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

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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 Globotruncanita aegyptica, Gansserina gansseri, Globotruncanella havanensis, Globotruncanita angulata and Pseudotruncatella 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 morsai, Woodringina claytonensis and Parasubbotina pseudobulloides. The late Palaeocene is marked by originiation of the morozovellids, acarininids and globanomalinds, while the early Eocene is characterized by a tropical assemblage, dominated by muriate 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, Morozovellidae, and to a lesser degree Turborotalia, Globigerinatheka and Hankenina. The middle/late Eocene boundary is marked by double extinction of the last muriate taxa Acarinina mcgowrani and Morozovellidae crassatus, which indicate a variable climate, water column instability, and loss of surface habitats. In contrast, Turborotalia and Globigerinatheka become more important in the late Eocene. The Eocene/Oligocene boundary is marked by the extinction of most warm water taxa including Turborotalia ceroazulensis group, Hankenina, Globigerinatheka and some subbotinids. The beginning of the early Oligocene is indicated by the domination of cool water taxa such as Dentoglobigerina, Globorotalioides, 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.

Keywords: biostratigraphy, lithology, upper Cretaceous, Palaeogene, planktonic foraminifera, Syria

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 clacey 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$_2$O$_2$), 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.


Petrographic and sedimentological analyses focused on thinsections 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.
central part of Syria. The Palmyrides are the most extensive and
topographically prominent tectonic zone in Syria. This area rep-
resents a 400 km long and 100 km wide intracratonic 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 com-
monly 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-montain basin, lies between
the Jihar fault and the short-wavelength folds of the southern Pal-
myrides (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 depo-
centre 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 pro-
posed by BREW (2001). The examined succession spans the
Campanian to Oligocene time interval and is represented by four
lithostratigraphic units – the Shiranish Formation (upper Cam-
panian–Maastrichtian), Kermav Formation (Palaeocene), Jaddala
Formation (Eocene) and Chilou Formation (Oligocene).

4.1. Shiranish Formation
(Upper Campanian–Maastrichtian)
The Shiranish Formation (Fig. 2) is characterized by argillaceous
limestones, marls, chert and sporadic disc shaped or ovoid cal-
careous 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 lime-
stones, marls, chert and sporadic disc shaped or ovoid cal-
careous 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.
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 sufficiently silty with planktonic foraminifera. Cherts are composed of very fine granular quartz with patches of chaledony, 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 aggregate of crystals with irregular edges marking the silification front. Glauconite grains are 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, Racemigumbelina fructicosa, Pseudotextularia elegans, Globotruncana conica, Gansserina gansseri (Pl. 1, Fig. 1), Plummerita hantkeninoides, Globotruncana pschadae, Globotruncana angulata, Globotruncana conica (Pl. 1, Fig. 2), Rugoglobigerina macrocephala, Globotruncana aegyiacta (Pl. 1, Fig. 3), Globotruncana arca (Pl. 1, Fig. 4), Globotruncana ventricosa (Pl. 1, Fig. 5), Globotruncanella havanensis (Pl. 1, Fig. 6), Globotruncanaeus stuartii 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 rosseta, Rugoglobigerina rugosa (Pl. 1, Fig. 7), Globotruncana bulloides (Pl. 1, Fig. 8), Macroglobigerinelloides prairiellihens (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 bolli and Pseudotextularia elegans (Pl. 1, Fig. 15) and Planoglobulina sp. The assemblage of small benthic foraminifera includes Oridorsalis umbonatus, Cibicidoides sp., Bolivinoides sp., Pellenia sp., Triaxia 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; GRAFE, 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,
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–P1 after OLSSON et al. (1999) and WADE et al. (2011). This association contains the following taxa: Eoglobigerina ebulloides (Pl. 2, Fig. 1), E.edita, Parasubbotina pseudobulloides (Pl. 2, Fig. 2), Woodwardingerina 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. ehenbergi, Morozovella praeguembelata, Parasubbotina pseudobulloides and Chiloguembelina midwaysensis first appeared in the early Palaeocene and continue into the late Palaeocene. The species Morozovella praeguembelata (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: Neoepontides, Pullenina, 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 praeguembelata, 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, Figs. 8 and 9), M. praeguembelata, A carcinina mckannai, Igorina pusilla (Pl. 2, Fig. 10), I. tadjikistanensis and I. albeeri. 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. subbotinæ, Subbotina velascoensis, Acarinina coalingensis (Pl. 2, Fig. 13), A. soldadoensis (Pl. 2, Fig. 14) and A carcinina sp. (Pl. 2, Fig. 15). Microperforate biserial species are represented by Chiloguembelina midwaysensis, C. wilcoxensis, C. crinita and Zeauvigerina waiparensis. 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 A carcinina sihaiyaensis (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 A carcinina, 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 subbotinæ (Pl. 3, Fig. 1), Morozovella aequa (Pl. 3, Fig. 2), Morozovella acuta, A carcinina coalingensis, A carcinina soldadoensis, Subbotina velascoensis, Globanomalina planocoenica (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, A carcinina primitiva, A carcinina pentacamerata (Pl. 3, Fig. 3), Igorina broedermani (Pl. 3, Fig. 5), and A carcinina cuneicamerata (Pl. 3, Fig. 6). In addition, Morozovella formosa, A carcinina pseudotopilensis and A carcinina quater 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 A carcinina, which is represented by the following species: A carcinina 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. linaptera (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 Guembelitioides nutalli (BERGGREN & PEARSON, 2005; WADE et al., 2011). In addition, the lowermost part of the middle Eocene is characterized by the common occurrence of A carcinina 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 A carcinina pentacamerata, A. cuneicamerata, A. praetopilensis and A. primitiva. A carcininids 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: Pararhabdus griffini, Praemurica lozanoi, Globanomalina australiformis and Catapsydrax unicus. Specimens of the genera Hankenkina (H. dumblei, Pl. 4, Fig. 1) and Globigerinatheca represented with the species G. curvy (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. Pseudoastigerina microa and P. wilcoxiensis 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 obtara, Chiloguembelina sp. and Streptochilus martini. The triserial species Jenkinsina columbia is present with a few specimens per sample.

In the upper part of the middle Eocene, which approximately corresponds to Zones E13, E14 and E15) contain very rich and highly diverse planktonic foraminiferal assemblages. Acarininids remain a dominant component and are represented by Acarinina mcgowrani, Morozovelloides crassatus and small acarininids made up to 40% of the total assemblage. They become replaced by an increasing number of turborotalids, subbotinids and globigerinathekids. In the latest middle Eocene, species with cooler water preference such as Subbotina, Dentoglobigerina, Catapsydrax and Turborotalia 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 crassatus 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/lower 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 meddziai, 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 cunalis (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 Globigerinatheca 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). Hankeninids are represented by rare occurrences of Hankenkina alabamensis (Pl. 5, Fig. 7), H. nanggulanensis and Cribrohankenkina inflata. 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 galavis (Pl. 5, Fig. 10), and D. tripartita, whereas D. pseudovezezuelana 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 obtara, 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. microa (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 Oligocene/Eocene (E/O) boundary is marked by the extinction of all hankeninids and the last representative of the genus Globigerinatheca - 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 turnover. Most of the specialized warm water taxa such as the Turborotalia cerroazulensis group, globigerinathekids and hankeninids, which were important constituents of the middle and late Eocene planktonic foraminiferal community were replaced by cooler 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 chilopelona (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-
including Dentoglobigerina tripartita (Pl. 6, Fig. 2), D. pseudovenezueliana, D. tapurienis (Pl. 6, Fig. 3), Subbotina gortani, S. corpulentata, S. utilissiindex, S. angiporoidea, Turborotalia ampliapertura (Pl. 6, Fig. 4) and T. increbescens. Small sized species such as Pseudohastiglutenia naguewiichiensis (Pl. 6, Fig. 5), Tenuitella gemma, Tenuitella sp., Globigerina officinalis (Pl. 6, Fig. 6) are also common. Small sized biserial taxa such as Chiloguembelia 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 Chiloguembelia 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 Ciperoellidae 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 Chiloguembelia 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 Globotruncanita (G. ouachitaensis, G. occulusa). 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 chiplolensis, Tenuitella angustiambulcata, streptohilus pristinus, and rare specimens of Chiloguembelia cubensis and Jenkinsina cumbiana. 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 Cassigerinella chiplolensis specimens occurred in the planktonic foraminiferal association. This occurrence as well as the composition of the entire planktonic foraminiferal assemblage 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 latitudinal thermal gradients (HUBER et al., 1995), and the formation of deep warm, saline bottom waters (thermohaline 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 world 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 Pseudoguembelia species (ABRAMOVICH et al., 2003). Most species such as Globotruncanella, Contusotruncanella, 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 Globigerinoides and Racemiguembelia occupied the thermocline layer, whereas Rugoglobigerina, Pseudotextularia and heterohelicids inhabited 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), *Woodringia claytonensis* (Pl. 2, Fig. 3), *Subbotina trivialis* and *Parasubbotina pseudobulloides* (Pl. 2, Fig. 2), which likely belong to the earliest Palaeocene Zones P0–P2. 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 *Morozovellia* 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; QUILLÉVÉRE & NORRIS, 2003; BIRCH et al., 2012). In addition, opportunistic (r-strategists) species subtubinids and globanomalids, 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 (ZA-CHOS 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 δ13C 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 *Morozovella*) 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, 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 subtubinids, parasubtubinids and globanomalids 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, globigerinathekills, and by the common occurrence of the opportunistic species (r-mode life strategists) subtubinids, 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 FUCÉK et al., 2010). The last representatives of the larger muricate taxa *Acarinina mczgavranii* and *Morozovelloides crassatus* had their highest occurrence (HO) at the middle/late Eocene boundary (WADE, 2004; PREMEC FUCÉK et al., 2010; WADE et al., 2012).

The cooling that began in the middle Eocene significantly affected the **late Eocene** planktonic foraminiferal community
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 Globigerinatethaka, 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 species of the small spiny symbiont bearing genera Ciperoella (C. ciperoensis, C. angulisuralis), 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 ouachitensis, G. occlusa, Ciperoella angulisuralis, C. ciperoensis, and Globigerinatetha officinalis. These spinoce 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 production 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 Maasstrichtian planktonic fauna is highly diversified with the domination of warm water taxa such as Contusotruncana contusa, Racemigbulinella fructicosa, Globotruncanae aegyptiaca, Globotruncanae ventricose, Gansserina gansseri, Globotruncanella havanensis, Globotruncanaita angulata, Globotruncanaita stuarti, Rugoglobigerina macrocephala, Macroglobigerinelloides alvarezi and Pseudoextullaria 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, Globomalinia 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 spineless 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 Acarbonina 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 palaeoecological and palaeoceanographic trends with the domination of the muricate species Morozovella, Acarbonina and Igorina which hosted algal photosymbions 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 Acarbonina 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, Globigerinatetha and Hantkenina. In contrast to mid latitudes, the three important genera Turborotalia, Globigerinatetha and Hantkenina are present in low numbers in the investigated area. Double extinction of the last muricate taxa Acarbonina megowrani and Morozovelloides crassatus 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, *Hanktenina*, *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 spinozo surface dweller *Ciprelloa ciperozensis* 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**


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)
Globoconacea aygptiaca NAKKADY, 1950
Globoconacea arca (CUSHMAN, 1926)
Globoconacea bulboides VOGLER, 1941
Globoconacea conica (WHITE, 1928)
Globoconacea insignis GANDOLFI, 1955
Globoconacea rosetta (CAREY, 1926)
Globoconacea ventricosa WHITE, 1928
Globoconacea havaensis (VOORWIJK 1957)
Globoconacea pschadai (KELLER, 1946)
Globoconanita angulata (TILEV, 1951)
Globoconanita conica (WHITE, 1928)
Globoconanita stuarti (De LAPPARENT, 1918)
Heterohelix globulosa (EHRENBERG, 1840)
Heterohelix striata (EHRENBERG, 1840)
Macrogloboconellinoidea alvarezi (ETERNO OLVERA, 1959)
Macrogloboconellinoidea bulbii (PESSAGNO, 1967)
Macrogloboconellinoidea praehillichen (PESSAGNO, 1967)
Maricohedbergella holmdelensis (OLSSON, 1964)
Maricohedbergella mommouthensis (OLSSON, 1960)
Plummerita hantkenina (BRÖNNIMANN, 1954)
Pseudotextularia elegans (RZEHAK, 1891)
Racemiguembelina fructiosa (EGGER, 1902)
Radotruncana calcarata (CUSHMAN, 1927)
Radotruncana subspinoso (PESSAGNO, 1960)
Rugoglobigerina macrocephala BRÖNNIMANN, 1952
Rugoglobigerina rugosa (PLUMMER, 1926)

**Palaeogene**

Acarinina bullbrooki (BOLLI, 1957)
Acarinina colangensis (CUSHMAN & HANNA, 1927)
Acarinina collactea (FINLAY, 1939)
Acarinina cuneicamerata (BLOW, 1979)
Acarinina echinate (BOLLI, 1957)
Acarinina megovranri WADE & PEARSON, 2006
Acarinina mckannai (WHITE, 1928)
Acarinina medizzi (TOUMARKINE & BOLLI, 1975)
Acarinina pentacamerata (SUBBOTINA, 1947)
Acarinina praeotopenilsen (BLOW, 1979)
Acarinina primitive (FINLAY, 1947)
Acarinina pseudotopenilsen SUBBOTINA, 1953
Acarinina querta (BOLLI, 1957)
Acarinina rohri (BRÖNNIMANN & BERMÜDEZ, 1953)
Acarinina sibaiyaensis (EL-NAGGAR, 1966)
Acarinina soldadoensis (BRÖNNIMANN, 1952)
Acarinina topilensis (CUSHMAN, 1925)
Cassigeriella chipolesis (CUSHMAN & PONTON, 1932)
Catapsydrax unicusus BOLLI, LOEBLICH & TAPPAN, 1957

**Chiloguembelina adriatica** PREMEC FUČEK, HERNITZ KUČENJAK & HUBER, 2018
**Chiloguembelina andreae** PREMEC FUČEK, HERNITZ KUČENJAK & HUBER, 2018
**Chiloguembelina crinita** (GLAESNNER, 1937)
**Chiloguembelina cubensis** (GLAESNNER, 1934)
**Chiloguembelina midwayensis** (CUSHMAN, 1940)
**Chiloguembelina morsei** (KLINE, 1943)
**Chiloguembelina otoara** (FINLAY, 1940)
**Chiloguembelina wilcoxiensis** (CUSHMAN & PONTON, 1932)
**Ciperoella anguilloficialis** (BLOW, 1969)
**Ciperoella angulisuturalis** (BOLLI, 1957)
**Ciperoella ciperoensis** (BOLLI, 1954)
**Cribrohankenina inflata** (HOWE, 1928)
**Dentogloboconella galavisi** (BERMÚDEZ, 1961)
**Dentogloboconella pseudovenezeluana** (BLOW & BANNER, 1962)
**Dentogloboconella tapurien** (BLOW & BANNER, 1962)
**Dentogloboconella tripartita** (KOCHE, 1926)
**Eoglobigerina edita** (SUBBOTINA, 1953)
**Eoglobigerina eobulloides** (MOROZOVA, 1959)
**Globanomaconella archeocompressa** (BLOW, 1979)
**Globanomaconella australformis** (JENKINS, 1966)
**Globanomaconella chapmani** (PARR, 1938)
**Globanomaconella compressa** (PLUMMER, 1927)
**Globanomaconella ehrenbergi** (BOLLI, 1957)
**Globanomaconella imitata** (SUBBOTINA, 1953)
**Globanomaconella planocompressa** (SHUTSKAYA, 1965)
**Globanomaconella planocomtica** (SUBBOTINA, 1953)
**Globanomaconella pseudomenardii** (BOLLI, 1957)
**Globigerinatheka 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 aheari** (CUSHMAN & BERMÜDEZ, 1949)
**Igorina bredermannii** (CUSHMAN & BERMÜDEZ, 1949)
**Igorina pusilla** (BOLLI, 1957)
**Igorina tadjikistanensis** (BYKOV, 1953)
**Jenkinsina cimbriana** (HOWE, 1928)
**Morozovella acuta** (TOULMIN, 1941)
**Morozovella aqua** (CUSHMAN & RENZ, 1942)
**Morozovella angulata** (WHITE, 1928)
**Morozovella aragonensis** (NUTTALL, 1930)
**Morozovella crater** (HORNIBROOK, 1958)
**Morozovella edgar** (PREMOLO SILVA & BOLLI, 1973)
**Morozovella formosa** (BOLLI, 1957)
Morozovella occlusa (LOEBLICH & TAPPAN, 1957)
Morozovella pasionensis (BERMUDÉZ, 1961)
Morozovella praemungulata (BLOW, 1979)
Morozovella subbotinæ (MOROZOVA, 1939)
Morozovella velascoensis (CUSHMAN, 1925)
Morozovelloides bandyi (FLEISHER, 1974)
Morozovelloides coronatus (BLOW, 1979)
Morozovelloides crassatus (CUSHMAN, 1925)
Morozovelloides lehneri (CUSHMAN & JARVIS, 1929)
Paragloborotalia griffinoidea 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)
Pseudojastigerina naguewichtiensis (MYATLIUK, 1950)
Pseudojastigerina 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 canialensis (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)
Plate 1
Figs. 1–15, Upper Campanian–Maastrichtian; scale bar 100 μm.
Plate 2

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

Plate 3
Figs. 1–12, Lower Eocene, scale bar 100 μm
Plate 4

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

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 cuni-
Plate 6

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