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THE MIDDLE EOCENE AGE OF THE SUPPOSED LATE OLIGOCENE SEDIMENTS IN THE FLYSCH OF THE PAZIN BASIN (ISTRIA, OUTER DINARIDES)

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Babić, Lj., Hernitz-Kučenjak, M., Ćorić, S. & Zupanič, J.: The Middle Eocene age of the supposed Late Oligocene sediments in the flysch of the Pazin Basin (Istria, Outer Dinarides). Nat. Croat., Vol. 16, No. 2., 83–103, 2007, Zagreb.

The dating of the flysch sediments of the coastal Dinarides is critical for considering the evolution of the Dinaric chain. The flysch of the Pazin Basin, Istria has been considered to be Late Lutetian to Late Eocene in age by many workers. The recently reported Late Oligocene age of a part of this flysch (ŠPARICA *et al.*, 2005) is highly relevant when considering the sedimentary and tectonic evolution of the area, as well as the western Dinarides in general. The importance of the Late Oligocene dating, and the character of the succession of the area in question, which shows similarities with Middle Eocene sediments in other parts of the basin, provoked the need for a reevaluation of the dating of these specific sediments. The results presented here support the Middle Eocene age of these sediments, which is consistent with the dating proposed by previous workers, and agrees with the character of the relevant sedimentary succession.

Key words: Eocene, Oligocene, planktonic foraminifera, nannoplankton, flysch, Pazin Basin, Istria, Croatia

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Dosadašnja istraživanja i shvaćanja, kako o starosti, tako i karakteru slijeda sedimenata fliša Pazinskoga bazena u Istri, upućivala su na ukupnu starost fliša od kasnoga lutecija do starijega priabonija. Međutim, nedavno su prikazani podaci, prema kojima jedan dio tih sedimenata odgovara kasnom oligocenu, što je bitna novost za razmatranje razvitka toga bazena, kao i orogena Dinarida. Ovaj rad odgovara na potrebu dodatne provjere starosti tih sedimenata zbog važnosti odnosnoga datiranja. Prikazani rezultati temelje se na usporedbi karaktera i slijeda sedimenata iz predjela odakle potječu nedavni podaci o oligocenu sa sedimentima drugih dijelova Pazinskoga bazena, te na biostratigrafskom datiranju pomoću planktonskih foraminifera i nanoplanktona. Ustanovljene biozone odgovaraju gornjem luteciju i donjem bartoniju, dakle, donjemu dijelu ukupnoga raspona starosti Pazinskoga fliša.

Ključne riječi: Eocen, Oligocen, planktonske foraminifere, nanoplankton, fliš, Pazinski bazen, Istra, Hrvatska

INTRODUCTION

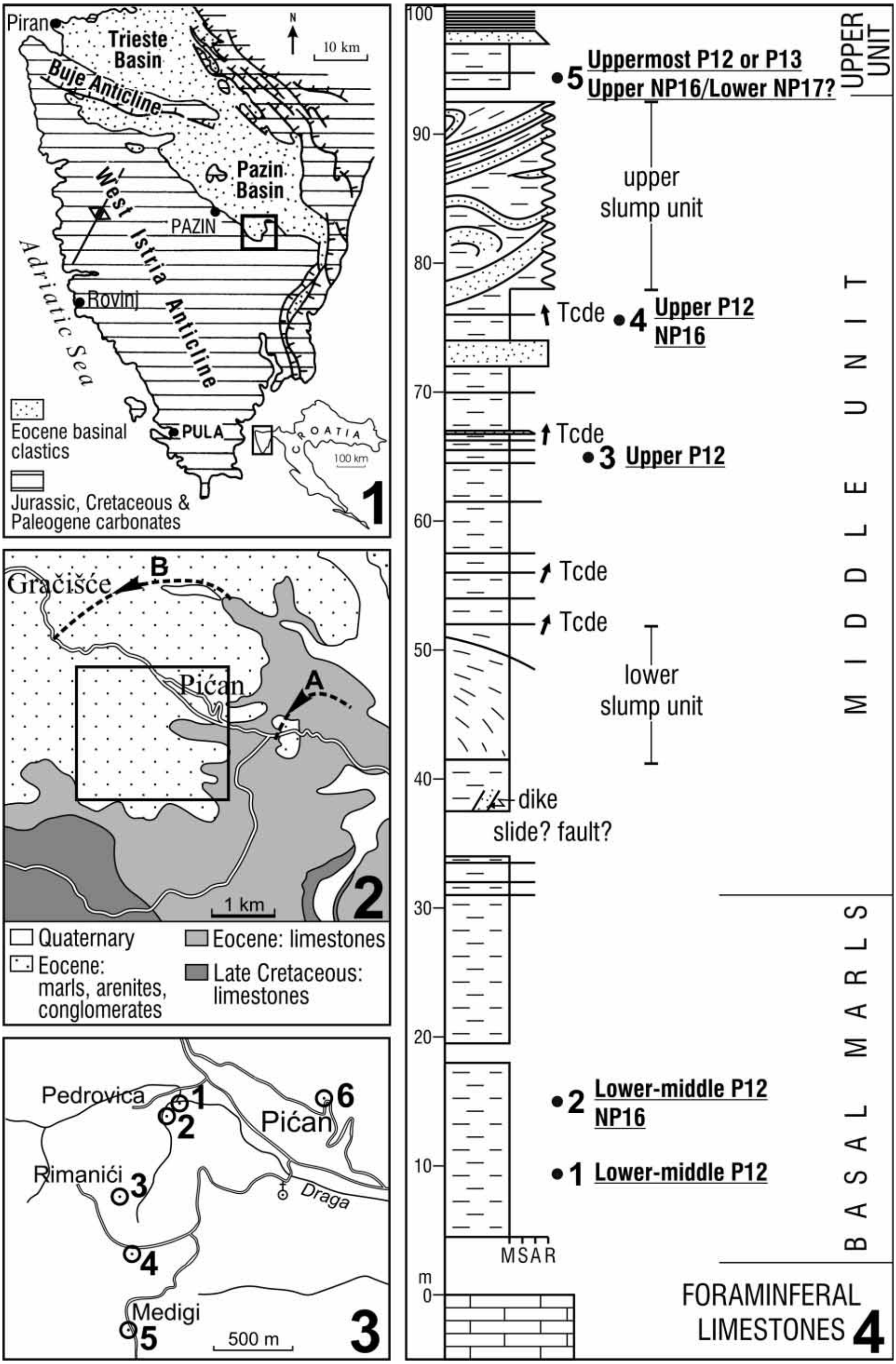
The flysch of the Istrian peninsula is one of the three main flysch areas in the coastal Dinarides, the other two occurring in the northern Dalmatian and Split areas. The flysch unit of the Pazin Basin in Istria (Fig. 1) has been considered as Middle to Late Eocene in age since a long time ago. Early datings were based on macrofossils, nummulites, and comparisons to similar deposits in other areas, especially those in Italy (SCHUBERT, 1905; D'AMBROSI, 1931; LIPPARINI, 1935). Subsequent workers applied planktonic foraminiferal and nannoplankton biostratigraphies in various parts of the Pazin flysch. Thus, MULDINI-MAMUŽIĆ (1965), KRAŠENINNIKOV *et al.* (1968), and PICCOLI & PROTO-DECIMA (1969) found planktonic foraminiferal associations and zones, which correspond to today's widely applied P11, P12, P13, and P14 zones of BERGGREN *et al.* (1995), while BENIĆ (1991) identified nannoplank-

Fig. 1. Geological situation of the Pazin Basin in Istria. Simplified after POLŠAK & ŠIKIĆ (1969), ŠIKIĆ *et al.* (1969, 1972), and GEOLOŠKI ZAVOD LJUBLJANA & GEOLOŠKI INSTITUT ZAGREB (1969). Framed is the map in Fig. 2.

Fig. 2. Geological map of the SE part of the Pazin Basin (simplified after ŠIKIĆ *et al.*, 1969). The framed area is shown in Fig. 3. Sections A (DROBNE *et al.*, 1979; PAVLOVEC *et al.*, 1991) and B (ŽIVKOVIĆ & BABIĆ, 2003) located close to the study area are discussed in the text.

Fig. 3. Location of outcrops sampled for biostratigraphic dating in the SW environs of Pićan.

Fig. 4. Sedimentary succession in the SW environs of Pićan based on the observations made in the area between Draga, Pedrovica, and Rimanići, and, in the environs of Medigi (see Fig. 3). M, S, A, R are mudstone, siltstone, arenite, and rudite, respectively. Arrows denote paleotransport directions measured on flute casts. Thick dots with numbers refer to the position of five biostratigraphic samples (locations in Fig. 3). Sample 6 is located out of the area represented by the log (see Fig. 3). ⇒


Piran
Trieste Basin
Buje Anticline
West Istria Anticline
Pazin Basin
PAZIN
Rovinj
Adriatic Sea
PULA
N
10 km
CROATIA
100 km
Eocene basinal clastics
Jurassic, Cretaceous & Paleogene carbonates
1
Gračišće
B
Pićan
A
1 km
2
Quaternary
Eocene: marls, arenites, conglomerates
Eocene: limestones
Late Cretaceous: limestones
Pedrovica
Pićan
Rimanići
Draga
Medigi
500 m
1
2
3
4
5
6
3
Uppermost P12 or P13
Upper NP16/Lower NP17?
upper slump unit
Tcde
Upper P12
NP16
Upper P12
lower slump unit
dike
slide? fault?
Lower-middle P12
NP16
Lower-middle P12
MSAR
m
UPPER UNIT
MIDDLE UNIT
BASAL MARLS
FORAMINFERAL LIMESTONES
4

ton zones NP16, NP17, and the lowermost NP18 of MARTINI (1971). These datings are similar but more accurate as compared to the early ones.

The recently reported Late Oligocene dating of a 110 m thick succession occurring in the southern part of the Pazin Basin is based on nannoplankton and palynomorphs, and partly, on larger foraminifera (ŠPARICA *et al.*, 2005; Figs. 2 and 3). According to these authors the relevant succession occurs in the upper part of the overall Pazin flysch succession and shows certain differences in the character of sediments compared to the surrounding Eocene flysch sediments. ŠPARICA *et al.* (2005) are certainly right in claiming that the Late Oligocene age of these sediments can be very important for considering the stratigraphy and sedimentary evolution of the area. In fact, the Oligocene age of a part of the Pazin flysch shouldn't come as a surprise considering new datings made in another coastal Dinaric flysch area, the Split flysch in Central Dalmatia. Previous age determinations of the Split clastics established a Middle to Late Eocene age (KERNER, 1916; MARINČIĆ *et al.*, 1977), with a presumed Oligocene age of the marginal breccias (MARINČIĆ *et al.*, 1977), while the work on nannoplankton biostratigraphy provided Oligocene and Miocene ages of a large portion of the flysch sediments (de CAPOA *et al.*, 1995).

As the character of the sediments and the sedimentary succession of the Pićan area, which we have been investigating for some time, appear correlatable to those exposed in other parts of the Pazin Basin, we had doubts concerning the Late Oligocene age reported for Pićan sediments. Keeping also in mind the importance of a reliable dating of the relevant succession, we decided to check the proposed age by a detailed study of the sediments and the sedimentary succession in question, by comparing them to the rest of the Pazin Basin, and by new dating based on planktonic foraminifera and nannoplankton. This work presents the results which suggest that the relevant sediments correspond to the lower portion of the Pazin Basin succession, and are Late Lutetian and Early Bartonian in age.

OUTLINE GEOLOGY AND BIOSTRATIGRAPHY OF THE PAZIN BASIN

The overall structure of the Istrian peninsula is shown in Fig. 1, which also shows the position of the Pazin Basin. A major part of Istria consists of thick platform carbonates ranging in age from the Middle Jurassic to Middle Lutetian (VLAHOVIĆ *et al.*, 2003; DROBNE, 1977). The overlying flysch succession, including the basal marls, has a thickness of more than 450 m (ŠIKIĆ & POLŠAK, 1973). The basal marls of Middle Lutetian age are a few tens of metres thick and are known as Globigerina Marls (SCHUBERT, 1905; KRAŠENNINIKOV *et al.*, 1968). These marls are succeded by an alternation of marls and gravity displaced calcarenites, calcirudites and sandstones deposited in a NW-SE elongated basin (MAGDALENIĆ, 1972), which is Late Lutetian to earliest Priabonian in age (SCHUBERT, 1905; D'AMBROSI, 1931; MULDINI-MAMUŽIĆ, 1965; KRAŠENINNIKOV *et al.*, 1968; PICCOLI & PROTO-DECIMA, 1969; BENIĆ, 1991). While the sandstones were deposited by longitudinal flows, the carbonate strata originated by deposition from NNE-directed, transversal flows deriving from a southerly situated carbonate uplift (BABIĆ & ZUPANIČ, 1996).

The recent report by ŠPARICA *et al.* (2005) presented a new dating, i.e. the Late Oligocene age for a 110 m thick clastic succession described from the area of Pićan. The present work addresses the results related to this area (Figs. 2 and 3).

METHODS

The study area was delineated based on the description of the area and sediments by ŠPARICA *et al.* (2005) (Figs. 2 and 3). They reported certain differences between their studied sediments and the directly surrounding Eocene flysch sediments. The later include the areas east and north of Pićan, where there are two sections previously dated by DROBNE *et al.* (1979), and ŽIVKOVIĆ & BABIĆ (2003), respectively, as the Middle Eocene (A and B in Fig. 2). The reconstruction of the sedimentary succession in the study area poses difficulties caused by synsedimentary slumps and slides, and the lack of reliable exposures for some parts of the succession. In spite of that, it was possible to compose a synthetic log (Fig. 4) using partial, locally measured logs, mapping, tracing specific horizons, as well as numerous local observations. The field study of the features, origin, and succession of sediments has been combined with the study of 39 thin sections used to determine the composition of the arenites and rudites, with the intention of using all of the resulting data for comparison with relevant features of the rest of the Pazin Basin flysch.

The biostratigraphic dating was performed using analysis of planktonic foraminifera and nannoplankton from marls. For this purpose different horizons of the succession were sampled. Six samples have been analysed for planktonic foraminifera, and four for nannoplankton. Determination of the planktonic foraminiferal genera and species is based on TOUMARKINE & LUTERBACHER (1985), and PEARSON *et al.* (2006). The planktonic foraminiferal zones were identified according to BERGGREN *et al.* (1995), BERGGREN & PEARSON (2005), and PEARSON *et al.* (2006), and nannoplankton zones according to MARTINI (1971). The ages of the identified biozones are adopted from BERGGREN *et al.* (1995).

DESCRIPTION OF SEDIMENTARY SUCCESSION AND BIOSTRATIGRAPHY

The following description of the sedimentary succession, which is about 100 m thick, also includes a short description of limestones which are regarded to underly the relevant succession (Fig. 4).

Underlying limestones

The underlying limestones are poorly bedded skeletal packstones to rudstones. They contain *Nummulites*, *Assilina*, and *Discocyclina*, less *Sphaerogypsina*, *Asterigerina*, and *Operculina*, other benthic foraminifera, along with other skeletal constituents which include fragments of echinoids, bryozoans, bivalves, and corallinaceans. Going upwards, the limestones additionally comprise planktonic foraminifera and glauconite grains. Even further upwards, there are more planktonic foraminifera and fine-grained matrix, while larger foraminifera become dominated by *Discocyclina* and small nummulites.

Basal marls

The marls overlying Foraminiferal Limestones are massive, but show cyclicity manifested by alternating layers, which are more and less resistible to weathering as a consequence of a slight difference in carbonate content. They may contain very rare intercalations of up to 1 cm thick calcilutites, which are commonly bioturbated. The marls are rich in planktonic foraminifera and nannoplankton.

Planktonic foraminiferal associations in two samples (Figs. 3 and 4) indicate the lower to middle part of zone P12 of BERGGREN *et al.* (1995), which corresponds to zone E10 and the lower part of zone E11 of BERGGREN & PEARSON (2005) and PEARSON *et al.* (2006). This is based on the presence of the following planktonic foraminifera species (Plates 1 and 2): *Turborotalia possagnoensis* (TOUMARKINE & BOLLI), *T. frontosa* (SUBBOTINA), *Globigerinatheka index* (FINLAY), *G. subconglobata* (SHUTSKAYA), *G.* cf. *mexicana* (CUSHMAN), *Morozovelloides crassatus* (CUSHMAN), *Hantkenina dumblei* WEINZIERL & APPLIN, *H.* sp., *Subbotina corpulenta* (SUBBOTINA), *Acarinina praetopilensis* (BLOW), *A. collactea* (FINLAY), *Chiloguembelina cubensis* (PALMER), and *Pseudohastigerina micra* (COLE).

Very rich, well-preserved calcareous nannoplankton in sample 2 (Figs. 3 and 4; Plates 3 and 4) is characterised by the absence of *Blackites gladius* (LOCKER, 1972) VAROL, 1989 and scarce presence of *Chiasmolithus* cf. *solitus* (BRAMLETTE & SULLIVAN, 1961) LOCKER, 1968, which indicates the *Discoaster tanii nodifer* Zone (Zone NP16 of MARTINI, 1971). The presence of *Cribrocentrum reticulatum* (GARTNER & SMITH, 1967) Perch-Nielsen, 1973, *Reticulofenestra umbilica* (LEVIN, 1965) MARTINI & RITZKOWSKI, 1968, *R. hillae* BUKRY & PERCIVAL, 1971, and *Sphenolithus furcatolithoides* LOCKER, 1967 confirms this stratigraphical determination. Accompanying species are *Chiasmolithus grandis* (BRAMLETTE & RIEDEL, 1964) RADOMSKI, 1968, *Clausiococcus fenestratus* (DEFLANDRE & FERT, 1954) PRINS, 1979, *Clausiococcus vanheckiae* (PERCH-NIELSEN, 1986) de KAENEL & VILLA, 1996, *Coccolithus eopelagicus* (BRAMLETTE & RIEDEL, 1954) BRAMLETTE & SULLIVAN, 1961, *C. formosus* (KAMPTNER, 1963) WISE, 1973, *C. miopelagicus* BUKRY, 1971, *C. pelagicus* (WALLICH, 1871) SCHILLER, 1930, *Cyclicargolithus floridanus* (ROTH & HAY, 1967) BUKRY, 1971, *Discoaster nodifer* (BRAMLETTE & RIEDEL, 1954) BUKRY, 1973, *D. saipanensis* (BRAMLETTE & RIEDEL, 1954), *Helicosphaera bramlettei* MÜLLER, 1970, *H. seminulum* BRAMLETTE & SULLIVAN, 1961, *Lanternithus minutus* STRADNER, 1962, *Reticulofenestra dictyoda* (DEFLANDRE, 1954) STRADNER, 1968, *Sphenolithus moriformis* (BRÖNNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967, *S. spiniger* BUKRY, 1971, *Thoracosphaera saxea* STRADNER, 1961, and *Zygrhablithus bijugatus* (DEFLANDRE, 1954) DEFLANDRE, 1959. The following taxa described from the Middle Eocene of Tanzania (NP15, NP16) were recognized: *Calcidiscus*? cf. *C. henriksenia*e BOWN, 2005, and *Sphenolithus runus* BOWN & DUNKLEY JONES, 2006.

The middle unit

The subsequent part of the succession consists of marls alternating with carbonate beds, and slumps (Fig. 4).

The marls are similar to the basal marls, including their richness in planktonic foraminifera and nannoplankton. Two 8 cm wide sedimentary dikes in the lower part of the unit contain rhodoliths, nummulites, other skeletal particles, and marl clasts.

The carbonate beds are mainly 2 to 10 cm thick calcarenites. They may change their thickness laterally at short distances, which may result in their lensoid appearance. Their bases are commonly erosional showing scours, flute casts, groove casts, together with ichnofossils. Coarser particles, usually larger foraminifera, may occur scattered at their bottoms or even constitute a thin basal layer. The flute casts indicate paleotransport towards azimuths between 6° and 22° (Fig. 4). Several examples show a partial Bouma sequence Tcde (Fig. 4) including their top portions represented by calcisiltite to calcilutite. The calcarenites contain biogene particles including nummulites, discocyclinas, rhodoliths, and their fragments, less *Asterigerina*, *Sphaerogypsina*, *Operculina*, bryozoans, echinoid particles, and planktonic foraminifera, together with glauconite grains, finer skeletal debris, limestone clasts and marl intraclasts. There are also cm- to mm-thick calcisiltites and calcilutites (not shown in Fig. 4), which might represent Tde and Te Bouma-type beds. These may be intensely bioturbated. A one metre thick, massive calcirudite to calcarenite bed cantaining limestone clasts, rhodoliths, and marl intraclasts occurs at the height of 72 m (Fig. 4).

The lower slump unit (Fig. 4, between 40 and 50 m) consists of marls, which include a thin calcarenite intercalation.

The upper slump unit (Fig. 4) is characterised by various attitudes of beds, folds and pieces of carbonate beds, as well as marls. It might represent a complex of several slides and slumps. Carbonate beds include erosionally based calcirudites and calcarenites, some of which show normal grading. The beds may considerably change their thicknesses laterally. Some of them pinch out by gradually loosing their lower portions, thus revealing the scour and fill process. The composition of these beds is similar to that of the underlying carbonate intercalations described above. The difference is mainly related to more common coarser grained lithologies, which include a more common occurrence of whole rhodoliths, large specimens of larger foraminifera, and larger marl and limestone clasts compared to other constituents. There is also a specific sediment type, poorly exposed in isolated outcrops, seemingly a part of thick beds, which probably represent parts of this slump unit. It consists of nummulites, rhodoliths, bivalves, gastropods, rare corals, marl clasts, and marl matrix, and easily disintegrates into loose particles.

Planktonic foraminiferal associations in two samples (3 and 4 in Figs. 3 and 4) indicate the upper part of zone P12 of BERGGREN *et al.* (1995), i.e. zone E11 of BERGGREN & PEARSON (2005), and PEARSON *et al.* (2006). This is based on the presence of *Turborotalia pomeroli* (TOUMARKINE & BOLLI), *T. altispiroides* BERMUDEZ, *Subbotina corpulenta* (SUBBOTINA), *S. jacksonensis* (BANDY), *Morozovelloides crassatus* (CUSH-

MAN), *Hantkenina dumblei* WEINZIERL & APPLIN, *H. compressa* PARR, *Globigerinatheka mexicana* (CUSHMAN), *G. subconglobata* (SHUTSKAYA), *G. euganea* PROTO DECIMA & BOLLI (SHUTSKAYA), *G.* sp., *Acarinina praetopilensis* (BLOW), *A. collactea* (FINLAY), *Subbotina corpulenta* (SUBBOTINA), *S. eocaena* (GUEMBEL), *Pseudohastigerina micra* (COLE), *Chiloguembelina cubensis* (PALMER), and *Catapsydrax unicavus* BOLLI, LOEBLICH & TAPPAN (Plates 1 and 2).

The calcareous nannoplankton assemblage in one sample (4 in Figs. 3 and 4) is comparable to the association described from the basal unit and also indicates nannoplankton Zone NP16 (*Discoaster tanii nodifer* Zone).

The upper unit

This thin unit is tentatively interpreted to represent the cover of the upper slump unit, although without decisive field evidence. Its lower part consists of marls and carbonate beds similar to those in the middle unit. In contrast, the less than 2 m thick upper part of the unit (Fig. 4) consists of an alternation of cm-thick mudstones and fine-grained sandstones. The sandstones consist predominantly of carbonate particles, and contain about 20% quartz grains.

The planktonic foraminiferal association (sample 5 in Figs. 3 and 4) corresponds to the uppermost P12 or, more probably, to the P13 zone of BERGGREN *et al.* (1995), i.e. to the upper part of zone E11, or zone E12 of BERGGREN & PEARSON (2005), and PEARSON *et al.* (2006). This is based on the presence of *Turborotalia cerroazulensis* (COLE), *Globigerinatheka euganea* PROTO DECIMA & BOLLI, *G. subconglobata* (SHUTSKAYA), *G. euganea* PROTO DECIMA & BOLLI – *Orbulinoides beckmanni* (SAITO) – transitional form, *Subbotina linaperta* (FINLAY), *S. eocaena* (GUEMBEL), *Acarinina praetopilensis* (BLOW), *Paragloborotalia nana* (BOLLI), and *Globorotaloides* sp. (Plates 1 and 2).

A very abundant, well preserved calcareous nannoplankton assemblage from sample 5 (Plates 3 and 4; 5 in Figs. 3 and 4) contains biostratigraphically important species *Helicosphaera compacta* BRAMLETTE & WILCOXON, 1967. According to PERCH-NIELSEN (1985) this form has its first occurrence near the base of nannoplankton Zone NP17. VAROL (1989) used the first occurrence of *H. compacta* to define the Lutetian/Bartonian boundary. He established nannoplankton Zone NNTe10 (corresponding to NP16) for the North Sea area. This Zone was subdivided into subzones A and B with the first occurrence of *H. compacta*. Based on the presence of this form and the absence of *Chiasmolithus oamaruensis* (DEFLANDRE, 1954) Hay, 1966, this part of the section can be assigned to the upper part of the NP16/NP17? nannoplankton Zone (MARTINI, 1971). Accompanied are: *Calcidiscus*? cf. *C. henrikseniae, Chiasmolithus* sp., *Clausiococcus vanheckiae*, *Coccolithus eopelagicus*, *C. formosus*, *C. miopelagicus*, *C. pelagicus*, *Coronocyclus bramlettei* (HAY & TOWE, 1962) BOWN, 2005, *Cribrocentrum reticulatum*, *Cyclicargolithus floridanus*, *Discoaster barbadiensis* TAN, 1927, *D. deflandrei* BRAMLETTE & RIEDEL, 1954, *D. elegans* BRAMLETTE & SULLIVAN, 1961, *D. nodifer*, *D. saipanensis*, *D. tanii* BRAMLETTE & RIEDEL, 1954, *Ericsonia obruta* PERCH-NIELSEN, 1971, *Helicosphaera bramlettei*, *H. seminulum*, *H. reticulata* BRAMLETTE & WILCOXON, 1967, *Pontosphaera exlis* (BRAMLETTE & SULLIVAN, 1961) ROMEIN 1971, *P. ocellata* (BRAMLETTE & SULLIVAN, 1961) PERCH-NIELSEN, 1984, *Reticulofenestra bisecta* (HAY, 1966) ROTH, 1970, *R. dictyoda*, *R. hillae*, *R. scripsae* (BUKRY & PERCIVAL, 1971) ROTH, 1973, *R. umbilica*, *Sphenolithus editus* PERCH-NIELSEN, 1978, *S. moriformis*, *S. predistentus* BRAMLETTE & WILCOXON, 1967, *S. spiniger*, and *Z. bijugatus*.

In addition, the sample collected close to the town of Pićan (6 in Fig. 3), out of the area represented by the log (Fig. 4) contains the planktonic foraminiferal association probably indicating the upper P12, but could also be slightly younger. Similarly, abundant, well-preserved calcareous nannoplankton in the same sample 6 corresponds to the upper NP16/NP17, as in the case of sample 5.

DISCUSSION

Underlying limestones

The features of the underlying limestones are typical for the uppermost portion of the widespread and well known unit of Foraminiferal Limestones, which has been described in Istria by many authors (e.g. ĆOSOVIĆ *et al.*, 2004). They already show the transition to so-called Crab Beds based on the change in the foraminiferal association, increasing importance of planktonic foraminifera and increasing proportion of the fine-grained component. This part of the Foraminiferal Limestones is Middle Lutetian in age based on the Alveolina biostratigraphy studied in the close vicinity, east of Pićan (A in Fig. 2; DROBNE, 1977; DROBNE *et al.*, 1979; PAVLOVEC *et al.*, 1991).

Basal marls

The features of the basal marls, such as abundant plankton, cyclicity, as well as the inferred thickness and vertical position between the Foraminiferal Limestones below and the alternation of marls and gravity displaced sediments above (Fig. 4), correspond to the Lutetian Globigerina Marls of SCHUBERT (1905), which is the well known unit of the Istrian stratigraphy described by many authors (e.g. SCHUBERT, 1905; D'AMBROSI, 1931; GOHRBANDT *et al.*, 1962; MAGDALENIĆ, 1972; ŠIKIĆ & POLŠAK, 1973). The outstanding abundance of planktonic foraminifera in these marls has already been reported by GOHRBANDT *et al.* (1962), and the cyclicity in the basal marls of the Pićan area has been described by LUŽAR-OBERITER *et al.* (2004), and explained as a consequence of orbital forcing. Very rare intercalations of calcilutite laminae may be regarded as the first, very modest input of the carbonate material, which will become more important in the overlying unit.

The identification of the lower to middle part of the zone P12 (=E10 to lower E11) corresponding to the Late Lutetian (BERGGREN *et al.*, 1995) is consistent with the correlation presented above. The identification of the NP16 of MARTINI (1971) provides the same, but slightly wider dating of the Late Lutetian to Early Bartonian (BERGGREN *et al.*, 1995). The lowermost part of this unit, not exposed at the studied locality, may belong to zone P11, as suggested by the identification of this zone immediately above the Foraminiferal Limestones in two sections east and north of Pićan (A and B in Fig. 2) (DROBNE *et al.*, 1979; PAVLOVEC *et al.*, 1991; ŽIVKOVIĆ &

BABIĆ, 2003). Hence, the NP16 reported by DROBNE *et al.* (1979), PAVLOVEC *et al.* (1991), and BENIĆ (1991) from the lowermost 8 m of marls in the section east of Pićan (A in Fig. 2), being younger than the P11 (BERGGREN *et al.*, 1995), probably derived from a slightly higher horizon in the section than the first 8 m of marls.

The middle unit

The features of the marls alternating with carbonate beds are similar to those of the basal marls suggesting their hemipelagic character.

Internal structures, erosional bases, paleotransport directions, and particle types of the calcarenites reflect deposition from turbidity currents flowing towards the NNE, as well as the carbonate source areas to the SSW. A similar origin and derivation may be inferred for the calcirudite bed at 72 m (Fig. 4). These features are consistent with the paleotransport model for the Pazin Basin flysch, which comprises the transversal paleotransport of the carbonate detritus towards the NNE, and contrasting longitudinal paleotransport of mixed, carbonate-siliciclastic detritus (BABIĆ & ZUPANIČ, 1996).

Slumps and slides may reflect the lower slope or base-of-slope settings, the interpretation of which can be extended to the entire middle unit of the studied succession. The features of the carbonate beds involved in slumping reflect their previous deposition on the slope by debris flows and eroding turbidity currents, which may have been channelised. The subequent destabilisation by earthquakes and/or load of overlying deposits caused their downslope movement. The origin of bioclastic dikes in the marls was probably related to one of such mass movement events provoking mobilisation and injection of a previous bioclastic deposit into the marly sediment.

In general, the rather thick package of alternating hemipelagic marls, carbonate detritic beds, and mass wasting products deposited on the slope and base-of-slope may be ragarded as the marginal deposits of the relevant foreland basin reflecting the supply from the foreland area situated to the SSW. By ascribing these sediments to the lower part of the flysch succession, we should also mention that previous workers have already reported on the importance of carbonate beds specifically in the lower part of the flysch succession of the Pazin Basin (STACHE, 1864, 1889; SCHUBERT, 1905; D'AMBROSI, 1931; LIPPARINI, 1935; SALOPEK, 1954; MULDINI-MAMUŽIĆ, 1965).

The planktonic foraminiferal associations of the upper zone P12 (=E11) do not leave doubts concerning the age of these sediments. Namely, the relevant interval corresponds to the uppermost Lutetian and lower Bartonian (BERGGREN *et al.*, 1995), which is actually the age of the lower-middle part of the Pazin Basin flysch succession (e.g. MULDINI-MAMUŽIĆ, 1965; KRAŠENINNIKOV *et al.*, 1968; BENIĆ, 1991). The relevant dating is consistent with the identification of the NP16 (Fig. 4) corresponding to late Lutetian and early Bartonian times (BERGGREN *et al.*, 1995). The correlation and dating presented above are also consistent with the similarity existing between the succession described here and the succession exposed east of Pićan (ŽIVKOVIĆ & BABIĆ, 2003; B in Fig. 2). The similarity consists in the presence of the alternation of marls and carbonate beds of zone P12, which overly the basal marls of the upper P11/lower P12, which in turn follow above the Foraminiferal Limestones in both cases.

The upper unit

The alternation of marls and carbonate beds in the lower part of the unit is similar to the alternation of hemipelagic marls and turbiditic carbonate beds in the middle unit, and its origin is considered similar. The upper part of the unit reflects a change to a sandstone-dominated deposition. Such a change has previously been described from the Pazin Basin flysch, and it occurs within the lower part of the overall flysch succession of this basin (STACHE, 1864, 1889; SCHUBERT, 1905; D'AMBROSI, 1931; LIPPARINI, 1935; SALOPEK, 1954; MAGDALENIĆ, 1972).

Both the P12 and P13 zones have previously been identified in the section north of Pićan (B in Fig. 2; ŽIVKOVIĆ & BABIĆ, 2003). The uppermost P12/P13 (Fig. 4) is consistent with the upper NP16/NP17? and corresponds to the early Bartonian (BERGGREN *et al.*, 1995).

CONCLUSION

The age of the sedimentary succession studied in the SW environs of Pićan, Pazin Basin, corresponds to the lower part of the planktonic foraminiferal zone P12, to the upper part of this zone, and to the uppermost P12/probable P13, i.e. to the planktonic foraminiferal zones E10, E11, and probable E12. In the same time, the studied succession corresponds to the nannoplankton zone NP16, and to the upper zone NP16/NP17? The identified biozones correspond to the Late Lutetian and Early Bartonian.

The lower part of the studied succession overlies the Middle Eocene Foraminiferal Limestones and corresponds to the basal marls known as the Globigerina Marls. It is followed by marls, carbonate turbidites, debrites, and slumps. The carbonate character of detritic sediments in this part of the succession is known from other parts of the Pazin Basin, where they occupy the same position in the overall vertical succession. Finally, the uppermost part of the studied succession reflects the transition from carbonate-dominated to sandstone-dominated lithologies, also known to occur in the lower part of the flysch succession. Hence, the features of the sediments, their origin, and their vertical succession, as well as their ages in the SW environs of Pićan are correlatable to those known from other parts of the Pazin Basin, and, more precisely, to the lower part of the overall Pazin Basin succession.

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SAŽETAK

Srednjoeocenska starost navodnih oligocenskih sedimenata u flišu Pazinskoga bazena (Istra, Vanjski Dinaridi)

Lj. Babić, M. Hernitz Kučenjak, S. Ćorić, & J. Zupanič

U brojnim radovima, kako stranih, tako i domaćih istraživača, starost pazinskoga fliša smatrana je eocenskom i ukupni dokazivani raspon obuhvaćao je srednji-gornji lutecij, bartonij i najdonji priabonij. Nedavni prikaz istraživanja starosti jednoga dijela tih sedimenata u južnom dijelu bazena uvrštava ih u gornji oligocen. Ovo uvrštavanje može imati veliki utjecaj na razumijevanje stratigrafije i razvitka Istre i Dinarida. Zbog toga, ali i zbog položaja, karaktera i slijeda odgovarajućih sedimenata, za koje smo prethodnim radom smatrali da odgovaraju donjem dijelu pazinskog fliša, bilo je potrebno provjeriti novo oligocensko datiranje. To je učinjeno pomoću usporedbe položaja, karaktera i vertikalnog slijeda sedimenata s drugim predjelima bazena, te pomoću biostratigrafije na temelju planktonskih foraminifera i nanoplanktona. Pokazalo se da se radi o donjem dijelu ukupnog slijeda Pazinskoga bazena. Analiza planktonskih foraminifera pokazala je donji dio zone P12, gornji dio zone P12, te vjerojatno zonu P13. Analiza nanoplanktona pokazala je zonu NP16, gornji dio zone NP16, odnosno donji dio zone NP17. Ove biozone odgovaraju gornjem luteciju i donjem bartoniju.

Plate 1

SEM photomicrographs of planktonic foraminifera. Location and vertical position of samples are shown in Figs. 3 and 4, respectively.

1. *Morozovelloides crassatus* (CUSHMAN), Sample 1
2. *Turborotalia frontosa* (SUBBOTINA), Sample 1
3. *Turborotalia frontosa* (SUBBOTINA), Sample 1
4. *Hantkenina* sp., Sample 2
5. *Turborotalia possagnoensis* (TOUMARKINE & BOLLI), Sample 1
6. *Turborotalia possagnoensis* (TOUMARKINE & BOLLI), Sample 1
7. *Globigerinatheka index* (FINLAY), Sample 2
8. *Globigerinatheka* sp., Sample 6
9. *Acarinina collactea* (FINLAY), Sample 4
10. *Acarinina praetopilensis* (BLOW), Sample 3
11. *Hantkenina dumblei* WEINZIERL & APPLIN, Sample 4
12. *Hantkenina compressa* PARR, Sample 4

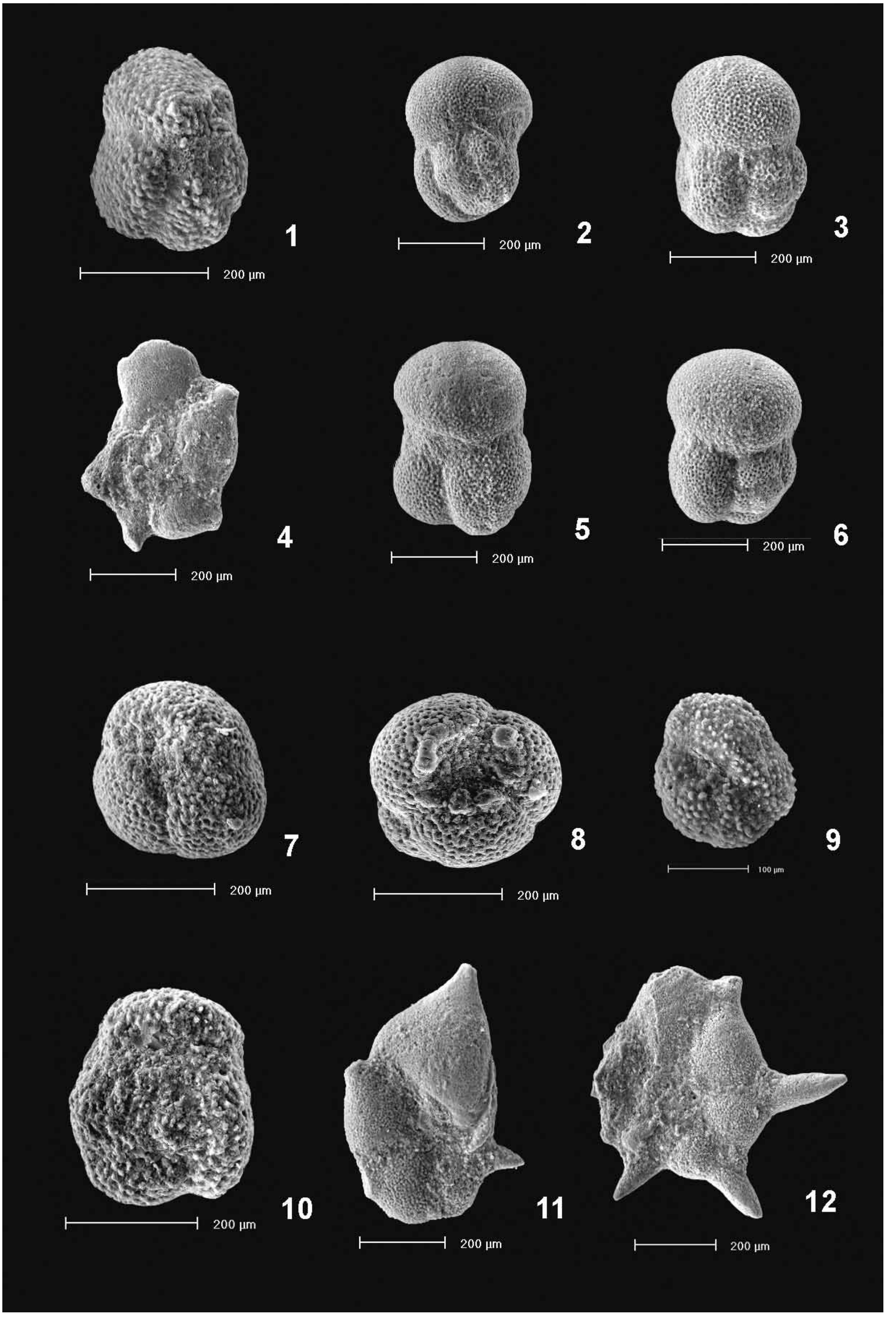
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Plate 2

SEM photomicrographs of planktonic foraminifera. Location and vertical position of samples are shown in Figs. 3 and 4, respectively.

1. *Turborotalia pomeroli* (TOUMARKINE & BOLLI), Sample 6
2. *Globigerinatheka subconglobata* (SHUTSKAYA), Sample 6
3. *Globigerinatheka mexicana* (CUSHMAN), Sample 6
4. *Turborotalia altispiroides* BERMUDEZ, Sample 6
5. *Turborotalia altispiroides* BERMUDEZ, Sample 3
6. *Subbotina jacksonensis* (BANDY), Sample 3
7. *Globigerinatheka euganea* PROTO DECIMA & BOLLI – *Orbulinoides beckmanni* (SAITO) – transitional form, Sample 5
8. *Turborotalia cerroazulensis* (COLE), Sample 5
9. *Subbotina linaperta* (FINLAY), Sample 5
10. *Globigerinatheka euganea* PROTO DECIMA & BOLLI, Sample 5
11. *Subbotina eocaena* (GUEMBEL), Sample 5
12. *Acarinina praetopilensis* (BLOW), Sample 5

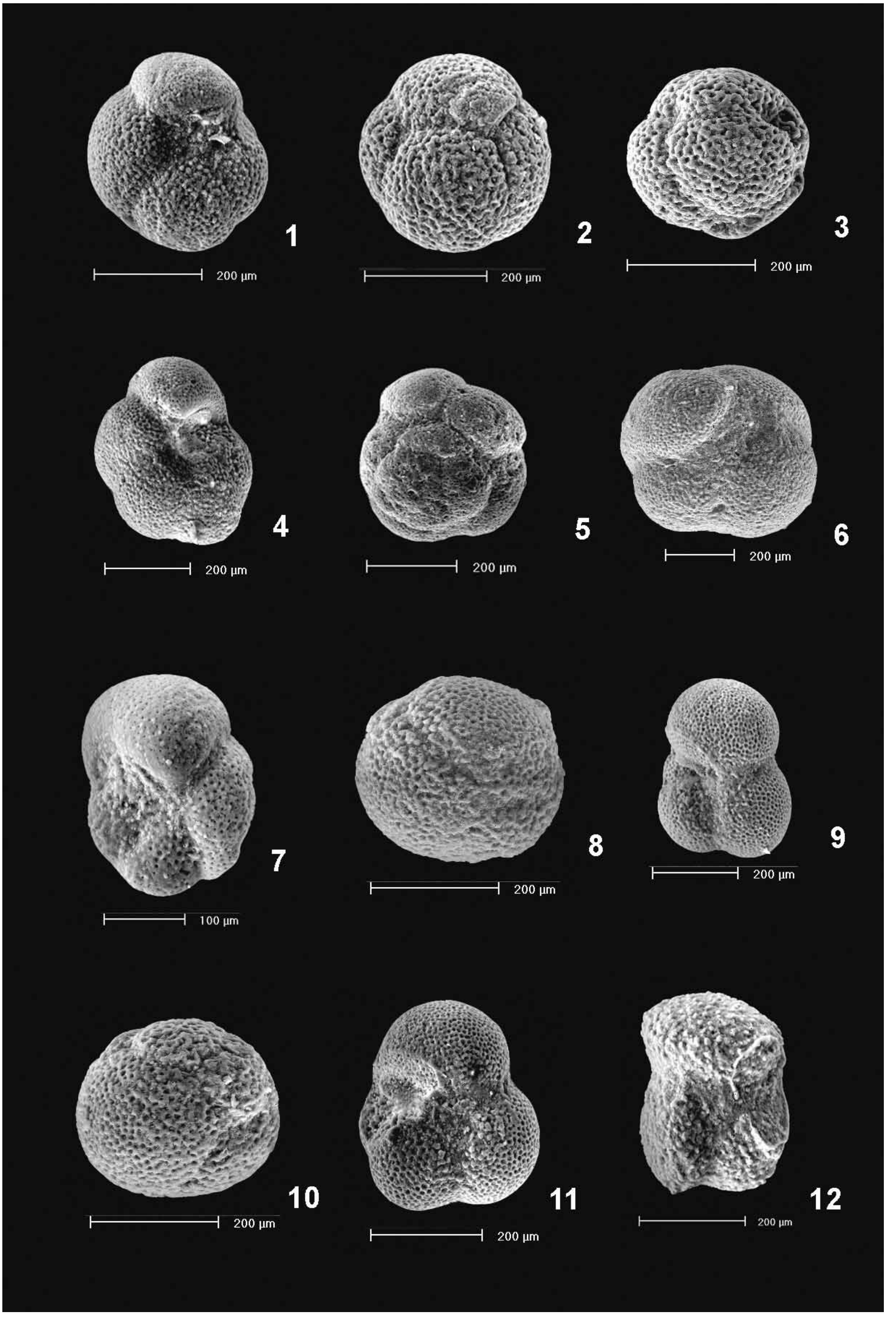
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Plate 3

Light micrographs of calcareous nannoplankton. Location and vertical position of samples are shown in Figs. 3 and 4, respectively.

1. *Pontosphaera exilis* (BRAMLETTE & SULLIVAN, 1961) ROMEIN, 1979, Sample 5.
2. *Pontosphaera obliquipons* (DEFLANDRE, 1954) ROMEIN, 1979, Sample 6.
3. *Calcidiscus*? cf. *C. henrikseniae* BOWN, 2005, Sample 5.
4, 12, 16. *Helicosphaera reticulata* BRAMLETTE & WILCOXON, 1967, Sample 5.
5. *Pontosphaera ocellata* (BRAMLETTE & SULLIVAN, 1961) PERCH-NIELSEN, 1984, Sample 5.
6, 8, 10. *Helicosphaera compacta* BRAMLETTE & WILCOXON, 1967, Sample 5.
7. *Lanternithus minutus* STRADNER, 1962, Sample 2.
9, 13, 15. *Helicosphaera bramlettei* MÜLLER, 1970, Sample 5.
11 *Zygrhablithus bijugatus* (DEFLANDRE, 1954) DEFLANDRE, 1959, Sample 2.
14. *Helicosphaera seminulum* BRAMLETTE & SULLIVAN, 1961, Sample 5.
17. *Discoaster nodifer* (BRAMLETTE & RIEDEL, 1954) BUKRY, 1973, Sample 2.
18, 19. *Discoaster saipanensis* (BRAMLETTE & RIEDEL, 1954), Sample 5.
20. *Discoaster deflandrei* BRAMLETTE & RIEDEL, 1954, Sample 5.
21. *Discoaster tanii* BRAMLETTE & RIEDEL, 1954, Sample 5.
22. *Discoaster barbadiensis* TAN, 1927, Sample 5.

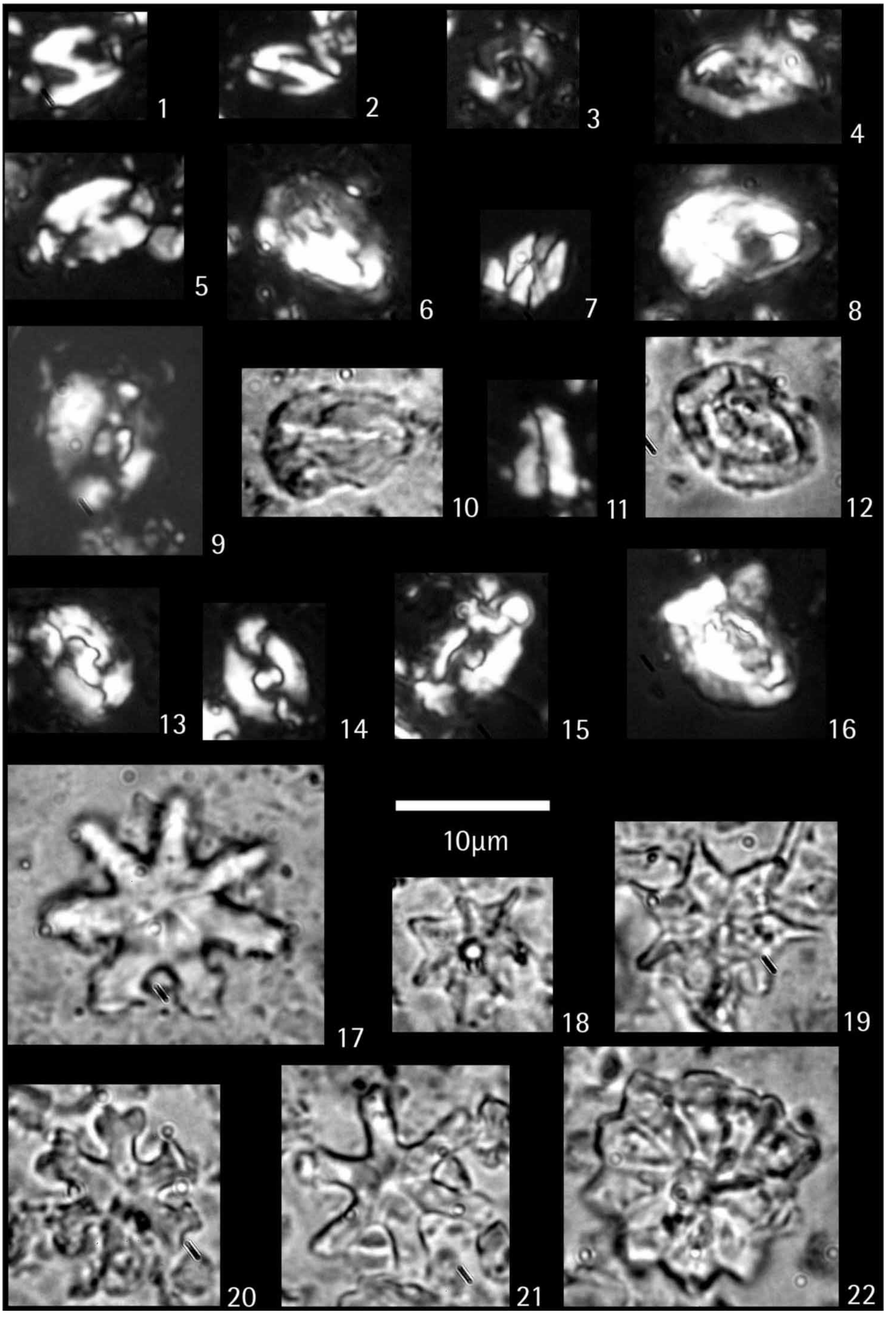
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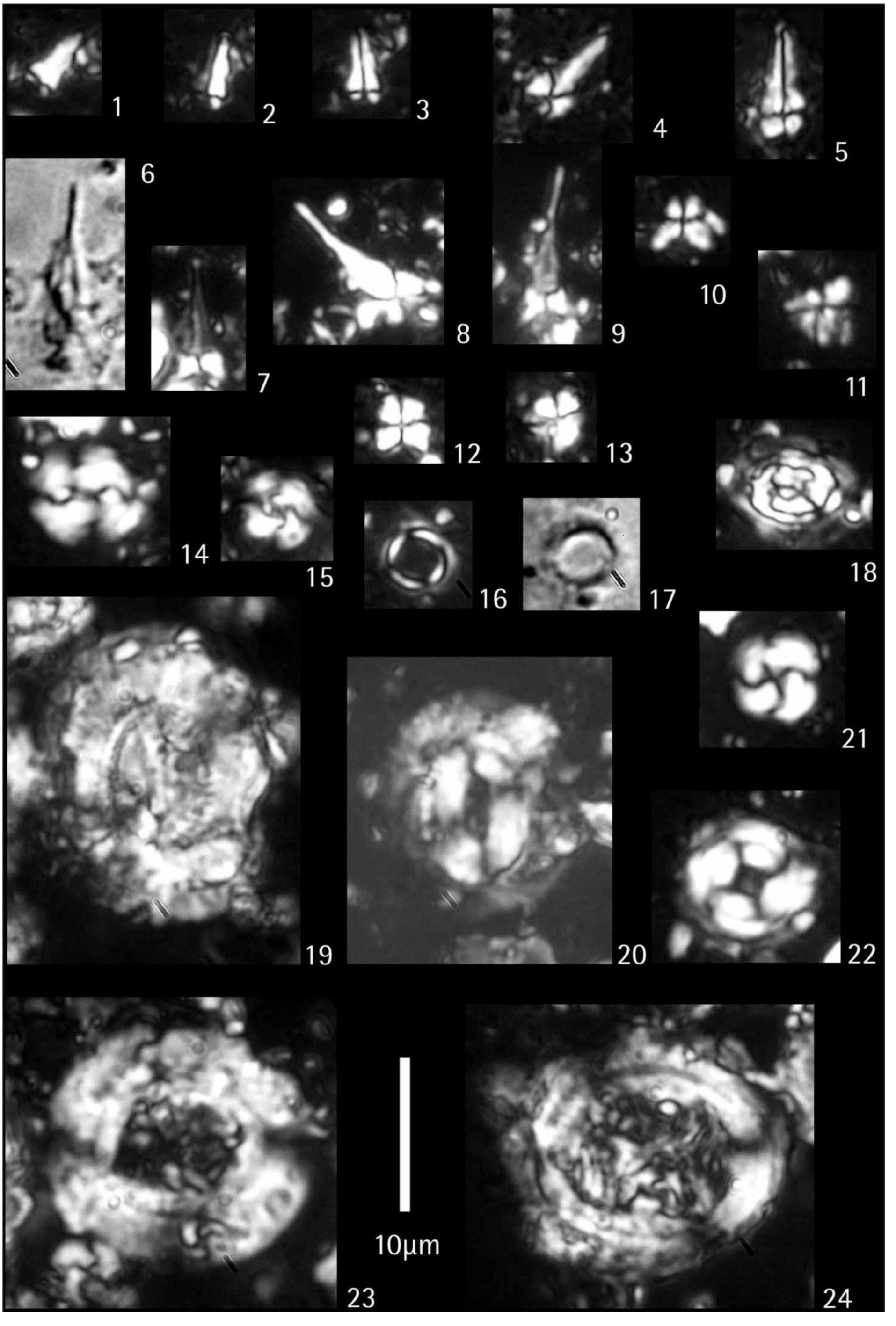
Plate 4

Light micrographs of calcareous nannoplankton. Location and vertical position of samples are shown in Figs. 3 and 4, respectively.

1.–3. *Sphenolithus predistentus* BRAMLETTE & WILCOXON, 1967, Sample 5.
4, 5. *Sphenolithus radians* DEFLANDRE 1952, Sample 2.
6.–9. *Sphenolithus runus* BOWN & DUNKLEY JONES, 2006, Sample 2.
10, 11. *Sphenolithus spiniger* BUKRY, 1971, Sample 5.
12, 13. *Sphenolithus moriformis* (BRÖNNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967, Sample 5.
14. *Reticulofenestra bisecta* (HAY, 1966) ROTH, 1970, Sample 5.
15. *Cyclicargolithus floridanus* (ROTH & HAY, 1967) BUKRY, 1971, Sample 5.
16, 17. *Coronocyclus bramlettei* (HAY & TOWE, 1962) BOWN, 2005, Sample 5.
18. *Clausicoccus vanheckiae* (PERCH-NIELSEN, 1986) de KAENEL & VILLA, 1996, Sample 5.
19. *Coccolithus eopelagicus* (BRAMLETTE & RIEDEL, 1954) BRAMLETTE & SULLIVAN, 1961, Sample 2.
20. *Coccolithus miopelagicus* BUKRY, 1971, Sample 2.
21. *Cribrocentrum reticulatum* (GARTNER & SMITH, 1967) PERCH-NIELSEN, 1973, Sample 5.
22. *Coccolithus formosus* (KAMPTNER, 1963) WISE, 1973, Sample 5.
23. *Reticulofenestra umbilica* (LEVIN, 1965) MARTINI & RITZKOWSKI, 1968, Sample 2.
24. *Chiasmolithus grandis* (BRAMLETTE & RIEDEL, 1964) RADOMSKI, 1968, Sample 2.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