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Planktonic foraminiferal biostratigraphy and paleoecology of Upper Cretaceous deposits from the Palmyride Region, Syria

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ABSTRACT

This study represents a detailed micropalaeontological investigation of the composition and diversity of planktonic foraminiferal assemblages from the upper Turonian to Maastrichtian interval of two deep exploration wells (Al Mahr-1 and Palmyra-1) in the Palmyride area of Syria. In combination with lithostratigraphic analysis, this detailed biostratigraphic study provided important new palaeoecological and palaeoclimatic interpretations and insights into the nature of deposition along the northern passive margin of Gondwana during the Late Cretaceous.

The investigated strata belong to three lithostratigraphic units (from base to top): the upper part of the Judea Formation (upper Turonian–lowermost Santonian), the Soukhne Formation (Santonian–lower Campanian), and the Shiranish Formation (upper Campanian–Maastrichtian). The results represent the first detailed determination of planktonic foraminifera from the Palmyride region. The presence of rich and diverse foraminiferal associations enabled the establishment of the following nine late Turonian to Maastrichtian biostratigraphic zones, based on documented index-taxa and/or the entire microfossil assemblages: I) Biozone I; II) Biozone II; III) Biozone III; IV) *Contusotruncana plummerae* Zone; V) Biozone V; VI) *Globotruncanella havanensis* Zone; VII) *Pseudoguembelina palpebra* Zone; VIII) *Racemiguembelina fructicosa* Zone; and IX) *Abathomphalus mayaroensis* Zone. The late Turonian to early Campanian foraminiferal assemblages (biozones I–IV) are dominated by opportunistic taxa (r-strategists) and suggest a generally fluctuating subtropical climate and deposition an outer shelf environments. The well-preserved and highly diversified late Campanian to Maastrichtian foraminiferal assemblages (biozones V–IX) imply the presence of a well-stratified water column, tropical to subtropical climate, and deposition in outer shelf to upper bathyal environments. A decrease in the number of globotruncanid species during the late Maastrichtian indicates a less stratified water column and unfavourable environmental conditions for K-strategists.

The common occurrence of phosphate grains in the Soukhne Formation (Santonian–lower Campanian) represents an important indicator of specific geological and palaeoenvironmental conditions, such as oxygen deficiency, upwelling and transgression. These conditions support the interpretation of the domination by opportunistic planktonic foraminiferal taxa (heterohelicids and muricohedbergellids) in Biozone II.

Keywords: Planktonic foraminifera, Biostratigraphy, Phosphatic grains, Upper Turonian–Maastrichtian, Palmyride region, Syria

1. INTRODUCTION

The Palmyride area is part of the northern Arabian platform (Fig. 1). The Arabian platform was located on the northern passive margin of Gondwana bordering the Tethys Ocean for most of the Phanerozoic. The Palmyride fold belt was established at the site of an inverted Mesozoic rift basin and developed as a linear trough genetically related to the Levantine margin rift system, which formed along a Gondwana Proterozoic suture zone (BREW, 2001). Ongoing extension produced a 6 km thick and 200 km laterally extensive Palaeozioc and Mesozoic sedimentary succession (BREW, 2001). Tectonic evolution of the area has been strongly influenced by geological activity along the Arabian plate boundaries: the Dead Sea transform fault to the west, the Bitlis suture and East Anatolian fault to the north, and the Zagros suture to the east (Fig. 1).

This study focuses on the Upper Cretaceous (upper Turonian–Maastrichtian) succession from two deep exploration wells Al Mahr-1 and Palmyra-1, and was aimed at age determination and correlation (litho- and biostratigraphic) of strata based on their microfossil assemblages (mainly planktonic and some benthic foraminifera). Planktonic foraminifera have been abundant in most oceanic environments since their appearance in the Middle Jurassic and are the most commonly used microfossil group for biostratigraphic zonation and reconstruction of past sea surface-water conditions and palaeoclimate (HEMLEBEN et al., 1989; MURRAY, 1991).

Many studies have focused on biostratigraphic evolution of Cretaceous planktonic foraminifera (e.g., ROBASZYNSKI et al., 1984; 2000; CARON, 1985; SLITER, 1989; ROBASZYNSKI & CARON, 1995; PETRIZZO, 2003; PREMOLI SILVA & VERGA, 2004; SARI, 2006, 2009; BABAZADEH et al., 2007; HUBER et al., 2008; PETRIZZO et al., 2011; GARDIN et al., 2012). Previous biostratigraphic investigations of the Upper Cretaceous deposits in the Palmyride area were undertaken on material from deep exploration wells by LUČIĆ (2001), STANKOVIĆ et al. (2003; 2005), and DACER et al. (2007), but not in a great detail.

The main purpose of this paper is to establish planktonic foraminiferal zonation of the upper Turonian–Maastrichtian succession of the Palmyride area based on the microfossil assemblages and/or index taxa present in order to improve palaeoenvironmental interpretations of deposition in the Palmyride basin during the late Cretaceous. The biostratigraphic zonation is compared with the regional Tethyan zo-

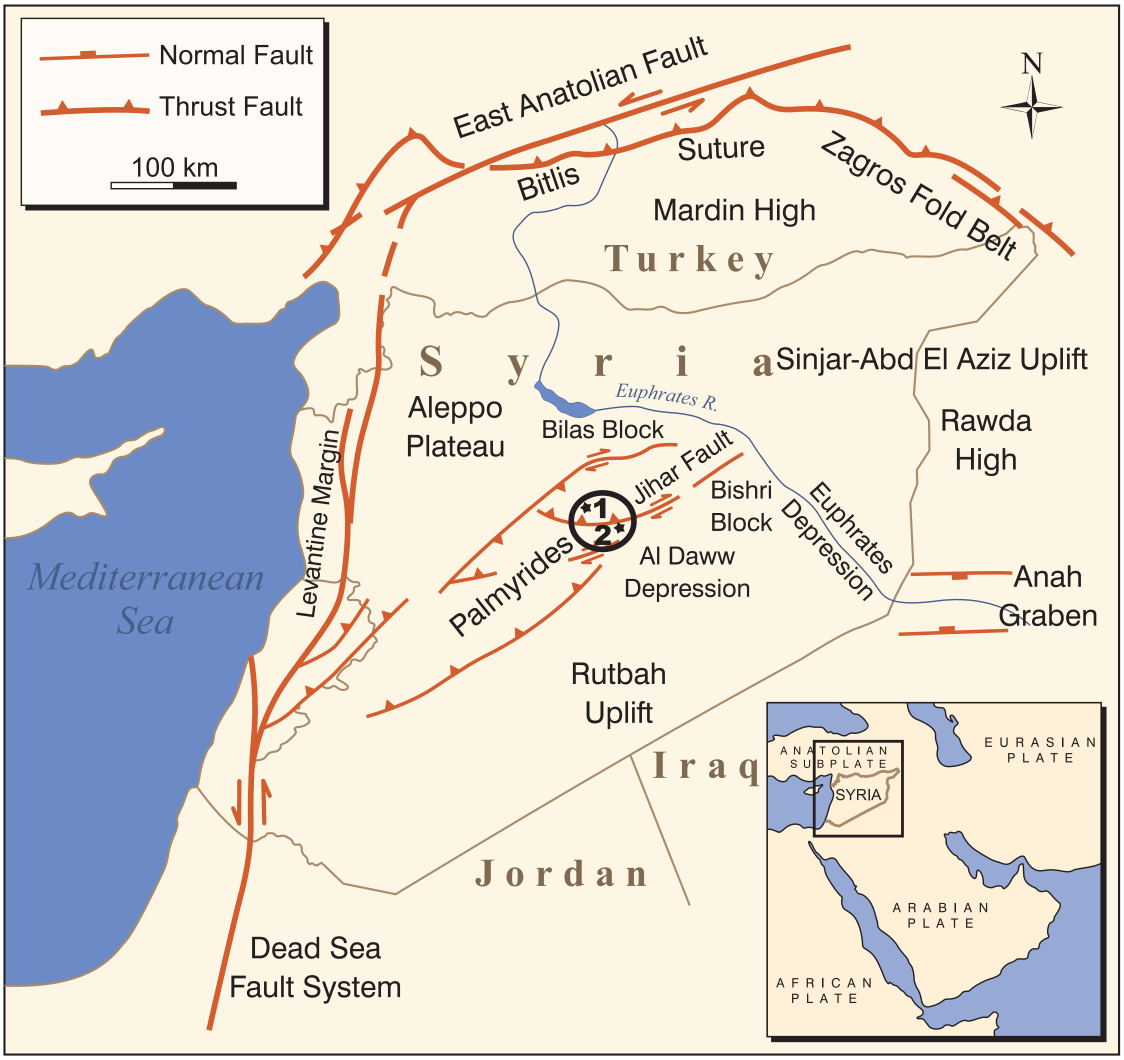


Figure 1: Map showing major tectonic zones in Syria and the surrounding areas (modified from LITAK et al., 1998) and the study area in the Palmyride region. A circle represents the approximate location of the Hayan block with the Al Mahr-1 (1) and Palmyra-1 (2) exploration wells; distance between the wells is about 50 km.

nation. Documenting variations in planktonic foraminiferal assemblages and any associated lithological changes are critical for making palaeoclimatic and palaeoceanographic interpretations. Santonian to early Campanian sediments rich in phosphate grains are examined here as an important indicator of specific geological and palaeoenvironmental conditions. The data obtained are compared to those from other coeval regional successions in order to establish the significance of the Palmyride strata, as part of the Arabian platform, for better understanding of the sedimentary evolution of the broader Tethyan region and its response to global environmental changes.

2. GEOLOGICAL SETTING

Regionally the investigated area is also known as the Hayan exploration block (Fig. 1), which is located in the Palmyride area, an intracontinental transpressive mountain range (LUČIĆ, 2001). The Palmyrides represent the most distinct tectonic and structural unit in central Syria as a zone of subdued topography that extends from the Dead Sea Fault Zone to the west, and disappears to the east at the Euphrates Graben or depression (Fig. 1). The Palmyrides are 400 km long and 100 km wide, stretching southwest–northeast across Syria with a maximum altitude of around 1300 m (LUČIĆ & FORŠEK, 2000; BREW, 2001; BREW et al., 2001; HERNITZ KUČENJAK et al., 2006; WOOD, 2011).

In the Palmyride area, Mesozoic deposits of Early Triassic to Late Cretaceous age were observed in all deep wells (LUČIĆ et al., 2002). Unlike the Upper Triassic and Jurassic deposits (maximum 700 m thick), which can either exhibit substantially reduced thickness (to 200 m minimum) or be absent in some places due to erosion or non-deposition, the Cretaceous strata are present throughout the region (approx. 800 m thick). The oldest deposits exposed on the surface are Upper Triassic evaporites interbedded with shales. Jurassic deposits are represented by different varieties of carbonate rocks, and Lower Cretaceous deposits consist of dolomites and limestones with rare interbeds of anhydrite and shale. In the Late Cretaceous there was a deepening of the depositional system, which resulted in the deposition of shales and marly limestones with a gradual increase in the amount of marl up-section (PONIKAROV, 1966a, b; LUČIĆ et al., 200.

For the purpose of the Syrian Petroleum Company (SPC), the investigated Upper Cretaceous succession is subdivided into three lithostratigraphic units (Figs. 2, 3): 1) the upper part of the Judea Formation (upper Turonian–lowermost Santonian); 2) the Soukhne Formation (Santonian–lower Campanian); and 3) the Shiranish Formation (upper Campanian–Maastrichtian); (MOUTY & AL-MALEH, 1983). The Judea Formation is represented by limestones and dolomitic limestones with thin intercalations of yellow to brownish yellow marl. The Soukhne Formation is characterized by calcareous horizons in the lower part, and by clayey limestones, marls and phosphatic deposits in the upper part. Argillaceous limestones, marls, chert and ovoid calcareous concretions (10–30 cm in diameter) are present in the Shiranish Formation.

3. MATERIAL AND METHODS

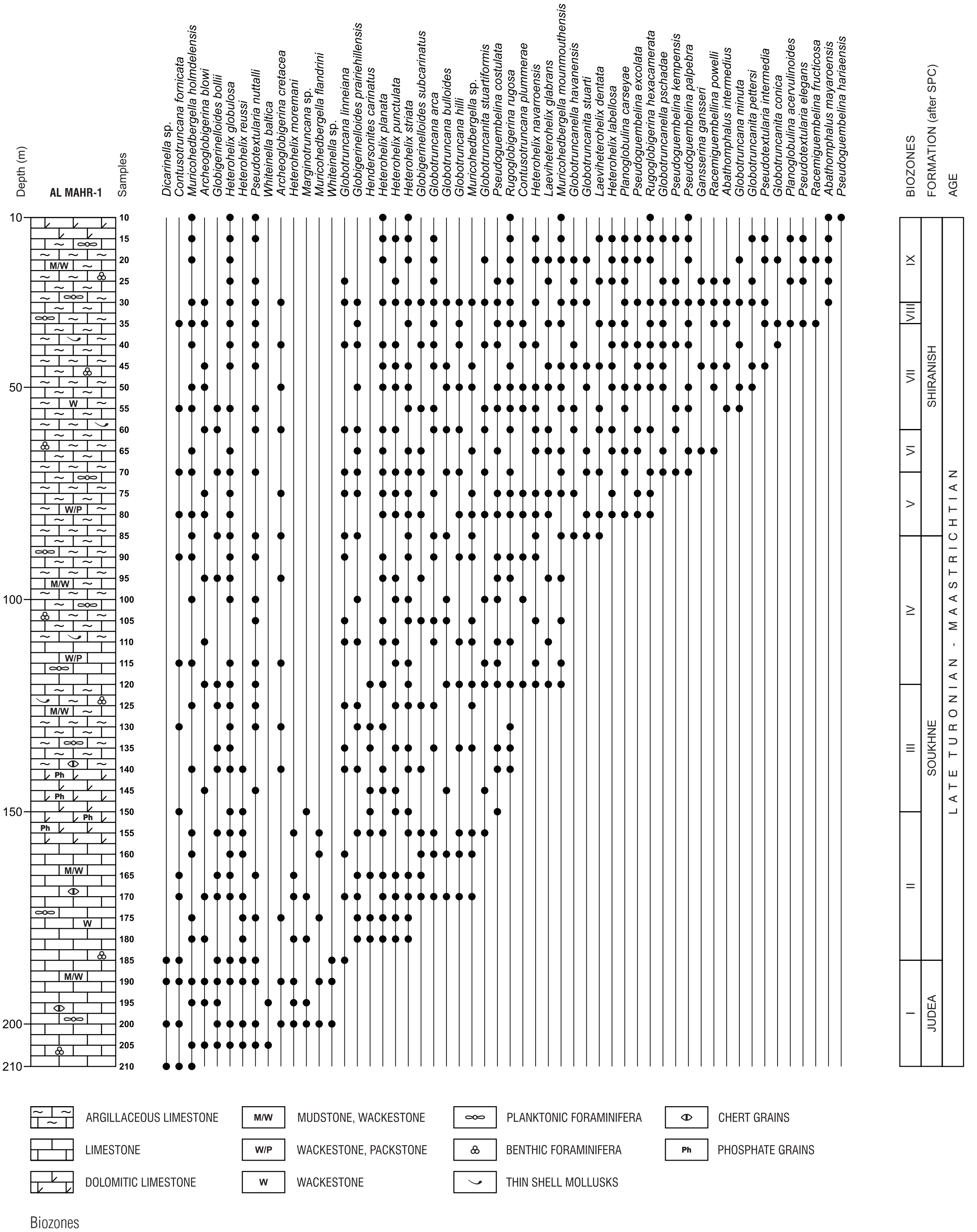
The foraminiferal study is based on analyses of 81 samples of Upper Cretaceous deposits obtained as drill cuttings from two deep exploration wells (Al Mahr-1 and Palmyra-1) drilled in the Hayan exploration block in the Palmyride area. Samples of drill cuttings from mud samples were collected every 5–10 metres. Most of the analyzed samples contain very well preserved planktonic and benthic foraminifera.

Samples for micropalaeontological analyses were disaggregated in tap water and diluted with hydrogen peroxide, then washed through 63 μm, 125 μm, and 160 μm sieves, dried and examined on an Olympus SZX16 stereomicroscope. Representative aliquots of approximately 300 planktonic foraminiferal specimens were counted for quantitative planktonic foraminiferal analyses. The term "„dominant" was used for species that constitute more than 10% of the planktonic foraminiferal assemblage, whereas the terms "„common", "„fewand "„rare" refer to species comprising 3–10%, 1–3%, and <1% of the assemblage, respectively. Plankton/benthic ratios were determined for each biozone on at least 300 specimens from the entire foraminiferal assemblages in >63 μm grain fraction and were used for palaeoecologic and palaeoenvironmental interpretations.

Petrographic thin-sections were made of 35 samples throughout the Upper Cretaceous interval for the purpose of lithological interpretation. Prepared petrographic thin-sections were stained with Alizarin red – S after the method of EVAMY & SHEARMAN (1962) in order to distinguish carbonate minerals. A detailed study of foraminiferal morphology was performed on a scanning electron microscope (SEM). The overall preservation of foraminifera is good although their original calcite shells have been recrystallized.

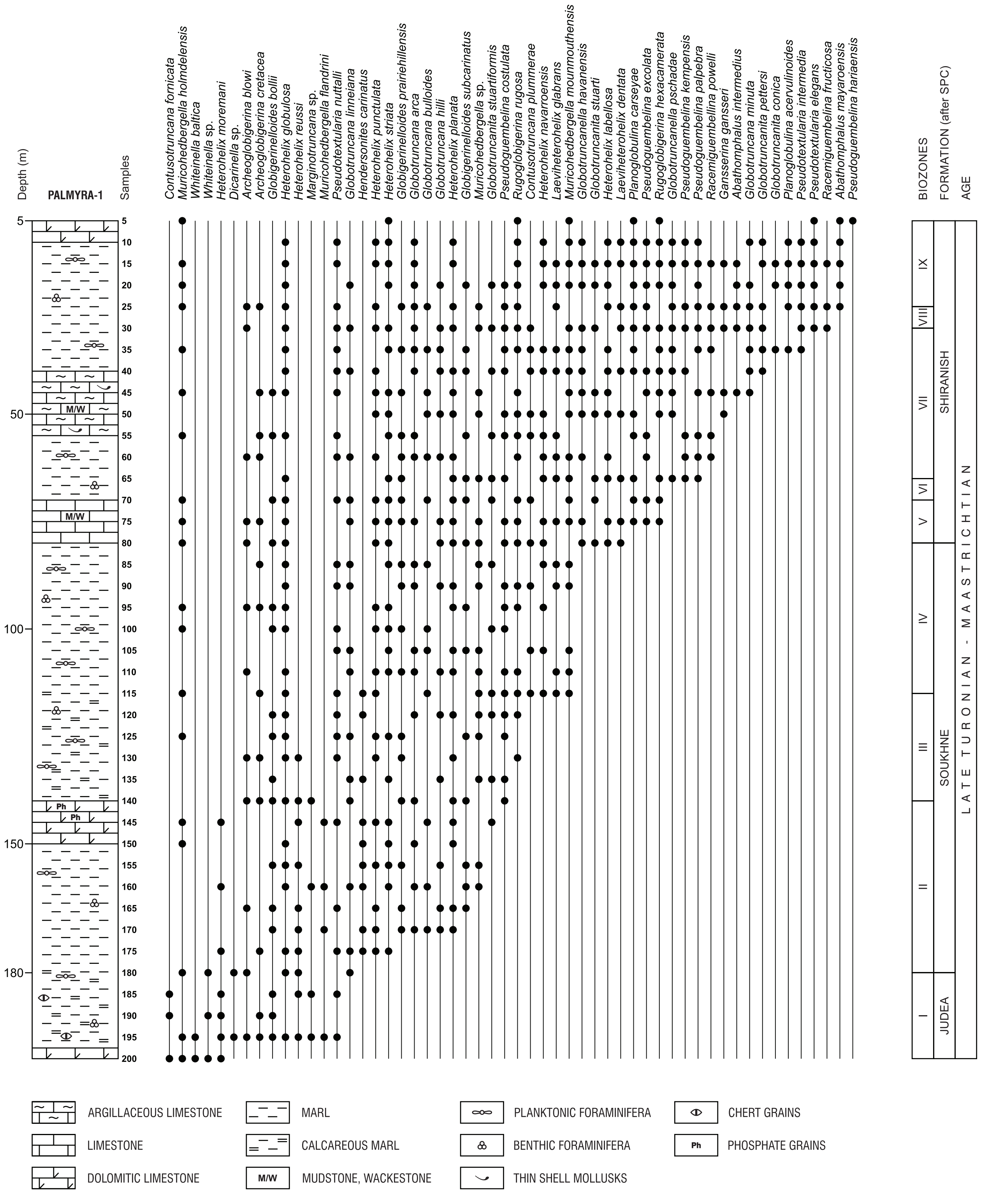
The micropalaeontological investigation was focused on the vertical distribution, diversity and composition of mainly planktonic and less abundant benthic foraminiferal assemblages (Figs. 2–3) according to GAWOR-BIEDOWA (1984), LOEBLICH & TAPPAN (1988), ISMAIL (1992), BOLLI et al. (1994), LY & KUHNT (1994), KAIHO (1998), PREMOLI SILVA &VERGA (2004), ISMAIL et al. (2007), HAMPTON et al. (2007), and GASIŃSKI & UCHMAN (2009). The presence of rich and diverse foraminiferal associations enabled biostratigraphic zonation of the Upper Turonian to Maastrichtian deposits based on documented index-taxa and/or the entire microfossil assemblages. Standard planktonic foraminiferal zonation after ROBASZYNSKI et al. (1984), CARON (1985), ROBASZYNSKI & CARON (1995), PREMOLI SILVA & SLITER (1994), ROBASZYNSKI et al. (2000), PREMOLI SILVA &VERGA (2004), SARI (2006, 2009), HUBER et al. (2008), OGG et al. (2008), PETRIZZO et al. (2011) AND PÉREZ-RODRÍGUEZ et al. (2012) have been used. A zonal sheme which emphasizes the lowest (LO) and the highest occurrences (HO) of index taxa and/or selected species in microfossil associations has been applied.

Phosphatic grains of the Soukhne Formation deposits were also analyzed using SEM back-scattered electron imaging (BSE) and energy dispersive X-ray analysis (EDX). The semi-quantitative X-ray elemental mapping of P, F, Cl



Biozones
I (Late Turonian–Early Santonian)
II (Middle–Late Santonian)
III (Early Campanian)
IV Globotruncana plummerae Zone (Early–Middle Campanian)
V (Late Campanian)
VI Globotruncanella havanensis Zone (Late Campanian)
VII Pseudoguembellina palpebra Zone (Late Campanian)
VIII Racemiguembelina fructicosa Zone (Late Campanian–Early Maastrichtian)
IX Abathomphalus mayaroensis Zone (Late Maastrichtian)

Figure 2: Stratigraphic column of the Al Mahr-1 exploration well showing stratigraphic distribution of planktonic foraminifera (Formation names after SPC – Syrian Petroleum Company).



Biozones
I (Late Turonian–Early Santonian)
II (Middle–Late Santonian)
III (Early Campanian)
IV Globotruncana plummerae Zone (Early–Middle Campanian)
V (Late Campanian)
VI Globotruncanella havanensis Zone (Late Campanian)
VII Pseudoguembellina palpebra Zone (Late Campanian)
VIII Racemiguembelina fructicosa Zone (Late Campanian–Early Maastrichtian)
IX Abathomphalus mayaroensis Zone (Late Maastrichtian)

Figure 3: Stratigraphic column of the Palmyra-1 exploration well showing stratigraphic distribution of planktonic foraminifera (Formation names after SPC – Syrian Petroleum Company).

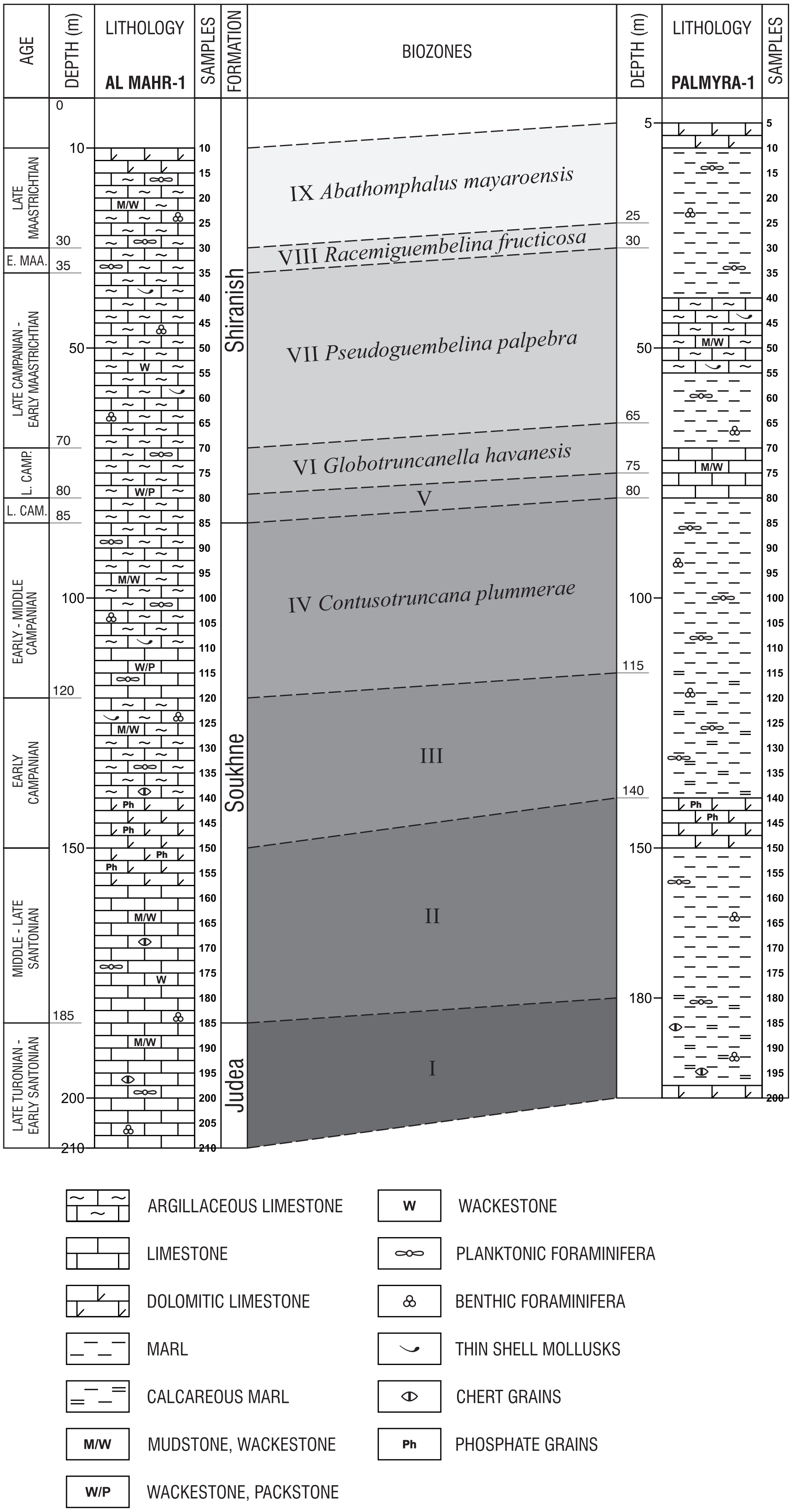


Figure 4: Correlation between the two exploration wells (Al Mahr-1, Palmyra-1) showing planktonic biozones and lithology.

and Ca was performed using a FEI Quanta 450 SEM with EDAX TEAM EDS at Smith College (Northampton, Massachusetts, USA).

4. BIOSTRATIGRAPHY

Biostratigraphic subdivision of the investigated Upper Cretaceous successions is based on planktonic foraminifera. Stratigraphic ranges of the identified microfossil assemblages indicate a late Turonian to Maastrichtian age. Stratigraphic relationships between the identified planktonic foraminiferal species are shown in Figs. 2 and 3, whereas the lithostratigraphic and biostratigraphic biozonation correlation between Al Mahr-1 and Palmyra-1 are presented in Fig. 4.

The upper Turonian to lowermost Santonian deposits contain planktonic and benthic foraminiferal assemblages characteristic of this stratigraphic range. These poorly diversified microfossil assemblages have equal proportions of small benthic and planktonic foraminifera. The Santonian to lower Campanian strata, on the other hand, are characterized by a moderately diversified microfossil assemblage with increased abundance and diversity of planktonic foraminifera, and the absence of nominal taxon/zonal markers. High diversity microfossil assemblages with a dominance of planktonic foraminifera and well-preserved index taxa are present in the upper Campanian to upper Maastrichtian deposits.

Previous studies of late Cretaceous planktonic foraminifera from the Palmyrides only generally indicated the age of the deposits (STANKOVIĆ et al., 2003, 2005; DACER et al., 2007). Biostratigraphy of the upper Turonian to Maastrichtian successions from the Al Mahr-1 and Palmyra-1 wells is correlated with the existing and well-established planktonic foraminiferal zonation for the Tethyan realm (ROBASZYNSKI & CARON, 1995; ROBASZYNSKI et al., 2000; PREMOLI SILVA & VERGA, 2004), Fig. 5. Since the zonal markers are very rare or absent, alternative planktonic foraminiferal species as well as the whole planktonic foraminiferal association enable application of standard biozonation (ROBASZYNSKI et al., 1984; CARON, 1985; SLITER, 1989; PREMOLI SILVA & SLITER, 1994; ROBASZYNSKI & CARON, 1995; ROBASZYNSKI et al., 2000; PREMOLI SILVA & VERGA, 2004; CHACON et al., 2004; HUBER et al., 2008; SARI, 2009; PETRIZZO et al., 2011; PEREZ-RODRÍGUEZ et al., 2012).

Nine biozones have been identified in the upper Turonian to Maastrichtian succession: Biozone I, Biozone II, Biozone III*,* IV *Contusotruncana plummerae* Zone, Biozone V, VI *Globotruncanella havanensis* Zone, VII *Pseudoguembelina palpebra* Zone, VIII *Raceemiguembelina fructicosa* Zone, and IX *Abathomphalus mayorensis* Zone. A list of taxa together with author names and year of publication are provided in the Appendix. All of the diagnostic species and some additional taxa typical of the studied foraminiferal assemblages are illustrated in Figs. 6–9.

Biozone I (Figs. 6A–D)

Age. Late Turonian–Early Santonian

Interval. Al Mahr-1 (185–210 m, Figs. 2 and 4), Palmyra-1 (180–200 m, Figs. 3, 4)

Assemblage characteristics. As index taxa were not observed, the lowest occurrence (LO) of *Contusotruncana fornicata* and *Globigerinelloides bollii* has been used to define the lower boundary of this Zone. This biozone may correspond to the *Dicarinella concavata* Zone (PREMOLI SILVA & SLITER, 1994; ROBASZYNSKI & CARON, 1995; ROBASZYNSKI et al., 2000; PREMOLI SILVA & VERGA, 2004; SARI, 2006, 2009).

The foraminiferal assemblage of this interval is composed of rare non-keeled planktonic foraminifera with a wide stratigraphic range: *Archaeoglobigerina blowi, A. cretacea* (Figs. 6C, D), *Whiteinella balthica*, *Whiteinella* sp., *Dicarinella* sp. (Fig. 6A) and *Marginotruncana* sp. (Fig. 6B). In the middle of the biozone *Muricohedbergella holmdelensis* and *Pseudotextularia nuttalli* have their lowest occurrence. The most abundant species in the assemblage are *Heterohelix reussi, H. moremani,* and *H. globulosa,* comprising 38% of the total planktonic association. Biozone I is also characterized by very common *Pseudotextularia nuttalli*, *Muricohedbergella holmdelensis, Muricohedbergella flandrini*, marginotruncanids and whiteinellids. In addition, the following small calcareous benthic foraminifera are present and account for up to 50% of the total foraminiferal association: *Bulimina ovulum*, *Gyroidinoides globosus*, *Bulimina* sp., *Gavellinela* sp. (Figs. 9A, B), *Lenticulina* sp., and *Nodosaria* sp.

Lithology and palaeoenvironment. Brownish grey to grey limestone (mudstone/wackestone to foraminiferal wackestone), dolomitic limestone and marl with equal proportions of planktonic and calcareous benthic foraminifera indicate accumulation within outer shelf environments.

Biozone II (Figs. 6E–I)

Age. Middle–Late Santonian

Interval. Al Mahr-1 (150–185 m, Figs. 2 and 4), Palmyra-1 (140–180 m, Figs. 3, 4)

Assemblage characteristics. Because of the absence of a zonal marker, the lower boundary of this Zone is defined approximately by the LO of *Globotruncana linneiana,* whereas the upper boundary coincides with the disappearance of all dicarinellids and whiteinellids. This biozone may correspond to the *Dicarinella asymetrica* Zone (PREMOLI SILVA & SLITER, 1994; ROBASZYNSKI & CARON, 1995; ROBASZYNSKI et al., 2000; PREMOLI SILVA & VERGA, 2004; SARI, 2006, 29).

The first half of Biozone II is characterized by the LO of several new taxa such as *Globotruncana bulloides*, *G. hilli*, *G. arca*, *Hendersonites carinatus, Heterohelix striata, H. punctulata, H. planata*, *Globigerinelloides prairiehillensis* and *G. subcarinatus.* Dominant species in this Zone are *Heterohelix globulosa* and *H. reussi* (Fig. 6I), while *Pseudotextularia nuttalli* and *Heterohelix punctulata* are very common*.* The following planktonic foraminifera continue from the underlying zone: *Archaeoglobigerina blowi* (Figs. 6E, F), *A. cretacea*, *Contusotruncana fornicata* (Figs. 6G, H), *Globigerinelloides bollii*, *Muricohedbergella holmdelensis* and *Marginotruncana* sp. *Globotruncana arca*, *G. bulloides,* and *G. linneiana* range throughout Biozone II but are

Figure 5: Proposed biozonation for the Upper Cretaceous succession and stratigraphic range of selected species of the Palmyride region compared with the zonal schemes for Tethys (ROBASZYNSKI and CARON, 1995; PREMOLI SILVA & VERGA, 2004). Timescale was adapted from OGG et al. (2008), and sea-level curve is from HAQ et al. (1987). Grey area indycates the presence of phosphate grains.

not present in every sample. In the upper part of this biozone *Globotruncanita stuartiformis* appears for the first time, while *Heterohelix moremani* and *Muricohedbergella flandrini* have their highest occurrence. The genus *Heterohelix* is very abundant and diverse (6 species), and comprises a very high percentage (46%) of the planktonic association. Among calcareous benthic foraminifera, common taxa with a wide stratigraphic range include: *Bulimina ovulum* (Fig. 9D), *Praebulimina reussi, P. kickapoensis, Gyroidinoides globosus, Bulimina* sp., and *Lenticulina* sp. Small benthic foraminifera make up to 40% of the microfossil assemblage.

Lithology and palaeoenvironment. Foraminiferal mudstone/wackestone, marl, dolomitic limestones with phosphate grains and foraminiferal assemblage of Biozone II indicate open marine, most probably outer shelf depositional environments.

Biozone III (Figs. 6J–N)

Age. Early Campanian

Interval. Al Mahr-1 (120–150 m, Figs. 2 and 4), Palmyra-1 (115–140 m, Figs. 3, 4)

Assemblage characteristics. The main characteristic of the microfossil assemblage is the disappearance of marginotruncanids at the base of this biozone while *Pseudoguembelina costulata* has its lowest occurrence. *Rugoglobigerina rugosa* first occurs in the middle part of Biozone III, whereas *Heterohelix reussi* has its highest occurrence (HO). This bi-

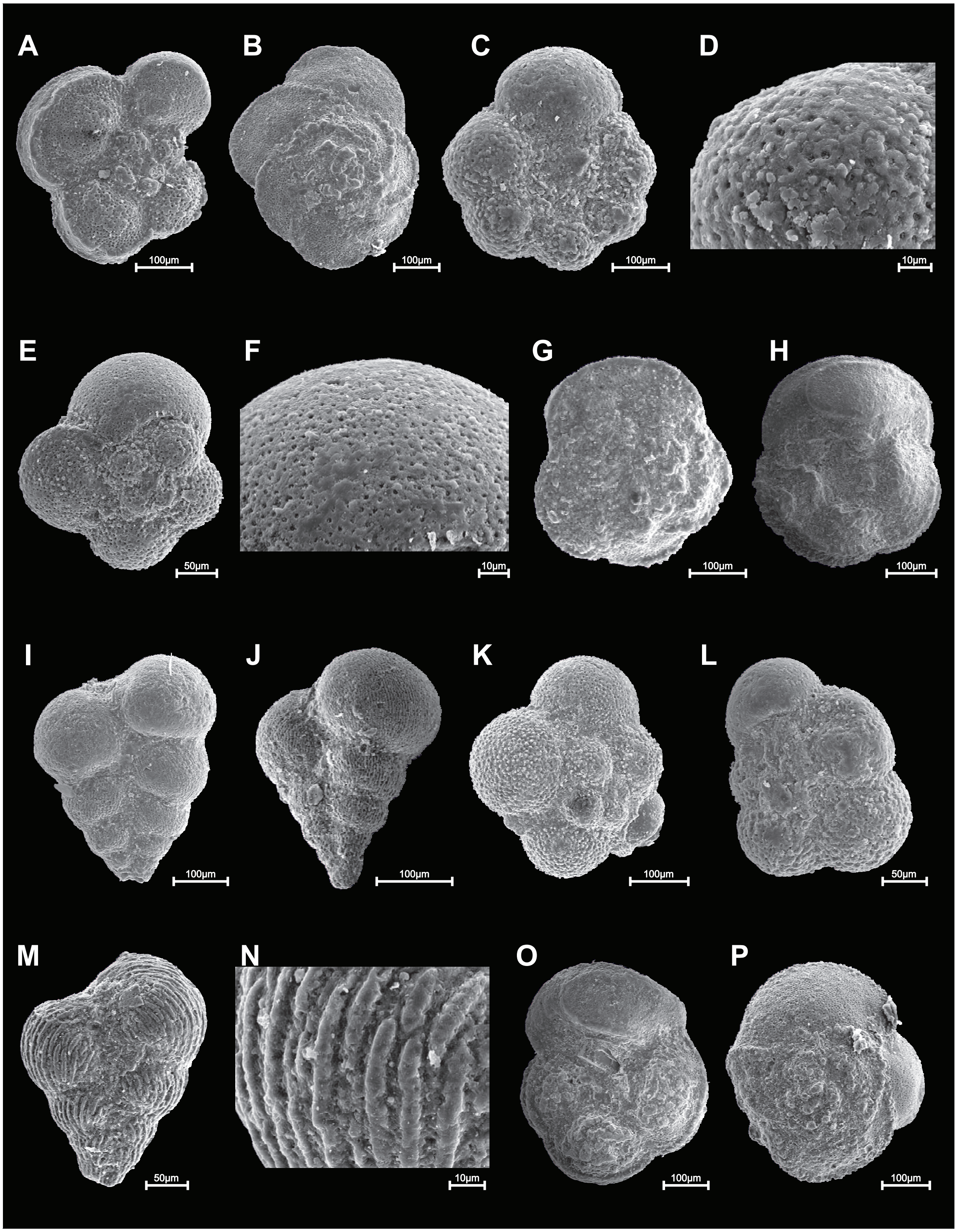


Figure 6: SEM photomicrographs of selected planktonic foraminifera observed in Biozone I (A–D), Biozone II (E–I), Biozone III, (J–N) and *Contusotruncana plummerae* Zone (Biozone IV, O, P). A *Dicarinella* sp., Palmyra-1, interval 190–200 m. B *Marginotruncana* sp., Al Mahr-1, interval 190–200 m. C, D *Archaeoglobigerina cretace* (C), and detail of the wall texture (D), Al Mahr-1, interval 185–190 m. E, F *Archaeoglobigerina blowi* (E), and detail of the wall texture (F), Palmyra-1, interval 160–170 m. G, H *Contusotruncana fornicata,* Al Mahr-1, interval 155–160 m. I *Heterohelix reussi*, Palmyra-1, interval 140–150 m. J *Heterohelix globulosa*, Palmyra-1, interval 130–140 m. K, L *Muricohedbergella holmdelensis*, Palmyra-1, interval 120–130 m. M, N *Heterohelix striata* (M), and detail of the wall texture (N), Al Mahr-1, interval 120–130 m. O, P *Contusotruncana plummerae*, Palmyra-1, interval 100–110 m.

ozone may correspond to the *Globotruncanita elevata* Zone (CARON, 1985; SLITER, 1989; PREMOLI SILVA & SLITER, 1994; ROBASZYNSKI & CARON, 1995; ROBASZYNSKI et al., 2000; PREMOLI SILVA & VERGA, 2004; CHACON et al., 2004).

Dominant species in the planktonic foraminiferal assemblage are *Hendersonites carinatus*, *Heterohelix striata*, *H. punctulata* and *Pseudotextularia nuttalli*, while *Globigerinelloides bollii* is very common. In addition, the microfossil assemblage contains the following planktonic foraminifera that continue from Biozone II: *Archaeoglobigerina cretaca, A. blowi Contusotruncana fornicata*, *Globotruncana linneiana*, *G. bulloides*, *G. hilli, G. arca*, *Globotruncanita stuartiformis*, *Heterohelix globulosa* (Fig. 6J), *H. planata*, *Globigerinelloides prairiehillensis, G. subcarinatus*, *Muricohedbergella holmdelensis,* and *Muricohedbergella* sp. Specimens of the genus *Heterohelix* remain diverse and constitute the most abundant group in the microfossil association with 47% of the planktonic foraminiferal assemblage. Most of the calcareous benthic foraminifera that persisted from the underlying Biozone II, and comprise up to 35% of the microfossil assemblage, include *Bulimina ovulum*, *Bulimina* sp. (Fig. 9E), *Gyroidinoides globosus*, *Lenticulina rotulata*, *Lenticulina* sp., and *Oridosalis* sp.

Lithology and palaeoenvironment. Argillaceous limestone (mudstone/wackestone) and marl together with microfossils of Biozone III suggest an open marine, most probably outer shelf depositional environment.

Biozone IV: *Contusotruncana plummerae* **Zone (Figs. 6O, P, 7A, B)**

Definition. Stratigraphic interval from the LO of *Contusotruncana plummerae* to the LO of *Radotruncana calcarata* (PETRIZZO et al., 2011)

Age. Early to Middle Campanian

Interval. Al Mahr-1 (85–120 m, Figs. 2 and 4), Palmyra-1 (80–115 m, Figs. 3, 4)

Assemblage characteristics. Beside the LO of the zonal marker *Contusotruncana plummerae* (Figs. 6O, P) the lower boundary of this biozone is also characterized by the LO of *Hendersonites carinatus* and by the first occurrence of *Laeviheterohelix glabrans*, *Muricohedbergella mounmouthensis* and *Heterohelix navarroensis.*

The planktonic foraminiferal assemblage is similar to that in Biozone III. However, planktonic foraminifera are more abundant and the overall number of species increased. The dominant species include *Heterohelix striata, H. planata, Pseudoguembelina costulata* and *Pseudotextularia nuttalli*. In addition, the assemblage is characterized by common *Muricohedbergella holmdelensis, M. monmouthensis*, *Globigerinelloides bollii* (Fig. 7A), *G. subcarinatus* and *Heterohelix globulosa.* Other species in this Zone include: *Archaeoglobigerina blowi* (Fig. 7B), A. *cretacea, Contusotruncana fornicata, Globotruncana arca*, *G. bulloides*, *G. linneiana*, *G. hilli, Globotruncanita stuartiformis*, *Heterohelix punctulata*, *Globigerinelloides prairiehillensis, Muricohedbergella* sp. and *Rugoglobigerina rugosa*. Representatives of the genus *Heterohelix* decrease in abundance to 32%, whereas pseudoguembelinids increase in diversity as well as in abundance and can account for up to 10.5% of the total assemblage.

The amount of calcareous benthic foraminifera decreases to 30% of the assemblage. The most common taxa include *Bulimina ovulum, Gavelinella monterelensis* (Fig. 9C), *Gyroidinoides globosus*, *Lenticulina rotulata*, *Lenticulina* sp. (Fig. 9F), *Gavelinella* sp., *Gyroidinoides* sp., and *Cibicidoides* sp.

Lithology and palaeoenvironment. Argillaceous limestone (wackestone), marl, as well as calcareous marl with abundant planktonic foraminifera (70%) indicate outer shelf to upper bathyal depositional environments.

Biozone V (Figs. 7C–G)

Age. Late Campanian

Interval. Al Mahr-1 (80–85 m, Figs. 2 and 4), Palmyra-1 (75–80 m, Figs. 3, 4)

Assemblage characteristics. Since the zonal marker is very rare and generally poorly preserved, the base of Biozone V is marked by the LO of *Laeviheterohelix dentata*, *Globotruncanella havanensis* and *Globotruncanita stuarti*. This biozone may correspond to the *Radotruncana calcarata* Zone (ROBASZYNSKI & CARON, 1995; PREMOLI SILVA & SLITER, 1994; ROBASZYNSKI et al., 2000; PREMOLI SILVA & VERGA, 2004; SARI, 2006, 2009; HUBER et al., 2008).

The species *Heterohelix labellosa* appears in the middle part of Biozone V. The planktonic foraminiferal assemblage of this Biozone is abundant and highly diversified. Most planktonic foraminifera persist from the underlying Biozone IV, including *Archaeoglobigerina blowi*, *A. cretacea*, *Contusotruncana fornicata*, *Globotruncana arca* (Figs. 7E, F), *G. bulloides, G. linneinana, G. hilli, Heterohelix globulosa*, *H. navarroensis, H. planata, H. punctulata, H. striata*, *Globigerinelloides bollii*, *G. prairiehillensis* (Fig. 7G), *G. subcarinatus*, *Laeviheterohelix glabrans, Muricohedbergella holmdelensis*, *M. mounmouthensis, Muricohedbergella* sp*.*, *Pseudoguembelina costulata*, *Pseudotextularia nuttalli* (Fig. 7C), and *Rugoglobigerina rugosa* (Fig. 7D). The genus *Heterohelix* constitutes 38% of the assemblage and remains the most abundant group in the planktonic association. In comparison with previous biozones, the diversity of Biozone V increases and the total number of planktonic foraminifera reaches 27 species.

Small benthic foraminifera comprise less than 20% of the assemblage and include *Bolivina incrassatea*, *Gavelinella monterelensis*, *Gavelinella* sp., *Gyroidinoides globosus*, *Lenticulina rotulata*, *Lenticulina* sp., *Neoflabelina reticulata*, *Serovaina complanata*, and *Cibicidoides* sp.

Lithology and palaeoenvironment. Argillaceous limestone and calcareous marl with abundant planktonic foraminifera (80%) indicate outer shelf to upper bathyal depositional environments.

Biozone VI: *Globotruncanella havanensis* **Zone (Figs. 7H–J)**

Definition. Partial range Zone from the LO of *Globotruncanella havanensis* to the LO of *Pseudoguembelina palpebra* (HUBER et al., 2008)

Age. Late Campanian

Interval. Al Mahr-1 (70–80 m, Figs. 2 and 4), Palmyra-1 (65–75 m, Figs. 3,4)

Assemblage characteristics. The zonal marker *Globotruncanella havanensis* (Fig. 7H) is relatively rare, while species *Pseudoguembelina excolata*, *Planoglobulina carseyae* and *Rugoglobigerina hexacamerata* have their lowest occurrence at the base of the Biozone IV.

The following planktonic foraminifera continue from the underlying Biozone V: *Archaeoglobigerina blowi*, *A. cretacea*, *Contusotruncana fornicata*, *Globotruncana arca*, *G. buloides, G. linneinana, G. hilli, Globotruncanita stuartiformis*, *G. stuarti, Heterohelix globulosa*, *H. navarroensis* (Figs. 7I, J), *H. planata, H. punctulata, H. striata*, *Globigerinelloides bollii*, *G. prairiehillensis, G. subcarinatus*, *Laeviheterohelix glabrans, L. dentata, Muricohedbergella holmdelensis*, *M. mounmouthensis, Muricohedbergella* sp., *Pseudoguembelina costulata*, *Pseudotextularia nuttalli*, and *Rugoglobigerina rugosa.* In the middle of the biozone *Globotruncanella petaloidea, Rugoglobigerina macrocephala* and *Guembelitria turrita* have their LO. Species of genus *Heterohelix* remain the most abundant group in the microfossil assemblage with 37.5% representation. Globotruncanids increase in diversity (8 species) and abundance (13.5%), and become an important component of the planktonic assemblage. In addition, small benthic foraminifera comprise 15% of the total fauna and include *Bolivina incrassata, Gavelinella monterelensis*, *Gavelinella* sp., *Gyroidinoides globosus*, *Lenticulina rotulata*, *Lenticulina* sp., *Neoflabelina reticulata*, *Serovaina complanata*, *Cibicidoides* sp. (Fig. 9H), and an agglutinated form *Spiroplectamina* sp. (Fig. 9G).

Lithology and palaeoenvironment. Marl and argillaceous limestone (mudstone/wackestone) with abundant planktonic foraminifera (85%) suggest outer shelf to upper bathyal depositional environments.

Biozone VII: *Pseudoguembelina palpebra* Zone (Figs. 7K–P, 8A)

Definition. Partial range Zone from the LO of *Pseudoguembelina palpebra* to the LO of *Racemiguembelina fructicosa* (HUBER et al., 2008)

Age. Late Campanian–Early Maastrichtian

Interval. Al Mahr-1 (35–70 m, Figs. 2 and 4), Palmyra-1 (30–65 m, Figs. 3, 4)

Assemblage characteristics. Pseudoguembelina palpebra (Fig. 7N) is consistently present in this biozone. The first occurrence of *Globotruncanella pschadae, Pseudoguembelina kempensis* and *Racemiguembelina powelli* is recorded in the lower part of this biozone. *Gansserina gansseri* (Figs. 7O, P) is present, but very rare, throughout this interval. Very common species in the assemblage include *Heterohelix globulosa*, *Pseudoguembelina costulata* (Fig. 7M), *Heterohelix striata*, and *H. navarroensis*. Common species include *Heterohelix labellosa*, *Pseudoguembelina excolata*, *Pseudotextularia nuttalli*, and *Rugoglobigerina rugosa* (Figs. 7L, 8A). Other representative species are *Archaeoglobigerina blowi*, *A. cretacea*, *Contusotruncana fornicata*, *Globotruncana arca, G. bulloides*, *G. linneiana*, *G. hili, Globotruncanella havanensis*, *G. petaloidea*, *Globotruncanita stuarti*, *G. stuartiformis*, *Guembelitria turrita*, *G. cretacea, Heterohelix planata, H. punctulata*, *Globigerinelloides bollii*, *G. prairiehillensis*, *G. subcarinatus, Laeviheterohelix dentata, L. glabrans, Muricohedbergella holmdelensis, M. mounmothensis, Muricohedbergella* sp., *Planoglobulina carseyae, Rugoglobigerina hexacamerata* (Fig. 7K), and *R. macrocephala.* The middle part of Biozone VII is characterized by the lowest occurrence of *Abathomphalus intermedius, Globotruncanella minuta* and *Globotruncanita pettersi*, while *Globigerinelloides bollii* become extinct. The upper part of this Biozone is also characterized by the lowest occurrences of *Pseudotextularia intermedia* and *Globotruncanita conica*. In comparison with Biozone VI, biodiversity significantly increases throughout Biozone VII and reaches the maximum of 41 species. This increase is partly related to speciation of globotruncanids, (represented by 12 species). The genus *Heterohelix* remains the dominant group with 34% abundance, whereas pseudoguembelinids remarkably increase up to 17%. Globotruncanids, despite numerous species, represent 15% of the planktonic foraminiferal population.

Among calcareous benthic foraminifera the most common taxa are: *Bolivina incrassata*, *Bolivinoides miliaris*, *Gavelinella monterelensis*, *Gavelinella* sp., *Gyroidinoides globosus*, *Lenticulina rotulata* (Fig. 9J), *Lenticulina* sp., *Neoflabelina reticulata* (Fig. 9I), *Oridorsalis umbonatus*, *Serovaina complanata*, *Cibicidoides* sp., *Nodosaria* sp., and agglutinated *Spiroplectammina* sp. The proportion of small benthic foraminifera significantly decreases and they make up only 10% of the microfossil assemblage.

Lithology and palaeoenvironment. Marl and argillaceous limestone (mudstone/wackestone) with high proportions of planktonic species (up to 90%) imply continuous deepening of this marine realm and deposition in outer shelf to upper bathyal environments.

Biozone VIII: *Racemiguembelina fructicosa* Zone (Figs. 8B–E)

Definition. Partial range Zone from the LO of *Racemiguembelina fructicosa* to the LO of *Abathomphalus mayaroensis* (HUBER et al., 2008; PEREZ-RODRÍGUEZ et al., 2012)

Age. Early Maastrichtian

Interval. Al Mahr-1 (30–35 m, Figs. 2 and 4), Palmyra-1 (25–30 m, Figs. 3, 4)

Assemblage characteristics. Beside the nominate species *Racemiguembelina fructicosa* (Fig. 8E)*, Planoglobulina acervulinoides* and *Pseudotextularia elegans* are also recorded for the first time in the lower part of this biozone. In the same horizons *Contusotruncana fornicata* and *C. plummerae* have their HO. Dominant species in the assemblage are *Heterohelix globulosa*, *H. striata* and *H. navarroensis*. Common species include *Rugoglobigerina rugosa* and *R. macrocephala*. The planktonic foraminiferal assemblage is similar to that in Biozone VII (41 species) and consists of the following species: *Abathomphalus intermedius, Archae-*

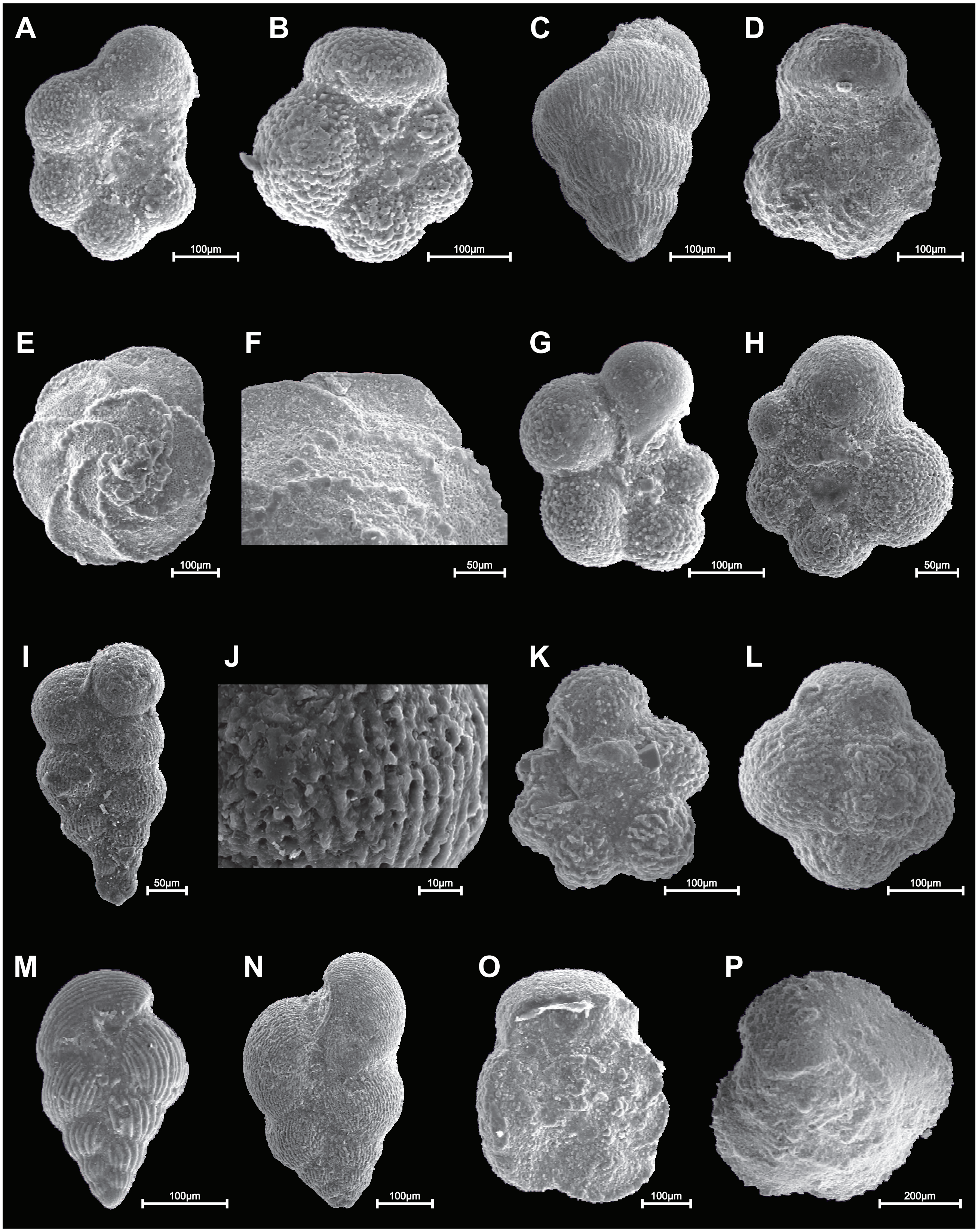


Figure 7: SEM photomicrographs of selected planktonic foraminifera observed in *Contusotruncana plummerae* Zone (Biozone IV, A, B), Biozone V (C–G), *Globotruncanella havanensis* Zone (Biozone VI, H–J) and *Pseudoguembelina palpebra* (Biozone VII, K–P). A *Globigerinelloides bollii*, Al Mahr-1, interval 95–100 m. B *Archaeoglobigerina blowi*, Al Mahr-1, interval 85–90 m. C *Pseudotextularia nuttalli*, Al Mahr-1, interval 80–85 m. D *Rugoglobigerina rugosa*, Al Mahr-1, interval 80–85 m. E, F *Globotruncana arca* (E), and detail of the wall texture (F), Palmyra-1, interval 75–80 m. G *Globigerinelloides prairiehillensis*, Palmyra-1, interval 75–80 m. H *Globotruncanella havanensis*, Palmyra-1, interval 65–70 m. I, J *Heterohelix navarroensis* (I), and detail of the wall texture (J), Palmyra-1, interval 60–65 m. K *Rugoglobigerina hexacamerata*, Al Mahr-1, interval 65–70 m. L *Rugoglobigerina rugosa*, Al Mahr-1, interval 65–70 m. M *Pseudoguembelina costulata*, Al Mahr-1, interval 60–65 m. N *Pseudoguembelina palpebra*, Palmyra-1, interval 50–60 m. O, P *Gansserina gansseri*, Al Mahr-1, interval 45–50 m (O), and Palmyra-1, interval 40–50 m (P).

oglobigerina blowi, *A. cretacea*, *Contusotruncana fornicata*, *Gansserina gansseri*, *Globotruncana arca, G. bulloides*, *G. linneiana*, *G. hilli,Globotruncanella havanensis*, *G. minuta*, *G. petaloidea* (Fig. 8B), *Globotruncanita conica, G. stuarti, G. stuartiformis* (Figs. 8C, D), *G. pettersi, Guembelitria turrita*, *G. cretacea, Heterohelix labellosa*, *H. planata, H. punctulata*, *Globigerinelloides bollii*, *G. prairiehillensis*, *G. subcarinatus, Laeviheterohelix dentata, L. glabrans, Muricohedbergella holmdelensis, M. mounmothensis, Muricohedbergella* sp.*, Planoglobulina carseyae, Pseudoguembelina costulata, P. excolata, P. kempensis,P. palpebra, Pseudotextularia nuttalli, P. intermedia, Rugoglobigerina hexacamerata*, and *Racemiguembelina powelli.* Representatives of the genus *Heterohelix* increase in abundance to 38%, and rugoglobigerinids are more common here than in the underlying biozones and make up to 14% of the planktonic foraminiferal association. Pseudoguembelinids that reached a peak in the previous biozone drop in abundance to 8%, and globotruncanids also decrease in occurrence towards to the top of Biozone VII.

Small benthic foraminifera comprise less than 10% of the assemblage and include *Bolivina incrassata, Gavelinella monterelensis*, *Gavelinella* sp., *Gyroidinoides globosus*, *Lenticulina rotulata, Lenticulina* sp., *Neoflabelina reticulata, Stensioeina pommerana* (Figs. 9K, L), *Cibicidoides* sp., and agglutinated species *Gaudryina laevigata.*

Lithology and palaeoenvironment. Marl and argillaceous limestone (mudstone/wackestone) contain a high proportion of rich and very well preserved planktonic foraminifera suggesting deposition in upper to middle bathyal environments.

Biozone IX: *Abathomphalus mayaroensis* Zone (Figs. 9F–P)

Definition. Interval Zone from the LO of the nominal taxon to the extinction of most of the Cretaceous planktonic foraminifera (PREMOLI SILVA & SLITER, 1994**;** ROBASZYNSKI & CARON, 1995; ROBASZYNSKI et al., 2000; PREMOLI SILVA & VERGA, 2004; CHACON et al., 2004)

Age. Late Maastrichtian

Interval. Al Mahr-1 (10–30 m, Figs. 2 and 4), Palmyra-1 (5–25 m, Figs. 3, 4)

Assemblage characteristics. The zonal marker *Abathomphalus mayaroensis* (Figs. 8F, M, N) is represented by a few specimens. Very common species in the planktonic foraminiferal assemblages include *Heterohelix globulosa, H. striata*, *Rugoglobigerina rugosa*, *Heterohelix navarroensi, H. planata* and *Muricohedbergella mounmouthensis*, while common species include *Heterohelix labellosa, Globotruncana arca*, *Rugoglobigerina macrocephala* and *Muricohedbergella holmdelensis*. This very well preserved and highly diverse assemblage also contains other species such as *Globotruncana hilli*, *Globotruncanella havanensis*, *G. minuta*, *G. petaloidea, G. pschade, Globotruncanita conica* (Fig. 8P), *G. stuarti*, *G. stuartiformis* (Figs. 8K, L), *G. pettersi*, *Guembelitria cretacea, Heterohelix punctulata, Pseudoguembelina excolata* (Figs. 8G, H), *P. kempensis, P. palpebra, Pseudotextularia elegans* (Figs. 8I, J), *P. intermedia*, *P. nuttalli, Planoglobulina carseyae*, and *Rugoglobigerina hexacamerata*.

A large overturn in planktonic fauna occurred within Biozone IX due to the extinction and disappearance of many species at the base of the biozone, including: *Archaeoglobigerina blowi*, *A. cretacea, Globotruncana bulloides* and *Globigerinelloides prairiehillensi.* Furthermore, species such as *Abathomphalus intermedius* (Fig. 8O), *Gansserina gansseri*, *Globotruncana linneiana, Pseudoguembelina costulata* and *Racemiguembelina powelli* become rare and then disappear in the middle part of Biozone IX. Species of the genus *Heterohelix* remain the dominant group in the planktonic assemblage with the same abundance of 36%, whereas globotruncanids and rugoglobigerinids have almost the same abundance as in the underlying Biozone VIII. The very high overall diversity (40 species) of Biozone IX, although somewhat lower than in Biozone VIII, dramatically decreases at the end of the zone when most planktonic foraminiferal species become extinct. Only a few species such as *Muricohedbergella holmdellensis, M. monmouthensis* and *Guembelitria cretacea* cross the Cretaceous/Palaeogene boundary.

The calcareous benthic species *Bolivinoides draco* (Fig. 9P) is also characteristic of *Abathomphalus mayaroensis* Zone (GAWOR-BIEDOWA, 1984). In addition to this species, many other small benthic foraminifera also occur: *Bolivina incrassata*, *Gyroidinoides globosus* (Fig. 9N), *Lenticulina rotulata*, *L. münsteri*, *Neoflabelina reticulata*, *Stensioeina pommerana, Cibicidoides* sp. (Fig. 9M) as well as agglutinated forms *Gaudryina laevigata* (Fig. 9O) and *Spiroplectammina* sp.

Lithology and palaeoenvironment. Marl, argillaceous limestone (mudstone/wackestone) and slightly dolomitized limestone (foraminiferal wackestone) contain rich and very well preserved foraminiferal assemblages (plankton/benthos ratio is 94:6), suggesting a permanent open-marine influence and deposition in upper to middle bathyal environments.

5. INTERPRETATION AND DISCUSSION

This detailed study of the Late Turonian–Maastrichtian planktonic and benthic foraminiferal assemblages provides the basis for biostratigraphic and palaeoenvironmental interpretations of the successions examined. A total of 56 planktonic foraminiferal species belonging to 20 different genera have been identified. Abundant and moderately to highly diverse and generally well preserved planktonic foraminiferal assemblages enabled biozonation and identification of the following biozones: Biozone I, Biozone II, Biozone I, IV *Contusotruncana plummerae* Zone, Biozone V, VI *Globotruncanella havanensis* Zone, VII *Pseudoguembelina palpebra* Zone, VIII *Racemiguembelina fructicosa* Zone and IX *Abathomphalus mayorensis* Zone. Identification of possible stratigraphic gaps in the Upper Cretaceous successions examined here was very difficult because the drill cuttings were sampled every 5–10 metres. According to BREW (2001), the Upper Cretaceous strata succession of the Palmyride area is characterized by progressively deeper water environments. Evidence for some minor compression and uplift has been documented for the latest Cretaceous of this area, together with an associated minor sedimentary hiatus at the Creta-

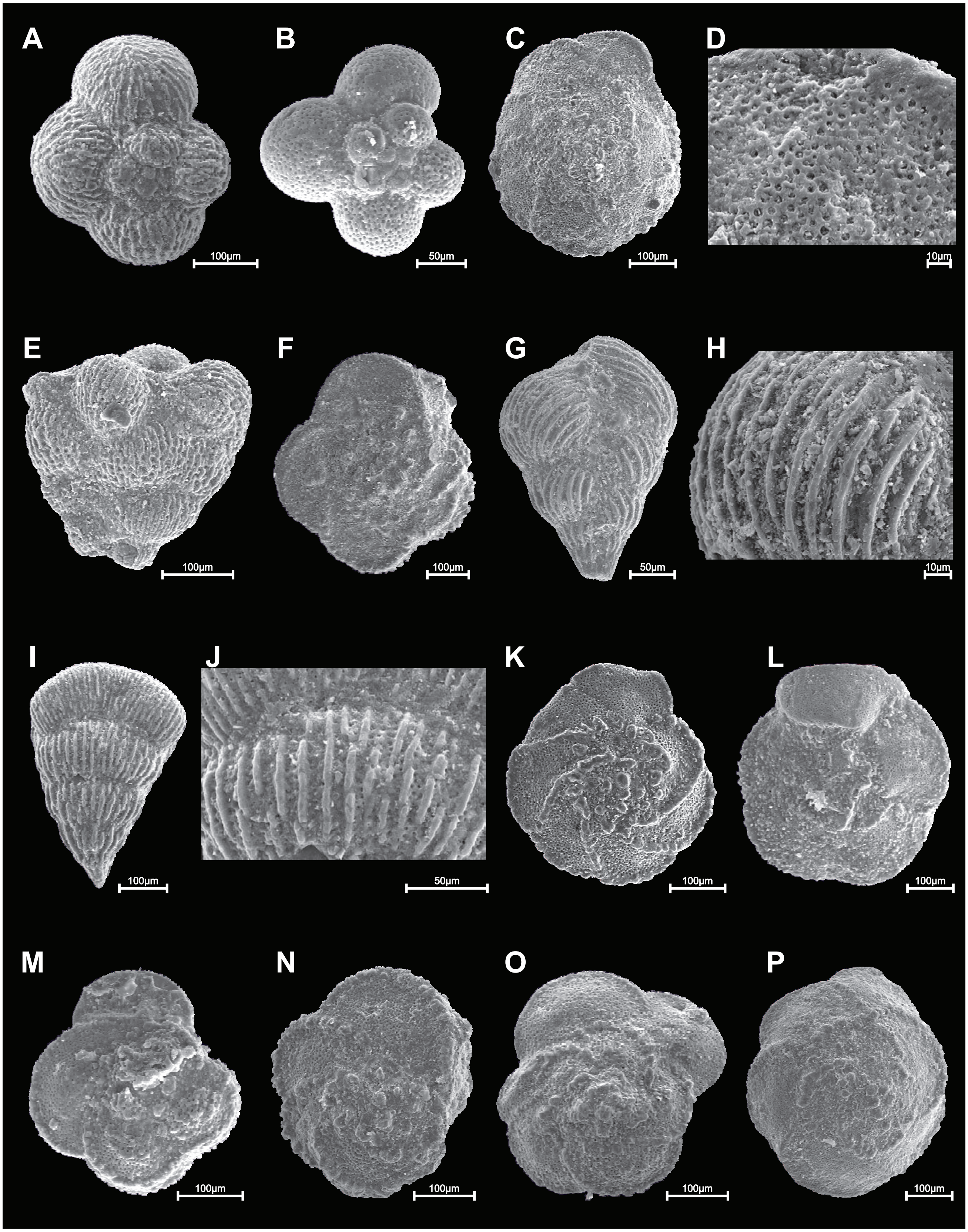


Figure 8: SEM photomicrographs of selected planktonic foraminifera observed in the *Pseudoguembelina palpebra* Zone (Biozone VII, A) *Racemiguembelina fructicosa* Zone (Biozone VIII, B–E) and *Abathomphalus mayaroensis* Zone (Biozone IX, F–P). A *Rugoglobigerina rugosa*, Palmyra-1, interval 40–50 m. B *Globotruncanella petaloidea*, Al Mahr-1, interval 30–35 m. C, D *Globotruncanita stuartiformis* (C), and detail of the wall texture (D), Al Mahr-1, interval 30–35 m. E *Racemiguembelina fructicosa*, Palmyra-1, interval 25–30 m. F *Abathomphalus mayaroensis*, Al Mahr-1, interval 30–35 m. G, H *Pseudoguembelina excolata* (G), and detail showing wall texture (H), Palmyra-1, interval 20–25 m. I, J *Pseudotextularia elegans* (I), and detail showing wall texture (J), Palmyra-1, interval 20–25 m. K, L *Globotruncanita stuartiformis*, Al Mahar-1, interval 20–25 m. M, N *Abathomphalus mayaroensis*, Al Mahr-1, interval 15–20 m (M), and Palmyra-1, interval 10–20 m (N). O *Abathomphalus intermedius*, Palmyra-1, interval 10–20 m. P *Globotruncanita conica*, Palmyra-1, interval 10–20 m.

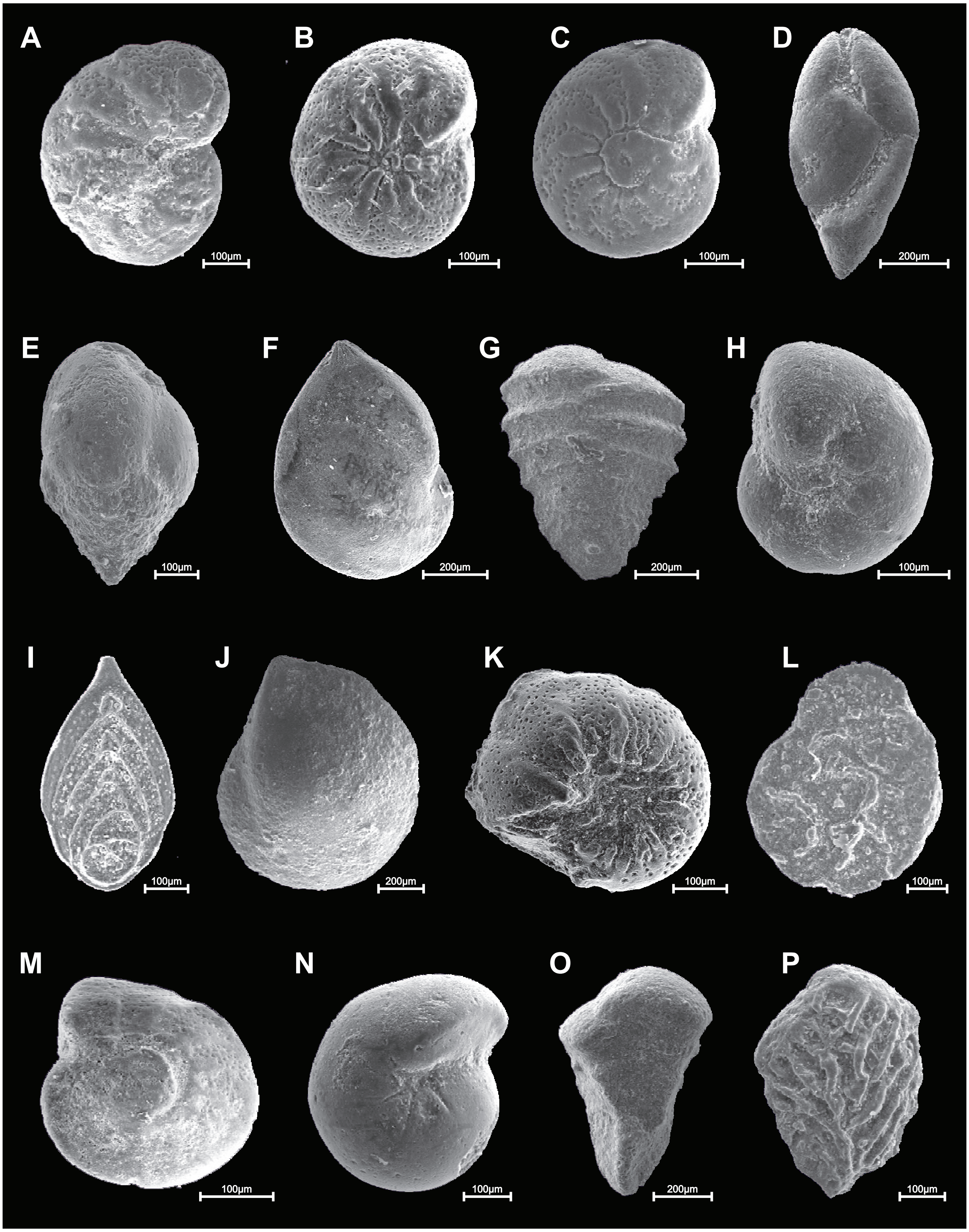


Figure 9: SEM photomicrographs of selected benthic foraminifera observed in the upper Turonian–Maastrichtian sequence of the Palmyride Region. A, B *Gavelinella* sp., Al Mahr-1, interval 185–190 m (A), and Palmyra-1, interval 180–190 m. C *Gavelinella monterelensis*, Al Mahr-1, interval 115–120 m. D *Bulimina ovulum*, Al Mahr-1, interval 150–155 m. E *Bulimina* sp., Palmyra-1, interval 130–140 m. F *Lenticulina* sp., Palmyra-1, interval 90–100 m. G *Spiroplectammina* sp., Al Mahr-1, interval 70–80 m. H *Cibicidoides* sp., Palmyra-1, interval 65–75 m. I *Neoflabelina reticulata*, Palmyra-1, interval 50–60 m. J *Lenticulina rotulata*, Al Mahr-1, interval 45–50 m. K, L *Stensioeina pommerana*, Al Mahr-1, interval 25–30 m. M *Cibicidoides* sp., Palmyra-1, interval 15–25 m. N *Gyroidinoides globosus*, Palmyra-1, interval 15–25 m. O *Gaudryna laevigata*, Al Mahr-1, interval 15–20 m. P *Bolivinoides draco*, Palmyra-1, interval 10–20 m.

ceous/Palaeogene boundary (BREW, 2001). To the northeast of the Palmyride area, however, a widespread unconformity has been documented for the Turonian–Coniacian. According to BREW (2001), during the Campanian and early Maastrichtian in the Palmyride area of Syria, progressively deeper water carbonate facies and pelagic marly limestones of the Shiranish formation were deposited. A significant period of Late Cretaceous deformation in northeastern Syria began in the latest Campanian or earliest Maastrichtian (BREW, 2001). The boundary between the Soukhne (massive limestone) formation and the syn-extensional Shiranish formation is unconformable, suggesting a major pre-extensional stratigraphic hiatus in that area.

The foraminiferal assemblage of Biozone I (late Turonian–early Santonian, upper part of the Judea Formation; Figs. 2–5 and 10) is moderately preserved. This biozone may corespond to the *Dicarinella concavata* Zone, and is characterized by the LO of *Gobigerinelloides bollii* and *Contusotruncana fornicata*, as well as by abundant *Heterohelix reussi, H. globulosa* and *H. moremani.* Opportunistic (r-strategists) biserial taxa heterohelicids and globular archeoglobigerinids (PREMOLI SILVA & SLITER, 1999; PETRIZZO, 2002, 2003) are important components in this biozone. The dominant species *Heterohelix globulosa* inhabits subsurface levels in the water column (ABRAMOVICH et al., 2003). Domination of opportunistic biserial heterohelicids and other genera with simple morphology (*Muricohedbergella*, *Pseudotextularia*, *Archeoglobigerina* and *Whiteinella*), which comprise up to 87 % of the total planktonic foraminiferal assemblage, indicate palaeoceanographic conditions favorable for opportunistic (r-strategist) organisms, such as a high productivity ocean with generally cooler but fluctuating climate, well developed oxygen minimum zone, common up-wellings and cyclic eutrophications of the surface water (BOERSMA & PREMOLI SILVA, 1989; NEDERBRAGT et al., 1998; PETRIZZO, 2002).

On the other hand, the occurrence of K-strategists (*Dicarinella* and *Marginotruncana*), although present in a smaller percentage in the planktonic assemblage, indicates warm stable episodes with oligotrophic oceanic conditions and well developed water column stratification, which are favourable for these two groups with more complex test architecture (PETRIZZO, 2002). Almost equal proportions of small benthic and planktonic foraminifera in limestones (mudstone/wackestone to foraminiferal wackestone) and marl suggest deposition in outer shelf environments (OLSSON & NYONG, 1984; BOERSMA, 1988; MURRAY, 1991; GRÄFE, 2005

The most important characteristic of Biozone II (middle–late Santonian, the Soukhne Formation; Figs. 2–5 and 10) is the high level of speciation of planktonic foraminifera. This Biozone is determined by the first appearance of several new taxa including *Globotruncana linneiana, G. arca, G. bulloides*, *G. hilli, Hendersonites carinatus, Heterohelix planata, H. punctulata, H. striata*, *Globigerinelloides prairiehillensis,* and *Globotruncanita stuartiformis*, which may suggest the *Dicarinella asymetrica* Zone. The foraminiferal assemblage is moderately diverse and better preserved relative to biozone I. Heterohelicids experienced speciation during this Biozone; their abundance increased to 46.5%, and they remained a dominant group until the end of the Cretaceous. As opportunistic planktonic foraminifera heterohelicids inhabit more nutrient-rich waters and are indicators of cooler and unstable environments (NEDERBRAGT, 1991; NEDERBRAGT et al., 1998; PETRIZZO, 2002). Their speciation is most likely induced by a somewhat cooler but variable climate and anoxic events during the middle Santonian. Beside heterohelicids, other small-sized forms with simple test-morphology, such as muriciohedbergellids, archeoglobigerinids and globigerinelloids, are very common in the planktonic assemblage. All of these groups belong to opportunistic taxa that have a great reproductive potential in eutrophic and somewhat mesotrophic environments with a very well developed oxygen minimum layer (NEDERBRAGT, 1991). Small-sized heterohelicids indicate expansion of the oxygen minimum zone (OMZ) due to increased surface water productivity and depletion of oxygen in subsurface waters by oxidation of organic carbon (LECKIE, 1987; LECKIE et al., 1998; KELLER & PARDO, 2004; PARDO & KELLER, 2008; ASHCKENAZI-POLIVODA et al., 2011). Heterohelicidae were found to be very common in most of the OMZ suggesting high productivity and/or some tolerance to subsurface oxygen depletion (ASHCKENAZI-POLIVODA et al., 2011). In addition, abundant phosphate grains in the upper part of this zone, support the interpretation that Biozone II was characterized by high palaeoproductivity, relatively constant and high food supply and moderate increase in bottom water aeration. Very high productivity during this biozone was supported by a fluctuating climate and up-welling cycles, which brought nutrient-rich water into the environments inhabited by heterohelicids and upper-middle bathyal benthic foraminifera. At the upper boundary of Biozone II all dicarinellids and whiteinellids became extinct. The proportion of planktonic species increased and reached up to 60% of the microfossil assemblage present in foraminiferal mudstone/wackestone, marl and dolomitic limestones that represent an open marine, most probably outer shelf environments (OLSSON & NYONG, 1984; BOERSMA, 1988; MURRAY, 1991; GRÄFE, 2005).

Biozone III (early Campanian, the Soukhne Formation; Figs. 2–5 and 10) is marked by the disappearance of marginotruncanids in its base and by the LO of *Pseudoguembelina costulata* and *Rugloglobirerina rugosa.* This planktonic assemblage may correspond to the *Globotruncanita elevata* Zone. Planktonic and benthic foraminiferal assemblages are rich and moderately to well preserved. The proportion of planktonic species reaches up to 65% and indicates further deepening of this realm (BOERSMA, 1988; MURRAY, 1991; GRÄFE, 2005; DARVISHZAD & ABDOLALIPOUR, 2009). The most common species are opportunistic (r-strategists) taxa: *Hendersonites carinatus, Heterohelix punctulata, H. striata* and *Pseudotextularia nuttalli.* Although characterized by different deposits, i.e., limestone (foraminiferal mudstone/wackestone) and calcareous marl, relative to Biozone II, the deposition of these strata continued within the same open marine, probably outer shelf settings.

Phosphate grains are very common in dolomitic limestones from the upper part of Biozone II in Al Mahr-1 (Figs. 2 and 4), and in the uppermost part of Biozone II and the lowermost part of Biozone III in Palmyra-1 (Figs. 3, 4). Abundant phosphate grains generally indicate some very specific geological and palaeoenvironmental conditions, such as oxygen deficiency, upwelling conditions, and transgressive intervals (HAQ et al., 1987; REISS, 1988; ALMOGI-LABIN et al., 1993; WIDMARK & SPEIJER, 1997; JARVIS et al., 2002; PUFHAL et al., 2003; SOUDRY et al., 2006; ASHCKENAZI-POLIVODA et al., 2011). It is possible that such palaeoceanographic conditions, especially upwelling, increased food supply and primary production in the surface and subsurface marine environments, and thus also indirectly affected higher production and domination of oportunistic (r-strategists) planktonic foraminiferal species during Biozones II and III.

The lowest occurrence of *Laeviheterohelix glabrans* and *Muricohedbergella mounmouthensis* and rare *Contusotruncana plummerae* in the planktonic foraminiferal assemblage of Biozone IV (middle–late Campanian, the Shiranish Formation; Figs. 2–5 and 10) suggest the *Contusotruncana plummerae* Zone. This biozone has been appointed by PETRIZZO et al. (2011) for the lower–middle Campanian of tropical and subtropical areas because of the difficulties in using the first occurrence datum of *Globotruncana ventricosa* in low latitude successions from the Tethyan Realm. Species of the genus *Heterohelix* dominated in the previous Biozone III but decrease to 32.5% in Biozone IV, whereas the abundance of two genera *Muricohedbergella* and *Pseudoguembelina* significantly increases up to 15% and 10.5%, respectively. Although the opportunistic (r-strategists) species are still dominant, the specialized taxa (K-strategists) such as globotruncanids (PREMOLI SILVA & SLITER, 1999; PETRIZZO, 2002; DUBICKA & PERYT, 2012) increase in the overall number of species and also slightly increase in abundance within this planktonic assemblage. This indicates mesotrophic to more oligotrophic environmental conditions that are favorable for keeled globotruncanids. The well-preserved foraminiferal assemblage and high proportion of planktonic foraminifera (70%) in the argillaceous limestones marl and calcareous marls of Biozone IV suggest an open marine, probably outer shelf to upper bathyal environment (BOERSMA, 1988; MURRAY, 1991; GRÄFE, 2005).

The lowest occurrence of planktonic foraminifera *Laeviheterohelix dentata*, *Globotruncanella havanensis* and *Globotruncanita stuarti* in Biozone V (late Campanian, the Shiranish Formation; Figs. 2–5 and 10) may suggest the *Radotruncana calcarata* Zone. The well-preserved foraminiferal assemblage is rich, diverse and has an increased number of K-strategists (keeled globotruncanids; PREMOLI SILVA & SLITER, 1999). Globotruncanids have a complex test morphology and usually inhabit the subsubsurface water column (PETRIZZO, 2002; ABRAMOVICH et al., 2003; DUBICKA & PERYT, 2012), which implies good stratification of the water column and a tropical to subtropical climate during the late Campanian (LECKIE, 1989; HUBER et al., 1995; DARVISHZAD & ABDOLALIPOUR, 2009). Deposits and sedimentary settings remain the same as for Biozone IV, i.e., deep-water marine environments.

The zonal marker *Globotruncanella havanensis* is relatively rare in Biozone VI (late Campanian, the Shiranish Formation; Figs. 2–5 and 10), and the base of this Biozone is indicated by the LO of *Pseudoguembelina excolata*, *Planoglobulina carseyae* and *Rugoglobigerina hexacamerata*. The foraminiferal assemblage is rich and well preserved. Although the opportunistic group heterohelicids stay dominant group in the planktonic assemblage with 37.5% abundance, K-strategists, such as keeled globotruncanids, become an important component in the planktonic foraminiferal assemblage with 9 species and 13.5% abundance. These point to stable environmental conditions, such as an oligotrophic ocean with a tropical to subtropical climate, well stratified water column, stable thermocline and other favourable palaeoceanographic parameters for r/K and K-selected group of planktonic foraminifera (LECKIE, 1989; MURRAY, 1991; DARVISHZAD & ABDOLALIPOUR, 2009). Abundance of species from the genus *Globigerinelloide*s and *Muricohedbergella* (r-selected forms) show inverse trends in comparison with the previous biozones and decrease to 7.5% and 6%, respectively (Fig. 10). The proportion of planktonic species increased and reached up to 85% of the microfossil assemblage present in marl and argillaceous limestone (mudstone/wackestone) that represent an open marine, outer shelf to upper bathyal environments (OLSSON & NYONG, 1984; BOERSMA, 1988; MURRAY, 1991; GRÄFE, 2005).

The *Pseudoguembelina palpebra* Zone (Biozone VII, late Campanian–early Maastrichtian, the Shiranish Formation; Figs. 2–5 and 10) is characterized by the LO of *P. palpebra*, which is consistently found throughout the interval in moderate abundance. Also, the lowest occurrence of *Globotruncanella pschadae, Pseudoguembelina kempensis* and *Racemiguembelina powelli* is recorded in the lower part of this biozone. *Gansserina gansseri* is very rare and poorly preserved in the investigated samples, and therefore *P. palpebra* serves as a better zonal marker for the uppermost Campanian, as also reported by HUBER at al. (2008) from subtropical North Atlantic (Blake Nose). The planktonic foraminiferal assemblage of Biozone VII is rich, very well preserved and in comparison with Biozone VI, biodiversity throughout this interval significantly increases (to 41 species). Opportunistic representatives of the genus *Heterohelix* are still the dominant group in the planktonic assemblage with 34% abundance. Also, the genus *Pseudoguembelina,* known as a successful surface and subsurface dweller in tropical and subtropical open ocean (NEDERBRAGT, 1989; HUBER, 1992; ABRAMOVICH et al., 2003), significantly increased in abundance up to17%. Species of the genus *Pseudoguembelina* are strongly photosymbiotic and their expansion is related to favourable palaeoecological conditions in the Late Cretaceous ocean, such as the presence of warm and oligotrophic surface ocean waters (D´HONDT & ZACHOS, 1998; ABRAMOVICH et al., 2003). The proportion of planktonic foraminifera accounts for up to 90% of the microfossil assemblages found in marl and argillaceous limestone (mudstone/wackestone), which implies further deepening of this realm and deposition in outer shelf to upper bathyal environments (BOERSMA, 1988; MURRAY, 1991; GRÄFE, 2005; DARVISHZAD & ABDOLALIPOUR, 2009).

The lowest occurrence of planktonic foraminifera *Planoglobulina acervulinoides* and *Peudotextularia elegans* in association with the rare zonal marker *Racemiguembelina fructicosa*, is indicative of Biozone VIII (early–late Maastrichtian, the Shiranish Formation; Figs. 2–5 and 10). This biozone is characterised by a diverse and very well preserved planktonic foraminiferal assemblage with 41 species, similar to that from Biozone VII. Rugoglobigerinids increased in abundance and reached up to 14% of the assemblage, while representatives of the genus *Heterohelix* still dominate the assemblage with 38%. Species of the genus *Rugoglobigerina* inhabit surface and subsurface habitats (ABRAMOVICH et al., 2003), and are known as symbiotic organisms (D´HONDT & ZACHOS, 1998). Speciation of planktonic foraminifera in this biozone is likely supported by good water column stratification and opening of new niches favourable for all groups of planktonic foraminifera. Many subsurface dwellers, such as several species of the genus *Globotruncana,* acquired adaptation to the thermocline habitat (ABRAMOVICH et al., 2003). All of these changes correspond very well to the documented global sea level fluctuations and alternating cooler and warmer periods in the early to late Maastrichtian (HAQ et al., 1987; Fig. 5). During Zone VIII the sedimentary setting was a deep sea environment (upper bathyal), as a result of further deepening of this sedimentary realm.

The planktonic foraminiferal assemblage of the latest Cretaceous *Abathomphalus mayaroensis* Zone (Biozone IX**,** late Maastrichtian, the Shiranish Formation; Figs. 2–5 and 10) is very similar to those in Biozone VIII and is rich in the overall number of species (39) as well as in the number of individuals. An important characteristic of this biozone is the increased number of K-strategist species of globotruncanids (15.5%), and planoglobulinids (4%), whereas rugoglobigerinids retained their abundance (14%). Some opportunistic species of the genus *Muricohedbergella* also show an increase and constitute 9% of the assemblage, while members of the genus *Globigerinelloides* (2%) decrease in abundance (Fig. 10). Species of the genus *Heterohelix* have an almost equal abundance (36%) compared to Biozone VIII.

Composition of the planktonic foraminiferal assemblage with a significantly higher percentage of K-strategist specialists, which inhabit subsurface and thermocline layers, indicates an oligotrophic ocean with a very well stratified water column supported by a stable thermocline (PREMOLI SILVA & SLITER, 1999; PEARSON et al., 2001; ABRAMOVICH et al., 2003). On the other hand, the symbiont-bearing taxa *Rugoglobigerina*, *Pseudoguembelina* and *Heterohelix* were very well adapted to surface and subsurface oligotrophic ocean water (D´HONDT & ZACHOS, 1998; PEARSON et al., 2001; ABRAMOVICH et al., 2003). In the upper part of Biozone IX, the decreased numbers of globotruncanid species indicate fluctuating climate, sea-level changes and up-welling cycles which could cause instability in the water column and unfavourable environmental conditions for K-strategists (ABRAMOVICH & KELLER, 2002; HAQ et al., 1987). This high diversity abruptly decreases at the end of the Biozone, when most planktonic foraminiferal species became extinct. Marl, argillaceous limestone (mudstone/wackestone), and slightly dolomitized limestone (foraminiferal wackestone) contain rich and very well preserved foraminiferal assemblages, whereas planktonic foraminifera reach over 90% of the entire community suggesting deposition in upper bathyal environments (BOERSMA, 1988; MURRAY, 1991; GRÄFE, 2005; DARVISHZAD & ABDOLALIPOUR, 2009). All these facts indicate the Late Cretaceous as being a long, warm and relatively stable period with palaeoceanographic conditions favourable for all groups of planktonic foraminifera which inhabited different niches in a well stratified water column (LECKIE, 1989; HUBER et al., 1995; PREMOLI SILVA & SLITER, 1999; PETRIZZO, 2002, PEARSON et al., 2001; ABRAMOVICH et al., 2003; DUBICKA & PERYT, 2012).

The Soukhne Formation (Santonian–Early Campanian, Biozones II and III, Figs. 2–4) contains phosphate grains. Similar phosphate deposits are widespread in many parts of the Levantin region (i.e., Israel, Jordan, Iraq, Turkey and Egypt; AL MALEH & MOUTY, 1994; PUFHAL et al., 2003; ABED at al., 2005; BAIOUMY & TADA, 2005; SOUDRY et al., 2006; ASHCKENAZI-POLIVODA et al., 2011; SCHNEIDER-MOR et al., 2012). The phosphate deposits in Syria formed in response to a high-productivity upwelling regime that persisted on the southern margins of the Tethys during the Late Cretaceous (AL MALEH & MOUTY, 1994). The planktonic assemblages associated with phosphate grains in the Palmyride strata are characterized by domination of opportunistic (r-strategists) taxa such as the genus *Heterohelix* (Biozone II and III, Figs. 2, 3), which indicates a highly productive photic zone (REISS, 1988; ALMOGI-LABIN et al., 1993; WIDMARK & SPEIJER, 1997; PUFHAL et al., 2003) and a low oxygen environment (ASHCKENAZI-POLIVODA et al., 2011). The benthic assemblages found with phosphates have abundant specimens of the genus *Bulimina*, which are commonly documented from highly productive, low-oxygen settings from around the world, including for example South America, Morocco, Egypt, Jordan, Iraq and Israel (PUFHAL et al., 2003; ASHCKENAZI-POLIVODA et al., 2011). An additional factor that contributed to the formation of phosphate was the enrichment in phosphorous from P-rich deep waters that upwelled in the Palmyrida Basin by currents flowing along the northern edge of the Arabian platform (SOUDRY et al., 2006). Warming of the upwelled water and the abundance of nutrients caused the proliferation of plankton, which assimilated, stored and concentrated phosphate. After the deposition of plankton, a large amount of phosphate dissolved and became concentrated in the sea-floor sediments (AL MALEH & MOUTY, 1994).

Such high primary productivity and sea floor phosphogenesis prevailed mainly on the southeastern Tethyan margins as a result of persistent upwelling circulation that recycled dissolved phosphorous from the intermediate-depth waters and distributed it to the photic zone (SOUDRY et al.,

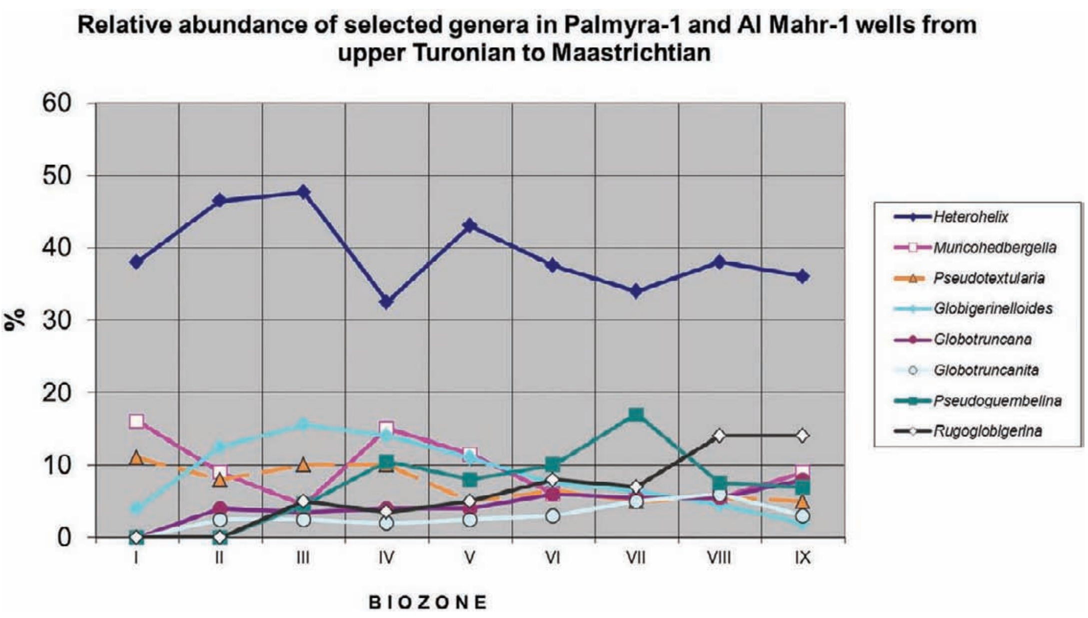


Figure 10: Percentage of Late Cretaceous genera in the planktonic foraminiferal assemblages from the study area in Syria.

2006). The phosphates developed during transgressive periods that promoted carbonate sediment starvation. Simple (internally homogenous) P_2O_5-enriched phosphate nodules probably replaced calcite nodule precursors in suboxic conditions as a result of processes that involved oceanic upwelling, exhumation and burial coupled with alternating oxic and suboxic conditions (MARSHALL-NEILL & RUFFELL, 2004). The presence of phosphate is an important indicator of oxygen deficiency, upwelling conditions, transgressive intervals, and omission surfaces (TRAPPE, 2001), and any future studies of this Cretaceous stratigraphic interval should also include detailed analyses of the associated phosphate grains.

6. CONCLUSIONS

The stratigraphic analysis of the Upper Cretaceous strata from the Palmyride area in Syria included a detailed micropalaeontological investigation of foraminferal assemblages and rock types obtained from drill cuttings in two deep exploration wells (Al Mahr-1 and Palmyra-1).

Nine biozones have been identified in the upper Turonian to Maastrichtian succession: Biozone I, Biozone II, Biozone III, IV *Contusotruncana plummerae* Zone, Biozone V, VI *Globotruncanella havanensis* Zone, VII *Pseudoguembelina palpebra* Zone, VIII *Raceemiguembelina fructicosa* Zone, and IX *Abathomphalus mayorensis* Zone.

During the late Turonian to early Campanian (Biozone I to III) in the investigated Palmyride strata, domination of opportunistic taxa (*Heterohelix, Globigerinelloides, Archaeoglobigerina, and Muricohedbergella)* implies upwelling, low oxygen conditions and subtropical climate. On the other hand, the rich and highly diversified planktonic assemblages (Biozone IV to IX) with many K-selected taxa (i.e., ornamented keeled globotruncanids, rugoglobigerinids, planoglobulinids, pseudoguembelinids) indicate a tropical to subtropical climate and well-stratified water column during the late Campanian and into the Maastrichtian. In the upper part of Biozone IX, the decreased numbers of globotruncanid species indicate a less stratified water column and unfavourable environmental conditions for K-strategists. A dramatic faunal turnover at the end of this Biozone is marked by the extinction of most planktonic foraminifera, with only a few species (e.g., *Muricohedbergella holmdelensis, M. montmouthensis* and *Guembelitria cretacea*) present across the Cretaceous/Palaeogene boundary.

Phosphate grains are very common in dolomitic limestone of the upper part of Biozone II in Al Mahr-1 and in the uppermost part of Biozone II and lowermost part of Biozone III in Palmyra-1 (Soukhne Formation). The phosphate occurrence helps improve the late Santonian–early Campanian stratigraphic interpretation of this interval because similar deposits occur during this time period elsewhere along the southeastern margins of Tethys (Israel, Jordan, Iraq, Turkey and Egypt). The presence of phosphate in the study area indicates oceanic upwelling that caused increased food supply and influenced higher primary marine production, and thus indirectly affected higher production and domination of oportunistic planktonic foraminifera in Biozones II and III.

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APPENDIX 1

List of taxa cited in the text and figure explanations, in alphabetical order according to genus

Planktonic foraminifera
Abathomphalus intermedius (BOLLI, 1951)
Abathomphalus mayaroensis (BOLLI, 1951)
Archaeoglobigerina blowi PESSAGNO, 1967
Archaeoglobigerina cretacea (D’ORBIGNY, 1840)
Contusotruncana fornicata (PLUMMER, 1931)
Contusotruncana plummerae (GANDOLFI, 1955)
Dicarinella sp.
Gansserina gansseri (BOLLI, 1951)
Gglobigerinelloides bollii (PESSAGNO, 1967)
Gobigerinelloides prairiehillensis (PESSAGNO, 1967)
Globigerinelloides subcarinatus (BRÖENNIMANN, 1952)
Globotruncana arca (CUSHMAN, 1926)
Globotruncana bulloides VOGLER, 1941
Globotruncana hilli PESSAGNO, 1967
Globotruncana linneiana (D’ORBIGNY, 1839)
Globotruncanella havanensis (VOORWIJK, 1937)
Globotruncanella minuta CARON & GONZALEZ DONOSO, 1984
Globotruncanella petaloidea (GANDOLFI, 1955)
Globotruncanella pschadae (KELLER, 1946)
Globotruncanita conica (WHITE, 1928)
Globotruncanita pettersi (GANDOLFI, 1955)
Globotruncanita stuarti (DE LAPPARENT, 1918)
Globotruncanita stuartiformis (DALBIEZ, 1955)
Guembelitria cretacea CUSHMAN, 1933
Guembelitria turrita NEDERBRAGT, 1990
Hendersonites carinatus (CUSHMAN, 1938)
Heterohelix globulosa (EHRENBERG, 1840)
Heterohelix labellosa NEDERBRAGT, 1990
Heterohelix navarroensis LOEBLICH, 1951
Heterohelix moremani (CUSHMAN, 1938)
Heterohelix planata (CUSHMAN, 1938)
Heterohelix punctulata (CUSHMAN, 1938)
Heterohelix reussi (CUSHMAN, 1938)
Heterohelix striata (EHRENBERG, 1840)
Laeviheterohelix dentata (STENESTAD, 1968)
Laeviheterohelix glabrans (CUSHMAN, 1938)
Marginotruncana sp.
Muricohedbergella flandrini (PORTHAULT, 1970)
Muricohedbergeela holmdelensis (OLSSON, 1964)
Muricohedbergella mounmouthensis (OLSSON, 1960)
Muricohedbergella sp.
Planoglobulina carseyae (PLUMMER, 1931)
Planoglobulina acervulinoides (EGGER, 1899)
Pseudoguembelina costulata (CUSHMAN, 1938)
Pseudoguembelina excolata (CUSHMAN, 1926)
Pseudoguembelina kempensis ESKER, 1968
Pseudoguembelina palpebra BRÖENNIMANN & BROWN, 1953
Pseudotextularia elegans (RZEHAK, 1891)
Pseudotextularia intermedia DE KLASZ, 1953
Pseudotextularia nuttalli (VORWIJK, 1937)
Racemiguembelina fructicosa (EGGER, 1902)
Racemiguembelina powelli SMITH & PESSAGNO, 1973
Rugoglobigerina macrocephala BRÖENNIMANN, 1952
Rugoglobigerina hexacamerata BRÖENNIMANN, 1952
Rugoglobigerina rugosa (PLUMMER, 1926)
Whiteinella balthica DOUGLAS & RANKIN, 1969
Whiteinella sp.

Benthic foraminifera
Bolivinoides draco (MARSSON, 1878)
Bolivinoides miliaris HILTERMANN & KOCH, 1950
Bolivina incrassata REUSS, 1851
Bulimina ovulum REUSS, 1844
Bulimina sp.
Cibicidoides sp.
Gaudryina laevigata FRANKE, 1914
Gavelinella monterelensis (MARIE, 1941)
Gavelinella sp.
Gyroidinoides globosus HAGENOW, 1842
Gyroidinoides sp.
Lenticulina rotulata (LAMARCK, 1804)
Lenticulina münsteri (ROEMER, 1839)
Lenticulina sp.
Neoflabelina reticulata (REUSS, 1851)
Nodosaria sp.
Oridorsalis umbonatus (REUSS, 1851)
Oridorsalis sp.
Praebulimina reussi (MORROW, 1934)
Praebulimina kickapoensis (COLE, 1938)
Serovaina complanata (CUSHMAN & STAINFORTH, 1945)
Spiroplectammina sp.
Stensioeina pommerana BROTZEN, 1936

APPENDIX 2

Distribution of Late Cretaceous genera of planktonic foraminiferal assemblage from Al Mahr-1 and Palmyra-1 wells.

DEPTH (m)	180-185	145-150	125-130	90-95	80-85	65-70	40-45	25-30	20-25
BIOZONE	I	II	III	IV	V	VI	VII	VIII	IX
SPECIES RICNESS	14	22	22	24	27	32	41	41	40
Abathomphalus intermedius							1	2	1
Abathomphalus mayaroensis									1
Archaeoglobigerina blowi	15	16	10	6	6	3	3	2	
Archaeoglobigerina cretacea	12	11	5	2	3	2	2	1	
Contusotruncana fornicata	17	14	5	6	7	4	2		
Contusotruncana plummerae				2	6	2	3		
Dicarinella sp.	9	5							
Gansserina gansseri							2	1	2
Gglobigerinelloides bollii	11	17	27	19	15	8			
Gobigerinelloides prairiehillensis		11	15	9	13	7	12	9	
Globigerinelloides subcarinatus		9	8	14	9	9	8	6	7
Globotruncana arca		4	4	5	4	9	6	8	14
Globotruncana bulloides		3	3	3	4	2	2	1	
Globotruncana hilli		3	3	2	3	4	2	4	11
Globotruncana linneiana		2	2	3	3	4	7	6	
Globotruncanella havanensis						10	6	5	7
Globotruncanella minuta							1	1	3
Globotruncanella petaloidea						5	3	3	3
Globotruncanella pschadae							3	3	2
Globotruncanita conica							1	2	1
Globotruncanita pettersi							3	6	3
Globotruncanita stuarti					3	4	2	6	2
Globotruncanita stuartiformis		7	8	7	6	6	9	7	4
Guembelitria cretacea								1	1
Hendersonites carinatus		17	34						
Heterohelix globulosa	38	33	19	14	32	30	29	34	29
Heterohelix labellosa					11	14	14	12	14
Heterohelix moremani	31								
Heterohelix navarroensis				8	17	27	23	31	21
Heterohelix planata		14	14	32	8	7	6	12	17
Heterohelix punctulata		21	33	9	16	9	9	7	11
Heterohelix reussi	35	31	18						
Heterohelix striata		19	35	34	29	32	25	32	27
Laeviheterohelix dentata					5	6	10	4	6
Laeviheterohelix glabrans				6	4	8	7	7	5
Marginotruncana sp.	11	4							
Muricohedbergella flandrini	18								
Muricohedbergeela holmdelensis	25	19	9	21	18	8	13	7	12
M. mounmouthensis				17	15	7	4	11	17
Muricohedbergella sp.		7	6	7	5	4			
Planoglobulina carseyae						7	6	5	8
Pseudoguembelina costulata			15	31	26	23	26	7	4
Pseudoguembelina excolata						6	9	8	7
Pseudoguembelina kempensis							3	4	6
Pseudoguembelina palpebra							13	7	7
Pseudotextularia elegans								11	11
Pseudotextularia intermedia							2	1	1
Pseudotextularia nuttalli	30	23	33	30	16	21	14	6	4
Racemiguembelina fructicosa								1	1
Racemiguembelina powelli							2	2	1
Rugoglobigerina hexacamerata						4	5	9	10
Rugoglobigerina macrocephala							5	15	12
Rugoglobigerina rugosa			16	11	17	21	12	24	26
Whiteinella balthica	11								
Whiteinella sp.	9								
(%) PLANKT. FORAM.	51.22	59.30	64.27	70.21	80.34	85.17	91.24	92.56	93.98
(%) BENT. FORAM.	48.78	40.67	35.72	29.79	19.66	15.05	8.76	7.44	6.02