

Research papers

Middle Eocene dinoflagellate cyst biostratigraphy from the southwestern Tethyan margin: Revised age assessments of sediments near Larache Province, northwestern Morocco

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ABSTRACT

Palynological analyses are performed on the imprecisely dated 'Upper Cretaceous–lower Eocene' marly and marly limestones succession from the Thare section at Arbaa Ayacha, western External Rif (northwestern Morocco) to reassess the previous calcareous microplankton-based age determination of the sediments. The succession yields well to moderately preserved palynological associations that are mainly composed of organic-walled dinoflagellate cysts, suitable for biostratigraphic analysis. The sediments are here reassessed as being of middle Bartonian age using the recently well-calibrated distribution patterns of several index taxa like *Glaphyrocysta semitecta*, and *Rhombodinium perforatum*. These, taken together with the composition of the background assemblages allow quite precise designation of the section to the interval corresponding to magnetochrons C18n.1r to C18n.1n following correlation to the Bartonian/Priabonian Global Stratotype Section and Point (GSSP) section at Alano di Piave, NE Italy. Our results further underline the potential of marine palynological analysis emphasizing organic-walled dinoflagellate cysts in biostratigraphic and paleoenvironmental analyses of the Mediterranean Paleogene.

1. Introduction

As part of the southern margin of the former Tethyan Ocean, in consequence of the various phases of Mesozoic–Cenozoic convergence of the African and European plates, the geology of the northern Moroccan Rif Chain (Fig. 1) is notoriously complex, and its tectonostratigraphic evolution is still poorly understood (e.g., Slimani and Chekar, 2023). Throughout the Rif domains, viz., the Internal Rif, the Rif Flysch Nappes, and the External Rif (cf. Durand-Delga and Fontboté, 1980; Patriat et al., 1982) the scattered, often deformed packages of mainly marine Late Cretaceous to Paleogene sediments typically consist of highly similar marls and marly limestones. Their dating and subsequent mapping is still most often based on early studies of scarce and often poorly

preserved planktonic foraminifera (e.g., Leblanc, 1967–1971; Haddad and Scalante, 1994–1996). Until the present day, the tectonic complexity, the lithological similarities between the marly deposits of different ages, and the scarcity, or even absence, of notably calcareous microfossils likely caused by the tectonism and even metamorphism that has affected their preservation, hampers better understanding of the evolution of the Rif system (e.g., Slimani et al., 2016; Chekar et al., 2018; Slimani and Chekar, 2023).

Yet, the recent employment of marine palynology, emphasizing organic-walled dinoflagellate cyst ('dinocyst') analysis, has allowed significant reassessment and refinement of the ages previously assigned to this 'Late Cretaceous to early Eocene' interval (e.g., Slimani et al., 2008, 2010, 2012, 2016, 2021a, 2021b; Slimani and Toufiq, 2013;

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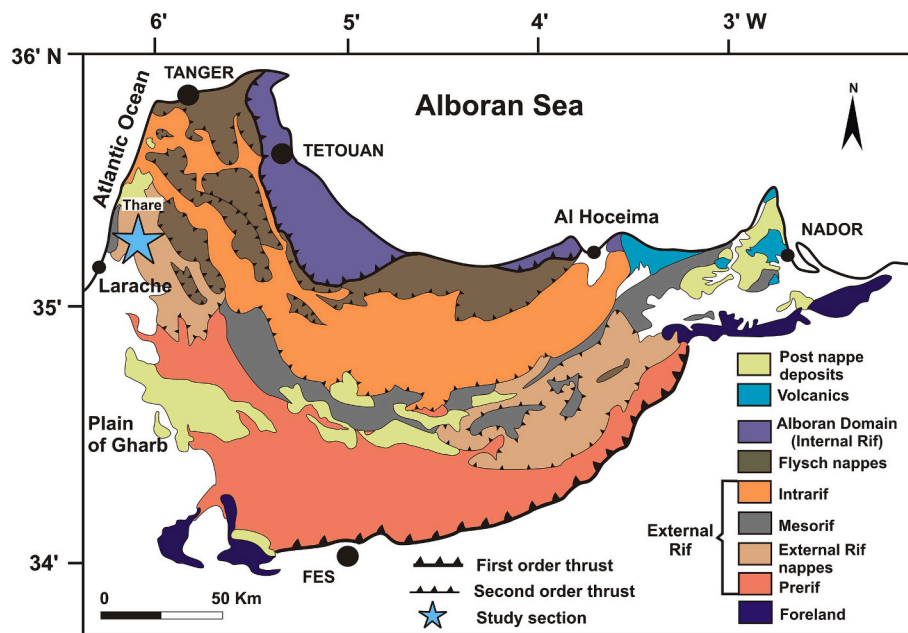


Fig. 1. Simplified structural map of the Rif Chain, modified after Michard et al. (2008).

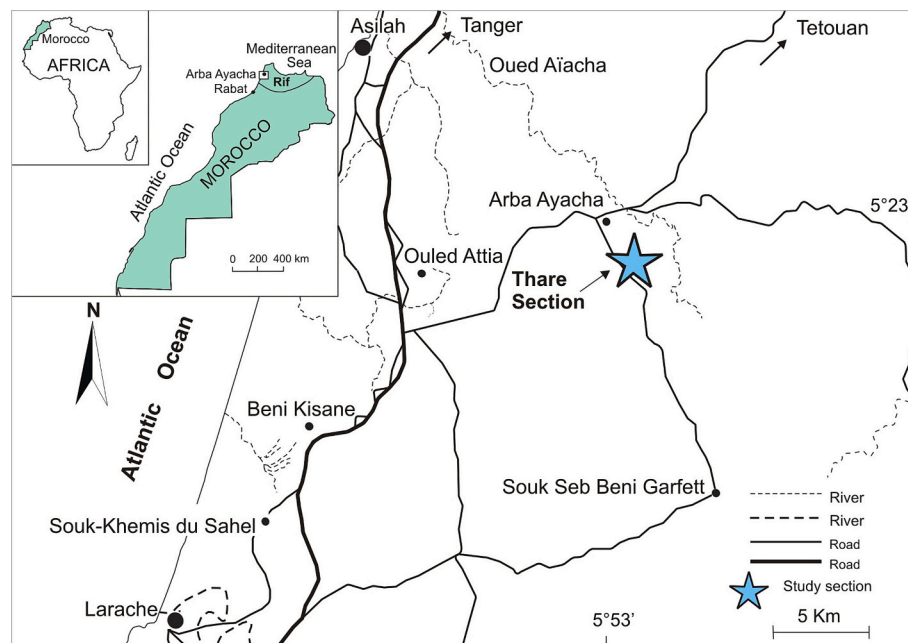


Fig. 2. Location map of the Thare section, Larache region, western External Rif, northwestern Morocco.

Guédé et al., 2014; Jbari et al., 2020, and Jbari and Slimani, 2022). One such example involves the deposits in the Arba Ayacha region, notably the Tahar and Sekada sections (Guédé et al., 2014; Slimani et al., 2016; Aboutofail and Slimani, 2024). There, the upper part of the 'Upper Cretaceous-lower Eocene' marly and marly limestones succession was recently re-dated by these authors with much improved precision as in fact being late Paleocene to early Eocene in age. In fact, and most significantly, it turned out that the Sekada section includes a complete coverage of the paleo-climatologically important Paleocene-Eocene Thermal Maximum (PETM) interval, a first ever from this part of the western Tethys (Aboutofail and Slimani, 2024). In recent follow up studies, while searching for more PETM sections in the area, we focused on the nearby Thare section, thought to contain a correlative interval. This since that section, also located nearby Arba Ayacha in the Larache

Province, western External Rif Chain (northern Morocco; see Figs. 1, 2), is also composed of similar gray-brown marls and overlying gray-brown marly limestones (and, e.g., also previously assigned to the 'Late Cretaceous to early Eocene', see Fig. 3). However, and quite surprisingly, our pilot marine palynological studies revealed that the presumed coeval interval of the Thare section is, instead, likely of middle Eocene age, rather than Ypresian or older, given the occurrences of typical Bartonian species like *Rhombodinium draco* and *R. perforatum* (cf. Bijl et al., 2021).

While our efforts over the past decade have resulted in the broad documentation of the Paleogene dinocyst distribution at a multitude of locations across the Rif Chain (see e.g., Slimani and Chekar, 2023, for an overview) their more precise chronostratigraphic calibration leaves much to desire. Our interpretations were thus far mainly based on



Fig. 3. Geological setting, adapted from the 1:500,000 geological map of the Rif Chain (Suter, 1980), of the Thare section, Larache region, western External Rif, northwestern Morocco.



Fig. 4. Middle Bartonian sedimentary interval in the Thare section, Larache region, western External Rif, northwestern Morocco, a panoramic view where the samples were collected; 1: Gray-brown marly limestones, 2: gray-brown marls. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

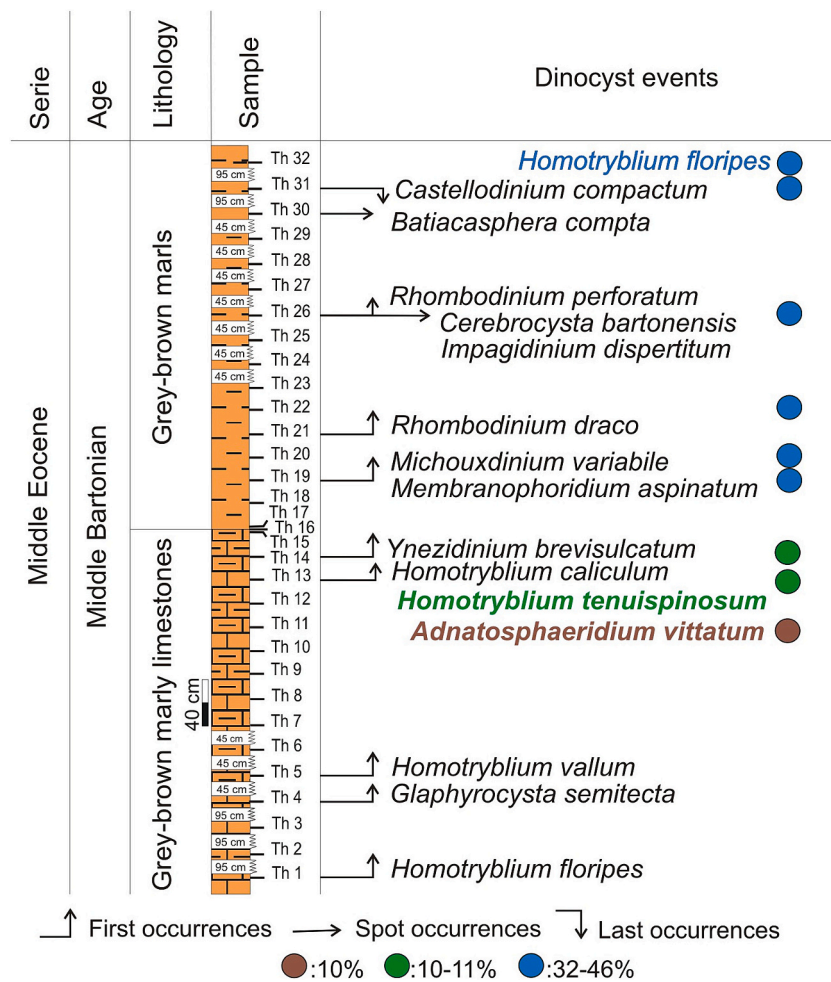
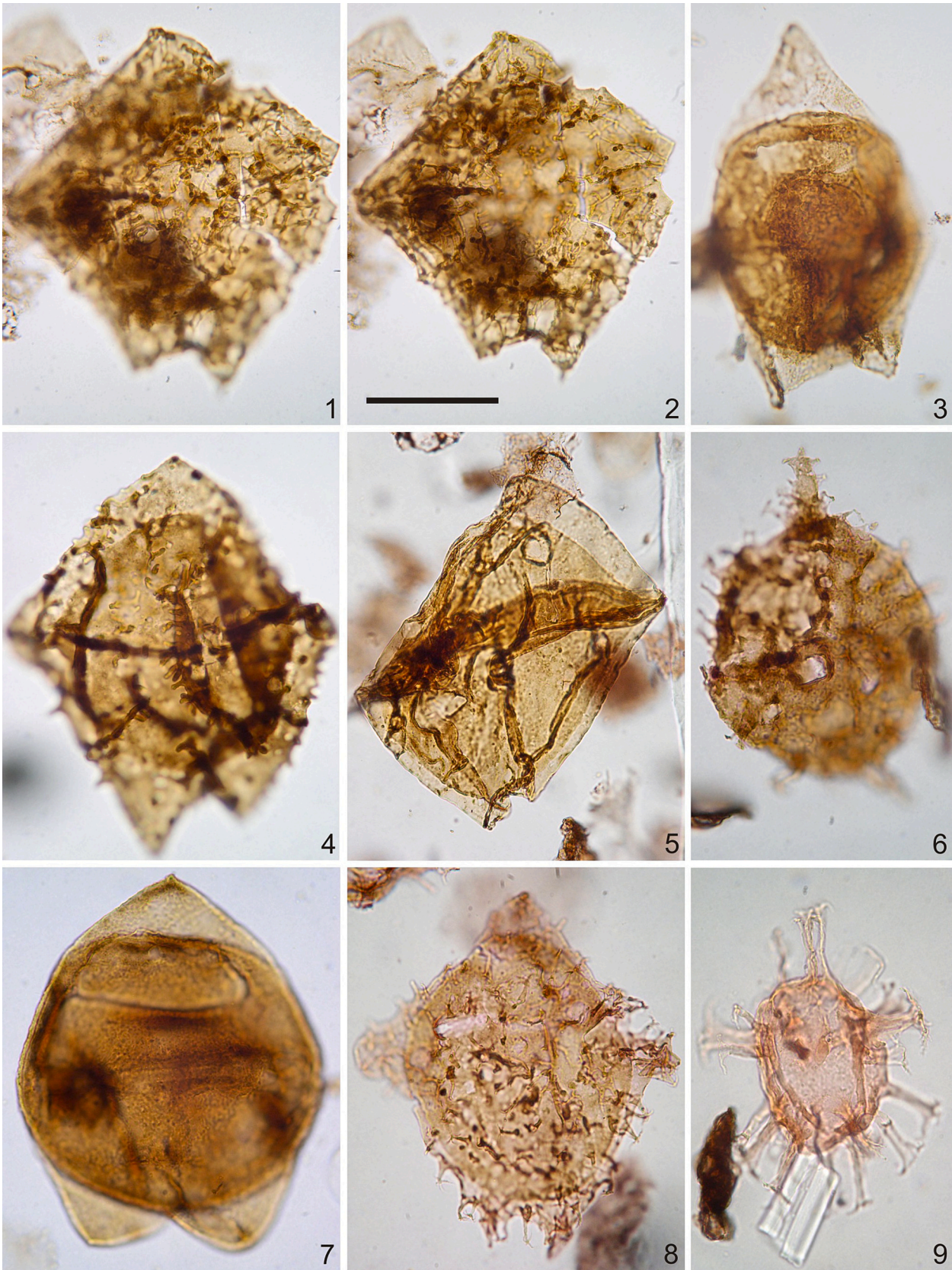


Fig. 5. Stratigraphic log, sampling and recapitulation scheme of the biostratigraphy of the Middle Bartonian sedimentary interval in the Thare section, Larache region, western External Rif, northwestern Morocco.

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Plate 1. Dinoflagellate cysts from the Middle Bartonian sedimentary interval in Morocco. Scale bars represent 40 µm.

- 1, 2. *Michouxdinium variable*; sample Th32, slide 1, EF 40/2; 1. dorsal surface; 2. ventral surface with focus on processes and their distal trabeculae, and plate boundaries.
3. *Deflandrea phosphoritica*; sample Th26, slide 1, EF T22/2; dorsal surface with focus on the precingular archeopyle.
4. *Castellodinium compactum*; sample Th30, slide 3, EF V46/4; dorsal surface with focus on the intercalary archeopyle and ornaments.
5. *Rhombodinium draco*; sample Th21, slide 2, EF37/1.
6. *Fibrocysta vectensis*; sample Th12, slide 1, EF K48/1; dorsal surface with focus on the precingular archeopyle.
7. *Deflandrea leptodermata*; sample Th20, slide 2, EF Z32; dorsal surface with focus on intercalary archeopyle and wall structure.
8. *Wetzeliiella articulata*; sample Th13, slide 2, EF K47/3; dorsal surface with focus on the intercalary archeopyle and processes.
9. *Cordodphaeridium gracile*; sample Th22, slide 1, EF H40; focus on the precingular archeopyle and processes.

comparison with often equally poorly calibrated studies from NW Europe, hence to sections located in other basins, and other climatic belts, with very differing environmental conditions than along the southwestern Tethyan, and African Atlantic margins in Morocco. Similarly, by employing marine palynological studies from infra- (Para) Tethyan to central and southern Eurasian Paleogene locations (e.g., Iakovleva and Heilmann-Clausen, 2010, 2021; Iakovleva and Aleksandrova, 2013; Iakovleva, 2015, 2017, and many others), also no truly meaningful conclusions could be drawn since these also suffer from relatively poor calibration and are derived from differing environmental settings as well. In effect, to date, regarding the Paleogene, only in the central Tethyan Realm, a few sections, i.e., the Global Stratotype Section and Point (GSSP) of the Eocene/Oligocene (E/O) boundary at Massignano and a few other E/O transitional (EOT) to Oligocene sections in central Italy have robust, multidisciplinary, independent magneto- or at least biostratigraphic calibration (e.g., Premoli Silva et al., 1988; Brinkhuis and Biffi, 1993; Hyland et al., 2009; Pross et al., 2010). Except for a handful of relatively well calibrated studies of specific intervals of the older Paleogene in the Tethyan Realm (see overviews in e.g., Iakovleva, 2025; Mannucci et al., 2025), or even from the eastern equatorial Atlantic Ocean (e.g., Awad and Oboh-Ikuenobe, 2016, 2018; Frieling et al., 2018; Kegel et al., 2025), very limited data are available at this point. However, going down-section, for the older middle Eocene (Bartonian) interval in the Tethyan Realm, this situation has now ameliorated significantly by the recent work of Iakovleva (2025) who documented the distribution of index taxa in the Bartonian/Priabonian GSSP section at Alano di Piave, NE Italy. That study, fitting the key-dinocyst distribution squarely next to the solid multidisciplinary integrated chrono-, cyclo- bio- and geochemical stratigraphic work of the International Commission of Stratigraphy (ICS) working group led by Claudia Agnini of Padova University now provides an important new avenue for dinocyst event calibration (see e.g., Agnini et al., 2011, 2014, 2021; Galeotti et al., 2019). This, in turn, now allows us to take a first step in further improving dinocyst-based age assessment in the Paleogene of the Rif Chain by taking the outcome of the quantitative marine palynological study of the Thare section as a test case.

2. Material and methods

In the External Rif domain of northwestern Morocco, considered part of the southern Tethyan margin (Leblanc, 1979; Chalouan et al., 2001; Michard et al., 2002), three main tectonic subunits are identified, from North to South, viz. 1) the Intrarif, which is composed of three structural units, including the Tangier Unit (Albo-Aptian to Miocene) where the study area is located; 2) the Mesorif which consists of Liassic to Miocene strata; and 3) the Prerif, which forms the southernmost part of the Rif Chain, with facies consisting mainly of marly clays (Suter, 1980). In turn, the latter is composed of the Internal Prerif (Jurassic) and External Prerif (Upper Miocene) (Durand-Delga et al., 1962). The Thare section

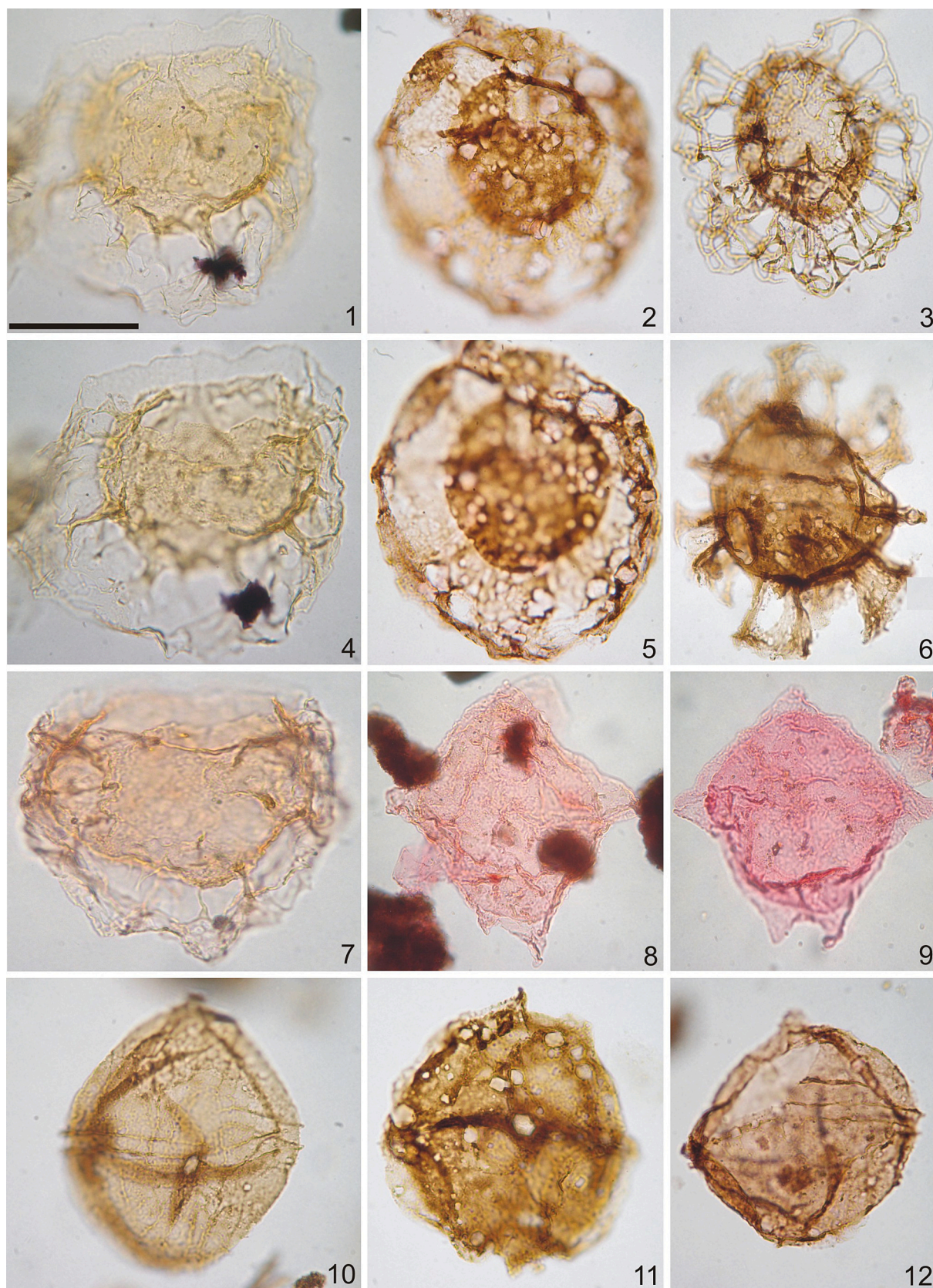
(geographic coordinates: 35°22'30"N and 5°53'25" W), located in the western External Rif, is part of the aforementioned Tangier Unit, some 47 km northwest of the Larache Province, and 1.5 km south of the Arba Ayacha village (Fig. 2). The studied interval in the Thare section is exposed on the western flank of Thare Oul Lfkih (Figs. 3, 4). The interval consists of gray-brown marls overlain by gray-brown marly limestones, which alternate with centimeter-sized beds of limestone and sandstone. These deposits outcrop in subvertical stratification, but with a north-south strike, and were previously assigned to the 'Upper Cretaceous and lower Eocene' by Suter (1980) in the 1: 500,000 geological map of the Rif Chain (Figs. 3, 4).

We collected thirty-two samples, with a relatively higher resolution (every 20 cm) for the 14 samples around the lithological transition from the gray-brown marly limestones and the gray-brown marls, but more spaced (every 45 to 95 cm) for the 18 samples over the rest of the studied interval. We also collected two samples at 5 cm below and above the lithological boundary, respectively (Fig. 5).

The samples were treated following a laboratory protocol, adapted to local chemical products by Slimani et al. (2016). They were washed, dried and crushed and then treated with cold 20% hydrochloric acid (HCl) for 2 to 4 h to dissolve carbonates. After rinsing with distilled water, the residues underwent two successive 48-h treatments with cold 48% hydrofluoric acid (HF) to dissolve silicates. After another rinsing with distilled water, the remaining residues were boiled in HCl (20%) for 20 min to remove the silicofluorides, newly formed during the HF treatment, and then rinsed with distilled water until neutralization. The residues were sieved using a nylon screen with a mesh size of 15 µm, then stained with safranin (C₂₀H₁₉ClN₄) and mounted in glycerin jelly on microscope slides. Two and, when possible, three slides per sample were prepared, depending on the palynomorph richness. The slides were scanned, and a maximum of 400 specimens of dinoflagellate cysts were counted using an Olympus BX43 transmitted light microscope. All slides are kept in the botanical collection of the national herbarium (RAB) of the Scientific Institute, Mohammed V University of Rabat (Morocco). The taxonomy of the dinocyst species corresponds to that cited in the latest Lentin and Williams Index (Fensome et al., 2019). Furthermore, we employed the 'PalSys' web-based platform <http://PalSys.org> (e.g., Bijl and Brinkhuis, 2023) and DINOSTRAT (Bijl, 2022) for taxonomic and stratigraphic queries as well.

3. Results

The palynomorph associations in the Thare section are dominated by dinocysts, which are diverse and well to moderately preserved. Other groups, like sporomorphs, and e.g., fragments of microforaminiferal test linings, for example, are generally sporadic to absent. This while remains of various groups of prasinophytes (green algae), e.g., like *Pediastrum* spp. can sometimes be abundant at certain levels. In this study some seventy dinocyst taxa were recognized, including a few



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Plate II. Dinoflagellate cysts from the Middle Bartonian sedimentary interval in Morocco. Scale bars represent 40 μm .

- 1, 4. *Glaphyrocysta semitecta*; sample Th28, slide 1, EF W33/2; 1. dorsal surface, 4. ventral surface.
- 2, 5 *Thalassiphora pelagica*; sample Th14, slide 2, EF H43; 1. dorsal surface with focus on the precingular archeopyle, 5. ventral surface.
3. *Adnatosphaeridium vittatum*; sample Th22, slide 2, EF F59/4.
6. *Cordosphaeridium fibrospinosum*; sample Th22, slide 1, EF Q45/1, lateral surface.
7. *Glaphyrocysta semitecta*; sample Th26, slide 1, EF Y32; 1. ventral surface.
8. *Rhombodinium perforatum*; sample Th28, slide 1, EF K55/2, dorsal surface.
9. *Rhombodinium perforatum*; sample Th29, slide 2, EF Q45, dorsal surface.
10. *Cribroperidinium giuseppi*; sample Th32, slide 2, EF O51; focus on the wall structure.
11. *Muratodinium fimbriatum*; sample Th32, slide 1, EF T25.
12. *Cribroperidinium tenuitubulatum*; sample Th20, slide 2, EF J38/4; focus on the precingular archeopyle and wall structure.

stratigraphic index species (so indicated in Table 1). Higher abundances or acmes of certain dinocyst taxa are also highlighted in brown in Table 1 as well; all taxa are listed in alphabetical order in Appendix A, and in order of their first stratigraphic occurrence in Table 1.

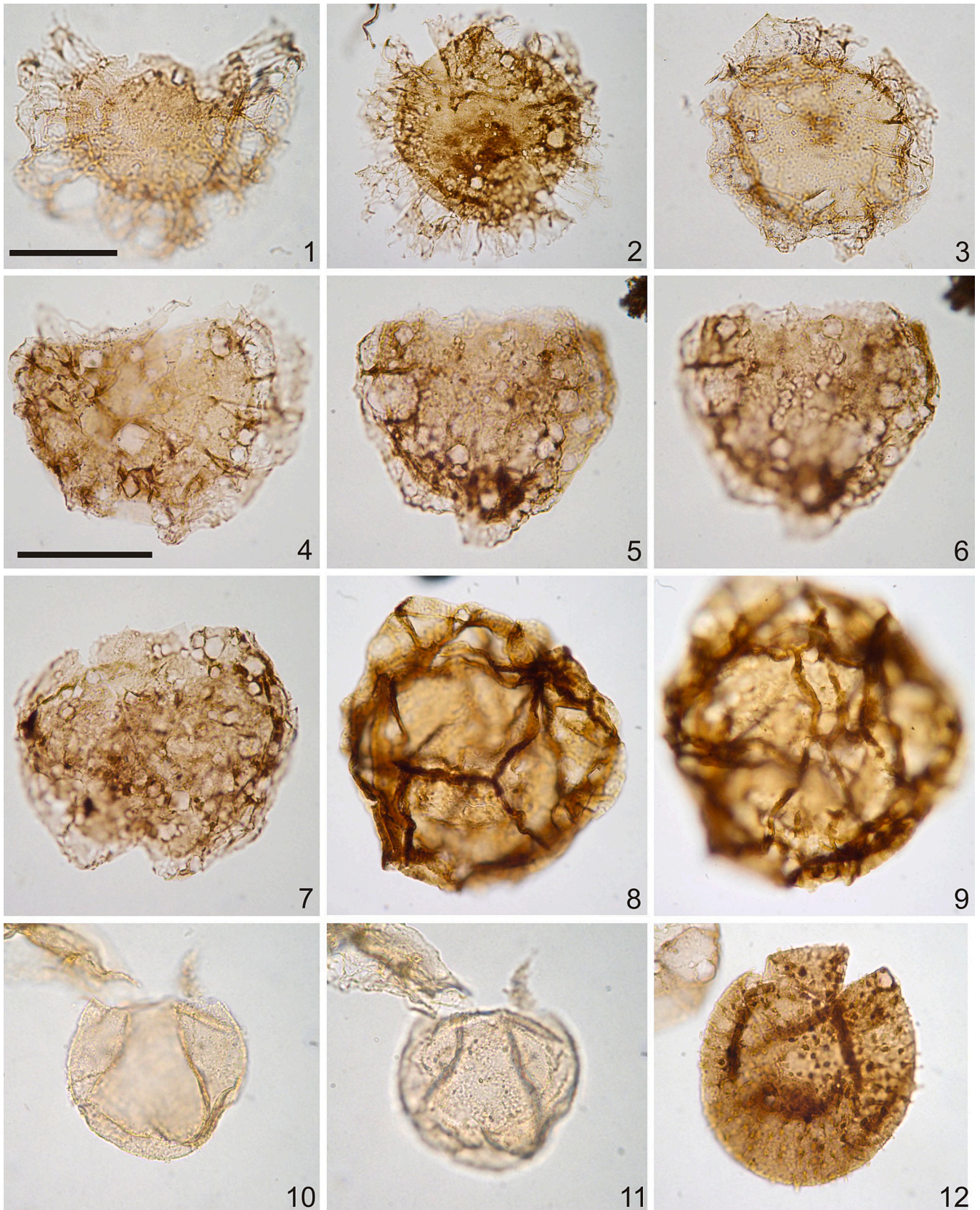
The lower part of the section (sampling interval Th1–Th16), corresponding to the gray-brown marly limestones, yields assemblages containing many long-ranging taxa quasi-cosmopolitan species (e.g., like *Spiniferites ramosus*, *Hystrichokolpoma rigaudiae*, *Operculodinium centrocarpum*, *Cordosphaeridium fibrospinosum*, *Cordosphaeridium gracile*, and *Thalassiphora pelagica*). Noteworthy, this part of this section is also characterized by higher abundance of species known to be capable of dealing with restricted marine settings like *Wetzeliella*, *Adnatosphaeridium*, *Glaphyrocysta*, *Fibrocysta*, and *Homotryblium* spp. which exceed ~60% at certain levels (compare e.g., Frieling and Sluijs, 2018), further confirmed by higher numbers of the fresh-water derived *Pediastrum* spp. The overlying gray-brown marls corresponding to sample interval Th17–Th32 also yields diverse dinocyst assemblages, very similar to the lower part, including higher abundance (generally exceeding ~40%) of *Homotryblium* spp. (in this case mainly *H. floripes* and similar morphotypes like *H. cf. vallum*). This while upsection more open marine conditions are suggested by the sometimes equally abundant *Spiniferites* and *Operculodinium* spp., besides spot occurrences of some of the typical oceanic *Impagidinium* species (cf. Frieling and Sluijs, 2018). This suggests an overall deepening of the paleoenvironmental setting, along the former Tethyan margin, with episodic influx from more restricted marine settings such as salt marshes and carbonate shelves. Future studies should provide more detailed interpretations.

In terms of the occurrences of stratigraphic ‘index’ species, and particularly those that have been documented at the Alano GSSP (Iakovleva, 2025), the distribution patterns of *Glaphyrocysta semitecta*, and *Rhombodinium perforatum*, and the last occurrences of *Castellodinium compactum* (morphologically very similar to *Wilsonidium tabulatum* sensu Iakovleva (2025) and, to a lesser extent *Fibrocysta vectensis* are important. In addition, the presence of *Homotryblium floripes* and allied forms from the base of the section upwards is here considered significant as well. This since this species has not been reported from calibrated pre-Bartonian sections anywhere (see e.g., the PalSys database), and/but does occur in the lowermost samples from Alano, assigned to the early Bartonian (~basal Chron 18r, Iakovleva, 2025; Iakovleva pers. comm. 2025). Furthermore, the presence of *Membranophoridium aspinatum*, *Michouxdinium variabile*, and *Rhombodinium draco* may be taken to broadly support a Bartonian or younger age as well (cf. Bijl, 2022). Notably, the distribution patterns of the abovementioned taxa, taken together with the background assemblages, now allow quite precise designation of the entire Thare section to the mid Bartonian, specifically the interval corresponding to magnetochrons C18n.1r to C18n.1n following Iakovleva (2025).

4. Discussion

Of particular interest for our age assessment is the distribution pattern of *Glaphyrocysta semitecta* in the Thare section, as it is here recorded from between samples Th3 and Th4, from the gray-brown marly limestones, onwards. The occurrence of this species is inconsistent in the marly limestone, but consistent in the gray-brown marls, and even more abundant in samples Th22, and Th23 (Table 1, Fig. 5). As mentioned, this pattern mimics its distribution pattern at Alano GSSP in the interval assigned to magnetochrons C18n.1r to C18n.1n (cf. Iakovleva, 2025). While being first described from the basal Type Bartonian in the UK (Bujak, 1980; later calibrated against Chron C19n by Hooker and King 2019), there are indications even pointing at a slightly earlier first appearance datum (FAD) in the UK as mentioned in Iakovleva (2025). Other ‘latest Lutetian’ records are reported from deposits assigned to NP15 nannofossil Zone from the Danish Basin (Heilmann-Clausen and Van Simaey, 2005), but much more consistently so from the early Bartonian onwards, e.g., from an interval calibrated against Chron C19n in Western Siberia (Iakovleva and Heilmann-Clausen, 2010), from the CP14a nannofossil Zone from northeastern Ukraine (Iakovleva, 2015) and questionably from the nannofossil Zone CNE13 from Crimea (Vasilyeva and Musatov, 2023). Other, unequivocal mid Bartonian records are reported from widely separated areas like Belgium (De Coninck, 1986, 1995a, 1995b), Kazakhstan (Vasilyeva, 2013; Oreshkina et al., 2015) and Greenland (Nøhr-Hansen, 2024). Younger records (Priabonian-Rupelian) are even more widespread, reported from Germany (Mohamed and Egger, 2019), Uzbekistan (Iakovleva et al., 2020), central and NE Italy (Brinkhuis and Biffi, 1993; Brinkhuis, 1994; Wilpshaar et al., 1996; Van Mourik and Brinkhuis, 2005) and the Karaburun area in the southern margin of the Western Black Sea Basin (Kaya et al., 2025) and even from the Southern Ocean (Bijl et al., 2013). In any case, it seems likely to us that the FO of *G. semitecta* in the Thare section is delayed when compared to NW Europe, exactly like the situation at Alano. In a recent contribution, Brinkhuis et al. (2025, fig. 4) considered the spatial and temporal distribution of this species in the Tethyan Realm to be related to a series of discrete incursions from the Atlantic and NW European domains in response to stepwise progressive climatic cooling during the latter part of the Eocene when compared to the calibrated stable isotopic oxygen (temperature) information presented in Westerhold et al. (2020).

As mentioned by Brinkhuis et al. (2025), of potential interest are the small morphological differences between early and later models of *Glaphyrocysta semitecta*. The former, early morphologies have a distinct, often quite coarsely granulated periphragm, and a more irregularly perforated outer membrane than their younger, earliest Oligocene counterparts (see e.g., Brinkhuis et al., 2025, plates XX–XXIII, and Iakovleva, 2025, plate IX). The former (more granulated) morphologies



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Plate III. Dinoflagellate cysts from the Middle Bartonian sedimentary interval in Morocco. Scale bars represent 40 µm.

1. *Glaphyrocysta exuberans*; sample Th23, slide 2, EF J34/2; ventral surface with focus on the apical archeopyle and processes.
2. *Glaphyrocysta ordinata*; sample Th32, slide 2, EF M25.
3. *Glaphyrocysta? vicina*; sample Th23, slide 2, EF F50/2; ventral surface.
4. *Glaphyrocysta? vicina*; sample Th23, slide 2, EF M39; ventral surface.
- 5, 6. *Membranophoridium aspinatum*; sample Th31, slide 3, EFJ43/3; 5. dorsal surface, 6. ventral surface.
7. *Membranophoridium aspinatum*; sample Th31, slide 1, EF M36/4; dorsal surface
- 8, 9. *Ynezidinium brevisulcatum*; sample Th30, slide 2, EF J42/2; 8. ventro-apical surface, showing 1'/6" contact characterizing the genus *Ynezidinium*; 9. dorso-antapical surface.
- 10, 11. *Batiacasphaera compta*; sample Th32, slide 2, EF M35.
12. *Kallosphaeridium nigeriense*; sample Th32, slide 3, E30; focus on the archeopyle

are comparable to the ones we encountered in the Thare section (see Plate II, figs. 1, 4 and 7), in that sense further confirming a mid-Bartonian age. This while the morphology of the specimens found in lower Oligocene sections from northeastern Morocco, such as the Ennayemiyene I and II and Bourkha sections (Slimani and Chekar, 2023) as well as the Ben Attaya (Mahboub et al., 2019), M'karcha (Slimani et al., 2019) and Tsoul (Mahboub and Slimani, 2020) match those, less granulated forms depicted from the earliest Oligocene in Italy and Turkey (compare e.g., Brinkhuis and Biffi, 1993; Brinkhuis, 1994; Brinkhuis et al., 2025). These observations and possible significance must be further confirmed by future work.

The FO of the classic late Eocene index taxon *Rhombodinium perforatum* is recorded between samples Th25–Th26 in the gray-brown marls at Thare (Table 1, Fig. 5). As mentioned, Iakovleva (2025, p. 13) recently documented its oldest-known, well-calibrated occurrence from the Bartonian (40.1085 Ma; middle Subchron 18n.2n), at Alano, NE Italy. It was already known to range from the late Bartonian (Châteauneuf and Gruas-Cavagnetto, 1978) into the Priabonian (Costa and Downie, 1976; Powell, 1992; Brinkhuis, 1994; Stover and Hardenbol, 1994; De Coninck, 1995a, 1995b, 1999; Köthe, 2012; Gedl, 2013, 2014; Williams et al., 2004; Heilmann-Clausen and Van Simaëys, 2005; Andreeva-Grigorovich et al., 2011; Iakovleva and Heilmann-Clausen, 2010; King, 2016; Houben et al., 2019; Iakovleva and Aleksandrova, 2013; Iakovleva et al., 2019; Sancay and Bati, 2020). In Morocco, *R. perforatum* was also recorded in deposits assigned to the Priabonian (Slimani et al., 2019; Slimani and Chekar, 2023).

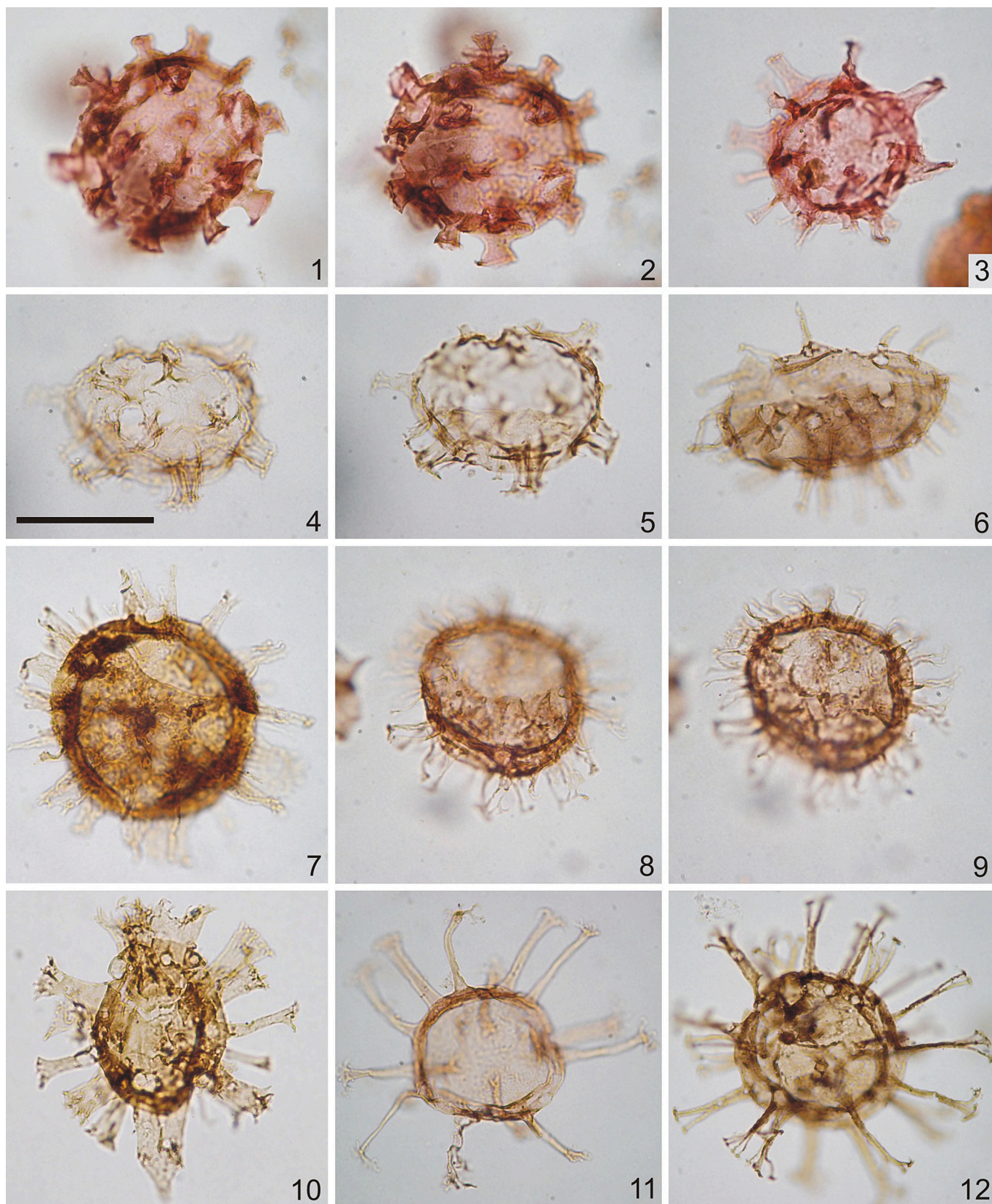
Another index event is the LO of *Castelodinium compactum*, recorded between samples Th30 and Th31 in the gray-brown marls (Table 1, Fig. 5). The LO of *Castelodinium compactum* was previously reported from 'the Bartonian' in southwestern France (Michoux, 1988), as well as from northern Morocco (Chekar et al., 2016, 2018; Mahboub and Slimani, 2020). This species occurs in the Lutetian through lower Bartonian interval of the section of the Ravninnaya R-43 borehole, Lower Volga region (Vasilyeva, 2024), and in Lutetian but absent in Bartonian deposits from the North Caucasus (Iakovleva et al., 2020). Please note that we consider *Castelodinium compactum* morphologically closely related to, if not identical to *Wilsonidium tabulatum*. The LO of the latter is employed in Iakovleva's (2025) selection of index events, being calibrated against the top of Chron C18n.1n. In most publications where both taxa are identified, they have similar ranges throughout.

Although not employed by Iakovleva (2025), she (pers. comm. 2025) does confirm the occurrence of *Homotryblium floripes* in basal samples at Alano. Furthermore, the FO of *Homotryblium floripes* was reported from the presumed latest Lutetian in the (now outdated) stratigraphic charts of Drugg and Stover (1975), Williams and Bujak (1985) and Williams et al. (2004). This event was also reported in assumed 'latest Lutetian' deposits from France (Châteauneuf, 1980; Michoux, 1985), Ukraine (Iakovleva, 2015) and other European regions. Earlier, on that basis, in

the Mediterranean region of Morocco, the FO of this species is reported from the back then assumed uppermost Lutetian from the Ibn Batouta and Tattofte sections (western External Rif) by Chekar et al. (2016, 2018). Its widespread and consistent occurrence in northern Morocco in the Bartonian and younger times is further documented in the Ennayemiyene I and II section (western External Rif) by Slimani and Chekar (2023), and in the Ben Attaya, M'karcha and Tsoul sections (eastern External Rif) by Mahboub et al. (2019), Slimani et al. (2019) and Mahboub and Slimani (2020), respectively.

In addition to the taxa discussed above, despite having no well-calibrated records, the respective FOs of *Membranophoridium aspinatum* and *Michouxidinium variabile*, both recorded in sample Th19 in the gray-brown marls (Table 1, Fig. 5) may be taken to support a mid-Bartonian age of the Thare section as well. This since the FO of *Membranophoridium aspinatum* was reported first (as '*Chiropteridium aspinatum*') in type Bartonian deposits in southern England (Bujak et al., 1980) and subsequently in Belgium (De Coninck, 1986), northwestern Europe (Powell, 1992), South Carolina (Van Pelt et al., 2000), Danish Basin (Heilmann-Clausen and Van Simaëys, 2005; Schiøler, 2005), West Siberia (Iakovleva and Heilmann-Clausen, 2010; Iakovleva, 2011) and northern Morocco (Chekar et al., 2018; Slimani et al., 2019; Mahboub and Slimani, 2020; Slimani and Chekar, 2023).

The FO of *Michouxidinium variabile* has been reported first (as '*Kisselevia variabilis*') from the type Bartonian in England (Bujak et al., 1980). It has subsequently been recorded in various assumed Bartonian deposits from Belgium (De Coninck, 1995a, 1995b); South Carolina (Van Pelt et al., 2000), Germany (Köthe and Piesker, 2007), West Siberia (Iakovleva and Heilmann-Clausen, 2010; Iakovleva, 2011) and Ukraine (Iakovleva, 2015). Similarly, the FO of *Rhombodinium draco* is recorded between samples Th20 and Th21 in the gray-brown marls (Table 1, Fig. 5). This event has also been reported from the Bartonian in the type area (Bujak et al., 1980) and from other sections in northwestern Europe (Stover et al., 1996; King, 2016), at ~40.5 Ma in the Northern Hemisphere mid-latitudes (Williams et al., 2004), England (Cotton et al., 2021); Denmark (Heilmann-Clausen and Van Simaëys, 2005); Peritethys (Iakovleva, 2017), Western Siberia (Iakovleva and Aleksandrova, 2013). The FO of this species defines the base of the *Rhombodinium draco* dinocyst Zone in northwestern Europe (Powell, 1992; Köthe, 2012); Kazakhstan (Iakovleva and Heilmann-Clausen, 2021) and Armenia (Iakovleva et al., 2024). Iakovleva et al. (2024, p. 38, 39) consider that the FO *Rhombodinium draco* is one of the most important biostratigraphic events of the Lutetian–Bartonian transition on a global scale, and taking into account, in particular, the fact that the stratotype and the criteria of the Lutetian–Bartonian GSSP boundary are not yet definitively defined, the issue of the precise stratigraphic level of the FO of *Rhombodinium draco* arises. Iakovleva et al. (2024) document the FO of *Rhombodinium draco* in the south Armenian Shagap section in an interval calibrated against the CNE14 nannofossil Zone, in turn in or near



(caption on next page)

Plate IV. Dinoflagellate cysts from the Middle Bartonian sedimentary interval in Morocco. Scale bars represent 40 µm.

- 1, 2. *Homotryblium caliculum*; sample Th13, slide 2, EF W43.
3. *Homotryblium abbreviatum*; sample Th11, slide 2, EF L36/3
- 4, 5. *Homotryblium cf. vallum*; sample Th15, slide 1, EF V30/4;
6. *Polysphaeridium subtile*; sample Th22, slide 2, EF Q53/2.
7. *Amphrosphaeridium multispinosum*; sample Th15, slide 2, EF L34/4; dorsal surface with focus on the precingular archeopyle and processes.
- 8, 9. *Cleistosphaeridium diversispinosum*; sample Th21, slide 2, EF H28/2; focus on the apical archeopyle (8) and processes.
10. *Hystrichokolpoma rigaudiae*; sample Th15, slide 1, EF T28.
11. *Homotryblium tenuispinosum*; sample Th19, slide 1, EF X44/3.
12. *Homotryblium floripes*; sample Th32, slide 2, EF V37/2.

the Lutetian–Bartonian boundary interval. At Alano, *Rhombodinium draco* occurs already in the lowermost sample analyzed (Iakovleva, 2025; Iakovleva, pers. comm., 2025).

5. Conclusions

In an attempt to more precisely date presumed ‘Late Cretaceous to early Eocene’ sedimentary successions in the tectonically complex Rif Chain, we now employed recently well-calibrated dinocyst events, and further supporting evidence of the Thare section, located in the western External Rif (northwestern Morocco), previously thought to be of Late Cretaceous–early Eocene age. We found the specific distribution patterns of *Homotryblium floripes*, *Glaphyrocysta semitecta*, and *Rhombodinium perforatum*, taken together with the background assemblages to allow quite precise designation of the section to the mid Bartonian, specifically the interval corresponding to chrons C18n.1r to C18n.1n following Iakovleva (2025).

Declaration of competing interest

No conflict of interest was reported by authors.

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Appendix A

List of dinoflagellate cyst taxa and a prasinophytes, cited or figured in this manuscript. All dinoflagellate cyst taxa are listed alphabetically by genus and all species are followed by references of their authors (following the latest Lentin and Williams Index of fossil dinoflagellates: Fensome et al., 2019) and where possible by plate and figure references in brackets.

- Achomosphaera* spp.
Adnatosphaeridium vittatum Williams and Downie, 1966c (Plate II, fig. 3).
Amphrosphaeridium multispinosum (Davey and Williams, 1966b) Sarjeant, 1981 (Plate IV, fig. 7).
Areoligera coronata (Wetzel, 1933b) Lejeune-Carpentier, 1938a.
Areoligera senonensis Lejeune-Carpentier, 1938a.
Batiacasphaera compta Drugg, 1970b (Plate III, fig. 10, 11).
Castellodinium compactum (Michoux, 1988) Williams et al., 2015 (Plate I, fig. 4).
Cerebrocysta bartonensis Bujak et al., 1980.
Cleistosphaeridium diversispinosum Davey et al., 1966 (Plate IV; figs. 8, 9).
Cordosphaeridium fibrospinosum Davey and Williams, 1966b (Plate II, fig. 6).

Cordosphaeridium gracile (Eisenack, 1954b) Davey and Williams, 1966b (Plate I, fig. 9).

Cribroperidinium giuseppi (Morgenroth, 1966a) Helenes, 1984 (Plate II, fig. 10).

Cribroperidinium tenuitubulatum (Gerlach, 1961) Helenes, 1984 (Plate II, fig. 12).

Deflandrea leptodermata Cookson and Eisenack, 1965a (Plate I, fig. 7).

Deflandrea phosphoritica Eisenack, 1938b (Plate I; fig. 3).

Fibrocysta bipolaris (Cookson and Eisenack, 1965b) Stover and Evitt, 1978.

Fibrocysta brevispinosa Slimani et al., 2012.

Fibrocysta vectensis (Eaton, 1976) Stover and Evitt, 1978 (Plate I, fig. 6).

Florentinia ferox (Deflandre, 1937b) Duxbury, 1980.

Glaphyrocysta exuberans (Deflandre and Cookson, 1955) Stover and Evitt, 1978 (Plate III, fig. 1).

Glaphyrocysta ordinata (Williams and Downie, 1966c) Stover and Evitt, 1978 (Plate III, fig. 2).

Glaphyrocysta semitecta (Bujak in Bujak et al., 1980) Lentin and Williams, 198 (Plate II, figs. 1, 4, 7).

Glaphyrocysta? vicina (Eaton, 1976) Stover and Evitt, 1978 (Plate III, figs. 3, 4).

Homotryblium abbreviatum Eaton, 1976 (Plate IV, fig. 3).

Homotryblium caliculum Bujak et al., 1980 (Plate IV, figs. 1, 2).

Homotryblium floripes (Deflandre and Cookson, 1955) Stover, 1975 (Plate IV, fig. 12).

Homotryblium tenuispinosum Davey and Williams, 1966b (Plate IV, fig. 11).

Homotryblium cf. vallum Stover, 1977 (Plate IV, figs. 4, 5).

Remarks. It differs from *Homotryblium vallum* sensu stricto by the more flared distal termination of the processes. *Homotryblium vallum* was first described from the Lower Oligocene–Lower Miocene interval by Stover (1977). Its FO was reported in the upper Eocene and Oligocene in different areas in the Northern Hemisphere (Williams et al., 1993; Brinkhuis and Biffi, 1993; Brinkhuis, 1994; Stover and Hardenbol, 1994; Stover et al., 1996; Gedl, 2004; Van Simaëys, 2004; Awad and Oboh-Ikuenobe, 2018). However, in Morocco, *Homotryblium vallum*, which resembles the species called herein *Homotryblium cf. vallum*, was reported for the first time earlier in the Lutetian (Chekar et al., 2018) and Bartonian (Slimani et al., 2019; Slimani and Chekar, 2023), and also later in the Priabonian and Rupelian (Slimani and Chekar, 2023). Further taxonomic examination of our species *Homotryblium cf. vallum* found in different regions of Morocco is necessary to achieve its correct determination.

Hystrichokolpoma rigaudiae Deflandre and Cookson, 1955 (Plate IV, fig. 10).

Hystrichokolpoma truncatum Biffi and Manum, 1988.

Hystrichokolpoma unispinum Williams and Downie, 1966a.

Impagidinium disperitum (Cookson and Eisenack, 1965a) Stover and Evitt, 1978.

Impagidinium maculatum (Cookson and Eisenack, 1961b) Stover and Evitt, 1978.

Impagidinium patulum (Wall, 1967) Stover and Evitt, 1978.

Kallosphaeridium nigeriense Jan du Chêne et al., 1985a (Plate III, fig. 12).

- Kallosphaeridium yorubaense* Jan du Chêne and Adediran, 1985.
Lejeunecysta globosa Biffi and Grignani, 1983.
Lejeunecysta hyalina (Gerlach, 1961) Artzner and Dörhöfer, 1978.
Lingulodinium machaerophorum (Deflandre and Cookson, 1955) Wall, 1967.
Membranophoridium aspinatum Gerlach, 1961 (Plate III, figs. 5–7).
Michouxdinium variabile (Bujak in Bujak et al., 1980) Williams et al., 201 (Plate I, figs. 1, 2).
Muratodinium fimbriatum (Cookson and Eisenack, 1968) Drugg, 1970b (Plate II, fig. 11).
Oligosphaeridium complex (White, 1842) Davey and Williams, 1966b.
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967.
Polysphaeridium bififormum Islam, 1983b.
Polysphaeridium subtile Davey and Williams, 1966b (Plate IV, fig. 6).
Pterodinium ayachense Guédé and Slimani in Guédé et al., 2014.
Rhombodinium draco Gocht, 1955 (Plate I, fig. 5).
Rhombodinium perforatum (Jan du Chêne and Châteauneuf, 1975) Lentin and Williams, 1977b (Plate II, figs. 8, 9).
Spiniferella cornuta subsp. *kasira* Slimani et al., 2012.
Spiniferites membranaceus (Rossignol, 1964) Sarjeant, 1970.
Spiniferites mirabilis (Rossignol, 1964) Sarjeant, 1970.
Spiniferites ramosus (Ehrenberg, 1837b) Mantell, 1854.
Thalassiphora pelagica (Eisenack, 1954b) Eisenack and Gocht, 1960 (Plate II, figs. 2, 5).
Wetzeliella articulata Wetzell in Eisenack, 1938b (Plate I, fig. 8).
Ynezidinium brevisulcatum (Michoux, 1985) Lucas-Clark and Helenes, 2000 (Plate III, figs. 8, 9).
Ynezidinium pentahedrias (Damassa, 1979b) Lucas-Clark and Helenes, 2000.
- Data availability**
- No data was used for the research described in the article.
- References**
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