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Danian/Selandian unconformity in the central and southern Western Desert of Egypt

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ABSTRACT

A regional unconformity at the Danian–Selandian (D/S) boundary is recorded in Western Desert, Egypt, based upon field study, biostratigraphic analyses and paleoenvironmental parameters. This unconformity is marked by the absence of the topmost part of planktonic foraminifera *Igorina albeari*/*Globanomalina pseudomenardii* (P3b) Subzone and the uppermost part of the equivalent calcareous nannofossil *Ellipsolithus macelus* NP4 Zone (NTp8A-B Subzones) in all the sections studied. Furthermore, benthic foraminiferal turnover across the D/S unconformity is observed to be associated with a sharp lithological break from place to place due to submerged paleo-lows and highs. In all the studied sections, intensive reworking of older Danian faunas is recorded within the basal part of Selandian transgressive deposits.

1. Introduction

The Danian/Selandian boundary is still uncertain, even after the assignment of global stratotype section and point (GSSP) for the base of the Selandian at the Zumaya section, in northern Spain. This may be due to the variations in the stratigraphic range of different marker microplanktonic bioevents from different palaeolatitudes (Orue-Etxebarria et al., 2007; Arenillas, 2011; Farouk and Faris, 2013). This conflict may be solved by the integration between different faunal groups, especially planktonic foraminifera and calcareous nannofossils, allow for high-resolution biozonation and an increase in ability to correlate between deep and shallower basins.

The Danian/Selandian successions in the Western Desert of Egypt are marked by widely distributed, condensed sections rich in calcareous planktonic faunal assemblages. These successions are marked by distinct vertical and lateral facies changes. A considerable number of previous papers deal with the microplanktonic biostratigraphy and paleoenvironments of the Danian/Selandian boundary in the Nile Basin of Egypt (e.g., Speijer, 2003; Guasti et al., 2005a,b; Obaidalla et al., 2009; Soliman and Obaidalla, 2010; Youssef, 2009; Sprong et al., 2009, 2011; Sprong et al., 2012). Previous studies mentioned a prominent organic-rich layer associated with a short-term sea-level fall coinciding with the P3a/P3b boundary, situated at the base of the calcareous nannofossil Subzone NTp7B known as latest Danian Event (LDE, ~61.7 Ma) and representing a mild precursor of the Paleocene–Eocene Thermal Maximum (PETM), a proposed early Paleocene hyperthermal (Speijer, 2003; Bornemann et al., 2009; Youssef, 2009; Sprong et al., 2013). A few previous studies have been undertaken on the Danian/Selandian boundary in the Western Desert (e.g., Luger, 1985; Bassiouni et al., 1991; Tantawy et al., 2001; Hewaidy et al., 2006; El-Azabi and Farouk, 2011; Boukhary et al., 2013) but the Danian/Selandian boundary had not been identified in the Western Desert despite definition of the global stratotype. Therefore, the main objective of the present study is to identify the nature of the Danian/Selandian boundary in the Western Desert of Egypt and its relation to the eustatic sea level change.

2. Geologic setting and lithostratigraphic framework

Tectonically, Said (1962) divided Egypt into two major provinces; the more deformed Unstable Shelf including the northern territories of Egypt, north of the Bahariya–Cairo–Suez line, and the less deformed Stable Shelf to the south of this line, which geographically includes most of Egypt and the sections studied here.

Lithostratigraphically, the Upper Cretaceous–Lower Paleogene of the Western Desert of Egypt is marked by complex vertical and lateral facies changes controlled predominantly by two factors: (1) eustatic sea-level variations, and (2) syn-sedimentary tectonic activities created irregular paleotopographic basins with

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submerged structural highs and lows, reflecting three main facies types named, from north to south: Farafra, Nile Valley and Garra El-Arbain Facies (Issawi, 1972; El-Azabi and Farouk, 2011; Fig. 1). Farafra Facies includes El-Hefhuf, Khoman, Upper Dakhla, Tarawan, Esna and Farafra formations; Nile Valley Facies includes Duwi, Dakhla, Tarawan, Esna and Thebes formations, while the Garra El-Arbain Facies comprises Duwi, Dakhla, Kurkur, Garra and Dungal formations.

The studied interval within the Danian/Selandian successions exhibits many lateral and vertical facies changes and no regional pattern to the relation between lithostratigraphic and biostratigraphic boundaries across the D/S contact of the Western Desert. In the Farafra Oasis, the D/S successions occurs at the boundary between the Upper Kharga Shale Member and Tarawan Formation, while in the Dakhla–Kharga Oasis, it lies within the Upper Kharga Shale Unit of the Dakhla Shale, and at Beris Oasis, it coincides within the Kurkur Formation (Fig. 2).

3. Materials and methods

The study area covers a large area of the Egyptian Western Desert between 24°30′N to 27°30′N and 27°00′E to 31°00′E (Fig. 1). Four sections were selected and measured in Farafra, Dakhla, Kharga and Beris oases to study the horizontal and vertical variability of Danian/Selandian deposits (Fig. 1). The section at Farafra Oasis lies along the Ain Dalla-Farafra road, to approximately 30 km from Farafra Oasis toward the west (27°22′48″N, 27°49′42″E). The section at Dakhla Oasis lies at 50 km north-east of Gharb El-Mawohb at the main escarpment (about 10 km north-east of the land mark Qur El-Malik hills between 26°2′37″N, 28°13′18″E). The section in Kharga Oasis lies at 20 km NE of Ezbet Tuleib at the foot slopes of eastern scarp faces (25°43′10.58″N, 30°44′34″E). The section in Beris Oasis lies 10 km of Ezbet Ain Barqas at the foot slopes of eastern scarp face (24°42′1.00″N 30°40′44″E). Samples collected from these four stratigraphic sections were processed for foraminifera and calcareous nannofossils using standard micropaleontology methods. The standard Paleogene planktonic foraminiferal zonal scheme of Berggren and Pearson (2005) and the nannofossil Zones of Martini (1971) based on the highest and lowest occurrences, (HOs, LOs) of the different marker species were used. The relative frequency data of benthic foraminifera in the studied sections were subjected to a cluster analysis. It has proven to be a useful technique for grouping faunal components into informal depth-related associations. Q-mode cluster analysis reveals seven benthic associations, which correspond fairly closely to lithological units.

4. Results

The GSSP across the Danian/Selandian (D/S) boundary has been defined in the Zumaya section (Schmitz et al., 2011), northern Spain close to the LO of *Fasciculithus tympaniformis* just below the NP4/NP5 zonal boundary and within the planktonic foraminif-

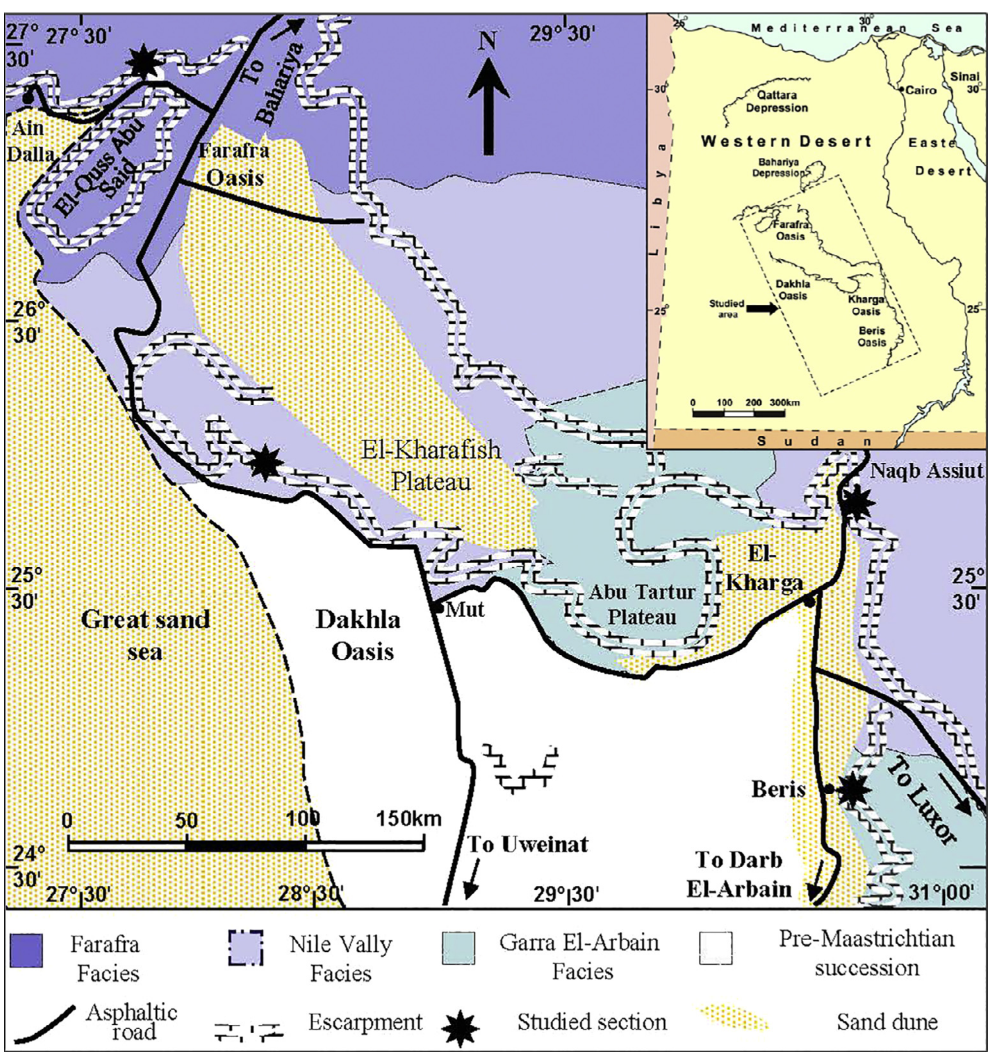

Fig. 1. Location map of the studied area and environs showing the distribution of the different facies types, Western Desert, Egypt (modified after El-Azabi and Farouk, 2011).

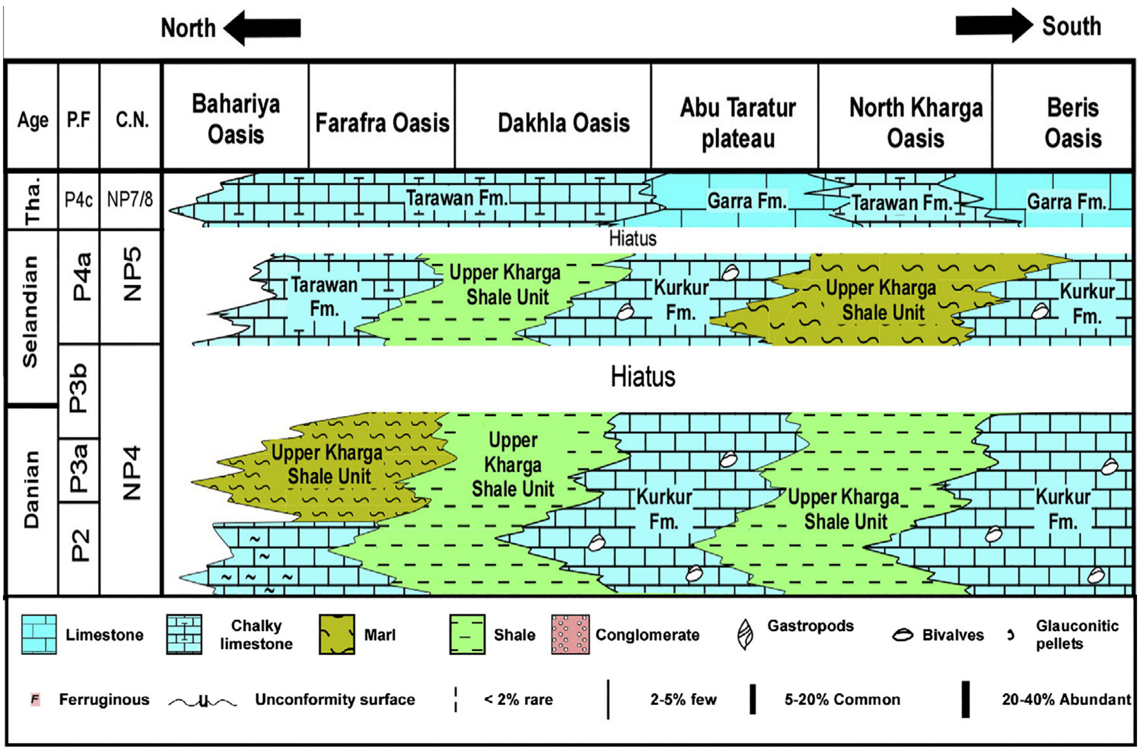

Fig. 2. Lithofacies correlations showing the lateral and vertical of the Danian/Selandian successions in Western Desert.

era *Morozovella angulata–Globanomalina pseudomenardii* (P3) Zone (Bernaola et al., 2009; Schmitz et al., 2011; Monechi et al., 2013). In the following subchapters a detailed description of the D/S boundary in the studied sections is provided.

4.1. Farafra section

4.1.1. Lithology

The Danian/Selandian boundary coincides at the boundary between the Upper Kharga Member of the Dakhla Formation and the Tarawan Formation. The Upper Kharga Member in the Farafra Oasis is characterized by extreme condensation successions and composed of two informal units; the lower unit consists of argillaceous limestone with thickness of about 2 m. The upper unit has a reduced thickness ranging from 1 to 5 m and consists of calcareous mudstone with many gypsum veinlets. It unconformably underlies the Selandian–Thanetian Tarawan Formation, which is composed of massive, chalky limestone full with limonitic macrofossils and dissected gravelly chert with an irregular basal surface which marks the Danian/Selandian boundary (Fig. 2).

4.1.2. Planktonic foraminifera

The studied interval in the Farafra Oasis is marked by a high diversity and abundance of well-preserved planktonic foraminifera.

P3 Zone is defined as the interval from the LO of the *Morozovella angulata* to the LO of the *Globanomalina pseudomenardii*. It is subdivided into two subzones (Berggren et al., 1995; Olsson et al., 1999) *Morozovella angulata–Igorina albeari* Interval Subzone (P3a) and *Igorina albeari–Globanomalina pseudomenardii* Interval Subzone (P3b). The P3a/P3b subzonal boundary is delineated at the LO of *Igorina albeari* (Fig. 3).

The LO of *Morozovella angulata* occurs at the base of the Upper Kharga Shale Unit, indicating the base of Zone P3. At the transition between Zone P2 and P3, the muricate genera (*Morozovella*, and *Igorina*) are first appeared. Intensive reworking of older Danian planktonic foraminifera, especially the *Praemurica* spp., are observed in the lower part of the P3a Subzone. The planktonic assemblage of this subzone is dominated by morozovellids with angular conical chambers throughout their youngest whorl, such as *Morozovella M. conicotruncata*, *M. praeangulata*, *M. angulata*, *M. praecursoria* in addition to *Subbotina triloculinoides*, *Globanomalina compressa* and *Praemurica uncinata* (Fig. 4).

One meter above the base of the Upper Kharga Shale Unit, *Igorina albeari* is first appeared, indicating the base of the P3b Subzone. The assemblage of this interval is similar to that of the underlying P3a Subzone with additional species appearing, such as *Subbotina triangularis*, *M. apanthesma*, *Parasubbotina varianta*, *P. variospira*, *Igorina albeari* and *I. pusillla* and absence of *Praemurica uncinata* (Fig. 4). The base of the Tarawan Formation is characterized by sharp turnover and abrupt LO of dominated angular morozovellids such as *Morozovella velascoensis*, *M. occlusa* and *Subbotina velascoensis*, *M. acuta*, *M. aequa*, and *Igorina laevigata* simultaneous with the LO of *Globanomalina pseudomenardii* which is considered a marker species for the P4 Zone, indicating a hiatus between the P3/P4 zonal boundary (Fig. 3). The LO of the mentioned Morozovellid group was reported recently within the top part of P3b Zone in the GSSP (Arenillas, 2011) and also in the most complete sections in Egypt (Farouk and Faris, 2013).

4.1.3. Calcareous nannofossils

The *Ellipsolithus macelus* Zone (NP4) which is defined as the interval from the LO of *Ellipsolithus macellus* to the LOs of *Fasciculithus tympaniformis* was subdivided into six subzones: NTp6, NTp7A, NTp7B, NTp8A, NTp8B and NTp8C, in ascending order according to Varol (1989). The D/S boundary is bracketed within the NTp8 Zone. The NTp8A, NTp8B and NTp8C Subzones are identified by the LO of their respective zonal markers, i.e. LO of *Sphenolithus primus*, *L. ulii* and *L. janii*. In the present study, the characteristic taxa recorded in the calcareous mudstone of the

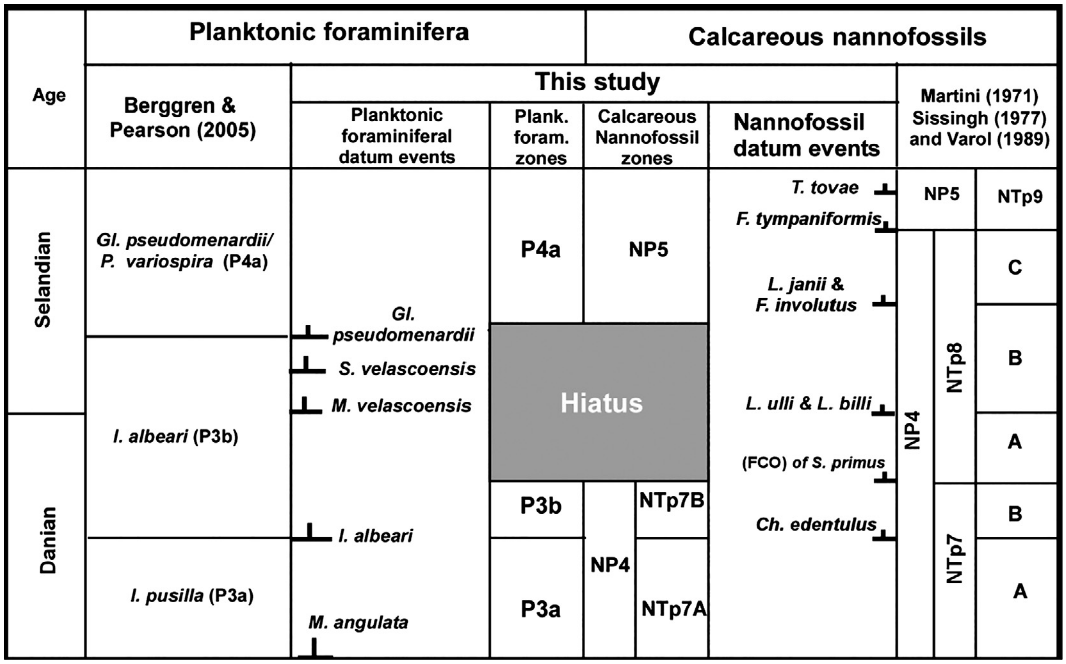

Fig. 3. Comparison between planktonic foraminifera and calcareous nannofossil biozonations with those of stander schemes.

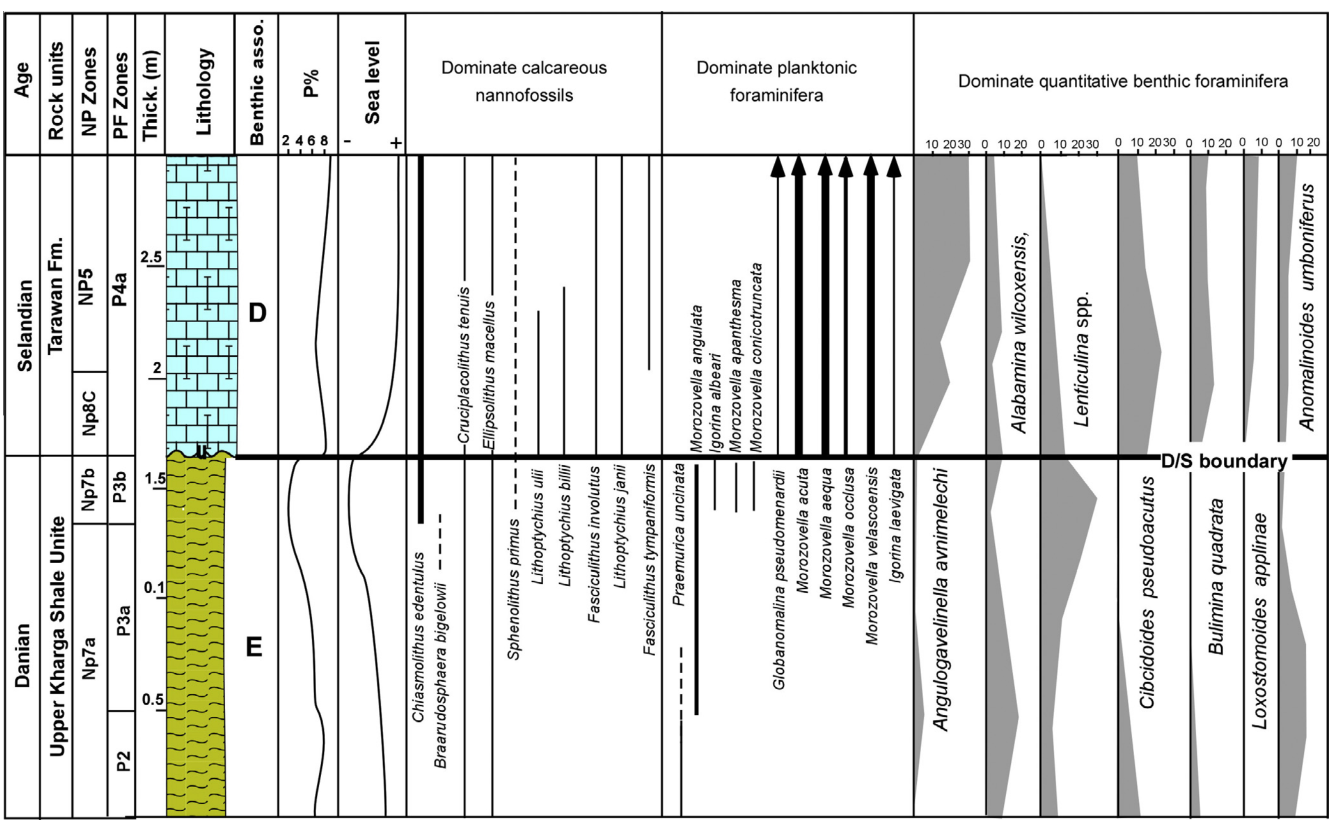

Fig. 4. Stratigraphic distribution of dominate calcareous nannofossils, planktonic foraminifera, and benthic foraminifera in the Farafra section; for symbol key see Fig. 2.

upper unit of the Upper Kharga Shale Member include *Ellipsolithus macellus*, *Chiasmolithus edentulus*, *Thoracosphaera operculata*, *Ericsonia cava*, *E. subpertusa*, *Cruciplacolithus tenuis*, *C. primus*, and very rare occurrence of *Sphenolithus primus* and *Placozygus sigmoides* indicating on Subzone NTp7B. The lowest rare occurrence (LRO) of *Sphenolithus primus* starts within the NTp7A Subzone, while the lowest continuous occurrence (FCO) of *Sphenolithus primus* is a reliable marker for delineating the base of the NTp8A Subzone, as reported by Steurbaut and Sztrakos (2008) and Bernaola et al. (2009). The base of the Tarawan Formation is marked by first simultaneous appearance of the calcareous nannofossils *Lithoptychius ulii*, *L. billii*, *L. janii*, and *Fasciculithus involutus*

indicating the absence of the topmost part of NP4 Zone (NTp8A-B subzones) is missing. Above 0.5 m from the base of Tarawan Formation, the LO of *F. tympaniformis* can be easily used as a marker for the NP4/NP5 zonal boundary. Nannofossils within NP5 are frequent to common with moderate to good preservation. It includes *Lithoptychius pileatus*, *L. janii*, *L. merlotii*, *Fasciculithus involutus*, *F. richardii*, *F. tympaniformis* and *Bomolithus elegans*; in addition to *Toweius tovae* and *T. eminens* appear in the higher level within NP5 Zone (Figs. 3 and 4).

4.1.4. Benthic foraminifera

The benthic foraminiferal assemblages in the Farafra section during the Danian P2 and P3 Zones are dominated by *Anomalinoides umboniferus* (E) associations (Table 1 and Fig. 5) which reflect a middle neritic shelf (Speijer, 2003; Sprong et al., 2012). The base of the Selandian is characterized by a sharp increase of P/b ratio ~80–90%. It is dominant by *Angulogavelinella avnimelechi* (D) association indicating a new transgressive phase (Fig. 5; Table 1). The *Angulogavelinella avnimelechi* association was recorded from outer neritic deposits in Egypt (Luger, 1985; Speijer and Schmitz, 1998; Speijer, 2003; Sprong et al., 2012).

4.2. Dakhla section

4.2.1. Lithology

The Danian–Selandian boundary in the Dakhla Oasis occurs within the Upper Kharga Shale Member of the Dakhla Formation. It consists of shale with abundant glauconitic sand and agglutinated foraminifera with low-carbonate and planktonic content. The D/S boundary is characterized by shale with hematitic coating followed by Selandian greenish gray shale with less content of glauconite (Figs. 2 and 6). Toward the south at the Dakhla and Kharga oases, the Selandian carbonate part of the Tarawan Formation is changed into shale related to topmost part of the Upper Kharga Shale Member.

4.2.2. Planktonic foraminifera

In general, the identified taxa in the studied interval are very rare, where sporadic, few *Morozovella velascoensis*, *Subbotina velascoensis* and *Globanomalina pseudomenardii* are recorded directly above the hematitic shale indicating the base of the P4 Zone (Fig. 6).

4.2.3. Calcareous nannofossils

They are rare and poorly diversified with a moderate preservation including several barren intervals within the studied interval. Typical taxa of the NP4 Zone are recorded as *Braarudosphaera bigelowii*, *Ericsonia cava*, *E. subpertusa*, *Ellipsolithus macellus*, *Cruciplacolithus tenuis*, *Chiasmolithus danicus*, *Neochiastozygus modestus*, *Thoracosphaera operculata*, *Coccolithus pelagicus.* Due to the rarity and very shallow environments, the present study cannot classify the NP4 Zone according to Varol (1989). On the other hand, the lowest common occurrence (LCO) of *Braarudosphaera*, which marked the D/S boundary in the type area in Denmark, can be used easily in the present study. Previously, the End Acme of *Braarudosphaera* is not recorded in the Tethyan sections (Bernaola et al., 2009; Faris and Farouk, 2012). In the present study, it can be used due to shallower facies if compared to other sections in Egypt, where the common occurrence of *Braarudosphaera bigelowii* is observed in the Dakhla section associated with an abrupt lithological transition from glauconitic shale topped by ferrugineous shale during the Danian, to gray shale in Selandian (Fig. 6).

4.2.4. Benthic foraminifera

The studied interval across the Danian–Selandian boundary in the Dakhla section is characterized by low-carbonate sediments, low P/B ratios (5–10%) with *Haplophragmoides/Ammobaculites* (A) associations (Fig. 6; Table 1). Some sporadic calcareous benthic foraminiferal assemblages are recorded near the base of Selandian transgression (e.g., *Valvulineria esnehensis*, *V. aegyptiaca*, *Anomalinoides desertorum*, *Cibicidoides farafrensis*, *Quinqueloculina* sp., *Spiroloculina* sp.). This assemblage is typical for restricted hyposaline, near shore facies associated with a broad marginal carbonate shelf of Abu Tartur Plateau. Similar faunal associations have occasionally been found in marginal marine conditions in an intertidal setting (4–10 m water depth), as mentioned by Berggren (1974).

4.3. Kharga section

4.3.1. Lithology

The Danian–Selandian interval studied in the Kharga Oasis occurs within the Upper Kharga Shale Member, which consists of dark greenish gray shale containing microfossils, followed by purple-brown, laminated shales rich in organic material, whereas the transgressive Selandian succession consists of dark-gray, foraminiferal marly shales (Figs. 2 and 7). The Upper Kharga Shale Member shows a strong lateral facies changes in the Kharga Oasis, where it occurs in transitional zone between dominated carbonate rocks of Garra El-Arbain Facies (Fig. 2).

Table 1
The most frequently benthic species in each foraminiferal association. Paleo-water depth estimates of selected taxa based on data from Berggren (1974), Speijer and Schmitz (1998), Speijer (2003), Alegret and Thomas (2004) and Sprong et al. (2012a), Sprong et al., 2013.

Assemblage (A) Restricted hyposaline near shore < 10 m	Assemblage (B) Inner–Middle shelf 30–70 m	Assemblage (C) Inner–Middle shelf 30–70 m	Assemblage (D) Outer shelf 100–200 m	Assemblage (E) Middle–outer shelf 70–450 m
	Siphogenerinoides eleganta	*Lenticulina midwayensis*	*Angulogavelinella avnimelechi*	*Anomalinoides umboniferus*
Haplophraggmoides rota	*Neoeponides duwi*	*Lenticulina pondi*	*Loxostomoides applinae*	*Anomalinoides sinaensis*
Haplophraggmoides advenus	*Lenticulina williamsoni*	*Lenticulina isidis*	*Bulimina exigua*	*Anomalinoides desertorum*
Haplophraggmoides calculus	*Lenticulina pondi*	*Lenticulina obesa*	*Bulimina farafraensis*	*Lenticulina isidis*
Ammobaculited agrestis	*Dentalina consobrina*	*Marginulinopsis tuberculata*	*Bulimina quadrata*	*Gyroidinoides girrardanus*
Ammobaculited plummerae		*Siphogenerinoides eleganta*	*Anomalinoides grandis*	*Gavelinella brotzeni*
Trochammina albertensis		*Spiroplectammina esnaensis*	*Alabamina wilcoxensis*	*Marginulinopsis tuberculata*
Trochammina bohmi		*Gyroidinoides girrardanus*	*Gyroidinoides girardanus*	*Pyramidulina limonensis*
Valvulinaria esnehensis			*Gyroidinoides globosus*	*Lagena sulcata*
Valvulinaria aegyptiaca			*Lenticulina navicula*	*Ramulina arkadelphiana*
Anomalinoides desertorum			*Sprioplectammina esnaensis*	*Ramulina navarroana*
			Psudocavulina amorpha	*Gaudryina pyramidata*
			Psudocavulina farafraensis	*Pseudoclavulina farafraensis*
				Spiroplectammina esnaensis

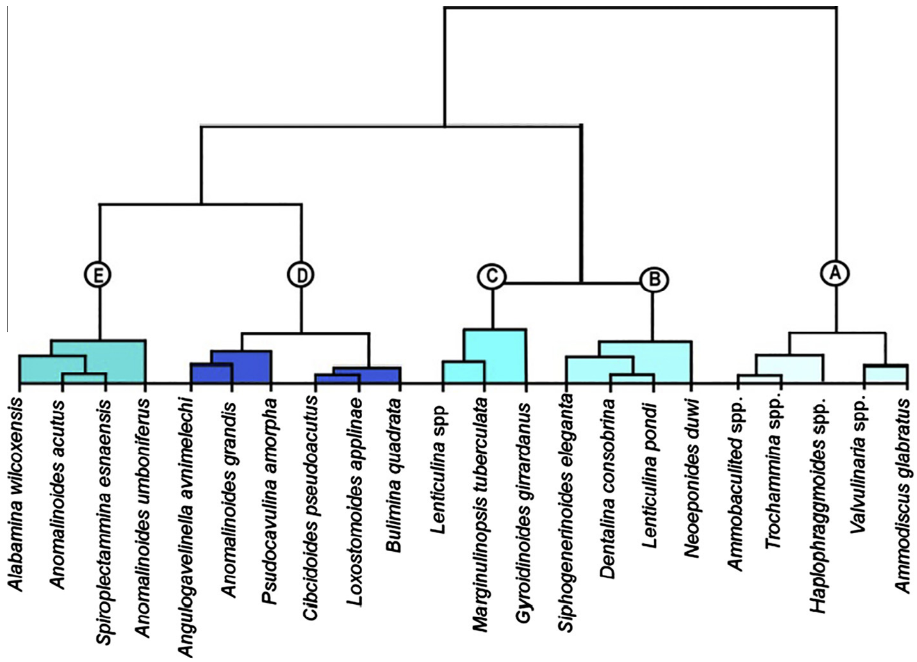

Fig. 5. Dendrogram clustering benthic foraminifera.

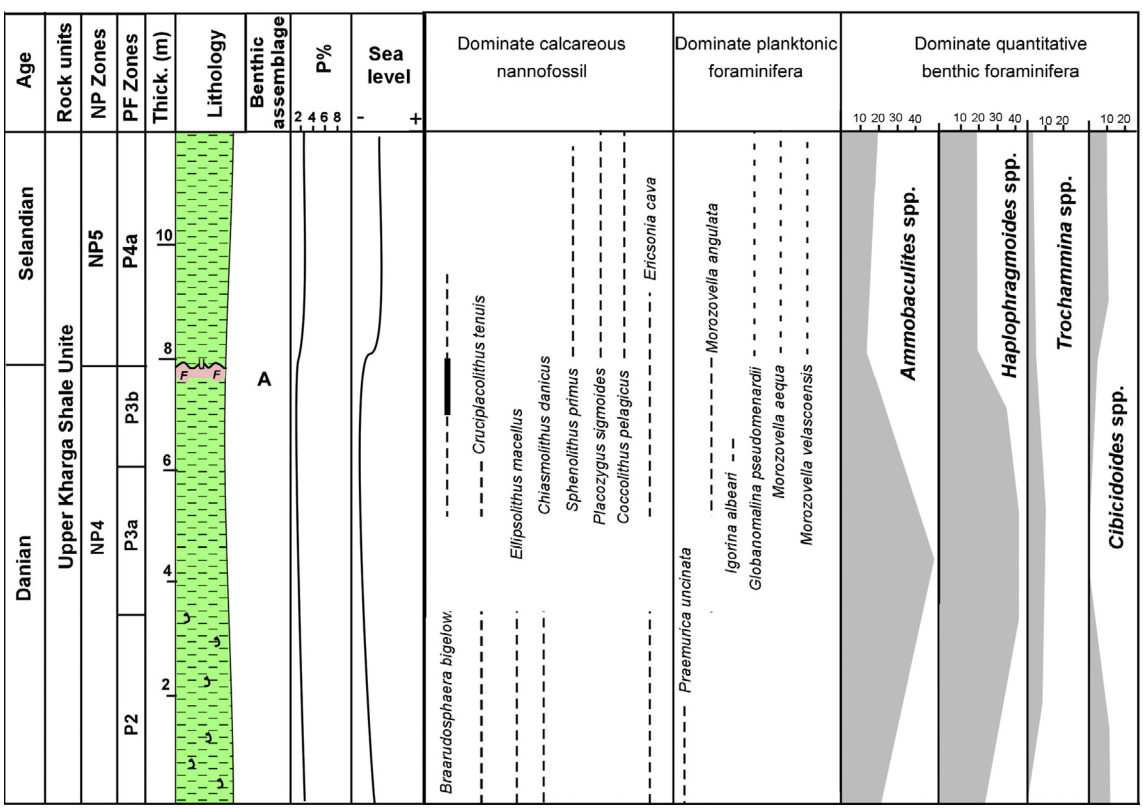

Fig. 6. Stratigraphic distribution of dominate calcareous nannofossils, planktonic foraminifera, and benthic foraminifera in the Dakhla section; for symbol key see Fig. 2.

4.3.2. Planktonic foraminifera

Similar observation in the transition between the P2 and P3a zones in the Farafra Oasis is recorded also in the Kharga Oasis. The LO of *Igorina albeari* occurs within the marker bed of purple-brown shale pointing to the latest Danian, which was recorded previously from a different localities in the Nile Basin (Speijer, 2003; Sprong et al., 2012). The base of the Selandian occurs with the base of foraminiferal marly shales with marked Morozovellid group (e.g., *Morozovella velascoensis*, *M. occlusa*, *M. aequa* and *M. acuta*), simultaneous with LO of *Globanomalina pseudomenardii* marker of P4 Zone, which refers to an unconformity between P3b/P4a subzones (Fig. 7).

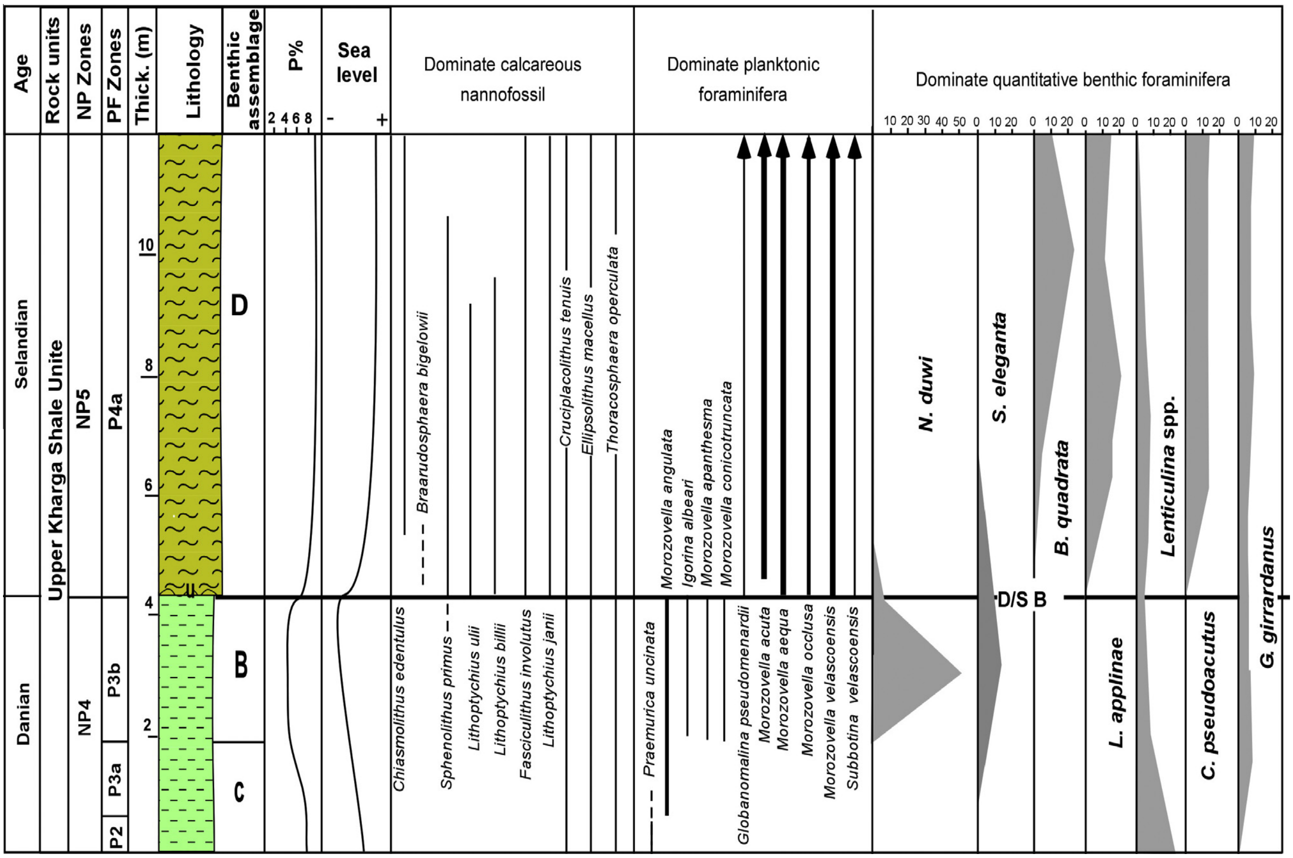

Fig. 7. Stratigraphic distribution of dominate calcareous nannofossils, planktonic foraminifera, and benthic foraminifera in the Kharga section; for symbol key see Fig. 2.

4.3.3. Calcareous nannofossils

Nannofossils are frequent to common with moderate to good preservation in the Danian–Selandian interval studied. The different marker bioevents and nannofossils assemblages are closely similar to that of Farafra Oasis (Fig. 7).

4.3.4. Benthic foraminifera

During the latest Danian P2 Zone, the *Lenticulina* spp. associations (Fig. 5 and Table 1) comprised about 32–41% associated with the presences of *Marginulinopsis tuberculata*, *Siphogenerinoides eleganta*, *Spiroplectammina esnaensis*. *Lenticulina* spp. has a wide bathymetrical range, but the drop of the P/B ratio and diversity indicates an inner middle neritic depth (Fig. 7). A nominative species of *Neoeponides duwi* is found in short interval and attains up to ~75–90% (*Neoeponides duwi* (B) associations; Fig. 7; Table 1) during the P3b Subzone. It is termed the "*Neo-duwi* event", within the D/S transition in the southern Tethyan region marked by organic-rich dark bed characterized by anomalous faunal assemblages. This event is now considered as the LDE recorded in the Nile basin sections (Speijer, 2003; Guasti et al., 2005a,b; Sprong et al., 2012, 2013). It coincides with a rapid sea-level fall, with estimated amplitude of ~50 m or less as indicated also by P/B ratio from ~20% to 40% (Speijer, 2003; Sprong et al., 2012). The base of the Selandian transgression occurs within the marl of the uppermost part of the Upper Kharga Shale Member. It is dominated by *Angulogavelinella avnimelechi* (D) assemblage (Table 1), which typically refers to the outer neritic (Alegret and Thomas, 2004).

4.4. Beris section

4.4.1. Lithology

The D/S boundary occurs within Kurkur Formation of Garra El-Arbain facies. It consists of coquinal limestone beds intercalated with shale, fossiliferous with well-preserved mollusks (e.g., *Ostrea orientalis*, *Venericardia libyca*, *Nemocardium fecundum*, *Paraglans altirostris* and *Turritella* spp.). Interval of Danian–Selandian is barren of foraminiferal tests and calcareous nannofossils represented a lateral facies change of the Upper Kharga Member. In the present study, the Kurkur Formation is barren unconformably underlies the Thentian Garra Formation, which consists of a massive limestone unit containing frequent but poorly-preserved planktonic foraminifera topped by burrowed limestone nearly barren of foraminifera; it is an equivalent to the Tarawan Formation but deposited in shallower environments (Fig. 2). It is worthy to mention that the base of the Kurkur Formation coincides with the Cretaceous/Paleogene boundary in the Sinn El Kaddab area, Aswan, Egypt (Youssef, 2003). The Kurkur Formation is attributed to the *Morozovella angulata* Zone in the lower part and *Planorotalites pseudomenardii* Zone in the upper part at the southwest Aswan of Egypt (Hewaidy, 1994). On the basis of nannofossil zones, the *Helicolithuus kleinpelii* (NP6) is detected in the upper part of the Kurkur Formation (Faris and Hewaidy, 1995). In the present study, the *Discoaster mohleri* (NP7/8) Zone is recorded for the basal part of the Garra Formation underlies barren interval of the Kurkur Formation. These observations suggests, the D/S boundary may be occurs within the Kurkur Formation. A correlative unconformity is recorded in Beris section below a phosphatic conglomerate bed of 20–30 cm thick, with carbonate and chert gravels embedded in a clayey matrix within the Kurkur Formation (Fig. 8).

5. D/S unconformity

Field exploration and biostratigraphic analyses of the studied transect sections showed, based on observed planktonic foraminifera and calcareous nannofossil indicators, that the latest Danian

upper P3b planktic foraminiferal and upper NP4 calcareous nannofossil biozones are incomplete in the whole studied sections due to erosion and non-deposition related to sea-level fall across the D/S boundary (Fig. 9). Evidences of a regional unconformity at the D/S boundary in the Western Desert of Egypt are as follows:

- A sharp lithological break differs in terms of lithostratigraphy from one location to another due to submerged paleo-lows and highs.
- In all the studied sections, intensive reworking of older Danian faunas is recorded at the basal part of the Selandian transgressive deposits.
- One of the most interesting events is the first diversification of *Lithoptychius* (e.g. *Lithoptychius ulii and L. billii*; Aubry et al., 2012) marking the upper part of the NP4 Zone, which coincides with the Danian/Selandian (D/S) boundary, as recorded at the GSSP (Bernaola et al., 2009; Schmitz et al., 2011; Monechi et al., 2013). In the present study, the marker species of *Lithoptychius ulii*, *L. billii*, *L. janii*, *L. pileatus*, *L. merloti* and *Fasciculithus involutus* appear together at the base of Selandian suggesting a hiatus due to the absence of the NTp8A-B subzones near the Danian/Selandian boundary (Fig. 3).
- Several recent studies (e.g., Arenillas and Molina, 1997; Premoli Silva et al., 2003; Steurbaut and Sztrakos, 2008; Obaidalla et al., 2009; Faris and Farouk, 2012; Farouk and Faris, 2013) suggest that *M. velascoensis M. occlusa* and *Subbotina velascoensis* appear somewhat within the P3b Subzone and is located at the top of the equivalent nannofossil NP4 Zone slightly below the *Globanomalina pseudomenardii* P4 Zone. In the present study, the LOs of *Morozovella velascoensis*, *M. occlusa* and *Subbotina velascoensis M. acuta*, *M. aequa*, appear together with *Globanomalina pseudomenardii*, a marker species of the P4 Subzone, indicating an absence of uppermost part of the P3b Subzone (Fig. 3).

A marked change in the foraminiferal planktonic assemblage is noted within the P3b/P4 zonal boundary (D/S boundary) represented by (1) a sharp extinction of *Morozovella angulata*, *M. conicotruncata*, *Subbotina triloculinoides* and *Igorina pusillla*; (2) the simultaneous first appearance of the planktonic foraminifera velascoensis group (*Morozovella velascoensis*, *M. occlusa M. acuta*, *M. aequa*) and *Subbotina velascoensis* with lowest occurrence the marker species *Globanomalina pseudomenardii* of P4 Zone indicating the topmost of the P3b Subzone are incomplete, indicating a hiatus between the Danian/Selandian (D/S) boundary (Fig. 3).

- A sharp benthic foraminiferal change across the D/S boundary with a dramatic decrease in the P/B ratio, as well as in the total foraminiferal number and its diversification, followed by a new transgressive phase simultaneously with the base Selandian (base P4), is clearly observed in the all studied sections.

6. Distribution offoraminiferal assemblages along the paleodepth

Benthic foraminiferal assemblages and other paleobathymetrical indicators (e.g., Planktonic/benthic ratio, diversity and facies types) reflect two submerged paleo-lows of middle nertic to an outer neritic setting at the Farafra and north Kharga sections, where Dakhla and south Kharga oases sections were located in a slightly shallower position within two submerged paleo-highs. In

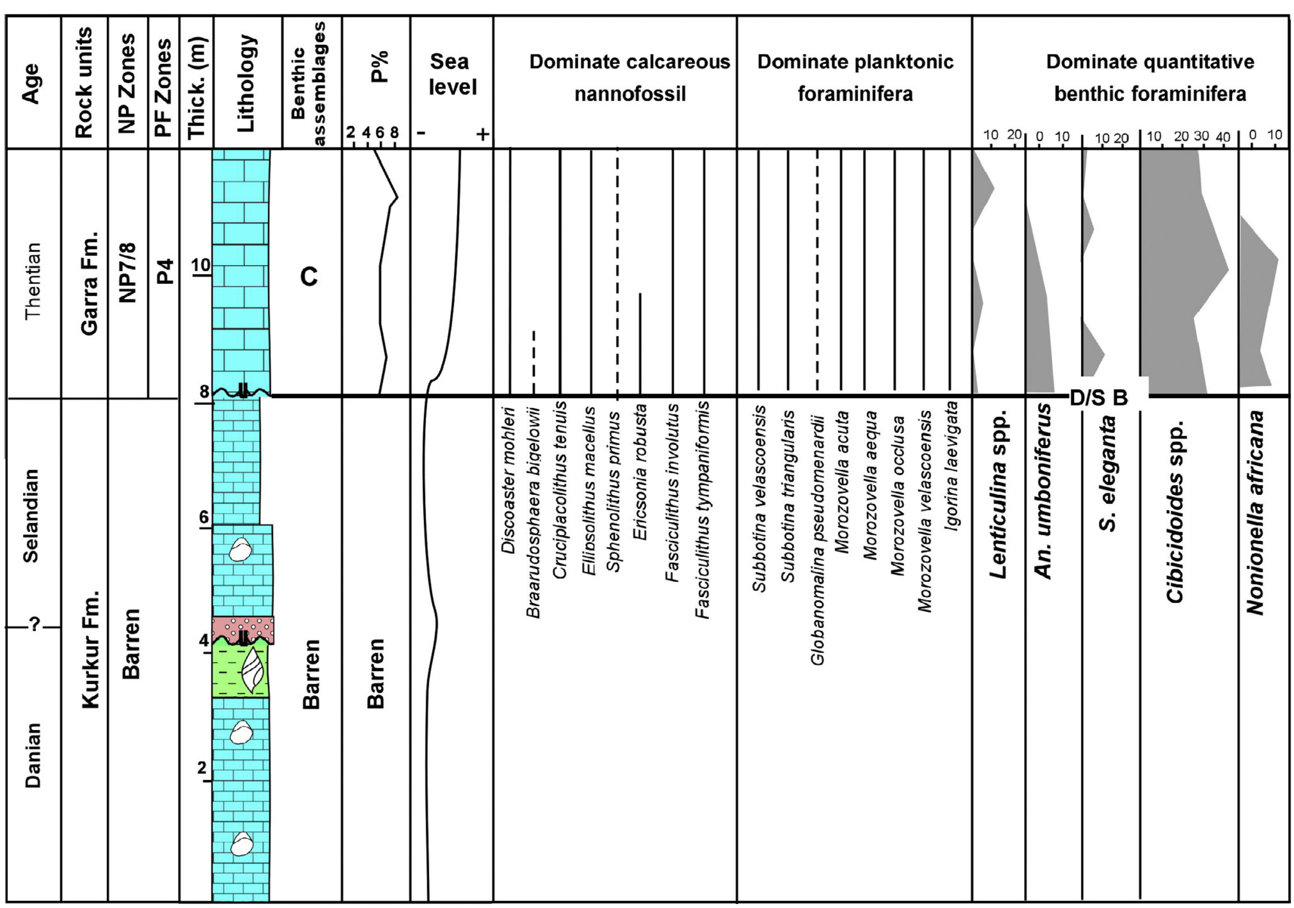

Fig. 8. Stratigraphic distribution of dominate calcareous nannofossils, planktonic foraminifera, and benthic foraminifera in the Beris section; for symbol key see Fig. 2.

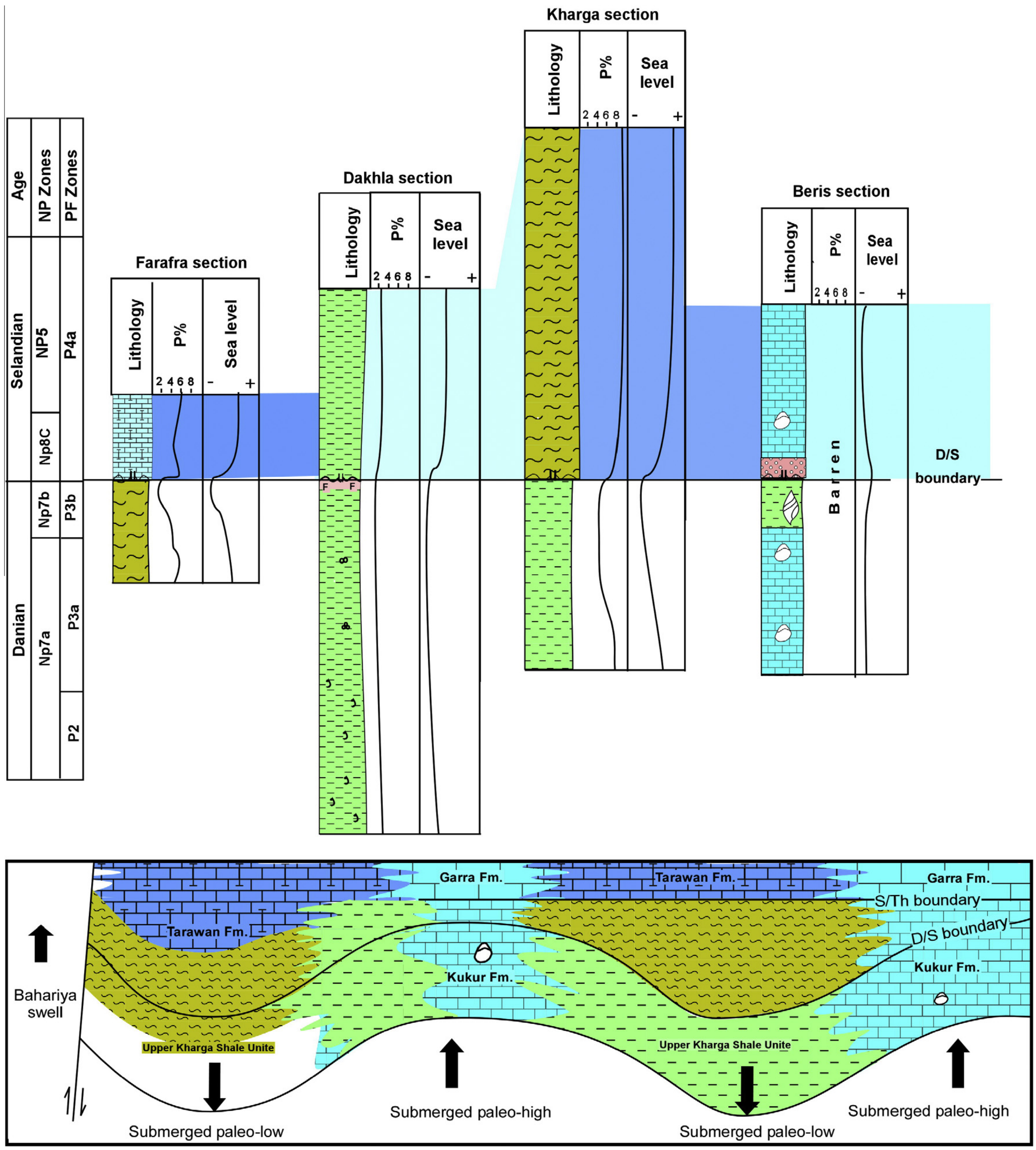

Fig. 9. Correlation of the four studied sections showing the vertical and lateral litho.-biofacies variations, P/B% and the relative sea level changes; for symbol key see Fig. 2.

general, submerged palaeo-lows are marked by high content ranging from 40% to 90% planktonic/benthic ratio (P/B%), indicated on deeper facies at Farafra and north Kharga, decreased to 3–20% (P/B%) at submerged palaeo-highs of Dakhla and south Kharga oasis (Fig. 8).

6.1. Submerged paleo-lows

In submerged palaeo-lows, high P/B values (~40–90%) are observed in the submerged paleo-low indicating the deeper facies at Farafra and Kharga oases.

In Farafra Oasis, during the P3a Subzone on the submerged, *Anomalinoides umboniferus* assemblage with P/(P + B) ratio of 40–60% indicates on middle neritic (~30–100 m depth; Speijer, 2003). The beginning of *Globanomalina pseudomenardii* Zone, the paleo-lows area is generally characterized by a sharp increase of P/B ratio ~80–90% associated with *Angulogavelinella avnimelechi* (D) assemblages indicated on outer neritic (~100–200 m depth).

In Kharga Oasis, the *Lenticulina* spp. assemblage of inner to middle neritic (30–50 m depth) is recorded during the P2 Zone and P3a Subzone. The benthic foraminiferal assemblage is changed significantly toward the "Late Danian Event [LDE]" associated with a sudden incursion of the shallow water benthic foraminifera *Neoponides duwi* association at the Nile Valley facies. However, the lithological expression and the *Neo-duwi* event characterizing the LDE is recorded only in the submerged palaeo-low of the Nile Vally Facies within the P3b Subzone and not observed in any of the Farafra and Garra facies types. A transgressive phase was observed also at the base of Selandian at the Kharga Oasis, where the *Angulogavelinella avnimelechi* (D) assemblage with a sharp increase of P/B ratio ~70–80% is recorded (Fig. 9).

6.2. Submerged paleo-highs

Submerged palaeo-highs at Dakhla and south Kharga oasis is characterized by dramatically changed of P/B ratio to lowest per-

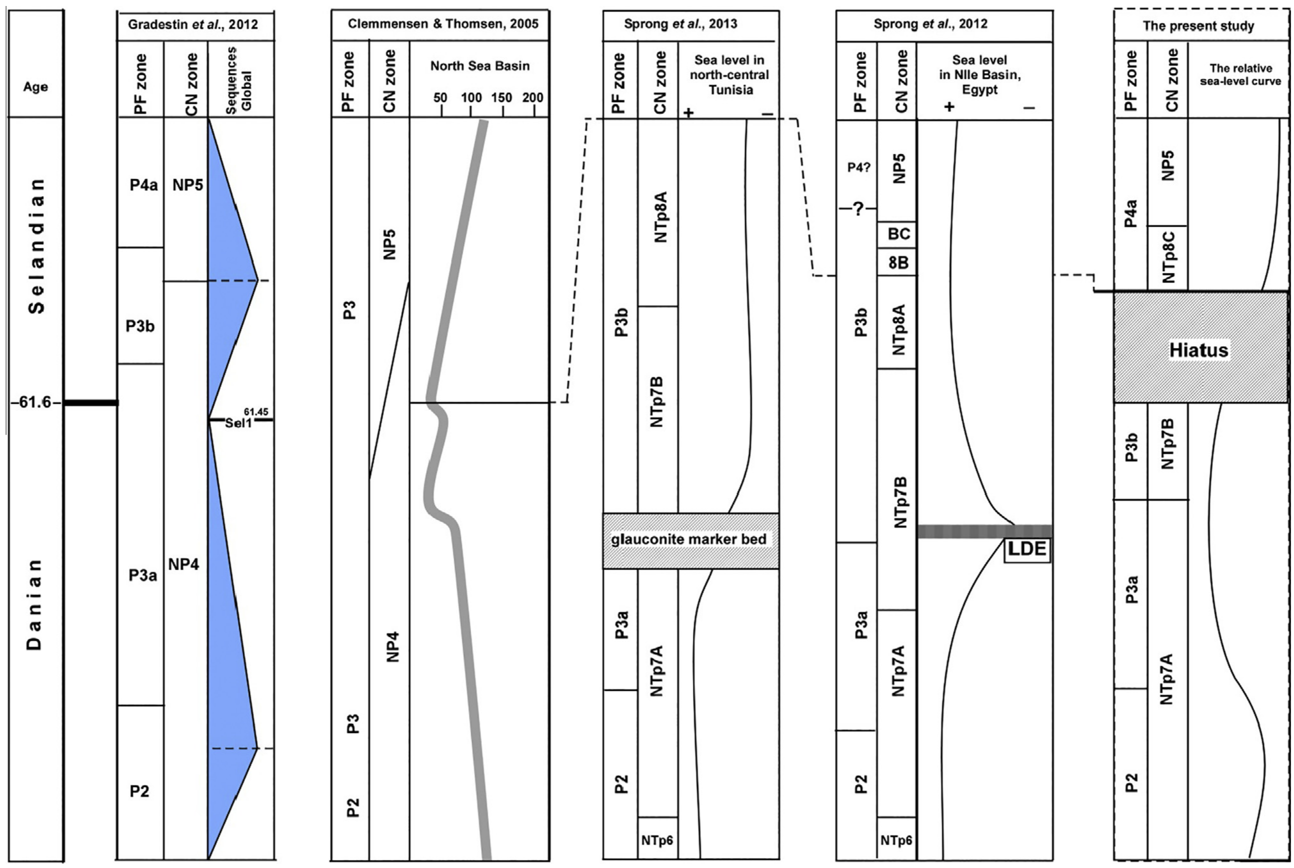

Fig. 10. Comparison of the inferred Danian–Selandian sea-level curves against the biostratigraphy. (See above-mentioned references for further information.)

cent of about ∼3–20%, with common agglutinated benthic foraminifera of *Haplophragmoides*/*Ammobaculites* (A) assemblage during the Danian in the Dakhla Oasis. A slight rise in relative sea level is observed, characterized by a P/(P + B) ratio of 10–20% and the first appearance *Cibicidoides* spp. within (A) assemblage (Fig. 9). Toward the south, this succession changes laterally to the equivalent Kurkur Formation, which is characterized by limestone, rich in mollusks (*Venericardia* spp.) and lacks of foraminifera tests. It is also characterized by a conglomerate bed within the Kurkur Formation, which is interpreted as a basal transgressive lag across the D/S boundary.

7. Relative sea level curve

A relative sea level fall starts with the P3b topped by a regional hiatus between the D/S boundary in stable shelf of Western Desert (Figs. 9 and 10). This contact is marked by erosion and non-deposition related to sea-level fall and/or tectonic activity associated with dramatic extinction and turnover of the benthic foraminiferal changes. The cause of the changes at the D/S boundary is extremely difficult to distinguish between eustasy and tectonic movements. To verify a eustatic origin, they must also have a wide geographical extent. In most cases, if sea-level changes are due to eustasy, they should be simultaneous in tectonically unconnected and widely separated basins (Clemmensen and Thomsen, 2005). Late Danian regressions have been recognized in Egypt (Issawi, 1971; Hendriks et al., 1985; Luger, 1985; Lüning et al., 1998; Speijer, 2003; Hewaidy et al., 2006; El-Azabi and Farouk, 2011; Sprong et al., 2012; Farouk and Faris, 2013) as well as in other different regions, such as Northwest Europe, North Atlantic, East America and North African (Thomsen and Heilmann-Clausen, 1985; Hardenbol et al., 1998; Steurbaut and Sztrakos, 2008; Schmitz et al., 2011). This reflects a wide geographical extent for the Late Danian regressive phase. On the other hand, the absence of latest Danian deposits and faunal breaks indicates a major tectonic uplift event caused subaerial exposures in whole Western Desert. This, followed by basal Selandian transgression, characterized by high abundance and diversity of planktonic foraminifera, as well as the presence of deep-water benthic species, reflects a well-known deepening episode in all studied sections during the base Selandian (lower part of *Globanomalina pseudomenardii* Zone). It is also marked by palaeontological changes associated with a peak abundance of planktonic foraminifera characterized by well-preserved, high-diversity *Morozovella* group.

The early Selandian marine transgressions are well known from different parts in Egypt (Luger, 1985; Speijer, 1994; Lüning et al., 1998; El-Azabi and Farouk, 2011; Farouk and Faris, 2013). They are also well documented in North Sea Basin (Clemmensen and Thomsen, 2005; Fig. 9) and SW France (Steurbaut and Sztrakos, 2008). This transgression might correspond to the major transgression identified by Haq et al. (1987) and recalibrated by Hardenbol et al. (1998) near lower part of *Globanomalina pseudomenardii* Zone (Fig. 9). In Tunisia, this marine transgressions do not correspond with those predicted by Guasti et al. (2005a,b) and Sprong et al. (2013), where a sea level fall started in the P3b Subzone, and continued into the P4 and P5 Zones (Fig. 10). Therefore, regional or local tectonic movements probably caused this difference across the Danian/Selandian boundary.

8. Conclusions

The most salient results of our study are the following: (1) a sharp lithological break differs in terms of lithostratigraphy from one location to another due to submerged paleo-lows and highs;

(2) occurrence of high reworking and oxidized foraminiferal above this boundary; (3) the simultaneous appearance of the planktonic foraminifera velascoensis group (*Morozovella velascoensis*, *M. occlusa M. acuta*, *M. aequa*) and *Subbotina velascoensis* with lowest occurrence of the *Globanomalina pseudomenardii* marker species of P4 Zone, indicating that the upper part of P3b Subzone is missing; (4) the simultaneous appearance of the calcareous nannofossils *Sphenolithus primus*, *Lithoptychius ulii*, *L. billii*, *L. janii*, and *Fasciculithus involutus* indicating that the topmost part of NP4 Zone (NTp8A-B subzones) are missing in all studied sections; (5) benthic foraminiferal turnover across the D/S hiatus are observed and associated with distinct vertical changes in foraminiferal content and paleoenvironmental setting; (6) the Late Danian regressive event coincides with eustatic sea-level fall terminated by a regonial hiatus across the Danian/Selandian boundary associated with tectonic uplift in the whole Western Desert; (7) observed lateral variation of faunal content with lithology reflects submerged palaeo-highs at Dakhla and south Kharga oasis between two submerged paleo-lows at Farafra and Kharga oases.

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