Impacts of ocean acidification on planktonic foraminifera: a case study from the Cretaceous Paleocene transition at the Farafra Oasis, Egypt

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Abstract

This paper provides the change in seawater chemistry during the Cretaceous/ Paleocene transition of the Farafra Oasis (El-Aqabat and North Gunna sections) of Egypt. At the Late Cretaceous, a gradual warming is showed in the studied area.

During the warm environment of Late Maastrichtian the size reduction, "Lilliput effect" has been observed in many foraminiferal tests and planktonic low oxygen tolerant foraminifera were thriving and dwarfed *Heterohelix*, *Pseudogumbelina* and *Pseudotextularia* species. Other small genera are rare (e.g., *Hedbergella* and *Globigerinelloides*).

At zones CF7 and CF7/CF3 (cooling period) of the Khoman Formation of the El-Aqabat section (samples 1-17), the SEM imaging of planktonic foraminifera extracted from these zones (*Heterohelix striata, Pseudogumbelina costulata, P. excolata, Pseudotextularia deformis, Rugoglobigerina rugosa* and *R. hexacamerata*) revealed high ornamentation in the specimens of these zones. The specimens of zone P1c (warm water), around K/Pg boundary marked signs of dissolution and deformation, the dissolution of the calcareous foraminifera was evident on the test surface. The same observation has been recorded around K/Pg boundary at zone CF2 and P2 (warm water) of the North Gunna section (lithology change from chalk to argillaceous limestone at the Aqabat section and from chalk to shale at North Gunna section respectively due to an increase of CO_2).

Keywords

Cretaceous, Paleocene, Farafra Oasis, Ocean Acidification, Dissolution.

1. INTRODUCTION

The modern global warming due to increased CO_2 levels has caused a renewed in the mechanics of ancient warm climates. The early Paleogene (ca. 45-60 Ma) has been characterized by greenhouse intervals containing significant abrupt and transient warming events that led to major changes in oceanic environments, profound turnover in marine communities, including extinction and disturbance of global chemical cycles which resulted in the Cretaceous oceanic anoxic events (Jenkyns, 1980). The increasing atmospheric carbon dioxide (CO_2) concentration is the main reason causing global warming and Ocean Acidification (OA) (Caldeira & Wickett, 2003, 2005; Feely *et al.*, 2004; Orr *et al.*, 2005). The elevated pressure of CO_2 ($p$$CO_2$) in seawater can create an impact on marine organisms through decreased calcium carbonate ($CaCO_3$) saturation (Hart *et al.*, 2014). Biserial and triserial planktonic forms represent the dominant of the planktonic assemblage of the end-Cretaceous mass extinction (Keller & Abramovich, 2009). Biserial planktonic foraminifera are intermittently abundant in planktonic assemblages throughout the Upper Cretaceous to the Cenozoic and they occur in the rarely studied small size fraction (63-125 µm) (d'Hondt, 1991; Liu & Olsson, 1992; Olsson *et al.*, 1999; Berggren & Pearson, 2005 and Huber *et al.*, 2006).

Khanna *et al.* (2013) demonstrated that test ornamentation of benthic foraminifera *Haynes inagermanica* (Ehrenberg, 1840) is sensitive to decreasing seawater PH. At higher CO_2 levels the functional ornamentation of the aperture area and umbilical features were dissolved.

Canudo & Molina (1992) illustrated that low latitude group characterized by warm morphogroups such as *Rugoglobigerina*, *Contusotruncana*, *Hedbergella*, *Morozovella*, *Igorina*, *Acarinina* and *Praemurica*. Meanwhile, the high latitude group characterized the cold morphogroups such as *Globotruncana*, *Subbotina*, *Parasubbotina*, *Eoglobigerina* and *Globanomalina*. Various authors (e.g., Bolli, 1971; Darling *et al.,* 2006; Darling & Wade, 2008) used the coiling direction of planktonic foraminifera as a palaeoceanographical proxy. The dominance of right-coiled specimens indicates warm surface waters, left-coiled specimens prefer cooler surface waters (e.g.,

Carter & Hart, 1977; Bauch & Erlenkeuser, 2003; Bauch & Kandiano, 2007).

The present work aims to investigate the effects of differential ocean acidification (OA) on the surface of planktonic foraminiferal assemblages at the Cretaceous-Paleocene transition of the Farafra Oasis of Egypt (Fig. 1), because at the end-Cretaceous event (66 Mya) many pelagic calcifying species went extinct at this time (e.g., Marshall & Ward, 1996; Bown, 2005; Jiang *et al.*, 2010 and Renne *et al.*, 2013). This present study is carrying to evaluate shelled planktonic foraminifera, morphological features and ornamentation on the test that are sensitive to decreasing seawater pH.

2. MATERIALS AND METHODS

To achieve the scope of the present study, the following investigations had been achieved:

1. Two field trips were performed during seasons 2010-2011 and 2011-2012 to measure two stratigraphic sections (El-Aqabat and North Gunna, Figs 2, 3), where 28 and 56 rock samples were collected from the two study sections respectively.

2. About 80 grams of rock samples were dried at 50-60°C for 24 hours and soaked in a Na_2CO_3 solution for a day. After disintegration, the rock samples were washed over a 63 μm sieve and dried at 50-60°C. This treatment was repeated whenever the washed residues remained somewhat aggregated. After complete disaggregation, the dried residues were sieved into fractions (63-125 μm and 125-630 μm). A representative split for quantitative analysis (approximately >300 planktonic specimens) was obtained from the 63-125 μm and 125-630 μm fraction using a microsplitter. From these fractions, all planktonic specimens were picked, identified, counted and permanently stored on micropaleontological slides. Relative abundances are expressed as the proportion (percentage) of a species in the entire assemblage and foraminiferal numbers are expressed as the numbers of individuals per gram of sediment. The relative abundance of species was noted as abundant, >10%; common, 5-10%; few, 2-5%; and rare, <2% species.

3. The planktonic foraminifera were identified by using a binocular microscope and photographed by using JEOL JSM-5800 Scanning Electron Microscope of Assiut University. According to the important planktonic foraminiferal species, nine biozones and subzones for the Late Maastrichtian to the early Middle Paleocene interval are recognized in the studied sections (Figs 2, 3). The distribution of high and low latitude of planktonic morphogroup, test size and planktonic foraminiferal ornamentation counts in the El Aqabat and North Gunna sections have been shown in Figures 4, 5.
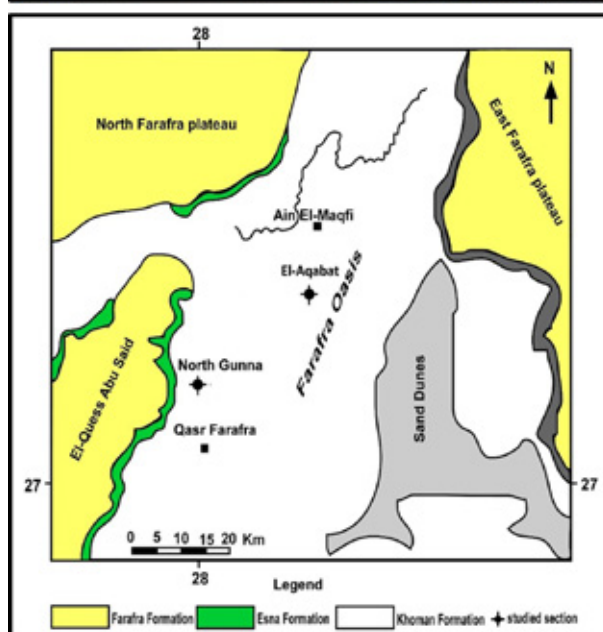

Fig. 1: Location map.

3. LITHOSTRATIGRAPHY

The floor of the Farafra depression is composed of chalk in the northern half, The Khoman Formation is well represented in the area to the north of Farafra Oasis and at the plateau between Farafra and Bahariya and it is persistent in lithological characters (Issawi *et al.*, 1999).

The stratigraphic succession of the North Gunna section of the Farafra Oasis represented by the Upper Cretaceous and Lower Paleocene strata (Fig. 2). Meanwhile, the stratigraphic succession of the El-Aqabat section is represented by one rock unit named by Khoman Formation (Fig. 3). Figure 6 shows the correlation between the two sections.

The stratigraphic succession of Late Cretaceous (Maastrichtian) to early-Middle Paleocene (Danian-Selandian) at the Farafra Oasis composes of carbonate and siliciclastic sediments, where two rock units could be recognized from base to top as follows:
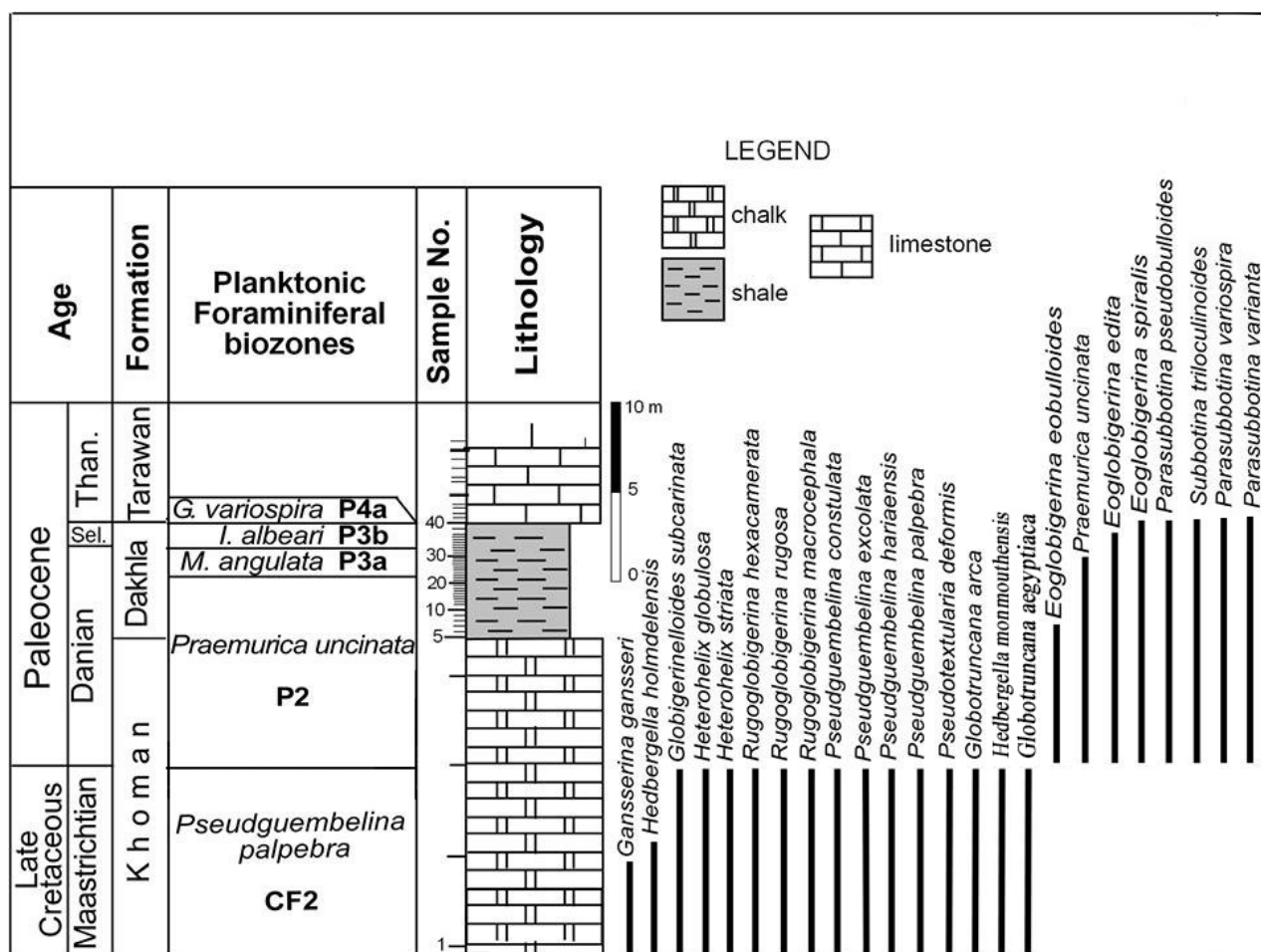
Fig. 2: Distribution range chart of the identified planktonic foraminiferal zone at the North Gunna section.

3.1. The Khoman Formation (El Akkad & Issawi, 1963)

In the Farafra Oasis, the Khoman Formation is characterized by snow white chalk and chalky limestone deposits. The top part of the Khoman Formation is hard limestone beds. The thickness of the formation attains 52 m at the El-Aqabat section, where the North Gunna section starts with the upper part of Khoman Formation of about 18 m thick succeeded upward by Dakhla, Tarawan, Esna and Farafra Formations.

The stratigraphic position of the Khoman Formation has been a matter of controversy. It has been assigned to the Maastrichtian (Kerdany & Cherif, 1990; Abdel Kireem & Samir, 1995), Campanian-Maastrichtian (Soliman & Ismail, 1993) and Maastrichtian-Danian (Obaidalla & Kassab, 2000). Moreover, Obaidalla *et al.* (2006) assigned the Khoman Formation at Naqb El-Bahariya area into the Campanian-Thanetian age. In the present work, the planktonic foraminiferal investigations assigned the Khoman Formation to the Maastrichtian-Selandian (see biostratigraphy below).

3.2. The Dakhla Formation (Said, 1962)

The Dakhla Formation is made up of light olive gray, dark greenish gray, dark yellowish brown shales with intercalated siltstone, fine sandstone and limestone. It underlies the Tarawan Formation with a disconformity relationship. The Dakhla Formation recorded only at the North Gunna section (about 8 m thick), where the upper part is a glauconitic bed. In the present study, the sediments of the Dakhla Formation are assigned to the Danian-Selandian age based on microfossil contents.

Major depositional hiatuses span the upper Maastrichtian through lower Paleocene in the two Farafra sections and appear to be linked primarily to major sea-level regressions and secondarily to regional tectonic activity (Bahariya arch uplift). The major eustatic sea-level changes may have been the primary controlling factors for widespread erosion and hiatuses, which is known in eustatic sea-level changes detailed by Haq *et al.* (1987) and Li *et al.* (1999).
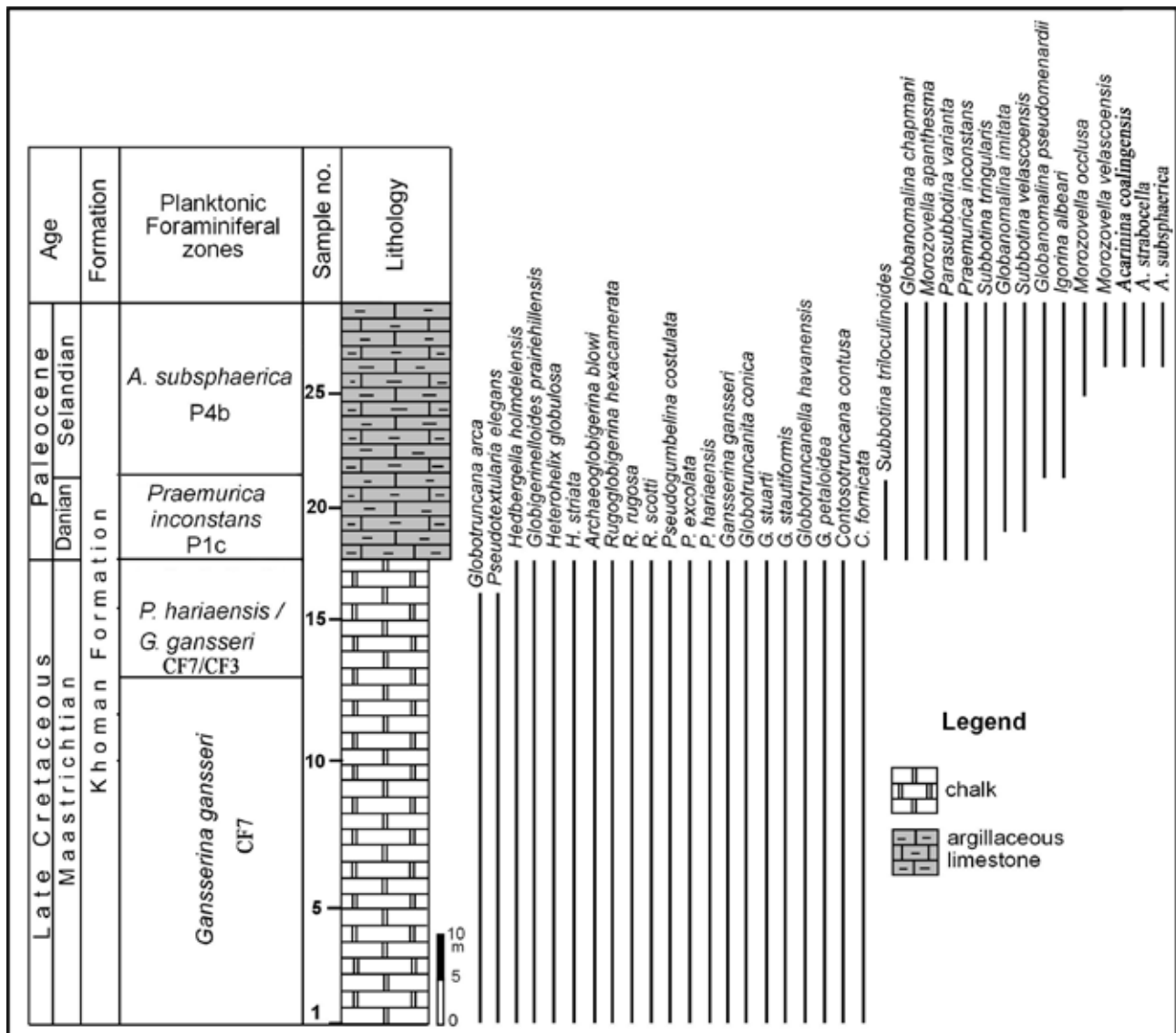
Fig. 3: Distribution range chart of the identified planktonic foraminiferal zone at the El Aqabat section.

4. BIOSTRATIGRAPHY

The biostratigraphic distribution of the planktonic foraminifera in the studied two sections at North Gunna and El Aqabat respectively is achieved in the present study for the first time (Figs 2, 3). The zonal scheme of Caron (1985), Li & Keller (1998a, b), Li *et al.* (1999), Arz & Molina (2002) and BouDagher-Fadel (2013) is used here for the Cretaceous planktonic foraminiferal zones. Meanwhile, the zonal scheme of Berggren *et al.* (1995) and Berggren & Pearson (2005) is using the Paleocene zones.

4.1. Cretaceous biozones

The present study of the planktonic foraminifer's enables the authors to classify the Upper Maastrichtian

sediments in the study area into three zones, arranged from older to younger as follows: Gansserina gansseri Zone, Pseudoguembelina hariaensis/G. gansseri Zone, Pseudoguembelina palpebra Zone.

4.1.1. Gansserina gansseri Zone (CF7)

Planktonic foraminiferal associations: The dominant species in this zone are *Globotruncana aegyptiaca* (Nakkady), *G. arca* (Cushman), *Globotruncanita conica* (White), *Gansserina gansseri* (Bolli), *Heterohelix globulosa* (Ehrenberg), *H. striata* (Ehrenberg), *Pseudotextularia deformis* (Kikoine), *P. elegans* (Rzehak), *Pseudogumbelina costulata* (Cushman), *P. excolata* (Cushman), *Rugoglobigerina rugosa* (Plummer), and *Hedbergella holmdelensis* (Olsson) and *H. monmouthensis* (Olsson).

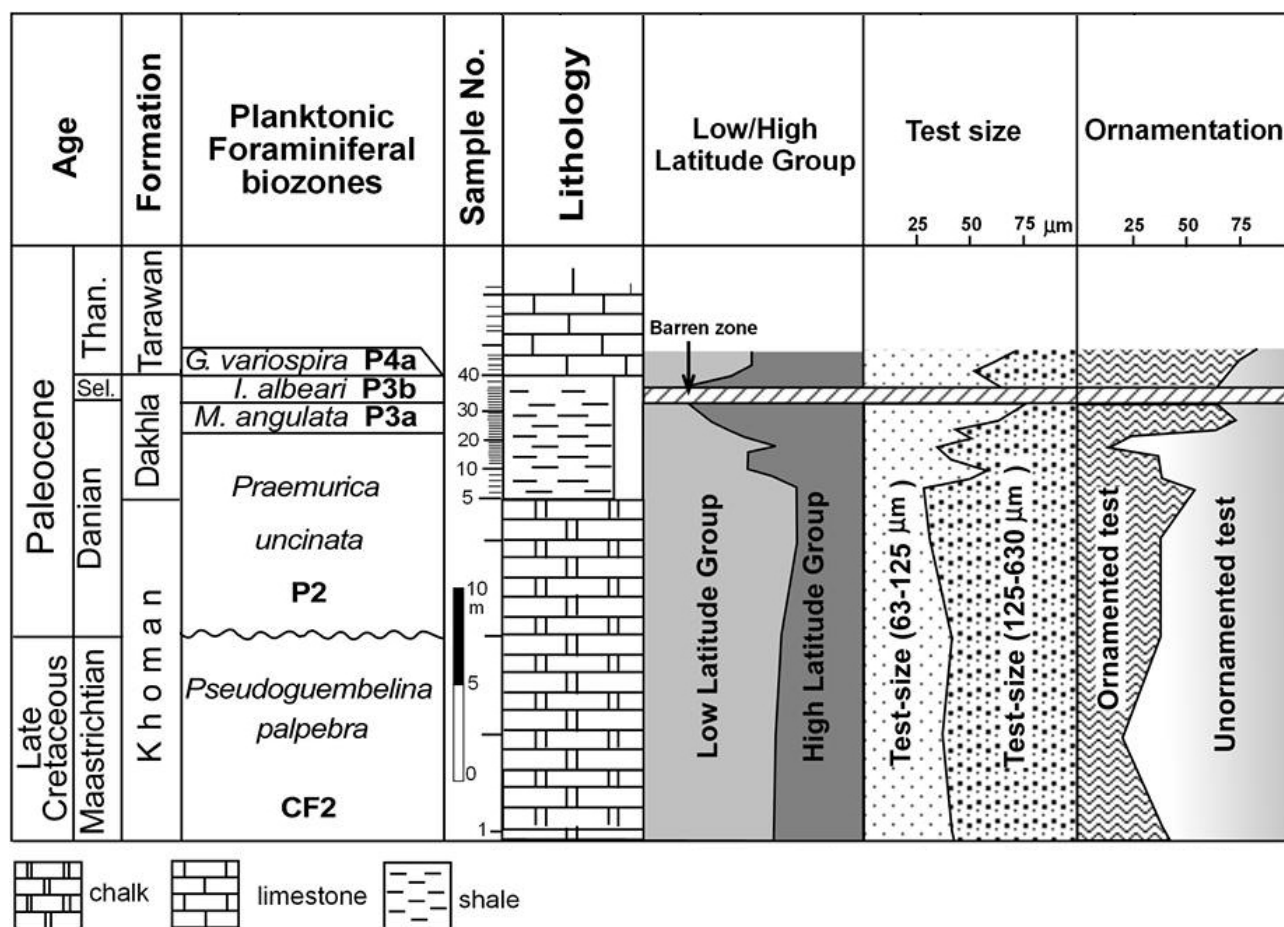**Occurrence:** El-Aqabat section (samples 1-12) (Fig. 3).
Age: Late Maastrichtian.

Fig. 4: The distribution of high and low latitude of planktonic morphogroup, test size and planktonic foraminiferal ornamentation counts in the North Gunna section.

4.1.2. Pseudoguembelina hariaensis/Gansserina gansseri Zone (CF7/CF3)

Planktonic foraminiferal associations: The dominant species in this zone are *Globotruncana aegyptiaca* (Nakkady), *G. arca* (Cushman), *Globotruncanita conica* (White), *Gansserina gansseri* (Bolli), *Heterohelix globulosa* (Ehrenberg), *H. striata* (Ehrenberg), *Pseudogumbelina costulata* (Cushman), *P. hariaensis* Nederbragt, *P. palpebra* Brönnimann and Brown, *Rugoglobigerina rugosa* (Plummer) and *Hedbergella holmdelensis* (Olsson).
Occurrence: El-Aqabat section (samples 13-17) (Fig. 3).
Age: Late Maastrichtian.

4.1.3. Pseudoguembelina palpebra Zone (CF2)

Planktonic foraminiferal associations: The dominant species in this zone are: *Globotruncana aegyptiaca* (Nakkady), *G. arca* (Cushman), *Globotruncanita conica* (White), *Heterohelix globulosa* (Ehrenberg), *H. striata* (Ehrenberg), *Pseudogumbelina costulata* (Cushman), *P. excolata* (Cushman), *P. palpebra* Brönnimann & Brown, *Rugoglobigerina hexacamerata* Brönimann,

R. rugosa (Plummer) and *Hedbergella holmdelensis* (Olsson).
Occurrence: North Gunna section (samples 1-3), (Fig. 2).
Age: Late Maastrichtian.

4.2. Paleocene biozones

The proposed Paleocene planktonic foraminiferal biozones of the studied sections are arranged from older to younger as follows: *Praemurica inconstans* (P1c), *Praemurica uncinata* (P2), *Morozovella angulata* (P3a), *Igorina albeari* (P3b), *Parasubbotina variospira* (P4a) and *Acarinina subsphaerica* (P4b).

4.2.4. Praemurica inconstans Zone (P1c)

Planktonic foraminiferal associations: The dominant species in this zone are *Eoglobigerina edita* (Subbotina), *E. eobulloides* (Morozova), *Parasubbotina pseudbulloides* (Plummer), *P. varianta* (Subbotina), *Subbotina inaequispira* (Subbotina), *S. triangularis*
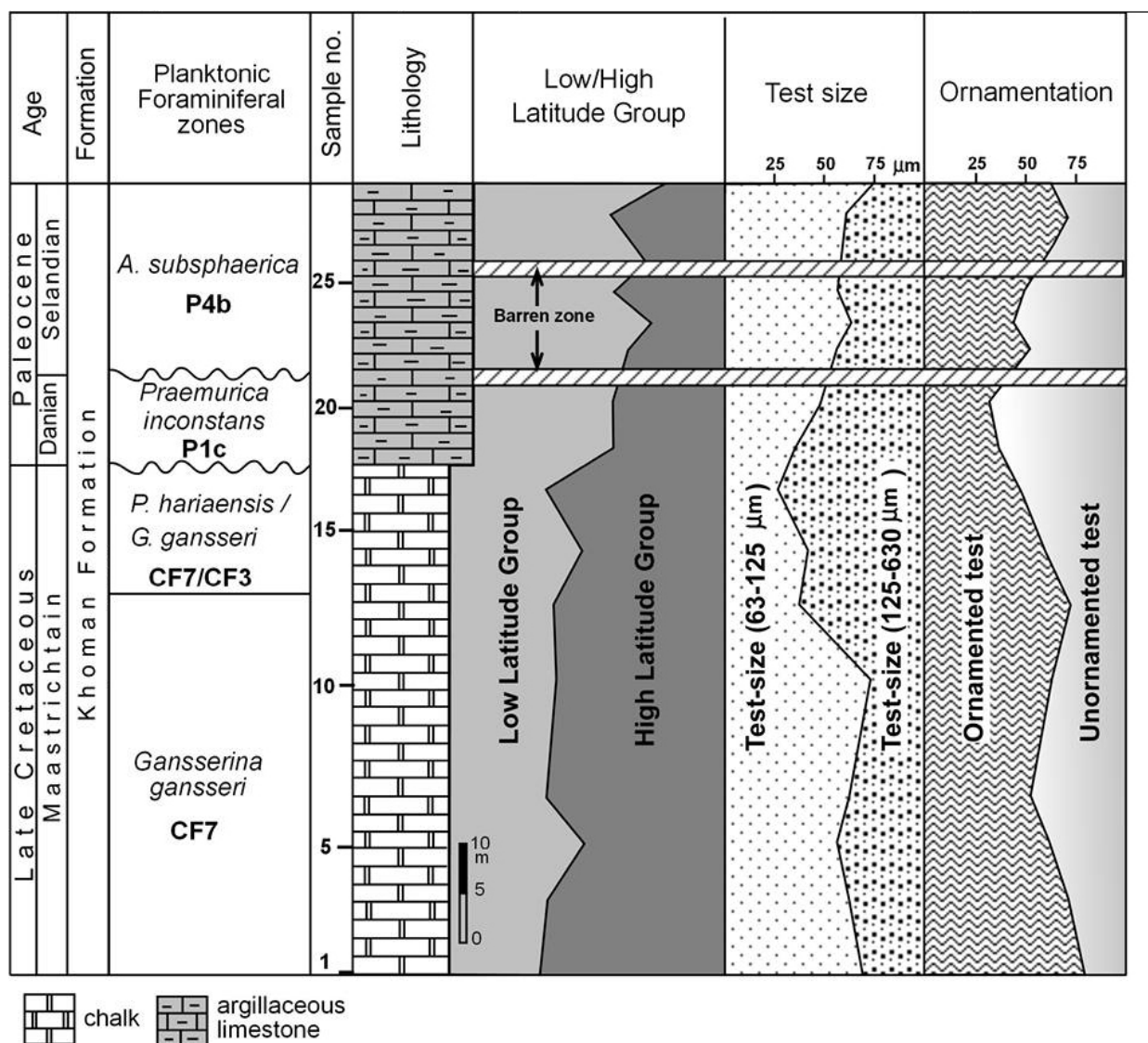
Fig. 5: The distribution of high and low latitude of planktonic morphogroup, test size and planktonic foraminiferal ornamentation counts in the El Aqabat section.

(White), *S. triloculinoides* (Plummer), *Praemurica inconstans* (Subbotina), *P. pseudoinconstans* (Blow), *Globanomalina archeocompressa* (Blow), *G. compressa* (Plummer) and *G. ehrenbergi* (Bolli).
Occurrence: El-Aqabat section (sample 18-20) (Fig. 3).
Age: Early Danian.

4.2.5. Praemurica uncinata Zone (P2)
Planktonic foraminiferal associations: The dominant species in this zone are *Eoglobigerina edita* (Subbotina), *Parasubbotina pseudbulloides* (Plummer), *P. varianta* (Subbotina), *Subbotina inaequispira* (Subbotina), *S. triangularis* (White), *S. triloculinoides* (Plummer), *S. trivialis* (Subbotina), *S. velascoensis* (Cushman), *Praemurica inconstans* (Subbotina), *P. pseudoinconstans* (Blow), *P. uncinata* (Bolli), *Globanomalina compressa* (Plummer) and *G. ehrenbergi* (Bolli).

Occurrence: North Gunna (samples 3-23) (Fig. 2).
Age: Late Danian.

4.2.6. Morozovella angulata Zone (P3a)
Planktonic foraminiferal associations: The dominant species in this zone are *Parasubbotina pseudbulloides* (Plummer), *P. varianta* (Subbotina), *P. variospira* (Belford), *Subbotina inaequispira* (Subbotina), *S. triangularis* (White), *S. triloculinoides* (Plummer), *S. trivialis* (Subbotina), *S. velascoensis* (Cushman), *Morozovella angulata* (White), *M. apanthesma* (Loeblich & Tappan), *M. conicotruncata* (Subbotina), *M. praeangulata* (Blow), *Igorina pusilla* (Bolli), *Praemuric inconstans* (Subbotina), *P. pseudoinconstans* (Blow), *P. uncinata* (Bolli), *Globanomalina champani* (Parr), *G. compressa* (Plummer) and *G. ehrenbergi* (Bolli).

Occurrence: North Gunna (samples 24-31) (Fig. 2).
Age: Late Danian.

4.2.7. Igorina albeari Zone (P3b)
Planktonic foraminiferal associations: The dominant species in this zone are *Parasubbotina varianta* (Subbotina), *P. variospira* (Belford), *Subbotina inaequispira* (Subbotina), *S. triangularis* (White), *S. triloculinoides* (Plummer), *S. velascoensis* (Cushman), *Acarinina strabocella* (Loeblich & Tappan), *Morozovella acuta* (Toulmin), *M. aequa* (Cushman & Renz), *M. angulata* (White), *M. apanthesma* (Loeblich & Tappan), *M. conicotruncata* (Subbotina), *M. occlusa* (Loeblich & Tappan), *Igorina albeari* (Cushman & Bermúdez), *I. pusilla* (Bolli), *Globanomalina champani* (Parr), *G. compressa* (Plummer) and *G. ehrenbergi* (Bolli).
Occurrence: North Gunna (sample 32- 34) (Fig. 2).
Age: Earliest Selandian.

4.2.8. Globanomalina pseudomenardii/Parasubbotina variospira Zone (P4a)
Planktonic foraminiferal associations: The dominant species in this zone are *Parasubbotina varianta* (Subbotina), *P. variospira* (Belford), *Subbotina inaequispira* (Subbotina), *S. triangularis* (White), *S. triloculinoides* (Plummer), *S. trivialis* (Subbotina), *S. velascoensis* (Cushman), *Acarinina strabocella* (Loeblich & Tappan), *Morozovella acuta* (Toulmin), *M. aequa* (Cushman & Renz), *M. angulata* (White), *M. apanthesma* (Loeblich & Tappan), *Igorina albeari* (Cushman & Bermúdez), *I. pusilla* (Bolli), *Globanomalina champani* (Parr), *G. compressa* (Plummer), *G. ehrenbergi* (Bolli), *G. pseudomenardii* (Bolli) and *Chiloguembelina wilcoxensis* (Cushman & Ponton).
Occurrence: North Gunna section (sample 35-39) (Fig. 2).
Age: Early Selandian.

4.2.9. Acarinina subsphaerica Zone (P4b)
Planktonic foraminiferal associations: The dominant species in this zone are *Subbotina inaequispira* (Subbotina), *S. triangularis* (White), *S. triloculinoides* (Plummer), *S. velascoensis* (Cushman), *Acarinina strabocella* (Loeblich & Tappan), *A. subsphaerica* (Subbotina), *A. coalingensis* (Cushman & Hanna), *Morozovella acuta* (Toulmin), *M. aequa* (Cushman & Renz), *M. angulata* (White), *M. apanthesma* (Loeblich & Tappan), *M. occlusa* (Loeblich & Tappan), *M. subbotinae* (Morozova), *M. velascoensis* (Cushman), *Igorina albeari* (Cushman & Bermúdez), *I. pusilla* (Bolli), *Globanomalina champani* (Parr), *G. compressa* (Plummer), *G. ehrenbergi* (Bolli), *G. pseudomenardii* (Bolli), *Chiloguembelina midwayensis* (Cushman) and *Ch. wilcoxensis* (Cushman & Ponton).
Occurrence: El-Aqabat section (samples 21-28) (Fig. 3).
Age: Late Selandian-Early Thanetian.

5. RESULTS

5.1. Paleotemperature of the Maastrichtian

Zones CF7 and CF7/CF3 recorded in the present work of the Khoman Formation of the El-Aqabat section (chalk, sample 1-17) are characterized by high abundance and diversity of the high latitude group (globotruncanids, Fig. 5), which exceed the low latitude group (rugoglobigerinids, contusotruncanids and hedbergellids). However, these faunal distributions suggest a cooling period (Canudo & Molina, 1992).
At North Gunna section (chalk, samples 1-3) the high abundance of *Plummerita hantkeninoides* is due to gradual warming started at the base of zone CF2 (Khoman Formation), which has been flourishing in warm waters (Li & Keller, 1998a, b). Moreover, two species present, *Globotruncana arca* and *Gansserina gansseri* are exhibiting dextral coiling, which indicates warm Tethyan localities (Malmgren, 1989). So this warming near the end of the Maastrichtian is a global event as shown by many authors (e.g. Keller *et al.*, 1993; Courtillot *et al.*, 1996 and Hoffmann *et al.*, 2000).

5.2. Paleotemperature of the Paleogene

At the El Aqabat section the argillaceous limestone of samples 18-20 show a warming event started at P1c Subzone (Dakhla Formation) and has been recorded at P2 Zone (upper Khoman and lower Dakhla formations) of the North Gunna section (consists of chalk to shale, samples 3-23), where the low latitude group including warm morphogroups (*Morozovella*, *Acarinina* and *Praemurica*) was exceeding the high latitude group, which include the cold morphogroups (*Subbotina*, *Parasubbotina*, *Eoglobigerina* and *Globanomalina*). During the Early Paleogene, the presence of acarininids and morozovellids indicate high values of paleotemperatures. In general, a dominance of right-coiled specimens of planktonic species; indicates warm surface waters (e.g., Carter & Hart, 1977; Bauch & Erlenkeuser, 2003; Bauch & Kandiano, 2007) (Figs 4, 5).
During the Late Paleocene of the North Gunna section (consists of shale, samples 24-34) the subzone P3a, P3b of the upper Dakhla Formation shows a cooling trend, where the cold-water morphotypes occurred in abundance (presence of *Subbotina*, *Parasubbotina, Eoglobigerina* and *Globanomalina*) (Fig. 4). In general dominance in left-coiled specimens of the planktonic forms is believed to prefer cooler surface waters (Darling & Wade, 2008). Subzone P4a of the upper most Dakhla Formation of the North Gunna section, (consists of shale, sample 35-39) (Fig. 4) and P4b of the upper most Khoman Formation of the Aqabat section (consists of argillaceous limestone, samples 21-28) (Fig. 5) are characterized by a warming episode and reached its maximum at the latest Paleocene,
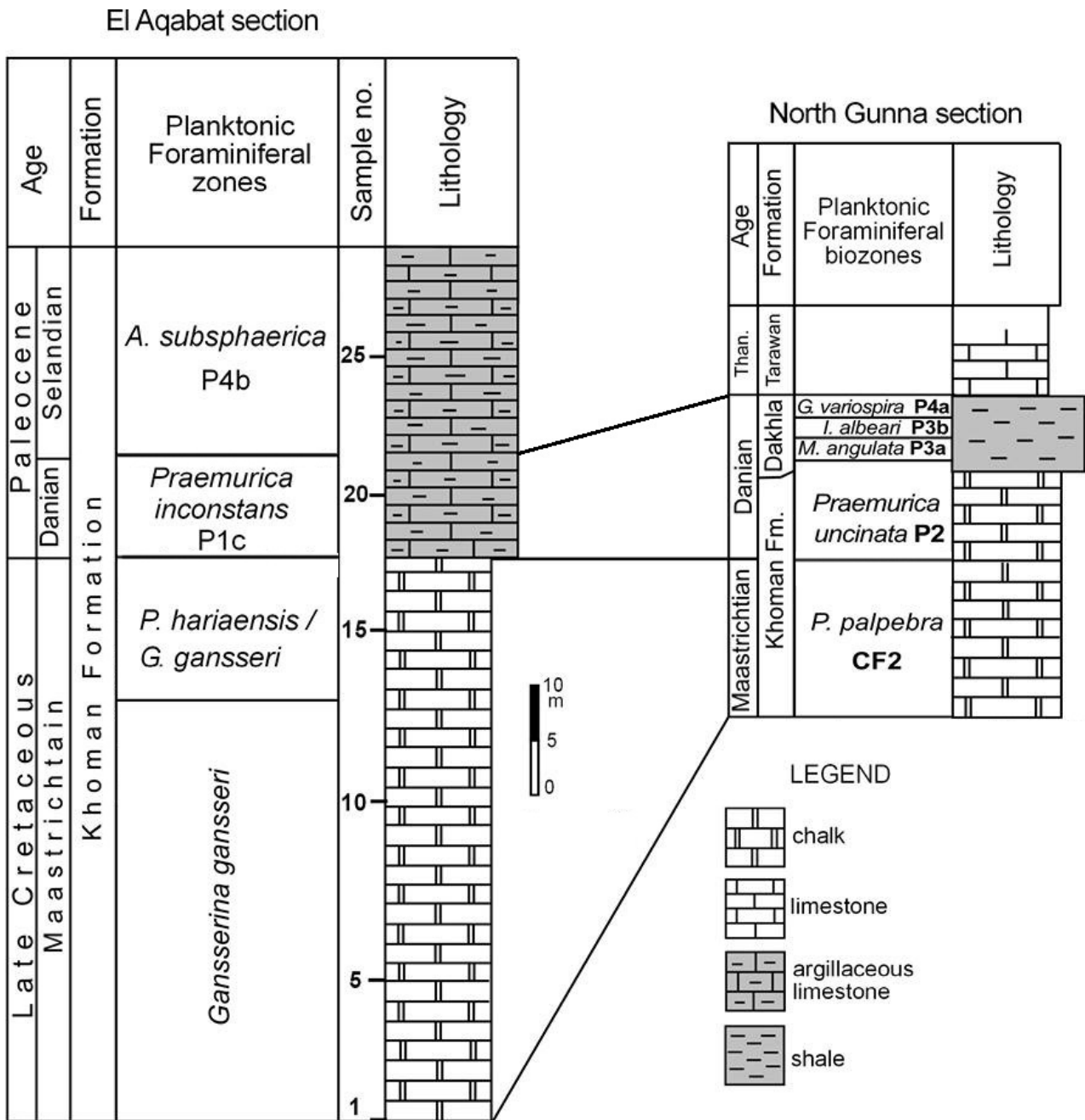
Fig. 6: The correlation between the Upper Cretaceous and Lower Paleocene at the El Aqabat and North Gunna sections.

where the low latitude group was exceeding the high latitude group. Zachos *et al.* (2001) illustrated that the climate history of the Early-Paleogene is marked by long-term global warming.

5.3. Extinctions of calcified planktonic foraminifera

Planktonic survivors at the K/Pg boundary of the two studied sections (El Aqabat and North Gunna) were small species (heterohelicids, rugoglobigerinids and hedbergellids) that lived in shallow waters and/or nearshore as suggested by Keller, 1989 and D'Hondt & Keller, 1991. Among these, surviving individuals were small for their species (Strong *et al.*, 1987) and first representatives of new species following the K/Pg boundary are also smaller than later individuals (*Eoglobigerina* spp.) at levels where more normal marine conditions returned (Smit, 1982). The intermediate water fauna, double keeled planktonic (*Globotruncana* spp.) became extinct first at the studied two sections, then, at the uppermost of oxygen-depleted waters the

shallow-water fauna, heterohelicids, rugoglobigerinids and hedbergellids, were not affected by oxygen-depleted waters and so survived as suggested by Jarvis *et al.* (1988). MacLeod & Keller, 1994 suggested that there is stepwise extinction, starting below the boundary and progressing above it.

At the El Aqabat section, during zones CF7 and CF7/CF3 of the Maastrichtian, an abundance of planktonic foraminiferal species was noted as common 5-10% and a major increase in species diversity noticed in the Early Maastrichtian (cold water). This trend corresponds to the onset of a global cooling that began at the Late Campanian and ended the Cretaceous greenhouse climate mode (Li & Keller, 1998a, 1999). At the North Gunna section, the end Maastrichtian zone CF2 (warm water) shows high biotic stress conditions and reduced the abundances of all planktonic foraminiferal species (species abundance was noted as few 2-5%) leading to their disappearance near the K/Pg boundary. Only a small number of heterohelicids, hedbergellids, globigerinellids, guembelitrids were able to adapt or tolerate the K/Pg environmental conditions (e.g., Koutsoukos, 1996; Luciani, 1997, 2002; Keller *et al.*, 2002; Keller & Pardo, 2004; Pardo & Keller, 2008).

5.4. Test size

Size reduction has been observed in many foraminiferal tests along the K/Pg boundary in the El Aqabat section (zones CF7/CF3 and P1c) and in the North Gunna section (zones CF2 and P2) of the Farafra Oasis (Figs 4, 5). Within the Late Maastrichtian environment (zone CF2, warm water) the planktonic low oxygen tolerant foraminifera were thriving as well as dwarfed species (*Heterohelix*, *Pseudogumbelina* and *Pseudotextularia*). This suggests an oxygen depleted water column and nutrient-rich surface waters (Urbanek, 1993; Keller & Abramovich, 2009), where the relative abundance of species was noted as low as 2-5% species. This suggests there are various factors as impacts volcanism, anoxia or dysoxia, greenhouse warming and near shore environments (e.g., Hart & Ball, 1986; Leckie, 1987; Keller, 1989; Hart & Leary, 1991; Keller, 1993; Hart, 1996; Leckie *et al.*, 1998, 2002; Keller, 2003; Keller *et al.*, 2004; Coccioni *et al.*, 2006).

5.5. Ornamentation

At zones CF7 and CF7/CF3 of the Khoman Formation of the El-Aqabat section the faunal distributions suggests a cooling period. The SEM imaging of planktonic foraminifera extracted from these zones *Heterohelix striata*, *Pseudogumbelina costulata*, *P. excolata*, *Pseudotextularia deformis*, *Rugoglobigerina rugosa*, *R. hexacamerata*, revealed high ornamentation (Fig. 7). The specimens of zone P1c of the Aqabat section
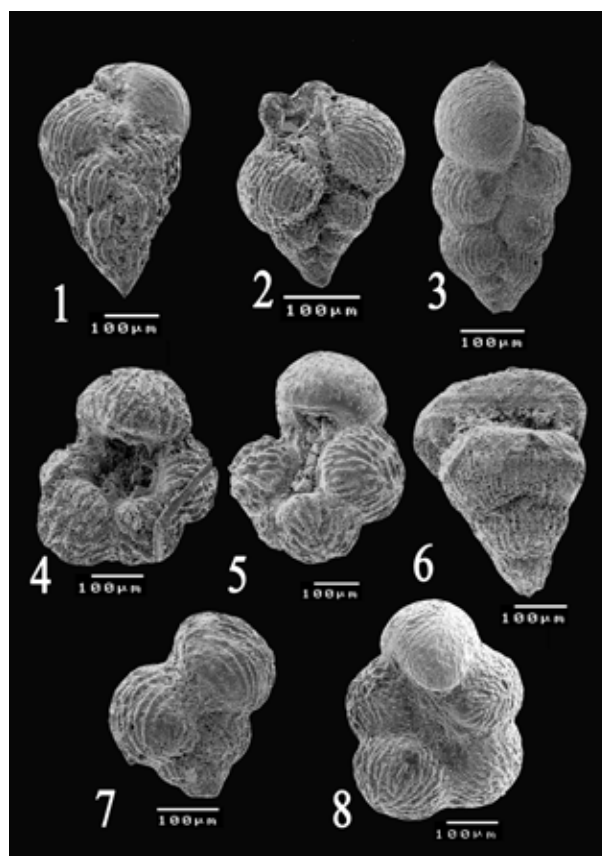

Fig. 7: Scale bar is 100 μm
1, 2: *Pseudogumbelina costulata* (Cushman). El-Aqabat section, zone CF7, sample No. 8
3: *Heterohelix globulosa* (Ehrenberg). North Gunna section, zone CF2, sample No. 2.
4, 5: *Rugoglobigerina rugosa* (Plummer). El-Aqabat section, zone CF3, sample No. 16.
6: *Pseudotextularia deformis* (Kikoine). El-Aqabat section, zone CF7, sample No. 10
7: *Psaudogumbelina excolata* (Cushman). North Gunna section, zone CF2, sample No. 2
8: *Rugoglobigerina hexacamerata* Brönimann. North Gunna section, zone CF2, sample No. 3.

(warm water) and zone CF2 and P2 (warm water) of the North Gunna section around K/Pg boundary (lithology change from chalk to argillaceous limestone at the Aqabat section and from chalk to shale at North Gunna section respectively) marked signs of dissolution and deformation (Fig. 8), the dissolution was evident on the test surface (Fig. 8F) along the suture of the test (Fig. 8A-D) and along the primary chamber (Fig. 8E). The planktonic foraminifera are vulnerable to dissolution because they have a porous chamber.

6. SUMMARY AND CONCLUSION

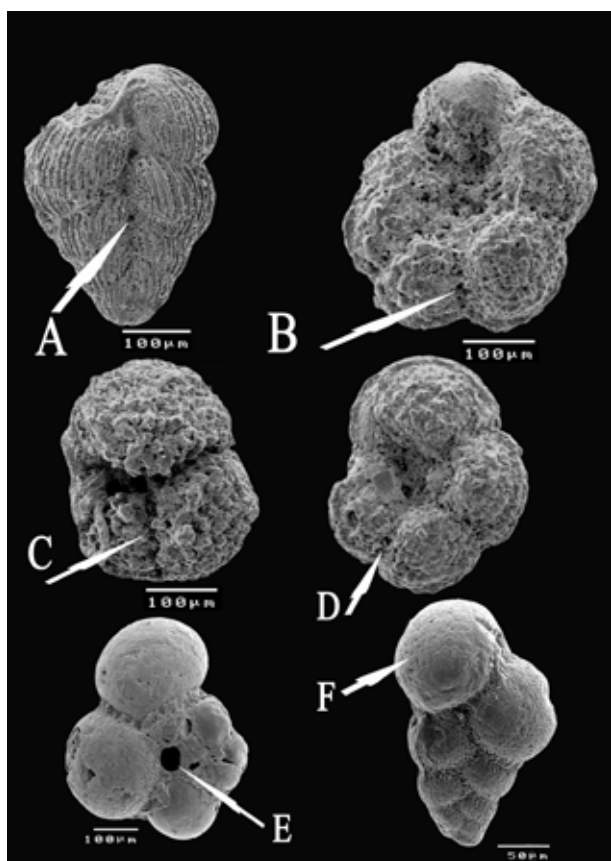1. At the Late Cretaceous, a gradual warming is showed at the base of zone CF2 due to the high abundance

Fig. 8: Scale bar is 100 μm

A. *Pseudogumbelina costulata* (Cushman), dissolution along the suture. El-Aqabat section, zone CF7, sample No. 8

B. *Globotruncana arca* (Cushman), dissolution along the suture. North Gunna section, zone CF2, sample No. 3.

C. *Acarinina coalingensis* (Cushman and Hanna), dissolution along the suture. El-Aqabat section, zone P4b, sample No. 26.

D. *Globotruncana aegyptica* (Nakkady), dissolution along the suture. El-Aqabat section, zone CF3, sample No. 14.

E. *Hedbergella monmouthensis* (Olsson), dissolution of the primary chamber. El-Aqabat section, zone CF7, sample No. 10.

F. *Heterohelix globulosa* (Ehrenberg), dissolution of the test surface. North Gunna section, zone CF2, sample No. 2.

of *Plummerita hantkeninoides*, which flourishing in warm waters.

2. At the Early Paleocene the warming event started at P1c Subzone and continued to P2 Zone (the low latitude group exceeding the high latitude group) as well as during the Early Paleogene the presence of both acarininids and morozovellids indicates high values of pale temperatures.

3. Size reduction, "Lilliput effect" had been observed in many foraminiferal tests along the K/Pg boundary in

the El Aqabat section (zones CF7/CF3 and P1c) and in the North Gunna section (zones CF2 and P2) of the Farafra Oasis. During the warm environment of Late Maastrichtian the planktonic low oxygen tolerant foraminifera was thriving as well as dwarfed species. The small species *Hedbergella* and *Globigerinelloides* are rare.

4. The specimens of zone P1c of the Aqabat section (warm water) and zone CF2 and P2 (warm water) of the North Gunna section around K/Pg boundary marked signs of dissolution and deformation (lithology change from chalk to argillaceous limestone at the Aqabat section and from chalk to shale at North Gunna section respectively due to an increase of CO_2), observed in weakened tests under high-CO_2 making calcifying foraminifera.

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