Foraminiferal biostratigraphy of the Pliocene–Pleistocene deep marine offshore, north Nile Delta, Egypt

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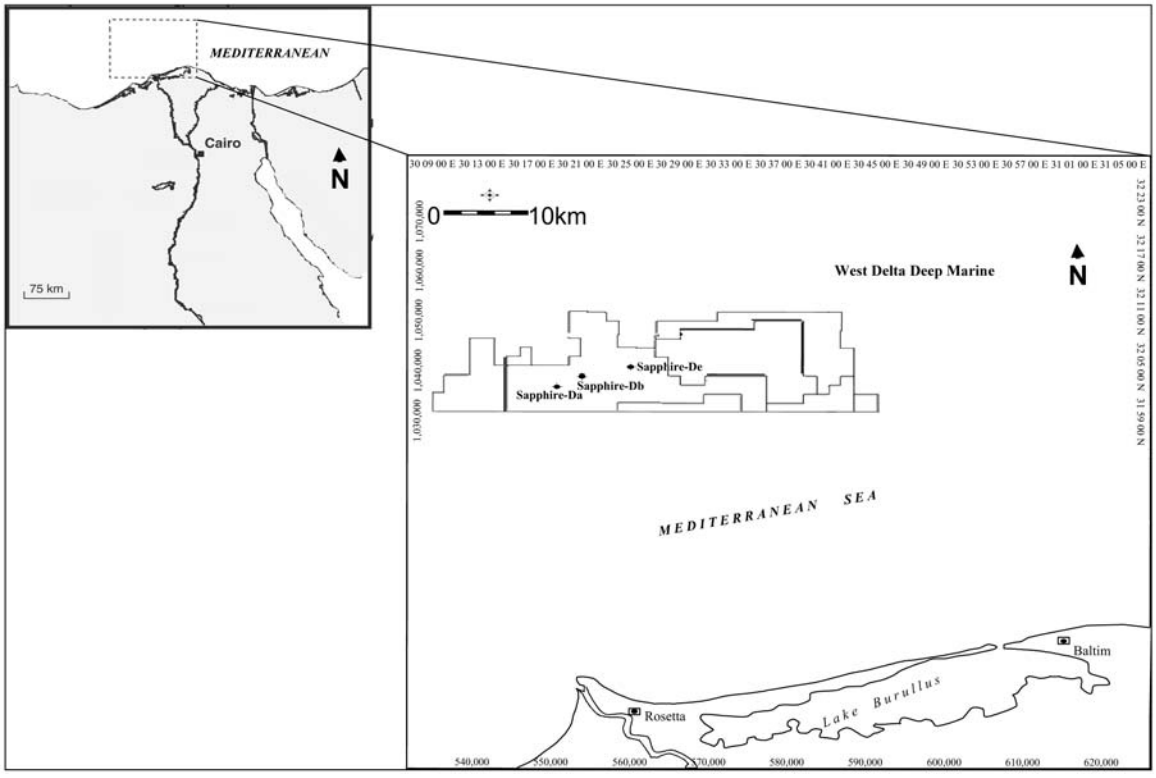
ABSTRACT: A high resolution biostratigraphic analysis of the Pliocene–Pleistocene sequence of the offshore Nile Delta region in West Delta Deep Marine Concession (WDDM), in which 29 planktonic foraminiferal species belonging to 8 genera and 51 benthic foraminiferal species belonging to 40 genera were identified, allowed the recognition of seven foraminiferal zones and two subzones. These are as follows: *Sphaeroidinellopsis* Acme Zone (MPl1), *Globorotalia margaritae* Zone (MPl2), *Globorotalia puncticulata / Globorotalia margaritae* Zone (MPl3), *Sphaeroidinellopsis* s.l. Zone (MPl4), *Globorotalia puncticulata* Subzone (MPl4a), *Globorotalia planispira* Subzone (MPl4b), *Globigerinoides elongatus* Zone (MPl5), *Globorotalia inflata* Zone (MPl6) and *Hyalinea balthica* Zone.

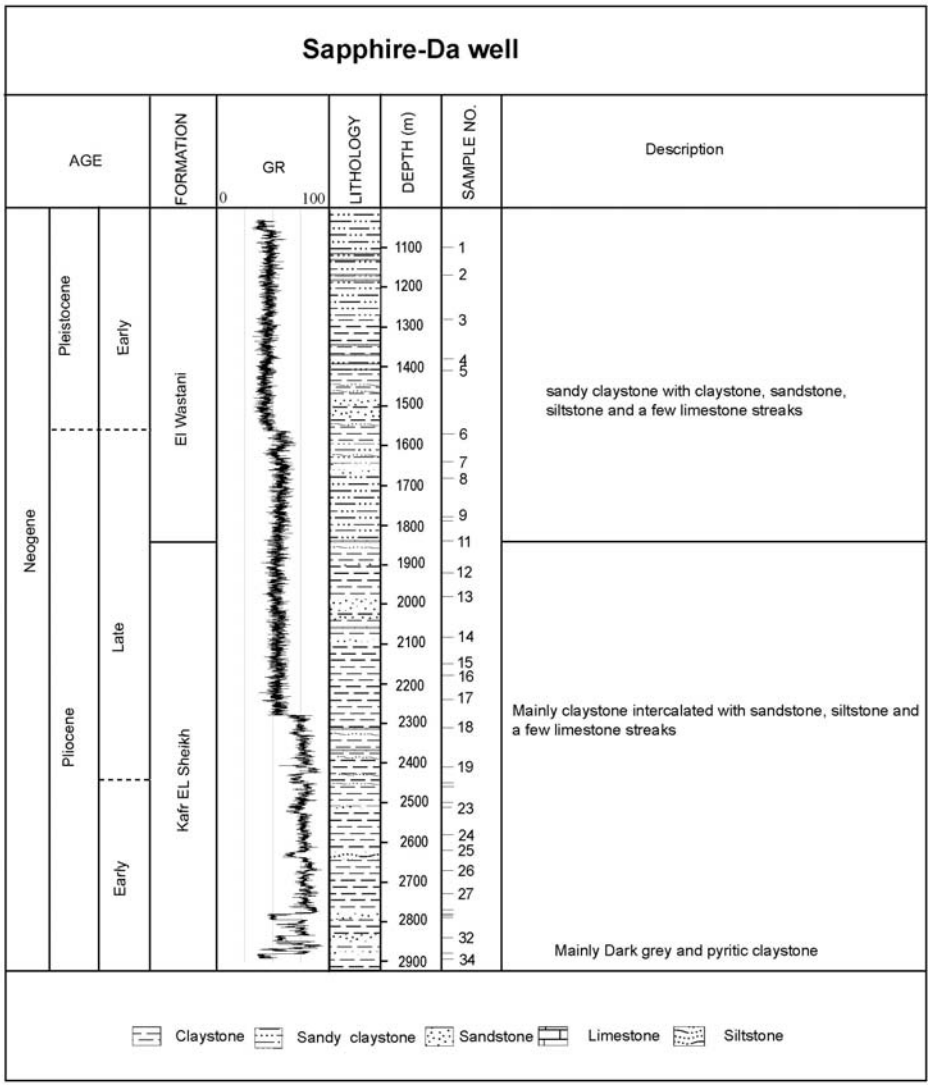
Keywords: Pliocene, Pleistocene, foraminifera, biostratigraphy, Nile Delta

INTRODUCTION

The Nile Delta, as in most of the northern part of Egypt, is covered by a thick sequence of Neogene clastics, which is considered as one of the most important gas provinces in Egypt. The success of gas exploration in the Nile Delta is a direct result of the several studies which have covered the area (Said 1962, 1990; Zaghloul 1976; Rizzini et al. 1978; Abdel-Kireem 1984; Abdou et al. 1984; Deibis et al. 1986; Sestini 1989; El Heiny et al 1990, 1992, 1996; Harwood et al. 1998; Abdel Aal et al. 2000; El Barkooky et al. 2002; Samuel et al. 2003; Ismail et al. 2010).



TEXT-FIGURE 1
Location map of Sapphire-Da, Db and De wells in Deep Marine Offshore, North Nile Delta



TEXT-FIGURE 2
Stratigraphic column of Sapphire-Da well.

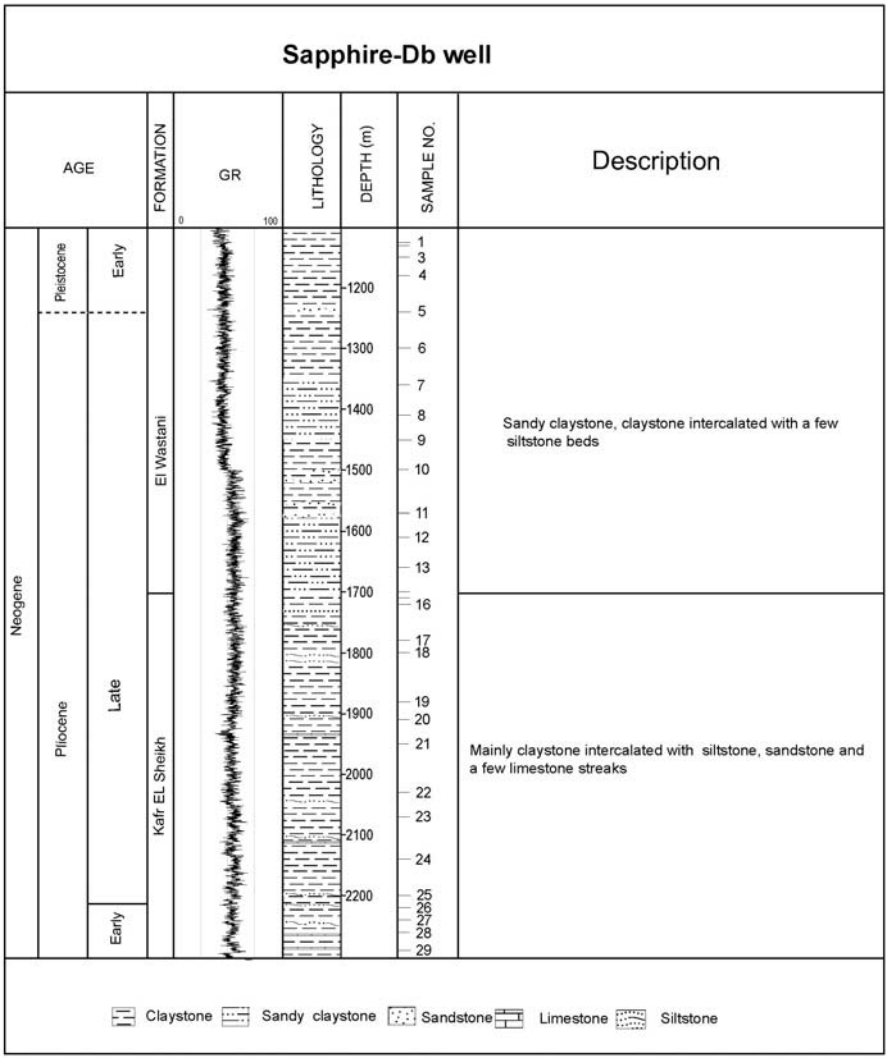
The foraminiferal biozones of the Pliocene–Pleistocene sequence were described in the Nile Delta by Viotti and Mansour (1969), Rizzini (1978), Abdou et al. (1984), Abdel-Kireem et al. (1984), El Bassiouni et al. (1987), Ayyad (1987) and Ismail et al. (2010) as shown in text-figure 9.

The published data on the Neogene of the Nile Delta are still rare and some of the publications on the Pliocene and Pleistocene stratigraphy and microfauna of the delta and its offshore extension are somewhat outdated and need revision.

The present research deals with the foraminiferal biostratigraphic analysis of the Pliocene–Pleistocene sequence of West Delta Deep Marine Concession through investigating samples selected from Sapphire–Da, Sapphire–Db and Sapphire–De wells (text-fig. 1). This study depends mainly on the qualitative and quantitative analyses of the recovered foraminiferal species, in combination with lithostratigraphic description of the cuttings and the well logs.

MATERIALS AND METHODS OF THE STUDY

Twenty grams of ditch cuttings samples were treated for biostratigrapic analysis. The samples were soaked in water with a small amount of hydrogen peroxide (10–15%), and then washed over 63µm sieve. The process was repeated till the water coming through the sieve became clean. The residue left on the sieve was dried at low temperature and screened into a set of sieves (63–100µm, 250µm, 400µm). The different species of foraminifera were separated, examined and photographed using a JEOL JSM–5400 LV scanning nicroscope. Qualitative analysis were carried out on the grain size fractions that mentioned before, while quantitative analysis were represented for the residue >100µm. The absolute frequency of foraminifera based on their numbers is given and the following division is used; specimens <5 are rare, specimens from 5–10 are common, specimens from 11–25 are abundant and specimens >25 are dominant. The classification of planktonic and benthic foraminifera followed here that of Souaya (1965, 1966), Kennett and Srinivasan



TEXT-FIGURE 3
Stratigraphic column of Sapphire-Db well.

(1983), Iaccarino (1985), Bolli and Saunders (1985), Morkhoven et al. (1986) and Loeblich and Tappan (1988).

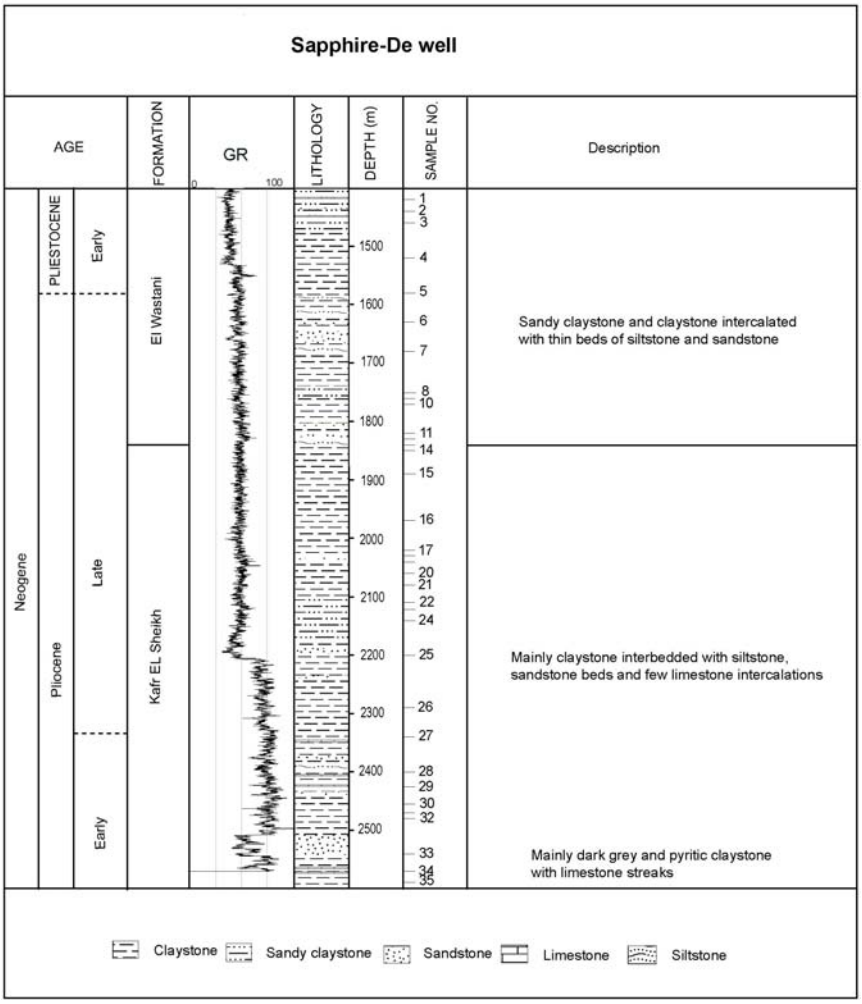
STRATIGRAPHY

The Pliocene–Pleistocene sediments were exposed mainly along the Nile valley as far as Aswan, along the Red Sea coast, in the Cairo–Suez district and the northern Western Desert (Said 1990). Also, these sediments occur in the subsurface of the Nile Delta region and discussed by many authors including Rizzini et al. (1978), Zaghloul et al. (1977), Deibis et al. (1986), El Heiny and Morsi (1992), E.G.P.C., (1994), Ismail et al. (2010).

The subsurface stratigraphy of the study area is based on the composite well logs, ditch cutting samples and the previous geological studies (text-figs. 2–4). In the following paragraphs, the description of the encountered rock units in the studied wells is adopted according to the stratigraphic terminology of Rizzini et al. (1978). In this terminology, the stratigraphic succession of the Pliocene–Pleistocene sequence, from older to younger, is as follows: Kafr El Sheikh Formation, composed mainly of claystone interbedded with siltstone, sandstone and a few limestone streaks, dated Early to Late Pliocene according to Deibis et al. (1986); El Wastani Formation, transitional between the shelf environment (below) and the coastal to continental environment (above); and Mit Ghamr Formation (Rizzini et al. 1978), composed of sandy claystone and claystone intercalated with thin beds of siltstone and sandstone beds and considered as Late Pliocene to Early Pleistocene age.

RESULTS

On the basis of the observed range and frequency of 80 recovered planktonic and benthic foraminiferal species in the three investigated wells, six Pliocene planktonic foraminiferal zones and two subzones of Cita (1975) emended by Sprovieri (1992) are defined. These are *Sphaeroidinellopsis* Acme Zone (MPl1), *Globorotalia margaritae* Zone (MPl2), *Globorotalia puncticulata – Globorotalia margaritae* Zone (MPl3), *Sphaeroidinellopsis* s.l. Zone (MPl4), *Globorotalia puncticulata* Subzone (MPl4a), *Globorotalia planispira* Subzone (MPl4b), *Globi-*

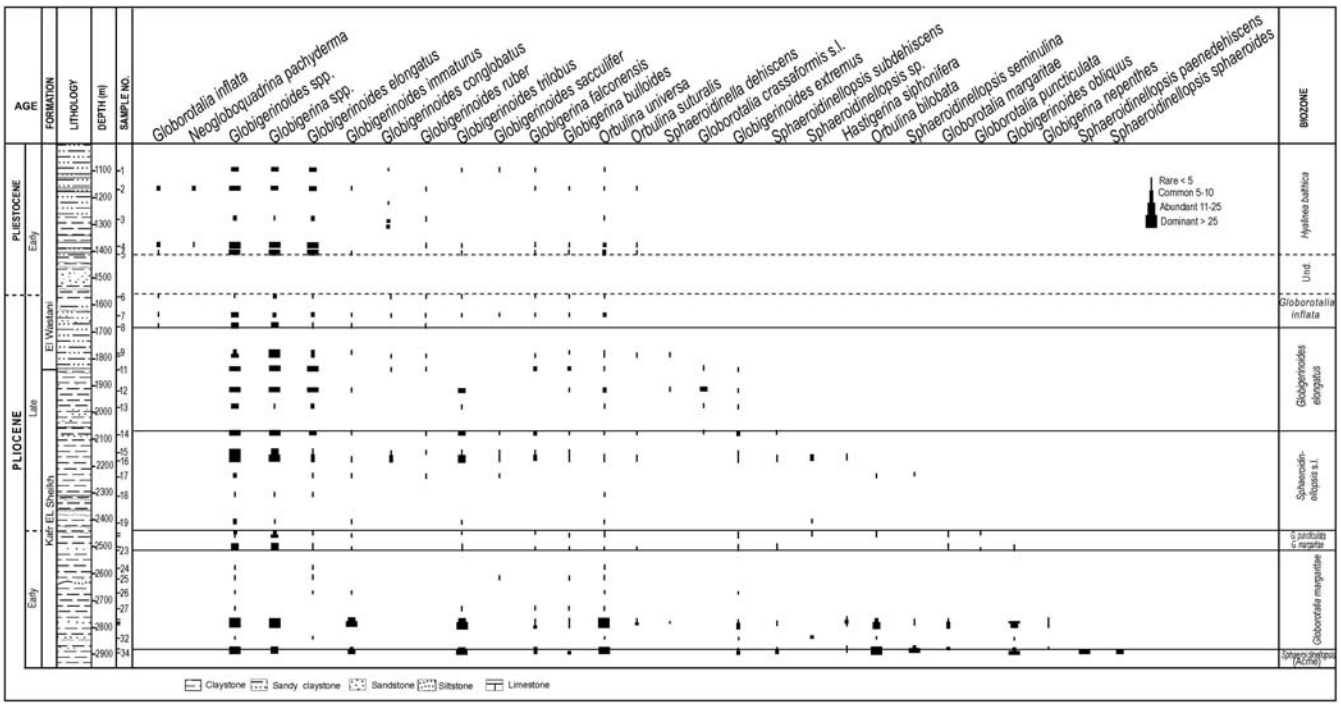


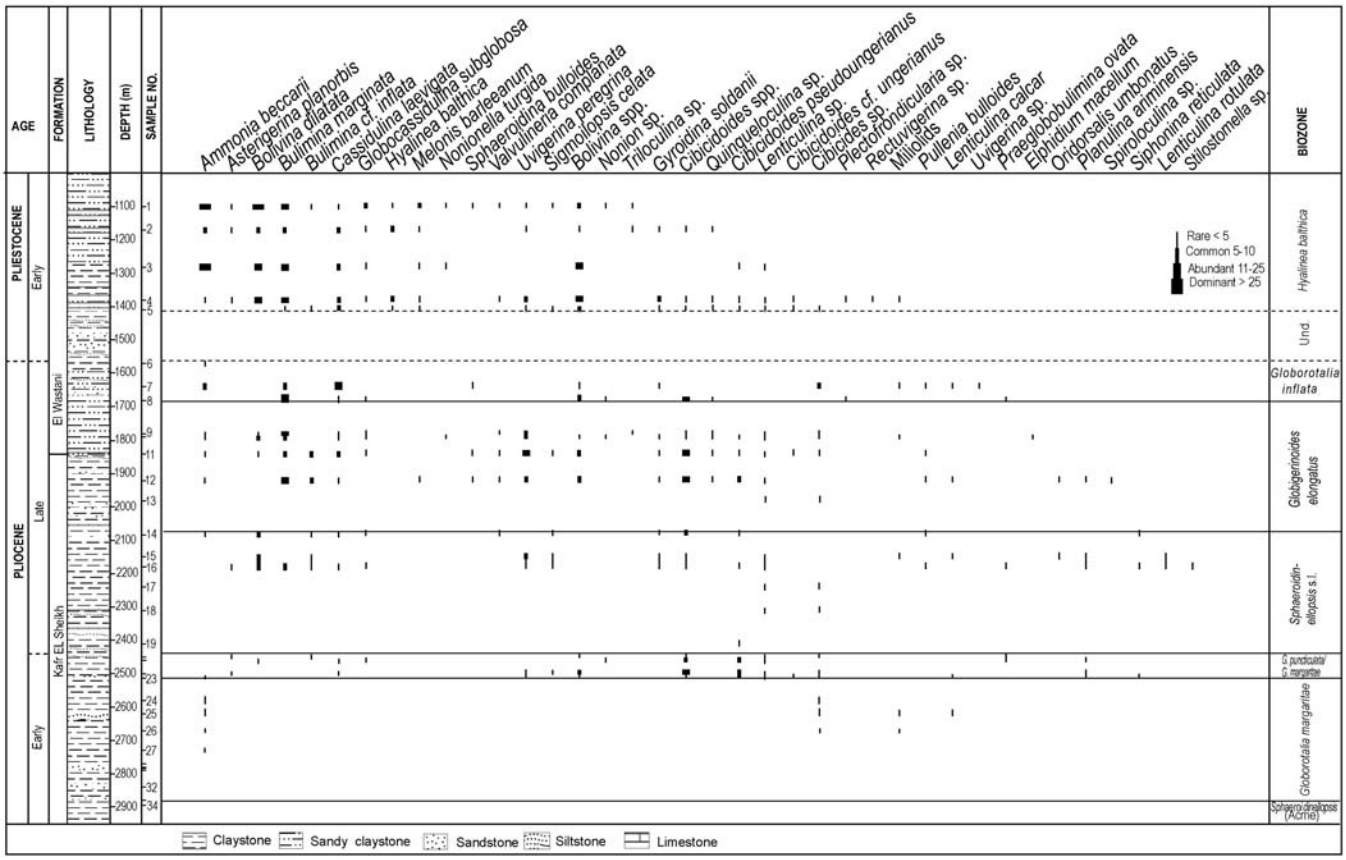
TEXT-FIGURE 4
Stratigraphic column of Sapphire-De well.

gerinoides elongatus Zone (MPl5), and *Globorotalia inflata* Zone (MPl6). FO (first occurrence) and LO (last occurrence) are used following the standard biostratigraphic terms for the appearance of species in the studied wells, as determined from cuttings samples.

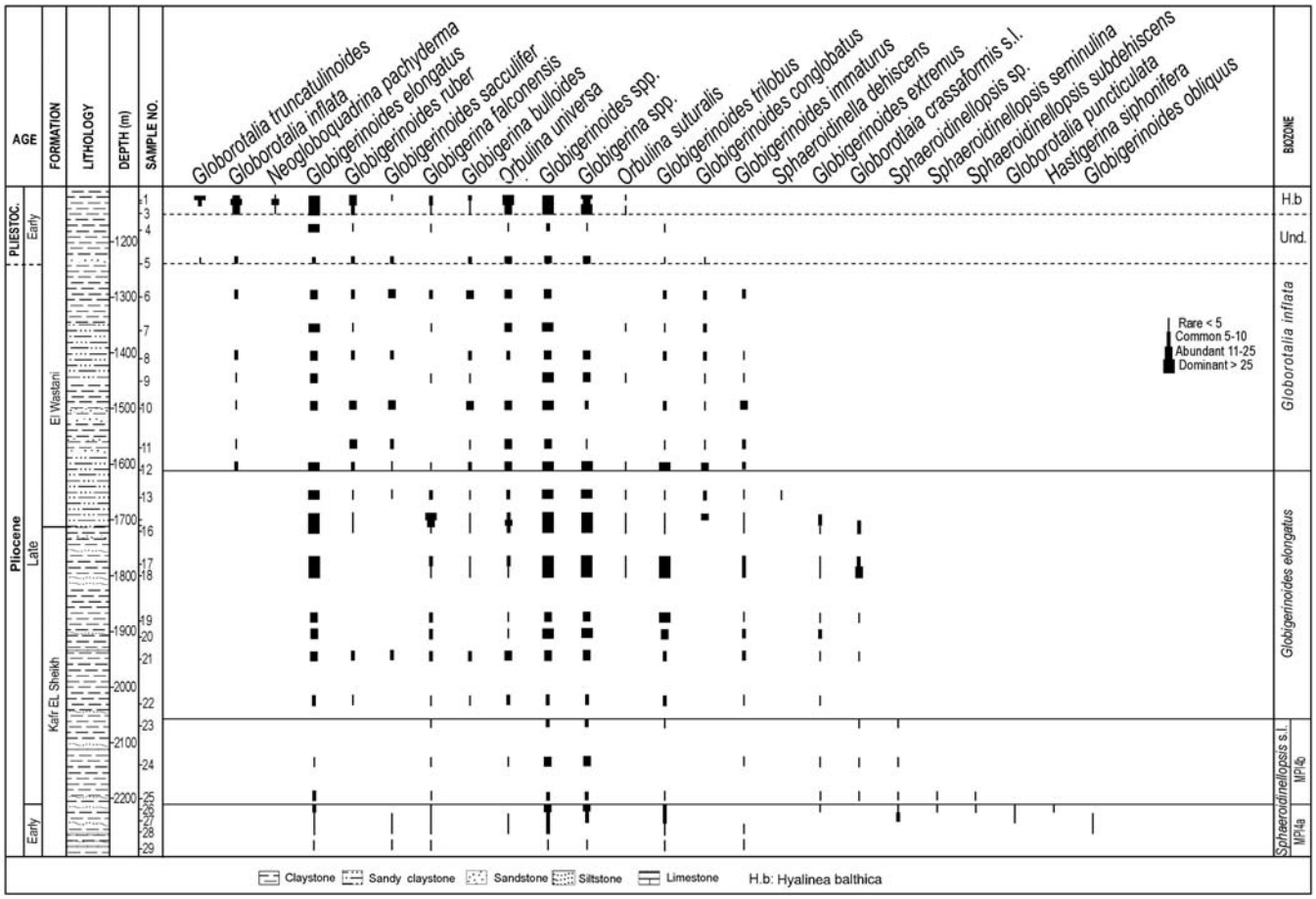
The planktonic assemblage of MPl1 and MPl2 zones is characterized by the occurrence of *Globigerinoides trilobus* (Reuss 1850), *Globigerinoides immaturus* LeRoy 1939, *Globigerina nepenthes* Todd 1957, *Globigerina falconensis* Blow 1959, *Globigerina bulloides* d'Orbigny 1826, *Orbulina universa* d'Orbigny 1839, *Orbulina suturalis* Brönnimann 1951, *Orbulina bilobata* (d'Orbigny 1846), *Globigerinoides obliquus* Bolli 1957, *Globigerinoides extremus* Bolli and Bermúdez 1965, *Sphaeroidinellopsis seminulina* (Schwager 1866), *Sphaeroidinellopsis subdehiscens* Blow 1969, *Sphaeroidinellopsis paenedehiscens* Blow 1969, *Sphaeroidinellopsis sphaeroides* Lamb 1969, *Globorotalia margaritae* Bolli and Bermúdez 1965 and *Hastigerina siphonifera* (d'Orbigny 1839). The benthic foraminifera recovered from these intervals are very poor to barren and represented mainly by *Planulina ariminensis* d'Orbigny 1826, *Lenticulina* sp and *Cibicides* sp.

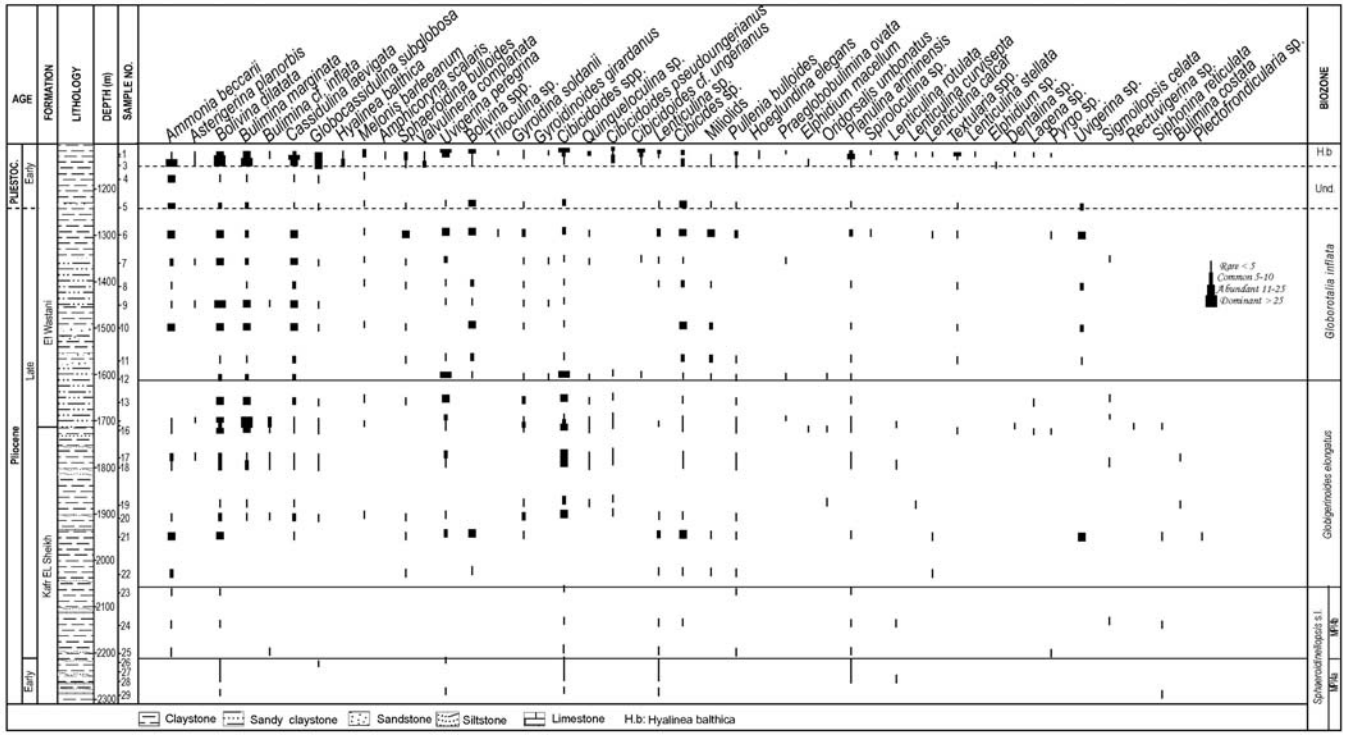
MPl3 Zone is characterized by the occurrence of the same planktonic assemblage of MPl1 and MPl2 zones, as well as *Globigerinoides sacculifer* (Brady 1877) and *Globorotalia puncticulata* (Deshayes 1832). The benthic foraminifera throughout this interval are characterized by the common occurrence of *Cibicidoides psuedoungerianus* (Cushman 1922), *Cibicidoides* spp. and *Bolivina* spp. Sphaeroidinellopsis s.l. Zone (MPl4 Zone) is subdivided into MPl4a and MPl4b subzones based on LO of *Globorotalia puncticulata* (Sprovieri 1992). This bioevent is present mainly in Sapphire–Db well, and therefor the MPl4 Zone interval has been subdivided. The planktonic assemblage of MPl4a is characterized by the occurrence of *Globigerinoides elongatus* (d'Orbigny 1826), *Globigerinoides trilobus* (Reuss 1850), *Globigerinoides immaturus* LeRoy 1939, *Globigerina falconensis* Blow 1959, *Orbulina universa* d'Orbigny 1839, *Globigerinoides extremus* Bolli and Bermúdez 1965, *Globorotalia crassaformis* s.l., *Sphaeroidinellopsis seminulina* (Schwager 1866), *Globigerinoides sacculifer* (Brady 1877), *Globorotalia puncticulata* (Deshayes 1832), S*phaeroidinellopsis subdehiscens* Blow 1969 and *Hastigerina siphonifera* (d'Orbigny 1839). The benthic foraminifera throughout the subzone are characterized by the



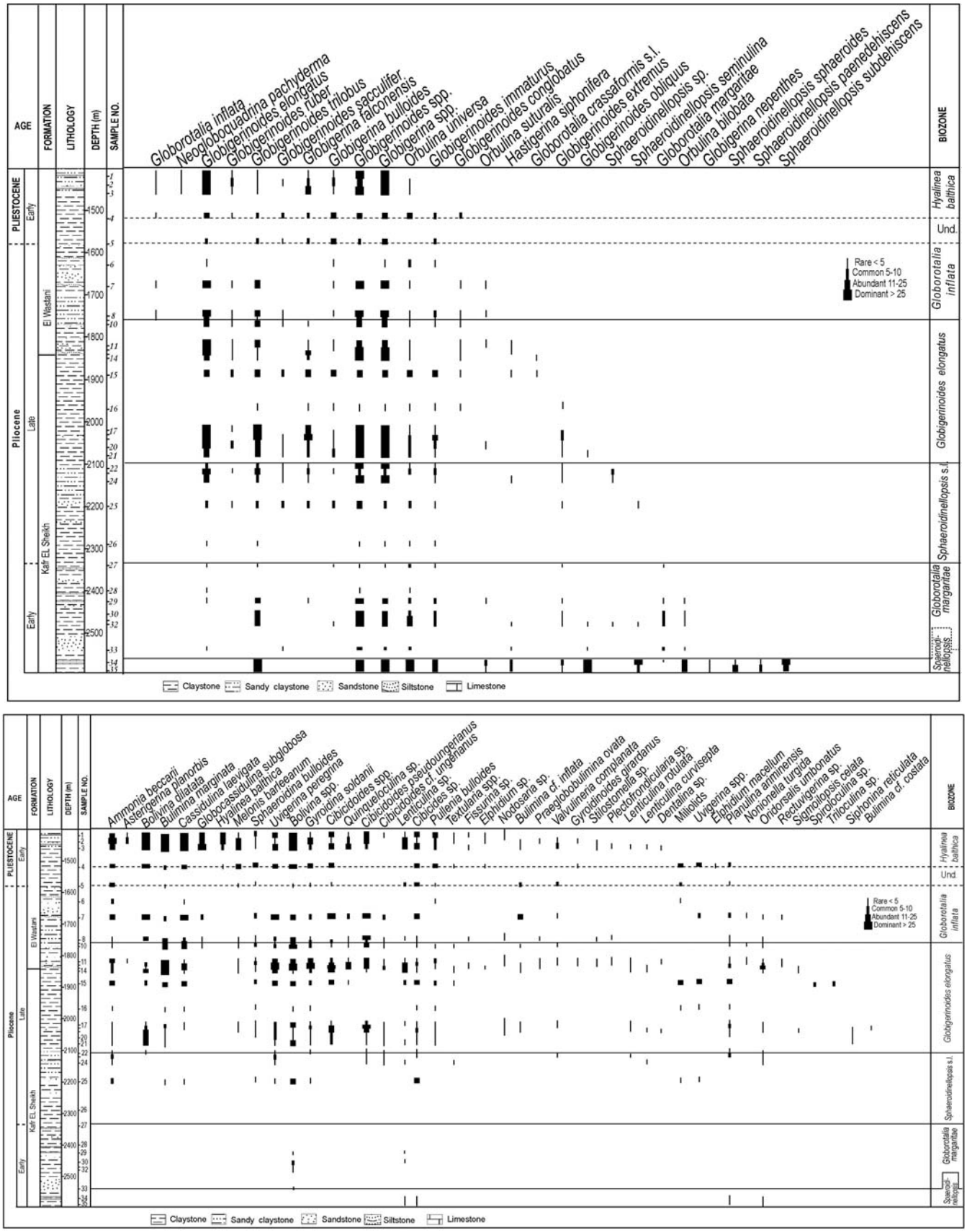


TEXT-FIGURE 5A, B
Stratigraphic distribution chart of the recorded foraminifera in Sapphire Da-well: a) planktonic; b) benthic.

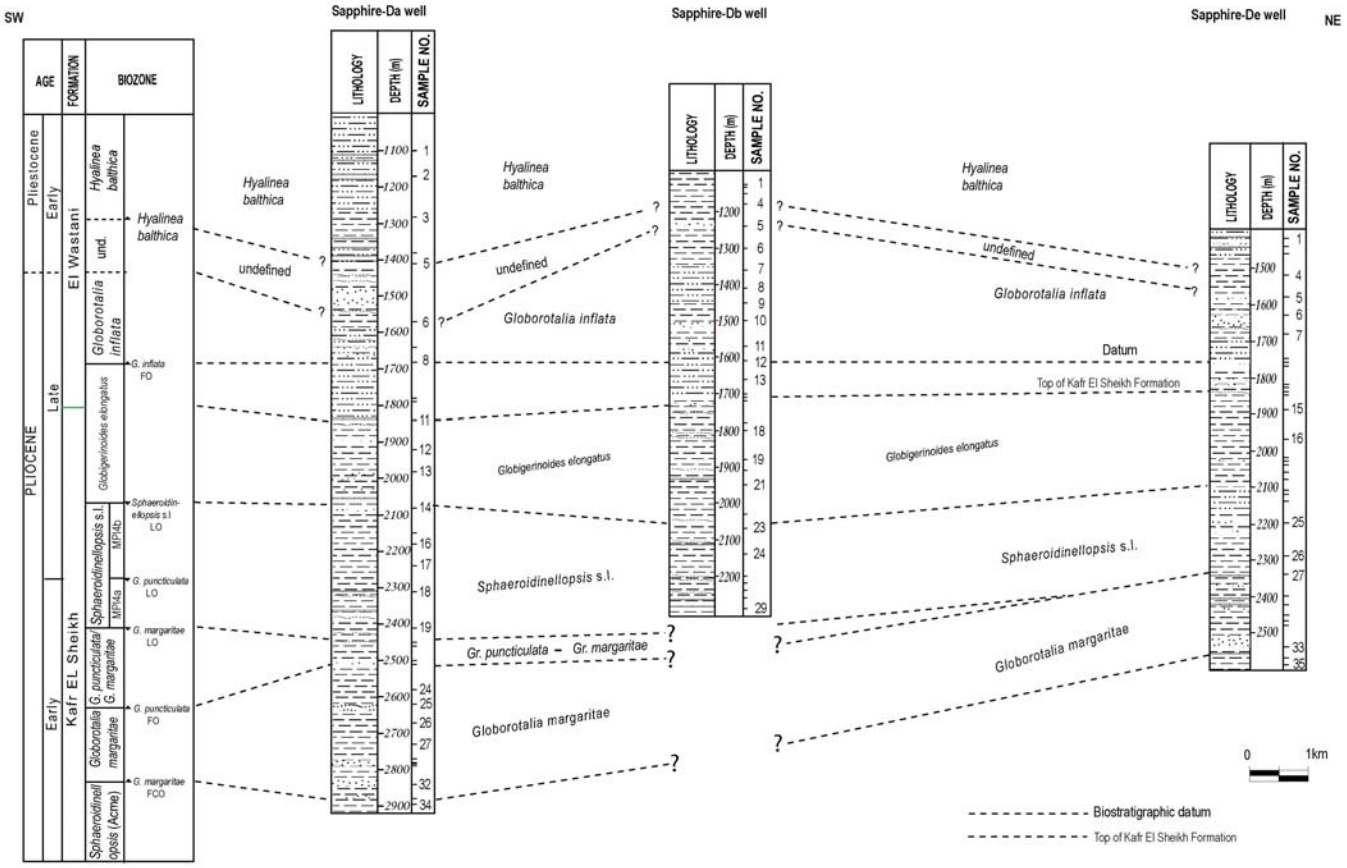




TEXT-FIGURE 6A, B
Stratigraphic distribution chart of the recorded foraminifera in Sapphire Db-well: a) planktonic; b) benthic



TEXT-FIGURE 7A, B
Stratigraphic distribution chart of the recorded foraminifera in Sapphire De-well: a) planktonic; b) benthic



TEXT-FIGURE 8
Biostratigraphic correlation chart of the proposed foraminiferal biozones in the studied wells.

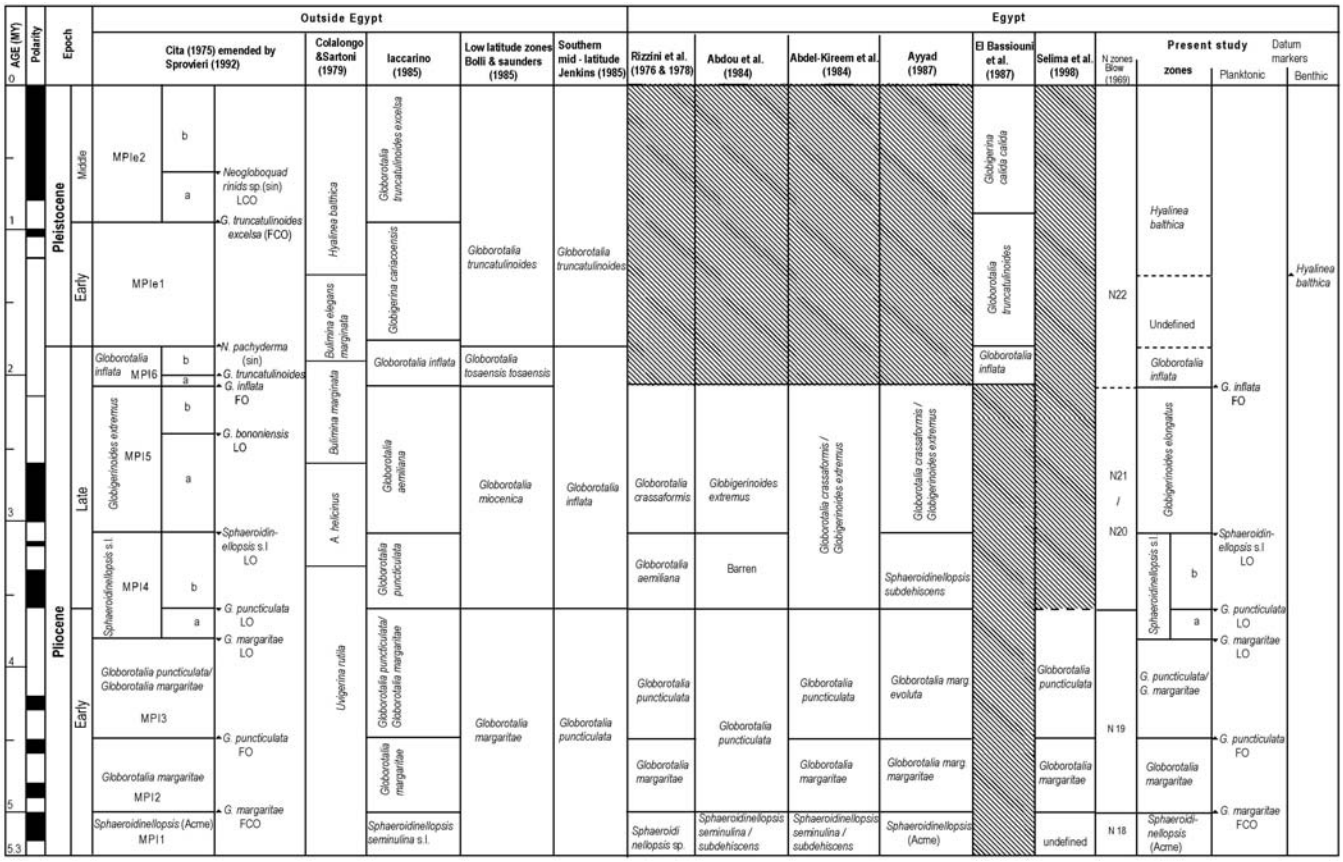
rare occurrence of *Ammonia beccarii* (Linné 1758), *Bolivina dilatata* (Ruess 1850), *Cibicidoides* spp., *Planulina ariminensis* d'Orbigny 1826 and *Lenticulina* sp. MPl4b Subzone is characterized by the same planktonic and benthic assemblage of MPl4a Subzone, except the absence of *Globorotalia puncticulata*.

MPl5 Zone is subdivided into MPl5a and MPl5b subzones based on LO of *Globorotalia bononiensis* (Sprovieri 1992). This bioevent is not present in the study Wells, and therefor MPl5 Zone interval has not been subdivided. The plankonic foraminifera of this zone are characterized by the presence of *Globigerinoides elongatus* (d'Orbigny 1826), *Globigerinoides trilobus* (Reuss 1850), *Globigerinoides ruber* (d'Orbigny 1839), *Globigerinoides conglobatus* (Brady 1879), *Globigerinoides immaturus* LeRoy 1939, *Globigerinoides sacculifer* (Brady 1877), *Globigerina bulloide*s d'Orbigny 1826, *Globigerina falconensis* Blow 1959, *Orbulina universa* d'Orbigny 1839, *Orbulina suturalis* Brönnimann 1951, *Globigerinoides extremus* Bolli and Bermúdez 1965, *Globorotalia crassaformis* s.l. and *Hastigerina siphonifera* (d'Orbigny 1839). The benthic foraminifera throughout the zone are characterized by the common occurrence of *Bulimina marginata* d'Orbigny 1826, *Uvigerina peregrina* Cushman 1923 and *Bolivina dilatata* (Ruess 1850).

MPl6 Zone is subdivided by Lourens et al. (2004) into MPl6a and MPl6b subzones based on FO of *Globorotalia truncatulinoides.* The marker species is rare in the study wells as in the Mediterranean region and the subzones can not be recognized. This zone is characterized by the presence of *Globigerinoides elongatus* (d'Orbigny 1826), *Globigerinoides trilobus* (Reuss 1850), *Globigerinoides ruber* (d'Orbigny 1839), *Globigerinoides conglobatus* (Brady 1879), *Globigerinoides sacculifer* (Brady 1877), *Globigerinoides immaturus* LeRoy 1939, *Globigerina falconens*is Blow 1959, *Globigerina bulloides* d'Orbigny 1826, *Orbulina universa* d'Orbigny 1839, *Orbulina suturalis* Brönnimann 1951 and *Globorotalia inflata* (d'Orbigny 1839). The benthic foraminifera throughout the intervals are characterized by the common occurrence of *Ammonia beccarii* (Linné 1758), *Bulimina marginata* d'Orbigny 1826, *Uvigerina peregrina* Cushman 1923, *Bolivina dilatata* (Ruess 1850), *Gyroidina soldanii* (d'Orbigny 1826) and *Cassidulina laevigata* d'Orbigny 1826. The planktonic assemblages of the Pleistocene interval are poor of useful biostratigraphic taxa, so the interval is distinguished on the basis of the benthic assemblage according to Colalongo and Sartoni (1979).

BIOSTRATIGRAPHY

The stratigraphic ranges of the identified species in the studied wells are tabulated in text figs (5–7) and the zones were corre-



TEXT-FIGURE 9
Correlation chart of the proposed Pliocene-Pleistocene biozones with other biozones in different areas.

lated with the other similar zones in the geographically related regions (text fig.9). The similarities and dissimilarities with different authors are also discussed. The foraminiferal zones and subzones will be described and the absolute ages are based on Lourens et al. (2004).

Pliocene planktonic foraminiferal biozones

***Sphaeroidinellopsis* Acme Zone (MPl1 Zone, Cita 1975a)**

Category. Acme zone

Age. Early Pliocene (Zanclean)

Definition. The lower limit of the zone is defined on the first appearance of open marine conditions after the Messinian salinity crisis (5.33 Ma), while the top is at first common occurrence of *Globorotalia margaritae* (5.08 Ma).

Occurrence. This biozone is found in Sapphire–Da and Sapphire–De wells.

In Sapphire–Da well, depth 2880–2895m (T.D), samples 33–34

In Sapphire–Db well, the samples are not available

In Sapphire–De well, it is most probably covered the interval 2565– 2590m (T.D), samples 34–35

Correlation: The described zone is correlated with *Sphaeroidinellopsis* Zone of Mediterranean as recognized by Cati et al. (1968), Borsetti et al. (1979), Thunell (1979), Iaccarino and Salvatorini (1982), Iaccarino (1985), and Violanti (2012), as well as in Turkey (Nazik 2004). Also this zone corresponds to the *Sphaeroidinellopsis* Zone defined from Early Pliocene of the Nile Delta (Rizzini et al. 1978; Abdou et al. 1984; Abdel–Kireem et al. 1984 and Ayyad 1987) and from the Western Desert (Mansour et al. 1969).

***Globorotalia margaritae* Zone (MPl2 Zone, Cita 1975a)'**

Category. Interval zone

Age. Early Pliocene (Zanclean)

Definition. Interval from first common occurrence of *Globorotalia margaritae* (5.08 Ma) to first occurrence of *Globorotalia puncticulata* (4.52 Ma).

Occurrence. This zone is found in Sapphire–Da and Sapphire–De wells only but in Sapphire–Db well the samples are not available.

In Sapphire–Da well, depth 2510–2880m, samples 23–33

In Sapphire–De well, depth 2340–2565m, samples 27–34

Correlations The zone is matched with *Globorotalia margaritae* of Mediterranean region as recognized by Cati et al. (1968), Bizon and Bizon (1972), Zachariase (1975), Bizon (1979), Borsetti et al. (1979), Iaccarino and Salvatorini (1982), Iaccarino (1985) and Violanti (2012). Also, this zone has been defined in the Nile Delta by Rizzini et al.(1978), Abdel-Kireem et al. (1984), Ayyad (1987) El-Heiny (1990) and in the Red Sea by Selima (1998).

***Globorotalia puncticulata – Globorotalia margaritae* Zone (MPl3 Zone, Cita 1975a)**

Category. Concurrent range zone.

Age. Early Pliocene (Zanclean)

Definition. Interval from first occurence of *Globorotalia puncticulata* (4.52Ma) to last occurence of *Globorotalia margaritae* (3.81 Ma).

Occurrence. This zone is recorded only in Sapphire–Da well and covers the interval 2440 – 2510m, samples 20–23. In Sapphire–De well this zone is not recorded, this is most probably due to unconformity or lack of samples, meanwhile in Sapphire–Db well, the samples throughout the interval are not available to determine this zone.

Correlation: Globorotalia puncticulata – Globorotalia margaritae Zone has been defined in the Mediterranean region by Bizon (1979). Iaccarino and Salvatorini (1982), Iaccarino (1985) and Violanti (2012). In Egypt, this zone is equivalent in part to *Globorotalia puncticulata* Zone of the Nile Delta, as characterized by Rizzini et al. (1978), Abdel-Kireem et al. (1984) and El-Heiny (1990), and in the Red Sea by Selima (1998).

***Sphaeroidinellopsis* s.l. Zone (MPl4 Zone, Cita 1975a)**

Category. Interval zone

Age. Early–Late Pliocene (Zanclean–Piacenzian)

Definition. Interval from last occurrence of *Globorotalia margaritae* (3.81 Ma) to last occurrence of *Sphaeroidinellopsis* s.l (3.19 Ma).

Occurrence. In Sapphire–Da well, depth 2070–2440m, samples 14–20

In Sapphire–Db well, the top is represented at 2060m, while the base is not determined due to samples are not available, samples 23–29

In Sapphire–De well, depth 2100–2340m, samples 22–27.

Remarks. The extinction of *Sphaeroidinellopsis* spp. is considered as a reliable bioevent in the Late Pliocene (Iaccarino 1985). This *Sphaeroidinellopsis* s.l. Zone is divided into two subzones MPl4a and MPl4b (Sprovieri 1992) based on the first downhole occurrence of *Globorotalia puncticulata*. This bioevent has been recorded only in Sapphire–Db well, this is most probably due to lack of samples in other two wells.

***Globorotalia puncticulata* (MPl4a Subzone, Sprovieri 1992)**

Category. Interval subzone

Age. Early Pliocene (Zanclean)

Definition. Interval from last occurrence of *Globorotalia margaritae* (3.81 Ma) to last occurrence of *Globorotalia puncticulata* (3.57 Ma).

PLATE 1

1,2 *Globigerinoides conglobatus* (Brady 1879), depth 1350–1360m, Sapphire–Db Well, El Wastani Fm., Late Pliocene / Pleistocene. 1) ventral view; 2) dorsal view

3,4 *Globigerinoides elongatus* (d'Orbigny 1826), depth 1350–1360m, Sapphire–Db Well, El Wastani Fm., Late Pliocene / Pleistocene. 3) ventral view; 4) dorsal view

5,6 *Globigerinoides obliquus obliquus* Bolli 1957, depth 2565–2570m, Sapphire–De Well, Kafr El Sheikh Fm., Early Pliocene. 5) ventral view; 6) dorsal view

7,8 *Globigerinoides obliquus extremus* Bolli and Bermúdez 1965, depth 2565–2570m, Sapphire–De Well, Kafr El Sheikh Fm., Early Pliocene. 7) ventral view; 8) dorsal view

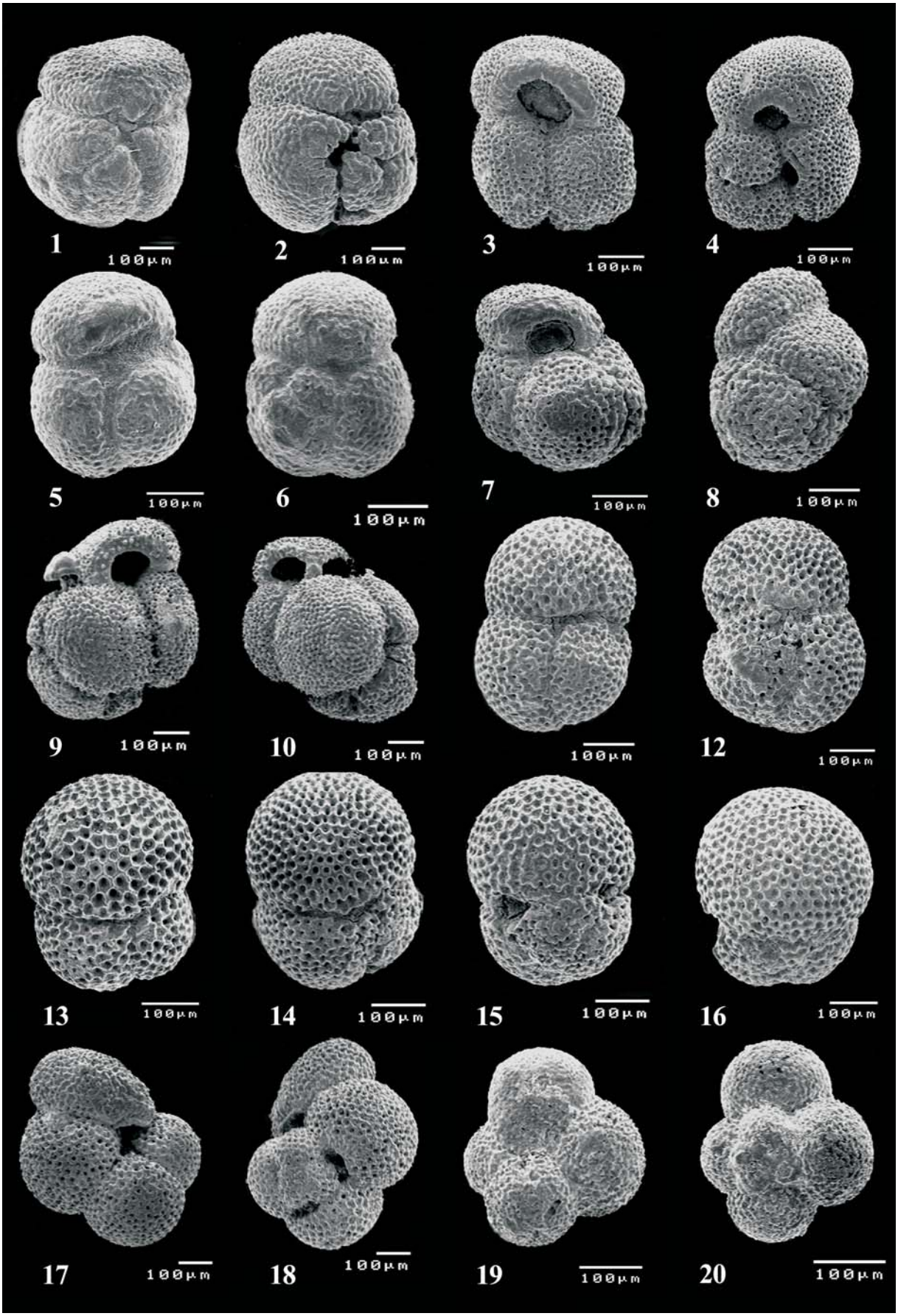
9,10 *Globigerinoides ruber* (d'Orbigny 1839), depth 1600–1610m, Sapphire–Db Well, El Wastani Fm., Late Pliocene. 9) ventral view; 10) dorsal view

11,12 *Globigerinoides trilobus immaturus* LeRoy 1939, depth 1770–1780m, Sapphire–Db Well, Kafr El Sheikh Fm., Late Pliocene. 11) ventral view; 12) dorsal view

13–16 *Globigerinoides trilobus trilobus* (Reuss 1850), depth 2020–2030m, Sapphire–De Well, Kafr El Sheikh Fm., Late Pliocene.

17,18 *Globigerinoides trilobus sacculifer* (Brady 1877), depth 2070–2080m, Sapphire–Da Well, Kafr El Sheikh Fm., Late Pliocene. 17) ventral view; 18) dorsal view

19,20 *Globigerina bulloides* d'Orbigny 1826, depth 2070–2080m, Sapphire–Da Well, Kafr El Sheikh Fm., Late Pliocene. 19) ventral view; 20) dorsal view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Occurrence. It is represented only in Sapphire–Db well, samples 26–29. The base of the subzone is not determined due to the samples are not available.

***Globorotalia planispira* (MPl4b Subzone, Sprovieri 1992)**

Category. Interval subzone

Age. Late Pliocene (Piacenzian)

Definition. Interval from last occurrence of *Globorotalia puncticulata* (3.57 Ma) to last occurrence of *Sphaeroidinellopsis* s.l (3.19 Ma).

Occurrence. The subzone is recorded only in Sapphire–Db well and covers the interval 2060–2210m, samples 23–26.

Correlation, Sphaeroidinellopsis Zone was described by Cita (1973, 1975); Thunell (1979) and Violanti (2012) in the Mediterranean and by Martinotti (1981) in Israel. In addition, it was recorded for the first time by Ayyad (1987) in the Nile Delta, Egypt.

***Globigerinoides elongatus* Zone (MPl5 Zone, Cita 1975a)**

Category. Interval zone

Age. Late Pliocene (Piacenzian)

Definition. Interval from last occurrence of *Sphaeroidinellopsis* s.l. (3.19 Ma) to first occurrence of *Globorotalia inflata* (2.09Ma).

Occurrence. In Sapphire–Da well, depth 1680–2070m, samples 8–14

In Sapphire–Db well, depth 1610–2060m, samples 12–23

In Sapphire–De well, depth 1760–2100m, samples 9–22

Remarks. This zone is equivalent to *Globigerinoides extremus* Zone of Cita (1973), defined as the interval from last occurrence of *Sphaeroidinellopsis* s.l. to the extinction of the zonal marker. Sprovieri (1992) subdivided MPl5 Zone into two parts, MPl5a and and MPl5b. The *Globorotalia bononiensis* Subzone (MPl5a) is defined as the interval from last occurrence *Sphaeroidinellopsis* s.l. to last occurrence of *Globorotalia bononiensis*., which is absent in the three studied wells, as in the cases of most studies in the Nile Delta (Rizzini et al. 1978; Abdou et al. 1984; Abdel–Kireem et al. 1984; and Ismail et al. 2010). The *Globorotalia incisa* Subzone (MPl5b) is defined as the interval from last occurrence of *Globorotalia bononiensis* to first occurrence of *Globorotalia inflata. Globigerinoides extremus* and *Globorotalia crassaformis* s.l. become extinct near the top of this subzone.

Correlation: Globigerinoides elongatus Zone is correlated with *Globorotalia crassaformis* s.l. Zone of Cati et al., (1968), the *Globorotalia crassaformis* Zone of Bizon and Bizon, (1972) and the *Globorotalia aemiliana* Zone of Iaccarino, (1985) for the Mediterranean region. It also corresponds to *Globorotalia crassaformis* Zone described by Martinotti (1981) in Israel and is matched with the upper part of *Globorotalia miocenica* of the low latitude area (Bolli and Sauders 1985).

In the Nile Delta, the studied biozone is equivalent to *Globorotalia crassaformis* Zone of Rizzini et al. (1978) and *Globigerinoides extremus* Zone of Abdou et al. (1984). Also, it is equivalent to *Globorotalia crassaformis/Globigerinoides extremus* Zone described by Ayyad (1987) and to the upper part of *Globigerinoides extremus* Zone as described by Abdel-Kireem et al. (1984).

***Globorotalia inflata* Zone (MPl6 Zone, Cita 1975a)**

Category. Interval zone.

Age. Late Pliocene (Piacenzian).

Definition. Interval from first occurrence of *Globorotalia inflata* (2.09 Ma) to first common occurrence of *Neogloboquadrina pachyderma* (Sin.) (1.79 Ma).

PLATE 2

1–4 *Globigerina nepenthes* Todd 1957, 1, 2: depth 2765–2770m, Sapphire–Da Well, Kafr El Sheikh Fm., Early Pliocene. 1) ventral view; 2) dorsal view; 3, 4: depth 2785–279m, Sapphire–Da Well, Kafr El Sheikh Fm., Early Pliocene. 3) ventral view; 4) dorsal view

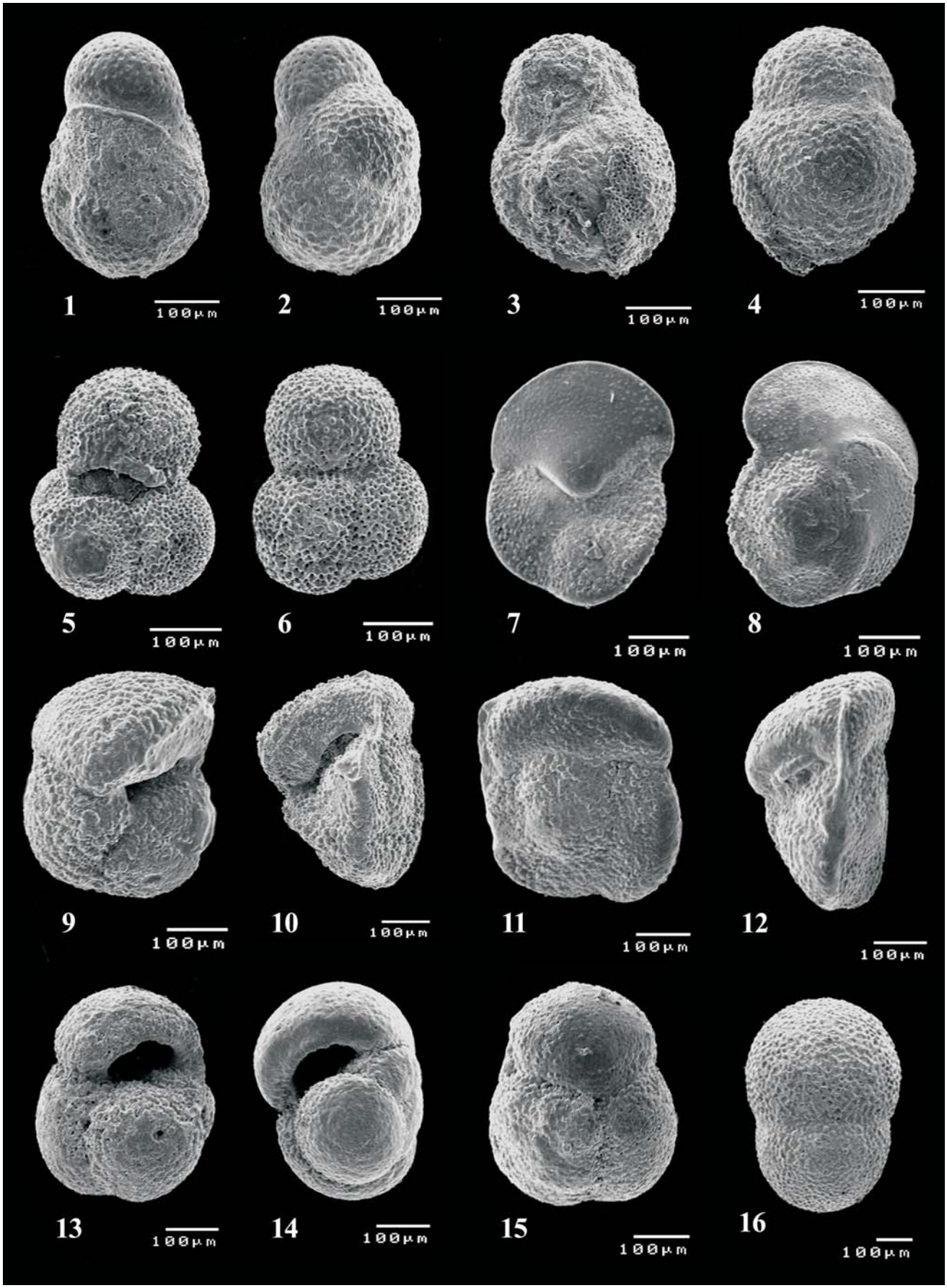
5,6 *Globigerina falconensis* Blow 1959, depth 2070–2080m, Sapphire–Da Well, Kafr El Sheikh Fm., Late Pliocene. 5) ventral view; 6) dorsal view

7,8 *Globorotalia margaritae* Bolli and Bermúdez 1965, depth 2450–2455m, Sapphire–De Well, Kafr El Sheikh Fm., Early Pliocene. 7) ventral view, 8) dorsal view

9–12 *Globorotalia crassaformis* s.l., depth 1910–1920m, Sapphire–Da Well, Kafr El Sheikh Fm., Late Pliocene. 9) ventral view; 10, 12) side view; 11) dorsal view

13–15 *Globorotalia inflata* (d'Orbigny 1839), depth 1600–1610m, Sapphire–Db Well, El Wastani Fm., Late Pliocene. 13) ventral view; 14) side view; 15) dorsal view

16 *Orbulina bilobata* (d'Orbigny 1846), depth 2890–2895m, Sapphire–Da Well, Kafr El Sheikh Fm., Early Pliocene.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Occurrence. In Sapphire–Da well, depth 1560–1680m, samples, 6 –8.

In Sapphire–Db well, depth 1240–1610m, samples, 5–12.

In Sapphire–De well, depth 1580–1760m, samples, 5–9.

Remarks. The last down hole occurrence of *Globorotalia inflata* corresponds to the lower boundary of MPl6 Zone. The upper boundary is characterized by the first common occurrence of *Neogloboquadrina pachyderma* (left coiling). Since *Neogloboquadrina pachyderma* (left coiling) is not abundant in the analyzed samples, the top of this zone could not be determined.

Lourens et al. (2004) subdivided the MPl6 Zone into two subzones, MPl6a and MPl6b on the basis of the first occurrence of *Globorotalia truncatulinoides* (2.0 Ma). In the Mediterranean, *Globorotalia truncatulinoides* is too uncommon (Iaccarino 1985) and the subzones can not be recognized.

Correlation. The zone is correlated with *Globorotalia inflata* Zone of the Mediterranean as used by Zachariasse (1975), Bizon (1979), Borsetti et al. (1979), Iaccarino and Salvatorini (1982;), Iaccarino (1985) and Violanti (2012). Also, it is matched with *Globorotalia tosaensis tosaensis* of low latitude areas (Bolli and Saunders 1985) and with the upper part of *Globorotalia inflata* Zone identified by Jenkins (1985) in mid latitude areas. In addition, this zone has been defined in the Nile Delta by El Bassiouni et al. (1987).

PLIOCENE–PLEISTOCENE BOUNDARY

The Pliocene–Pleistocene boundary was dated to 1.806 Ma and defined between the Gelasian stage of the Pliocene and Calabrian stage of the Pleistocene (Lourens et al. 2004). On the other hand, the Pleistocene series was proposed to include the GSSP of the Gelasian stage (Gibbard et al. 2010). Iaccarino (1985) considered that first occurrence of *Globigerina cariacoensis* occurs close to the Pliocene–Pleistocene boundary in the Mediterranean region. On the other hand, Cati et al. (1968), Bizon and Bizon (1972), Thunnel (1979), and Bizon (1979) placed the boundary at first appearance of *Globorotalia truncatulinoides*. Also, it is generally recognized by the first common occurrence of *Neogloboquadrina pachyderma* (sinistral) according to Sprovieri, (1993) and Lourens et al. (1992; 2004). In the study area, the low percentage of the sinistral coiling of *Neogloboquadrina pachyderma* and lack of samples did not allow to demarcate the base of the Pleistocene in the studied wells.

Pleistocene foraminiferal biozones

The analyzed samples of the studied wells are characterized by the presence of the benthic *Hyalinea balthica*. According to Bizon and Muller (1977) and Spaak (1983), *Hyalinea balthica* marks the base of Pleistocene. Colalongo and Sartoni (1979) and Pasini and Colalongo (2001) proposed that Santernian/Emilian boundary coincides with the first appearance of *Hyalinea balthica*.

In the study area, the Pleistocene interval was tentatively distinguished on the occurrence of *Hyalinea balthica* species and correlated it with the benthic scheme of Colalongo and Sartoni (1979) (text fig.9).

Hyalinea balthica Zone

Age. Pleistocene

Definition. The base of this zone is defined based on the first occurrence of *Hyalinea balthica,* while the top is tentatively defined due to the samples are not available.

Occurrence. In Sapphire–Da well, depth 1410–1090m, samples 1–5

In Sapphire–Db well, depth 1150–1121m, samples 1–3

In Sapphire–De well, depth 1520–1410m, samples 1–4

Remarks. In the studied wells, there is an undefined interval between the *Globorotalia inflata* Zone and *Hyalinea balthica* Zone. No direct evidence was found for dating this interval, either due to lack of any planktonic markers, or the samples are not available.

PLATE 3

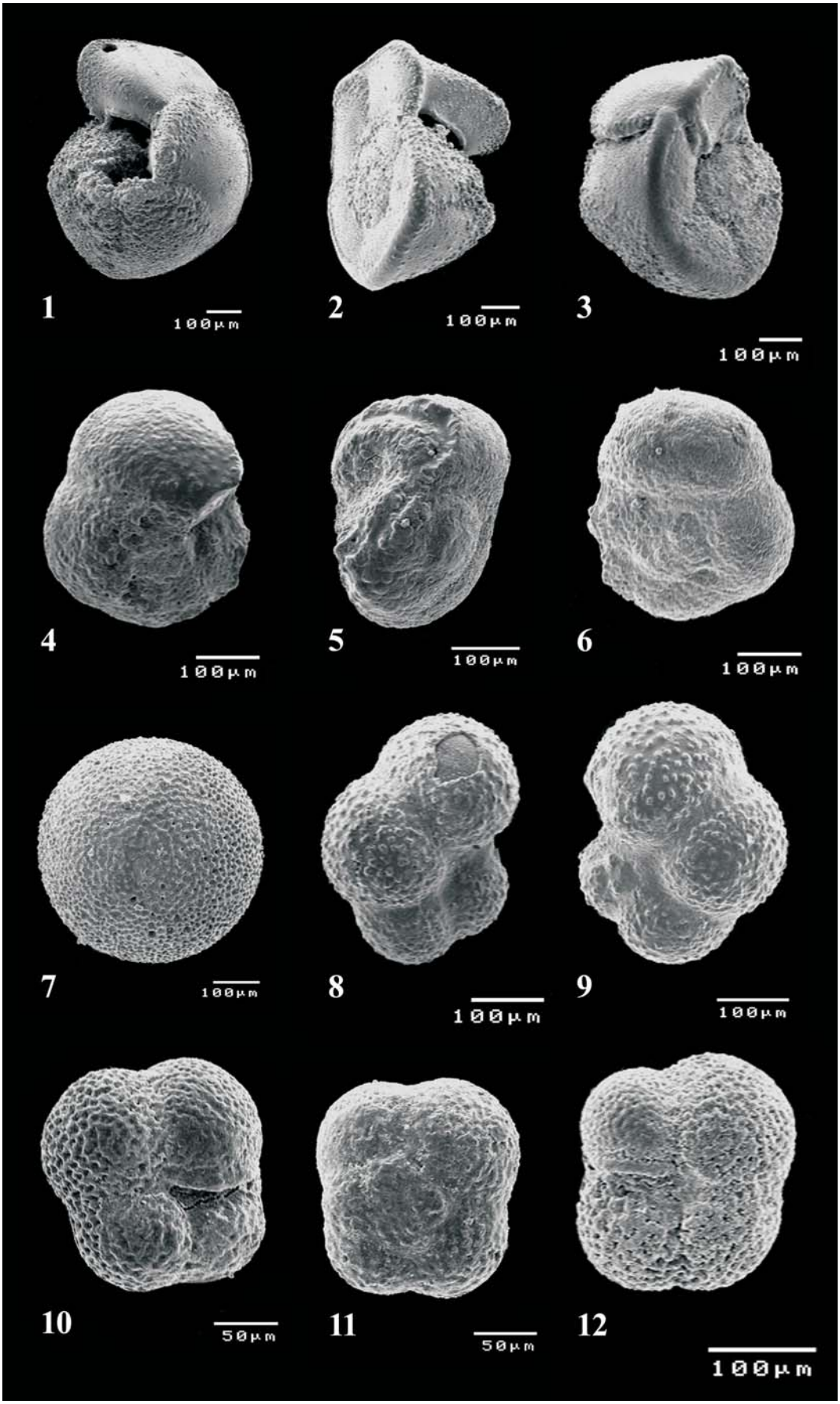
1–3 *Globorotalia truncatulinoides* (d'Orbigny 1839), depth 1121–1124m, Sapphire–Db Well, El Wastani Fm., Pleistocene. 1) ventral view; 2) side view; 3) dorsal view

4–6 *Globorotalia puncticulata* (Deshayes 1832), depth 2500–2510m, Sapphire–Da Well, Kafr El Sheikh Fm., Early Pliocene. 4) ventral view; 5) side view; 6) dorsal view.

7 *Orbulina universa* d'Orbigny 1939, depth 2890–2895m, Sapphire–Da Well, Kafr El Sheikh Fm., Early Pliocene.

8,9 *Hastigerina siphonifera* (d'Orbigny 1839), depth 2585–2590m, Sapphire–De Well, Kafr El Sheikh Fm., Early Pliocene. 8) ventral view; 9) dorsal view

10–12 *Neoqloboquadrina pachyderma* (Ehrenberg 1861), depth 1160–1170m, Sapphire–Da Well, El Wastani Fm., Pleistocene. 10, 11: Sinistral coiling: 10) ventral view; 11) dorsal view; 12, dextral coiling.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CONCLUSIONS

The study of foraminiferal biostratigraphy in cuttings from offshore wells penetrating the Pliocene–Pleistocene sequence in the West Delta Deep Marine Concession (WDDM) of the Nile Delta leads to the recognition of six Pliocene planktonic foraminiferal zones and two subzones, as well as one Pleistocene benthic foraminiferal Zone. These zones can be described as follows, in ascending stratigraphic order:

1– *Sphaeroidinellopsis* Acme Zone (MPl1) (Early Pliocene)

2– *Globorotalia margaritae* Zone (MPl2) (Early Pliocene)

3– *Globorotalia puncticulata* / *Globorotalia margaritae* Zone (MPl3) (Early Pliocene)

4– *Sphaeroidinellopsis* s.l. Zone (MPl4) (Early to Late Pliocene)

4.1— MPl4a Subzone (Early Pliocene)

4.2 — MPl4b Subzone (Late Pliocene)

5– *Globigrinoides elongatus* Zone (MPl5) (Late Pliocene)

6– *Globorotalia inflata* Zone (MPl6) (Late Pliocene)

7– *Hyalinea balthica* Zone (Pleistocene).

The established foraminiferal biozones are correlated with the most relevant Pliocene–Pleistocene biozone schemes from Mediterranean region and world wide. The Early to Late Pliocene zones are confirmed within the Kafr El Sheikh Formation by the distribution of planktonic foraminiferal markers in the studied wells. These markers are *Globorotalia margaritae, Globorotalia puncticulata*, *Globigerina nepenthes*, and *Globigerinoides extremus*, while the Pleistocene interval has been tentatively distinguished on the basis of the benthic species *Hyalinea balthica*. The low percentages of sinistral coiling *Neoqloboquadrina pachyderma* do not allow precuise demarcation of the base of the Pleistocene in the studied wells.

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PLATE 4

1–4 *Sphaeroidinellopsis seminulina* (Schwager 1866), 1, 2, depth 2585–2590m, Sapphire–De Well, Kafr El Sheikh Fm., Early Pliocene, 1) ventral view; 2) dorsal view; 3, 4, depth 2890–2895m, Sapphire–Da Well, Kafr El Sheikh Fm., Early Pliocene, 3) ventral view; 4) dorsal view

5–8 *Sphaeroidinellopsis paenedehiscens* Blow 1969: 5, 6, depth 2890–2895m, Sapphire–Da Well, Kafr El Sheikh Fm., Early Pliocene. 5) ventral view; 6) dorsal view; 7, 8, depth 2585–2590m, Sapphire–De Well, Kafr El Sheikh Fm., Early Pliocene. 7) ventral view; 8) dorsal view

9, 10 *Sphaeroidinellopsis subdehiscens* (Blow 1969), depth 2585–2590m, Sapphire–De Well, Kafr El Sheikh Fm., Early Pliocene. 9) ventral view; 10) dorsal view

11, 12 *Sphaeroidinellopsis sphaeroides* Lamb 1969, depth 2585–2590m, Sapphire–De Well, Kafr El Sheikh Fm., Early Pliocene. 11) ventral view; 12) dorsal view

13,14 *Sphaeroidinellopsis* sp., depth 2110–2120m, Sapphire–De Well, Kafr El Sheikh Fm., Late Pliocene. 13) ventral view; 14) dorsal view

15, 16 *Sphaeroidinella dehiscens* (Parker and Jones 1865), depth 1650–1660m, Sapphire–Db Well, El Wastani Fm., Late Pliocene.

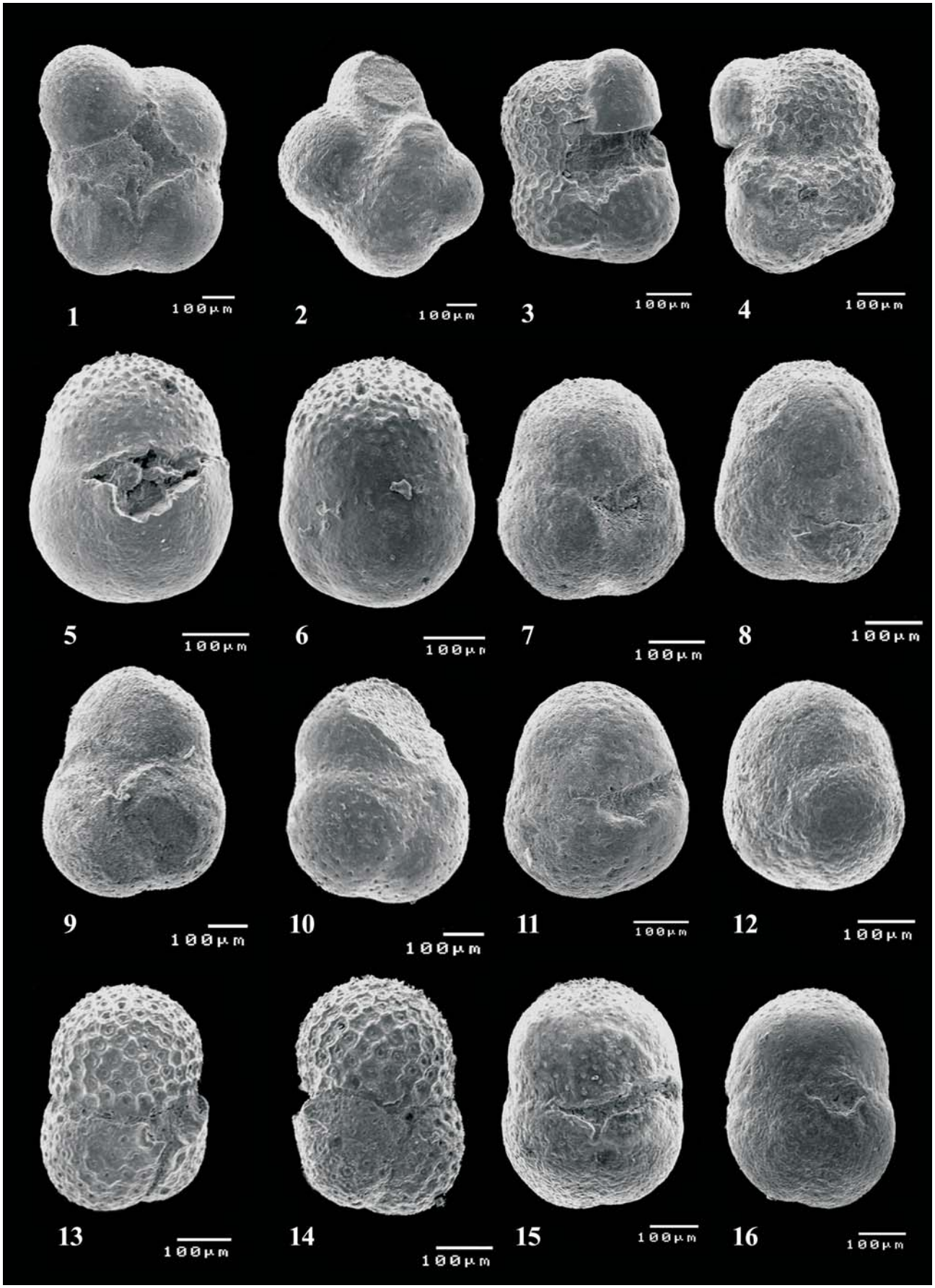
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PLATE 5

1–4 *Cibicidioides pseudoungerianus* (Cushman 1922), 1, 2, depth 1770–1780, Sapphire–Db Well, Kafr El Sheikh Fm., Late Pliocene. 1) ventral view; 2) side view; 3, 4, depth 2010–2020m, Sapphire–De Well, Kafr El Sheikh Fm., Late Pliocene. 3) ventral view; 4) dorsal view

5,6 *Cibicidioides* cf. *C. ungerianus* (d'Orbigny 1846), depth 2030–2040m, Sapphire–De Well, Kafr El Sheikh Fm., Late Pliocene

7,8 *Hyalinea balthica* (Schroeter 1783), depth 1450–1460m, Sapphire–De Well, El Wastani Fm., Pleistocene.

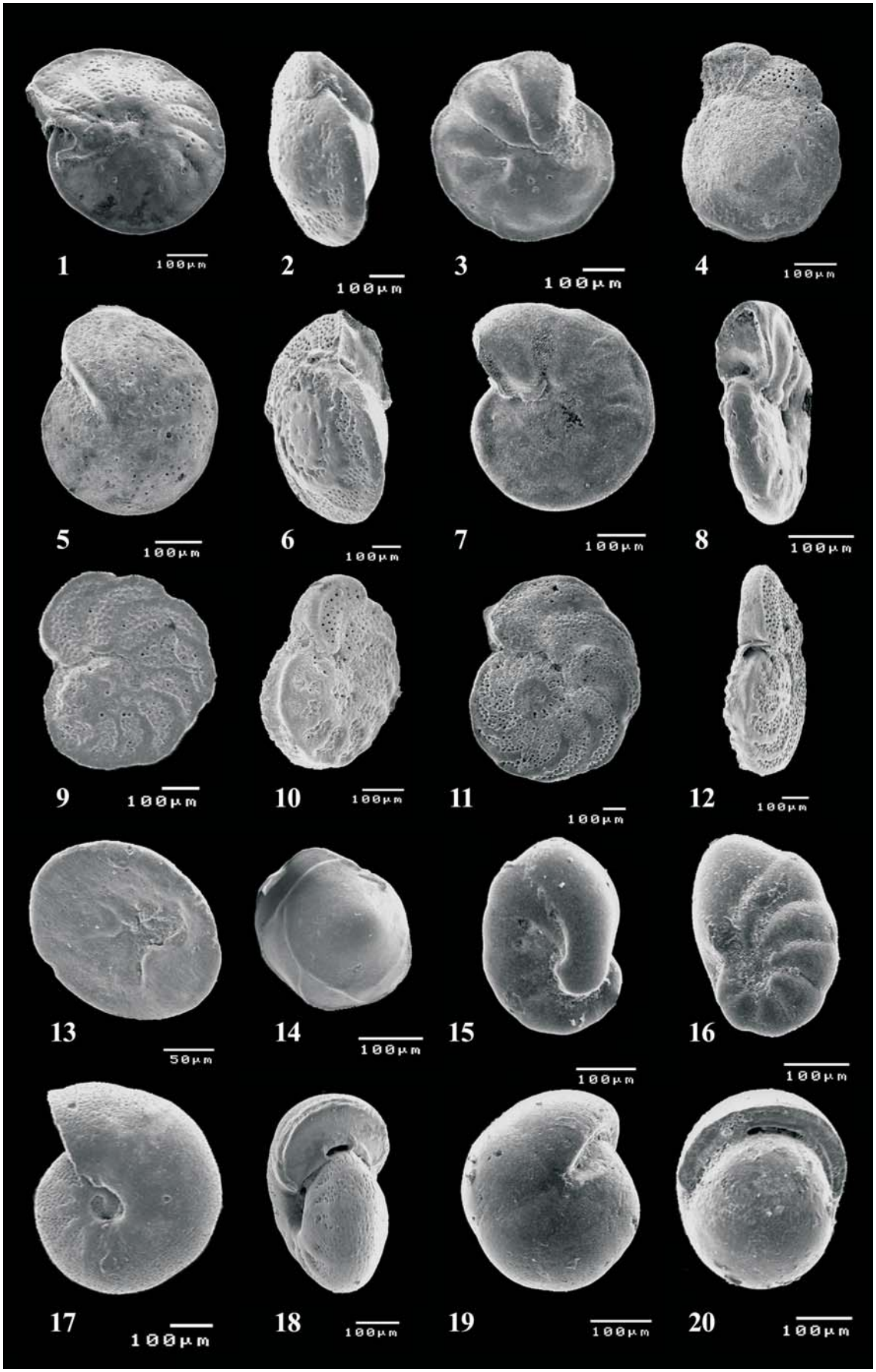
9–12 *Planulina ariminensis* d'Orbigny 1826, depth 1820–1830m, Sapphire–De Well, El Wastani Fm., Late Pliocene.

13,14 *Asterigerina planorbis* d'Orbigny 1846, depth 1410–1420m, Sapphire–De Well, El Wastani Fm., Pleistocene. 13) ventral view; 14) dorsal view

15,16 *Nonionella turgida* (Williamson 1858), depth 1820–1830m, Sapphire–De Well, El Wastani Fm., Late Pliocene

17,18 *Melonis barleeanum* (Williamson 1858), depth 1450–1460m, Sapphire–De Well, El Wastani Fm., Pleistocene

19,20 *Pullenia bulloides* (d'Orbigny 1826), depth 1450–1460m, Sapphire–De Well, El Wastani Fm., Pleistocene.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