Planktonic foraminiferal biostratigraphy and lithology of the Upper Cretaceous (upper Campanian-Maastrichtian) and Palaeogene succession of the Palmyrides (Syria)

Vlasta Premec Fućek[1,*], Morana Hernitz Kučenjak[2] and Gabrijela Pecimotika[2]

[1] Krvarić 36/1, 10 090 Zagreb; (*corresponding author: vlasta.pfucek@gmail.com)
[2] INA - Industrija nafte d.d., Lovinčićeva 4, 10 000 Zagreb, Croatia

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Abstract

An upper Campanian to upper Oligocene stratigraphic succession has been examined from six deep exploration wells in the Palmyrides area of Syria. Most of the sedimentary succession contains rich and well to moderately preserved planktonic foraminiferal assemblages that enable successful age determination. The upper Campanian and Maastrichtian planktonic fauna is highly diverse with domination of warm water taxa such as *Globotruncana aegyptiaca, Gansserina gansseri, Globotruncanella havanensis, Globotruncanita angulata* and *Pseudotextularia elegans*. The most dramatic turnover occurred across the Cretaceous/Palaeocene boundary when most planktonic foraminiferal species became extinct. The oldest Palaeocene planktonic foraminiferal assemblage, rich in the number of specimens, but not very diverse, includes the following species: *Eoglobigerina eobulloides, Globanomalina archeocompressa, Chiloguembelina morsei, Woodringina claytonensis* and *Parasubbotina pseudobulloides*. The late Palaeocene is marked by origination of the morozovellids, acarininids and globanomalinids, while the early Eocene is characterized by a tropical assemblage, dominated by muricate species, and by intensive speciation of *Acarinina* and *Subbotina* in the latest part. Most of these species continue into the middle Eocene and become a significant component of the planktonic community. The middle Eocene is characterized by intensive speciation and domination of warm water genera such as *Acarinina*, *Morozovelloides*, and to a lesser degree *Turborotalia*, *Globigerinatheka* and *Hantkenina*. The middle/late Eocene boundary is marked by double extinction of the last muricate taxa *Acarinina mcgowrani* and *Morozovelloides crasssatus*, which indicate a variable climate, water column instability, and loss of surface habitats. In contrast, *Turborotalia* and *Globigerinateheka* become more important in the late Eocene. The Eocene/Oligocene boundary is marked by the extinction of most warm water taxa including *Turborotalia cerroazulensis* group, *Hantkenina*, *Globigerinatheka* and some subbotinids. The beginning of the early Oligocene is indicated by the domination of cool water taxa such as *Dentoglobigerina*, *Globorotaloides*, *Tenuitella* and *Chiloguembelina*. Speciation of the spinose surface dweller *Ciperoella ciperoensis* group reflects warming in the late Oligocene. The combined observations of lithology with the diversity and composition of planktonic foraminifera assemblages indicate that the Palmyrides area in Syria was a Tethyan bioprovince with a tropical to subtropical climate from the late Campanian to the end of the Eocene with deposition in deep sea environments (upper bathyal to outer shelf). In contrast, Oligocene deposits and their microfossil content suggest temperate to warm climate conditions and sedimentation in middle to inner shelf environments.

1. INTRODUCTION

Upper Cretaceous and Palaeogene deposits drilled in six deep exploration wells in the Palmyrides, Syria comprise an approximately 1300 metre thick succession of marine strata. These deposits are predominantly composed of hemipelagic argillaceous limestones and marls (upper Cretaceous), deep water clayey limestones and marls (Palaeocene and Eocene), and sandstone, bioclastic limestone and marls (Oligocene). Their moderately to well preserved planktonic foraminiferal assemblages enable biostratigraphic determination. Calcitic planktonic foraminiferal tests provide a valuable record of their natural habitats in ancient seas and oceans, and geochemical analyses allow determination of their ecological niche position within the water column (SCHACKLETON et al., 1985; PEARSON et al., 1993; PEARSON et al., 2001; EDGAR et al., 2010; BIRCH et al., 2012). Morphological characteristics of the tests (shape and size, wall texture, etc.) are usually developed as a response to the biotic and abiotic requirements of

their natural habitats. These characteristics allow differentiation of four main upper ocean (i.e., photic zone) habitats: surface/subsurface, mixed-layers, thermocline and subthermocline. This study documents the composition, changes and frequency of the main planktonic foraminiferal groups during the geological time period spanning the late Campanian to the end of the Oligocene.

Here, the lithological characteristics and depositional environments of the upper Cretaceous to Palaeogene strata were determined, together with their correlation within the investigated Palmyrides area of Syria. Previous biostratigraphic investigations of the Upper Cretaceous and Palaeogene deposits from deep exploration wells in the Palmyride area were conducted by LUČIĆ (2001), STANKOVIĆ et al. (2003; 2005), DACER et al. (2007), HERNITZ KUČENJAK et al. (2005, 2006), HERNITZ KUČENJAK (2008) and PECIMOTIKA et al. (2014). Important biostratigraphic work on the Palaeogene deposits in Syria has been undertaken by KRASHENINNIKOV et al. (1996).

2. MATERIAL AND METHODS

The biostratigraphic, lithological and palaeoecological results were obtained from drill cuttings collected from six exploration wells (numbered J-1 to J-6), and from two cored intervals in the J-3 well (842.5–852 m and 1604–1613 m). Samples were collected every 10 to 20 m and a total of 453 samples were processed and analysed.

Sample preparation methods for micropalaeontological analyses varied according to the degree of lithification. Loose rock samples were prepared by a standard washing procedure that included soaking in water with a small amount of 10–15% hydrogen peroxide (H_2O_2), and washing after 24 hours under running water through 63 µm, 125 µm, 160 µm, 250 µm, 315 µm, and 630 µm sieves. These fractions were dried, and foraminifera were picked onto micropalaeontological slides. Standard micropalaeontological analyses were performed by a stereomicroscope. Scanning electron microscope (SEM) was used for a detailed study of planktonic foraminiferal morphology (e.g., wall texture, ornamentation). Petrographic thin-sections were also made from lithified rock samples.

Biostratigraphic interpretations were based on BERGGREN & PEARSON (2005), and WADE et al. (2011) for the Palaeogene, and on ROBASZYNSKI et al. (1984), CARON (1985), ROBASZYNSKI & CARON (1995), PREMOLI SILVA & SLITER (1995, 1999) and PREMOLI SILVA & VERGA (2004) for the upper Cretaceous. Determination of Palaeogene planktonic foraminiferal genera and species was based on SPEZZAFERRI (1994), OLSSON et al. (1999), IACCARINO et al. (2005), PREMOLI SILVA & PETRIZZIO (2006), PEARSON et al. (2006) and WADE et al. (2018). The micropalaeontological investigation of the Campanian and Maastrichtian planktonic foraminiferal genera and species was focused on the vertical distribution, diversity and composition of mainly planktonic and less abundant benthic foraminiferal assemblages according to GAWOR-BIEDOWA (1984), LOEBLICH & TAPPAN (1988), ISMAIL (1992), BOLLI et al. (1994), LY & KUHNT (1994), KAIHO (1998), PREMOLI SILVA & VERGA (2004), ISMAIL et al. (2007), and GASIŃSKI & UCHMAN (2009), SARI (2006, 2009), PETRIZZO et al. (2011) and PÉREZ-RODRÍGUEZ et al. (2012). Genera and species of benthic foraminifera were also determined and counted for the calculation of plankton/benthos ratios (VAN DER ZWAAN et al., 1990; MURRAY, 1991).

Petrographic and sedimentological analyses focused on thin-sections of rock samples taken every 10 to 20 m. The lithological column for each well is shown in Figure 2. Carbonate rocks were classified according to FLÜGEL (2010) and other rock types were classified using schemes published in PETTIJOHN (1975). Palaeoenvironmental interpretations were based upon the lithological and sedimentological analyses as well as the determined microfossil assemblages.

3. GEOLOGICAL SETTING

Syria is located within the Arabian plate (Fig. 1), and almost completely surrounded by active plate boundaries. Syria's western boundary is marked by the Dead Sea fault system, which separates the Arabian plate from the Levantine subplate. To the north is the Bitlis edge that represents the collision boundary between the Arabian and Eurasian plates. The Zagros fault system is situated to the east and southeast and it marks the collision boundary between the Arabian plate and Iran (BREW, 2001; BREW et al., 2001).

Tectonically, Syria can be divided into four major domains: 1) the Palmyride fold and thrust belt; 2) the Abd el Aziz – Sinjar uplift; 3) the Euphrates Graben or Depression; and 4) the Dead Sea Fault System (LITAK et al., 1998; BREW, 2001; BREW et al., 2001). The studied wells are located within the Hayan exploration block (Fig. 1), which is part of the Palmyride area in the
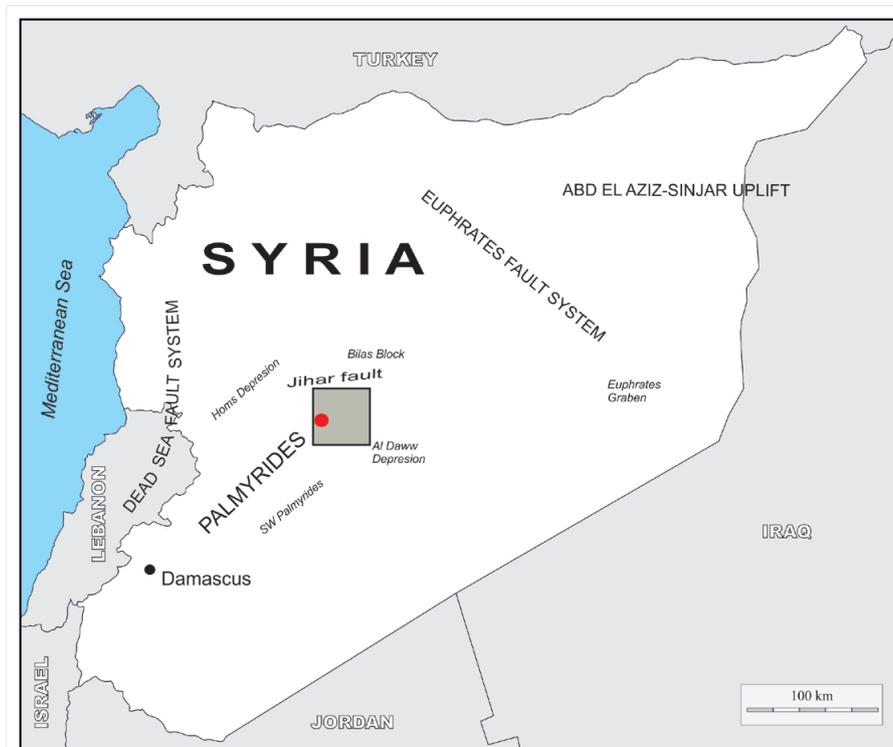
Figure 1. Map of Syria showing the main tectonic zones (modified from BREW, 2001). Dark gray square indicates the location of the Hayan exploration block in NE Palmyrides, limited by the Jihar fault and Bilas Block to the North, by the Al Daww Depression to the SE, the SW Palmyrides to the south, and by the Homs Depression to the NW. The red point signifies the location of the J–1 to J–6 wells.

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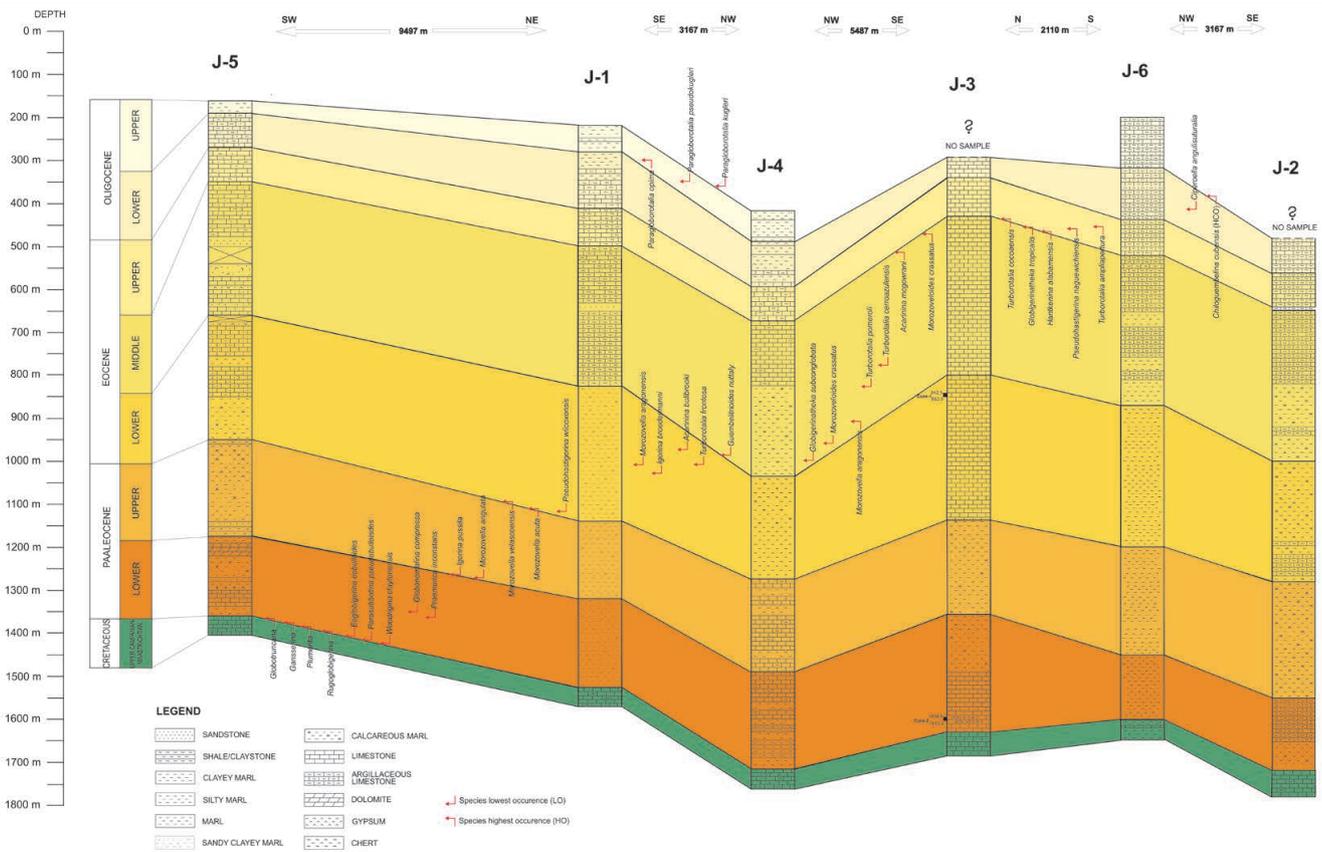
Figure 2. A schematic stratigraphic profile of the J-1 to J-6 wells. Cored intervals belong to J-3 well, core-1 (842.5–852.0 m), middle Eocene; core-2 (1604–1613 m), upper Palaeocene. Samples of the rock material from drill cuttings were taken every 10 to 20 metres. The Lowest (LO) and the Highest occurrences (HO) of the selected planktonic foraminiferal species are marked.

central part of Syria. The Palmyrides are the most extensive and topographically prominent tectonic zone in Syria. This area represents a 400 km long and 100 km wide intracontinental fold and thrust belt, extending from the Dead Sea Fault Zone in the west to the Euphrates fault system in the east (LUČIĆ & FORŠEK, 2000; BREW, 2001). It is formed in between the two relatively undeformed tectonic blocks known as the Allepo Plateau to the north and the Ruthbah uplift to the south.

Based on topography and structure, the Palmyrides are commonly subdivided into the SW or Frontal Palmyrides and the NE or Central Palmyrides separated by the Jihar fault (BREW, 2001). The southwestern Palmyrides are represented by a fold and thrust belt, whereas the northeastern Palmyrides include the Bilas and Bishri blocks. The low-relief Al Daww Depression, which is a 100 km long and 20 km wide inter-montaine basin, lies between the Jihar fault and the short-wavelength folds of the southern Palmyrides (LUČIĆ & FORŠEK, 2000; BREW, 2001; LUČIĆ et al., 2002; TOMLJENOVIĆ et al., 2008). The Hayan block is situated partly in the Al Daww depression and extends towards the Bilas block. Geophysical anomalies, identified both beneath and around the Palmyrides, indicate that during the Palaeozoic, Mesozoic and part of the Cenozoic this area was a tectonically unstable depocentre with 11 km thick deposits (MOUTY & AL-MALEH, 1983; CHAIMOV et al., 1992; BREW et al., 2001; KRIŽ et al., 2005; TOMLJENOVIĆ et al., 2008).

4. LITHOLOGY

This investigation follows the lithostratigraphic distribution proposed by BREW (2001). The examined succession spans the

Campanian to Oligocene time interval and is represented by four lithostratigraphic units – the Shiranish Formation (upper Campanian–Maastrichtian), Kermav Formation (Palaeocene), Jaddala Formation (Eocene) and Chilou Formation (Oligocene).

4.1. Shiranish Formation (Upper Campanian–Maastrictian)

The Shiranish Formation (Fig. 2) is characterized by argillaceous limestones, marls, chert and sporadic disc shaped or ovoid calcareous concretions (approx. 10–30 cm in diameter). Argillaceous limestone (mudstone/wackestone) and marls are composed of a clayey–microcrystalline calcitic matrix with abundant pelagic fauna. The abundance of planktonic foraminifera and the large amount of clayey detritus (sourced from the hinterland) evidently indicate an open-sea influence. Accordingly, these sediments were deposited in upper bathyal to outer shelf environments.

4.2. Kermav Formation (Palaeocene)

The Palaeocene deposits (Fig. 2) are composed of clayey limestones and marls with pelagic fauna. Clayey limestones and marls are generally grey in colour and may occasionally be yellowish or greenish, or locally dark grey. They are composed of micrite with variable amounts of clay and planktonic foraminifera. The lowermost Palaeocene deposits consist of fossiliferous marl with phosphate grains, yellow or light brown in colour, present in the cored interval of the J-3 well (core-2, 1604–1613 m). The only lithological differences relative to the underlying Cretaceous deposits (Shiranish Formation) are the greater amount of clayey components and the different microfossil assemblage. The lithological charac-

teristics of these deposits, as well as their microfossil association dominated by planktonic species (over 95%) indicate deposition in deep sea environments (outer shelf to upper bathyal).

4.3. Jaddala Formation (Eocene)

The upper Eocene deposits (Fig. 2) are composed of two different facies. The lower facies is represented by chalky marl, which is in places very rich in glauconite, while the upper part is generally calcareous. The amount of glauconite locally increases high enough to form a horizon of glauconitic sands and glauconitic marl.

The lower and middle Eocene deposits are generally represented by limestones, calcitic marls and clayey limestones with a chalky appearance. Chert is present in the lower part of these deposits as lenses, nodules and tabular beds. Clayey limestones/ chalky limestones are light grey to brownish-white mudstone/ wackestone types with a variable amount of clayey components. Planktonic and rare small benthic foraminifera are irregularly distributed within their micritic matrix. These limestones locally contain fine dispersed rounded to subrounded glauconite grains. Marls are grey to brownish grey in colour and in places slightly silty with planktonic foraminifera. Cherts are composed of very fine granular quartz with patches of chalcedony, which mostly have circular sections and resulted from infilling of the chambers of planktonic foraminifera or sponge spicules. In places, the siliceous matrix contains thin inclusions of micrite and microsparite in the shape of isolated crystals or fine aggregation of crystals with irregular edges marking the silicification front. Glauconite grains are well-sorted with rounded to sub-rounded edges, mostly fine to medium sand-sized particles, and some have microscopic fissures. Most of the glauconite grains have a homogenous and finely crystalline texture. Surrounding the glauconite grains is a mainly micritic or clayey micritic matrix with some ferruginous oxide spots. Lithological characteristics of these deposits, as well as their microfossil association with the domination of planktonic species indicate deposition in deeper sea environments (outer shelf to deep marine).

4.4. Chilou Formation (Oligocene)

The Oligocene deposits (Fig. 2) are represented by sandstone and conglomeratic sandstone with intercalations of sandy limestones or bioclastic limestones, which are yellow in colour, rich in large foraminifera, and alternating with marl and/or bioturbated limestone. Sandstones are grey to brownish red, fine- medium grained quartz arenite with subangular quartz grains in haematite and ferrous dolomite and, sporadically, calcite cement. Conglomeratic sandstones are composed of subrounded quartz grains in dolomite (mostly ferrous) cement. Limestones are light grey to yellowish in colour, mainly represented by homogenous or horizontally bioturbated mudstone/wackestone and rare sandy packestone, sporadically with fossil grains of mainly benthonic foraminifera and rare planktonic foraminifera or echinoids. In places, bioturbated limestones contain mud-balls, reaching 20–30 cm in diameter. Planktonic foraminifera are commonly pyritized. All types of limestones commonly contain nodules of different forms of chert as well as some detrital quartz arenite grains. Marls are yellowish, light grey to dark grey in colour, partly silty or sandy, and commonly contain pyrite. Moderately diverse microfossil associations of both planktonic and benthic foraminiferal species suggest temperate climate conditions. Plankton/benthos ratio and lithofacies characteristics indicate sedimentation in middle to inner shelf environments.

5. BIOSTRATIGRAPHY

This micropalaeontological study covers a time period of over 50 million years (BERGGREN et al., 1995; COHEN et al., 2013; WADE et al., 2011) with a sedimentary succession over 1300 m thick s (Fig. 2). Planktonic foraminiferal assemblages had changed during that time in the number of species, number of individuals, and test preservation. The micropalaeontological investigation of upper Cretaceous and Palaeogene microfauna was focused on the vertical distribution, diversity, and composition of mainly planktonic and less abundant benthic foraminiferal assemblages. Genera and species of benthic foraminifera were also determined and counted for the calculation of plankton/benthos ratios after VAN DER ZWAAN et al., 1990; MURRAY, 1991. The boundary between Palaeogene stratigraphic units was based on BERGGREN & PEARSON (2005) and WADE et al. (2011).

5.1. Late Campanian–Maastrichtian

Identification of late Cretaceous specimens is based on microscopic observations of thin-sections. Studied material contains well preserved and diverse associations of foraminifera, especially in the J-5 and J-6 wells (Fig. 2). These include highly diverse globotruncanids, rugoglobigerinids, globigerinelloids and heterohelicid planktonic foraminifera with rare small calcareous benthic foraminifera, and some inoceramids and echinoids.

This assemblage is composed of the following representatives: *Contusotruncana contusa*, *Racemiguembelina fructicosa*, *Pseudotextularia elegans*, *Globotruncanita conica*, *Gansserina gansseri* (Pl. 1, Fig. 1), *Plummerita hantkeninoides*, *Globotruncanella pschadae*, *Globotruncanita angulata*, *Globotruncanita conica* (Pl. 1, Fig. 2), *Rugoglobigerina macrocephala*, *Globotruncana aegyptiaca* (Pl. 1, Fig. 3), *Globotruncana arca* (Pl. 1, Fig. 4), *Globotruncana ventricosa* (Pl. 1, Fig. 5), *Globotruncanella havanensis* (Pl. 1, Fig. 6), *Globotruncanita stuarti* and *Goglobigerinelloides alvarezi*. According to HARDENBOL et al. (1998), the age of this unit is late Campanian to Maastrichtian.

This assemblage also contains the following species with a wider stratigraphic range: *Muricohedbergella monmouthensis*, *Globotruncana insignis*, *Globotruncana rosetta*, *Rugoglobigerina rugosa* (Pl. 1, Fig. 7), *Globotruncana bulloides* (Pl. 1, Fig. 8), *Macroglobigerinelloides prairiehillensis* (Pl.1, Fig 9), *Macroglobigerinelloides bolli* (Pl. 1, Fig. 10), *Muricohedbergella holmdelensis* (Pl. 1, Fig. 11), *Muricohedbergella monmouthensis* (Pl. 1, Fig. 12), *Heterohelix globulosa* (Pl. 1, Fig. 13), *Heterohelix striata*, *Archaeoglobigerina blowi* (Pl. 1, Fig. 14), *Contusotruncana fornicata*, *Globigerinelloides bollii* and *Pseudotextularia elegans* (Pl. 1, Fig. 15) and *Planoglobulina* sp. The assemblage of small benthic foraminifera includes *Oridorsalis umbonatus*, *Cibicidoides sp.*, *Bolivinoides sp.*, *Pullenia* sp., *Tritaxia* sp. and *Gavelinella* sp.

Such a planktonic foraminiferal assemblage with diverse keeled taxa is characteristic for the Tethyan warm water bioprovince. The high percentage (90–95%) of planktonic taxa within the microfaunal assemblage suggests an upper to middle bathyal depth for this interval (BOERSMA, 1988; MURRAY, 1991; GRÄFE, 2005). The high diversity of planktonic foraminifera abruptly decreases in the uppermost part of this unit in all six wells.

5.2. Early Palaeocene

The Cretaceous/Palaeocene boundary is marked by the extinction of most of the Cretaceous planktonic foraminifera (OLSSON et al., 1999; WADE et al., 2011). The lower Palaeocene deposits,

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composed of clayey limestones and dark gray marls, contain rare, recrystallized specimens of planktonic foraminifera. Therefore, in all the investigated wells the lowermost Palaeocene is an almost sterile interval. There are only two exceptions with well preserved microfauna. Samples collected in 1700–1710 m interval in the J-2 well contains the oldest Palaeocene planktonic foraminiferal association, rich in the number of specimens, but not very diverse. An almost identical planktonic community is determined from the cored interval (1604–1613 m) in the J-3 well, where fossiliferous marls contain abundant planktonic foraminifera characteristic most probably of the lowermost Palaeocene Zones P0–Pα after OLSSON et al. (1999) and WADE et al. (2011). This association contains the following taxa: *Eoglobigerina eobulloides* (Pl. 2, Fig. 1)*, E. edita, Parasubbotina pseudobulloides* (Pl. 2, Fig. 2)*, Woodringerina claytonensis* (Pl. 2, Fig. 3)*, Chiloguembelina morsei, Globanomalina archeocompressa* and *Subbotina trivialis*. In addition, sample 1540–1545 m in J-3 well contain also *Subbotina triloculinoides* (Pl. 2, Figs. 4 and 5) and *Chiloguembelina morsei* (Pl. 2, Fig. 6).

In the middle and upper part of the lower Palaeocene interval, a more diverse planktonic foraminiferal assemblage has been determined: *Globanomalina compressa, Praemurica pseudoinconstans, Praemurica inconstans, Subbotina triloculinoides* and *S. triangularis*. Some of the recognized species, such as *Globanomalina imitata, G. ehrenbergi, Morozovella praeangulata, Parasubbotina pseudobulloides* and *Chiloguembelina midwayensis* first appeared in the early Palaeocene and continue into the late Palaeocene. The species *Morozovella praeangulata* (Pl. 2, Fig. 7) is the first representative of an important Palaeocene genus that had its lowest occurrence (LO) in the uppermost part of this interval. Biserial genus *Chiloguembelina* is present in the entire interval and the genera *Praemurica* and *Globanomalina* are common in the upper part of this interval. Based on the planktonic foraminiferal assemblage, this interval approximately corresponds to the early Palaeocene Zones P1 to P2 after WADE et all. (2011). Although planktonic foraminifera dominate in the assemblage (90%), some smaller benthic genera are also present: *Neoeponides, Pullenia, Tritaxia, Dorothia* and *Stilostomella*.

5.3. Late Palaeocene

The upper Palaeocene deposits, present in all investigated wells, contain rich, highly diverse and moderately to very well preserved planktonic foraminiferal assemblages. The boundary between the lower and upper Palaeocene is defined by the lowest occurrence (LO) of *Igorina pusilla* and *Morozovella angulata* (OLSSON et al., 1999). Species which continue from the early Palaeocene and became extinct in the late Palaeocene include *Subbotina triangularis, Subbotina triloculinoides, Morozovella praeangulata, Parasubbotina pseudobulloides* and *Praemurica inconstans*. The main characteristic of the upper Palaeocene planktonic assemblage is the domination of warm water species with complex test morphology (ornamented taxa), including *Morozovella acuta, M. velascoensis, M. angulata* (Pl. 2, Fig. 8 and 9)*, M. praeangulata, Acarinina mckannai, Igorina pusilla* (Pl. 2, Fig. 10), *I. tadjikistanensis* and *I. albeari*. However, species with a thin and smooth wall texture such as *Globanomalina chapmani* and *Globanomalina pseudomenardii* are present with a few specimens each. *Subbotina cancellata* (Pl. 2, Fig. 11), *Subbotina* cf. *triangularis* (Pl. 2, Fig. 12) and *S. triloculinoides* are common. Furthermore, species that have their first appearance in this interval and cross the Palaeocene/Eocene boundary include *Morozovella aequa, M. subbotinae, Subbotina velascoensis, Acarin-*

ina coalingensis (Pl. 2, Fig. 13), *A. soldadoensis* (Pl. 2, Fig. 14) and *Acarinina* sp. (Pl. 2, Fig. 15). Microperforate biserial species are represented by *Chiloguembelina midwayensis, C. wilcoxensis, C. crinita* and *Zeauvigerina waiparaensis*. The rich and highly diversified assemblage indicates the biostratigraphic interval from Zone P3 to Zone P5 after WADE et al. (2011).

Benthic foraminifera appear with a small number of individuals per sample. The plankton/benthos ratio is approximately 90:10, indicating deep and open marine depositional environments.

5.4. Early Eocene

The Palaeocene/Eocene boundary is marked by the Lowest occurrence (LO) of *Acarinina sibaiyaensis* (BERGGREN and PEARSON, 2005; WADE et al., 2011).

The material studied contains rich and well preserved planktonic foraminiferal assemblages. *Pseudohastigerina wilcoxensis* has its first appearance in the lowermost part of the Lower Eocene and indicates the beginning of Zone E1. The lower part of the interval which most probably corresponds to Zones E1 to E3, is dominated by tropical warm water taxa such as *Acarinina, Morozovella* and *Igorina*. Many of the species recognized in this interval, which appeared in the late Palaeocene, continued into the early Eocene such as *Morozovella subbotinae* (Pl. 3, Fig. 1), *Morozovellaa aequa* (Pl. 3, Fig. 2), *Morozovella acuta, Acarinina coalingensis, Acarinina soldadoensis, Subbotina velascoensis, Globanomalina planoconica* (Pl. 3, Fig. 4) and *Chiloguembelina wilcoxensis*.

Species that first occurred in the middle part of the early Eocene (approximately correspond to the E4 to E6 Zones, Wade et al., 2011), and continued into the middle Eocene are; *Morozovella aragonensis, Morozovella crater, Acarinina primitiva, Acarinina pentacamerata* (Pl. 3, Fig. 3), *Igorina broedermani* (Pl. 3, Fig. 5), and *Acarinina cuneicamerata* (Pl. 3, Fig. 6). In addition, *Morozovella formosa, Acarinina pseudotopilensis* and *Acarinina quetra* are present with a few specimens.

The uppermost part of the lower Eocene interval which approximately corresponds to Zone E7 (WADE et al., 2011), is characterized by the first occurrence (FO) of several new species and genera and some of them will become important constituents of the middle Eocene fauna. Also significant is the speciation of the genus *Acarinina,* which is represented by the following species: *Acarinina bullbrooki* (Pl. 3, Fig. 7), *A. mcgowrani,* and *A. praetopilensis.* The first appearance of *Turborotalia frontosa,* (Pl. 3, Fig. 8), *Parasubbotina griffinae, Subbotina yeguaensis, S. eocaena* (Pl. 3, Figs. 9 and 10), *S. linaperta* (Pl. 3, Fig. 11), and *Subotina* sp. (Pl. 3, Fig. 12) have been observed in this interval and all these species continue into the middle Eocene. Small benthic foraminifera comprise only 10% of the total assemblage.

5.5. Middle Eocene

The base of the middle Eocene is defined by the lowest occurrence (LO) of *Guembelitrioides nuttally* (BERGGREN & PEARSON, 2005; WADE et al., 2011). In addition, the lowermost part of the middle Eocene is characterized by the common occurrence of *Acarinina bullbrooki*.

The planktonic foraminiferal assemblage of the interval, which roughly corresponds to the Zone E8 after WADE et al. (2011), is dominated by acarininids, represented by *Acarinina pentacamerata, A. cuneicamerata, A. praetopilensis* and *A. primitiva*. Acarininids together with other muricate taxa *(Morozovella,*

Igorina and rare *Morozovelloides*) comprise up to 45–50% of the total foraminiferal assemblage. Subbotinids are also common (20%) and include the following species: *Subbotina eocaena, S. yeguaensis, S. linaperta, S. crociapertura* and *S. senni*. Turborotalids are represented only by *Turborotalia frontosa*. Other species present include: *Parasubbotina griffinae, Praemurica lozanoi, Globanomalina australiformis* and *Catapsydrax unicavus*. Specimens of the genera *Hantkenina* (*H. dumblei*, Pl. 4, Fig. 1) and *Globigerinatheka* represented with the species *G. curry* (Pl. 4, Fig. 2) and *G. subconglobata* (Pl. 4, Fig. 3) are rare in this interval. The first representatives of the new Eocene genus *Morozovelloides* occur with only a few specimens of *M. bandy* (Pl. 6, Fig. 4) per sample. *Pseudohastigerina micra* and *P. wilcoxensis* are the dominant species in the small size fraction (<125 μm) and make up to 40% of the small taxa. Beside them *Planorotalites pseudoscitula, Acarinina collactea* and the biserial form *Chiloguembelina crinita* are also present.

Deposits from the middle part of the middle Eocene (approximately correspond to Zones E10, E11 and E12) contain very rich and highly diverse planktonic foraminiferal assemblages, typical of low latitude areas. Acarininids remain a dominant component and are represented by *Acarinina mcgowrani* (Pl. 4, Fig. 5), *A. praetopilensis, A. rohri,* and *A. topilensis* (Pl. 4, Fig. 6). After the extinction of the two last representatives of *Morozovella (M. aragonensis* and *M. crater)*, the new middle Eocene genus *Morozovelloides* expanded in this interval. Two new species *Morozovelloides crassatus* (Pl. 4, Fig. 7) and *M. coronatus* become an important component of the planktonic community and together with acarininids made up to 45% of the total microfauna, whereas species *Morozovelloides lehneri* (Pl. 4, Fig. 8) occurs rarely. Subbotinids are still present with 20% of the total assemblage with the most common species *S. eocaena* (Pl. 4, Fig. 9) and *S. linaperta* (Pl. 4, Fig. 10). This tropical/subtropical fauna is also characterized by relatively rare (1–2%) globigerinathekids as well as turborotalids (2–3%) represented by *Turborotalia frontosa, T. possagnoensis, T. pomeroli* (Pl. 4, Fig. 11) and *T. cerroazulensis* (Pl. 4, Fig. 12). Besides *Planorotalites* and *Pseudohastigerina*, the small size fraction is enriched by common microperforate biserial taxa *Chiloguembelina ototara, Chiloguembelina sp.* and *Streptochilus martini*. The triserial species *Jenkinsina columbiana* is present with a few specimens per sample.

In the upper part of the middle Eocene, which approximately corresponds to Zones E13, muricate species significantly decrease in abundance. *Acarinina mcgowrani, Morozovelloides crasatus* and small acarininids made up to 20% of the total assemblage. They become replaced by an increasing number of turborotalids, subbotinids and globigerinatekids. In the latest middle Eocene, species with cooler water preference such as *Subbotina, Dentoglobigerina, Catapsydrax* and *Turborotalita* become an important component in the microfossil assemblage. The latest middle Eocene is marked by the rare occurrence of the last large muricate representatives *Acarinina mcgowrani* and *Morozovelloides crasatus* and by their extinction at the middle/late Eocene boundary. The percentage of planktonic foraminifera in the middle Eocene deposits varies between 90 and 95%.

5.6. Late Eocene

The middle/upper Eocene boundary is marked by the double extinction of the last large muricate representatives *Acarinina mcgowrani* and *Morozovelloides crassatus* (WADE, 2004; WADE *et al.*, 2012). Small acarinids represented by *A meddizai, A. colactea* and *A. echinata* continue into the late Eocene. Based on the planktonic foraminiferal association standard biozonation from Zones E14 to E16 after WADE et al., (2011) have been recognized in the late Eocene interval (HERNITZ KUCENJAK et al., 2006). Planktonic foraminifera show significant changes in comparison with the middle Eocene assemblage. Turborotalids, which intensively diverse during the middle Eocene, become a more important component of the upper Eocene planktonic community and they are represented by *Turborotalia pomeroli, T. cerroazulensis* (Pl. 5, Fig. 1)*, T cocoaensis* (Pl. 5, Figs. 2 and 3) and *T. increbescens*. Species *Turborotalia ampliapertura* (Pl. 5, Fig. 4) occurred in the upper part of this interval which corresponds to Zone E15. The last species of this lineage *Turborotalia cunialensis* (Pl. 5, Fig. 5) appeared in the latest Eocene with very few specimens and indicates Zone E16 (WADE et al., 2011). Globigerinathekids was a successful group in the lower part of the late Eocene Zone E14 and comprised up to 5% of the total fauna. They are represented by *Globigerinatheka barry* (Pl. 5, Fig. 6)*, G. kugleri, G. luterbacheri* and *G. index.* They reduced in both diversity and number and only a few specimens of *G. index* are present in the middle part of this interval (Zone E15). Hantkeninids are represented by rare occurrences of *Hantkenina alabamensis* (Pl. 5, Fig. 7)*, H. nanggulanensis* and *Cribrohantkenina inflat*a. Subbotinids are still present with 20–25% of the assemblage and include *Subbotina linaperta* (Pl. 5, Fig. 8), *S. utilisindex*, *S. corpulenta, S. eocaena* and *S. yeguaensis* (Pl. 5, Fig. 9). During the late Eocene, dentoglobigerinids become more frequent, represented by the species *Dentoglobigerina galavisi* (Pl. 5, Fig. 10), and *D. tripartita*, whereas *D. pseudovenezuelana* occur sporadically. Small sized species *Globoturborotalita martini* and *G. ouachitaensis* (Pl. 5, Fig. 11) are also present at 3–4% of the planktonic assemblage. The microperforate biserial forms are represented by *Streptochilus martini* and *Chiloguembelina ototara*, which persisted from the middle Eocene, while *Chiloguembelina cubensis* first appeared before the Eocene/Oligocene boundary (Zone E16). During the late Eocene small acarinids become very rare and are observed only in the small size fraction (<125 μm). Pseudohastigerinids are represented by *P. micra* (Pl. 5, Fig. 12) and *P. naguawichensis* (125–160 μm fraction). Benthic foraminifera increase in abundance during the late Eocene and vary between 35 and 40%, indicating shallowing of the depositional realm.

5.7. Early Oligocene

The Eocene/Oligocene (E/O) boundary is marked by the extinction of all hantkeninids and the last representative of the genus *Globigerinatheka - G. tropicalis*. Planktonic foraminiferal Zones from O1 to O4 have been recognized (BERGGREN & PEARSON, 2005; WADE et al., 2011, 2018; HERNITZ KUCENJAK et al., 2006). The Eocene/Oligocene boundary represents a significant faunal overturn. Most of the specialized warm water taxa such as the *Turborotalia cerroazulensis* group, globigerinathekids and hantkeninids, which were important constituents of the middle and late Eocene planktonic foraminiferal community were replaced by cool water taxa such as *Dentoglobigerina, Catapsydrax, Globorotaloides, Tenuitella* and *Chiloguembelina* (KELLER, 1983; BOERSMA & PREMOLI SILVA, 1991; HERNITZ KUCENJAK et al., 2006). At the end of the late Eocene, just before the E/O boundary, *Chiloguembelina cubensis* (Pl. 6, Fig. 11) appeared, whereas *Cassigerinella chipolensis* (Pl. 6, Fig. 1) occurred immediately after the E/O boundary in Zone O1. The earliest Oligocene planktonic foraminiferal assemblage in Zones O1 and O2 comprises warm to temperate-water taxa in-

cluding *Dentoglobigerina tripartita* (Pl. 6, Fig. 2), *D. pseudovenezuelana*, *D. tapuriensis* (Pl. 6, Fig. 3), *Subbotina gortanii*, *S. corpulenta*, *S. utilisindex*, *S. angiporoides, Turborotalia ampliapertura* (Pl. 6, Fig. 4) *and T. increbescens*. Small sized species such as *Pseudohastigeina naguewichiensis* (Pl. 6, Fig. 5), *Tenuitella gemma*, *Tenuitella* sp., *Globigerina officinalis* (Pl. 6, Fig. 6) are also common. Small sized biserial taxa such as *Chiloguembelina ototara* (Pl. 6, Fig. 7), *C. andreae*, and *Streptochilus martini* are present only in the lower part of the early Oligocene (Zones O1 and O2), whereas *Chiloguembelina cubensis* (Pl. 6, Fig 8) and *C. adriatica* (Pl. 6, Fig. 9) occurred in the whole interval up to Zone O4.

In the upper part of the early Oligocene which corresponds to Zones O3 and O4, the planktonic foraminiferal association is somewhat different – the number of large globigerinids (*Dentoglobigerina*, *Subbotina*) is reduced, but the share of smaller, spinose forms such as specimens of *Ciperoella* group, *Ciperoella anguliofficinalis* (pl. 6, Fig. 10)*; C. angulisuturalis* (Pl. 6, Fig. 11), and *C. ciperoensis* (Pl. 6, Fig. 12) gradually increased.

The number of benthic foraminiferal taxa gradually increased towards the end of early Oligocene, and the plankton/benthos ratio is 50:50.

5.8. Late Oligocene

The boundary between the early and late Oligocene is marked by the highest common occurrence (HCO) of *Chiloguembelina cubensis* (BERGGREN et al., 1995; WADE et al., 2011; 2018), with the proportion of this species in the community of planktonic foraminifera from the smallest sieved fraction (125–63 mm) exceeding 5% (HERNITZ KUCENJAK et al., 2014; PREMEC FUĆEK et al., 2018). The lower part of the late Oligocene which corresponds to Zones O5 and O6 is characterized by large numbers of specimens of the genera *Ciperoella* (*C. angulisuturalis, C. ciperoensis, C. anguliofficinalis*), and *Globoturborotalita* (*G. ouachitaensis, G. occlusa*). The top of Zone O5 is marked by the last occurrence of *Paragloborotalia opima*. During Zones O6 and O7 small size taxa are observed, including: *Cassigerinella chipolensis*, *Tenuitella angustiumbilicata*, *Streptohilus pristinum,* and rare specimens of *Chiloguembelina cubensis* and *Jenkinsina columbiana*. In the uppermost part of the late Oligocene (Zone O7) the first appearance of the *Trilobatus primordius* has been observed. The boundary between the Oligocene and the Miocene is defined by the first occurrence of *Globorotalia kugleri* (BERGGREN *et al.*, 1995; BERGGREN & PEARSON, 2005, WADE et al., 2011; 2018). This planktonic foraminiferal species has not been observed in samples from the exploration wells examined here. However, in the latest Oligocene, close to the Miocene boundary, a large number of *Cassigerinela chipolensis* specimens occurred in the planktonic foraminiferal association. This occurrence as well as the composition of the entire planktonic foraminiferal association was used to place the Oligocene/Miocene boundary. The upper Oligocene benthic foraminiferal assemblage significantly increases both in diversity and in the number of specimens with plankton/benthos ratio of 30:70%.

6. DISCUSSION

The studied succession encompasses a long geological period from the upper Campanian to the end of the Palaeogene, which is characterized by global changes in ocean circulation and general cooling climatic trends (HAQ et al., 1987; HARDENBOL et al., 1998; ZACHOS, 2001; MACKENSEN, 2004; MILLER et al., 1987, 2008;). The late Cretaceous was characterized by low lati-

tudinal thermal gradients (HUBER et al., 1995), and the formation of deep warm, saline bottom waters (thermospheric circulation; HAQ, 1981; ALMOGI-LABIN et al. 1993; WIDMARK & SPEIJER, 1997). In contrast, the Palaeogene was characterized by general climatic cooling, which led to more pronounced latitudinal thermal gradients and changes in ocean circulation (thermohaline circulation; HAQ, 1981). Climatic changes in conjunction with global sea level fluctuation significantly affected planktonic foraminiferal populations in the late Cretaceous and Palaeogene in all word oceans (HAQ, 1981; HAQ et al., 1987; MILLER et al., 2008; KATZ et al., 2008). Most of the deposits examined here contain rich and well-preserved foraminiferal assemblages, which help in palaeoceanographic and palaeoclimatic interpretations of the investigated area.

6.1. Late Cretaceous planktonic foraminiferal assemblages

Late Cretaceous sediments contain rich and highly diverse foraminiferal assemblages which imply a well-stratified water column and warm surface water. The presence of ornamented and double-keeled globotruncanids which belong to highly specialized (K-strategist) genera indicate a long and relative stable period with a tropical to subtropical climate. Globotruncanids are usually regarded as intermediate to deep ocean dwellers and were geographically limited to the Tethyan tropical-subtropical belt during the Late Cretaceous (ABRAMOVICH et al., 2002, 2003; PETRIZZO, 2002).

Planktonic foraminiferal species from the upper Campanian to Maastrichtian interval inhabited a different niche in the stratified water column (ABRAMOVICH et al., 2003; HUBER et al., 1995; PETRIZZO, 2002). Deep-water habitats (subthermocline) were occupied by relatively few species *Globotruncanella havanensis, Gansserina gansseri* and *Planoglobulina* sp. The most stressful niche was the surface layer inhabited only by *Pseudoguembelina* species (ABRAMOVIC et al., 2003). Most species such as *Globotruncana*, *Contusotruncana*, *Rugoglobigerina*, *Pseudotextularia* and *Heterohelix* occupied subsurface depths of the mixed layer. The assemblages could also vary between the thermocline layer and the subsurface mixed layer during cool and warm intervals. During cool climate intervals, keeled globotruncanids and perhaps *Globigerinelloides* and *Racemiguembelina* occupied the thermocline layer, whereas *Rugoglobigerina, Pseudotextularia* and heterohelicids inhibited the subsurface mixed layer (ABRAMOVICH et al., 2003).

Sedimentation during the Late Campanian and Maastrichtian took place in pelagic environments (outer shelf to upper bathyal), as indicated by the high percentage of planktonic foraminifera (90–95%) and the presence of complex morphotypes (K-strategists) dominant in open oceans (ROBASZYNSKI and CARON, 1995; ABRAMOVICH et al., 2002, 2003). The high diversity of planktonic foraminifera abruptly decreases in the uppermost part of this unit indicating changes and possible cooling in the latest Cretaceous ocean.

6.2. Palaeogene planktonic foraminiferal assemblages

At the **Cretaceous/Palaeocene** (K/Pg) boundary, due to the catastrophic Chicxulub impact event, the planktonic foraminiferal assemblage was reduced to a minimum, with only a few species surviving across the boundary (OLSSON et al., 1999; ARENILLAS et al., 2006; MACLEOD et al., 2007; KOUTSOUKOS, 2014). However, a number of new genera and species originated in the earliest **Palaeocene** during a relative short period of about 60 kya (ARENILLAS et al., 2006; WADE et al, 2011; BIRCH et

al., 2012). Although the Cretaceous/Palaeogene boundary is not documented in the studied intervals, the oldest Palaeocene planktonic foraminiferal assemblage is documented in the J-2 well (sample 1700–1710 m) and in the cored interval (1604–1613 m) from the J-3 well. This early Palaeocene planktonic community is rich in the number of specimens but is not very diverse. It includes *Eoglobigerina eobulloides* (Pl. 2, Fig. 1), *E. edita, Globanomalina archeocompressa, Chiloguembelina morsei* (Pl. 2, Fig. 6), *Woodringina claytonensis* (Pl. 2, Fig.3), *Subbotina trivialis* and *Parasubbotina pseudobulloides* (Pl. 2, Fig. 2), which likely belong to the earliest Palaeocene Zones P0–Pα. Small species are represented by *Eoglobigerina eobulloides,* which dominates the assemblage and is together with *Parasubbotina pseudobulloides*, the first Palaeogene representative with a cancelate spinose wall texture (HEMLEBEN et al., 1991; OLSSON et al., 1999). These innovations enabled these small foraminifera to occupy the surface niche in the water column like recent planktonic species (HEMLEBEN et al., 1989). Isotopic data by BIRCH et al. (2012) suggest that these small early Palaeocene species had a rapid evolution after the Cretaceous/Palaeogene (K/Pg) mass extinction and inhabited a different niche in the thermally stratified water column. BIRCH et al. (2012) also identified a metabolic disequilibrium in carbon isotopes, which indicated the possible photosymbiotic relationship between foraminifera and algal symbionts. These data indicated that a photosymbiotic relationship may have been important in the early Palaeocene after the mass extinction. Although most of the surviving foraminiferal species belong to an opportunistic (r-strategist) group of organisms, the empty niche in the tropical to subtropical oligotrophic oceans provided them with an opportunity to evolve a new, more specialistic mode of life such as morphological adaptation to inhabit the surface and subsurface niche in the water column due to the metabolic requirements of the symbiotic algae (BÉ, 1982; HEMLEBEN et al., 1991). Consequently, the test morphology of the early Palaeocene species, including the spinose wall texture of *Eoglobigerina* and *Subbotina* or smooth surface of *Globanomalina*, are closely related to their preferred niche in the water column (BIRCH et al, 2012).

The **late Palaeocene** is characterized by intensive speciation of the muricate genera *Morozovella* and *Acarinina*, which dominate the assemblage. Together with the genus *Igorina* they form up to 50% of the assemblage. These species with ornamented tests live in the surface/subsurface layer of the photic zone because of the metabolic requirements of their symbionts (SCHACKLETON et al., 1985; D'HONDT et al, 1994, NORRIS, 1996; QUILLÉVÉRÉ & NORRIS, 2003; BIRCH et al., 2012). In addition, opportunistic (r-strategists) species subbotinids and globanomalinids, are also common inhabitants of the thermocline layers. A rich and highly diverse planktonic community indicates oligotrophic habitats, warm surface water, and a very well stratified water column with a stable thermocline. The diversity peaked in the upper part of the late Palaeocene. The predominance of planktonic foraminifera suggests sedimentation in deeper open sea environments (outer shelf to upper bathyal). The latest Palaeocene is assigned as a period of global warming (ZACHOS et al., 2001; GUASTY & SPEIJER, 2007). The boundary between the Palaeocene and the lower Eocene is marked by the extinction of several muricate species which was one of the most successful groups during the late Palaeocene. The boundary interval is marked by a negative shift in $\delta^{13}C$ values, i.e. the carbon isotope excursion (CIE), ALEGRET et al., 2006. This warm period, also known as the Palaeocene-Eocene Thermal Maximum (PETM), is characterized by stressful conditions in the upper mixed layer which was inhabited by muricate planktonic foraminifera with a symbiotic mode of life. Global warming that occurred during the PETM possibly caused the loss of the algal photosymbionts, i.e. bleaching (ALEGRET et al., 2006; LUCIANI et al., 2017 a, b). A similar event connected with muricate species extinction (*Acarinina* and *Morozovelloides*) is documented in the upper middle Eocene (WADE, 2004; WADE et al., 2012). In addition, an increase of primary production and eutrophication, and decrease in oxygen level may also be unfavourable elements in the upper mixed layer which led to the extinction of these K-mode strategists.

The **early Eocene** planktonic assemblage is also dominated by muricate warm-water taxa including *Acarinina, Morozovella* and *Igorina*, which comprise approximately 40% of the planktonic foraminiferal fauna. Muricate species which hosted algal photosymbionts and occupied the upper mixed layer, are the most important calcifiers during the early Eocene (PREMOLI SILVA & BOERSMA, 1988; PEARSON et al., 2006; LUCIANI et al., 2017 a, 2017 b). These low latitude assemblages are also characterized by the common *Subbotina* (20%), *Globanomalina* (3%) and *Chiloguembelina* (3%) species. Such domination of warm water taxa indicate a tropical climate, warm surface water and a well-stratified column inhabited by many muricate species. The well-stratified water column, however, provided many niches and supported the species that also prefer cooler sea water such as the subbotinids, parasubbotinids and globanomalinids which inhabited the thermocline layer. The upper part of the lower Eocene is characterized by significant speciation of the genera *Subbotina, Parasubbotina* and *Acarinina* and also the first appearance of the genus *Turborotalia*.

Most of the planktonic species that originated in the latest early Eocene continued into the **middle Eocene**. The trend of speciation continued into the middle Eocene when many new species originated (PREMOLI SILVA & BOERSMA, 1988; PEARSON et al., 2006). The speciation rate exceeded the extinction rate and resulted in the highest diversity of the plankton community during the Palaeogene. These highly diverse planktonic foraminiferal assemblages are characterized by the dominance of specialized (K-mode life strategists) acarininids, morozovelloids, globigerinathekids, and by the common occurrence of the opportunistic species (r-mode life strategists) subbotinids, turborotalids and catapsydraxids (PREMOLI SILVA & BOERSMA, 1988). All these observations suggest the presence of an oligotrophic ocean with a well-stratified water column that hosted many groups of planktonic foraminifera with different habitat preferences (PEARSON et al., 1993; PEARSON et al., 2001). The ocean stratification was supported by a tropical to subtropical climate and stable thermocline (PEARSON et al., 2001). Both a warm climate and the high intensity of sun light were also favourable for the symbiotic mode of life of the specialized forms with ornamented calcite tests such as *Acarinina* and *Morozovelloides* (WADE, 2004). In the upper part of the middle Eocene, the number of muricate species decreased in abundance, indicating cooling and the instability of the water column (SEXTON et al., 2006; PREMEC FUĆEK et al., 2010). The last representatives of the larger muricate taxa *Acarinina mcgavrani* and *Morozovelloides crassatus* had their highest occurrence (HO) at the middle/late Eocene boundary (WADE, 2004; PREMEC FUĆEK et al., 2010; WADE et al., 2012).

The cooling that began in the middle Eocene significantly affected the **late Eocene** planktonic foraminiferal community

(CAVELIER et al., 1981; PREMOLI SILVA & BOERSMA, 1988; BOERSMA & PREMOLI SILVA, 1991; HALLOCK et al., 1991; SPEZZAFERRI et al., 2002). This climatic change is associated with a shallowing of thermocline depth and increased delivery of nutrients to the surface waters (SPEZZAFERRI et al., 2002). These events caused a reduction in the abundance of shallow and warm water species of planktonic foraminifera (SPEZZAFERRI et al., 2002). Micropalaeontological results obtained from the studied wells are in accordance with these general trends. During the late Eocene, most changes in the planktonic foraminiferal assemblage were associated with the mixed layer and the upper part of the thermocline. Hantkeninids, globigerinatekids and turborotalids declined in abundance and diversity during this time. At the same time, the deeper dwelling forms such as *Subbotina*, *Dentoglobigerina*, *Catapsydrax* and *Globigerinoides* proliferated.

The cooling that started in the middle Eocene reached its maximum around the **Eocene/Oligocene boundary,** and this climate transition is marked by a distinct change in the association of planktonic foraminifera (KELLER, 1983, BOERSMA & PREMOLI SILVA, 1991; ZACHOS et al., 1996). Warm water species including representatives of the genera *Hantkenina*, *Cribrohantkenina* and *Globigerinatheka*, and most representatives of the genus *Turborotalia* became extinct. The surface mixed layer thinned due to shallowing of the thermocline (SPEZZAFERRI et al., 2002), resulting in higher diversity of the deeper dwelling and cool water forms (e.g., genera *Dentoglobigerina*, *Subbotina*, *Catapsydrax*). In addition, a size reduction in specimens of the genus *Pseudohastigerina* at the Eocene–Oligocene transition, indicated unfavourable environmental conditions.

The lower part of the **early Oligocene** is characterized by the predominance of the genera *Dentoglobigerina* and *Subbotina*. They inhabit the deeper part of the water column and do not have symbionts. Instead, they feed on organic particles in the water column (HEMLEBEN et al., 1989), which indicates blooming of phytoplankton and upwelling. A large number of individuals of the opportunistic genera such as *Dentoglobigerina*, *Subbotina* and *Pseudohastigerina* in the early Oligocene indicates thermocline shallowing due to mixing of the water mass, which in turn is an indicator of reduced temperatures (BOERSMA & PREMOLI SILVA, 1991).

Towards the top of the early Oligocene, there was a shift in the distribution of species within the available niches. This is reflected in an increase in the number of species in the mixed layer and the appearance of specimens of the small spinose symbiont bearing genera *Ciperoella* (*C. ciperoensis*, *C. angulisuturalis*), which are indicators of warmer water temperatures and oligotrophy (SPEZZAFERRI et al., 2002).

In the **late Oligocene** an increase in the number of species of planktonic foraminifera was documented in all wells. This especially applies to the species that inhabit the mixed layer – *Globoturborotalita ouachitaensis*, *G. occlusa*, *Ciperoella angulisuturalis*, *C. ciperoensis*, and *Globigerina officinalis*. These spinose species are adapted to oligotrophic conditions (HALLOCK et al., 1991; PEARSON, 1998; SPEZZAFERRI et al., 2002) and live in symbiotic relationships with photosynthetic algae, mostly dinoflagellates (HEMLEBEN et al., 1989). Furthermore, the species *Trilobatus primordius* had its first occurrence in the late Oligocene and indicates warmer climatic conditions. At the same time, the number of deep dwelling species (*Dentoglobigerina*, *Subbotina*, *Catapsydrax*) that fed mostly on particulate organic matter was reduced. These observations suggest reduced primary pro-

duction and oligotrophy, and gradual warming during the late Oligocene (SPEZZAFERRI & PREMOLI SILVA, 1991; SPEZZAFERRI et al., 2002).

8. CONCLUSION

This study focused on the rich, well-preserved and diverse planktonic foraminiferal assemblages found in upper Cretaceous to upper Oligocene deposits from exploration wells in the Palmyrides area of Syria. The upper Cretaceous strata predominantly consist of hemipelagic argillaceous limestones and marls with abundant pelagic microfauna. Palaeocene and Eocene deep-water clayey limestones and marls with a high percentage of planktonic foraminifera (90%) indicate upper bathyal to outer shelf environments. In contrast, Oligocene sandstone, bioclastic limestone and marls with an increasing percentage of benthic foraminifera (70%) indicate sedimentation in middle to inner shelf environments.

Global palaeoenvironmental changes are reflected in the composition, speciation and extinction of the examined planktonic foraminiferal population. The upper Campanian and Maastrichtian planktonic fauna is highly diversified with the domination of warm water taxa such as *Contusotruncana contusa*, *Racemiguembelina fructicosa*, *Globotruncana aegyptiaca*, *Globotruncana ventricose*, *Gansserina gansseri*, *Globotruncanella havanensis*, *Globotruncanita angulata*, *Globotruncanita stuarti*, *Rugoglobigerina macrocephala*, *Macroglobigerinelloides alvarezi* and *Pseudotextularia elegans*. The most dramatic change occurred at the Cretaceous/Palaeocene boundary when most planktonic foraminiferal species became extinct. The oldest documented Palaeocene planktonic foraminiferal assemblage in the investigated wells includes *Eoglobigerina eobulloides*, *Globanomalina archeocompressa*, *Chiloguembelina morsei*, *Woodringina claytonensis* and *Parasubbotina pseudobulloides*. This assemblage is rich in the number of specimens but is not very diverse and indicates a relatively rapid recovery and occurrence of new species with novel abilities, such as spinose wall texture and possible photosymbiotic relationships with algae.

The late Palaeocene was characterized by the origination and domination of warm water taxa with complex test morphology such as *Morozovella* and *Acarinina* which imply a tropical to subtropical climate. The Palaeocene/Eocene boundary is assigned as a period of global warming known as the Palaeocene-Eocene Thermal Maximum (PETM), characterized by stressful conditions in the upper mixed layer which was inhabited by muricate planktonic foraminifera with a symbiotic mode of life. Even though the plankton were affected, most planktonic foraminiferal species successfully survived into the Eocene and there were no major extinctions.

Similar palaeoclimatic and palaeoceanographic trends with the domination of the muricate species Morozovella, Acarinina and Igorina which hosted algal photosymbionts and occupied the upper mixed layer continued into the early Eocene. The upper part of the early Eocene is characterized by significant speciation of the genera *Subbotina, Parasubbotina* and *Acarinina* and also first appearance of the genus *Turborotalia*.

The middle Eocene was characterized by intensive speciation and the domination of warm water genera such as *Morozovelloides*, *Turborotalia*, *Globigerinatheka* and *Hantkenina*. In contrast to mid latitudes, the three important genera *Turborotalia*, *Globigerinatheka* and *Hantkenina* are present in low numbers in the investigated area. Double extinction of the last muricate taxa *Acarinina mcgowrani* and *Morozovelloides crasssatus* oc-

curred at the middle/late Eocene boundary and indicates a changeable climate and water column instability.

The Eocene/Oligocene boundary is marked by the extinction of most warm water taxa including the *Turborotalia cerroazulensis* group, *Hantkenina, Globigerinatheka* and some subbotinids, in association with intensive short-term global cooling. The beginning of the Oligocene is characterized by the domination of cool water taxa such as *Dentoglobigerina, Globorotaloides, Tenuitella* and *Chiloguembelina*. Speciation of the spinoze surface dweller *Ciperoella ciperoensis* group in the late Oligocene is indicative of warming.

The lithology, diversity and composition of the planktonic foraminiferal assemblages indicate that the Palmyrides area in Syria was a Tethyan bioprovince with a tropical to subtropical climate from the late Campanian to the end of the Eocene, when deposition took place in deep open marine environments. In contrast, Oligocene deposits and the microfossil content suggest temperate to warm climate and sedimentation in middle to inner shelf environments.

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REFERENCES

ABRAMOVICH, S. & KELLER, G. (2002): High stress late Maastrichtian palaeoenvironment: inference from planktonic foraminifera in Tunisia.– Palaeogeography, Palaeoclimatolology, Palaeoecology, 178, 145–164.

ABRAMOVICH, S., KELLER, G., STÜBEN, D. & BERNER, Z. (2003): Characterization of late Campanian and Maastrichtian planktonic foraminiferal depth habitats and vital activities based on stable isotopes.– Palaeogeography, Palaeoclimatology, Palaeoecology, 202, 1–29. doi: 10.1016/S0031-0182(03)00572-8

ALEGRET, L., ORTIZ, S., ARENILLAS, I. & MOLINA, E. (2006): Palaeoenvironmental turnover across the Palaeocene/Eocene boundary at the Stratotype section in Dababiya (Egypt) based on benthic foraminifera.– Terra Nova, 17/6, 526–536. doi: 10.1111/j.1365-3121.2005.00645.x

ALMOGI-LABIN, A., BEIN, A. & SASS, E. (1993): Late Cretaceous upwelling system along the southern Tethys (Israel): interrelationship between productivity, bottom water environmens, and organic matter preservation.– Paleoceanography, 8, 671–690. doi: 10.1029/93PA02197

ARENILLAS, I., ARZ, J.A., GRAJALES-NISHIMURA, J., MURILLO-MUÑETON, G., ALVAREZ, W., CAMARGO-ZANOGUERA, A., MOLINA, E. & ROSALES-DOMÍNGUEZ, C. (2006): Chicxulub impact event is Cretaceous/Paleogene boundary in age: New micropaleontological evidence.– Earth and Planetary Science Letters, 249, 241–257. doi: 10.1016/j.epsl.2006.07.020

BÉ, A.W.H. (1982): Biology of Planktonic Foraminifera.– In: BUZAS, M.A. & SEN GUPTA, B.K. (eds.): Notes for a Short Course, 219.– University of Tennessee, Dep. Geol. Sci., Studies in Geology, New Orleans, 51–89.

BERGGREN, W.A. & PEARSON, P.N. (2005): A revised tropical to subtropical Paleogene planktonic foraminifera zonation.– Journal of Foraminiferal Research, 35/4, 279–298.

BERGGREN, W.A., KENT, D.V., SWISHER C.C. & AUBRY, M. (1995): A Revised Cenozoic geochronology and chronostratigraphy.– In: BERGGREN, W.A., KENT, D.V., AUBRY, M. & HARDENBOL, J. (eds.): Geochronology, Time Scales and Global Stratigraphic Correlation.– Special publication of Society for Sedimentary Geology, 129–212. doi: 10.2110/pec.95.04.0129

BIRCH, H.S., COXALL, H.K. & PEARSON, P.N. (2012): Evolutionary ecology of Early Paleocene planktonic foraminifera: size, depth habitat and symbionts.– Paleobiology, 38/3, 374–390. doi: 10.1666/11027.1

BOERSMA, A. (1988): Foraminifera.– In: HAQ, B.U. & BOERSMA, A. (eds.): Introduction to Marine Micropaleontology.– Elsevier Science, Singapore, 19–78. doi: 10.1016/B978-044482672-5/50002-7

BOERSMA, A. & PREMOLI SILVA, I. (1991): Distribution of Paleogene planktonic foraminifera – analogies with the Recent?– Palaeogeography, Palaeoclimatology, Palaeoecology, 83, 29–48. doi: 10.1016/0031-0182(91)90074-2

BOLLI, H.M., BECKMANN, J.P. & SAUNDERS, J.B. (1994): Benthic foraminifera biostratigraphy of the south Caribbean region.– Cambridge University Press, 408 p.

BREW, G.E. (2001): Tectonic evolution of Syria interpreted from integrated geophysical and geological analysis.– PhD Thesis, Cornell University, Ithaca, New York, 323 p.

BREW, G., BARAZANGI, M., AL-MALEH, A.K. & SAWAF, T. (2001): Tectonic and geologic evolution of Syria.– GeoArabia, 6/4, 573–616.

CARON, M. (1985): Cretaceous planktonic foraminifera.– In: BOLLI, H.M., SAUNDERS, J.B. & PERCH NIELSEN, K. (eds.), Planktonic Stratigraphy.– Cambridge University Press, Cambridge, 17–86.

CAVELIER, C., CHATEAUNEUF, J., POMEROL, C., RABUSSIER, D., RENARD, M. & VERGNAUD-GRAZZINI, C. (1981): The geological events at the Eocene/Oligocene boundary.– Palaeogeography, Palaeoclimatology, Palaeoecology, 36, 223–248. doi: 10.1016/0031-0182(81)90108-5

CHAIMOV, T.A., BARAZANGI, M., AL-SAAD, D., SAWAF, T. & GEBRAN, A. (1992): Mesozoic and Cenozoic deformation inferred from seismic stratigraphy in the southwestern intracontinental Palmyride fold-thrust belt, Syria.– Geol. Soc. Am. Bull., 104, 704–715. doi: 10.1130/0016-7606(192)104

COHEN, K.M., FINNEY, S.C., GIBBARD, P.L. & FAN, J.-X. (2013; updated): The ICS International Chronostratigraphic Chart. Episodes, 36, 199–204.

URL: http://www.stratigraphy.org/ICSchart/ChronostratChart2020-01.pdf

DACER, G., STANKOVIĆ, D., MESIĆ, I.A. & IVANIČEK, Z. (2007): Upper Campanian to Maastrichtian foraminiferal assemblages of the Palmyra region, Syria.– Geophysical Research Abstracts, Cd, European Geosciences Union, Vienna, 9.

D'HONDT, S., ZACHOS, J.C. & SCHULTZ, G. (1994): Stable isotops signals and photosymbiosis in Late Paleocene planktic foraminifera.– Paleobiology, 20/3, 391–406.

EDGAR, K.M., WILSON. P.A., SEXTON, P.F., GIBBS, S.J., ROBERTS, A.P. & NORRIS, R.D. (2010): New biostratigraphic, magnetostratigraphic and isotopic insights into the Middle Eocene Climatic optimum in low latitudes.– Palaeogeography, Palaeoclimatology, Palaeoecology, 297, 670–682. doi: 10.1016/j.palaeo.2010.09.016

FLÜGEL, E. (2010): Microfacies of Carbonate Rocks.– Springer, 984 p. doi: 10.1007/978-3-642-03796-2

GASIŃSKI, M.A. & UCHMAN, A. (2009): Latest Maastrichtian foraminiferal assemblages from the Husów region (Skole Nappe, Outer Carpathians, Poland).– Geologia Charpatica, 60/4, 283–294. doi: 10.2478/v10096-009-0020-5

GAWOR-BIEDOWA, E. (1984): Foraminiferal zonation of the Upper Cretaceous deposites in Poland (except for the Carpathians and Sudeten). Second international Symposium of Benthic Foraminifera, Pau, Benthos′83.– Revue de Paléobiologie, 1, 213–233.

GRÄFE, K.U. (2005): Late Creatceous benthic foraminifers from the Basque-Cantabrian Basin, northern Spain.– Journal of Iberian Geology, 31/2, 277–298.

GUASTI, E. & SPEIJER, R.P. (2007): The Paleocene–Eocene Thermal Maximun of the planktic foraminiferal record.– GSA Special Papers, 424, 53–67.

HALLOCK, P. (1987): Fluctuations in the trophic resource continuum: A factor in global diversity cycles.– Paleoceanography, 215, 457–471. doi: 10.1029/PA002i005p00457

HALLOCK, P., PREMOLI SILVA, I. & BOERSMA, A. (1991): Similarities between planktonic and larger foraminiferal evolutionary trends through Paleogene paleoceanographic changes.– Palaeogeography, Palaeoclimatology, Palaeoecology, 83, 49–64. doi: 10.1016/0031-0182(91)90075-3

HAQ, B.U. (1981): Paleogene paleoceanography: Early Cenozoic oceans revisited.– Oceanographica Acta, Suppl. to Vol. 4, Proc. 26th Int. Geol. Congress, 71–82.

HAQ, B.U., HARDENBOL, J. & VAIL, P.R. (1987): Chronology of fluctuating sea levels since the Triassic.– Science, 235, 1156–1167. doi: 10.1126/science.235.4793.1156

HARDENBOL, J., THIERRY, J., FARLEY, M.B., JACQUIN, T., DE GRACIANSKY, P.C. & VAIL, P.R. (1998): Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins.– SEPM Special Publication 60, 3–13. doi: 10.2110/pec.98.02.0003

HEMLEBEN, C., SPINDLER, M. & ANDERSON, O.R. (1989): Modern Planktonic Foraminifera.– Springer-Verlag, New York, 363 p. doi: 10.1007/978-1-4612-3544-6

HEMLEBEN, C., MUHLEN, D., OLSSON, R.K. & BERGGREN, W. (1991): Surface texture and the first occurrence of spines in planktonic foraminifera from the early Tertiary.– Geologische Jahrbuch, 128, 117–146.

HERNITZ KUČENJAK, M., PREMEC FUĆEK, V. & SLAVKOVIĆ, R. (2005): Planktonic Foraminifera turnover at the Eocene/Oligocene Boundary (Palmyra Region, Syria).– In: VELIĆ, I., VLAHOVIĆ, I & BIONDIĆ, R. (eds.): Proceedings, Third Croatian Geological Congress, Opatija, 55–56.

HERNITZ KUČENJAK, M., PREMEC FUĆEK, V., SLAVKOVIĆ, R. & MESIĆ, I.A. (2006): Planktonic foraminiferal biostratigraphy of the Late Eocene and Oligocene in the Palmyride area, Syria.– Geologia Croatica, 59/1, 19–39.

HERNITZ KUČENJAK, M. (2008): Oligocene planktonic foraminiferal associations from selected localities of Neotethys.– Master Thesis, University of Zagreb, Faculty of Science, Zagreb, 101 p.

HERNITZ KUČENJAK, M., PREMEC FUĆEK, V., HUBER, B.T. & WADE, B.S. (2014): The test size and abundance variations in planktonic foraminifera *Chiloguembelina cubensis* and *C. ototara* as response to climatic events in the Oligocene. CBEP 2014, Ferrara, Italy, July 1–6.– In: DICKENS, G. & LUCIANI, V.

Premec Fućek et al.: Planktonic foraminiferal biostratigraphy and lithology of the Upper Cretaceous (upper Campanian-Maastrichtian) ...   **31**

Geologia Croatica

(eds.): Rendiconti online della Società Geologica Italiana, Roma, 31, 103–104. doi: 10.3301/ROL.2014.68

HUBER, B., HODELL, D.A. & HAMILTON, C.R. (1995): Middle–Late Cretaceous of the southern high latitudes: Stable isotopic evidence for minimal equator-to-poole thermal gradients.– GSA Bulettin, 1164–1191. doi: 10.1130/0016-7606(1995)107<1164:MLCCOT>2.3.CO;2

IACCARINO, S.M., PREMOLI SILVA, I., BIOLZI, M., FORESI, M., LIRER, F. & PETRIZZO, M.R. (2005): Practical Manual of Oligocene to Middle Miocene Planktonic Foraminifera.– International School on Planktonic Foraminifera, Universita degli Studi di Perugia, Università degli Studi di Parma, Universita degli Studi di Milano, 124 p.

ISMAIL, A.A. (1992): Maastrichtian-Early Eocene benthonic foraminiferal biostratigraphy and palaeoecology of west central Sinai, Egypt.– M.E.R.C. Ain Shams University, Earth Science Series, 6, 139–150.

ISMAIL, A.A., HUSSEIN-KAMEL, Y., BOUKHARY, M. & GHANDOUR, A.A.A. (2007): Campanian-Early Eocene Stratigraphy of the Southern Galala Plateau, Eastern Desert, Egypt.– Geologia Croatica, 60/2, 115–137.

KAIHO, K. (1998): Phylogeny of deep-sea calcareous trochospiral benthic foraminifera: evolution and diversification.– Micropaleontology, 44/3, 291–311. doi: 10.2307/1486051

KATZ, M., MILLER, K.G., WRIGHT, J.D., WADE, B.S., BROWNING. J.V., CRAMER, B.S. & ROSENTHAL, Y. (2008): Stepwise transition from the Eocene greenhouse to the Oligocene icehouse.– Nature geoscience, 1, 44/3, 229–334. doi: 10.1038/ngeo179

KELLER, G. (1983): Biochronology and paleoclimatic implications of Middle Eocene to Oligocene planktonic foraminiferal faunas.– Marine Micropaleontology, 7, 463–486.

KOUTSOUKOS, E.A.M. (2014): Phenotypic plasticity, speciation, and phylogeny in early Danian planktic foraminifera.– Journal of Foraminiferal Research, 44/2, 109–142. doi: 10.2113/gsjfr.44.2.109

KRASHENINNIKOV, V.A., GOLOVIN, D.I. & MOURAVYOV, V.I. (1996): The Paleogene of Syria – Stratigraphy, Lithology, Geochronology.– Geologisches Jahrbuch Reiche B, B 86, 136.

KRIŽ, J., FORŠEK, G., IVKOVIĆ, Ž. & LUČIĆ, D. (2005): Hydrocarbon discoveries in Syria-Carboniferous, Permian and Triassic petroleum systems.– In: VELIĆ, I., VLAHOVIĆ, I. & BIONDIĆ, R. (eds.): Proceedings, Third Croatian Geological Congress, Opatija, Croatia, 79–80.

LITAK, R.K., BARAZANGI, M., BREW, G., SAWAF, T. & AL-YOUSSEF, W. (1998): Structure and evolution of the petroliferous Euphrates graben system, southeast Syria.– AAPG Bulletin, 82/6, 1173–1190.

LOEBLICH, A.R. & TAPPAN, H. (1988): Foraminiferal genera and their classification. Treatise on invertebrate paleontology.– Van Nostrand Reinhold Company, 970 p.

LUCIANI, V., D'ONOFRIO, R., DICKENS, G.R., & WADE, B.S. (2017a): Did photosymbiont bleaching lead to the demise of planktic foraminifer Morozovella at the Early Eocene Climatic Optimum?– Paleoceanography, 32, 1115–1136.

LUCIANI, V., D'ONOFRIO, R., DICKENS, G.R. & WADE, B.S. (2017b): Planktic foraminiferal response to early Eocene carbon cycle perturbations in the southeast Atlantic Ocean (ODP Site 1263).– Global and Planetary Change, 158, 119–133. doi: 10.1016/j.gloplacha.2017.09.007

LUČIĆ, D. & FORŠEK, G. (2000): Palmyride evolution: geologic, stratigraphic and structural overview (Central Syria).– In: VLAHOVIĆ, I. & BIONDIĆ, R. (eds.): Proceedings, Second Croatian Geological Congress, Cavtat, Croatia, 311–316.

LUČIĆ, D. (2001): Litostratigraphical and petrographical Guidebook of the typical facies in the wider area of Hayan Block (Palmyrides, Syria).– INA Report, Damascus, 47 p.

LUČIĆ, D., MARETIĆ, S., FORŠEK, G., TAKAČ, D. & MESIĆ, I. (2002): Mesozoic Carbonate Facies and Reservoirs in Central Palmyrides, Syria.– Abstract, Cd, American Association of Petroleum Geologists Conference, Cairo.

LY, A. & KUHNT, W. (1994): Late Cretaceous benthic foraminiferal assemblages of the Casamance shelf (Senegal, NW Africa). Indication of a late Cretaceous oxygen minimum zone.– Revue de Micropaléontologie, 37/1, 49–74.

MACKENSEN, A. (2004): Changing Southern Ocean palaeocirculation and effects on global climate.– Antarctic Science, 16/4, 369–386. doi: 10.1017/S0954102004002202

MACLEOD, K.G., WHITNEY, D.L., HUBER, B.T. & KOEBERL, C. (2007): Impact and extinction in remarkably complete Cretaceous-Tertiary boundary sections from Demerara Rise, tropical western North Atlantic.– GSA Bulletin, 119, 1/2, 101–115. doi: 10.1130/B25955.1

MILLER, K.M., BROWNING, J.V., AUBRY, M.-P., WADE, B.S., KATZ, M.E., KULPECZ, A.A. & WRIGHT, J.D. (2008): Eocene–Oligocene global climate and sea-level changes: St. Stephens Quarry, Alabama.– GSA Bulletin, 120, 1/2, 34–53. doi: 10.1130/B26105.1

MILLER, K.G., JANECEK, T.R., KATZ, M. & KEIL, D.J. (1987): Abyssal circulation and benthic foraminiferal changes near the Paleocene/Eocene boundary.– Paleoceanography, 2/6, 741–761. doi: 10.1029/PA002i006p00741

MOUTY, M. & AL-MALEH, K. (1983): The geological study of the Palmyridian chain using ideal geological sections for exploration purposes and geological survey.– General Establishment of Geology and Mineral Resources, Ministry of Petroleum and Mineral Resources, Damascus, Syria, 4, 950 p.

MURRAY, J.W. (1991): Ecology and Paleoecology of Benthic Foraminifera.– Longman Scientific & Technical, Essex, 397 p.

NORRIS, R.D. (1996): Symbiosis as an evolutionary innovation in the radiation of Paleocene planktonic foraminifera.– Paleobiology, 22, 461–480.

OLSSON, R.K., HEMLEBEN, C., BERGGREN, W.A. & HUBER, B.T. (1999): Atlas of Paleocene Planktonic Foraminifera.– Smithsonian Contributions to Paleobiology, No. 85, Smithsonian Institution Press, Washington D.C., 252 p. doi: 10.5479/si.00810266.85.1

PEARSON, P.N., SHACKLETON, N.J. & HALL, M.A. (1993): Stable isotope paleoecology of middle Eocene planktonic foraminifera and multi-species isotope stratigraphy, DSDP Site 523, South Atlantic.– Journal of Foraminiferal Research, 23/2, 123–140. doi: 10.2113/gsjfr.23.2.123

PEARSON, P.N. (1998): Stable isotopes and the study of evolution in planktonic foraminifera.– In: NORRIS, R.D. & CORFIELD, R.M. (eds.): Isotope Paleobiology and Paleoecology.– Paleontol. Soc. Papers, 4, 138–178. doi: 10.1017/S1089332600000425

PEARSON, P.N., DITCHFIELD, P.W., SIGNANO, J., HARCOURT-BROWN, K.G., NICHOLAS, C.J., OLSSON, R.K., SHACKLETON, N.J. & HALL, M.A. (2001): Warm tropical sea surface temperatures in the late Cretaceous and Eocene epochs.– Nature, 413, 481–487. doi: 10.1038/35097000

PEARSON, P.N., OLSSON, R.K., HUBER, B.T., HEMLEBEN, C. & BERGGREN, W.A. (2006): Atlas of Eocene Planktonic Foraminifera.– The Cushman Foundation for Foraminiferal Research, Special Paper, 41, 513 p.

PECIMOTIKA, G., CVETKO TEŠOVIĆ, B. & PREMEC FUĆEK, V. (2014): Planktonic foraminiferal biostratigraphy and paleoecology of Upper Cretaceous deposits from the Palmyride Region, Syria.– Geologia Croatica, 67/2, 87–110. doi: 10.4154/GC.2014.07

PÉREZRODRÍGEZ, I., LEES, J.A., LARRASOANA, J.C., ARZ, J.A. & ARENILLAS, I. (2012): Planktonic foraminiferal and calcareous nannofossil biostratigraphy and magnetostratigraphy of the uppermost Campanian and Maastrichtian at Zumaia, northern Spain.– Cretaceous Research, 37, 100–126. doi: 10.1016/j.cretres.2012.03.011

PETRIZZO, M.R. (2002): Palaeocenographic and palaeoclimatic inferences from Late Cretaceous planktonic foraminiferal assemblages from the Exmouth Plateau (ODP Sites 762 and 763, eastern Indian Ocean).– Marine Micropaleontology, 45, 117–150.

PETRIZZO, M.R., FALZONI, F. & PREMOLI SILVA, I. (2011): Identification of the base of the lowertomiddle Campanian Globotruncana ventricosa Zone: comments on reliability and global correlations.– Cretaceous Research, 32, 387–405.

PETTIJOHN, F.J. (1975): Sedimentary Rocks.– 3rd ed., Harper and Row, New York, NY.

PREMEC-FUĆEK, V., PEARSON, P.N. & HERNITZ KUČENJAK, M. (2010): The biostratigraphy and stable isotope paleoecology of the late Middle Eocene planktonic foraminifera (North Adriatic Sea, Croatia).– FORAMS 2010, September 5–10, Abstract book, 165–166.

PREMEC-FUĆEK, V., HERNITZ KUČENJAK, M. & HUBER, B. (2018): Taxonomy, biostratigraphy, and phylogeny of Oligocene Chiloguembelina and Jenkinsina.– In WADE et al. (eds.): Atlas of Oligocene Planktonic Foraminifera. Cush. Found. Spec Publ., 46, 528 p.

PREMOLI SILVA, I. & BOERSMA, A. (1988): Atlantic Eocene planktonic foraminiferal historical biogeography and paleohydrogeographic indices.– Paleogeography, Paleoclimatology, Paleoecology, 67, 315–356.

PREMOLI SILVA, I. & SLITER, W., V. (1995): Cretaceous planktonic foraminiferal biostratigraphy and evolutionary trends from the Bottacioni section, Gubbio, Italy.– Paleontographica Italica 82, 1–89.

PREMOLI SILVA, I. & SLITER, W.V. (1999): Cretaceous Paleoceanography: Evidence from planktonic foraminiferal evolution.– In: BARRERA, E. & JOHNSON, C.C. (eds.): The Evolution of Cretaceous Ocean–Climatic System.– GSA, Special Paper, 332, 301–328. doi: 10.1130/0-8137-2332-9.301

PREMOLI SILVA, I. & VERGA, D. (2004): Practical manual of Cretaceous planktonic Foraminifera. International School on Planktonic Foraminifera.– In: VERGA, D. & RETTORI, R. (eds.): International School on Planktonic Foraminifera, 3rd Course: Cretaceous. University of Perugia and Milano, Tipografia Pontfelecino, Perugia (Italy), p. 283.

PREMOLI SILVA, I. & PETRIZZO, M.R. (2006): Practical Manual of Eocene Planktonic Foraminifera.– International School on Planktonic Foraminifera, Universita degli Studi di Perugia, Universita degli Studi di Milano. Perugia, 248 p.

QUILLÉVÉRÉ, F., NORRIS, R., MOUSSA, I. & BERGGREN, W. (2001). Role of photosymbiosis and biogeography in the diversification of early Paleogene acarinids (planktonic foraminifera).– Paleobiology, 27/2, 311–326.

ROBASZYNSKI, F., CARON, M., GONZALES, J.M. & WONDERS, A.H. (eds.) (1984): Atlas of Late Cretaceous globotruncanids.– Revue de Micropaleontologie, 26, 145–305.

ROBASZYNSKI, F. & CARON, M. (1995): Foraminifers planctoniques du Crétacé: commentaire de la zonation Europe-Méditerrané.– Bulletin de la Société Géologique de France, 6, 681–692.

SARI, B. (2006): Upper Cretaceous planktonic foraminiferal biostratigraphy of the Bey Dağlari Autochthon in the Korkuteli area, western Taurides, Turkey.– Journal of Foraminiferal Research, 36, 241–261. doi: 10.2113/gsjfr.36.3.241

SARI, B. (2009): Planktonic foraminiferal biostratigraphy of the Coniacian-Maastrichtian sequences of the Bey Dağlari Autochton, western Taurides, Turkey: thin-section zonation.– Cretaceous Research, 30, 1103–1132.

SEXTON, P.F., WILSON, P.A. & PEARSON, P.N. (2006): Palaeoecology of late middle Eocene planktic foraminifera and evolutionary implications.– Marine Micropaleontology, 60/1–6, 1–15. doi: 10.1016/j.marmicro.2006.02.006

SHACKLETON, N.J., CORFIELD, R.M. & HALL, M.A. (1985): Stable isotope data and the ontogeny of Paleocene planktonic foraminifera.– Journal of Foraminiferal Research, 15/4, 321–336. doi: 10.2113/gsjfr.15.4.321

SPEZZAFERRI, S. & PREMOLI SILVA, I. (1991): Oligocene planktonic foraminiferal biostratigraphy and paleoclimatic interpretation from Hole 538A, DSDP Leg 77, Gulf of Mexico.– Paleogeography, Paleoclimatology, Palaeoecology, 83, 217–236. doi: 10.1016/0031-0182(91)90080-B

SPEZZAFERRI, S. (1994): Planktonic foraminiferal biostratigraphy and taxonomy of the Oligocene and lower Miocene in the oceanic record. An overview.– Paleontographica Italica, 81, 1–187.

SPEZZAFERRI, S., BASSO, D. & COCCIONI, R. (2002): Late Eocene planktonic foraminiferal response to an extraterrestrial impact at Massignano GSSP (Northeastern Appennines, Italy).– Journal of Foraminiferal Research, 32/2, 188–199. doi: 10.2113/0320188

STANKOVIĆ, D., PREMEC FUĆEK, V., HERNITZ KUČENJAK, M., MARIĆ ĐUREKOVIĆ, Ž., IVAK, P., SLAVKOVIĆ, R. & BARBIĆ, Z. (2003): Biostratigraphy and sedimentology of the Campanian and Maastrichtian sediments in the Palmyra-1 well, Palmyrides, Syria.– In: VLAHOVIĆ, I. (ed.): Abstracts book, 22nd IAS Meeting of Sedimentology, Opatija, Croatia, p. 201.

STANKOVIĆ, D., MESIĆ, I.A., IVANIČEK, Z., HERNITZ KUČENJAK, M. & PREMEC FUĆEK, V. (2005): Upper Campanian to Maastrichtian foraminiferal assemblages of the Palmyra region, Syria.– In: VELIĆ, I., VLAHOVIĆ, I. & BIONDIĆ, R. (eds.): Proceedings, Third Croatian Geological Congress, Opatija, Croatia, p. 127.

TOMLJENOVIĆ, B., VESELI, V. & TAKAČ, D. (2008): Surface and subsurface structural styles in central Syria.– Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Croatia, 81 p.

VAN DER ZWAAN, G.J., JORISSEN, F.J. & DE STIGTER, H.C. (1990): The depth dependency of planktonic/benthic foraminiferal ratios: Constraints and applications.– Marine Geology, 95, 1–16. doi: 10.1016/0025-3227(90)90016-D

WADE, B.S. (2004): Planktonic foraminiferal biostratigraphy and mechanisms in the extinction of Morozovella in the late middle Eocene.– Marine Micropaleontology, 51, 23–38. doi: 10.1016/j.marmicro.2003.09.001

WADE, B.S., PEARSON, P.N., BERGGREN, W.A. & PÄLIKE, H. (2011): Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale.– Earth-Science Reviews, 104, 111–142. doi: 10.1016/j.earscirev.2010.09.003

WADE, B.S. (2012): Successive extinction of muricate planktonic foraminifera (Morozovelloides and Acarinina) as a candidate for marking the base Priabonian.– Newsletters on stratigraphy, 45/3, 245–262. doi: 10.1127/0078-0421/2012/0023

WADE, B.S., OLSSON, R., PEARSON, P.N., HUBER, B.T. & BERGGREN, W.A. (2018): Atlas of Oligocene planktonic foraminifera.– The Cushman Foundation for Foraminiferal Research, Special Publication, 46, 528 p.

WIDMARK, J.G.V. & SPEIJER, R.P. (1997): Benthic foraminiferal faunas and trophic regimes at the terminal Cretaceous Tethyan seafloor.– Palaios, 12, 354–371. doi: 10.2307/3515335

ZACHOS, J., PAGANI, M., SLOAN, L., THOMAS, E. & BILLUPS, K. (2001): Trends, rhythms, and aberrations in global climate 65 Ma to present.– Science, 292, 686–693. doi: 10.1126/science.1059412

ZACHOS, J.C., QUINN, T.M. & SALAMY, K.A. (1996): High-resolution (10⁴ years) deep-sea foraminiferal stable isotope records of the Eocene–Oligocene climate transition.– Paleoceanography, 11/3, 251–266.

Appendix

List of planktonic foraminifera species cited in the text and figure explanation, in alphabetic order according to genus:

Cretaceous

Archaeoglobigerina blowi PESSAGNO, 1967

Contusotruncana contusa (CUSHMAN, 1926)

Contusotruncana fornicata (PLUMMER, 1931)

Gansserina gansseri (BOLLI, 1951)

Globotruncana aegyptiaca NAKKADY, 1950

Globotruncana arca (CUSHMAN, 1926)

Globotruncana bulloides VOGLER, 1941

Globotruncana conica (WHITE, 1928)

Globotruncana insignis GANDOLFI, 1955

Globotruncana rosetta (CARSEY, 1926)

Globotruncana ventricosa WHITE, 1928

Globotruncanella havanensis (VOORWIJK 1937)

Globotruncanella pschadae (KELLER, 1946)

Globotruncanita angulata (TILEV, 1951)

Globotruncanita conica (WHITE, 1928)

Globotruncanita stuarti (De LAPPARENT, 1918)

Heterohelix globulosa (EHRENBERG, 1840)

Heterohelix striata (EHRENBERG, 1840)

Macroglobigerinelloides alvarezi (ETERNOD OLVERA, 1959)

Macroglobigerinelloides bollii (PESSAGNO, 1967)

Macroglobigerinelloides prairiehillensis (PESSAGNO, 1967)

Muricohedbergella holmdelensis (OLSSON, 1964)

Muricohedbergella monmouthensis (OLSSON, 1960)

Plummerita hantkeninoides (BRÖENNIMANN, 1952)

Pseudotextularia elegans (RZEHAK, 1891)

Racemiguembelina fructicosa (EGGER, 1902)

Radotruncana calcarata (CUSHMAN, 1927)

Radotruncana subspinosa (PESSAGNO, 1960)

Rugoglobigerina macrocephala BRÖENNIMANN, 1952

Rugoglobigerina rugosa (PLUMMER, 1926)

Palaeogene

Acarinina bullbrooki (BOLLI, 1957)

Acarinina coalingensis (CUSHMAN & HANNA, 1927)

Acarinina collactea (FINLAY, 1939)

Acarinina cuneicamerata (BLOW, 1979)

Acarinina echinate (BOLLI, 1957)

Acarinina mcgowrani WADE & PEARSON, 2006

Acarinina mckannai (WHITE, 1928)

Acarinina medizzai (TOUMARKINE & BOLLI, 1975)

Acarinina pentacamerata (SUBBOTINA, 1947)

Acarinina praetopilensis (BLOW, 1979)

Acarinina primitive (FINLAY, 1947)

Acarinina pseudotopilensis SUBBOTINA, 1953

Acarinina quetra (BOLLI, 1957)

Acarinina rohri (BRÖNNIMANN & BERMÚDEZ, 1953)

Acarinina sibaiyaensis (EL-NAGGAR, 1966)

Acarinina soldadoensis (BRÖNNIMANN, 1952)

Acarinina topilensis (CUSHMAN, 1925)

Cassigeriella chipolensis (CUSHMAN & PONTON, 1932)

Catapsydrax unicavus BOLLI, LOEBLICH & TAPPAN, 1957

Chiloguembelina adriatica PREMEC FUĆEK, HERNITZ KUČENJAK & HUBER, 2018

Chiloguembelina andreae PREMEC FUĆEK, HERNITZ KUČENJAK & HUBER, 2018

Chiloguembelina crinita (GLAESSNER, 1937)

Chiliguembelina cubensis (PALMER, 1934)

Chiloguembelina midwayensis (CUSHMAN, 1940)

Chiloguembelina morsei (KLINE, 1943)

Chiloguembelina ototara (FINLAY, 1940)

Chiloguembelina wilcoxensis (CUSHMAN & PONTON, 1932)

Ciperoella anguliofficinalis (BLOW, 1969)

Ciperoella angulisuturalis (BOLLI, 1957)

Ciperoella ciperoensis (BOLLI, 1954)

Cribrohantkenina inflata (HOWE, 1928)

Dentoglobigerina galavisi (BERMÚDEZ, 1961)

Dentoglobigerina pseudovenezuelana (BLOW & BANNER, 1962)

Dentoglobigerina tapuriensis (BLOW & BANNER, 1962)

Dentoglobigerina tripartita (KOCH, 1926)

Eoglobigerina edita (SUBBOTINA, 1953)

Eoglobigerina eobulloides (MOROZOVA, 1959)

Globanomalina archeocompressa (BLOW, 1979)

Globanomalina australiformis (JENKINS, 1966)

Globanomalina chapmani (PARR, 1938)

Globanomalina compressa (PLUMMER, 1927)

Globanomalina ehrenbergi (BOLLI, 1957)

Globanomalina imitata (SUBBOTINA, 1953)

Globanomalina planocompressa (SHUTSKAYA, 1965)

Globanomalina planoconica (SUBBOTINA, 1953)

Globanomalina pseudomenardii (BOLLI, 1957)

Globigerina officinalis SUBBOTINA, 1953

Globigerinatheka barri BRÖNNIMANN, 1952

Globigerinatheka curryi PROTO DECIMA & BOLLI, 1970

Globigerinatheka index (FINLAY, 1939)

Globigerinatheka kugleri (BOLLI, LOEBLICH & TAPPAN, 1957)

Globigerinatheka luterbacheri BOLLI, 1972

Globigerinatheka subconglobata (SHUTSKAYA, 1958)

Globigerinatheka tropicalis (BLOW & BANNER, 1962)

Globoturborotalita martini (BLOW & BANNER, 1962)

Globoturborotalita occlusa (BLOW & BANNER, 1962)

Globoturborotalita ouachitaensis (HOWE & WALLACE, 1932)

Guembelitrioides nuttalli (HAMILTON, 1953)

Hantkenina alabamensis CUSHMAN, 1924

Hantkenina dumblei WEINZIERL & APPLIN, 1929

Hantkenina nanggulanensis HARTONO, 1969

Igorina albeari (CUSHMAN & BERMÚDEZ, 1949)

Igorina broedermanni (CUSHMAN & BERMÚDEZ, 1949)

Igorina pusilla (BOLLI, 1957)

Igorina tadjikistanensis (BYKOVA, 1953)

Jenkinsina columbiana (HOWE, 1939)

Morozovella acuta (TOULMIN, 1941)

Morozovella aequa (CUSHMAN & RENZ, 1942)

Morozovella angulata (WHITE, 1928)

Morozovella aragonensis (NUTTALL, 1930)

Morozovella crater (HORNIBROOK, 1958)

Morozovella edgari (PREMOLI SILVA & BOLLI, 1973)

Morozovella formosa (BOLLI, 1957)

Morozovella occlusa (LOEBLICH & TAPPAN, 1957)
Morozovella pasionensis (BERMUDÉZ, 1961)
Morozovella praeangulata (BLOW, 1979)
Morozovella subbotinae (MOROZOVA, 1939)
Morozovella velascoensis (CUSHMAN, 1925)
Morozovelloides bandyi (FLEISHER, 1974)
Morozovelloides coronatus (BLOW, 1979)
Morozovelloides crassatus (CUSHMAN, 1925)
Morozovelloides lehneri (CUSHMAN & JARVIS, 1929)
Paragloborotalia griffinoides OLSSON & PEARSON, 2006
Parasubbotina pseudobulloides (PLUMMER, 1927)
Planorotalites pseudoscitula (GLAESSNER, 1937)
Praemurica inconstans (SUBBOTINA, 1953)
Praemurica? lozanoi (COLOM, 1954)
Praemurica pseudoinconstans (BLOW, 1979)
Pseudohastigerina micra (COLE, 1927)
Pseudohastigerina naguewichiensis (MYATLIUK, 1950)
Pseudohastigerina wilcoxensis (CUSHMAN & PONTON, 1932)
Streptochilus martini (PIJPERS, 1933)
Streptochilus pristinum BRÖNNIMANN & RESIG, 1971
Subbotina cancellata BLOW, 1979
Subbotina corpulenta (SUBBOTINA, 1953)

Subbotina crociapertura BLOW, 1979
Subbotina eocaena (GUEMBEL, 1968)
Subbotina linaperta (FINLAY, 1939)
Subbotina senni (BECKMANN, 1953)
Subbotina triangularis (WHITE, 1928)
Subbotina triloculinoides (PLUMMER, 1927)
Subbotina trivialis (SUBBOTINA, 1953)
Subbotina utilisindex (JENKINS & ORR, 1973)
Subbotina velascoensis (CUSHMAN, 1925)
Subbotina yeguaensis (WEINZIERL & APPLIN, 1929)
Tenuitella gemma (JENKINS, 1966)
Trilobatus primordius (BLOW & BANNER, 1962)
Turborotalia ampliapertura (BOLLI, 1957)
Turborotalia cerroazulensis (COLE, 1928)
Turborotalia cocoaensis (CUSHMAN, 1928)
Turborotalia cunialensis (TOUMARKINE & BOLLI, 1970)
Turborotalia frontosa (SUBBOTINA, 1953)
Turborotalia increbescens (BANDY, 1949)
Turbototalia pomeroli (TOUMARKINE & BOLLI, 1970)
Turbototalia possagnoensis (TOUMARKINE & BOLLI, 1970)
Woodringina claytonensis LOEBLICH & TAPPAN, 1957
Zeauvigerina waiparaensis (JENKINS, 1966)

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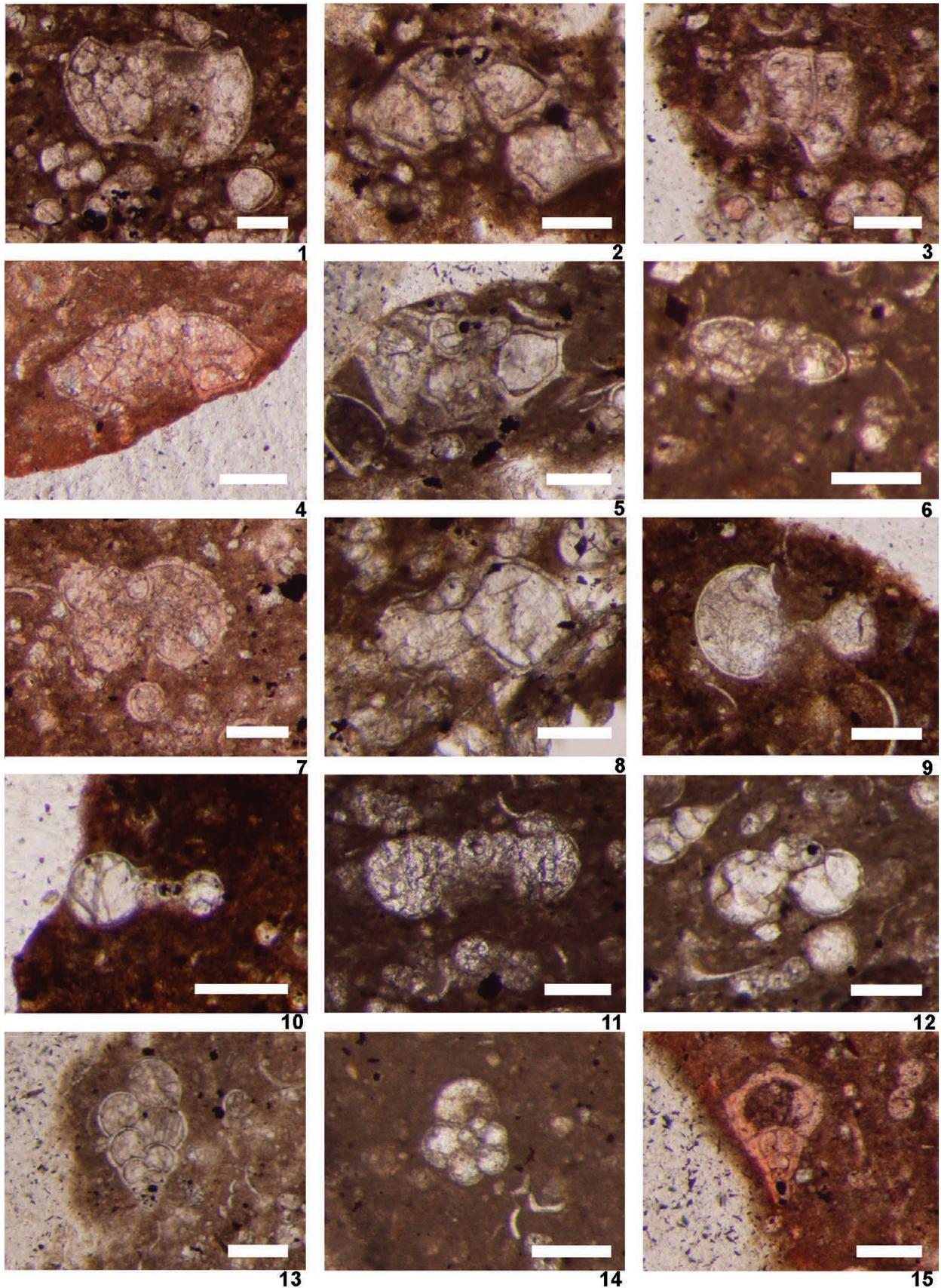
Plate 1

Figs. 1–15, Upper Campanian–Maastrichtian; scale bar 100 μm.

1. *Gansserina gansseri*, J-5, 1360–1370 m; **2.** *Globotruncanita conica*, J-5, 1370–1380 m; **3.** *Globotruncana aegyptiaca*, J-3, 1540–1545 m; **4.** *Globotruncana arca*, J-3, 1540–1545 m; **5.** *Globotruncana ventricosa*, J-4, 1735–1755 m; **6.** *Globotruncanella havanensis*, J-5, 1360–1370 m; **7.** *Rugoglobigerina rugosa*, J-5, 1340–1350 m; **8.** *Globotruncana bulloides*, J-5, 1370–1380 m; **9.** *Macroglobigerinelloides prairiehillensis*, J-4, 1735–1755 m; **10.** *Macroglobigerinelloides bolli*, J-4, 1735–1755 m; **11.** *Muricohedbergella holmdelensis*, J-4, 1735–1755 m; **12.** *Muricohedbergella monmouthensis*, J-4, 1735–1755 m; **13.** *Heterohelix globulosa*, J-5, 1340–1350 m; **14.** *Archaeoglobigerina blowi*, J-4, 1735–1755 m; **15.** *Pseudotextularia elegans*, J-5, 1340–1350 m.
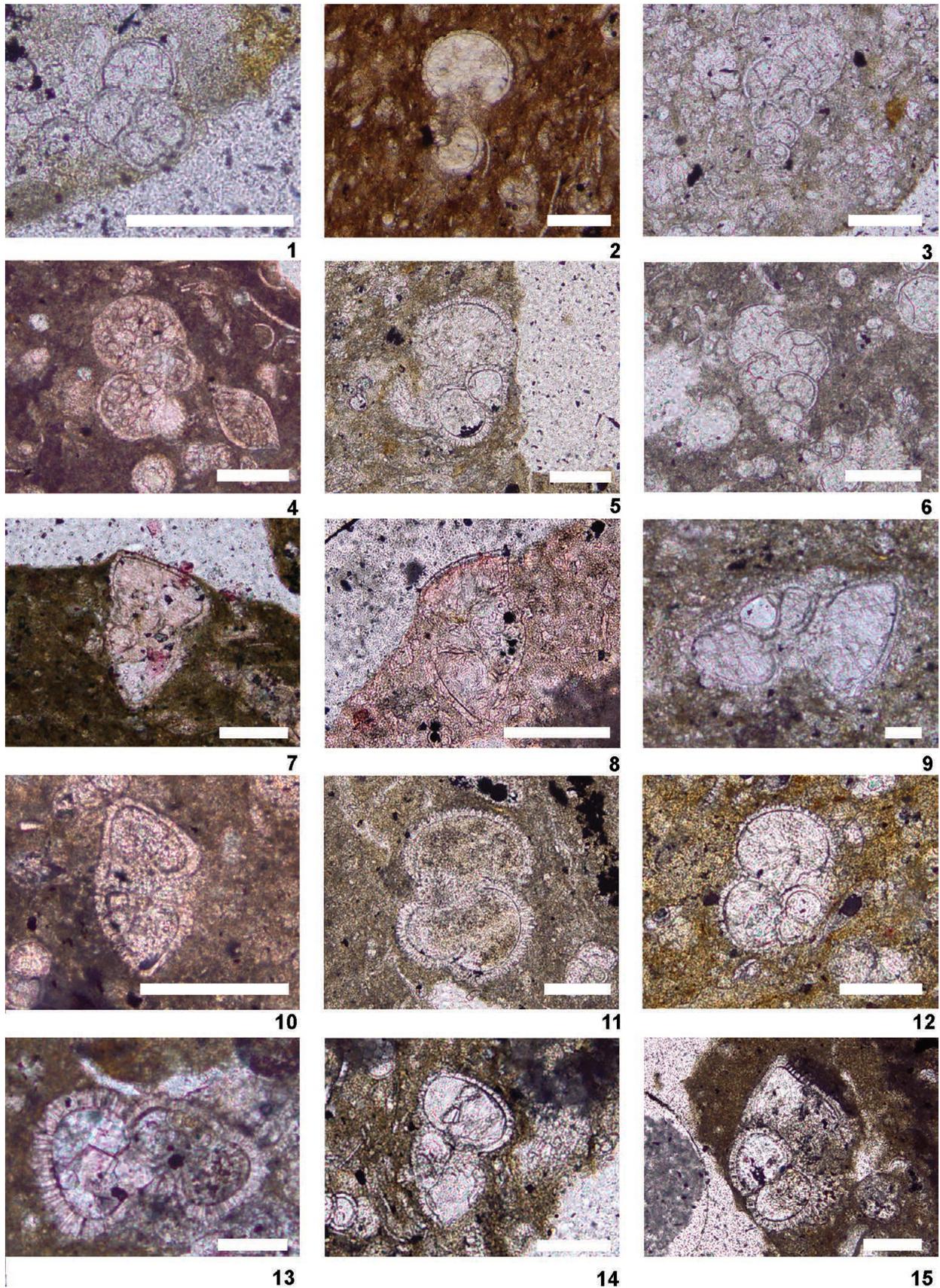
Plate 2

Figs. 1–7, Lower Palaeocene; Figs. 8–15; Upper Palaeocene; scale bar 100 μm

1. *Eoglobigerina eobulloides*, 1700–1710 m; **2.** *Parasubbotina pseudobulloides*, J-3, Core-2, 1604–1613 m, I m, 20 cm; **3.** *Woodringina claytonensis*, J-2, 1700–1710 m; **4.** and **5.** *Subbotina triloculinoides*, J-3, 1540–1545 m; **6.** *Chiloguembelina morsei*, J-3, 1540–1545 m; **7.** *Morozovella praeangulata*, J-2, 1550–1560 m; **8.** *Morozovella angulata*, J-3, 1285–1290 m; **9.** *Morozovella angulata* J-2, 1540–1550 m; **10.** *Igorina pussila*, J-2, 1510–1520 m; **11.** *Subbotina cancellata*, J-2, 1450–1460 m; **12.** *Subbotina* cf. *triangularis*, J-2, 1270–1280 m; **13.** *Acarinina coalingensis*, J-2, 1370–1380 m; **14.** *Acarinina* cf. *soldadoensis*, J-2, 1285–1290 m; **15.** *Acarinina* sp., J-2, 1300-1310 m.

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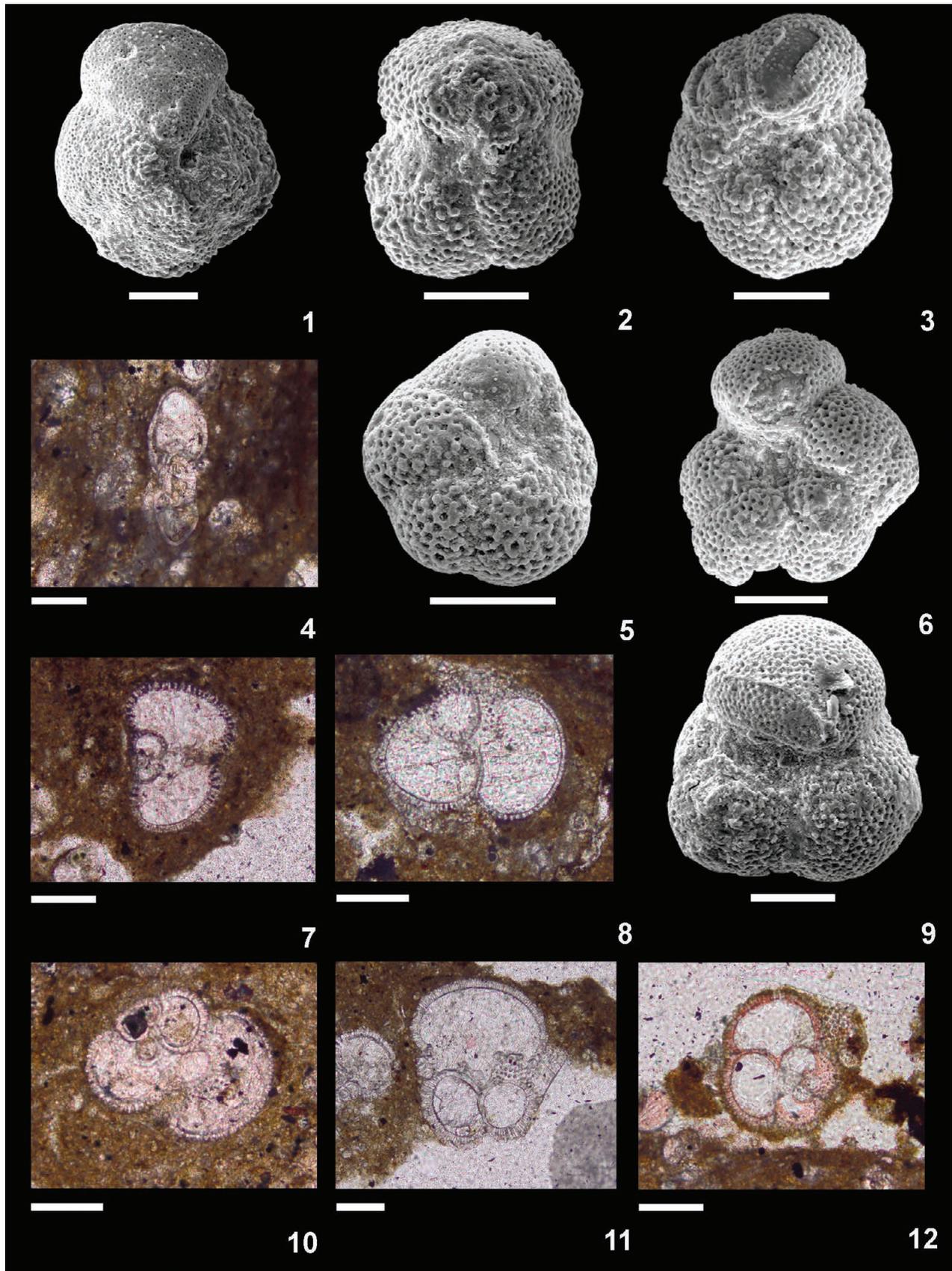
Plate 3

Figs. 1–12, Lower Eocene, scale bar 100 μm

1. *Morozovella subbotinae*, J-2, 1160–1180 m; **2.** *Morozovella aequa*, J-2, 1160–1180 m; **3.** *Acarinina pentacamerata*, J-3, Core-1 (842-852 m), VII m, 70 cm; **4.** *Globano-malina planoconica.*, J-2, 1070–1080 m; **5.** *Igorina* cf. *broedermanni*, J-2, 1200–1220 m; **6.** *Acarinina cuneicamerata*, J-3, Core-1 (842–852 m), VII m, 70 cm; **7.** *Acarinina bullbrooki*, J-2, 1160–1170 m; **8.** *Turborotalia frontosa*, J-1, 885-890 m; **9.** *Subbotina eocaena*, J-2, 1160–1180 m; **10.** *Subbotina eocaena* J 2, 1190–1200 m; **11.** *Subbotina linaperta*, J-2, 1100-1110 m; **12.** *Subbotina* sp., J-2, 1160-1170 m.
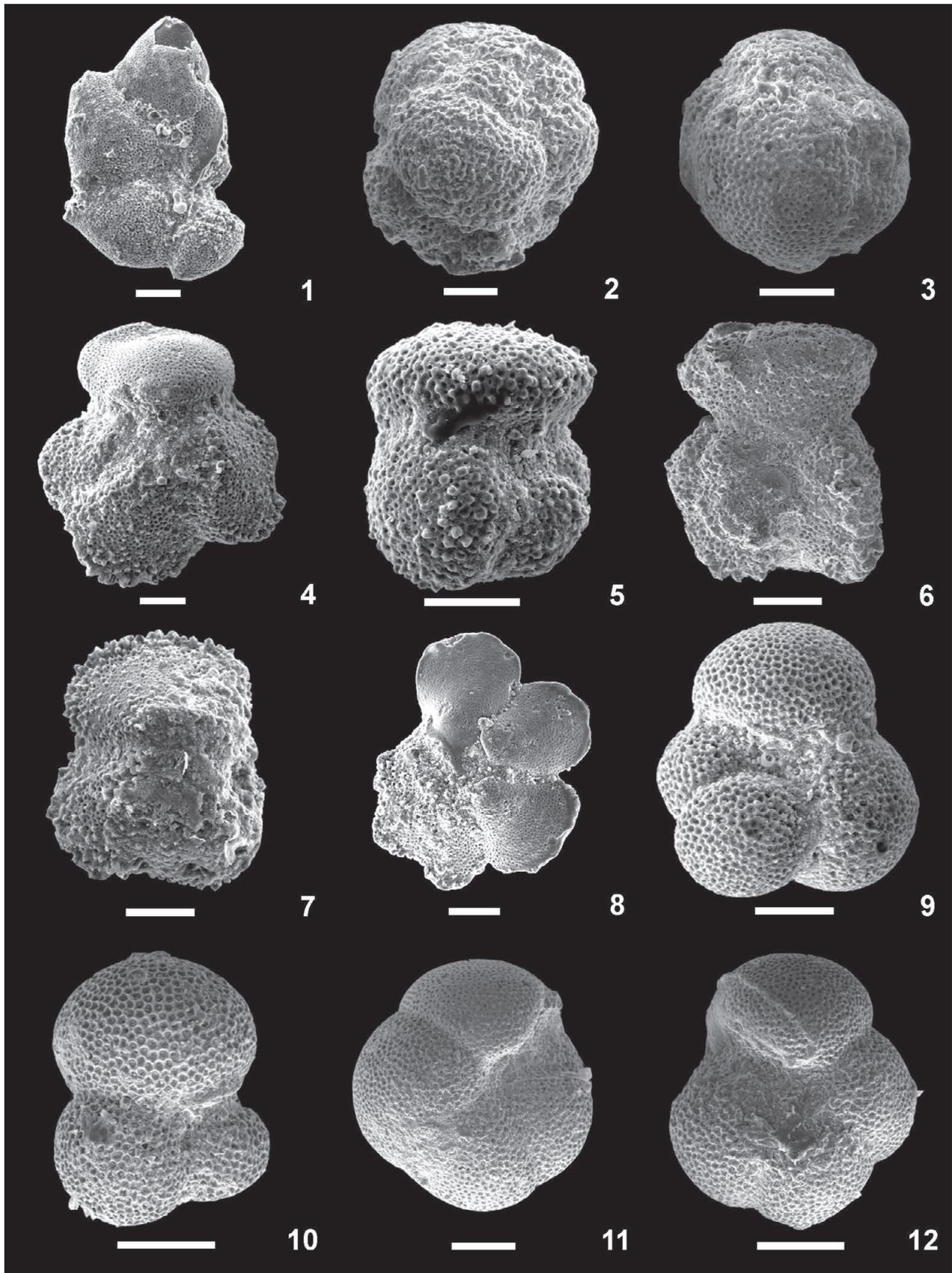
Plate 4
Figs. 1–12, Middle Eocene, scale bar 100 µm
1. *Hantkenina* cf. *dumblei*, J-3, 520–530 m; **2.** *Globigerinatheka curryi*, J-3, 520–530 m; **3.** *Globigerinatheka subconglobata*, J-3, 520–530 m; **4.** *Morozovelloides* cf. *bandyi*, J-2, 720–740 m; **5.** *Acarinina mcgowrani*, J-2, 680–700 m; **6.** *Acarinina topilensis*, J-1, 540–550 m; **7.** *Morozovelloides crassatus*, J-3, 520-530 m; **8.** *Morozovelloides lehneri*, J-2, 720–740 m; **9.** *Subbotina eocaena*, J-3, 520–530 m; **10.** *Subbotina linaperta*, J-1, 540–560 m; **11.** *Turbototalia pomeroli*, J-1, 700–720 m; **12.** *Turborotalia cerroazulensis*, J-1, 600–610 m.

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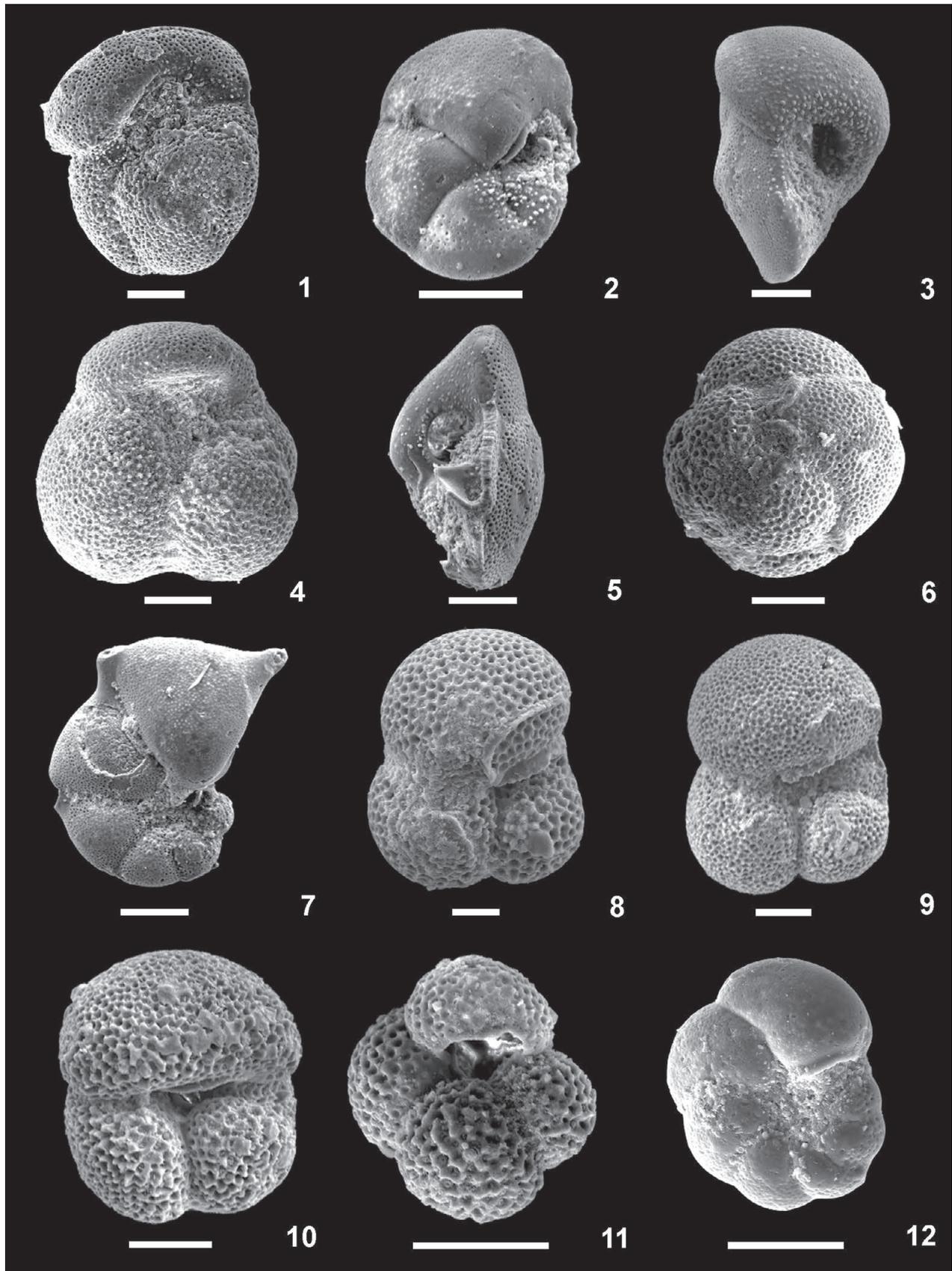
Plate 5

Figs. 1–12, Upper Eocene, scale bar 100 μm

1. *Turborotalia cerroazulensis*, J-3, 370–380 m; **2.** and **3.** *Turborotalia cocoaensis*, J-6, 440–460 m; **4.** *Turborotalia ampliapetura*, J-2, 560–580 m; **5.** *Turborotalia cunialensis*, J-6, 440–460 m; **6.** *Globigerinatheka barri*, J-2, 600–620 m; **7.** *Hantkenina alabamensis*, J-5, 280–290 m; **8.** *Subbotina linaperta*, J-3, 370–380 m; **9.** *Subbotina yeguaensis*, J-6, 440–460 m; **10.** *Dentoglobigerina galavisi*, J-6, 440–460 m; **11.** *Globoturborotalita ouachitaensis*, J-6, 440–460 m; **12.** *Pseudohastigerina micra*, J-2, 600–620 m.
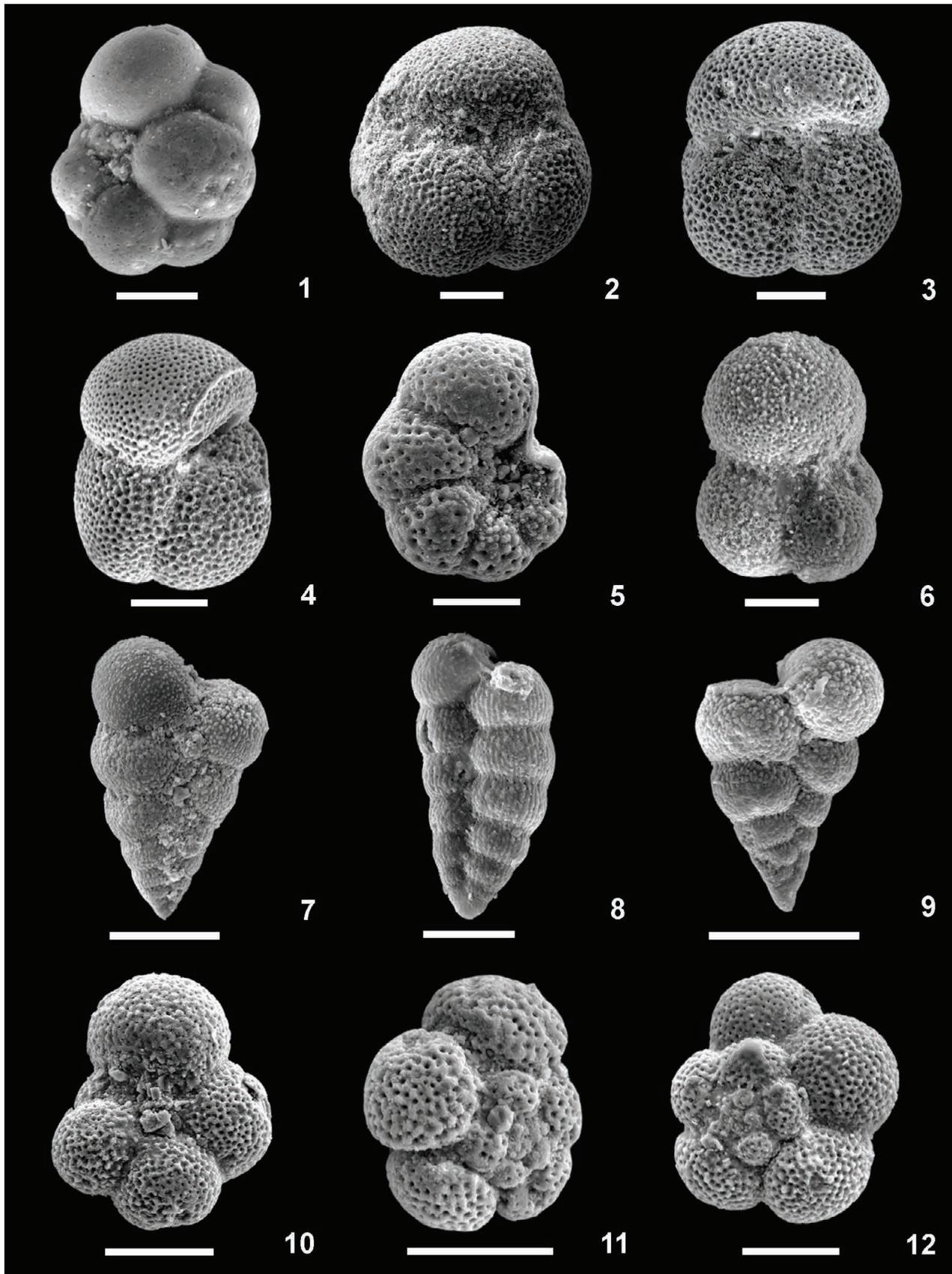
Plate 6

Figs. 1–12, Oligocene; scale bar 100 μm, except Figs. 1, 5, 10–50 μm.

1. *Cassigeriella chipolensis*, J-5, 190–200 m; **2.** *Dentoglobigerina tripartita*, J-6, 400–420 m; **3.** *Dentoglobigerina tapuriensis*, J-6, 400–420 m; **4.** *Turborotalia ampliapertura*, J-6, 360–380 m; **5.** *Pseudohastigerina naguewichiensis*, J-5, 220–230 m; **6.** *Globigerina officinalis*; J-1, 240–250 m; **7.** *Chiloguembelina ototara*, J-6, 400–420 m; **8.** *Chiloguembelina cubensis*, J-6, 360–380 m; **9.** *Chiloguembelina adriatica*, J-6, 360–380 m; **10.** *Ciperoella anguliofficinalis*, J-5, 160–170 m; **11.** *Ciperoella angulisuturalis*, J-4, 455–475 m; **12.** *Ciperoella ciperoensis*, J-4, 455–475 m.