Taxonomic revision of selected Late Jurassic (Tithonian) calcareous nannofossils and the application of mobile mounting

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With 10 figures

Abstract: In this study, the mobile mounting technique is used to investigate the morphologic characteristics of Polycostella senaria, Hexalithus geometricus, Nannoconus erbae and Nannoconus infans in different views, observed through rotation of the specimens in a mobile medium. We demonstrate that discrepancies in the published ranges are primarily caused by misunderstood taxonomic concepts representing these forms. Using this technique, we mapped and compared the side views of these forms to their equivalent plan views. The side/plan views of the following have also been mapped: Conusphaera maledicto, Conusphaera mexicana mexicana, Conusphaera rothii rothii, Paleomicula maltarica, Sikoraea steinhaueri, and Trapezopentus dennei. We have established one new genus Sikoraea and ten new species Calcicalathina clipeus, Conusphaera maledicto, Cyclagelosphaera centrumelliptica, Cyclagelosphaera paucisegmenta, Ellipsagelosphaera clausa, Ellipsagelosphaera supergesta, Nannoconus magnadiscus, Paleomicula jacovidesii, Sikoraea steinhaueri, and Watznaueria moshtovitzii. In addition, we have introduced a new subspecies Conusphaera rothii minor and the following four new combinations Micrantholithus imbricatus, Polycostella parvistellatus, Trapezopentus dennei, and Trapezopentus valentinei.

Key words: Calcareous nannofossils, Tithonian, mobile mounting technique, new taxa.

1. Introduction

In Gradstein et al. (2012), the base of Chron M22An (base of the Hybonoticeras hybonotum Ammonite Zone) represents the base of the Tithonian, whereas the top of the Tithonian (i.e. Jurassic/Cretaceous boundary) is placed at the base of Chron M18r (within the Berriasella jacobi Ammonite Zone). Channel et al. (2010) placed the base of Chron M18r at the FO [First Occurrence] of Nanoconus steinmannii minor in the Torre de’ Bussi section, whereas they place it between the FO of Nanoconus globulus minor and the FO of Nanoconus wintereri in the Colme di Vignola Section in Italy.

sil study on magnetostratigraphically-dated land sections and DSDP Sites 391C and 534A. Their high resolution calcareous nannofossil zonation scheme include additional calcareous nannofossil events as well as primary calcareous nannofossil events. They were able to directly correlate some of the calcareous nannofossil events to M-sequence polarity zones as well as calpionellid and ammonite zones.

The aim of this study is to revive the simple mobile mounting method of calcareous nannofossil analysis in order to improve understanding of Tithonian calcareous nannofossil structures and map the different profiles of the same specimens. This approach is considered to improve the current Tithonian calcareous nannofossil taxonomy and its application for biostratigraphic resolution. The stratigraphic ranges of the Tithonian species *Polycostella senaria*, *Hexalithus geometricus*, *Nannoconus erbae* and *Nannoconus infans* have been reported as being diachronous in several publications, and during routine studies performed by the authors. Detailed studies have been published by Bralower et al. (1989), Casellato (2010) and Bergen et al. (2014) in which they independently analyzed similar sample sets from DSDP Site 534, but ultimately producing different and unique stratigraphic ranges of the above species (Fig. 1). All other events, however, display good correlation.

2. Materials and methods

Tithonian sediments were analyzed on a global scale from various basins, including Angles (Vocontian Basin, 43°56′15″ N, 6°32′5″E), southeast France, Dorset, Porcupine Basin, Yemen, Kuwait, Oman, Saudi Arabia, Eastern Gulf of Mexico, Canada (Newfoundland and Labrador Sea), Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534, 28°20.6′ N, 75°22.9′ W) and Ibera Abyssal Plain, Atlantic Ocean (ODP Leg 149, Site 901A, 40°40.477′ N, 11°3.587′ W). This includes: Site 534: A total of 36 samples were analyzed from the Tithonian and lowermost Berriasian interval (Fig. 2). An additional 76 samples were collected from the Oxfordian to Barremian interval and are currently understudy. Site 901A: We analyzed 9 samples from the Tithonian interval. Angles: We studied 35 samples in 4 composite sections. Of these, 20 samples were analyzed from the Berriasian to Lower Hauterivian section, 4 samples were studied from the Barremian to Lower Aptian section, 7 samples were analyzed from the Aptian section and 4 samples were studied from the Upper Albian-Lower Cenomanian section. Dorset: A total of 310 samples were studied from the Hettangian to Kimmeridgian interval. Eastern Gulf of Mexico: Approximately 75 samples collected from 3 wells were analyzed from the Tithonian to Lower Berriasian section. Arabian Peninsula: Over 400 samples were studied from the Tithonian to Berriasian interval, from various wells in Yemen, Saudi Arabia, Oman and Kuwait. Porcupine Basin: About 40 samples collected from 2 wells were studied, spanning the Tithonian to lowermost Berriasian interval. Newfoundland and Labrador Sea: Over 300 samples collected from various wells were analyzed from the Pliensbachian to Berriasian interval. About 75 of these samples are from the Tithonian to lowermost Berriasian section.

The samples were prepared routinely using simple smear slide technique and studied using a Leica DM2500P light microscope. The photographs were taken using an Olympus DP73 digital camera. All the photomicrographs were taken using polarized and phase contrast light, and a gypsum plate. Selected samples were also prepared using the short centrifuging method (Edwards 1963; Piñeaar 1966; Varol 1989) to obtain high quality photographs.

Selected samples were prepared in mobile mounts to gain more information about the structure of certain species and map the plan and side views of the forms. This approach is essential, particularly in instances when the width and thickness of a species are similar in size. These species often naturally and randomly settle in plan and side views. The side views of some species, which were previously described from plan views, have erroneously been described as different species (see below). A simple technique has been employed for performing the mobile mounting. A suspension containing a “slurry” of calcareous nannofossils is smeared onto the slides, then dried in the normal method. The dried sediments are then scraped onto another slide and mixed with immersion oil. Finally, a cover slip is placed on the mixture before examination. The technique will be improved considerably if a less viscous mounting medium can be found. The less viscous type of glycerin or silicon Kel-F, routinely used by Bramlette & Sullivan (1961) awaits testing.

Depositories: The studied type material is stored in the Equinor (Statoil), Houston Office (2107 City West Blvd, Houston, TX 77042, USA). The repository number is 17M Tithonian Collection [Slide Box 1/1] in Room 17.507. The type material from DSDP and ODP cores are also stored at the Bremen repository (Germany) and at College Station repository (USA).

3. Biostratigraphy

All biostratigraphic events should, ideally, be constrained by magnetic reversal calibration and radiometric dating. It is not often possible, however, to incorporate these tools during standard biostratigraphic analysis. Calibration of the key bioevents is obtained by cross-correlating these bioevents with other previously calibrated nannofossil events (e.g., Gradstein et al. 2012) plotted on an age/depth curve. The availability of multidisciplinary datasets allows the calcareous nannofossil events to be calibrated by cross-correlation with palynological and micropalaeontolog-
Fig. 1. Summary events from DSDP Site 534.
tical events previously calibrated with standard chronostratigraphy. The primary bioevents of the Tithonian to Early Berriasian are presented in Fig. 3.

The Tithonian-Berriasian boundary corresponds to the base of Zone CC1 of Sissingh (1977) and is defined by the FO of Nannoconus steinmannii steinmannii and Nannoconus kamptneri kamptneri (Gradstein et al. 2012: 764) although the same boundary is placed at the FO of Nannoconus steinmannii minor and Nannoconus kamptneri minor in the same publication (Gradstein et al. 2012: 796). We prefer to use FO of Nannoconus steinmannii minor and Nannoconus kamptneri minor and/or top of Polycostella seneria (increase) and Conusphaera maledicto. In a proprietary studied carried out on the Arabian Peninsula, these events correspond to the influx of small globular Calpionella alpina often used to identify the Tithonian-Berriasian boundary (Reháková & Michalik 1997; Lacova et al. 1999; Wimbledon et al. 1999; López-Martínez et al. 2013). Moreover, these events
Fig. 3. Major Tithonian to Early Berriasian calcareous nannofossil events.
also correspond to major formation boundaries on the Arabian Peninsula.

4. Taxonomy

Selected Tithonian species were examined in mobile mounts to map their side and plan views. This method of analysis has necessitated a revision of the certain species definitions. These revisions are essential for consistent identification of the problematic species, and to construct robust and reliable zonation schemes and biostratigraphy practices. The newly mapped species are discussed below, in addition to some associated and related forms. The species with side views mapped to plan views include Conusphaera maledicto, Conusphaera mexicana mexicana, Conusphaera rothii rothii, Paleomicula maltica, Polycostella infans, Polycostella senaria, Sikoraea steinhaueri, and Trapezopentus dennei.

We have established one new genus Sikoraea, and eleven new species Calcicalathina clypeus, Conusphaera maledicto, Conusphaera rothii minor, Cyclagelosphaera centrumelliptica, Cyclagelosphaera paucisegmentsa, Ellipsagelosphaera clausa, Ellipsagelosphaera supergesta, Nannoconus magnadiscus, Paleomicula jacovidesii, Sikoraea steinhaueri, and Watznaueria moshkovitzii. In addition, we have also introduced three new combinations Micrantholithus imbricatus, Trapezopentus dennei and Trapezopentus valentinei, and discussed the associated species Conusphaera mexicana minor, Cyclagelosphaera deflandri, Hexalithus noeliæ, Hexalithus strictus, Nannoconus compressus, and Nannoconus wintereri. We established size dependent new species after years of tracking their sizes and their stratigraphic ranges around the world. A new term is introduced for the placolith, from Latin pelaga, main – referring to the tube cycle and shield, excluding the central area and its structures. The species are described in alphabetical order facilitate easy access.

**Calcicalathina Thierstein 1971**

**Type species:** Schizosphaerella oblongata Worsley 1971.

**Remarks:** Loxolith having a low or high narrow wall and granulated central area without a distal process.

**Calcicalathina clypeus** Varol & Bowman n. sp.

**Fig.** 5.26–5.29

**Etymology:** From Latin *clypeus*, shield - referring its shield like structure in the central area.

**Holotype:** Fig. 5.26–5.29 (same specimen)

**Type locality:** Angles, Vocontian Basin, sotheast France.

**Type horizon:** Lower Valanginian.

**Dimensions of holotype:** Length = 8.00 µm; width = 5.55 µm.

**Diagnosis:** Medium-sized species (6.0–10.0 µm) of *Calcicalathina* having a large granular central area with four segments along the long axis at the margin of central area.

**Description:** The segments are only visible at 45° and confined to the apex of the central area, leaving an unshielded rectangular area along the short axis. The roughly granular central area is well separated from the single cycle wall, and strongly birefringent without a distal process.

**Remarks:** Calcicalathina clypeus differs from other low-walled species of *Calcicalathina erbae* (Bergen 1998) by having four segments at the apex of the central area.

**Occurrence:** Calcicalathina clypeus was recorded from Upper Tithonian–Upper Valanginian sediments of Yemen, Upper Tithonian–Berriasian sediments of Kuwait and Oman, Upper Tithonian sediments of Eastern Gulf of Mexico, and Lower Valanginian sediments of Angles, Vocontian Basin, southeast France.

**Stratigraphic range:** Upper Tithonian–Upper Valanginian.

**Conusphaera** Trejo 1969

**Synonym:** Cretaturbella Thierstein 1971.

**Type species:** Conusphaera mexicana Trejo, 1969.

**Remarks:** Truncated conical nannolith having a protolith narrow outer wall and a central core with radially arranged segments which are straight or curved. It is subcircular to elliptical in plan view.

**Conusphaera maledicto** Varol & Bowman n. sp.

**Figs.** 6.17–6.20, 7.1–7.8

1996 *Conusphaera mexicana minor* Bralover, 1989. – De Kaenel & Bergen, pl. 1, figs. 1–12, 15–17

1996 *Conusphaera cf. mexicana minor* Bralover 1989. – De Kaenel & Bergen, pl. 4, figs. 13–14
**Etymology:** From Latin *maledicto*, fence – referring its fencelike appearance in the light microscope (LM).

**Holotype:** Fig. 7.5–7.8 (same specimen in mobile mount).

**Type locality:** De Soto Canyon, Gulf of Mexico.

**Type horizon:** Upper Tithonian.

**Dimensions of holotype:** Height = 2.52 µm; width (maximum) = 3.57 µm.

**Diagnosis:** Small species (< 4.0 µm) of *Conusphaera* having a central core with straight (un-curved) lateral elements. The four narrow, birefringent lateral segments of the central core and the thin, non-birefringent outer wall segments are visible in side view (at 0°). The species is strongly elliptical in plan view, and the core segments are birefringent whilst the protolith outer segments are non-birefringent.

**Description:** Small species (< 4.0 µm) of *Conusphaera* having a truncated conical shape. The width of the species is often greater than its height. The central core has four core segments visible in side view in the LM. Individual segments are not visible in plan view. The central core is strongly birefringent, whereas the outer protolith wall is non-birefringent.

**Remarks:** *Conusphaera maledicto* is easily distinguished from other small species of *Conusphaera*. It differs from *Conusphaera mexicana minor* by consistently having four core segments in side view (at 0°) in the light microscope and being strongly elliptical in plan view. In side view *Conusphaera mexicana minor* has only two core segments and is sub-circular in plan view. It is distinguished from *Conusphaera rothii minor* by having straight core segments. Curving of core segments are distinct in side view (displaying a spiraling pattern across the core), and in plan view in *Conusphaera rothii minor*. The species has an essentially similar structure to *Conusphaera rothii*, but differs from it by being smaller than 4.0 µm. *Conusphaera maledicto* is differentiated from *Conusphaera sinespina* (De Kaenel & Bergen 1996) by having a central core, whereas the latter has a plate with radial elements. *Conusphaera maledicto* is believed to be erroneously included into *Conusphaera mexicana minor*.

**Occurrence:** *Conusphaera maledicto* was recorded in Lower to Upper Tithonian sediments of the Arabian Peninsula, Eastern Gulf of Mexico, Canada (Newfoundland and Labrador Sea), Blake-Bahama Basin of the Atlantic Ocean (DSDP Leg 76, Site 534) and Iberia Abyssal Plain, Atlantic Ocean (ODP Leg 149, Site 901A).

**Stratigraphic range:** Lower Tithonian–Upper Tithonian.

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**Conusphaera mexicana mexicana** Trejo 1969

**Fig. 7.9–7.12**

**Remarks:** Large species (> 4.0 µm) of *Conusphaera* having a central core with straight (un-curved) lateral elements. Only two wide core elements are visible in the light microscope (at 0°). The species is subcircular in top view, and the radial elements are not distinct. *Conusphaera mexicana mexicana* is distinguished from *Conusphaera rothii rothii* by lacking a spiral pattern across the core in the LM.

**Stratigraphic range:** Lower Tithonian–Lower Aptian.

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**Conusphaera mexicana minor** Bown & Cooper 1989

**Fig. 6.28, 6.29**

**Remarks:** Small species (< 4.0 µm) of *Conusphaera* having a central core with straight (un-curved) lateral elements. Only two wide core elements are visible in the light microscope (at 0°). The species is subcircular in top view. *Conusphaera mexicana minor* is distinguished from elliptical *Conusphaera sinespina* by having a central core, whereas the latter possesses a plate with radial elements.

**Stratigraphic range:** Lower Tithonian – Upper Tithonian.

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**Conusphaera rothii minor** Varol & Bowman n. sp.

**Fig. 6.25, 6.30**

**Etymology:** From Latin *minor*, small – referring to its small size.
Fig. 5. Nannofossils from De Soto Canyon, Gulf of Mexico. 1–8: *Polycostella infans*, same specimen in mobile mount; 9–16: *Polycostella infans*, same specimen in mobile mount; 17–20: *Trapezopentus dennei*, same specimen in mobile mount; nannofossils from DSDP Leg 76, Site 534. 21–24: *Trapezopentus dennei* core 91–2, 145 cm; 25, 30: *Nannoconus wintereri*, core 91–2, 145 cm; nannofossil from Angles, SE France. 26–29: *Calcicalathina clipeus* [holotype].
Fig. 6. Nannofossils from De Soto Canyon, Gulf of Mexico. 1–16: *Polycostella senaria*, 1–8 same specimen and 9–16 same specimen in mobile mount; 17–20: *Conusphaera maledicto*, same specimen in mobile mount; Nannofossils from DSDP Leg 76, Site 534. 21–24: *Nannoconus compressus*, core 95–3, 64 cm; 25, 30: *Conusphaera rothii minor* core 93–2, 41 cm [holotype]; 26–27: *Nannoconus magnadiscus*, Core 91–2, 145 cm [holotype]; 28–29: *Conusphaera mexicana minor* core 96–3, 9 cm.
Fig. 7. Nannofossils from De Soto Canyon, Gulf of Mexico. 1–8: Conusphaera maledicto, 1–4 same specimen and holotype 5–8 same specimen in mobile mount; 9–12: Conusphaera mexicana mexicana, same specimen in mobile mount; 13–20: Conusphaera rothii rothii, same specimen in mobile mount; nannofossils from DSDP Leg 76, Site 534. 21–24: Hexalithus strictus, core 91–2, 145 cm; 25–28: Hexalithus noeliae, core 91–2, 145 cm; 29–30: Polycostella? beckmannii, core 95–3, 64 cm.
**Holotype:** Fig. 6.25, 6.30 (same specimen).

**Type locality:** DSDP Leg 76, Site 534, Core 93, Section 2, 41 cm.

**Type horizon:** Upper Tithonian.

**Dimensions of holotype:** Height = 3.56 µm; width (max) = 3.88 µm.

**Diagnosis:** Small species (<4.0 µm) of *Conusphaera* having a central core with curved lateral elements. The spiraling pattern across the core is observed in side view in the LM. It is elliptical with strongly curved birefringent lateral elements in plan view.

**Description:** Small species (<4.0 µm) of *Conusphaera* having a truncated cone shape. Its width is slightly greater or equal to its height. The central core has curved lateral elements visible in side and plan views. The spiraling pattern across the core is observed in side view in the LM. It is elliptical with strongly curved birefringent lateral elements in plan view.

**Remarks:** This subspecies has an essentially similar structure to *Conusphaera rothii*, but differs from it by being smaller than 4.0 µm. It is distinguished from other small species of *Conusphaera* by having a central core with curved lateral elements. In contrast, *Conusphaera mexicana minor* and *Conusphaera maledicto* have non-curving segments in their central core. This species is believed to be erroneously included into *Conusphaera mexicana minor*.

**Occurrence:** *Conusphaera rothii minor* was recorded in Lower to Upper Tithonian sediments of Arabian, Eastern Gulf of Mexico, Canada (Newfoundland and Labrador Sea), Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534) and Iberia Abyssal Plain, Atlantic Ocean (ODP Leg 149, Site 901A).

**Stratigraphic range:** Lower Tithonian – Upper Tithonian.

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**Cyclagelosphaera Noël 1965**

**Type species:** *Cyclagelosphaera margerelii* Noël. 1965.

**Remarks:** Circular placolith having a double tube cycle and a unicycle proximal and distal shield. The entire coccolith is birefringent.

**Cyclagelosphaera centrumelliptica**  
**VAROL & BOWMAN n. sp.**

**Fig. 8.6–8.9**

**Etymology:** From Latin *centrum elliptica*, elliptical center – referring its elliptical central area.

**Holotype:** Fig. 8.6–8.9 (same specimen)

**Type locality:** DSDP Leg 76, Site 534, Core 80, Section 1, 53 cm.

**Type horizon:** Lower Valanginian.

**Dimensions of holotype:** Diameter = 8.43 µm; length (central area) = 3.87 µm; width (central area) = 2.86 µm.

**Diagnosis:** Relatively large (6.0–10.0 µm) circular *Cyclagelosphaera* having a distinctly elliptical and closed central area.

**Description:** *Cyclagelosphaera centrumelliptica* is a circular species having a distinctly elliptical and closed central area with a smooth appearance. The proximal shield is relatively small, but easily detectable by its first order yellow birefringence colour in cross-polarized light (XPL). The tube cycle is not easily distinguished from the shields or central area.

**Remarks:** *Cyclagelosphaera centrumelliptica* is distinguished from other species of *Cyclagelosphaera* by having a large and elliptical central area. *Cyclagelosphaera deflandrei* has variants with an elliptical central area, but these forms are much larger (>12.0 µm) with a very narrow central area.

**Occurrence:** *Cyclagelosphaera centrumelliptica* was recorded from Upper Kimmeridgian to Lower Valanginian sediments of Eastern Gulf of Mexico, Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534) and Iberia Abyssal Plain, Atlantic Ocean (ODP Leg 149, Site 901A).

**Stratigraphic range:** Upper Kimmeridgian – Lower Valanginian.

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**Cyclagelosphaera deflandrei** (MANIVIT 1966)

**ROTH 1973**

**Synonym:** Watznaueria manivitiae Bukry, 1973.
Fig. 8. Nannofossils from DSDP Leg 76, Site 534. 1–5: Cyclagelosphaera paucisegmenta, core 91–2, 145 cm [holotype]; 6–9: Cyclagelosphaera centrumelliptica, core 80–1, 53 cm [holotype]; 10–17: Ellipsagelosphaera clausa, core 88–2, 109 cm [14–17 holotype]; 18–20: Watznaueria moshkovitzii, core 113–1, 2 cm [holotype].
Remarks: Very large (>12 µm) and strictly circular species of Cyclagelosphaera having a very narrow and closed central area. The central area is often approximately 3x smaller than the width of the pelagia (including tube cycle and shields). The entire species is highly birefringent (first order yellow to red birefringence colors). BUKRY (1973) introduced Watznaueria manivitiae as a substitute for Coccolithus deflandrei MANIVIT (1966) because Watznaueria deflandrei (Noël. 1965) REINHARDT 1971 (ex Actinosphaera) had already been transferred to Watznaueria. The large and circular forms are commonly and correctly assigned to Cyclagelosphaera deflandrei MANIVIT (1966). In this case, the substitute Watznaueria manivitiae has no holotype (or shares same holotype with Cyclagelosphaera deflandrei).

Occurrence: Cyclagelosphaera deflandrei was recorded in Upper Callovian to Lower Hauerivian sediments of Arabian Peninsula; Kimmeridgian – Lower Hauerivian sediments of Eastern Gulf of Mexico; Upper Tithonian–Lower Berriasian of Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534).

Stratigraphic range: Upper Tithonian–Upper Berriasian.

Ellipsagelosphaera NOËL, 1965

Type species: Ellipsagelosphaera frequens NOËL, 1965.

Remarks: Elliptical to circular placolith having double tube cycle, a unicycle proximal and distal shield and a disjunct bar in the central area. The entire coccolith is birefringent.

Ellipsagelosphaera clausa VAROL & BOWMAN n. sp.

Fig. 8.10–8.17

2009 Ellipsagelosphaera manivitiae/britannica. – GHAUD et al., fig. 4.24, 4.25.

2010 Watznaueria britannica (large) (STRADNER 1963) REINHARDT, 1964. – CASELLATO, pl. 2, fig. 2.

Etymology: From Latin clausa, closed – referring to its closed central area by a traverse bar.

Holotype: Fig. 8.14–8.17 (same specimen).

Type locality: DSDP Leg 76, Site 534, Core 88, Section 2, 109.

Type horizon: Middle Berriasian.

Dimensions of holotype: Length = 10.84 µm; width = 9.81 µm; length (central area) = 2.17 µm; width (central area) 1.73 µm.

Diagnosis: Large (>10.00 µm) and elliptical species of Ellipsagelosphaera with a narrow central area filled by a traverse bar.

Description: Ellipsagelosphaera clausa is a large elliptical species with a small central area cloaked by a traverse bar. It produces a first order yellow birefringence in XPL. The bar consists of two short segments diverging away from each other as they meet the inner tube cycle. Each segment is further divided into two equal limbs at the middle. The adjacent limbs of the segments act optically different, whereas the diagonal limbs of the segments appear optically similar. The central structure appears like a low angle cross, because of the diverging segments and similar optical properties of the diagonal limbs (Fig. 4).
Remarks: *Ellipsagelosphaera clausa* is easily distinguished from other species of *Ellipsagelosphaera* by its large size, its yellow birefringence color and small central area cloaked by a transverse bar.

Occurrence: *Ellipsagelosphaera clausa* was recorded in Upper Callovian to Lower Hauterivian sediments from the Arabian Peninsula; Oxfordian to Lower Hauterivian sediments from the Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534); Oxfordian to Upper Valanginian sediments from the Eastern Gulf of Mexico and Upper Bathonian to Oxfordian sediments from Newfoundland and Labrador Sea (Canada).

Stratigraphic range: Upper Bathonian–Lower Hauterivian.

*Ellipsagelosphaera supergesta* Varol & Bowman n. sp. Fig. 9.25–9.30

1996 *Ellipsagelosphaera britannica* (Stradner 1963) Reinhardt 1964. – Gale et al., fig. 6n.

1999 *Ellipsagelosphaera britannica* (Stradner, 1963) Reinhardt, 1964 – Aguirre-Urreta et al., pl. 4, fig. 4.

2003 Watznaueria communis Reinhardt 1964 – Kessels et al.; fig. 4.9–10.

2009 *Ellipsagelosphaera britannica* morphotype E (Stradner 1963) Reinhardt 1964. – Giraud et al., fig. 4.18.

2010 *Ellipsagelosphaera britannica* (Stradner 1963) Reinhardt 1964. – Tiraboshi & Erba, fig. 5.1; non fig. 5.3.

Etymology: From Latin supergesta, plugged – referring to a bar plugged the central area.

Holotype: Fig. 9.25–9.30 (same specimen).

Type locality: DSDP Leg 76, Site 534, Core 113, Section 1, 2 cm.

Type horizon: Oxfordian.

Diagnosis: Medium-sized (<10 µm) elliptical species of *Ellipsagelosphaera* having a very narrow central opening blocked by a very short bar.

Dimensions of holotype: Length = 7.20 µm; width = 5.90 µm; diameter (central area) = 1.21 µm.

Description: *Ellipsagelosphaera supergesta* has a very narrow and almost circular central area cloaked by a very short traverse bar with two segments. The tube cycle is often distinct and easily differentiated from the shields. This elliptical form produces first order white birefringence colour in XPL.

Remarks: *Ellipsagelosphaera supergesta* is distinguished from *Ellipsagelosphaera clausa* by being smaller than 10.0 µm with first order white birefringence colour rather than first order yellow birefringence color of *E. clausa*. It is distinguished from *Ellipsagelosphaera britannica* (Stradner 1963) Perch-Nielsen 1968 and *Ellipsagelosphaera lucasi* (Noël 1965) by having a very narrow central area entirely blocked by a traverse bar, whereas the latter species has an open central area on either side of the traverse bar. The abundance pattern of *Ellipsagelosphaera supergesta* differs from that of *Ellipsagelosphaera britannica* and *Ellipsagelosphaera lucasi*.

Occurrence: *Ellipsagelosphaera supergesta* was recorded in Lower Bajocian to Upper Albian sediments from the Arabian Peninsula; Oxfordian to Lower Aptian sediments from the Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534); Oxfordian to Upper Hauterivian sediments from the Eastern Gulf of Mexico and the Lower Bajocian to Lower Berriasian sediments from Newfoundland and Labrador Sea (Canada).

Hexalithus Gardet 1955

Type species: *Hexalithus locali* Gardet 1955.

Remarks: Round to almost hexagonal nannolith having six triangular segments (outer periphery of the segments are straight or convex). Species of *Hexalithus* can resemble *Polycostella* species in plan view, but is differentiated from them by having sutures meeting at the periphery of the edges rather than vertices typical of *Polycostella* species.

*Hexalithus noeliae* Loeblich & Tappan 1966 Fig. 7.25–7.28

Remarks: Round species of *Hexalithus* with six triangular segments with a rounded outer periphery. There may be some constrictions where the sutures meet the periphery, which may give the lobate appearance at the periphery.

Hexalithus strictus Bergen 1994

Fig. 7.21–7.24

Remarks: Semi-hexagonal species of *Hexalithus* with five triangular segments and one lozenge-shape segment. Four of the sutures meet at the vertices, whereas two sutures meet at the periphery at the edge of the nannolith. *Hexalithus strictus* is distinguished from *Hexalithus noeliae* by having one of its segments in lozenge-shape. It differs from *Polycostella*...
Fig. 9. Nannofossils from De Soto Canyon, Gulf of Mexico. 1–20: Sikoraea steinhaueri, 1–14 same specimen in mobile mount; [15–20 holotype]; nannofossils from DSDP Leg 76, Site 534. 21–24: Micrantholithus imbricatus, core 71–1, 66 cm; 25–30: Ellipsagelosphaera supergesta, core 113–1, 2 cm [holotype].
species by having some sutures meet at the periphery of the edges of the nannolith, whereas other sutures meet at the periphery at the vertices of the nannolith. The sutures in *Polycostella* species always meet at the periphery of the vertices.

**Stratigraphic range:** Lower Tithonian–Lower Berriasian.

*Micrantholithus* Deflandre 1950  
**Type species:** *Micrantholithus flos* Deflandre 1950.  
**Remarks:** Stellate or subcircular pentalith having sutures meet at the periphery of the pentagonal vertices.

*Micrantholithus imbricatus* (Manivit 1966)  
**Varol & Bowman n. comb.**  
Fig. 9.21–9.24  
1966 *Braarudosphaera imbricate* Manivit, p. 268, Fig. 4a, b.  
1972 *Braarudosphaera irregularis* Bybell & Gartner.

**Remarks:** Species of *Micrantholithus* having some sutures meeting at the periphery of the pentalith whereas other sutures meet at the vertices of the pentalith.

**Stratigraphic range:** Lower Tithonian–?Middle Eocene.

*Nannoconus* Kamptner 1931  
**Type species:** *Nannoconus steinmannii* Kamptner, 1931.  
**Synonyms:** *Brachiolithus* Noël 1959, *Nannosphaeroidina* Coom 1968.

**Remarks:** Various shaped (e.g., conical, globular, cylindrical, etc.) nannoliths having spirally-arranged segments around an axial canal. The species has a tangential c-axis (i.e. c-axis is perpendicular to the length of the Nannoconus). The species possesses longitudinal ridges, a low angle wall cycle and fine triangular segments which are weakly birefringent to non-birefringent retained in *Polycostella*.

*Nannoconus compressus* Bralower & Thierstein in Bralower et al. 1989  
**Fig. 6.21–6.24**

**Remarks:** Relatively small (3.0–8.0 µm), fusiform to truncated elliptical species of *Nannoconus* having a very narrow and undetectable canal and birefringent coarse segments. It has very low-angle wall cycle.

**Stratigraphic range:** Lower Tithonian–Lower Berriasian.

*Nannoconus magnadiscus* Varol & Bowman n. sp.  
**Fig. 6.26, 6.27**

**Etymology:** From Latin *magna*, great and *discus*, disc – referring to its large disc shape.

**Holotype:** Fig. 6.26, 6.27 (same specimen).

**Type locality:** DSDP Leg 76, Site 534, Core 91, Section 2, 145 cm.

**Type horizon:** Upper Tithonian.

**Dimensions of holotype:** Diameter = 10.47 µm.

**Diagnosis:** Large (>10.00 µm) and disc shape *Nannoconus*.

**Description:** *Nannoconus magnadiscus* is always observed in plan view due to the its low height (<3.0 µm). It has a moderately thin wall cycle with a high-angle and very narrow canal which is often not visible.

**Remarks:** *Nannoconus magnadiscus* is superficially like *Cyclagelosphaera brezae* Applegate & Bergen 1988, but differs from it by having a tangential c-axis in XPL.

**Occurrence:** *Nannoconus magnadiscus* was recorded worldwide, including the North Sea, Arabian Peninsula, Eastern Gulf of Mexico and Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534).

**Stratigraphic range:** Upper Tithonian–Upper Berriasian.

*Nannoconus wintereri* Bralower & Thierstein in Bralower et al. 1989  
**Fig. 5.25, 5.30**

**Remarks:** Relatively small (4.0–8.0 µm) pear to tapering conical species of *Nannoconus* having approximately equal width and height. It is often observed with a truncated conical cavity with very narrow apical and basal apertures.

**Stratigraphic range:** Upper Tithonian–Lower Berriasian.

*Palaeomicula* Varol & Jakubowski 1989  
**Type species:** *Tetralithus quadrisphenus* Worsley 1971.

**Remarks:** Square to round nannolith consisting of four segments, with a tangential c-axis (perpendicular to the length of the segments).
**Paleomicula jacovidesii** VAROL & BOWMAN n. sp.  
Fig. 10.15–10.30

**Etymology:** In honor of micropaleontologist Jake Jacovides, Millennia, Lechlade, Glos. GL7 3QQ, United Kingdom.

**Holotype:** Fig. 10.19–10.22 (same specimen)

**Type locality:** De Soto Canyon, Gulf of Mexico.

**Type horizon:** Upper Tithonian.

**Dimensions of holotype:** Diameter = 5.78 µm.

**Diagnosis:** Medium-sized (4.0–7.0 µm) circular species of *Palaeomicula* having four imbricated and triangular segments positioned along the sinusoidal sutures.

**Description:** *Paleomicula jacovidesii* is a circular nannolith having four smooth imbricated and triangular segments and distinct sinusoidal sutures. The thick imbricated edges of the segments along the sinusoidal sutures can be clearly observed.

**Remarks:** *Paleomicula jacovidesii* is easily distinguished from the other species of *Paleomicula* by being circular and having sinusoidal sutures and imbricated triangular segments. *Tetratalithus quadratisphenus* and *Palaeomicula maltica* have quadrate outlines with wedge-shaped segments.

**Occurrence:** *Paleomicula jacovidesii* was recorded in Upper Tithonian sediments of the Eastern Gulf of Mexico and the Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534).

**Stratigraphic range:** Upper Tithonian.

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**Polycostella Thierstein 1971**

**Type species:** *Polycostella senaria* Thierstein 1971.

**Emended diagnosis:** We retained *Polycostella* for the species with a nannoconid structure, having five to seven triangular-shaped segments and a straight or concave outer periphery.

**Remarks:** Relatively small (3.0–8.0 µm) nannolith having five to seven longitudinal ridges. The wall cycles are thin and low-angled, and the canal is very narrow. The species is stellate in plan view, and the sutures extend from the center (between the triangular segments) and meet at the periphery of the vertices. It is strongly birefringent in plan view, but weakly birefringent or non-birefringent in side view. The height and width of specimens vary greatly but are often similar in size. The size of the species follows a noticeable trend, as the height of the species decreases over time. *Polycostella beckmannii* possibly does not belong to this genus, since it does not show the typical *Nannoconus* structure in side view.

**Speciation:** The high forms (5.0–8.0 µm) are assigned to *Polycostella senaria*, whilst the low forms (<5.0 µm) are assigned to *Polycostella infans*. This subdivision is consistent with the respective holotypes.

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**Polycostella? beckmannii** Thierstein 1971  
Fig. 7.29–7.30

**Remarks:** Small (<6.0 µm) globular species with six to eight ridges. We have not observed any nannoconid structure while mobile mounting, therefore this species should be transferred to another genus. Until we fully understand the structure this species is retained in *Polycostella?*. The stratigraphic range of this species is diachronous, particularly its highest occurrence. It is possibly the direct result of the adoption of different species concepts among workers.

**Stratigraphic range:** Lower Tithonian – Upper Tithonian.
Fig. 10. Nannofossils from De Soto Canyon, Gulf of Mexico. 1–14: *Palaeomicula maltica*, same specimen in mobile mount; 15–30: *Palaeomicula jacovidesii*, [holotype 19–22 same specimen].
Remarks: *Polycostella infans* was originally described in side view, therefore its appearance in top view was unknown. In this study, we proved that *Hexalithus geometricus* is the top view of *Polycostella infans*.

**Stratigraphic range:** Upper Tithonian–Lower Berriasian.

*Polycostella parvistellatus* (Varol 1991)
Varol & Bowman n. comb.

2014 *Polycostella parvistellatus* (Varol 1991). – Bergen et al., p. 99, pl. 2, figs. 7–8 (Invalid ICN Art. 41.5).

**Emended diagnosis:** Small (<6.0 µm) nannoconid having five longitudinal ridges. The wall cycles are thin and low-angled, and the axial canal is very narrow. It is stellate in plan view and has sutures between the segments, which meet at the periphery of the vertices of the nannolith. It is strongly birefringent in plan view, but weakly birefringent or non-birefringent in side view.

**Remarks:** *Polycostella parvistellatus* is distinguished from *Polycostella senaria* by having five ridges rather than six ridges characteristic of *Polycostella senaria*.

**Stratigraphic range:** Upper Tithonian–Lower Berriasian.

*Polycostella senaria* Thierstein 1971

Fig. 6.1–6.16

**Synonym:** *Nannoconus erbae* Casellato 2010, p. 373, pl. 4, figs. 7–12.

**Emended diagnosis:** Medium-sized (4.0–8.0 µm) nannoconid with six longitudinal ridges. The wall cycles are thin and low-angled, and the canal is very narrow. It is stellate in plan view, and the sutures between the segments meet at the periphery of the vertices. It is strongly birefringent in plan view, but weakly birefringent or non-birefringent in side view. The height and width of specimens vary greatly but are often similar in size. The size of the species follows a noticeable trend, as the height of the species decreases over time.

**Remarks:** *Polycostella senaria* was originally described in plan view, therefore its side view was unknown. In this study, we proved that *Nannoconus erbae* is the side view of *Polycostella senaria*.

**Stratigraphic range:** Upper Tithonian – Lower Berriasian.

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**Sikoraea Varol & Bowman n. gen.**

**Type species:** *Sikoraea steinhaueri* Varol & Bowman n. gen., n. sp.

**Etymology:** In honour of calcareous nannofossil technician Steve Steinhauer – Bugware; Tallahassee, Florida, USA.

**Diagnosis:** Birefringent and fusiform nannolith having a smooth surface with longitudinal slits which are confined to its apex.

**Description:** *Sikoraea* is birefringent in both plan and side views, having an axial (radial) c-axis, which is parallel to the length of the nannolith. In side view, species are elliptical with the longitudinal slits confined to its apex. The slits do not extend to the lateral axis. In plan view, species are subcircular to circular, with eight radiating ridges. The ridges alternate between narrow and wider sizes. The narrow ridges interlock into slits but are not usually visible in side view.

**Remarks:** It appears different than any other genus and is difficult to compare.

*Sikoraea steinhaueri* Varol & Bowman n. gen., n. sp.

Fig. 9.1–9.20

**Etymology:** In honor of calcareous nannofossil technician Steve Steinhauer – Bugware; Tallahassee, Florida, USA.

**Diagnosis:** Birefringent and fusiform nannolith having a smooth surface with longitudinal slits which are confined to its apex.

**Holotype:** Fig. 9.15–9.20 (same specimen).

**Type locality:** De Soto Canyon, Gulf of Mexico.

**Type horizon:** Upper Tithonian.

**Dimensions of holotype:** Length = 5.13 µm; width = 3.89 µm.

**Description:** *Sikoraea steinhaueri* is birefringent in both plan and side views, having axial (radial) c-axis that is parallel to the length of the nannolith. In side view, the species is elliptical with the longitudinal slits confined to its apex. The slits do not extend to the lateral axis. In plan view, the species is subcircular to circular with eight radiating ridges. The ridges alternate between narrow and wider sizes. The narrow ridges interlock into slits but are not usually visible in side view.

**Remarks:** This is an unusual nannolith, and it is difficult to compare it to other species.
Occurrence: *Sikoraea steinhaueri* was recorded from Lower to Upper Tithonian sediments of the Eastern Gulf of Mexico and Lower Tithonian sediments of the Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534).

**Stratigraphic range:** Lower–Upper Tithonian.

*Trapezopentus* Wind & Cepek 1979 amend.

**Type species:** *Trapezopentus sarmatus* Wind & Cepek 1979.

**Synonym:** *Acadialithus* Howe 2017.

**Emended diagnosis:** Cylindrical nannolith made up of two cycles with five to seven segments. The ends of the segments often extend to form lateral projections. The large central area has no structure. The cycles are easily detached from each other under adverse preservational conditions.

*Trapezopentus dennei* (Howe 2017)

**Varol & Bowman** n. comb.

Fig. 5.16–5.24

2017 *Acadialithus dennei* Howe, p. 63, pl. 1, figs. 1–14; pl. 2, figs. 9–16.

**Remarks:** Species of *Trapezopentus* having six segments in each cycle.

**Stratigraphic range:** Upper Tithonian–Lower Berriasian.

*Trapezopentus sarmatus* Wind & Cepek, 1979

**Remarks:** Species of *Trapezopentus* having five segments in each cycle. Originally described as having a single cycle, but we have observed double cycle forms in Lower Valanginian and Berriasian sediments of the Jeanne d’Arc Basin, offshore east coast Canada.

**Stratigraphic range:** Lower Berriasian?–Upper Valanginian.

*Trapezopentus valentinei* (Howe 2017)

**Varol & Bowman** n. comb.

2017 *Acadialithus valentinei* Howe, p. 63, fig. 1; pl. 1, figs. 15–20; pl., figs. 1–16.

**Remarks:** Species of *Trapezopentus* having seven segments in each cycle.

**Stratigraphic range:** Upper Tithonian–Lower Berriasian.

Watznaueria Reinhardt 1964


**Type species:** *Watznaueria angustoralis* Reinhardt, 1964.

**Remarks:** Elliptical placolith with unicycle distal and proximal shields and a tube cycle. Central area may be closed, open or spanned by a plate or grill, without a bar or cross. The entire coccolith is birefringent.

Watznaueria moshkovitzii Varol & Bowman n. sp.

Fig. 8.18–10.20

1983 *Cyclagelosphaera deflandrei* (Manivit 1966) Roth 1973. – Roth, pl. 2, figs. 1–2 (figure caption was erroneously named as *Cyclagelosphaera cuvillieri*).

1987 *Watznaueria manivitea* Bukry 1973. – Moshkovitz & Ehrlich, pl. 1, figs. 1–7, non pl. 1, figs. 8–11.


1998 *Watznaueria manivitea* Bukry 1973. – Bown & Cooper, figs. 4.8, 8.


2010 *Watznaueria manivitea* (large) Bukry 1973. – cassellato, pl. 2, fig. 6; pl. 9, fig. 8.

**Etymology:** In honor of nannofossil specialist Dr. S. Moshkovitz, Israel.

**Holotype:** Fig. 8.18–8.20 (same specimen)

**Type locality:** DSDP Leg 76, Site 534, Core 113, Section 1, 2 cm.

**Type horizon:** Oxfordian.

**Dimensions of holotype:** Length = 15.52 µm; width = 14.58 µm; length (central area) = 5.63 µm; width (central area) = 4.10 µm.

**Diagnosis:** Very large species of *Watznaueria* (> 13.0 µm) having a closed central area. The entire species is highly birefringent (first order yellow to red-colored birefringence).

**Description:** This subcircular to broadly elliptical species has a distinctly elliptical and closed central area. The width
of the central area is often narrower than the width of the pelaga (including the tube cycle and shields). It is very highly birefringent and displays first order yellow to red-colored birefringence.

Remarks: Watznaueria moshkovitzii is easily distinguished from any other species of Watznaueria by its huge size. Bukry (1973) introduced Watznaueria manivitiae as a substitute for Coccolithus deflandrei from any other species of Conusphaera. In this study, the mobile mounting technique was used to map different profiles of Conusphaera. Remarks: Watznaueria moshkovitzii is easily distinguished from any other species of Watznaueria by its huge size. Bukry (1973) introduced Watznaueria manivitiae as a substitute for Coccolithus deflandrei from any other species of Conusphaera. In this study, the mobile mounting technique was used to map different profiles of Conusphaera. Remarks: Watznaueria moshkovitzii is easily distinguished from any other species of Watznaueria by its huge size. Bukry (1973) introduced Watznaueria manivitiae as a substitute for Coccolithus deflandrei from any other species of Conusphaera. In this study, the mobile mounting technique was used to map different profiles of Conusphaera. Remarks: Watznaueria moshkovitzii is easily distinguished from any other species of Watznaueria by its huge size. Bukry (1973) introduced Watznaueria manivitiae as a substitute for Coccolithus deflandrei from any other species of Conusphaera. In this study, the mobile mounting technique was used to map different profiles of Conusphaera.

Occurrences: Watznaueria moshkovitzii was recorded in Upper Callovian to Lower Hauterivian sediments from the Arabian Peninsula (except Yemen); the Blake-Bahama Basin, Atlantic Ocean (DSDP Leg 76, Site 534); Upper Callovian – Lower Kimmeridgian sediments of Dorset, UK; Upper Tithonian – intra-Berriasian sediments of Porcupine Basin and intra-Kimmeridgian – Oxfordian sediments of the Eastern Gulf of Mexico and Yemen.

Stratigraphic range: Upper Callovian–Lower Hauterivian.

5. Conclusions

In this study, the mobile mounting technique was used to map different profiles of Conusphaera maledicto, Conusphaera mexicana mexicana, Conusphaera rothii rothii, Paleomicula maltica, Polycostella infans, Polycostella senaria, Sikoraea steinhaueri, and Trapezopentus dennei. Calibration of the key bioevents were obtained by cross-correlating these bioevents with other previously calibrated nannofossil events (e.g., Gradstein et al. 2012) plotted on an age/depth curve. We have established one new genus Sikoraea and ten new species Calccalathina clipesus, Conusphaera maledicto, Cyclagelosphaera centrumelliptica, Cyclagelosphaera paucisegmenta, Ellipsagelosphaera clausa, Ellipsagelosphaera supergesta, Nannococcus magnadiscus, Paleomicula jacobidestia, Sikoraea steinhaueri, and Watznaueria moshkovitzii. In addition, we also introduced a new subspecies Conusphaera rothii minor and the following four new combinations Micranolithus imbricatus, Polycostella parvistellatus, Trapezopentus dennei, and Trapezopentus valentinei.

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