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Planktonic Foraminiferal Biostratigraphy of the Late Eocene and Oligocene in the Palmyride Area, Syria

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Key words: Biostratigraphy, Planktonic foraminifera, Late Eocene, Oligocene, Palmyride area, Syria.

Abstract

Three deep exploration wells in the Palmyride area (Syria) have been drilled through Oligocene and Eocene deposits. A detailed micropalaeontological investigation has been performed on the planktonic foraminiferal assemblage from drill cuttings. Standard planktonic foraminiferal zones from P15 to P22 (E15 to O6) have been identified. The test morphology and diversity of the foraminiferal assemblage indicate a general cooling trend during the late Eocene and Oligocene. The specialized Eocene forms (K-mode life strategy) such as turborotaliids, globigerinathekids and hantkeninids become extinct in the uppermost late Eocene. The Oligocene is characterized by the dominance of cooler, opportunistic planktonic foraminifera (r-mode life strategy), such as pseudohastigerinids, chiloguembelinids, globigerinids and tenuitellids. A very low number of benthic foraminifera in late Eocene cuttings implies sedimentation in a deep, open sea environment. A gradual increase of the benthic foraminiferal proportion through the Oligocene indicates shallowing of the sedimentary environment.

1. INTRODUCTION

In different geological periods, planktonic foraminifera were deposited over an extensive portion of the world oceans and seas, and are often found in large numbers. Industrial application of planktonic foraminiferal biostratigraphic studies began in the middle of the last century in the Gulf Coast region of the USA and quickly spread through the principal oil-producing parts of the world (STAINFORTH et al., 1975; BOERSMA, 1988). This has resulted in the recognition of their usefulness for both local and regional biostratigraphic zonation and correlation (BOLLI & SAUNDERS, 1985; BERGGREN et al., 1995).

Numerous biostratigraphic studies of planktonic foraminifera have originated from the Former Soviet Union – the first zonal scheme for planktonic foraminifera was published by SUBBOTINA (1947) for sections of the Caucasus Mountains. Afterwards, a large number of planktonic foraminiferal studies were published, e.g. BOLLI (1957), BLOW (1979), TOUMARKINE & LUTERBACHER (1985), BERGGREN & MILLER (1988), and others. A revised geochronology and geochronostratigraphic study was published by BERGGREN et al. (1995). Further investigations of the planktonic foraminiferal ranges from different parts of the world have provided knowledge for a new zonation (BERGGREN & PEARSON, 2005; PEARSON et al., 2006).

Important biostratigraphical work on the Palaeogene deposits in Syria has been undertaken by KRASHENINNIKOV et al. (1996). A previous biostratigraphic investigation in the Palmyride area, on material from deep exploration wells was done by HERNITZ KUČENJAK et al. (2005).

In the present work, a planktonic foraminiferal fauna from three deep exploration wells Jihar–1, Jihar–4 and Jihar–5 drilled in the Palmyride area (Fig. 1) has been examined. A rich, highly to moderately diverse and well preserved planktonic foraminiferal association enabled biostratigraphical zonation of the late Eocene and Oligocene deposits (Fig. 3). On the basis of the composition of the foraminiferal assemblages, diversity, changes of test morphology and wall texture, palaeoecological and palaeoclimatic interpretations have been made.

2. MATERIAL AND METHODS

The detailed biostratigraphic study was based on material from drill cuttings from three deep exploration wells (Jihar–1, Jihar–4 and Jihar–5) drilled in the Hayan exploration block in the Palmyride area (Fig. 1). Samples for micropalaeontological analyses were taken at every 10 m in Jihar–1 and Jihar–5 wells and at 20 m intervals in the Jihar–4 well. Samples were soaked in water with a small amount of hydrogen peroxide and then washed under running water through 63 μm, 125 μm, 160 μm and 630 μm sieves. These four fractions were dried in a drier and from each fraction foraminifera were picked out onto micropalaeontological slides. Microfossil associations were examined on a stereo microscope, whereas a detailed study of the

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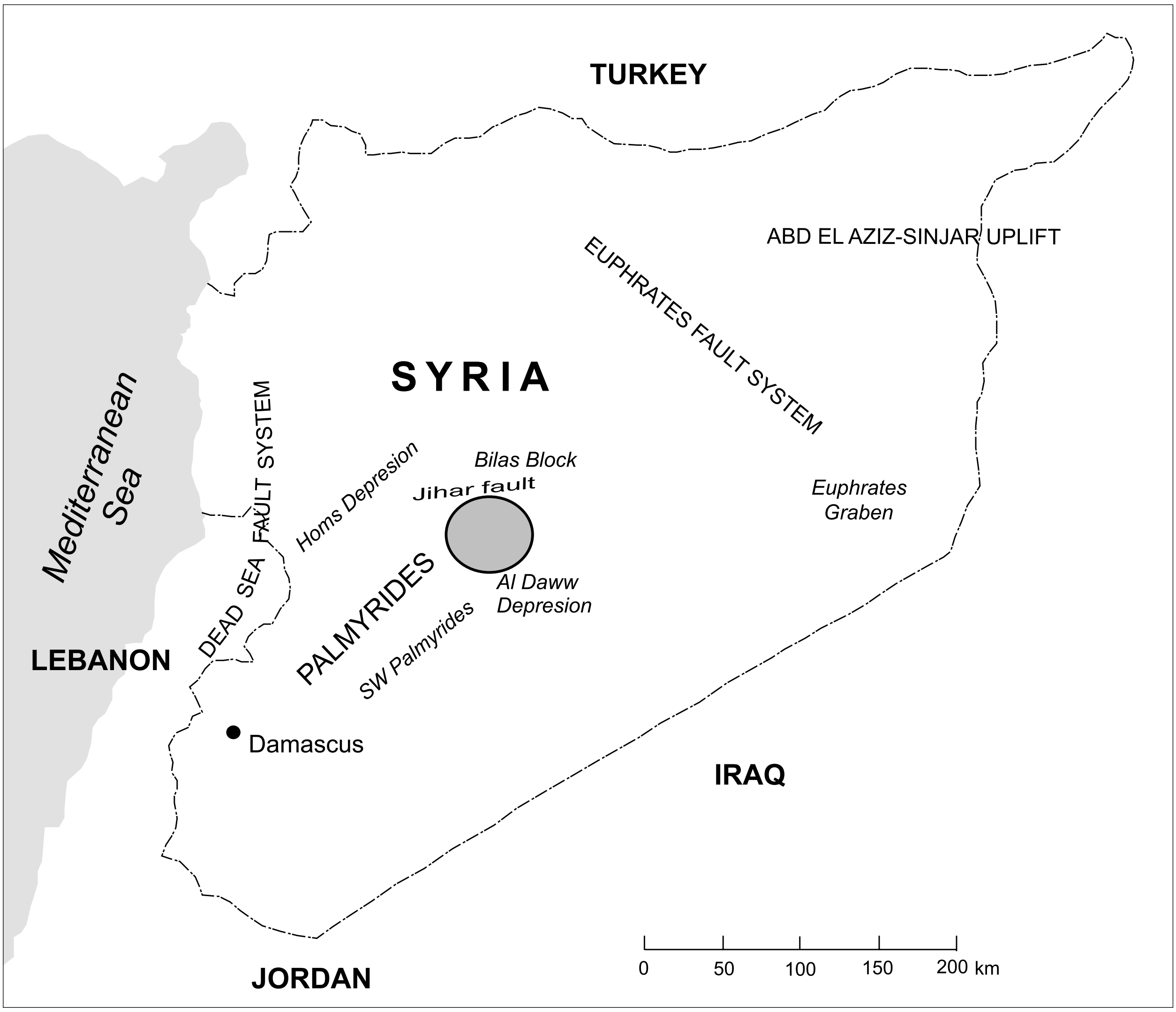

Fig. 1 Map of Syria showing the location of the main tectonic zones (modified from BREW, 2001). A circle represents the approximate location of the Hayan exploration block.

planktonic foraminiferal morphology was performed on scanning electron microscope (SEM).

Biostratigraphic interpretation was based on the standard planktonic foraminiferal biozonation (P zones) – BERGGREN et al. (1995), and new planktonic foraminiferal biozonation (E and O zones) – BERGGREN & PEARSON (2005) and PEARSON et al. (2006) (Fig. 2).

Determination of the planktonic foraminiferal genera and species was based on BOLLI & SAUNDERS (1985), TOUMARKINE & LUTERBACHER (1985), SPEZZAFERRI (1994), IACCARINO et al. (2005) and PREMOLI SILVA & PETRIZZO (2006). The classification scheme used follows LOEBLICH & TAPPAN (1988).

Here, determination of planktonic foraminiferal biozones was based on the last occurrence (LO) of the index taxa to avoid possible mistakes as a result of mixing different foraminiferal associations in drill cuttings. The only exception is the boundary between zones O3 (P20) and O4 (P21a) which is defined by the first occurrence (FO) of *Globigerina angulisuturalis*. Because of the difficulty in identification of the first occurrence of the zonal marker, this boundary is an approximation.

3. GEOLOGICAL SETTING

The foraminiferal fauna has been studied from the Hayan exploration block (Fig. 1), which is situated in the Palmyride area (Central part of Syria). The Palmyrides are an inverted Mesozoic rift basin (LUČIĆ & FORŠEK, 2000; BREW, 2001; BREW et al., 2001). Inversion began in the Late Cretaceous, but the majority of the inversion took place in the Miocene (BREW, 2001).

Syria can be divided into four major tectonic zones: the Palmyride area, the Abd el Aziz–Sinjar area, the Euphrates Fault System, and the Dead Sea Fault System (BREW, 2001; BREW et al., 2001). The Palmyrides are an intracontinental mountain fold belt which extend

EPOCH		AGE	PLANKTONIC FORAMINIFERAL ZONES: Berggren et al. (1995)		Berggren & Pearson (2005)		This work	
MIOCENE	EARLY	AQUIT-ANIAN	M1b	*Gt. kugleri / Gq. dehiscens* CRZ	not studied		not studied	
			M1a	*Gd. primordius* PRZ				
OLIGOCENE	LATE	CHATIAN	P22	*Gl. ciperoensis* PRZ	O6	*Gl. ciperoensis* PRZ	O6	*Gl. ciperoensis*
			P21 b	*Gl. angulisuturalis / Pg. opima* s.s. ISZ	O5	*Pg. opima* HOZ	O5	*Pg. opima*
	EARLY	RUPELIAN	P21 a	*Gl. angulisuturalis / Ch. cubensis* CRSZ	O4	*Gl. angulisuturalis / Ch. cubensis* CRZ	O4	*Gl. angulisuturalis / Ch. cubensis*
			P20	*Gl. sellii* PRZ	O3	*Gl. sellii* PRZ	O3	*Gl. sellii*
			P19	*T. ampliapertura* IZ	O2	*T. ampliapertura* HOZ	O2	*T. ampliapertura*
			P18	*Ch. cubensis - Pseudohastigerina* spp. IZ	O1	*P. naguewichiensis* HOZ	O1	*P. naguewichiensis*
EOCENE	LATE	PRIABONIAN	P17	*T. cerroazulensis* IZ	E16	*H. alabamensis* HOZ	E16 E15	*H. alabamensis* *G. index*
			P16	*T. cunialensis / Cr. inflata* CRZ	E15	*G. index* HOZ		
			P15	*Po. semiinvoluta* IZ	E14	*G. semiinvoluta* HOZ	E14	*G. semiinvoluta*

Fig. 2 Biostratigraphical zonation based on the planktonic foraminifera (after BERGGREN & PEARSON, 2005); abbreviations: IZ – Interval Zone, CRZ – Concurrent-range Zone, PRZ – Partial-range Zone, CRSZ – Concurrent-range Subzone, ISZ – Interval Subzone, HOZ – Highest-occurrence Zone.

from the Dead Sea Fault Zone in the west, and join the Euphrates fault system in the east (LUČIĆ & FORŠEK, 2000; BREW, 2001). The Palmyrides extend 400 km approximately southwest to northeast across Syria, and they are 100 km wide (LUČIĆ & FORŠEK, 2000; BREW, 2001). They can be further divided on the basis of topography and structure into the southwestern Palmyrides (a fold and thrust belt) and the northeastern Palmyrides – the Bilas and Bishri blocks. The Jihar fault separates the two areas (BREW, 2001). Between the Jihar fault and the short-wavelength folds of the southern Palmyrides lies the low-relief Al Daww Depression (LUČIĆ & FORŠEK, 2000; BREW, 2001), which is a 100 km long and 20 km wide inter-montaine basin. The Hayan block is situated partly in the Al Daww depression and extends towards the Bilas block.

In the geological evolution of Syria during the Palaeogene, five main steps have been observed by KRASHENINNIKOV et al. (1996), which correspond to the following lithostratigraphic formations: calcareous clays and marls in the Palaeocene and Lower Eocene; alternation of limestones and flints in the uppermost Lower Eocene; chalky and nummulitic limestones in the Middle Eocene; alternation of chalky and hard fine-grained limestones in the Upper Eocene and finally shallow biogenic limestones with terrigenous sediments at the top of the Palaeogene formations, deposited during the Oligocene.

In the Palmyrides, the Oligocene marine sedimentation stopped at the Neogene boundary, and the marine Palaeogene is overlain by continental sediments or by unconformable and transgressive marine Lower Miocene deposits.

4. LITHOLOGY

In the studied exploration area, the Middle Eocene argillaceous limestones underlie the Upper Eocene deposits. These argillaceous limestones are greyish white to grey–greenish wackestone/packstones. They occasionally grade into calcareous marl, grey to brownish in colour. In places there are a few occurrences of grey quartz arenites. The Upper Eocene sedimentary rocks (biozones E14 to E16) are represented by greyish–white to grey–greenish argillaceous limestones of wackestone to wackestone/packstone types. Occasional occurrences of marls have been found, but only in the Jihar–4 well. The Lower Oligocene sediments are composed of light grey to grey marls, and white to grey–greenish argillaceous limestones of wackestone/packstone types. Deposits of the Upper Oligocene consist of grey, sporadically sandy–clayey marls, with occurrences of very light grey fine- to medium-grained quartz arenites. The Upper Oligocene deposits are overlain by the light grey sandstones of quartz wacke to quartz arenite type, and grey to brownish grey marls, possibly Early Miocene in age.

According to the lithological characteristics of deposits and composition of the foraminiferal association (plankton/benthos ratio approx. 70:30), the Upper Eocene rocks were probably deposited in the open shelf environment, whereas the Oligocene deposits (plankton/benthos ratio approx. 40:60) were accumulated in the outer to middle shelf environment.

5. PLANKTONIC FORAMINIFERAL BIOZONATION OF THE LATE EOCENE TO OLIGOCENE

The frequency of planktonic foraminifera in the samples enables application of standard planktonic foraminiferal zonations (BERGGREN et al., 1995; BERGGREN & PEARSON, 2005; PEARSON et al., 2006 – Fig. 2).

Zones E14 (P15) and E15/E16 (P16/P17) have been identified in the Upper Eocene. Zones from O1 (P18) to O6 (P22) have been recognized in the Oligocene sedimentary succession (Fig. 3).

Zone E14 *Globigerinatheka semiinvoluta* – BERGGREN & PEARSON, 2005; PEARSON et al., 2006 (approx. = *Ponticulasphaera semiinvoluta* Zone P15 – BERGGREN et al., 1995)

Intervals: Jihar–1 (approx. 460 to 500 m), Jihar–4 (approx. 635 to 675 m), Jihar–5 (approx. 310 to 350 m).

In the material studied, a very well preserved planktonic foraminiferal association has been presented. The lower boundary of this Zone is defined by the extinction of all morozovellids and large acarininids and corresponds very well with previous investigations in the Mediterranean and Atlantic areas (PREMOLI SILVA & BOERSMA, 1988; PREMEC-FUĆEK et al., 1998; WADE, 2004).

Only very small muricate species, such as *Acarinina medizzai* TOUMARKINE & BOLLI and *Acarinina collactea* (FINLAY), persisted across the Middle/Late Eocene boundary as in other Mediterranean bioprovinces (PREMOLI SILVA & BOERSMA, 1988; PREMEC-FUĆEK et al., 1998). In the investigated wells, *A. medizzai* (Pl. 1, Figs. 1–4) and *A.collactea* became extinct at the end of Zone E14. In that interval, the *Turborotalia* lineage was represented by *Turborotalia cerroazulensis* (HOWE & WALLACE), *T. pomeroli* (TOUMARKINE & BOLLI), *T. cocoaensis* (CUSHMAN), and transitional forms between *T. pomeroli* and *T. cerroazulensis* (Pl. 1, Fig. 6). The microperforate species *Pseudohastigerina micra* (COLE) (Pl. 1, Fig. 5) was very frequent in the foraminiferal association of zone E14. Furthermore, *Subbotina cryptomphala* (GLAESNER), *S. eocaena* (GUEMBEL), *S. angiporoides* (HORNIBROOK), *S. yeguaensis* (WEINZIERL & APPLIN), *Globigerinatheka luterbacheri* BOLLI, *G. index* (FINLAY), and *Hantkenina alabamensis* CUSHMAN (Pl. 1, Figs. 8 & 9) have been identified. As the zone marker, *Globigerinatheka semiinvoluta* (KEIJZER), in the analysed samples has not been presented, the top of Zone E14 is defined approximately by the last occurrence of the *Acarinina medizzai* (PREMOLI SILVA & PETRIZZO, 2006; PEARSON et al., 2006).

Zone E15 *Globigerinatheka index* – BERGGREN & PEARSON, 2005; (approx. upper part of *Ponticulasphaera semiinvoluta* Zone P15 and lower part of *Turborotalia cunialensis/ Cribrohantkenina inflata* Zone P16 – BERGGREN et al., 1995) and Zone E16 *Hantkenina alabamensis* – BERGGREN & PEARSON, 2005 (approx. upper part of *Turborotalia cunialensis/ Cribrohantkenina inflata* Zone P16 and *Globigerina gortanii gortanii – Turborotalia centralis* P17 – BERGGREN et al., 1995)

Intervals: Jihar–1 (410 to approx. 460m), Jihar–4 (595 to approx. 635 m), Jihar–5 (270 to approx. 310 m).

Separation of Zones E15 and E16 has not been possible because the index taxon *Globigerinatheka index* (FINLAY) has only been found in the Jihar–1 well.

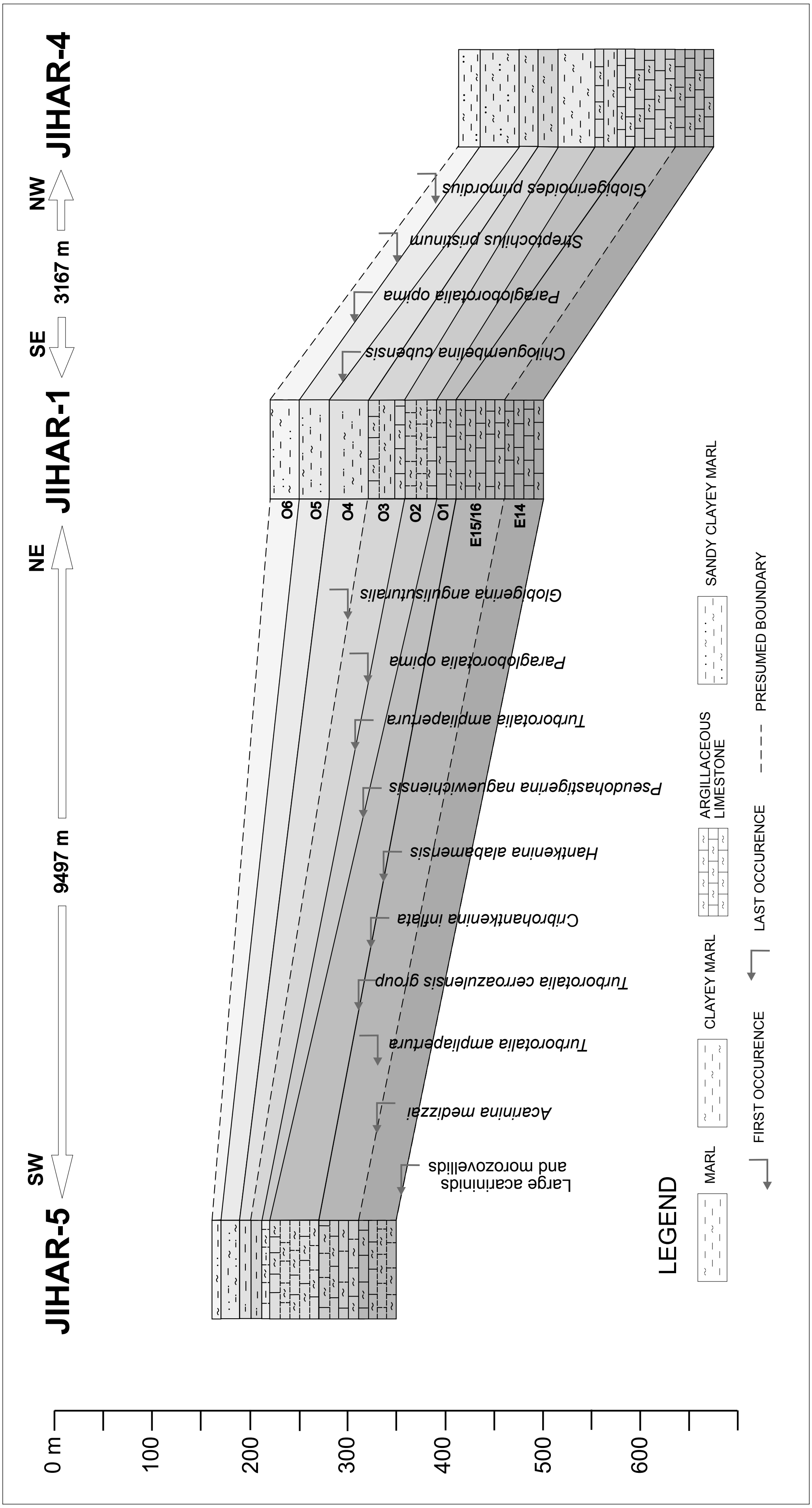

Fig. 3 Schematic profile of the exploration wells with planktonic foraminiferal biozones and last occurrence (LO) and approx. first occurrence (FO) of index taxa.

The planktonic foraminiferal assemblage of these intervals consists of a few representatives of the *Turborotalia* lineage which do not extend beyond the Eocene/Oligocene boundary – *Turborotalia cerroazulensis* (HOWE & WALLACE) (Pl. 2, Figs. 4–6), *T. pomeroli* (Pl. 2, Figs. 8 & 9), and *T. cocoaensis* (CUSHMAN) (Pl. 2, Figs. 1–3), whereas species including *T. increbescens* (BANDY) and *T. ampliapertura* (BOLLI) persist into the Early Oligocene. *Cribrohantkenina inflata* (HOWE) (Pl. 2, Fig. 7), is a species with a very short stratigraphic range, from the upper part of Zone E14 to the end of E16 (PEARSON et al., 2006), and has only been observed in the Jihar–5 well. Small microperforate species *Pseudohastigerina micra* (COLE), *P. naguewichiensis* (MYATLIUK), biserial *Chiloguembelina cubensis* (PALMER) and tenuiteliids in the 63–125 µm size fraction have also been observed. In the late Eocene assemblage, the coexistence of *Subbotina cryptomphala* (GLAESNER), *S. yeguaensis* (WEINZIERL & APPLIN), *S. linaperta* (FINLAY), *S. corpulenta* (SUBBOTINA) (Pl. 1, Fig. 7), *Catapsydrax dissimilis* (CUSHMAN & BERMUDEZ), *C. unicavus* BOLLI (Pl. 1, Fig. 10), *Globigerina officinalis* SUBBOTINA, *Globigerinatheka luterbacheri*, BOLLI and *Dentoglobigerina galavisi* (BERMUDEZ) (Pl. 1, Figs. 11 & 12) have been observed.

Zone O1 *Pseudohastigerina naguewichiensis* – BERGGREN & PEARSON, 2005 (approx. *Chiloguembelina cubensis – Pseudohastigerina* sp. P18 – BERGGREN et al., 1995)

Intervals: Jihar–1 (390–410 m), Jihar–4 (555–595 m), Jihar–5 (220–270 m).

The Eocene/Oligocene boundary is marked by the faunal overturn which is indicated by the extinction of specialized forms, such as the *Turborotalia cerroazulensis* s.s. group, globigerinathekids and hantkeninids (KELLER, 1983; BOERSMA & PREMOLI SILVA, 1991). In the earliest Rupelian, the planktonic foraminiferal assemblage comprises mostly round-chambered forms such as high and low spired subbotinids, catapsydracids, dentoglobigerinids, microperforate tenuitellids, pseudohastigerinids and chiloguembelinids (IACCARINO et al., 2005). The assemblage of this zone in the investigated wells is characterized by the occurrence of globigerinids and dentoglobigerinids such as *"Globigerina" rohri* (BOLLI) (Pl. 3, Fig. 7), *"Globigerina" venezuelana* HEDBERG, *"Globigerina" euapertura* JENKINS, *Dentoglobigerina globularis* (BERMUDEZ) (Pl. 3, Fig. 4) and *D. baroemoensis* (LE ROY) (Pl. 3, Figs. 5 & 6). *Turborotalia increbescens* (BANDY) (Pl. 2, Figs. 11 & 12) and *T. ampliapertura* (BOLLI) (Pl. 2, Fig. 10) are the representatives of the *Turborotalia* lineage persisting across the Eocene/Oligocene boundary. Small microperforate species in the samples of this zone are *Pseudohastigerina naguewichiensis* (MYATLIUK) (Pl. 3, Figs. 2 & 3), *Chiloguembelina cubensis* (PALMER) and tenuitelids. Species which range from the Middle Eocene, *Paragloborotalia nana* (BOLLI) (Pl. 3, Fig. 1) are also represented. The top of Zone O1 is marked by the extinction of *Pseudohastigerina naguewichiensis* (BERGGREN & PEARSON, 2005). In the investigated wells the last occurrence of *P. naguewichiensis* has been observed in the following samples: Jihar–1 – 390–400 m, Jihar–4 – 555–575 m, Jihar–5 – 220–230 m.

Zone O2 *Turborotalia ampliapertura* – BERGGREN & PEARSON, 2005 ("*Turborotalia ampliapertura"* P19 – BERGGREN et al., 1995)

Intervals: Jihar–1 (360–390 m), Jihar–4 (515–555 m), Jihar–5 (210–220 m).

The base of Zone O2 is defined by the last appearance datum of *Pseudohastigerina naguewichiensis*. The planktonic foraminiferal association from Zone O2 consists of large forms such as *"Globigerina" tapuriensis* BLOW & BANNER, *"Globigerina" venezuelana* HEDBERG, *Catapsydrax martini* (BLOW & BANNER), *"Globigerina"* sp. and *Dentoglobigerina* sp. (Pl. 3, Figs. 11 & 12). Representatives of the microperforate planktonic foraminifera are still present – *Cassigerinella chipolensis* (CUSHMAN & PONTON), *Chiloguembelina cubensis* (PALMER) and *Tenuitellinata* sp. Moreover, in samples from the Palmyra region *Turborotalia ampliapertura* (BOLLI) (Pl. 3, Figs. 8 & 9), *Turborotalia increbescens* (BANDY) (Pl. 3, Fig. 10), *Globoturborotalita ouachitaensis* (HOWE & WALLACE) and *Globigerina praebulloides* BLOW have been observed. The top of Zone O2 is defined by the last appearance datum of *Turborotalia ampliapertura* (BERGGREN et al., 1995; BERGGREN & PEARSON, 2005). In the Jihar–1 well the last occurrence of *T. ampliapertura* is in the 360–370 m sample, in Jihar–4 at 515–535 m, and in Jihar–5 at the 210–220 m samples.

Zone O3 *Globigerina sellii* – BERGGREN & PEARSON, 2005 (*Globigerina sellii* P20 – BERGGREN et al., 1995)

Intervals: Jihar–1 (approx. 320–360 m), Jihar–4 (approx. 495–515 m), Jihar–5 (approx. 200–210 m).

The material of this Zone is characterised by the frequent occurrence of small microperforate planktonic foraminifera *Chiloguembelina cubensis* (PALMER), *Cassigerinella chipolensis* (CUSHMAN & PONTON), *Tenuitellinata angustiumbilicata* (BOLLI) (Pl. 4, Figs. 2 & 3) and *Tenuitella gemma* (JENKINS) (Pl. 4, Fig. 6). Further, in the planktonic foraminiferal association, larger forms such as "*Globigerina*" *tripartita* KOCH (Pl. 4, Fig. 4), "*Globigerina*" *venezuelana* HEDBERG (Pl. 4, Fig. 5), "*Globigerina*" sp., *Globorotaloides* sp. (Pl. 4, Fig. 1), *Dentoglobigerina* sp. and *Paragloborotalia opima* (BOLLI) are determined. Also small globigerinids, *Globigerina praebulloides* BLOW and *Globigerina praebulloides occlusa* BLOW & BANNER, are represented.

Due to difficulties in identifying the first appearance datum of the index species in the material from drill cuttings, the top of the zone is established approximately by the first occurrence of *Globigerina angulisuturalis* (BERGGREN et al., 1995; BERGGREN & PEARSON, 2005). First occurrence of *G. angulisuturalis* in the investigated Syrian wells has been recognized in the following samples: Jihar–1 – 200–210 m, Jihar–4 – 495–515 m and Jihar–5 – 320–330 m.

Zone O4 *Globigerina angulisuturalis/ Chiloguembelina cubensis* – BERGGREN & PEARSON, 2005 (*Globigerina angulisuturalis/ Chiloguembelina cubensis* P21a – BERGGREN et al., 1995)

Intervals: Jihar–1 (280 to approx. 320 m), Jihar–4 (475 to approx. 495 m), Jihar–5 (190 to approx. 200 m).

The planktonic foraminiferal association of this zone is very well preserved and diverse. Small globigerinids *Globigerina angulisuturalis* (BOLLI) (Pl. 4, Figs. 7–9), *G. ciperoensis* (BOLLI), *G. ouachitaensis* (HOWE & WALLACE) and *G. praebulloides* BLOW are very frequent in Zone O4 samples. Microperforate species *Chiloguembelina cubensis* (PALMER) (Pl. 4, Figs. 11 & 12), *Cassigerinella chipolensis* (CUSHMAN & PONTON), and *Tenuitella gemma* (JENKINS) are also documented from this interval, as well as larger forms *Catapsydrax martini* (BLOW & BANNER), "*Globigerina*" *tapuriensis* BLOW & BANNER, *"Globigerina" venezuelana* HEDBERG (Pl. 4, Fig. 10), *Paragloborotalia opima* (BOLLI), *Dentoglobigerina* sp. and *Globorotaloides* sp. The top of Zone O4 is marked by extinction of the microperforate biserial planktonic foraminifera *Chiloguembelina cubensis* (BERGGREN et al., 1995; BERGGREN & PEARSON, 2005). In the Jihar–1 well the LO of *C. cubensis* has been noticed in a sample at 280–290 m, in Jihar–4 at 475–495 m and in Jihar–5 at 190–200 m sample.

Zone O5 *Paragloborotalia opima* – BERGGREN & PEARSON, 2005 (*Globigerina angulisuturalis/ Paragloborotalia opima opima* P21b – BERGGREN et al., 1995)

Intervals: Jihar–1 (250–280 m), Jihar–4 (435–475 m), Jihar–5 (170–190 m).

The planktonic foraminiferal association in the lower Chatian consists of small spinose globigerinids *Globigerina angulisuturalis* (BOLLI), *Globigerina ciperoensis* (BOLLI) (Pl. 5, Fig. 1), *G. officinalis* SUBBOTINA and *G. praebullides* BLOW. In addition, *Paragloborotalia opima* (BOLLI) (Pl. 5, Figs. 5 & 6), *P. nana* (BOLLI) (Pl. 5, Figs. 8 & 9), and *"Globigerina"* sp. are also determined. Microperforate species *Cassigerinella chipolensis* (CUSHMAN & PONTON) (Pl. 5, Figs. 2 & 3), *Tenuitellinata angustiumbilicata* (BOLLI), and *Tenuitellinata* sp. in the 63 µm sieve fraction have been observed. The top of Zone O5 is marked by the last occurrence of *Paragloborotalia opima,* which has been recognized at 250–260 m in Jihar–1, at 435–455 m in Jihar–4 and at 170–180 m in Jihar–5.

Zone O6 *Globigerina ciperoensis* – BERGGREN & PEARSON, 2005 (*Globigerina ciperoensis* P22 – BERGGREN et al., 1995)

Intervals: Jihar–1 (approx. 220–250 m), Jihar–4 (approx. 415–435 m), Jihar–5 (approx. 160–170 m).

The assemblage of this Zone is characterised by the occurrence of *Globigerina angulisuturalis* (BOLLI) (Pl. 5, Figs. 11 & 12), *G. ciperoensis* (BOLLI) (Pl. 5, Figs. 4 & 7), *G. praebulloides* BLOW, *Dentoglobigerina baroemoensis* (LE ROY), and *Globigerina* sp. In the Jihar–5 well, a very rare microperforate biserial species *Streptohilus pristinum* BROENNIMANN & RESIG (Pl. 5, Fig. 10) has been found. Furthermore, microperforate *Tenuitellinata angustiumbilicata* (BOLLI) and *Tenuitella* sp. have also been determined. In this zone, the first appearance of *Globigerinoides primordius* BLOW & BANNER was observed. The boundary between the Oligocene and Miocene is marked by the first occurrence of *Globorotalia kugleri s.s.* (BERGGREN et al., 1995; BERGGREN & PEARSON, 2005). This planktonic foraminiferal species has not been found in samples from exploration wells, and the boundary of this zone is only approximately established. The following facts aided the establishment of the Eocene/Oligocene boundary: first, changes were evident in the foraminiferal association, i.e. an increased abundance of benthic foraminifera (*Neoeponides schreibersi* (GIANNINI & TAVANI), *Spiroplectinella carrinata* (D'ORBIGNY), *Lenticulina vortex* (FICHTEL & MOLL), *Heterolepa* sp., *Gyroidina* sp., *Cibicidoides* sp., *Marginulinopsis* sp., *Dentalina* sp.), and second, near the boundary, the Oligocene species *Globigerina ciperoensis* disappeared. Furthermore, correlation with Oligocene sedimentary rocks in the wider Syrian regions was also helpful. KRASHENINNIKOV et al. (1996) reported the regressive nature of the Oligocene deposits. In the Palmyrids the Oligocene marine sedimentary regime terminated at the Neogene boundary, and the marine Palaeogene is unconformably and transgressively overlain by marine Lower Miocene deposits.

6. PALAEOECOLOGY AND CLIMATIC CHANGES

Planktonic foraminifera have great potential in palaeoecological studies (MURRAY, 1991a). These tiny monocellular organisms with calcite shells are distributed throughout the world seas and oceans, from the polar water masses to the equator, and have different depth preferences of habitat in a stratified water column (HEMLEBEN et al., 1989; MURRAY, 1991a; PEARSON, 1998). Biotic and abiotic factors affect their diversity, morphology, and distribution. Abiotic factors which may influence the distribution of planktonic foraminifera are temperature, salinity, water density, nutrients, light, turbidity, and currents (HALLOCK, 1987; HEMLEBEN et al., 1989; MURRAY, 1991a). Biotic factors include food supply, symbiotic relationships, productivity and interfaunal relationships (BÉ, 1982; MURRAY, 1991a; HALLOCK et al., 1991). Planktonic foraminifera are, therefore, very useful in palaeooceanological and palaeoclimatological studies. Much of the world oceans in tropical and subtropical areas are well stratified and oligotrophic. The ecology of the various species in these environments is closely related to their preferred niche in the water column (HEMLEBEN et al., 1989; MURRAY, 1991a; PEARSON, 1998; COXALL et al., 2000; WADE, 2004; SEXTON et al., 2006). In general, planktonic foraminiferal species live in two preferred depth habitats:

(1) *Shallow-dwelling planktonic foraminifera* tend to have thinner or more porous, less dense shells, more globular chambers and they are often spinose (PEARSON, 1998). The function of spines is to carry external cytoplasm with symbionts and to prevent escape of prey (HEMLEBEN et al., 1989; PEARSON, 1998). Shallow-dwelling species have their primary aperture usually in the central position at the umbilical side of the test (PEARSON, 1998). Some of them have multiple supplementary apertures. Isotope analyses of the planktonic foraminiferal calcite shells provide one of the most important insights into oceanographic changes during Earth history. Stable isotope studies of the surface dwelling planktonic foraminifera usually indicate the lightest δ^{18}O and heaviest δ^{13}C values in modern as well as in fossil planktonic foraminiferal shells.

(2) The majority of modern *deeper-dwelling forms* and some ancient examples tend to have more angular and flattened chambers. The position of a primary aperture is more extraumbilical and there are no supplementary apertures (PEARSON, 1998). Detailed isotope analyses from two species *Turborotalia pomeroli* and *T. cerroazulensis* from the Adriatic Sea indicate a thermocline habitat for the *Turborotalia cerroazulensis* group (PREMEC FUĆEK & PEARSON, 2006). Species within the genera *Subbotina* and *Catapsydrax* are interpreted as having occupied a relatively deep thermocline habitat (PEARSON et al., 1993, 2001; SEXTON et al., 2006).

Late Eocene

The Upper Eocene succession of the Syrian wells contains a rich and diverse planktonic foraminiferal association. Muricate forms including *Acarinina medizzai* and *A. collactea* have only been represented in zone E14. Previous isotope investigations of acarininids show the lightest δ^{18}O values suggesting a habitat in the uppermost part of the water column. Most positive δ^{13}C values indicate a relationship with algal symbionts (SHACKLETON et al., 1985; PEARSON et al., 1993; D'HONDT et al., 1994; WADE, 2004; SEXTON et al., 2006). In the analysed samples, few species of *Globigerinatheka* in Zone E14 and Zone E15/E16 have been found. The Eocene genus *Globigerinatheka* includes spinose forms (PREMEC FUĆEK et al., 1998), as in many modern species in tropical and subtropical regions (HEMLEBEN et al., 1989), possessing algal symbionts. They are limited to the shallow, mixed layer of the oceans and seas because of the photosynthetic requirements of their algae (BÉ, 1982; MURRAY, 1991a). These aforementioned species indicate a subtropical to warm climatic bioprovince for the east Mediterranean area during the late Eocene. Representatives of the non-spinose genus *Turborotalia* (*T. pomeroli*, *T. cerroazulensis* and *T. cocoaensis*) occupy an upper thermocline habitat (PEARSON et al., 2001; WADE, 2004; PREMEC FUĆEK & PEARSON, 2006). Stable isotope records of the turborotalid tests show relatively light δ^{13}C signals suggesting that they have no association with algal symbionts (PREMEC FUĆEK & PEARSON, 2006). During the late Eocene, a few extinctions occurred. *Acarinina medizzai* and *Acarinina collactea* became extinct at the end of zone E14. Due to the absence of the zonal marker *Globigerinatheka semiinvoluta,* the last appearance of these two species has been used to approximately define the E14/E15 boundary (see distribution range of *A. medizzai* in PEARSON et al., 2006). Globigerinathekids decline in abundance and diversity and at the lower part of the E15/E16 (P16/P17) zone become extinct. In BERGGREN & PEARSON (2005), the LO of *Globigerinatheka* mark the top of the zone E15. The most dramatic extinction event happened close to the Eocene/Oligocene boundary when the last specimens of *Turborotalia cerroazulensis* (HOWE & WALLACE), *T. pomeroli* (TOUMARKINE & BOLLI) and *T. cocoaensis* (CUSHMAN) disappeared. Also *Cribrohantkenina inflata* (HOWE) disappeared almost simultaneously, while the species *Turborotalia increbescens* (BANDY) and *Turborotalia ampliapertura* (BOLLI) persisted in the early Oligocene. In the same horizons, typical Palaeogene opportunistic foraminifera including biserial heterohelicids, low spired subbotinids, and tenuitellids (HALLOCK et al., 1991) became more and more frequent in assemblages.

Eocene/Oligocene boundary

The significant changes of planktonic foraminiferal assemblages indicate a general cooling trend and eutrophication of the euphotic zone during late Eocene and Oligocene times (KELLER, 1983; BOERSMA & PREMOLI SILVA, 1991). A highly diversified, subtropical to warm fauna, where a K-mode life strategy predominated, was gradually replaced by less diverse assemblages dominated by r-strategy taxa indicating cooler waters. The Eocene/Oligocene boundary is marked by the extinction of *Hantkenina*. The climate event (Oi–1) occurs 200 kyr after the boundary (WADE & PÄLIKE, 2004) and is the result of the ocean temperature drop, the formation of Antarctic ice sheets and the development of heavy cold water circulation locally on the bottom of the ocean (CAVELIER et al., 1981; ZACHOS et al., 1996, 2001; MACKENSEN, 2004; WADE & PÄLIKE, 2004). The results of cooling have been a shallowing of thermocline depth and reduction in the abundance of shallow- and warm-water species (SPEZZAFERRI et al., 2002). The faunal overturn is indicated by the extinction of specialised Eocene forms (K-strategists), such as turborotalids, globigerinathekids, hantkeninids, and their replacement by generalised globigerinid form species. In addition, the decrease in the size of specimens is remarkable, as well as increased abundances of the opportunistic taxa and cool water indices, increased numbers of the non spinose, deeper dwelling forms, and reduction in diversity (PREMOLI SILVA & BOERSMA, 1988; BOERSMA & PREMOLI SILVA, 1991).

Oligocene

The investigated pseudohastigerinids, chiloguembelinids and tenuitelids within the planktonic foraminiferal association suggest cooler water conditions in the early Oligocene (SPEZZAFERRI & PREMOLI SILVA, 1991). Pseudohastigerinids did not persist into Zone O2.

The extinction of *Chiloguembelina cubensis* marks the top of Zone O4. Species of the *Globigerina ciperoensis* group (*G. ciperoensis*, *G. angulisuturalis*) were best adapted to the Late Oligocene environmental conditions. They possess a small lowered trochospiral test with a cancellate and spinose wall texture. These species are abundant at low latitudes outside upwelling areas, and they seem to prefer higher salinity water conditions (SPEZZAFERRI & PREMOLI SILVA, 1991; SPEZZAFERRI, 1994). In Zone O6, very tiny microperforate and the rare species *Streptochilus pristinum* (Pl. 6, Fig. 10) have been found. Furthermore, *Globigerinoides primordius* has its first occurrence in the planktonic foraminiferal assemblage of the late Oligocene. This species with a smooth and spinose wall texture indicates a shift to warmer climatic conditions in the Late Oligocene.

In the Late Eocene, predominance of the planktonic foraminifera, i.e. very low numbers of benthic foraminifera (*Cibicidoides*, *Lenticulina*, *Marginulinopsis*, *Heterolepa*, *Tritaxia*, *Anomalinoides*) implies sedimentation in a deeper, open-sea environment (VAN DER ZWAAN et al., 1990; MURRAY, 1991b). A gradual increase of the benthic foraminiferal proportions (*Cibicidoides*, *Lenticulina*, *Spiroplectinella*, *Gyroidina*, *Neoeponides*, *Marginulinopsis*, *Heterolepa*, *Stilostomella*, *Dentalina*) upwards through the Oligocene interval indicates shallowing of the sedimentary environment (VAN DER ZWAAN et al., 1990; MURRAY, 1991b).

7. CONCLUSION

The Palmyride area in Syria contains a succession of Upper Eocene to Upper Oligocene deposits. On the basis of a rich planktonic foraminiferal association, biozones from E14 (P15) to O6 (P22) have been identified. Biostratigraphic zonal boundaries are determined on the last occurrence of the index taxa. Significant changes marked by the extinction of muricate forms, except for small acarinids, have occurred at the beginning of Zone E14. During the Late Eocene, the number of warm shallow dwelling species decreases, thus indicating the onset of global cooling, which culminated in the earliest Oligocene. This significant climatic change is well documented by the planktonic foraminiferal assemblage collected from the studied area. A faunal overturn is indicated by the extinction of specialized Eocene forms (K-mode life strategy), such as turborotalids, globigerinathekids, hantkeninids and their replacement by cooler, opportunistic globigerinid forms. The early Oligocene, as a period of glacial episodes, is characterised by dominance of the r-strategist planktonic foraminiferal species, such as pseudohastigerinids, chiloguembelinids, globigerinids, and tenuitelids. The planktonic foraminiferal association of the Late Oligocene shows a trend towards warming, due to the presence of specimens from the *Globigerina ciperoensis* group and *Globigerinoides primordius*.

A very low number of benthic foraminifera in the association imply sedimentation in the deep, open-sea environment during the Late Eocene. Through the Oligocene, the proportion of benthic foraminifera in the assemblage gradually increased, thus indicating the shallowing of the sedimentary environment, connected with the global sea level decrease and regional tectonic events.

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PLATE 1

Fig. 1 *Acarinina medizzai* (TOUMARKINE & BOLLI), Jihar–1, interval 460–470 m, Zone E14.

Fig. 2 *Acarinina medizzai* (TOUMARKINE & BOLLI), Jihar–4, interval 635–655 m, Zone E14.

Fig. 3 *Acarinina medizzai* (TOUMARKINE & BOLLI), detail of the wall texture, Jihar–4, interval 635–655 m, Zone E14.

Fig. 4 *Acarinina* cf. *medizzai* (TOUMARKINE & BOLLI), Jihar–4, interval 635–655 m, Zone E14.

Fig. 5 *Pseudohastigerina micra* (COLE), Jihar–1, interval 460–470 m, Zone E14.

Fig. 6 *Turborotalia pomeroli* (TOUMARKINE & BOLLI) – *Turborotalia ceroazulensis* (HOWE & WALLACE) transition form, Jihar–1, interval 460–470 m, Zone E14.

Fig. 7 *Subbotina corpulenta* (SUBBOTINA), Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 8 *Hantkenina* cf. *alabamensis* CUSHMAN, Jihar–5, interval 310–320 m, Zone E14.

Fig. 9 *Hantkenina* cf. *alabamensis* CUSHMAN, detail of the wall texture, Jihar–5, interval 310–320 m, Zone E14.

Fig. 10 *Catapsydrax unicavus* BOLLI, Jihar–1, interval 410–420 m, Zone E15/16.

Fig. 11 *Dentoglobigerina galavisi* (BERMUDEZ), Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 12 *Dentoglobigerina galavisi* (BERMUDEZ), detail of the aperture and wall texture, Jihar–5, interval 280–290 m, Zone E15/16.

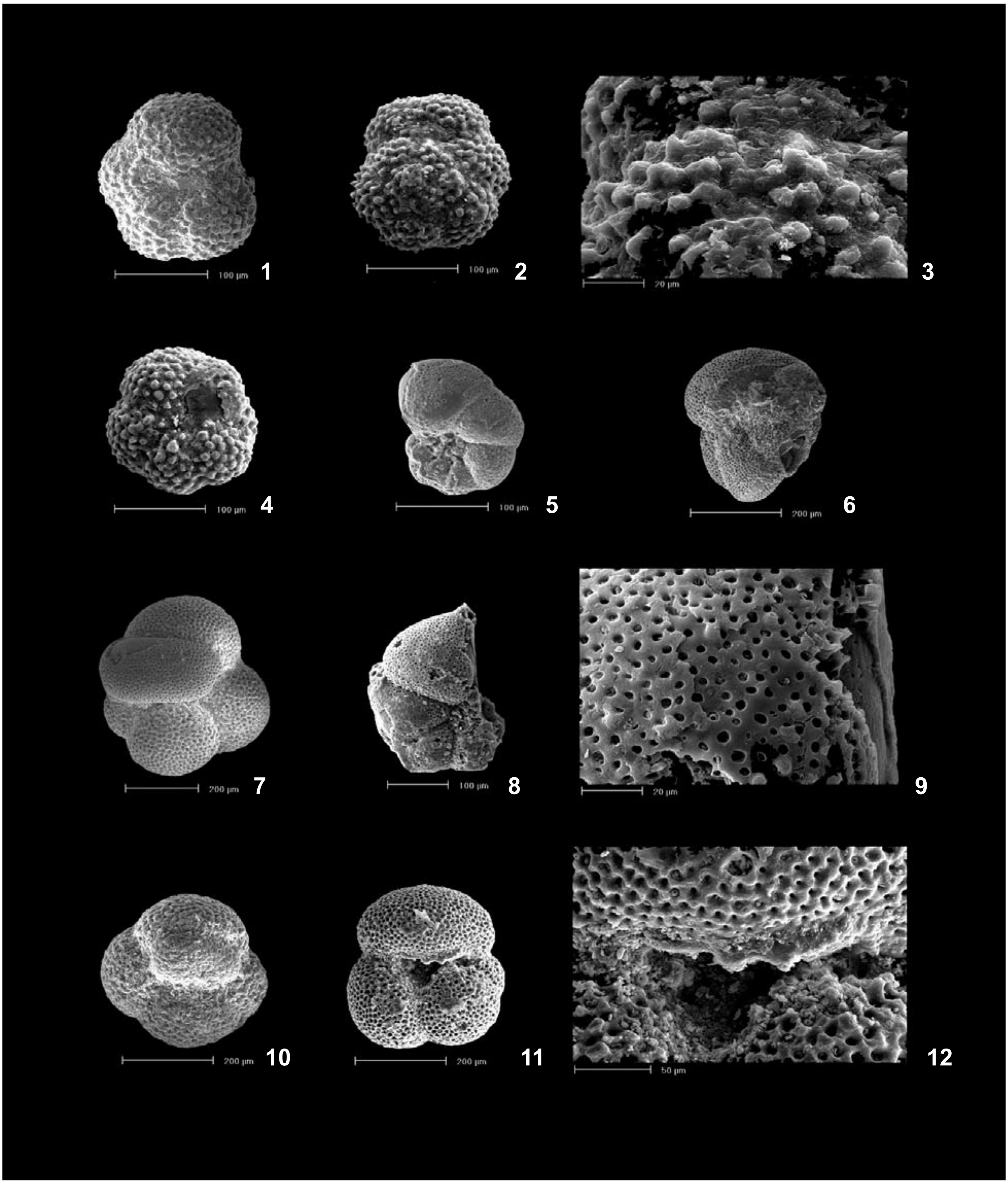
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PLATE 2

Fig. 1 *Turborotalia cocoaensis* (CUSHMAN), Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 2. *Turborotalia cocoaensis* (CUSHMAN), Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 3 *Turborotalia cocoaensis* (CUSHMAN), detail of the wall texture, Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 4 *Turborotalia cerroazulensis* (CUSHMAN), Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 5 *Turborotalia cerroazulensis* (CUSHMAN), Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 6 *Turborotalia cerroazulensis* (CUSHMAN), detail of the wall texture, Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 7 *Cribrohantkenina inflata* (HOWE), Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 8 *Turborotalia pomeroli* (TOUMARKINE & BOLLI), Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 9 *Turborotalia pomeroli* (TOUMARKINE & BOLLI), detail of the wall texture, Jihar–5, interval 280–290 m, Zone E15/16.

Fig. 10 *Turborotalia ampliapertura* (BOLLI), Jihar–5, interval 260–270 m, Zone O1.

Fig. 11 *Turborotalia increbescens* (BANDY) Jihar–5, interval 260–270 m, Zone O1.

Fig. 12 *Turborotalia increbescens* (BANDY) detail of the wall texture, Jihar–5, interval 260–270 m, Zone O1.

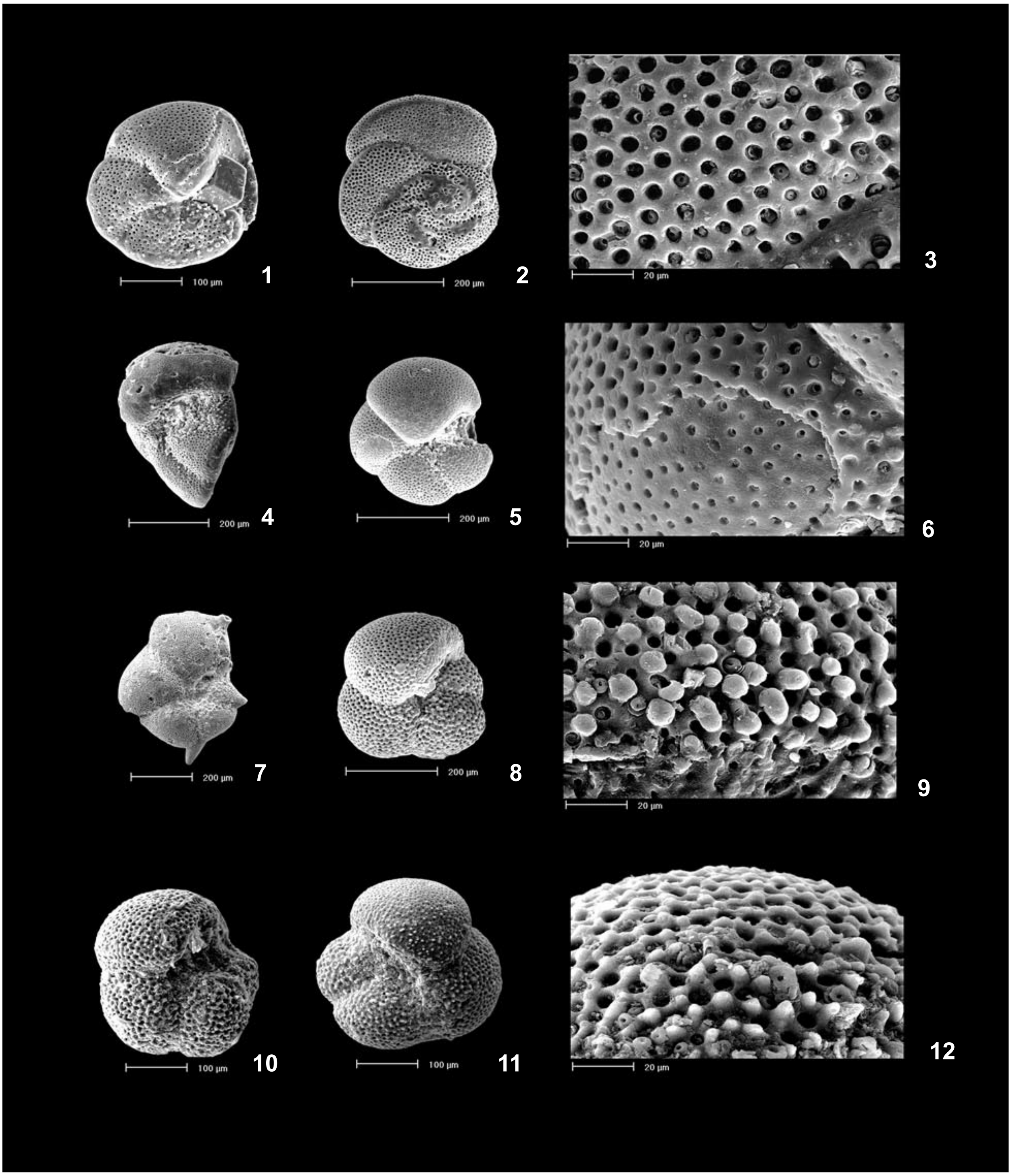
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PLATE 3

Fig. 1 *Paragloborotalia nana* (BOLLI), Jihar–5, interval 260–270 m, Zone O1.

Fig. 2 *Pseudohastigerina naguewichiensis* (MYATLIUK), Jihar–5, interval 220–230 m, Zone O1.

Fig. 3 *Pseudohastigerina naguewichiensis* (MYATLIUK), detail of the wall texture, Jihar–5, interval 220–230 m, Zone O1.

Fig. 4 *Dentoglobigerina globularis* (BERMUDEZ), Jihar–5, interval 260–270 m, Zone O1.

Fig. 5 *Dentoglobigerina baroemoensis* (LE ROY), Jihar–5, interval 260–270 m, Zone O1.

Fig. 6 *Dentoglobigerina baroemoensis* (LE ROY), detail of the wall texture, Jihar–5, interval 260–270 m, Zone O1.

Fig. 7 *“Globigerina“ rohri* BOLLI, Jihar–5, interval 250–260 m, Zone O1.

Fig. 8 *Turborotalia ampliapertura* (BOLLI), Jihar–5, interval 210–220 m, Zone O2.

Fig. 9 *Turborotalia ampliapertura* (BOLLI), detail of the wall texture, Jihar–5, interval 210–220 m, Zone O2.

Fig. 10 *Turborotalia increbescens* (BANDY), Jihar–4, interval 515–535 m, Zone O2.

Fig. 11 *Dentoglobigerina* sp., Jihar–5, interval 210–220 m, Zone O2.

Fig. 12 *Dentoglobigerina* sp., detail of the aperture and wall texture, Jihar–5, interval 210–220 m, Zone O2.

PLATE 3

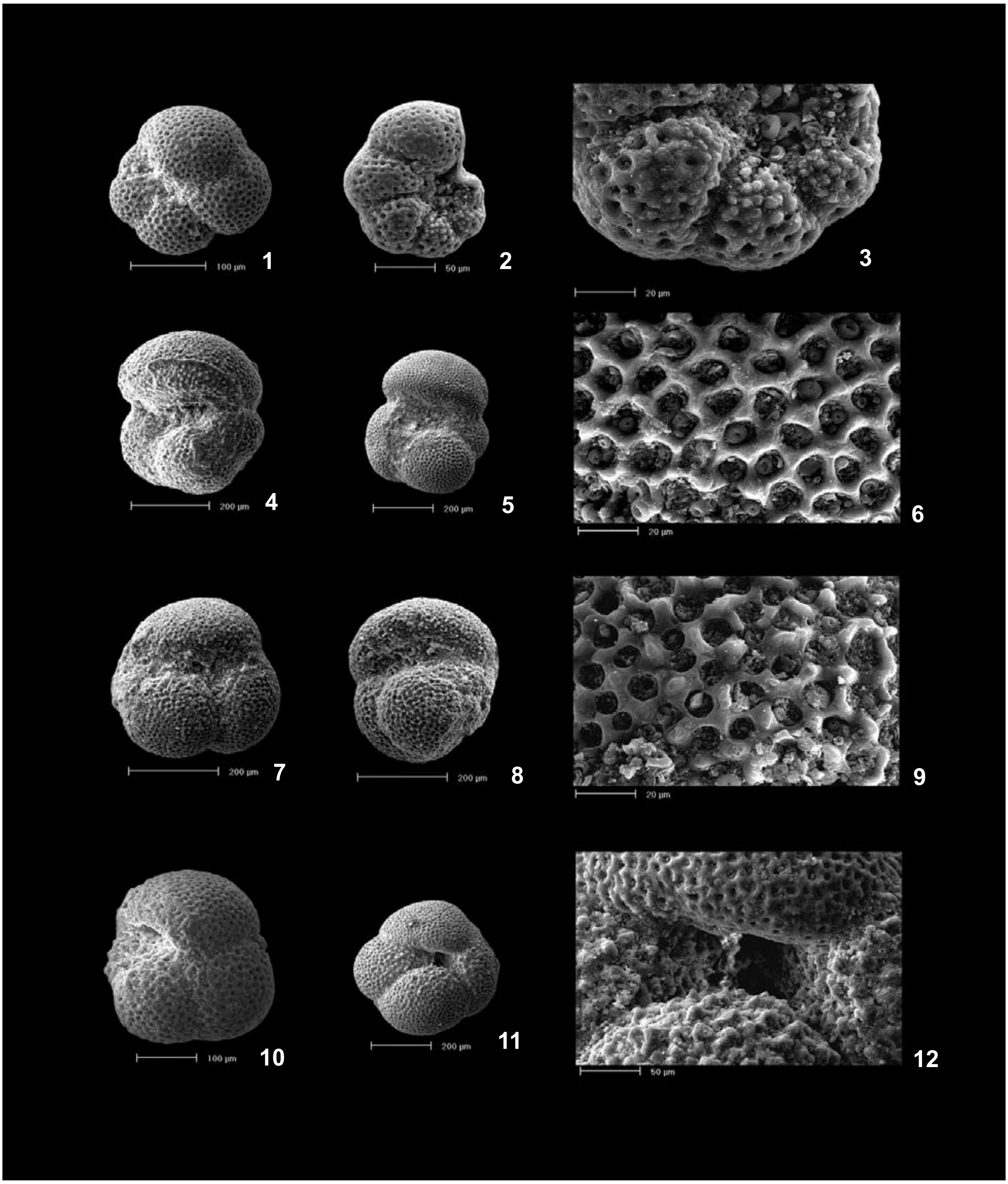
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PLATE 4

Fig. 1 *Globorotaloides* sp., Jihar–1, interval 350–360 m, Zone O3.

Fig. 2 *Tenuitellinata angustiumbilicata* (BOLLI), Jihar–1, interval 350–360 m, Zone O3.

Fig. 3 *Tenuitellinata angustiumbilicata* (BOLLI), detail of the wall texture, Jihar–1, interval 350–360 m, Zone O3.

Fig. 4 *“Globigerina” tripartita* KOCH, Jihar–1, interval 350–360 m, Zone O3.

Fig. 5 *“Globigerina” venezuelana* HEDBERG, Jihar–1, interval 350–360 m, Zone O3.

Fig. 6 *Tenuitella gemma* (JENKINS), Jihar–1, interval 350–360 m, Zone O3.

Fig. 7 *Globigerina angulisuturalis* (BOLLI), Jihar–5, interval 190–200 m, Zone O4.

Fig. 8 *Globigerina angulisuturalis* (BOLLI), detail of the wall texture, Jihar–5, interval 190–200 m, Zone O4.

Fig. 9 *Globigerina angulisuturalis* (BOLLI), detail of the wall texture, Jihar–5, interval 190–200 m, Zone O4.

Fig. 10 *“Globigerina” venezuelana* HEDBERG, Jihar–1, interval 310–320 m, Zone O4.

Fig. 11 *Chiloguembelina cubensis* (PALMER), Jihar–5, interval 190–200 m, Zone O4.

Fig. 12 *Chiloguembelina cubensis* (PALMER), detail of the wall texture, Jihar–5, interval 190–200 m, Zone O4.

PLATE 4

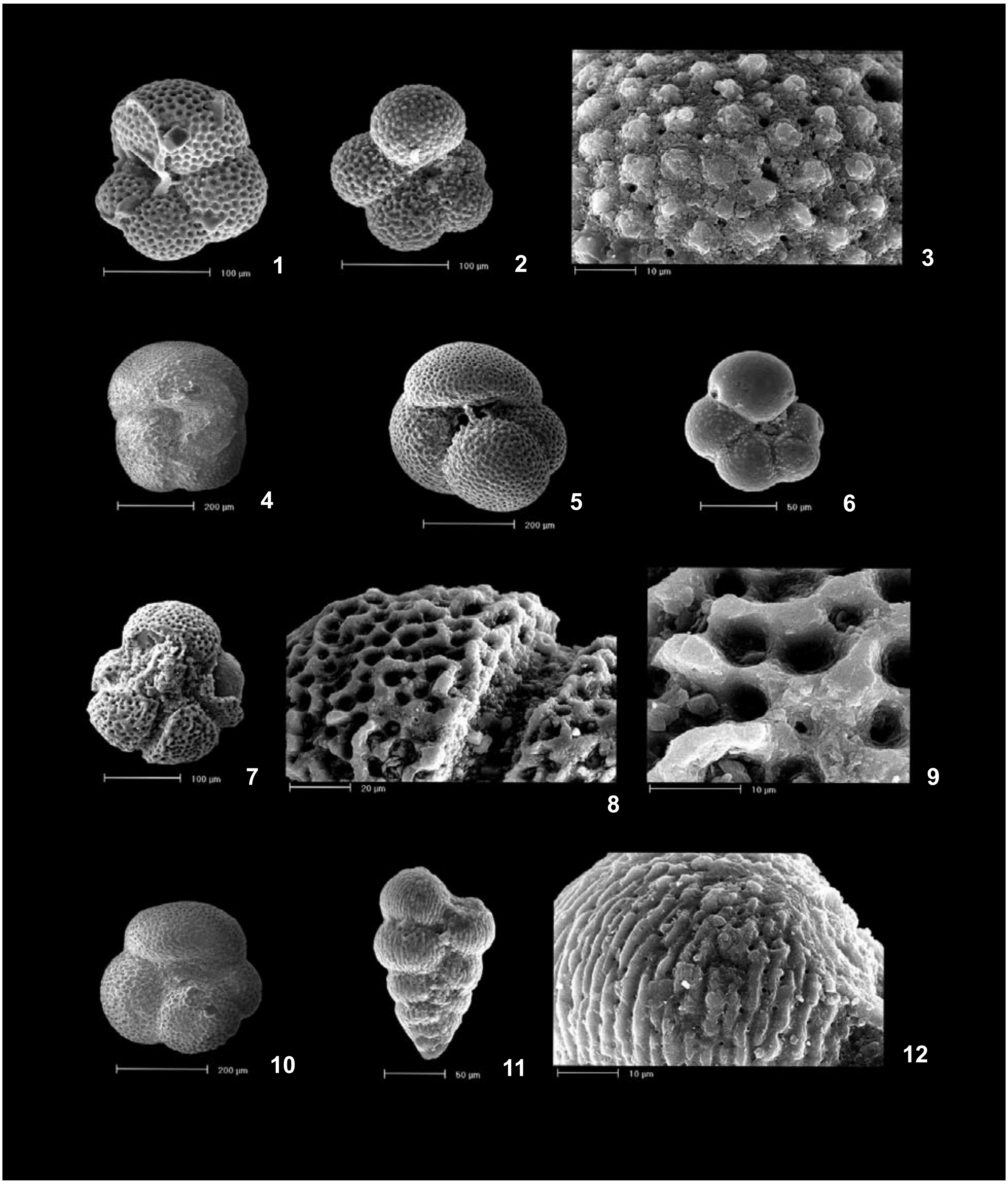
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PLATE 5

Fig. 1 *Globigerina ciperoensis* (BOLLI), Jihar–4, interval 455–475 m, Zone O5.

Fig. 2 *Cassigerinella chipolensis* (CUSHMAN & PONTON), Jihar–1, interval 250–260 m, Zone O5.

Fig. 3 *Cassigerinella chipolensis* (CUSHMAN & PONTON), detail of the wall texture, Jihar–1, interval 250–260 m, Zone O5.

Fig. 4 *Globigerina ciperoensis* (BOLLI), Jihar–5, interval 160–170 m, Zone O6.

Fig. 5 *Paragloborotalia opima* (BOLLI), Jihar–4, interval 455–475 m, Zone O5.

Fig. 6 *Paragloborotalia opima* (BOLLI), detail of the wall texture, Jihar–4, interval 455–475 m, Zone O5.

Fig. 7 *Globigerina ciperoensis* (BOLLI), detail of the wall texture, Jihar–5, interval 160–170 m, Zone O6.

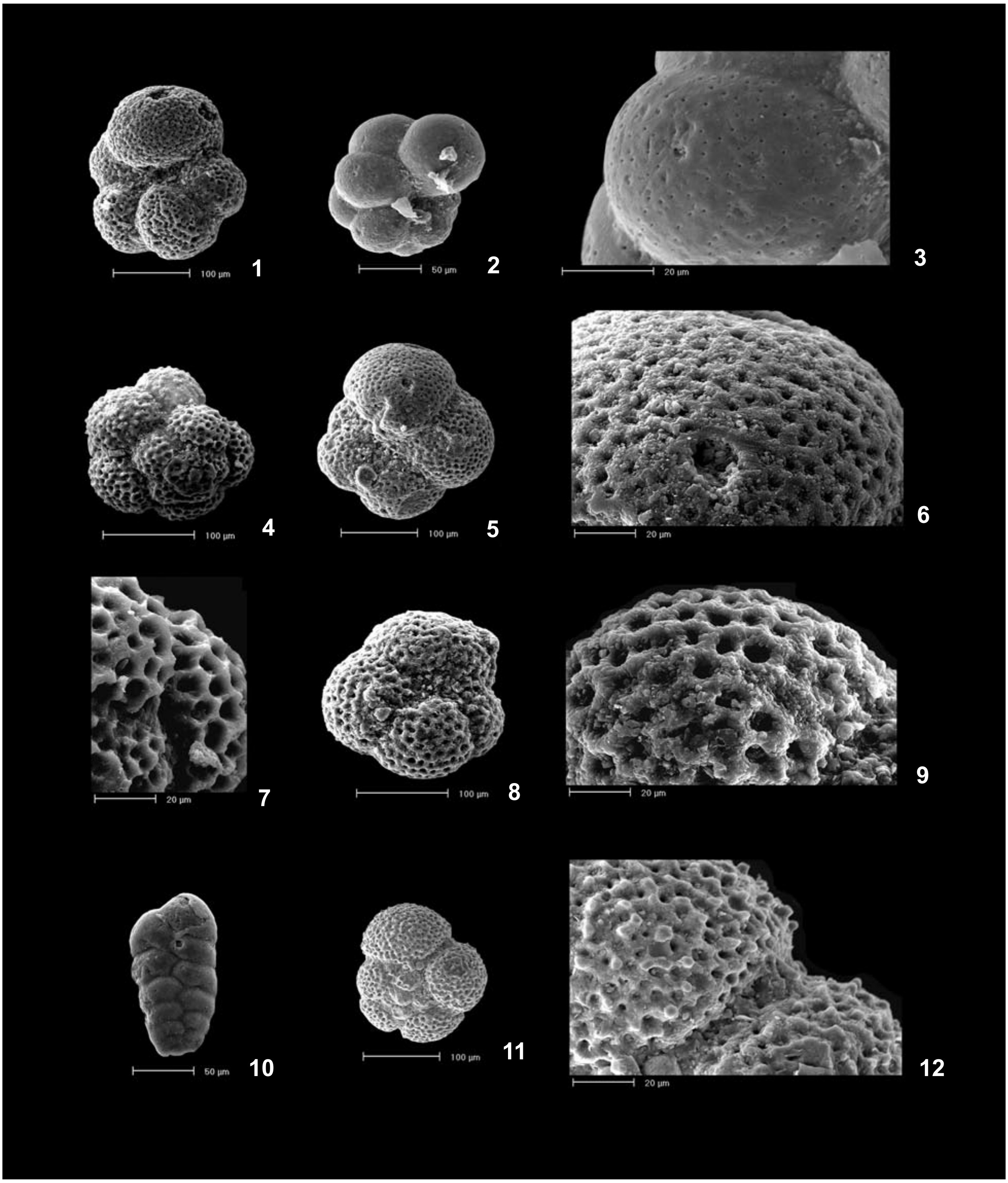
Fig. 8 *Paragloborotalia nana* (BOLLI), Jihar–5, interval 180–190 m, Zone O5.

Fig. 9 *Paragloborotalia nana* (BOLLI), detail of the wall texture, Jihar–5, interval 180–190 m, Zone O5.

Fig. 10 *Streptochilus pristinum* BROENNIMAN, Jihar–5, interval 160–170 m, Zone O6.

Fig. 11 *Globigerina angulisuturalis* (BOLLI), Jihar–1, interval 220–230 m, Zone O6.

Fig. 12 *Globigerina angulisuturalis* (BOLLI), detail of the wall texture, Jihar–1, interval 220–230 m, Zone O6.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