NEW CALCAREOUS NANNOFOSIL SPECIES FROM THE EARLY JURASSIC OF TETHYS

EMANUELA MATTIOLI

Key-words: Calcareous nannofossils, Early Jurassic, new species, evolution.

Abstract. Significant numbers of calcareous nannofossils belonging to the genera Lotharingius, Watznaueria and Carinolithus have been recorded from the Lower and Middle Jurassic of Tethys. Four new species of calcareous nannofossils are described in the present work. These species are age-diagnostic for the interval spanning the Late Domerian-Middle Toarcian, and help reconstructions of the phyletic relationships between the genera Lotharingius - Watznaueria and Calyculus - Carinolithus. Although never abundant, these new species are commonly found in the Toarcian and Aalenian of several Tethyan and some Boreal sections.

Introduction.

The Early Jurassic represents a very important period for calcareous nannofossils, because of their rapid evolution and diversification, diffusion throughout the Tethys ocean and North Europe shelves. During the Early Jurassic nannoplankton becomes one of the most important components of preservable marine phytoplankton.

After the pioneeristic taxonomic studies of the 1950’s, the nannofossil taxonomy and biostratigraphy received a great input in the last decade (Noël, 1965, 1973; Medd, 1971, 1979; Rood et al., 1971, 1973; Grün et al., 1974; Goy, 1981; Bown, 1987a, 1987b, Bown & Cooper, 1989; Cobianchi, 1990; De Kaenel & Berger, 1993). Some of these papers are based on the use of electron microscope. The present work is concerned with observations made mainly with the light microscope, the basic instrument for routine biostratigraphy.

Several ammonite-dated successions have been studied in Central Italy and compared to other Tethyan and North European areas (Tab. 1). Some time intervals, such as the Toarcian and Aalenian, contain rich and diverse nannofossil assemblages, in which some genera attain a particular importance in terms of both abundance and number of species. The genus Lotharingius, for example, becomes well diversified and very common in the Toarcian, being represented by several species. Among these, Lotharingius hauffii, is present with a great morphological variability. Morphometric studies and detailed observations of the central area structures allow to distinguish two new species closely related to L. hauffii, representing key forms to understand the Lower Jurassic evolutive lineage of the genus Lotharingius. Similarly, a great morphological variability exists both in the genera Calyculus and Carinolithus, with transitional characters from one genus to the other. A new species of Carinolithus is here described, and the links with the genus Calyculus are discussed.

Materials and methods.

Forty sections of age from Sinemurian to Kimmeridgian were investigated. Most of them are well dated on the basis of ammonite and/or dinoflagellate and radiolarian biostratigraphies. In some cases magnetostratigraphy has also been performed. Table 1 shows the locations, main characteristics, reference papers and the number of samples studied for each section. The investigation of more than 2000 samples representing different lithologies includes both quantitative and semiquantitative analyses. Smear slide preparation was as simple as possible to retain the original nannofossil assemblage.

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composition. Slides were examined mainly under light microscope (at 1000X magnification). Scanning electron microscope investigations were carried out only in a few samples with good preservation.

Preservation of nannofossils is generally moderate to poor, depending mainly on the different lithologies. In some time intervals (i.e. the Toarcian-Aalenian), concomitant with marly lithotypes, a better preservation of coccoliths has been observed. Absence of medium is in general to high in the Toarcian-Aalenian, while in the other intervals, it is rare to medium.

Morphometric studies have comprised the measure of the rim/central area and long/short axis ratios in some twenty specimens of all the considered species.

### Systematic Palaeontology

**Division** Prymnesiophyta Hibberd, 1976

**Class** Prymnesiophyceae Hibberd, 1976

**Family** Watznaueriaceae Rood, Hay & Barnard, 1971 emend. Bown, 1987b

**Genus** Lotharingius Noël, 1973 emend. Goy, 1979

**Lotharingius frodoi** sp. nov.

Pl. 1, fig. 1-5; Pl. 3, fig. 1, 2; Text-fig. 1

**Holotype.** Plate 1, fig. 1.

**Repository.** Dipartimento di Scienze della Terra, University of Perugia.

**Type locality.** Dotternhausen (Rohrbach quarry), SW Germany (Toarcian Posidonia Shales, Lias c), sample Dott. 3.

**Type stratum.** Lower Toarcian, caenarthrum Subzone, sample Dott. 3.

**Etymology.** Named after “Fredo”, the fantasy character of Tolkien's book "The lord of the rings".

**Diagnosis.** An elliptical species of the genus Lotharingius with a small, narrowly elliptical central area, bearing two buttresses aligned with the minor axis of the ellipse.

**Description.** A relatively small coccolith with a typical lotharingiacean rim. The general shape is narrowly elliptical. In distal view the inner and the outer cycles show comparable width. The outer cycle of the distal shield is formed by 20-25 counter-clockwise imbricating elements, displaying inclined sutures. The inner cycle is composed of 20-25 subsquare elements which display near radial sutures. The proximal shield, gently sloping inward, is slightly smaller than the distal...
### Calcareous nannofossils of Tethys

#### Fig. 1 - Comparison of morphological characters and stratigraphical distribution of the Lower Toarcian species of Watznaueriaceae. The dimensions of the holotypes are in brackets. AM = major axis of the ellipse; am = minor axis of the ellipse.

<table>
<thead>
<tr>
<th>species of the Watznaueriaceae</th>
<th>coccolith shape</th>
<th>central area</th>
<th>dimensions</th>
<th>outer mean, inner mean, area ratio</th>
<th>extinction cross arms</th>
<th>central area structures</th>
<th>stratigraphical distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>L. hauffii</em></td>
<td>subcircular to elliptical</td>
<td>small, subcircular to elliptical</td>
<td>AM:3.5-4μm am:3.2-3.5μm</td>
<td>1:1 to 2:1</td>
<td>1 to 1.2 mean 1.1</td>
<td>1 to 1.2 mean 1.19</td>
<td>slightly arcuated</td>
</tr>
<tr>
<td><em>L. frodoi</em> sp. nov.</td>
<td>elliptical</td>
<td>small, elliptical</td>
<td>AM:4.4-4.8μm am:3.8-4.5μm (3.65μm)</td>
<td>1:1</td>
<td>1 to 1.3 mean 1.15</td>
<td>1.25 to 1.3 mean 1.27</td>
<td>slightly arcuated</td>
</tr>
<tr>
<td><em>L. umbriensis</em> sp. nov.</td>
<td>subcircular to broadly elliptical</td>
<td>very small subcircular</td>
<td>AM:3.5-5.5μm am:3.3-4.5μm (3.35μm)</td>
<td>2:1</td>
<td>1.25 to 1.7 mean 1.42</td>
<td>1.05 to 1.1 mean 1.08</td>
<td>markedly arcuated</td>
</tr>
<tr>
<td><em>L. barozii</em></td>
<td>elliptical</td>
<td>wide, elliptical</td>
<td>AM:4.5-5.5μm am:4.5μm</td>
<td>1:1</td>
<td>0.7 to 0.75 mean 0.72</td>
<td>1.17 to 1.25 mean 1.22</td>
<td>slightly arcuated</td>
</tr>
<tr>
<td><em>L. sigillatus</em></td>
<td>elliptical</td>
<td>quite wide, elliptical</td>
<td>AM:5.6-6.5μm am:4.5-6μm</td>
<td>1:1 to 2:1</td>
<td>1.17 to 1.25 mean 1.22</td>
<td>buttress aligned with the major axis of the ellipse and a system of granular, radially disposed elements</td>
<td>Early Toarcian D.tenuicostatum Zone to Callovian</td>
</tr>
<tr>
<td><em>L. crucicentralis</em></td>
<td>elliptical</td>
<td>quite wide, elliptical</td>
<td>AM:5.5-7μm am:4.5-6μm</td>
<td>1:1 to 2:1</td>
<td>0.8 to 1.1 mean 0.93</td>
<td>1.07 to 1.4 mean 1.2</td>
<td>arcuated</td>
</tr>
<tr>
<td><em>L. velatus</em></td>
<td>elliptical</td>
<td>wide, elliptical</td>
<td>AM:6.8-7.5μm am:5.5-7.5μm</td>
<td>2:1</td>
<td>0.7 to 1 mean 0.9</td>
<td>1.1 to 1.2 mean 1.16</td>
<td>arcuated</td>
</tr>
<tr>
<td><em>W. colacicchii</em> sp. nov.</td>
<td>broadly elliptical</td>
<td>quite small, subcircular to subelliptical</td>
<td>AM:5.2-7μm (6μm) am:4.5-6.5μm (5μm)</td>
<td>2:1 to 3:1</td>
<td>1 to 1.4 mean 1.23</td>
<td>1.2 to 1.4 mean 1.23</td>
<td>markedly arcuated</td>
</tr>
<tr>
<td>Watznaueria sp. l</td>
<td>narrowly elliptical</td>
<td>small, narrowly elliptical</td>
<td>AM:6μm am:5μm</td>
<td>2:1 to 3:1</td>
<td>2 to 2.3 mean 2.11</td>
<td>1.25 to 1.3 mean 1.28</td>
<td>markedly arcuated</td>
</tr>
</tbody>
</table>
shield and is composed of around twenty elements, which show little or no imbrication.

In the central area, the inner wall is hardly visible. The central structures are limited to two buttresses aligned with the minor axis of the ellipse and probably bearing a spine. Often these bars have been observed to be loosen in some specimens; however the two inserts in the inner cycle of distal view are always visible.

Dimensions (holotype dimensions are in brackets): length, 4.0-4.8 \( \mu \text{m} \) (4.75 \( \mu \text{m} \)); width, 3.0-3.8 \( \mu \text{m} \) (3.65 \( \mu \text{m} \)).

Discussion. *Lotharingius frodoi* sp. nov. can be considered as a transitional form between the ancestral *L. hauffii* and the more evolved species of the genus *Lotharingius*; it appears shortly after *L. hauffii*. This species is distinguished from *L. hauffii* by the more elliptical shape of both the shield and the central area, and by the typical two buttresses within the latter. It differs from the other species of the genus *Lotharingius* by its small size and simple central area structure.

**Range.** *emaciatum* Zone (Upper Domerian) to Kimmeridgian. Although its range is fairly extended, it is usually rare and its occurrence is common only in the Lower Toarcian.

**Occurrence.** Central Italy - M. Cetona, Lower Toarcian; Colle d’Orlando, *tenuscostatum* Zone to Aalenian; Fiuninata, Middle Toarcian to Aalenian; Monte Serrone, Toarcian; Pozzale, *tenuscostatum* Zone to *serpentinus* Zone; Cima Panc, *emaciatum* Zone (Upper Domerian); Terminilletto, Aalenian to Kimmeridgian; Fonte Cervo, *emaciatum* Zone to *serpentinus* Zone; Filettino, Upper Domerian to Lower Toarcian; Sella dei due Corni, Upper Domerian to Middle-Late Toarcian. Portugal - Rabaçal, Lower Toarcian to Upper Toarcian. Greece - Kefalos, Upper Domerian to Lower Toarcian. Hungary - Kalvaria, Domerian-Toarcian. Germany - Dotternhausen, *seniculum* Zone to *faiciferum* Zone (Toarcian); Weilen unter den Rinnen, *opalum* Zone (Aalenian); Wistnau, *insulae* Subzone (Upper Toarcian).

**Diagnosis.** A subcircular species of the genus *Lotharingius*, with a very narrow central area with a cross aligned with the axes of the coccolith.

**Description.** A relatively small coccolith with a subcircular lotharingiacean rim. It is composed of two concavo-convex superimposed shields: the distal shield, larger than the proximal one, is bicyclic. In distal view, the outer cycle appears wider than the inner cycle, and it is constituted by 25-30 counter-clockwise imbricating elements, displaying markedly inclined sutures. The inner cycle is composed of 20-25 little subsquare elements with near radial sutures. The proximal shield is composed of approximately 25 elements showing little imbrication. In the very narrow central area, the central structures are characterized by four short equidimensional buttresses aligned with the axes of the ellipse, forming a little cross. Sometimes the cross is not preserved.

In light microscope with crossed nicols, the extinction pattern of the coccolith displays right angle bent arms due to: a) the optical discontinuity between the outer and inner cycles, b) the markedly inclined sutural lines among the various elements of the distal shield outer cycle and c) the marked concavo-convex shape of the coccolith.

**Dimensions:** length, 3.5-5.0 \( \mu \text{m} \) (3.6 \( \mu \text{m} \)); width, 3.3-4.5 \( \mu \text{m} \) (3.35 \( \mu \text{m} \)).

**Discussion.** *Lotharingius umbriensis* sp. nov. can be considered as a transitional form between the genus *Lotharingius* and the genus *Watznaueria*. The general organization and the crossed nicols extinction pattern of the coccolith closely resemble those of the Watznaueriaceae. It appears shortly after *L. hauffii*, from which it is distinguished by its subcircular shape both of the coccolith and of the central area, and by the extinction pattern. Moreover, the central structure of *L. hauffii* looks like a button completely isolated from the inner cycle of the distal shield, under crossed nicols. The well developed central cross of *L. umbriensis* sp. nov. is attached to the distal shield inner cycle, where four inserts are easily visible if the cross is not preserved. This new species is distinguishable from *L. frodoi* sp. nov. and the other species of the genus *Lotharingius* by its subcircular shape and small dimensions of the central area. This form is found commonly only in the Lower Toarcian.

**Range.** *emaciatum* Zone (Upper Domerian) to Aalenian.

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**PLATE 1**

All light micrographs crossed nicols, approximately X 3600.

Fig. 1-5 - Different specimens of *Lotharingius frodoi* sp. nov; Dott. 3, Dotternhausen, *exaratum* Subzone, Early Toarcian.

Fig. 6-12 - Different specimens of *Lotharingius umbriensis* sp. nov; 6: CO 7.20, Colle d’Orlando, *tenuscostatum* Zone, Early Toarcian; 7-12: Dott. 3, Dotternhausen, *exaratum* Subzone, Early Toarcian.
1. *Lotharingius frodoi*
2. *Lotharingius frodoi*
3. *Lotharingius frodoi*
4. *Lotharingius frodoi*
5. *Lotharingius frodoi*
6. *Lotharingius umbriensis*
7. *Lotharingius umbriensis*
8. *Lotharingius umbriensis*
9. *Lotharingius umbriensis*
10. *Lotharingius umbriensis*
11. *Lotharingius umbriensis*
12. *Lotharingius umbriensis*
Occurrence. Central Italy - M. Cetona, Lower Toarcian; Colle d’Orlando, tentoscostatum Zone to Aalenian; Fiuminata, Middle Toarcian to Aalenian; Monte Serrone, Toarcian; Pozzale, tentoscostatum Zone to serpentinus Zone; Cima Pancò, Early Toarcian; Terminillo, Aalenian; Fonte Cerro, enunciatum Zone to serpentinus Zone; Filetino, Upper Domerian to Lower Toarcian; Sella dei due Corni, Upper Domerian to Middle-Upper Toarcian. Portugal - Rabaçal, Lower Toarcian to Upper Toarcian. Greece - Lower Toarcian to Middle Toarcian. Hungary - Reka, serpentinus Zone (Lower Toarcian). Germany - Dottnerhausen, enunciatum Zone to falciferum Zone (Toarcian); Weilen unter den Rinnen, opalinum Zone (Aalenian); Wittnau, insigne Subzone (Upper Toarcian).

Genus Watznaueria Reinhardt, 1964

Remarks. The main differences between the genera Lotharingius and Watznaueria concern the general arrangement of the shield rather than the central area structures, that can be considered as a diagnostic feature for species diagnosis. In the genus Watznaueria the sutureal lines among the elements of the distal shield outer cycle appear more inclined than in the genus Lotharingius and the general shape of the coccolith is marked concavo-convex. In light microscope these features produce an extinction pattern with isogyres displaying right angle bent arms, revealing also the net optical discontinuity between the outer and inner cycles of the distal shield. In the genus Lotharingius the optical discontinuity in distal view is less marked. The author disagrees with the Bown’s statement (1987b) according to which the Bown’s statement (1987b) according to which the genus Lotharingius is distinguishable for possessing a distinctive central area cross and additional lateral bars. Some typical specimens of this genus have either a prominent longitudinal bar and subordinated radial elements (as in the case of Lotharingius sigillatus) or a series of granulations arranged longitudinally and radially (such as in Lotharingius velatus). Cross structures can be also present in the central area of species of the genus Watznaueria (see W. contracta).

Watznaueria colacicchii sp. nov. Mattioli & Reale

PLATE 2

All light micrographs crossed nicols, approximately X 3600.

Fig. 1-8 - Watznaueria colacicchii sp. nov.; 1: Witt. 100.80/100.82, Wittnau, insigne Subzone, Late Toarcian; 2: FLE 20.20, Fiuminata, Late Toarcian; 3: FLE 19.5, Fiuminata, Late Toarcian; 4: Witt. 100.80/100.82, Wittnau, insigne Subzone, Late Toarcian; 5: FLE 0, Fiuminata, Middle Toarcian; 6: FLE 27.60, Fiuminata, Early Aalenian; 7: FLE 0.35, Fiuminata, Middle Toarcian; 8: FLE 27.60, Fiuminata, Early Aalenian.

Fig. 9-12 - Carinolithus poalinbronei sp. nov.; 9: PO 3.6, Pozzale, tentoscostatum Zone, Early Toarcian; 10: Dott. 3, Dottnerhausen, exaratum Subzone, Early Toarcian; 11: FLE 27.60, Fiuminata, Early Aalenian; 12: FLE 27.60, Fiuminata, Early Aalenian.

Repository. Dipartimento di Scienze della Terra, University of Perugia.

Type locality. Wittnau, Germany (Upper Toarcian clays with Rosina).

Type stratum. Middle Toarcian, variabilis Zone, sample Witt. 100.80/100.82.

Etymology. Named in honour of the geologist Prof. Roberto Colacicchi, University of Perugia. This species was contemporaneously recognized by the author and Dr. Viviana Reale, University of Florence.

Diagnosis. A broadly elliptical to sub-circular species of the genus Watznaueria, with a reduced central area crossed by a system of bars forming a cross, aligned with the axes of the coccolith.

Description. This coccolith is generally broadly elliptical in shape, as well as the fairly reduced central area. The elements of the outer cycle of the distal shield (about 30) are clearly imbricated with inclined sutures. The inner cycle of the distal shield is about one third of the total width, its elements are small. The two shields have a concavo-convex shape. The reduced central area is almost completely filled with the cross aligned with the axes of the ellipse.

Dimensions: length 5.2-7.0 μm (6.0 μm); width 4.5-6.0 μm (5.0 μm).

Discussion. In light microscope under crossed nicols, the extinction pattern has very arcuated arms, clearly indicating the optical discontinuity between the inner and outer cycles of the distal shield. Watznaueria colacicchii sp. nov. is distinguished from the Mid-Jurassic W. contracta (Bown & Cooper, 1989) Cobianchi et al., 1992 by its smaller size and more open central area and from the other species of the genus Watznaueria for its central area structure. In poorly preserved material the cross is not observed; however Watznaueria colacicchii sp. nov. is distinguishable from Watznaueria sp. 1 in Cobianchi et al. (1992) by the four inserts of the cross that are always visible.

This species marks the entry of the genus Watznaueria and can be considered as an intermediate form between the small sub-circular Lotharingius (i.e. L. umbriensis) and the typically more elliptical and larger Watznaueria species.

The specimens figured as Lotharingius contractus by Reale et al. (1992), as Watznaueria aff. W. contracta.
and Lotharingius aff. L. contractus by Mattioli (1994; 1995) from the Middle and Upper Toarcian of central Italy should be assigned to W. colacicchii. The named specimens are smaller and possess a slightly wider central area compared to the holotype of L. contractus. In the Umbria-Marche area, the first occurrence of L. contractus was observed in the bifrons Zone and an increase in its size was recorded from the basal Aalenian (Reale et al., 1992; Baldanza & Mattioli, 1992). Probably, only the larger forms could be considered as unquestionable L. contractus.

Watznaueria contracta Cobianchi, Erba & Pirini Radizzani, 1992, is a new combination for Lotharingius contractus Bown & Cooper, 1989, based on the presence of a Watznaueriacean rim in this form. After a revision of the specimens of the Umbria-Marche area, the authors agree with Cobianchi et al. (1992) in this new combination. Typical specimens of W. contracta appear therefore in the Lower Aalenian of Umbria-Marche and Lombardy basins (Cobianchi et al., 1992; Mattioli, 1994; Mattioli et al., 1996, in progress), later than the occurrence of W. colacicchii.

Range. serpentinus Zone (Lower Toarcian) to Bajocian. Reale et al. (1992), bifrons Zone of central Italy. Mattioli (1994), Middle Toarcian of Fiuminata (central Italy). Mattioli (1995a), serpentinus Zone (Lower Toarcian) of Pozzale (central Italy).

Occurrence. Central Italy - Colle d’Orlando, Middle Toarcian (variabilis Subzone) to Lower Bajocian; Fiuminata, Middle Toarcian (variabilis Subzone) to Aalenian; Pozzale, serpentinus Zone (Lower Toarcian) to Aalenian; Cima Panco, Lower Toarcian to Aalenian; Colle Bertone, Upper Toarcian to Bajocian; Terminilleto, Aalenian to Bajocian; Sella dei due Corni, Lower Toarcian to Aalenian. Portugal - Rabacal, Middle to Upper Toarcian. Greece - Kaballos, Lower to Upper Toarcian. Germany - Wellen unter den Rinnen, opalinum Zone (Aalenian); Wittman, insignae Subzone (Upper Toarcian).

Order Podorhabdales Rood, Hay & Barnard, 1971
Family Calyculaceae Noël, 1973
Genus Carinolithus Prins in Grün et al., 1974
emended Bown, 1987b

Carinolithus poulnabronei sp. nov.

Pl. 2, fig. 9-12; Pl. 3, fig. 3; Text-fig. 2

1987 Calyculus sp., Crux, p. 55, pl. 1, fig. 16.
1995 Calyculus sp., Mattioli, pl. 2, fig. 1, 2.

Holotype. Plate 2, fig. 9.
Repository. Dipartimento di Scienze della Terra, University of Perugia.
Type locality. Pozzale section, Monti Martani, Central Italy (Lower Toarcian Marne di Monte Serrone Fm.).
Type stratum. Lower Toarcian, tenuicostatum Zone, sample PO 3.6.
Etymology. Named after “Poulnabrone” one of the most ancient and fascinating dolmens of Ireland.

Diagnosis. A thick species of the genus Carinolithus with a reduced proximal shield from which the elements of the distal shield, enlarging upward, extend to form a trumpet-like structure flaring at its distal extremity.

Description. The proximal shield is notably smaller than the distal shield and has a very reduced central area. In side view, the distal shield appears to be formed by few (10-12) wedge-shaped elements, whose extremity flares out to form a flat base displaying radial sutures. The axial canal, although reduced, tends to slightly enlarge distally to confer a lateral V-shape to the coccolith.

Dimensions: proximal shield, 3.0-4.0 μm (3.5 μm); distal shield, 6.0-7.0 μm (7.0 μm); rim height, 7.0-10.0 μm (9.0 μm).

Discussion. This species is distinguished from other Calyculus species for its more reduced axial canal, smaller dimensions of the proximal shield and very reduced central area in proximal view; from C. superbus for the thicker elements of the distal shield that confer to the coccolith a less elegant general shape; from C. cantaluppii for the lack of the enlargement of the vertical extension of the distal shield at one fifth of the height. Carinolithus poulnabronei sp. nov. has been often observed overgrown.

Carinolithus poulnabronei sp. nov. represents a transitional form from the genus Calyculus to the genus Carinolithus. The evolutive lineage between these two genera, according also to Crux (1987) and Bown (1987b), passes through a gradual vertical development of the elements of the distal shield, with the contemporary tendency to the closing of the central area of the proximal shield, of the axial canal, and the reduction of the proximal shield width. The transition between the two genera is fairly rapid and occurs within the tenuicostatum Zone.

PLATE 3

SEM photographs, the bar corresponds to 1 μm.
### Table: Morphological Characters and Stratigraphical Distribution of Lower Toarcian Components of the Family Calyculaceae

<table>
<thead>
<tr>
<th>Species</th>
<th>Morphology</th>
<th>Stratigraphical Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>§ <em>Calyculus cribrum</em></td>
<td>DS: 6-10 µm</td>
<td>Late Domerian (E. emaciatum Zone) to Late Toarcian (D. meneghinii Zone)</td>
</tr>
<tr>
<td></td>
<td>PS: 5-8 µm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H: 2-3 µm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>axial canal</td>
<td>wide</td>
</tr>
<tr>
<td></td>
<td>general shape</td>
<td>low basket</td>
</tr>
<tr>
<td></td>
<td>proximal/distal shield ratio</td>
<td>4:5</td>
</tr>
<tr>
<td>§ <em>Calyculus noelae depressa</em></td>
<td>DS: 6-10 µm</td>
<td>Late Domerian (E. emaciatum Zone) to Late Toarcian (D. meneghinii Zone)</td>
</tr>
<tr>
<td></td>
<td>PS: 5-8 µm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H: 4-5 µm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>axial canal</td>
<td>wide</td>
</tr>
<tr>
<td></td>
<td>general shape</td>
<td>low basket</td>
</tr>
<tr>
<td></td>
<td>proximal/distal shield ratio</td>
<td>4:5</td>
</tr>
<tr>
<td>§ <em>Calyculus noelae recondita</em></td>
<td>DS: 6-10 µm</td>
<td>Late Domerian (E. emaciatum Zone) to Late Toarcian (D. meneghinii Zone)</td>
</tr>
<tr>
<td></td>
<td>PS: 5-8 µm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H: 6-8 µm</td>
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</tr>
<tr>
<td></td>
<td>axial canal</td>
<td>wide</td>
</tr>
<tr>
<td></td>
<td>general shape</td>
<td>high basket</td>
</tr>
<tr>
<td></td>
<td>proximal/distal shield ratio</td>
<td>4:5</td>
</tr>
<tr>
<td><em>Carinolithus poulnabroni</em> sp. nov.</td>
<td>DS: 6-7µm (7)</td>
<td>D. tenuicostatum (Early Toarcian) to Late Toarcian (D. meneghinii Zone)</td>
</tr>
<tr>
<td></td>
<td>PS: 3-4µm (3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H: 7-10µm (10)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>axial canal</td>
<td>quite reduced</td>
</tr>
<tr>
<td></td>
<td>general shape</td>
<td>trumpet like</td>
</tr>
<tr>
<td></td>
<td>proximal/distal shield ratio</td>
<td>1:2</td>
</tr>
<tr>
<td><em>Carinolithus cantaluppii</em></td>
<td>DS: 3-4µm</td>
<td>H. tenuicostatum (Early Toarcian) to Late Toarcian (D. meneghinii Zone)</td>
</tr>
<tr>
<td></td>
<td>PS: 2.3-2.8µm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H: 8-10µm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>axial canal</td>
<td>very thin</td>
</tr>
<tr>
<td></td>
<td>general shape</td>
<td>funnel-shaped</td>
</tr>
<tr>
<td></td>
<td>proximal/distal shield ratio</td>
<td>1:2</td>
</tr>
<tr>
<td><em>Carinolithus superbus</em></td>
<td>DS: 3.5-5.5µm (3.5)</td>
<td>D. tenuicostatum (Early Toarcian) to Early Bajocian</td>
</tr>
<tr>
<td></td>
<td>PS: 2.3-2.8µm (3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H: 7-10µm (10)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>axial canal</td>
<td>very thin</td>
</tr>
<tr>
<td></td>
<td>general shape</td>
<td>trumpet like</td>
</tr>
<tr>
<td></td>
<td>proximal/distal shield ratio</td>
<td>1:2</td>
</tr>
</tbody>
</table>

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**Fig. 2** - Summary of morphological characters and stratigraphical distribution of the Lower Toarcian components of the Family Calyculaceae. The dimensions of the holotypes are in brackets. Dimensions and stratigraphical distribution of *C. cantaluppii* are from Cobianchi (1990). The symbol § is referred to the species grouped into *Calyculus* spp. DS = distal shield width; PS = proximal shield width; H = height of the vertical extension of the distal shield.

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Some considerations about evolutive lineages.

It is important to bear in mind that "... Evolution may be defined as the modification through time of genes and gene frequencies. In palaeontology it is seen as the modification through time of morphology, assuming that morphology is the phenotypic expression of the genotype. ..." (Bown, 1987b, p. 83). This observation lets us understand the importance of precise observations on morphometric variations, although our considerations concern parataxy, the objects of the study being single parts of the original organism.

During the Late Domerian-Early Toarcian time interval, the nanoplankton underwent an intense phase of diversification and turnover in the assemblage com-
position. Accelerated biological processes occurred at that time and several species and genera first appeared. The new species discussed in the present paper all first appeared during this intense phase of diversifications that lasted about four million years.

Radiating placolith rim group: Calyculaceae lineage.

The evolutive lineage between the genera *Calyculus* and *Carinolithus*, already discussed by Bown (1987b), passes through a gradual vertical development of the elements of the distal shield with the contemporary tendency to the closing of the axial canal and reduction of the total width and central area dimensions of the proximal shield. A similar evolutionary trend was first observed by Prins (1969), who considered these forms as evolved from *Crepidolithus crassus*. Crux (1987) considered as a significant evidence of the evolution of *Calyculus* sp. into *Discorhabdus* (= *Carinolithus*) *superbus* the development of a more circular shape of the coccolith and the reduction of the central area dimensions.

Within the genus *Calyculus*, specimens with a similar coccolith arrangement but with a different thic-
kness of the distal shield have been observed in side view, namely Calyculus cribrum, C. noelae depressa and C. noelae recondita. These forms are here grouped into the Calyculus spp. group (Fig. 2 and 3), as it is difficult to observe them in side view. The new species here described has to be placed within the genus Carinolithus, despite its thickness, because of the presence for the first time of a quite developed vertical extension of the distal shield and an almost reduced axial canal. A similar trend toward an increase of the height of the stem and reduction of the central area is observed also in the most common representative of the genus, C. superbus, that in some youngest forms appears exceptionally developed distally. Carinolithus cantaluppii could be considered as a species derived from C. poulnabronei (Fig. 3) by a reduction of the width of the proximal side of the stem, once demonstrated its younger occurrence with respect to C. poulnabronei.

The transition between the genera Calyculus and Carinolithus is observed to be fairly rapid and occurs within the tenuicostatum Zone (Fig. 3). The appearance of the genus Carinolithus in the lowermost part of the Toarcian is highly relevant for biostratigraphy.

Imbricating placolith rim group: Watznaueriaceae lineage.

The author agrees with the general tendency, already observed by Cobianchi et al. (1992), of an increase in coccolith size in successive new taxa both of Lotharingius and Watznaueria. Moreover, Cobianchi et al. (1992) evidenced some important morphological modifications in the evolution within the genus Lotharingius.
regarding both rim and central area structures (pp. 22-23).

The main modifications within the genus *Lotharingius* observed in the present paper pass trough: 1) an increase of the dimensions of the elliptical central area, with a consequent reduction of the ratio margin/central area dimensions; 2) an increase of the outer cycle with respect to the inner cycle in distal view; 3) the development of more complex central area structure, passing from simple bars or crosses aligned with the axes of the ellipse (i.e. in *L. frodoi* and *L. barozii*) to little and numerous granular elements, disposed both longitudinally and radially (i.e. in *L. velatus*).

The existence of specimens of *Lotharingius* with a monocyclic distal shield (i.e. *L. primigenius*) is questionable. More probable is the loss of some shield structure by dissolution, as already observed by Bown (1987b, p. 63). In the present paper it is hypothesized that, beginning from the most ancestral *Lotharingius* (i.e. *L. hauffii*), two evolutive lineages occurred (Fig. 4): 1) the *Lotharingius* lineage is characterized by an enhancement of the general elliptical shape, an increase of the dimensions of both coccolith and central area. In distal view, the outer/inner cycle ratio varies from 1:1 to 2:1 in the most evolved *Lotharingius* (Fig. 1). The central area structures evolved into an increasingly complex arrangement of granular elements, such as in *L. velatus* (Fig. 4); 2) the *Watznaueria* lineage includes: a) a tendency toward a broadly elliptical to subcicular shape of the coccolith, b) reduction of the central area, c) simplifications of the central structures and d) an increase of the optical discontinuity between the inner and outer cycle of the distal shield, due both to an accentuation of the concavo-convexity and to a major inclination and imbrication of the outer cycle elements. In distal view, the outer/inner cycle ratio is 2:1 to 3:1 (Fig. 1). The outer cycle is thus always more developed than the inner cycle.

*Watznaueria colacicchii* sp. nov. evolving from the most ancestral species of the genus *Lotharingius* underwent considerable reduction in size of the central area which resulted in a shrinking of the central cross complex (Fig. 4). Its occurrence is almost contemporary of *Watznaueria* sp. 1 of Cobianchi et al. (1992), characterized by a small and open central area. A common evolutive origin can be tentatively hypothesized for these two species.

**Species Index.**

Division Prymnesiophyta Hibberd, 1976
Class Prymnesiophyceae Hibberd, 1976
Order Eifellithales Rood, Hay & Barnard, 1971
Family Zygodiaceae Hay & Mohler, 1967
Genus Crepidolithus Noël, 1965
Crepidolithus crassus (Deflandre, 1954) Noël, 1965

Family Calyculaeae Noël, 1973
Genus Calyculae Noël, 1973
Calyculae cribrum Noël, 1974 emend. Goy 1979
Calyculae noaelae depressa (Goy in Goy et al., 1979) Crux, 1987
Calyculae noaelae recondita (Goy in Goy et al., 1979) Crux, 1987

Genus Carinolithus (Prins in Grün et al., 1974) Bown, 1987b
Carinolithus cantalappii Cobianchi, 1990
Carinolithus poulhaborosi sp. nov.

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Lotharingius barozii Noël, 1973
Lotharingius crucicentralis (Medd, 1971) Grün & Zweili, 1980
Lotharingius frodoi sp. nov.
Lotharingius hauffii Grün & Zweili in Grün et al., 1974
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Lotharingius sigillatus (Stradner, 1961) Prins in Grün et al., 1974
Lotharingius umbriatissimus sp. nov.
Lotharingius velatus Bown & Cooper, 1989

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Watznaueria colacicchii sp. nov. Mattioli & Reale
Watznaueria contracta (Bown & Cooper, 1989) Cobianchi, Erba & Pirini Radzrazzini, 1992
Watznaueria sp. 1 Cobianchi, Erba & Pirini Radzrazzini, 1992

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**REFERENCES**


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