Austrian Journal of Earth Sciences | Volume 106/2 | 89 - 114 | Vienna | 2013

Plankton stratigraphy of the Santonian at Morzg, Salzburg (Gosau Group, Northern Calcareous Alps, Austria)

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KEYWORDS

calcareous nannoplankton
planktonic foraminifera
dinoflagellate cysts
Upper Cretaceous
Eastern Alps
Gosau Group

Abstract

Montfort hill, lying in Morzg, within the southern outskirts of Salzburg, consists of Upper Cretaceous deposits of the Gosau Group. Alluvial fan deposits of the Kreuzgraben Formation (?Turonian) and Coniacian neritic limestone (Glanegg beds of the *Paratexanites serratomarginatus* ammonite zone) are overlain by bathyal marlstone ("Morzg beds"). Diverse planktonic assemblages (foraminifera, calcareous nannoplankton and dinoflagellate cysts) indicate that they lie in the upper part of the *Dicarinella asymetrica* planktonic foraminifera zone and the *Lucianorhabdus cayeuxii* calcareous nannoplankton zone (CC16 resp. UC12) of the middle to upper Santonian. As in the near-by Untersberg region (Eitelgraben section), the succession at Morzg is punctuated by a stratigraphic gap comprising the lower Santonian and probably parts of the middle Santonian.

Der Montforter Hügel im südlichen Salzburger Vorort Morzg besteht aus oberkretazischen Ablagerungen der Gosau-Gruppe. Über alluvialen Schwemmfächersedimenten der Kreuzgraben-Formation (?Turonium) und geringmächtigen Seichtwasserkalken des Coniaciums (Glanegger Schichten der *Paratexanites serratomarginatus*-Ammonitenzone) liegen bathyale Mergel („Morzg Schichten"). Diese enthalten reiche Plankton-Vergesellschaftungen (Foraminiferen, kalkiges Nannoplankton und Dinoflagellaten-Zysten), die eine Einstufung in die obere *Dicarinella asymetrica*-Foraminiferenzone und die *Lucianorhabdus cayeuxii*-Nannoplanktonzone (CC16 bzw. UC12) des Mittel- bis Ober-Santoniums erlauben. Wie am nahen Untersberg (Eitelgraben-Profil) ist in Morzg eine Schichtlücke ausgebildet, die das untere Santonium und vermutlich Teile des mittleren Santoniums umfasst.

1. Introduction

Recently, Lamolda et al. (2007 and 2013) proposed that the Olazagutia Section in northern Spain be selected to define the Global Boundary Stratotype and Section Point (GSSP) for the Coniacian/Santonian-boundary. The marker for the boundary is the first occurrence (FO) of the inoceramid bivalve *Platyceramus undulatoplicatus*. This bioevent lies within the calcareous nannoplankton *Lucianorhabdus cayeuxii* Zone and the planktonic foraminifera *Dicarinella asymetrica* Zone (close to the first occurrence of *Sigalia carpatica*). The micropaleontological results from the Olazagutia section are supported by data on excellently preserved planktonic assemblages from the Tanzania drilling Project (Petrizzio et al., 2013). In both sections, the *D. asymetrica* Zone is characterized by the presence of the nominate taxon and abundant large-sized marginotruncanids. Species of *Sigalia* (*S.carpatica*, *S. deflaensis*, *S. decoratissima*) are also typical for this zone (Salaj and Samuel, 1966; Weidich, 1984).

In the Eastern Alps, rich and diverse planktonic foraminifera

Figure 1: A,B…Geographical maps showing the position of the studied area, C….Geological sketch map of the Morzg area modified after Prey (1969) and position of the sampled outcrops (1…Morzg West, 2…Morzg Ost, 3…Rö).

assemblages of the Coniacian and Santonian occur in the Helvetic nappe system and in the Northern Calcareous Alps (see Oberhauser, 1968, for a compilation). Lithostratigraphically, the sections in the Northern Calcareous Alps are part of the Gosau Group. In the surroundings of Salzburg and in Bavaria, across the German border, planktonic assemblages of these deposits were particularly studied by Herm (1962), Oberhauser (1963a, 1963b), Butt (1981), and Wagreich (2003).

Montfort hill, near Morzg at Salzburg, is within the alluvial plain of the Salzach river (Fig. 1c). Fugger and Kastner (1885) correlated bioclastic limestone from this outcrop with the Glaneck (new spelling: Glanegg) beds from the near-by Glanegg hill (Fig. 1b). Brinkmann (1935) supported this correlation by the finding of the ammonite *Paratexanites serratomarginatus* at Morzg, the nominate taxon for the *P. serratomarginatus*-Zone of the Upper Coniacian (Kennedy et al., 1981). Overlying the limestone, grey marlstone occurs containing rich planktonic foraminifera faunas of the Santonian *Globotruncana concavata carinata*-Zone (Oberhauser, 1963b and 1968). The nominate taxon of this zone is now called *Dicarinella asymetrica* (see Appendix 1).

These previously published papers indicated that the Coniacian and Santonian should be present at Morzg. However, no detailed documentation of this section has been published. In this paper, planktonic assemblages (foraminifera, calcareous nannoplankton and dinoflagellate cyst) are evaluated in a multistratigraphic approach to establish a stratigraphic framework for the Morzg section.

2. Geological setting

Paleogeographically, the Gosau Group (Turonian-Lutetian) of the Eastern Alps was deposited in the northwestern Tethyan realm at a paleolatitude of 20° to 30° N. It comprises mainly siliciclastic and mixed siliciclastic-carbonate strata and was deposited after a late Early Cretaceous to Cenomanian episode of thrusting and nappe formation at the northern convergent margin of the Adriatic Plate (see Wagreich and Faupl, 1994, for a review).

The Gosau Group shows a two-fold subdivision (Reuss, 1854) into a lower part comprising terrestrial and shallow-water sediments (Lower Gosau Subgroup), and an upper part, consisting of deep-water deposits (Upper Gosau Subgroup). Subsidence, causing bathyal conditions, was due to subduction-driven tectonic erosion at the front of the Adriatic Plate, and affected the western part of the Northern Calcareous Alps in the Santonian whereas in the eastern part neritic conditions lasted till the Early Maastrichtian (Wagreich, 1993).

In the Salzburg area, the transgressional base of the Gosau Group shows two different facies developments. In the western part (Untersberg area), a shallow water limestone containing rudists rests with an erosional unconformity on Upper Jurassic platform deposits (Plassenkalk). This facies is restricted to the Juvavian nappe system, which represents the uppermost tectonic unit of the Northern Calcareous Alps. During Late Jurassic to Early Cretaceous times, gravitational tectonics caused the emplacement of the Juvavian nappe system on the Tyrolean nappe system (see Mandl, 1999, for a review). The Gosau successions to the east of Untersberg (Glanegg, Morzg, Salzburg town and Gaisberg) were deposited on the Tyrolean nappe system. There, thick alluvial fan deposits (Kreuzgraben Formation) overlie Upper Triassic to Upper Jurassic basin deposits (Prey, 1969). Variegated Santonian marlstones (Oberhauser, 1963a, Egger, 1990) are the oldest known marine Gosau Group deposits at Gaisberg. Lithostratigraphically, it was assigned to the Nierental Formation (Egger, 1990) or, alternatively, to the Grabenbach Formation (Wagreich, 2003).

3. Description of the Morzg section

The Kreuzgraben Formation, forming the base of the Morzg section, was described by Schlager (1959). However, during our sample surveys, only isolated blocks of this alluvial conglomerate were found at the southeastern foot of the Montfort hill. The clasts in the conglomerate originate exclusively from the Northern Calcareous Alps. The overlying Coniacian suc-

Figure 2: The Coniacian limestone at the eastern escarpment of the Montfort hill, Salzburg.

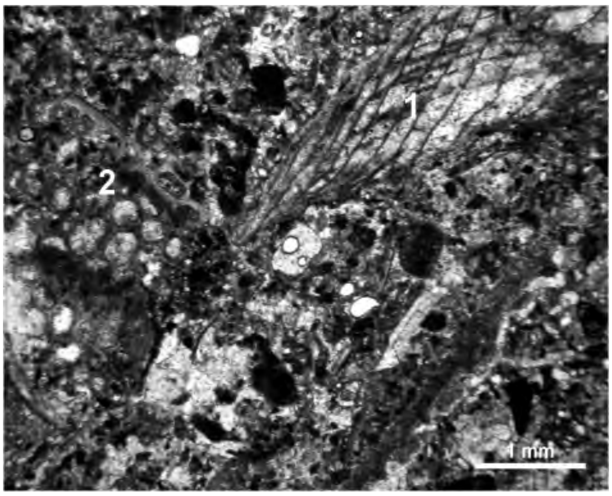

Figure 3: Thin-section photograph with rudists (1) and bryozoans (2) from the limestone exposed at the eastern Montfort hill.

Figure 4: Photograph of a marlstone outcrop at the western Montfort hill.

cession suggests a Turonian to early Coniacian age for the Kreuzgraben Formation.

Overlying the Kreuzgraben Formation, shallow-marine limestones (Glanegg beds) are exposed with a thickness of about 10 m; these form the southern escarpment of Montfort hill. Wavy and nodular bedding are common and consist of undulose planes at the top and base of the beds (Fig. 2). Bed thicknesses vary from thick or massive homogenous strata to thinner layers (< 0.2 m). Shale interbeds are almost completely missing. Layers rich in bioclastic material display sharp contacts with the finer grained facies, that form the major part of the cliff. Thin-sections (Fig. 3) reveal grainstones containing abundant small peloids, lumps and bioclasts (miliolid foraminifera, bryozoans, bivalves and gastropodes).

Overlying the Glanegg beds, grey marlstones occur (Fig. 4), showing yellowish weathering colours and blocky fracturing. Although the boundary between the limestone and the about 15 m thick marlstone is not exposed, the distinct difference in morphology suggests a sharp contact between the lithologies, as described at this stratigraphic level in other, near-by Gosau sections (Wagreich, 2003). Sandstone layers were not observed within the marlstone succession.

Bulk rock analysis of a dry powdered marlstone sample and clay mineral analysis of the < 2 µm fraction by X–ray diffraction (M. Peresson – oral communication) reveals that the marlstone is composed of 53 wt% calcite, 19 wt% dolomite, 8 wt% quartz and 20 wt% clay minerals. Illite (49 wt%) and smectite (41 wt%) are the dominant clay minerals, with chlorite (10 wt%) having a much lower abundance.

4. Material and Methods

The lowest sample of the marlstone (Morzg-Ost) was taken approximately 5 m above the top of the limestone, the highest sample is about 15 m above the limestone. Two outcrops (Morzg-Ost: 47°46´04“N, 013°03´29“E ; Morzg-West: 47°45´49“N, 013°02´59“E) exposing marlstone were sampled during our survey. One sample (Rö1/83) was taken from a temporary outcrop (47°46´04”N, 013°03´18”E) in 1983.

Samples for micropaleontological studies were processed by drying them overnight at 80°C. Subsequently, 200 g of sediment were treated with hydrogen peroxide for 24 hours, washed on a 0.063 mm-mesh sieve and, if not completely disintegrated, boiled with sodium hydroxide and sieved again. The washing residue of micropaleontological samples contained very few small quartz and very rare and very small mica grains. In the samples from the lower part of the section, tiny fragments of inoceramid shells and smooth-shelled ostracods occur. Countings for the assessment of the planktonic/benthic ratio were performed using the 150-400 micron fraction. Taxonomy and stratigraphic ranges of species are given in Appendix 1. The distribution of planktonic foraminifera within the section is shown in Tab. 1.

Calcareous nannoplankton species were studied in smear slides with a Zeiss Axioplan lightmicroscope under parallel and crossed polarization filters at a magnification of 1000x and were classified with the CC-zonal scheme of Sissingh (1977) and the UC-schemes of Burnett (1998). The majority of the specimens are slightly etched but all taxa were easily identified. A list of the 48 taxa encountered is given in Appendix 2.The reader is referred to Perch-Nielsen (1985) and Burnett (1998) for nannoplankton taxonomy.

For palynological analysis, three samples were processed following standard procedures. Between 30 and 100 g of dry sediment were crushed and treated by hydrochloric acid (HCl 35%) to remove minor carbonate, and hydrofluoric acid (HF 40%) to remove silicates. The residue was sieved on 15 µm nylon sieves. The palynodebris was mounted in glycerin jelly on 2 microscope slides (A, B) after extensive mixing to obtain homogeneity and then covered by a slide cover (20 x 40 mm). Both slides of each sample were counted for dinocysts. The taxonomy of the dinocysts is generally based on Fensome et al. (1993) and dinocyst nomenclature follows Fensome et al. (2008). The encountered taxa are listed in Appendix 3.

5. Results

5.1 Planktonic Foraminifera

The marlstone of the Morzg section yields a diverse planktonic foraminifera fauna (Appendix 1, Tab. 1 and Figs. 8-13). The fauna shows poor preservation and strong recrystallization. The assemblages are dominated by large marginotruncanids and high specimen numbers of the genus *Dicarinella*. Small heterohelicids are very frequent. The percentages of benthic foraminifera decrease towards the top of the section signalizing increasing paleodepths from outer shelf (in the lowermost sample Morzg Ost1/11 planktonic species form 71% of the assemblage; plankton/benthos ratio is 2.46) to upper bathyal conditions (in the highest sample Morzg 3/11 planktonic species form 89% of the assemblage; plankton/benthos ratio is 8.12). The rich benthic fauna of the latter sample is composed of small deeper water species (e.g. *Nothia*, *Ammodiscus*, *Gaudryina*, *Lenticulina*). The benthics will be documented elsewhere in an additional paper.

The assemblage is characterized by *Dicarinella asymetrica*, *D. concavata*, *Marginotruncana coronata*, *M. marginata*, *M. pseudolinneiana*, *M. sinuosa*, *Muricohedbergella flandrini*, *Sigalia carpatica*,and *S. decoratissima*.

The *D. asymetrica* Zone (Caron, 1985) was defined as a total range zone. Lamolda et al. (2007, 2013) recorded the FO of *D. asymetrica* already in the Coniacian of the Olazagutia section in Spain extending the corresponding zonal range. The overlying *Globotruncanita elevata* Zone, a partial range zone, is defined as the interval between the LO (last occurrence) of *D. asymetrica* and the FO of *Globotruncana ventricosa*. The range of *G. elevata* overlaps with that of *D. asymetrica* in the upper Santonian. As *G. elevata* is not present at Morzg, the entire marlstone succession can be assigned to the middle part of the *D. asymetrica* Zone. Gale et al. (2008) report on the LO of *D. asymetrica* in the Lower Campanian, however, as the Santonian/Campanian-boundary is not yet defined this chronostratigraphic assignment remains speculative.

Only in the lowermost sample (Morzg Ost was taken ca. 5 m above the top of the limestone) do *Dicarinella* cf. *imbricata* and *D. primitiva* occur. These species have their FO in the Turonian. Caron (1985) reports the LO of both species from the *D. concavata* Zone in the Coniacian. The data from Morzg suggest that these species reach well into the Santonian part of the *D. asymetrica* Zone whereas they are absent in the upper part. This upper part is characterized by the occurrence of *Sigalia decoratissima* (Butt, 1981); this was also found in the four other samples from Morzg.

At the GSSP section, the FO of S. carpatica is reported within the Coniacian part of the *D. asymetrica* –Zone and *Globotruncana linneiana* occurs in the lowermost Santonian (Lamolda et al. 2007, 2013). In the Bottaccione section in Italy, an overlap of *D. asymetrica* and *G. linneiana* is observed in the uppermost Santonian (Petrizzo et al., 2011). At Morzg, *G. lin-*

Genus	cf.	Species	Author	Morzg-Ost	Rö 1/83	Morzg 3/11	Morzg 2/11	Morzg 1/11
Praeglobotruncana		*hilalensis*	Barr	X	X	X	X	X
Contusotruncana	cf.	*fornicata*	(Plummer)	X	X	X	X	X
Dicarinella		*asymetrica*	(Sigal)	X	X	X	X	X
Dicarinella		*concavata*	(Brotzen)	X	X	X	X	X
Dicarinella	cf.	*imbricata*	(Mornod)	X				
Dicarinella		*primitiva*	(Dalbiez)	X				
Fingeria		*kingi*	(Trujillo)	X	X	X	X	X
Fingeria	cf.	*praeglobotruncaniformis*	Georgescu		X			
Globigerinelloides		*bollii*	Pessagno	X	X	X	X	X
Globigerinelloides		*ultramicrus*	(Subbotina)	X	X	X	X	X
Globigerinelloides		*prairiehillensis*	Pessagno		X			
Hastigerinoides		*clavatus*	(Brönnimann)	X	X	X	X	
Heterohelix		*globulosa*	(Ehrenberg)	X	X	X	X	X
Heterohelix	cf.	*globulosa*	(Ehrenberg)	X	X	X	X	X
Heterohelix		*planata*	(Cushman)	X	X	X	X	X
Heterohelix		*striata*	(Ehrenberg)	X	X	X	X	X
Heterohelix		*papula*	Belford	X	X	X	X	X
Huberella		*huberi*	Georgescu	X	X	X	X	X
Marginotruncana		*pseudolinneiana*	Pessagno	X	X	X	X	X
Marginotruncana		*coronata*	(Bolli)	X	X	X	X	X
Marginotruncana		*sinuosa*	Porthault	X	X	X	X	X
Marginotruncana		*marginata*	(Reuss)	X	X	X	X	X
Muricohedbergella		*flandrini*	(Porthault)	X	X	X	X	X
Muricohedbergella		*delrioensis*	(Carsey)		X	X	X	X
Muricohedbergella		*planispira*	(Tappan)	X	X	X	X	X
Planoheterohelix		*postmoremani*	Georgescu & Huber	X	X	X	X	X
Praegublerina		*pseudotessera*	(Cushman)	X	X		X	X
Pseudotextularia		*nuttalli*	(Voorwijk)	X	X	X	X	X
Schackoina	cf.	*cenomana*	(Schacko)		X	X		
Schackoina		*multispinata*	(Cushman & Wickenden)	X		X	X	
Sigalia		*carpatica*	Salaj & Samuel		X	X	X	X
Sigalia		*decoratissima*	(De Klasz)		X	X	X	X
Sigalia		*deflaensis*	(Sigal)		X	X	X	
Whiteinella		*baltica*	Douglas & Rankin	X	X	X	X	X

Table 1: Distribution of planktonic foraminifera species at Morzg.

neiana was not found but *Marginotruncana pseudolinneiana* is common. This latter species was originally described from the Santonian of the Gosau Basin by Pessagno (1967) and has its FO in the Turonian (Caron, 1985).

5.2 Calcareous Nannoplankton

All samples from Morzg yielded a uniform diverse calcareous nannoplankton assemblage showing moderate preservation (Fig. 5). All encountered taxa are listed in Appendix 2. Even very delicate species such as *Corrolithion signum* (Fig. 5/7), *Octolithus multiplus* (Fig.5/24), *Russellia laswelli* (Fig. 5/29), *Rotelapillus crenulatus* (Fig. 5/28), and *Tranolithus minimus* (Fig. 5/32) are present. In total, 48 calcareous nannoplankton taxa were recognized. Common species are *Watznaueria barnesae*, *Lucianorhabdus cayeuxii* (Fig. 5/16), *L. maleformis* (Fig. 5/17), *Eiffellithus eximius* (Fig. 5/10), *Cribrosphaerella ehrenbergii* (Fig. 5/8), and *Broinsonia enormis* (Fig. 5/3). *Micula staurophora* (Fig. 5/23), *Lithastrinus grillii* (Fig. 5/14), *Marthasterites simplex* (Fig. 5/19) and *Orastrum campanensis* (Fig. 5/25) occur sporadically at Morzg.

All samples represent the *Lucianorhabdus cayeuxii* Zone (Zone CC16) in the zonation proposed by Sissingh (1977). This zone is defined as the interval between the FO of *L. cayeuxii* and the FO of *Calculites obscurus*. In the zonation of Burnett (1998), this interval comprises Sub-Zone UC11c and the lowermost part of Zone UC12. *Lithastrinus septenarius*, which has its LO at the base of UC12 was not found at, Morzg. Consequently, the samples can be assigned to the lower part of Zone UC12 in the middle Santonian. However, it cannot be ruled out that the absence of *L. septenarius* is a matter of the general rare occurrence of the genus *Lithastrinus* at Morzg.

Several species of the genus *Zeugrhabdotus* (*Z. bicrescenticus*, Fig. 5/34, *Z. biperforatus*, *Z. embergeri*) were found in the Morzg samples, but *Z. diplogrammus* is absent. In southern England, this species has its LO in the middle part of the middle Santonian (Burnett, 1998). This can be taken as an indicator for a position of the Morzg samples in the upper middle Santonian to upper Santonian.

From Gosau sections of the Eastern Alps, Wagreich (1992) described a sub-species of *Lucianorhabdus cayeuxii* with a curved rod (*Lucianorhabdus cayeuxii* Type B). The FO of this sub-species was found close to the inferred Santonian-Campanian boundary within the *Calculitus obscurus* Zone. Single specimens of this curved form occur in the Morzg-West samples but *C. obscurus* was not found beside *Calculites ovalis* (Fig. 5/5). It is assumed that rare specimens of *L. cayeuxii* Type B are already present in the Santonian. Indicators for the Campanian were not found at Morzg. Burnett (1998) used the FO of *Orastrum campanensis* to define the Lower Campanian Sub-Zone UC13b, however, *O. campanensis* was found very close to the Coniacian-Santonian boundary by Blair and Watkins (2009).

5.3 Palynomorphs

Terrestrial palynomorphs show poor preservation and in most cases do not allow species determination. Draxler (oral communication) found no Upper Cretaceous genera but identified Upper Triassic taxa (*Paracirculina* sp., *Ovalipollis* cf. *lunzensis*), indicating that the terrestrial palynomorph assemblage is essentially reworked.

The marine palynomorph assemblage, which is composed of moderately well preserved Upper Cretaceous taxa (Appendix 3) shows low diversity and low abundances. In total, 17 organic-walled dinoflagellate species and sub-species were identified. Relatively common encountered species are *Chatangiella ditissima*, *Ch. granulifera*, *Ch. hexacalpis*, *Heterosphaeridium cordiforme*, *Spiniferites multibrevis*, *S. membranaceus*, *S. membranaceus*, *Pervosphaeridium intervelum*, *P. pseudhystrichodinium* and *P. monasteriense*. *Glaphyrocysta semiticta*, *Spinidinium echinoideum* subsp. *rhombicum*, *Apteodinium deflandrei*, *Spiniferites pseudofurcatus*, *Renidinium rigidum* and *Dinogymnium* sp. occur in low numbers.

Among the stratigraphically important species, *Renidinium rigidum* (Fig. 7/2, 3) has a very short range within the lower part of the middle Santonian in England (Prince et al., 1999). *Pervosphaeridium monasteriense* (Fig. 7/9) and *P. pseudhystrichodinium* (Fig. 7/15) were described by Yun (1981) from the Santonian of Germany. The FO of *P. intervelum* (Fig. 7/4-6) was recorded in the upper Santonian of England (Prince et al., 1999), whilst in southern Germany, *P. intervelum* occurs in the lower middle Campanian (Kirsch, 1991). *Chatangiella granulifera* (Fig. 6/6) and *Ch. ditissima* (Fig. 6/1-5) were recorded in the Santonian to Maastichtian from NW Canada (McIntyre, 1975). *Spinidinium echinoideum* subsp. *rhombicum* (Fig. 6/9)
ranges from the lower Coniacian to the upper Campanian (Williams and Bujak, 1985). It has been recorded in the upper Santonian to lower Campanian in both England (Prince et al., 1999) and in Iran (Ghasemi-Nejad et al., 2006). Yun (1981) recorded *Spinidinium echinoideum* subsp. *rhombicum* in the Santonian strata in NW Germany.

In summary, the encountered dinoflagellate cyst assemblage indicates an upper Santonian chronostratigraphic age because typical Campanian floral elements are absent, in particular, the genus *Areoligera*, which has its FO in the lower Campanian (see Williams et al., 2004).

6. Discussion

At Olazagutia, the proposed GSSP for the Coniacian/Santonian-boundary lies within the *Dicarinella asymetrica* Zone and the *Lucianorhabdus cayeuxii* Zone (CC16). Zone CC16 of Sissingh (1977) comprises Sub-Zone UC11c (lower Santonian) and a major part of Zone UC12 (middle and upper Santonian) in the zonation scheme of Burnett (1998). The boundary between Zones UC11 and UC12 is defined by the LO of *Lithastrinus septenarius*.

The absence of the nannofossil species *L. septenarius* and *Zeugrhabdotus diplogrammus*, the consistent occurrence of the planktonic foraminifer *Sigalia decoratissima* and the composition of the dinoflagellate cyst assemblage indicate a mid

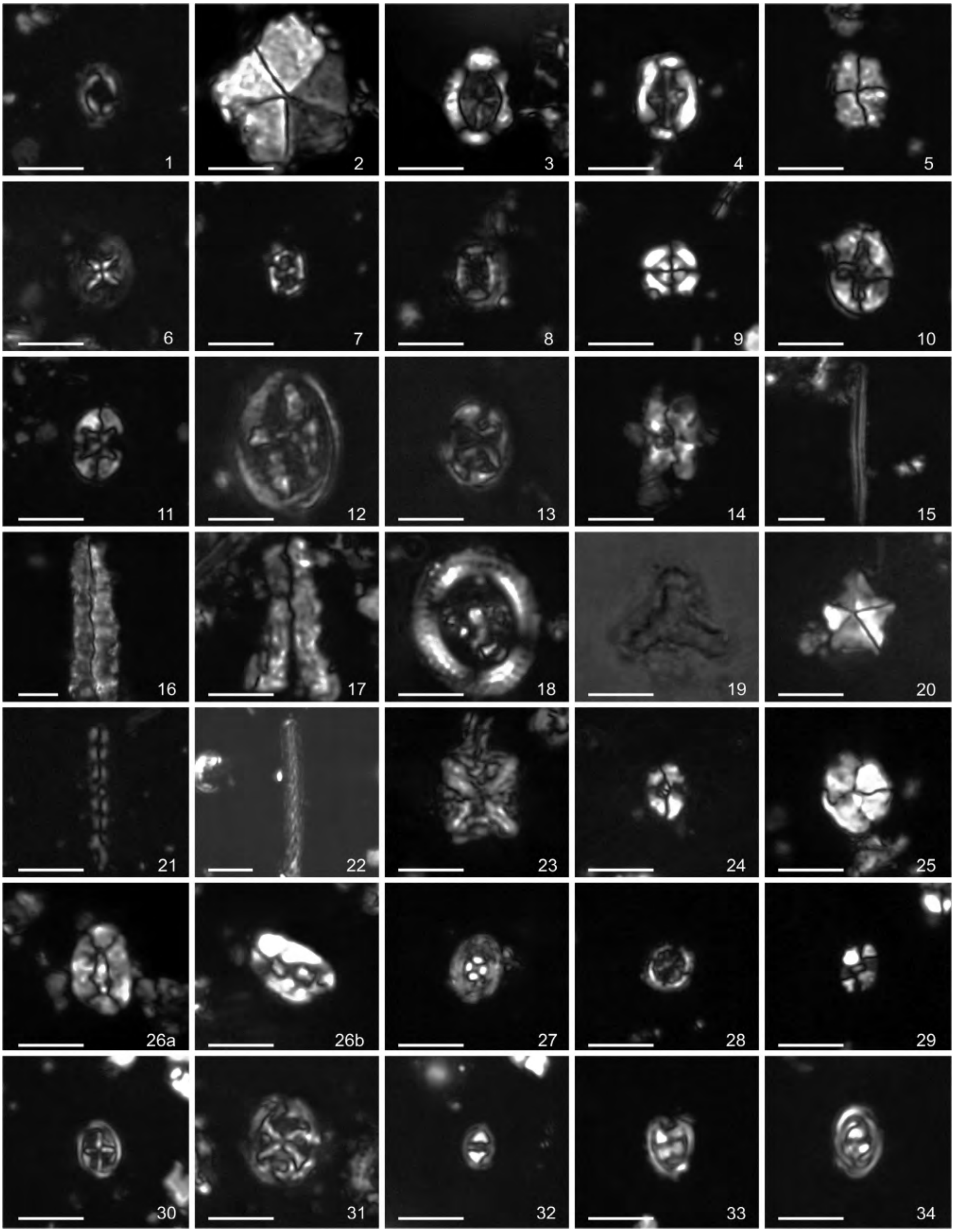

Figure 5: Light microscope images of calcareous nannoplankton species (scale of the bar is 10µm): (1) *Biscutum magnum*, (2) *Braarudosphaera bigelowii*, (3) *Broinsonia enormis*, (4) *Broinsonia signata*, (5) *Calculites ovalis*, (6) *Chiastozygus amphipons*, (7) *Corrolithion signum*, (8) *Cribrosphaerella ehrenbergii*, (9) *Cyclagelosphaera reinhardtii*, (10) *Eiffellithus eximius*, (11) *Eiffellithus gorkae*, (12) *Gartnerago segmentatum*, (13) *Helicolithus trabeculatus*, (14) *Lithastrinus grillii*, (15) *Lithraphidites carniolensis*, (16) *Lucianorhabdus cayeuxii*, (17) *Lucianorhabdus maleformis*, (18) *Manivitella pemmatoidea*, (19) *Marthasterites simplex*, (20) *Micrantholithus* cf *quasihoschulzii*, (21) *Microrhabdulus decoratus*, (22) *Microrhabdulus reticulatus*, (23) *Micula staurophora,* (24) *Octolithus multiplus*, (25) *Orastrum campanensis*, (26a,b) *Ottavianus giannus*, (27) *Rhagodiscus achylostaurion*, (28) *Rotelapillus crenulatus*, (29) *Russellia laswelli*, (30) *Staurolithites flavus*, (31) *Tegumentum stradneri*, (32) *Tranolithus minimus*, (33) *Tranolithus phacelosus*, (34) *Zeugrhabdotus bicrescenticus*.

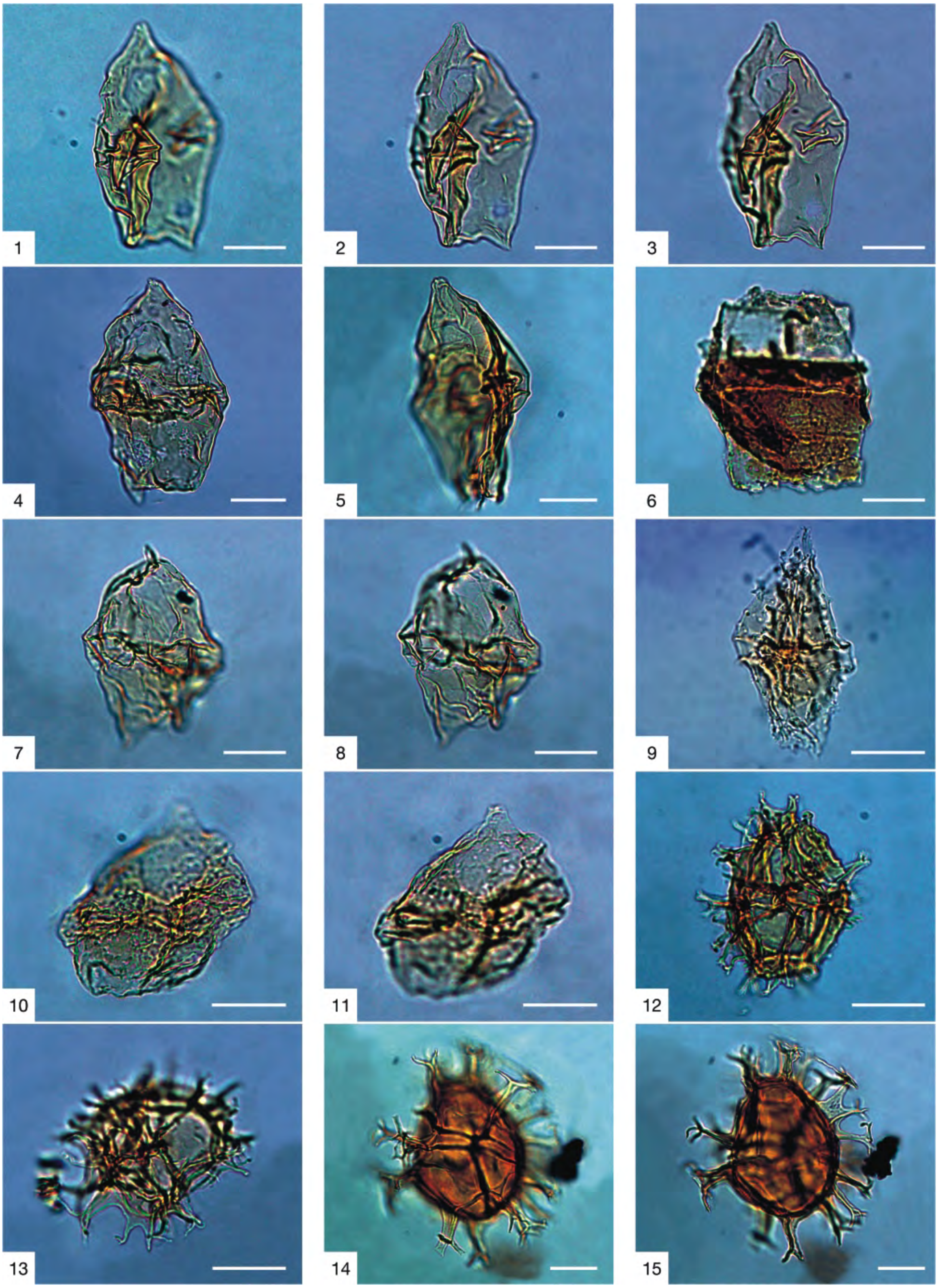

Figure 6: Light microscope images of dinoflagellate cysts (scale of the bar is 10µm): 1-5. *Chatangiella ditissima* (McIntyre), 6. *Chatangiella gra-nulifera* (Manum), 7, 8. *Chatangiella hexacalpis* Harker and Sarjeant, 9. *Spinidinium echinoideum* subsp. *rhombicum* (Cookson and Eisenack), 10, 11. *Apteodinium deflandrei* (Clarke and Verdier), 12. *Spiniferites multibrevis* (Davey and Williams), 13. *Spiniferites membrana-ceus* (Rossignol), 14, 15. *Spiniferites pseudofurcatus* (Klumpp).

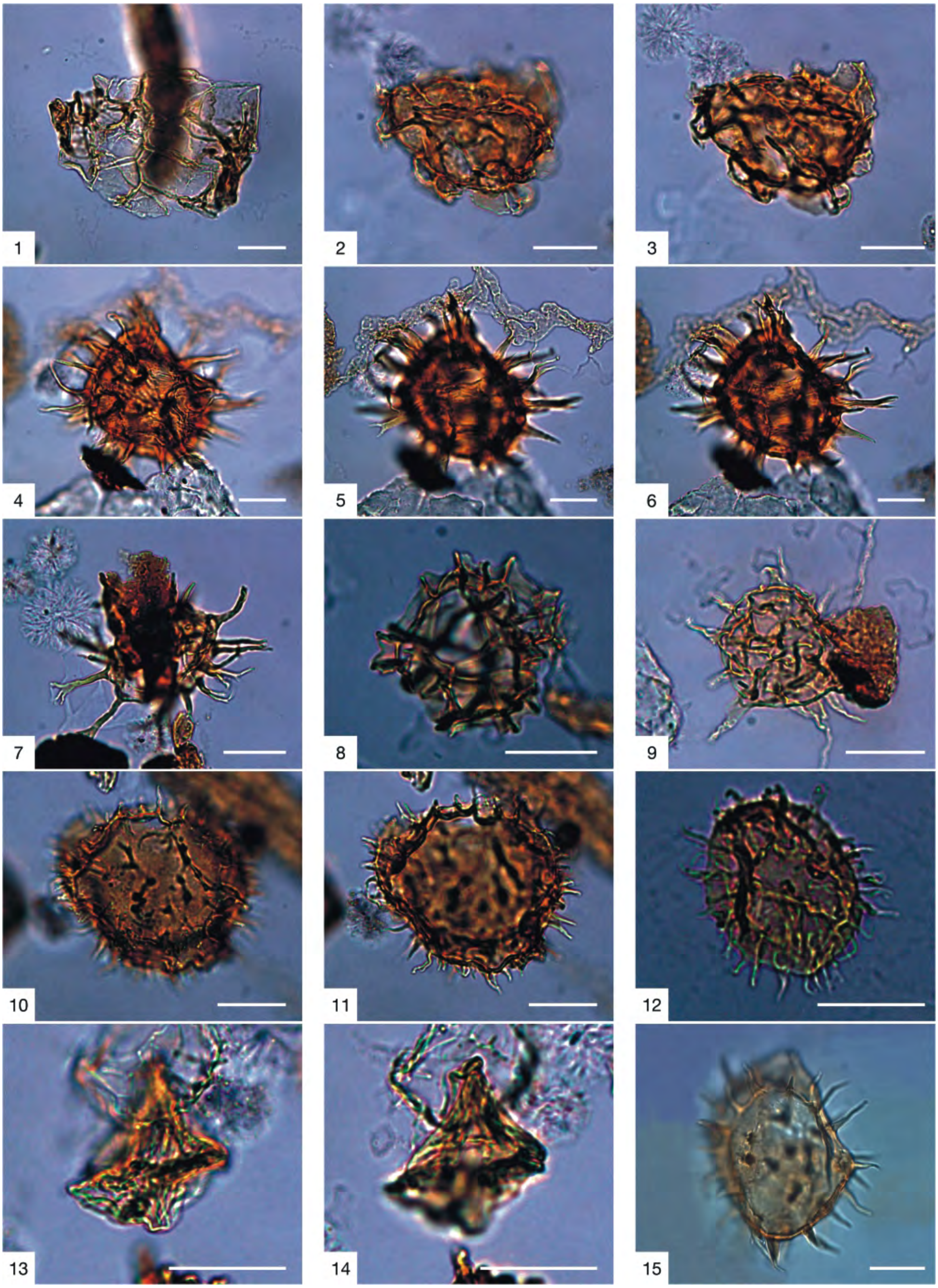

Figure 7: Light microscope images of dinoflagellate cysts (scale of the bar is 10µm): 1. *Glaphyrocysta semiticta* (Bujak), 2, 3. *Renidinium rigidum* (Prince, Jarvis andTocher), 4-6. *Pervosphaeridium intervelum* (Kirsch), 7. *Surculosphaeridium longifurcatum* (Firtion), 8. *Pterodinium cingulatum* subsp. *cingulatum* (Wetzel), 9. *Pervosphaeridium monasteriense* Yun Hyesu, 10, 11. *Heterosphaeridium cordiforme* Yun Hyesu, 12. *Heterosphaeridium cordiforme* Yun Hyesu, 13, 14. *Dinogymnium* sp., 15. *Pervosphaeridium pseudhystrichodinium* (Deflandre).

to late Santonian age for the bathyal marlstone at the Morzg section. The ammonite *Paratexanites serratomarginatus* from the neritic limestone in the lower part of the section indicates the upper Coniacian. This gives evidence for a strong increase in paleodepth between the late Coniacian and the middle to late Santonian. This event cannot be correlated to the global eustatic sea-level chart (Hardenbol et al. 1998) and is, therefore, interpreted as a result of regional tectonic subsidence.

A few kilometers to the west of Morzg, sections in the Lattengebirge (Röthenbach-Dalsenalm section) and Untersberg (Eitelgraben section) regions display bioclastic limestone overlain by Santonian marlstone of the *Dicarinella asymetrica*-Zone (*Globotruncana concavata* Zone in Herm, 1962). Butt (1981) subdivided this zone using the occurrence of *Sigalia decoratissima*, which has its FO in the middle part of the *D. asymetrica* Zone, and correlated the marlstone at the Eitelgraben section with the upper part of the marlstone at the Röthenbach-Dalsenalm section. The lower part of the *D. asymetrica*-Zone is absent at the Eitelgraben section, indicating a stratigraphic gap, that encompasses the lower and probably also parts of the middle Santonian.

The biostratigraphic data from Morzg presented in this paper indicate a similar situation to that at the Eitelgraben section. Moreover, the lithology of the marlstone shows the same characteristic features at both sections, particularly, similar planktonic/benthic ratios and the absence of siliciclastic beds. In contrast, sandstone beds are typical of the Grabenbach Formation and were interpreted as tempestites by Wagreich (2003). Due to progressive subsidence, the sea-floor in the sedimentation area fell below the wave base and tempestite sedimentation ended. The upper Santonian bathyal marlstone at the Eitelgraben and Morzg sections, therefore, cannot be assigned to the neritic Grabenbach Formation but seems to be a separate lithostratigraphic unit. Here we use the informal name “Morzg beds” for these deposits.

The Morzg beds show no indication of a source area composed of crystalline basement. However, the high amount of dolomite and the low percentage of clay minerals in the marlstone is conspicuous. As dolomite formation in bathyal settings is unknown, this dolomite is interpreted as a detrital component. This indicates a source area within the Northern Calcareous Alps (Wagreich et al., 2009) where Middle to Upper Triassic dolomites form successions up to two kilometers thick. This notion is supported by the occurrence of Triassic terrigenous palynomorphs (e.g. *Ovalipollis lunzensis*), these are ubiquitous in the terrestrial deposits of the Carnian Lunz Formation in the Northern Calcareous Alps. A substantial part of the clay mineral species and the small amounts of detrital quartz are assumed to have originated from this formation.

Progressive subsidence of the sedimentation area of the Gosau Group from west to east (Wagreich, 1993) suggests that the source area for the Triassic material was towards the east of Salzburg. Santonian samples (Hofergrabenmergel) from the type locality of the Gosau Group in western Upper Austria (Hradecká et al., 2003) display percentages of dolomite and clay minerals similar to the Morzg beds. Farther to the east, at the Weißenbachalm in Styria, the dolomite content in Santonian marlstone is less than 10 wt% but abundant reworked Triassic sporomorphs occur (Hradecká et al., 1999) and give further evidence for the erosion of Triassic deposits in the late Santonian.

7. Conclusion

Based on plankton stratigraphy, a stratigraphic gap comprising the lower and parts of the middle Santonian separates shallow-marine limestone to deep-marine marlstone at Morzg. This gives evidence for the onset of tectonically induced subsidence of the depositional area as early as around the Coniacian/Santonian-boundary. The composition of the Coniacian and Santonian rocks at Morzg do not indicate any source area from outside the Northern Calcareous Alps but suggest erosion of Middle and Upper Triassic deposits from the eastern part of the Northern Calcareous Alps.

Acknowledgement

We are indebted to Brian Huber (Smithsonian Institution, Washington) for his helpful comments on taxonomy of planktonic foraminifera and, in particular, on the determination of biserial species, and to Ilse Draxler (Vienna) for the determination of terrestrial palynomorphs. Gratefully we acknowledge the help of Mandana Peresson (Geological Survey of Austria) in analyzing the composition of the marlstone by XRD, of Markus Kogler in preparing the figures and plates, of Parwin Akrami in processing the micropaleontological samples, and of Sabine Gießwein in preparing the smear slides for nannoplankton investigations and operating the SEM. Hugh Rice corrected the English language of the original manuscript. Michael Wagreich and an anonymous reviewer provided helpful and constructive reviews.

Appendix

Appendix 1: Remarks on planktonic foraminifera systematics

References for the described species and their synonymy can be found in the compilations of Pessagno (1967), Caron (1985), Nederbragt (1991), Georgescu (1996, 2010), and Georgescu and Huber (2009).

Class Foraminifera d’Orbigny, 1826

Order Globigerinina Delage and Herouard, 1896

Dicarinella Porthault, 1970

Dicarinella asymetrica (Sigal)

Fig. 8/1-3

1952 *Globotruncana asymetrica* Sigal, p. 35, fig. 35.

1955 *Globotruncana (Globotruncana) ventricosa* White subsp. *carinata* Dalbiez, p.171, figs 8a-c.

1962 *Glt.concavata* (Brotzen) *carinata* Dalbiez – Edgell, p. 43, pl. 1, figs 1-3.
1963 *Globotruncana concavata carinata* Dalbiez – Küpper, p. 618, pl. 4, figs 4a-c.
1979b *Dicarinella asymetrica* (Sigal, 1952) – Robaszynski and Caron, p. 61, pl. 51, figs 1-2; pl. 52, figs1-2.
1985 *Dicarinella asymetrica* (Sigal) – Caron, p. 43, figs 17.3-4.
2007 *Dicarinella asymetrica* (Sigal, 1952) – Lamolda, Peryt and Ion, p.28, figs 5M1-2, 6F1-2.

Test large, planoconvex, loosely enrolled, subcircular, with flat spiral and elevated umbilical side. Umbilicus wide and deep, surrounded by high conical chambers with ad-umbilical ridge. Spiral sutures strongly curved raised and beaded, umbilical sutures radial depressed. Periphery with a double keel.

Stratigraphic range: Robaszynski and Caron (1979a) Coniacian and younger; Caron (1985) upper Santonian (*D. asymetrica* Zone); Georgescu (1996) (?late) Santonian; Petrizzo (2003) first occurrence in the lower third of *Texanites* ammonite zone, near the base of Santonian, last occurrence in the lowermost Campanian chron 33R; Gale et al. (2008) all Santonian to lower Campanian. Lamolda et al. (2007) upper Coniacian to Santonian.

Dicarinella concavata (Brotzen)
Fig. 8/4-6
1934 *Rotalia concavata* Brotzen, p. 66, pl. 3, fig. B.
1979b *Dicarinella concavata* (Brotzen, 1934) – Robaszynski and Caron, p. 71, pl. 54, figs 1-2; pl. 55, figs 1-2.
1985 *Dicarinella concavata* (Brotzen) – Caron, p. 45, figs 17.7-8.
2007 *Dicarinella concavata* (Brotzen, 1934) - Lamolda, Peryt and Ion, p.28, figs 6E1-2.

Test large, planoconvex, with circular outline. Spiral side flat, with petaloid chambers and elevated beaded sutures. Umbilicus wide, chambers subglobular to subconical, umbilical sutures radial. Periphery with double keel.

Stratigraphic range: Robaszynski and Caron (1979a) Coniacian and younger; Caron (1985) upper Coniacian to Santonian (*D. concavata* to *D. asymetrica* Zone); Georgescu (1996) upper Coniacian to middle Santonian; Gale et al. (2008) common in the Santonian, rare in the lower Campanian; Lamolda et al. (2007) FO in the lower Coniacian.

Dicarinella cf. *imbricata* (Mornod)
1950 *Globotruncana (Globotruncana) imbricata* Mornod, p. 589, fig. 5 (III a-d).
1979b *Dicarinella imbricata* (Mornod, 1950) – Robaszynski and Caron, p. 87, pl. 58, figs 1-2; pl. 59, figs 1-2.
1985 *Dicarinella imbricata* (Mornod) – Caron, p. 45, figs 18.4-5.

Test medium-sized, flat trochospiral, convex spiral and concave to flat umbilical side. Elongated petaloid chambers of the spiral side are slightly imbricate, chambers of the umbilical side flat and with radial sutures. Periphery with week beaded double keel. Species not entirely characteristic, appears only in the lowermost sample Morzg-Ost.

Stratigraphic range: Robaszynski and Caron (1979a) uppermost Cenomanian to ?lower Coniacian; Caron (1985) Turonian to Coniacian (*Whiteinella archaeocretacea* to lower *D. concavata* Zone).

Dicarinella primitiva (Dalbiez)
Fig. 8/7-8
1955 *Globotruncana (Globotruncana) ventricosa* White subsp. *primitiva* Dalbiez, p. 171, fig. 6.
1979b *Dicarinella primitiva* (Dalbiez, 1955) – Robaszynski and Caron, p. 93, pl. 60, figs 1-2.
1985 *Dicarinella primitiva* (Dalbiez) – Caron, p. 45, figs 18.6-8.

Test medium-sized, trochospiral with flat spiral and low conical umbilical side, outline elongate to subcircular, lobate, with narrow double keel. Spiral chambers petaloid, in the earlier part globular, sutures indistict to slightly depressed. Umbilical chambers inflated, sutures radial and depressed. Occcurrence only in the lowermost sample Morzg-Ost.

Stratigraphic range: Robaszynski and Caron (1979a) uppermost Turonian to Coniacian; Caron (1985) Coniacian to lower Santonian (*D. primitiva* to *D. concavata* Zone).

Marginotruncana Hofker, 1956
Marginotruncana coronata (Bolli)
Fig. 9/6-8
1945 *Globotruncana lapparenti* Brotzen, subsp. *coronata* Bolli, p. 233 , text-fig. 1 (21-22), pl. 9, figs 14-15.
1979b *Marginotruncana coronata* (Bolli, 1945) – Robaszynski and Caron, p. 103, pl. 62, figs 1-2.
1985 *Marginotruncana coronata* (Bolli) – Caron, p. 60, figs 26.1-2.

Test large, circular, flat trochospiral, only slightly convex on both sides. Spiral side with low crescent-shaped chambers with raised beaded sutures. Umbilical side with wide umbilicus, chambers sub-petaloid with an anterior edge, with raised beaded sutures. Periphery with double keel separated by a flat area.

Stratigraphic range: Robaszynski and Caron (1979a) middle Turonian to Coniancian and younger; Caron (1985) middle Turonian to lower Campanian (upper *Helvetotruncana helvetica* to lower *Globotruncanita elevata* Zone); Georgescu (1996) (?upper) Santonian to lower Campanian; Gale et al. (2008) in the Waxahachie spillway section only in the Santonian.

Marginotruncana marginata (Reuss)
Fig. 8/12-13; Fig. 9/1
1845 *Rosalina marginata* Reuss, p. 36, pl. 13, figs 18 a-b.
1979b *Marginotruncana marginata* (Reuss, 1845) – Robaszynski and Caron, p. 107, pl. 63, figs 1-2; pl. 64, figs 1-2.
1985 *Marginotruncana marginata* (Reuss) – Caron, p. 61, figs

26.3-4.

Test medium-sized, flat trochospiral. Slightly vaulted spiral side with petaloid chambers and beaded sutures. Peripheral outline circular, lobate with double keel. Umbilical side with subglobular chambers and depressed radial sutures.

Stratigraphic range: Robaszynski and Caron (1979a) upper Turonian to Coniacian and younger; Caron (1985) upper Turonian to Santonian (uppermost *H. helvetica* to *D. asymetrica* Zone); Georgescu (1996) (?upper) Santonian; Gale et al. (2008) in the Waxahachie spillway section only in the Santonian.

Marginotruncana pseudolinneiana Pessagno

Fig. 9/2-5

1967 *Marginotruncana pseudolinneiana* Pessagno, p. 310 , pl. 65, figs 24-27.

1979b *Marginotruncana pseudolinneiana* Pessagno – Robaszynski and Caron, p. 123, pl. 67, figs 1-2; pl. 68, figs 1-2.

1985 *Marginotruncana pseudolinneiana* Pessagno – Caron, p. 61, figs 26.7-8.

Test large, flat trochospiral with a box-like appearance, subcircular, slightly lobate. Spiral side flat, with crescent-shaped chambers and raised beaded sutures. Umbilical side with wide umbilicus, sub-petaloid chambers with a raised shoulder around the umbilicus and strongly beaded sutures. Periphery flat with two widely spaced keels.

Stratigraphic range: Robaszynski and Caron (1979a) middle Turonian to Coniacian; Caron (1985) middle Turonian to Santonian (upper *H. helvetica* to *D. asymetrica* Zone); Georgescu (1996) (?upper) Santonian to lower Campanian¸ Gale et al. (2008) in the Waxahachie spillway section only in the Santonian.

Marginotruncana sinuosa Porthault

Fig. 9/9-11

1979b *Marginotruncana sinuosa* Porthault – Robaszynski and Caron, p. 147, pl. 74, figs 1-2; pl. 75, figs 1-2.

1985 *Marginotruncana sinuosa* Porthault – Caron, p. 61, figs 27.9-11.

Test large, flat trochospiral, slightly biconvex. Spiral side with crescentic chambers and raised beaded sutures, chamber surface commonly undulating. Umbilical side with wide umbilicus, chambers elongate in coiling direction with strongly beaded V-shaped sutures. Periphery with double keel, which is narrow in the posterior part of the chamber and widens in the anterior part.

Stratigraphic range: Robaszynski and Caron (1979a) Coniacian and younger; Caron (1985) Coniacian to Santonian (*D. primitiva* to lower *D. asymetrica* Zone); Georgescu (1996) Coniacian to upper Santonian; Gale et al. (2008) Santonian to lowermost Campanian.

Contusotruncana Korchagin, 1982

Contusotruncana cf. *fornicata* (Plummer)

Fig. 9/12-15

1931 *Globotruncana fornicata* Plummer, p. 130, pl. 13, figs 4 a-c.

1984 *Rosita fornicata* (Plummer, 1931) – Robaszynski et al., p. 250, pl. 38, figs 1-5.

1985 *Rosita fornicata* (Plummer) – Caron, p.67, figs 28.3-4.

Test medium-sized, low to medium high trochospiral, with slightly undulating spiral surface. Spiral chambers crescentic with beaded sutures. Umbilical side with elongate chambers and V-shaped beaded sutures. Periphery with broad double keel.

Stratigraphic range: Caron (1985) Santonian to Maastrichtian (*D. asymetrica* to *Gansserina gansseri* Zone); Georgescu (1996) (?upper) Santonian to upper Maastrichtian.

Praeglobotruncana Bermudez, 1952

Praeglobotruncana hilalensis Barr

Fig. 8/9-11

1972 *Praeglobotruncana hilalensis* Barr, p. 15, pl. 2, fig. 4.

2011 *Bermudezina hilalensis* (Barr) – Georgescu, p. 188, pl. 3, figs 10-18; pl. 4, figs 1-9.

Test medium high trochospiral, planoconvex, spiral side with about 6 petaloid chambers in the final whorl. Periphery angled, keel-like with two series of pustules. Umbilicus wide, aperture a low arch with distinct flap. Spiral sutures curved, limbate in the earlier part, umbilical ones radial incised. Wall with coarse pustules, larger at the umbilical side.

The genus *Bermudezina* Georgescu, 2011 is not available as it is a homonym of *Bermudezina* Cushman, 1937, an agglutinated foraminiferal genus (fide Loeblich and Tappan, 1987, p. 137).

Stratigraphic range: Georgescu (2011) Turonian to lower Coniacian (*H. helvetica* to *D. concavata* Zone).

Fingeria Georgescu, 2010

Fingeria kingi (Trujillo)

Fig. 10/4-7

1960 *Rugoglobigerina kingi* Trujillo, p. 339, pl. 49, fig. 5.

1967 *Archaeoglobigerina bosquensis* Pessagno, p. 316, pl. 60, figs 7-12.

1985 *Archaeoglobigerina bosquensis* Pessagno – Caron, p. 43, figs 16.5-6.

2010 *Fingeria kingi* (Trujillo, 1960) – Georgescu, p. 157, pl. 2, figs 1-6.

2011 *Fingeria kingi* (Trujillo, 1960) – Georgescu, p. 192, pl. 4, fig. 16, pl. 5, figs 1-6.

Trochospiral test with 5-6 chambers in the final whorl. Chambers globular, periphery rounded, umbilicus open. Acc. to Georgescu (2010) the aperture is umbilical-extraumbilical with a triangular flap. Surface covered by coarse pustules, partly fused to costellae, the characteristic element in *Fingeria*. The species was generally determined as *Archaeglobigerina bosquensis*.

Stratigraphic range: Caron (1985) upper Coniacian to Santonian (*D. concavata* to *D. asymetrica* Zone); Gale et al. (2008) in the Santonian and lower Campanian; Georgescu (2011) Turonian to lower Campanian.

Fingeria cf. *praeglobotruncaniformis* Georgescu

2011 *Fingeria praeglobotruncaniformis* Georgescu, p. 196, pl. 5, figs 7-15, pl. 6, figs 1-8.

Medium to high trochospiral test with 5-6 chambers in the final whorl, surface covered by pustules, partly fused to costellae and arranged in a meridional pattern, similar to *Rugoglobigerina*. Differs from F. kingi by the higher trochospire and a compressed periphery. Very rare species, found only in one sample (Rö 1-83).

Stratigraphic range: Georgescu (2011) Santonian, lower part of *D. asymetrica* Zone.

Whiteinella Pessagno, 1967

Whiteinella baltica Douglas and Rankin

Fig. 10/1-3

1969 *Whiteinella baltica* Douglas and Rankin, p. 198, text-figs 9 A-C.

1979a *Whiteinella baltica* Douglas and Rankin – Robaszynski and Caron, p. 169, pl. 35, figs 1-4; pl. 36, figs 1-2.

1985 *Whiteinella baltica* Douglas and Rankin – Caron, p. 79, figs 37.1-3.

Test medium-sized, low trochospiral, biconvex, with 4 to 4 ½ chambers in the final whorl. Chambers subglobular, slightly compressed, sutures radial. Wall finely pustulose. Aperture umbilical-extraumbilical. Periphery rounded.

Stratigraphic range: Robaszynski and Caron (1979a) upper Cenomanian to Coniacian and younger; Caron (1985) upper Cenomanian to lowermost Santonian (*Rotalipora cushmani* to *D. concavata* Zone); Georgescu (1996) upper Cenomanian to middle Santonian.

Muricohedbergella Huber and Leckie, 2011

Muricohedbergella delrioensis (Carsey)

Fig. 10/8-9

1926 *Globigerina cretacea* d'Orbigny var. *delrioensis* Carsey, p. 43.

1979a *Hedbergella delrioensis* (Carsey, 1926) – Robaszynski and Caron, p. 123, pl. 22, figs 1-2; pl. 23, figs 1-3-

1985 *Hedbergella delrioensis* (Carsey) – Caron, p. 57, figs 25.6-7.

2006 *Hedbergella delrioensis* (Carsey, 1926) – Petrizzo and Huber, p. 185, pl. 7, figs 3-4.

2011 *Muricohedbergella delrioensis* (Carsey) – Huber and Leckie, p. 84.

Medium sized, flat trochospiral, with globular chambers fast increasing in size, deep umbilicus, periphery rounded, lobate outline. Wall covered by coarse pustules. Muricohedbergella differs from Hedbergella by the different wall texture, which is smooth in Hedbergella.

Stratigraphic range: Caron (1985) Aptian to lowermost Santonian (*Schackoina cabri* to *D. concavata* Zone); Huber and Leckie (2011) upper Albian and younger.

Muricohedbergella flandrini (Porthault)

Fig. 10/10-12

1970 *Hedbergella flandrini* Porthault, p. 64, pl. 10, figs 1-3.

1979a *Hedbergella flandrini* Porthault – Robaszynski and Caron, p. 129, pl. 24, figs 1-2pl. 25, figs 1-3.

1985 *Hedbergella flandrini* Porthault – Caron, p. 57, figs 25.12-14.

2011 *Muricohedbergella flandrini* (Porthault) – Huber and Leckie, p. 84.

Test large, low trochospiral with about 5-6 compressed chambers in the final whorl, periphery angled, outline lobate. Wall covered by pustules.

Stratigraphic range: Caron (1985) upper Turonian to lower Santonian (upper *Marginotruncana sigali* to lower *D. asymetrica* Zone); Georgescu (1996) (?upper) Santonian; Gale et al (2008) in the lower part of the Santonian, nearly absent in the upper Santonian and lowermost Campanian.

Muricohedbergella planispira (Tappan)

Fig. 10/13; Fig. 11/1-2

1940 *Globigerina planispira* Tappan, p. 122, pl. 9, figs 12 a-c.

1979a *Hedbergella planispira* (Tappan, 1940) – Robaszynski and Caron, p. 139, pl. 27, figs 1-3; pl. 28, figs 1-4.

1985 *Hedbergella planispira* (Tappan) – Caron, p. 59, figs 25.23-24.

2006 *Hedbergella planispira* (Tappan) – Petrizzo and Huber, p. 185, pl. 7, figs 1-2.

2011 *Muricohedbergella planispira* (Tappan) – Huber and Leckie, p. 84, figs 17.6-17.10.

Test rather small, very low trochospiral, periphery rounded, outline lobate, chambers globular, slowly increasing in size. Wall covered by small pustules.

Stratigraphic range: Caron (1985) Aptian to lower Coniacian (*Globigerinelloides blowi* to *D. primitiva* Zone); Gale et al. (2008) frequent in the Santonian and Campanian. FO in the lower Albian (Huber and Leckie, 2011).

Hastigerinoides Brönnimann, 1952

Hastigerinoides clavatus (Brönnimann)

Fig. 11/3-5

1952 *Globigerinella escheri clavata* Brönnimann, p. 49, pl. 1, figs 12-13, text-figs 24-26.

1985 *Hastigerinoides subdigitata* (Carman) – Caron, p. 57, figs 35.18-20.

2008 *Hastigerinoides clavata* (Brönnimann) – Georgescu and Huber, 57, pl. 2, figs 4-6.

Test small, planispiral, bi-umbilicate, with 4-5 globular, later one to two radially elongate chambers in the final whorl. Aperture is a high equatorial arch with a thin lip. Wall covered by strong pustules. According to Georgescu and Huber (2008) *H. subdigitata* is synonymous with *H. clavatus*.

Stratigraphic range: Caron (1985) Santonian to Campanian; Georgescu and Huber (2008) Coniacian – Santonian (*D. concavata* to *D. asymetrica* Biozone).

Globigerinelloides Cushman and Ten Dam, 1948

Globigerinelloides bollii Pessagno

Fig. 11/6-10

1967 *Globigerinelloides bollii* Pessagno, p. 275, pl. 62, fig. 5, pl. 81, figs 7-8, pl. 97, figs 1-2, pl. 100, fig. 3.

1983 *Globigerinelloides bollii* Pessagno – Krasheninnikov and Basov, p. 803, pl. 1, figs 12-14.

Test rather large, planispiral, bi-umbilicate with 6-7 globular chambers in the final whorl. Final chamber commonly inflated. Aperture a low equatorial arch with thin lip. Wall smooth to finely pustulose.

Stratigraphic range: Krasheninnikov and Basov (1983) Campanian-Maastrichtian; Gale et al. (2008) in the Santonian and Campanian.

Globigerinelloides prairiehillensis Pessagno

1967 *Globigerinelloides prairiehillensis* Pessagno, p. 277, pl. 60, figs 2-3, pl. 83, fig. 1, pl. 90, figs 1,2,4, pl. 97, figs 3-4.

1985 *Globigerinelloides prairiehillensis* Pessagno – Caron, p. 47, figs 19.14-15.

Planispiral, biumbilicate, 5-6 chambers in the final whorl, rapidly increasing in size, periphery rounded. Rare species, only in sample Rö 1-83.

Stratigraphic range: Pessagno (1967) Santonian-Maastrichtian; Caron (1985) Campanian-Maastrichtian.

Globigerinelloides ultramicrus (Subbotina)

Fig. 11/11-12

1949 *Globigerinella ultramicra* Subbotina, p. 33, pl. 2, figs 17-18.

1985 *Globigerinelloides ultramicra* (Subbotina) – Caron, p. 47, figs 29.18-19.

Test small, planispiral, bi-umbilicate, loosely enrolled, 7-8 globular chambers in the final whorl. Aperture a low equatorial arch with thin lip. Wall finely pustulose.

Stratigraphic range: Caron (1985) upper Albian to lower Maastrichtian (*Rotalipora appenninica* to *Globotruncanella havanensis* Zone); Georgescu (1996) uppermost Albian to lowermost Maastrichtian.

Schackoina Thalmann, 1932

Schackoina cf. *cenomana* (Schacko)

Fig. 11/13

1897 *Siderolina cenomana* Schacko, p. 166, pl. 4, figs 3-5.

1983 *Schackoina cenomana* (Schacko) – Krasheninnikov and Basov, p. 803, pl. 1, figs 1-3.

1985 *Schackoina cenomana* (Schacko) – Caron, p.76, figs 35.5-9.

Rare species. Test very small, pseudo-planispiral, bi-umbiliacate with 4 clavate chambers in the final whorl, ending in spines. Aperture equatorial. Wall finely pustulose.

Stratigraphic range: Krasheninnikov and Basov (1983) upper Cenomanian to Santonian; Caron (1985) Cenomanian.

Schackoina multispinata (Cushman and Wickenden)

Fig. 11/14

1930 *Hantkenina multispinata* Cushman and Wickenden, p. 40, pl. 6, figs 4-6.

1983 *Schackoina multispinata* (Cushman and Wickenden) – Krasheninnikov and Basov, p. 803, pl. 1, figs 4-7.

1985 *Schackoina multispinata* (Cushman and Wickenden) – Caron, p. 76, figs 35.10-13.

Test very small, irregular shape with inflated clavate chambers, ending in one or more tubulospines. Wall smooth.

Stratigraphic range: Krasheninnikov and Basov (1983) Campanian-Maastrichtian; Caron (1985) Cenomanian to lower Campanian (*Rotalipora brotzeni* to *Globotruncanita elevata* Zone); Georgescu (1996) lower Cenomanian to lower Campanian.

Sigalia Reiss, 1957

Sigalia carpatica Salaj and Samuel

Fig. 12/1-2

1963 *Sigalia carpatica* Salaj and Samuel, p. 105, pl. 7, figs 2-3.

1966 *Sigalia carpatica* Salaj and Samuel – Salaj and Samuel, p. 227, tab. 37, fig. 2.

1991 *Sigalia decoratissima carpatica* Salaj and Samuel – Nederbragt, p. 368, pl. 11, figs 2-3.

2007 *Sigalia carpatica* Salaj and Samuel, 1963 – Lamolda, Peryt and Ion, p. 28, figs 4M. P1-2, S1-2.

Test biserial, subtriangular, laterally compressed, periphery rounded. Chambers broad, curved, sutures thick limbate, partly beaded, wall smooth.

Stratigraphic range: Nederbragt (1991) Santonian (lower to middle part of *D. asymetrica* Zone); Georgescu (1996) first occurrence around the Coniacian-Santonian boundary.

Lamolda et al. (2007) upper Coniacian to lower Santonian.

Sigalia decoratissima (De Klasz)

Fig. 12/3-4

1953 *Ventilabrella decoratissima* De Klasz, p. 228, pl. 4, figs 5a-b.

1966 *Gublerina decoratissima* (de Klasz, 1953) – Salaj and Samuel, p. 229, tab. 37, figs 4-5.

1991 *Sigalia decoratissima decoratissima* (De Klasz) – Nederbragt, p. 368, pl. 11 figs 4 a-c.

Test similar to S. carpatica but becoming multiserial in the adult stage. Sutured raised and beaded. Wall smooth.

Stratigraphic range: Nederbragt (1991) Santonian (middle part of *D. asymetrica* Zone).

Sigalia deflaensis (Sigal)

Fig. 11/15; Fig. 12/15-16

1952 *Guembelina (Guembelina, Ventilabrella) deflaensis* Sigal, p. 36, text-fig. 41.

1966 *Sigalia deflaensis* (Sigal, 1952) – Salaj and Samuel, p.227, tab. 37, fig. 1.

1991 *Sigalia deflaensis deflaensis* (Sigal) – Nederbragt, p. 368, pl. 11, figs 5-6.

2007 *Sigalia deflaensis* (Sigal, 1952) – Lamolda, Peryt and Ion, p. 28, figs 4L, Q1-2, R1-2.

Test biserial, elongate triangular, laterally compressed, periphery rounded with thickened initial part. Chambers broader than high, reniform in the younger part. Sutures in the initial part limbate, later flat or slightly incised. Wall covered by fine costae, fading out in the younger part.

Stratigraphical range: Nederbragt (1991) Santonian (*D. asymetrica* Zone); Lamolda et al. (2007) upper Coniacian to lower Santonian.

Heterohelix Ehrenberg, 1843

Heterohelix globulosa (Ehrenberg)

Fig. 12/8-11

1840 *Textilaria globulosa* Ehrenberg, p. 135, pl. 4, figs 2, 4, 5, 7-8.

1938 *Gümbelina globulosa* (Ehrenberg) – Cushman, p. 6, pl. 1, figs 28-33.

1985 *Heterohelix globulosa* (Ehrenberg) – Caron, p. 60, fig. 24.5.

1991 *Heterohelix globulosa* (Ehrenberg) – Nederbragt, p. 341, pl. 2, figs 1-2.

2009 *Heterohelix globulosa* (Ehrenberg) – Georgescu and Huber, p. 351, pl. 7, figs 9-12.

Test large, biserial, with inflated globular chambers slowly increasing in size, with broadly rounded periphery. Sutures straight to slightly oblique. Wall finely costate.

Stratigraphic range: Georgescu and Huber (2009) upper Cenomanian to Maastrichtian (upper *R. cushmani* to *P. hariaensis* Zone).

Heterohelix cf. *globulosa* (Ehrenberg)

Fig. 12/12-14

Test large, biserial, with small globular to subglobular chambers in the juvenile part, followed by few large inflated globular chambers, giving a broad triangular fan-like outline. These inflated chambers are not recorded in *H. globulosa* s.str. Periphery broadly rounded. Wall finely costate.

Heterohelix papula Belford

Fig. 12/17-18; Fig. 13/1-2

1960 *Guembelina papula* Belford, p. 57, figs 6-9.

2000 *Heterohelix papula* (Belford) – Petrizzo, p. 498, figs 11.4 a-b.

Test biserial, rather large, laterally compressed. Chambers subglobular, broader than high, sutures straight, periphery broadly rounded. Wall finely costate.

Stratigraphic range: Petrizzo (2000) Santonian to ?Campanian; Petrizzo (2003) first occurrence slightly below *D. asymetrica*, slightly below calcareous nannoplankton *Lithastrinus grillii*, close to the Coniacian/Santonian boundary; Gale et al. (2007) FO in the upper Coniacian at the 5 m level of the Wall Mart section.

Heterohelix planata (Cushman)

Fig. 13/7-15

1938 *Gümbelina planata* Cushman, p. 12, pl. 2, figs 13-14.

1946 *Gümbelina planata* Cushman – Cushman, p. 105, pl. 45, figs 6-7.

1991 *Heterohelix planata* (Cushman) – Nederbragt, p. 346, pl. 3, figs 3-4.

2008 *Heterohelix planata* (Cushman) 1938 – Georgescu et al., p. 402, pl. 1, figs A1 a-b; pl. 3, figs 1-5.

Test small biserial, slender, laterally compressed. Chambers increase regularly in size, earlier ones subglobular, younger ones elongate to reniform. Sutures depressed, oblique to the test axis. Wall finely costate.

Stratigraphic range: Georgescu et al. (2008) Santonian to Maastrichtian (*D. asymetrica* to *Pseudoguembelina hariaensis* Zone).

Heterohelix striata (Ehrenberg)
Fig. 13/3-6

1840 *Textularia striata* Ehrenberg, p. 135, pl. 4, figs 1a, 2a, 3a.
1938 *Gümbelina striata* (Ehrenberg) – Cushman, p. 8, pl. 1, figs 34-40.
1985 *Heterohelix striata* (Ehrenberg) – Caron, p. 60, figs 24.12-13.
1991 *Heterohelix globulosa* (Ehrenberg) – Nederbragt, p. 341, pl. 2, fig. 2, non fig. 1.

Test medium-sized, biserial, elongate triangular, globular chambers, broadly rounded periphery, sutures straight. Wall coarsely costate.

Stratigraphic range: Caron (1985) Campanian-Maastrichtian; Nederbragt (1991) Turonian-Maastrichtian.

Huberella Georgescu, 2007
Huberella huberi Georgescu
Fig. 13/28-30

1991 *Pseudoguembelina costellifera* Masters – Nederbragt, p. 358, pl. 8, fig. 1, non fig. 2.
2007 *Huberella huberi* Georgescu, p. 214, pl. 2, figs 1-6; pl. 3, figs 1-3

Test small, biserial, subtriangular, laterally compressed. Chambers subglobular to reniform in the later stage, sutures depressed, slightly oblique to the longitudinal axis. Characteristic are the posterior chamber projections in the adult chambers (pl. 6, fig. 30, final chamber) which are difficult to be observed here because of preservation (comp. Georgescu, 2007). Wall finely costate.

Stratigraphic range: figured specimen of Nederbragt (1991) from the Santonian (uppermost *D. concavata* Zone); Georgescu (2007) Turonian (*H. helvetica* to base of *D. concavata* Zone).

Planoheterohelix Georgescu and Huber, 2009
Planoheterohelix postmoremani Georgescu and Huber
Fig. 13/16-23, 26-27

1991 *Heterohelix moremani* (Cushman) – Nederbragt, p. 344, pl. 3, fig. 2, non pl. 2, figs 6-7, pl. 3, fig. 1.
2009 *Planoheterohelix postmoremani* Georgescu and Huber, p. 346, pl. 5, figs 1-11.

Test small, slender biserial, chambers subglobular, younger ones subrectangular to reniform, sutures slightly oblique, periphery rounded. Wall finely costate.

Planoheterohelix differs from stratigraphically earlier biserial forms by a completely symmetrical test in edge view.

Stratigraphic range: Georgescu and Huber (2009) upper Cenomanian to Coniacian (upper *R. cushmani* to *D. concavata* Zone).

Praegublerina Georgescu, Saupe and Huber, 2009
Praegublerina pseudotessera (Cushman)
Fig. 13/24, 25, 31

1938 *Gümbelina pseudotessera* Cushman, p. 14, pl. 2, figs 19-21.
1946 *Gümbelina pseudotessera* Cushman – Cushman, p. 106, pl. 45, figs 16-20.
1991 *Heterohelix planata* (Cushman) - Nederbragt, p. 346, pl. 3, fig. 4, non fig. 3.
2008 *Praegublerina pseudotessera* (Cushman) – Georgescu, Saupe and Huber, p. 404, pl. 1, figs A2 a-b; pl. 3, figs 6-12.

Test small, biserial, laterally compressed, rapidly broadening, triangular. Chambers broader then high, becoming reniform in adult stage, overlapping along the median axis, sutures oblique. Chamber wall finely costate.

Georgescu et al. (2008) describe a central non-septate area between the two rows of chambers in the adult part of the test, which is difficult to demonstrate here because of preservation (in fig. 31 visible at the base of final chamber).

Stratigraphic range: Georgescu et al. (2008) Campanian to Maastrichtian (*Globotruncanita elevata* to *Abathomphalus mayaroensis* Zone).

Pseudotextularia Rzehak, 1891
Pseudotextularia nuttalli (Voorwijk)
Fig. 12/5-7

1937 *Guembelina nuttalli* Vorwijk, p. 192, pl. 2, figs 1-9.
1989 *Pseudotextularia nuttalli* (Vorwijk) – Nederbragt, p. 204, pl. 8, figs 2-3; text-fig. 9.
1991 *Pseudotextularia nuttalli* (Voorwijk) – Nederbragt, p. 364, pl. 10, figs 4, 6.
2007 *Pseudotextularia nuttalli* (Voorwijk, 1937) – Lamolda, Peryt and Ion, p. 28, figs 4N1-2, O1-2.

Test large, biserial, chambers inflated, broader than high, increasing rapidly in size. Periphery rounded, giving a fan-like appearance by the broad final chambers. Wall very finely costate in contrast to the coarsely costate *Pseudotextularia* elegans (Rzehak).

Stratigraphic range: Nederbragt (1991) Coniacian to Maastrichtian; Gale et al. (2008) in the Santonian and very rare in the lower Campanian.

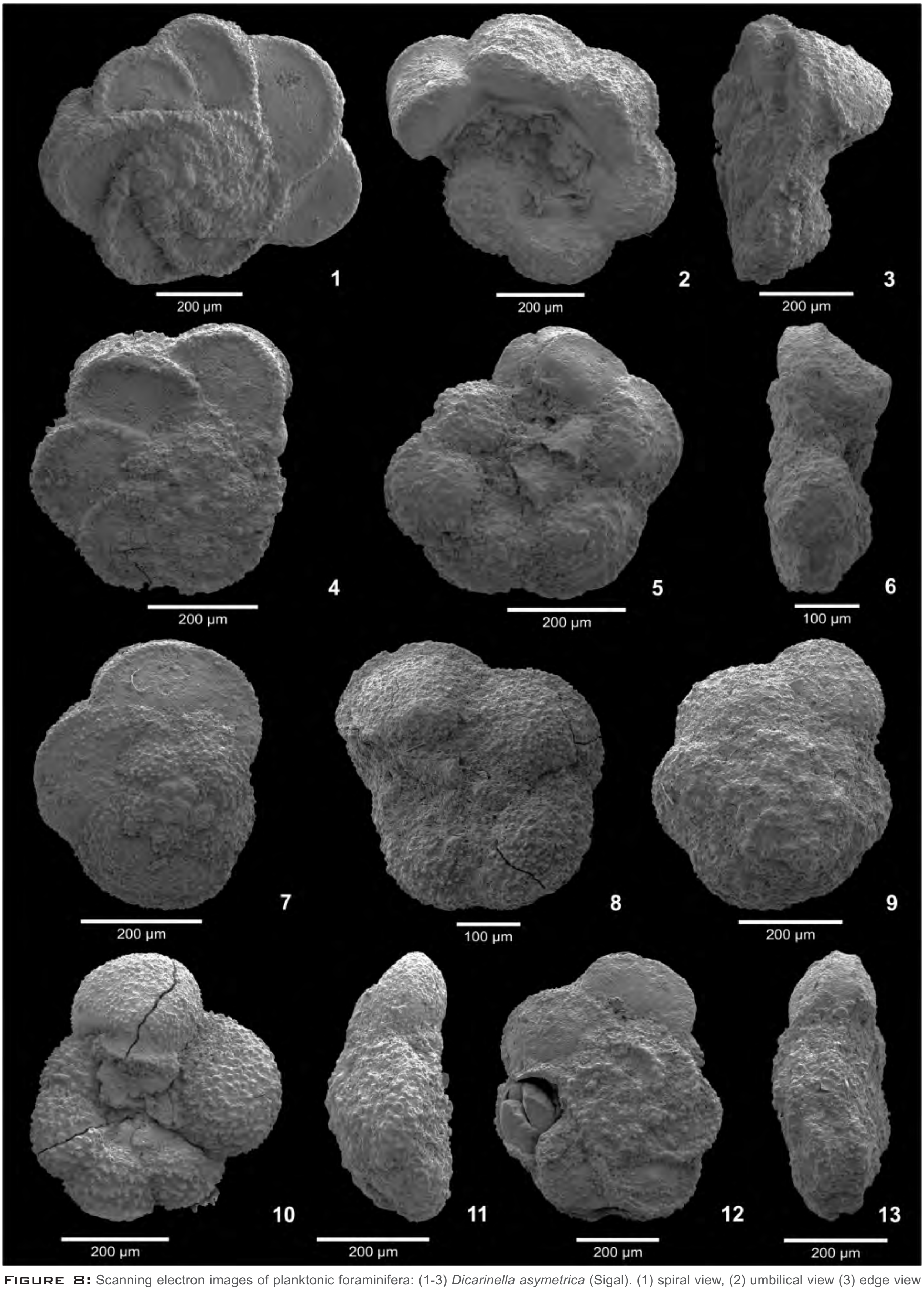

Figure 8: Scanning electron images of planktonic foraminifera: (1-3) *Dicarinella asymetrica* (Sigal). (1) spiral view, (2) umbilical view (3) edge view sample; (4-6) *Dicarinella concavata* (Brotzen). (4) spiral view (5) umbilical view (6) edge view; (7-8) *Dicarinella primitiva* (Dalbiez). (7) spiral view, (8) umbilical view; (9-11) *Praeglobotruncana hilalensis* Barr. (9) spiral view, (10) umbilical view, (11) edge view; (12-13) *Marginotruncana marginata* (Reuss). (12) spiral view, (13) edge view.

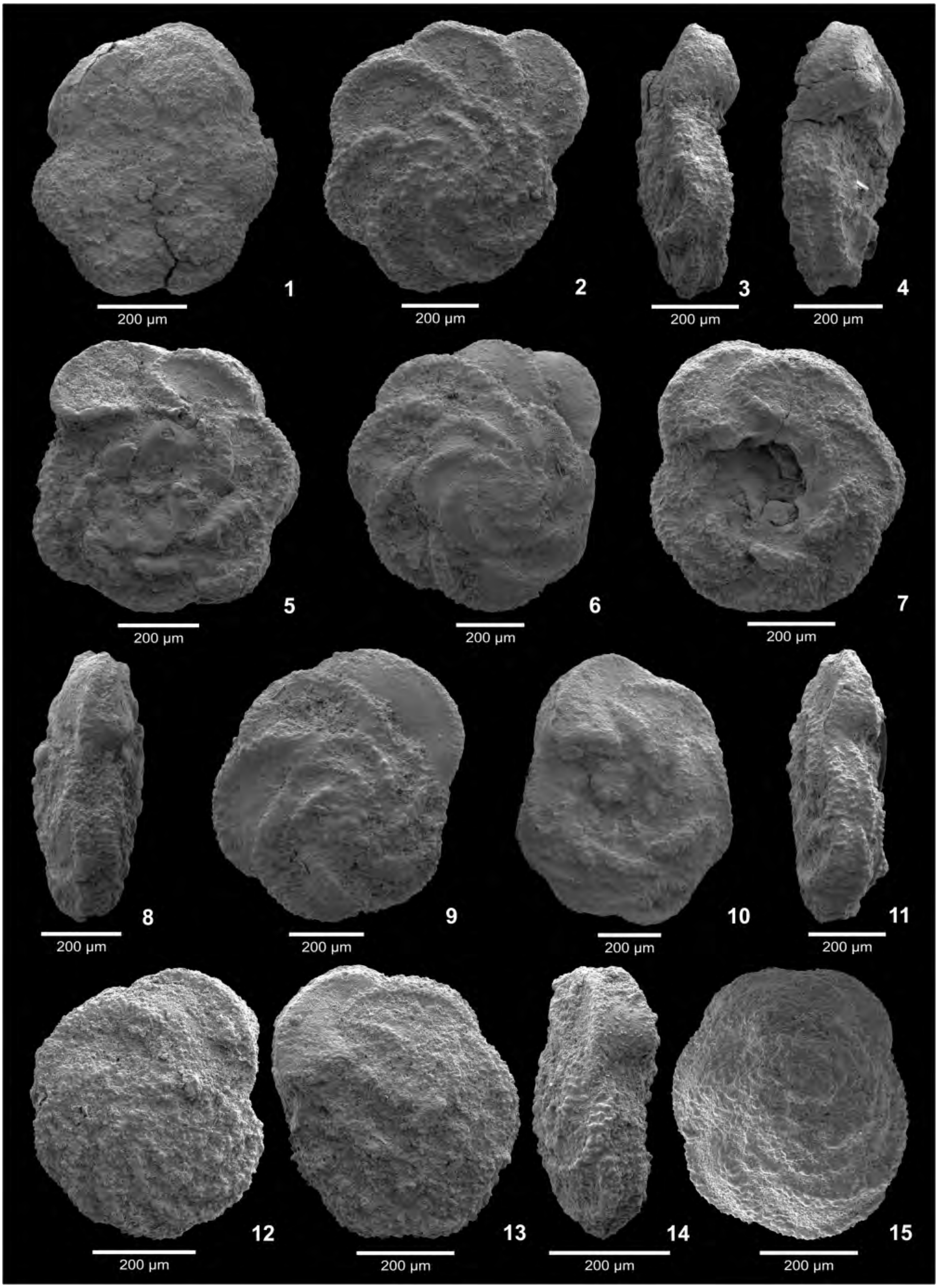

Figure 9: Scanning electron images of planktonic foraminifera: (1) *Marginotruncana marginata* (Reuss). Umbilical view; (2-5) *Marginotruncana pseudolinneiana* Pessagno. (2) spiral view, (3-4) edge views, (5) umbilical view; (6-8) *Marginotruncana coronata* (Bolli). (6) spiral view (8) edge view, (7) umbilical view; (9-11) *Marginotruncana sinuosa* Porthault. (9) spiral view, (10) umbilical view, (11) edge view; (12-15) *Contusotruncana* cf. *fornicata* (Plummer). (12) spiral view, (13) umbilical view, (14) edge view, (15) spiral view.

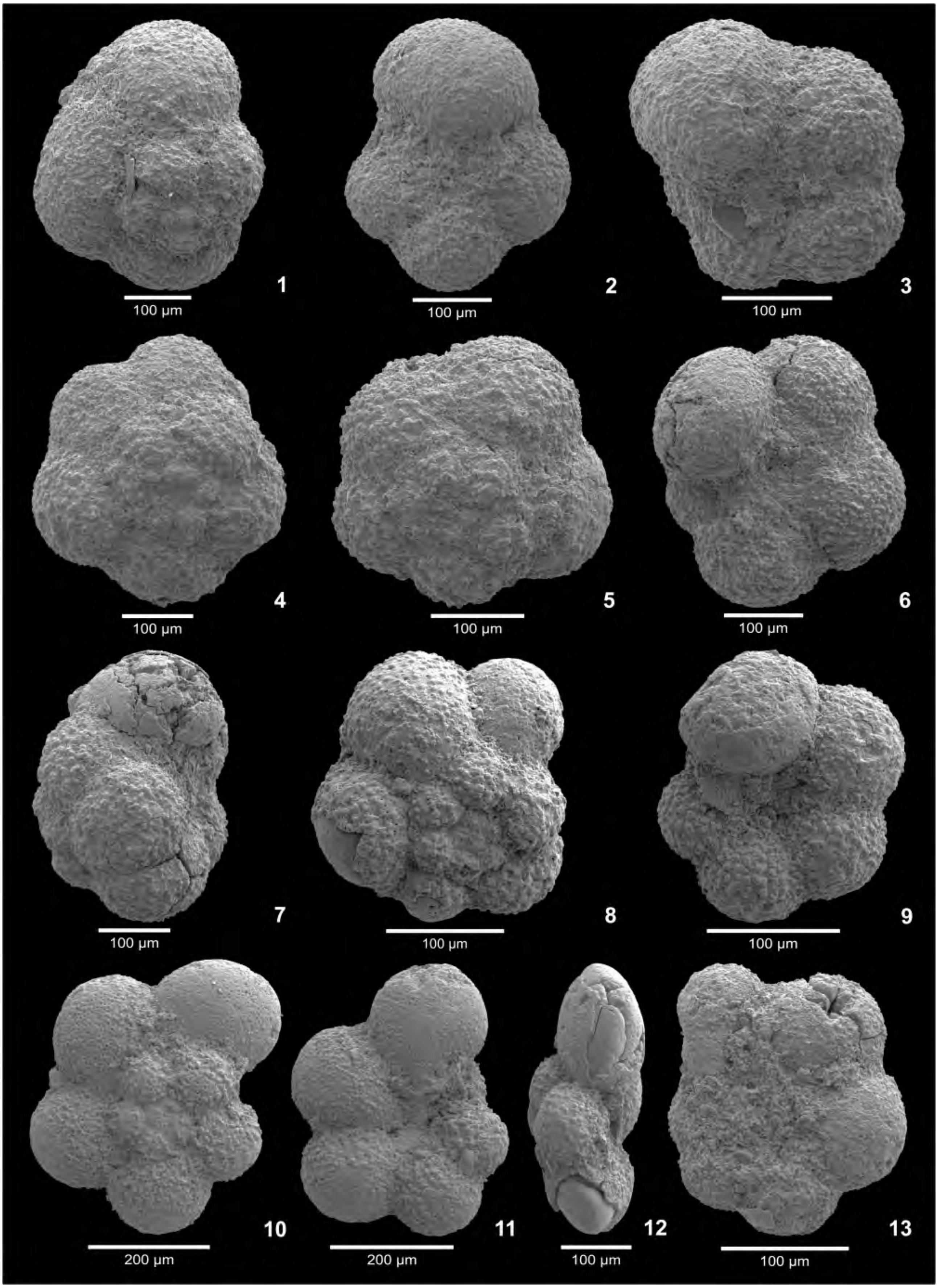

Figure 10: Scanning electron images of planktonic foraminifera: (1-3) *Whiteinella baltica* Douglas and Rankin. (1) spiral view, (2) umbilical view, (3) umbilical view; (4-7) *Fingeria kingi* (Trujillo). (4-5) spiral view, (6) umbilical view, (7) edge view; (8-9) *Muricohedbergella delrioensis* (Carsey). (8) spiral view, (9) umbilical view; (10-12) *Muricohedbergella flandrini* (Porthault). (10) spiral view, (11) umbilical view, (12) edge view; (13) *Muricohedbergella planispira* (Tappan). Umbilical view.

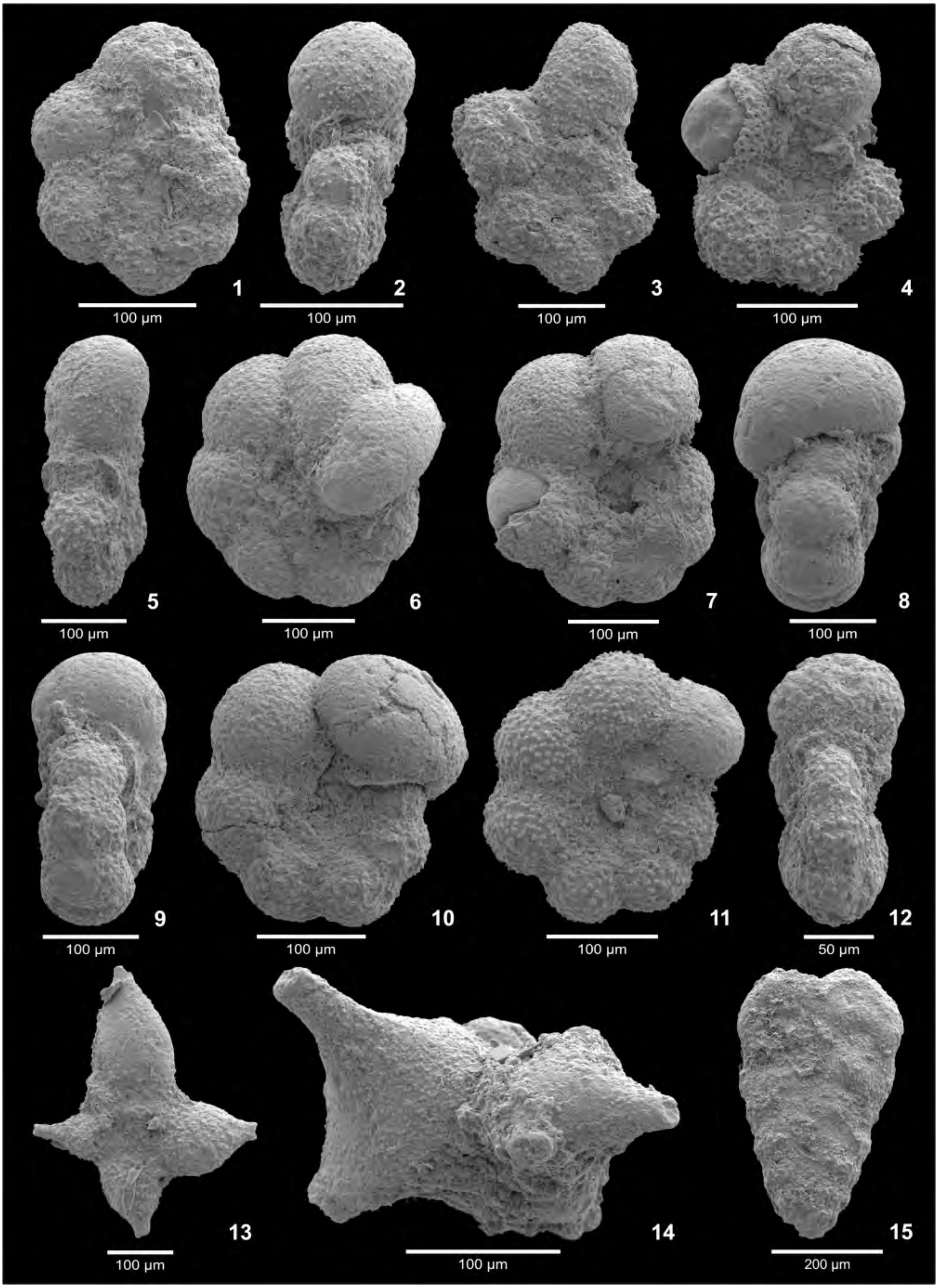

Figure 11: Scanning electron images of planktonic foraminifera: (1-2) *Muricohedbergella planispira* (Tappan). (1) spiral view, (2) edge view, (3-5) *Hastigerinoides clavatus* (Brönnimann). (3) lateral view (slightly trochospiral), (5) edge view, (4) lateral view (planispiral); (6-10) *Globigerinelloides bollii* Pessagno. (6-7) lateral views, (8-9) edge views, (10) lateral view; (11-12) *Globigerinelloides ultramicrus* (Subbotina). (11) lateral view, (12) edge view; (13) *Schackoina* cf. *cenomana* (Schacko). Lateral view; (14) *Schackoina multispinata* (Cushman and Wickenden); (15) *Sigalia deflaensis* (Sigal). Frontal view.

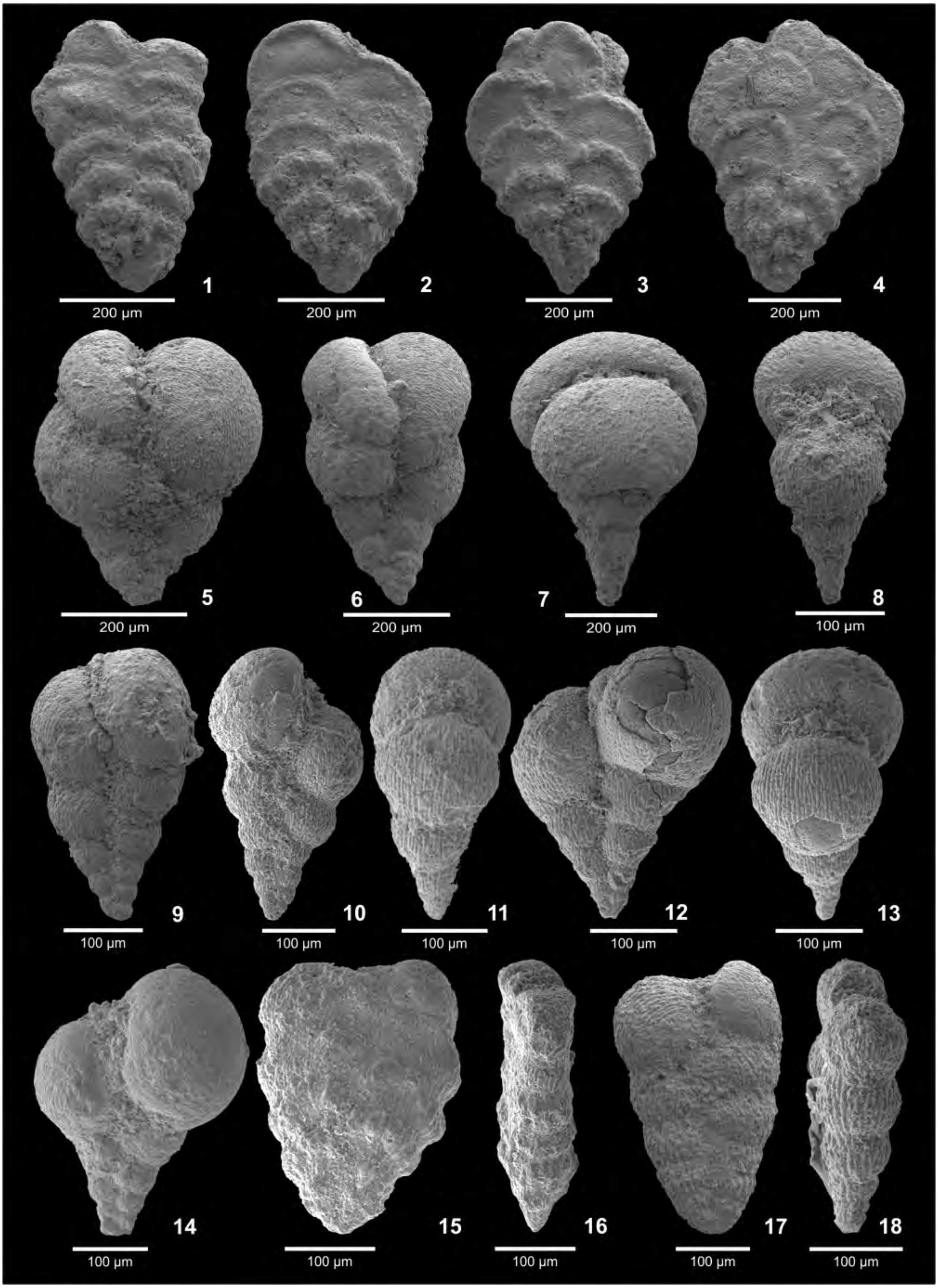

Figure 12: Scanning electron images of planktonic foraminifera: (1-2) *Sigalia carpatica* Salaj and Samuel. Frontal views; (3-4) *Sigalia decoratissima* (De Klasz). Frontal views; (5-7) *Pseudotextularia nuttalli* Voorwijk. (5-6) frontal views, (7) edge view; (8-11) *Heterohelix globulosa* (Ehrenberg). (8, 11) edge views, (9) frontal view, (10) frontal view; (12-14) *Heterohelix* cf. *globulosa* (Ehrenberg). (12, 14) frontal views, (13) edge view; (15-16) *Sigalia deflaensis* (Sigal). (15) frontal view, (16) edge view; (17-18) *Heterohelix papula* Belford. (17) frontal view, (18) edge view.

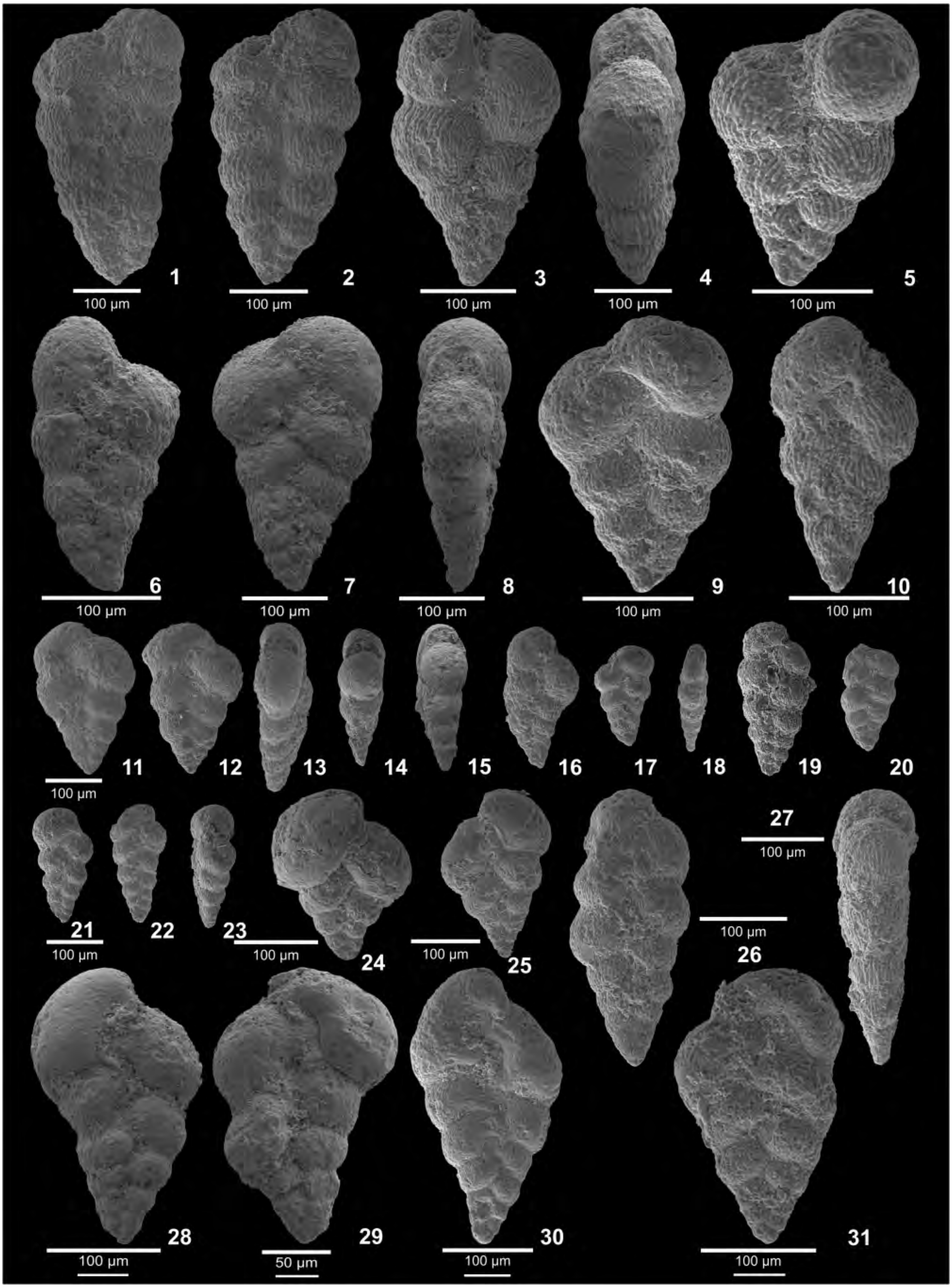

Figure 13: Scanning electron images of planktonic foraminifera: (1-2) *Heterohelix papula* Belford. Frontal views; (3-6) *Heterohelix striata* (Ehrenberg). (3, 5) frontal views, (4) edge view, (6) frontal view; (7-15) *Heterohelix planata* (Cushman). (7) frontal view, (8, 15) edge views, (9-12) frontal views, (13-14) edge views, (scale bar for images 11 to15 is 100 micron); (16-23, 26-27) *Planoheterohelix postmoremani* Georgescu and Huber. (16-17, 19-22, 26) frontal views,(18, 23, 27) edge views, (scale bar for images 16 to 23 is 100 micron); (24-25, 31) *Praegublerina pseudotessera* (Cushman). Frontal views; (28-30) *Huberella huberi* Georgescu. Frontal views.

Appendix 2: List of calcareous nannoplankton species

The reader is referred to Burnett (1998) for references on calcareous nannoplankton taxa.

Ahmuellerella regularis (Gorka, 1957) Reinhardt and Gorka, 1967
Biscutum constans (Gorka, 1957) Black, 1959
Biscutum magnum Wind and Wise in Wise and Wind, 1977
Braarudosphaera bigelowii (Gran and Braarud, 1935) Deflandre, 1947
Broinsonia enormis (Shumenko, 1968) Manivit, 1971
Broinsonia signata (Noel, 1969) Noel, 1970
Calculites ovalis (Stradner, 1963) Prins and Sissingh in Sissingh, 1977
Chiastozygus amphipons (Bramlette and Martini, 1964) Gartner, 1968
Corollithion signum Stradner, 1963
Cribrosphaerella ehrenbergii (Arkhangelsky, 1912) Deflandre 1952
Cyclagelosphaera reinhardtii (Perch-Nielsen, 1968) Romein, 1977
Eiffellithus eximius (Stover, 1966) Perch-Nielsen, 1968
Eiffellithus gorkae Reinhardt, 1965
Gartnerago segmentatum (Stover, 1966) Thierstein, 1974
Helicolithus trabeculatus (Gorka, 1957) Verbeek, 1977
Lithastrinus grillii Stradner, 1962
Lithraphidites carniolensis Deflandre, 1963
Lucianorhabdus cayeuxii Deflandre, 1959
Lucianorhabdus maleformis Reinhardt, 1966
Manivitella pemmatoidea (Deflandre in Manivit, 1965) Thierstein, 1971
Marthasterites furcatus (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959
Marthasterites simplex (Bukry, 1969) Burnett, 1998
Micrantholithus quasihoschulzii Burnett, 1998
Microrhabdulus decoratus Deflandre, 1959
Microrhabdulus reticulatus Shumenko, 1970
Micula staurophora (Gardet, 1955) Stradner, 1963
Nannoconus sp.
Octolithus multiplus (Perch-Nielsen, 1973) Romein, 1979
Orastrum campanensis (Cepek, 1970) Wind and Wise 1977
Placozygus fibuliformis (Reinhardt, 1964) Hoffmann, 1970
Prediscosphaera cretacea (Arkhangelsky, 1912) Gartner, 1968
Prediscosphaera spinosa (Bramlette and Martini, 1964) Gartner, 1968
Reinhardtites anthophorus (Deflandre, 1959) Perch-Nielsen, 1968
Retecapsa angustiforata Black, 1971
Retecapsa crenulata (Bramlette and Martini, 1961) Grün in Grün and Allemann, 1975
Rhagodiscus achylostaurion (Hill,1976) Doeven, 1983
Rhagodiscus angustus (Stradner) Reinhardt, 1971
Rhagodiscus reniformis Perch-Nielsen, 1973
Rotelapillus crenulatus (Stover, 1966) Perch-Nielsen, 1984
Staurolithites flavus Burnett, 1998
Tegumentum stradneri Thierstein in Roth and Thierstein, 1972
Tranolithus minimus (Bukry, 1969) Perch-Nielsen, 1984
Tranolithus orionatus (Reinhardt, 1966)
Watznaueria barnesae (Black, 1959) Perch-Nielsen, 1968
Watznaueria biporta Bukry, 1969
Zeugrhabdotus bicrescenticus (Stover, 1966) Burnett in Gale et al., 1996
Zeugrhabdotus biperforatus (Gartner, 1968) Burnett 1998
Zeugrhabdotus embergeri (Noel, 1958) Perch-Nielsen, 1984

Appendix 3: List of dinocyst taxa.

List of dinocyst taxa identified in this study, arranged in alphabetical order of the genus name. References for the described species are given according to the compilations of Fensome et al. (1993) and Fensome et al. (2008).

Apteodinium deflandrei (Clarke and Verdier, 1967) Lucas-Clark, 1987
Chatangiella ditissima (McIntyre, 1975) Lentin and Williams, 1976
Chatangiella granulifera (Manum, 1963) Lentin and Williams, 1976
Chatangiella hexacalpis Harker and Sarjeant in Harker et al., 1990
Dinogymnium sp.
Heterosphaeridium cordiforme Yun Hyesu, 1981
Pervosphaeridium intervelum Kirsch, 1991
Pervosphaeridium monasteriense Yun Hyesu, 1981
Pervosphaeridium pseudhystrichodinium (Deflandre, 1937b) Yun Hyesu, 1981. Emendation: Davey, 1969a
Pterodinium cingulatum subsp. *cingulatum* (Wetzel, 1933b) Below, 1981a
Renidinium rigidum Prince et al., 1999
Spinidinium echinoideum subsp. *rhombicum* (Cookson and Eisenack, 1974) Lentin and Williams, 1976
Spiniferites membranaceus (Rossignol, 1964) Sarjeant, 1970
Spiniferites multibrevis (Davey and Williams, 1966a) Below, 1982a
Spiniferites pseudofurcatus (Klumpp, 1953) Sarjeant, 1970. Emendation: Sarjeant, 1981
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854
Surculosphaeridium longifurcatum (Firtion, 1952) Davey et al., 1966

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Received: 14 October 2013
Accepted: 24 November 2013

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