. Palynological techniques-processing and microscopy. In: Jansonius, J., McGregor D.C. (Eds.), Palynology: principles and applications, 1. *American Association of Stratigraphic Palynologists Foundation, Dallas, Texas*, 29–50.

Woollam R. & Riding J.B. 1983. Dinoflagellate cyst zonation of the English Jurassic. *Institute of Geological Sciences Report,* 83(2), 42.

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