



Danian-Selandian sea-level change and biotic excursion on the southern Tethyan margin (Egypt)

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ABSTRACT

A study on Danian to Selandian foraminifera (planktic/benthic ratios, benthic assemblages) in 23 sections on a N-S transect in eastern Egypt documents a transient biotic excursion associated with sea-level fluctuation at ~60.5 Ma (Subbiochron P3a). In southern areas, the inner to middle neritic (30–70 m) *Neoeponides duwi* assemblage expanded into deeper parts of the shelf (~70–250 m), temporarily replacing the *Anomalinoidea umboniferus* and *Angulogavelinella avnimelechi* assemblages. In the deeper parts of the basin (~400–600 m) in the northern part of the transect, the *Gavelinella beccariiiformis* assemblage appears to have been persistent throughout the studied time interval. Biofacial and sedimentologic data suggest a relative sea-level fluctuation, possibly with an amplitude of 50–100 m, which may correlate with a eustatic sea-level cycle during the Danian-Selandian transition. During early sea-level rise, total organic carbon-enriched, partially laminated sediments, containing abundant fish-remains and planktic foraminifera (>99.5% planktics), were deposited, reflecting oxygen deficiency at the seafloor. The patterns of biotic and sea-level change at the Danian-Selandian transition strongly resemble those across the Paleocene-Eocene Thermal Maximum in the same basin, suggesting similar operative processes. Considering the close coincidence with a recently postulated brief period of oceanic warming at 60.5 Ma, the question arises whether the observed patterns in Egypt could in part be related to a global warming event, similar to the Paleocene-Eocene Thermal Maximum.

INTRODUCTION

The Danian and Selandian Stages are chronostratigraphically equivalent to the lower Paleocene and the lower upper (“middle”) Paleocene, respectively (Berggren et al., 1995, 2000). In western Europe, an unconformity between the Danian and Selandian Stages marks a sequence boundary in the Cenozoic cycle charts (Se-1 of Hardenbol, 1994; Sel 1, Hardenbol et al., 1998). According to Hardenbol et al. (1998) this sequence boundary correlates with the sequence boundary between cycles TA-1.3 and TA-1.4, which may have resulted from a eustatic sea-level fall and subsequent rise (Haq et al., 1988). If this sequence boundary was indeed controlled by eustatic sea-level

change, then the southern Tethyan (North African) margin must have recorded a similar sea-level history.

Tunisian and Libyan records do not provide support for a eustatic sea-level fluctuation during the Danian-Selandian transition (Kouwenhoven et al., 1997), but several records from Egypt seem to be in line with this part of the Haq et al. (1988) curve. Lüning et al. (1998) studied the stratigraphy of many Paleocene outcrops in eastern Sinai (Egypt), and correlated the local sequence boundary ThSin-1, with Sel 1 of Hardenbol et al. (1998) and with the TA1.3/TA1.4 sequence boundary of Haq et al. (1988). In the Aweina section (Eastern Desert, Egypt), Speijer and Schmitz (1998) documented a high-amplitude sea-level fluctuation from a succession of benthic foraminiferal assem-

blages within the Danian-Selandian transition, and tentatively correlated it with Danian-Selandian sequence boundary Se-1 of Hardenbol (1994).

The foraminiferal succession in Aweina included the transient occurrence of the shallow water *Discorbis* (= *Neoeponides*) *duwi* assemblage between deeper shelf benthic assemblages (Speijer and Schmitz, 1998). New observations on Danian-Selandian benthic foraminiferal assemblages from 23 sections on a N-S transect in eastern Egypt reveal the incursion of the *Neoeponides* *duwi* assemblage in other sections in the southern part of the transect. In this paper, I present a summary of these observations, provide a new view on the relationship between biotic and sea-level patterns during the Danian-Selandian transition, compare these with those related to the Paleocene-Eocene Thermal Maximum in the same basin, and speculate on possible implications from this comparison.

Danian-Selandian transition in the type region, Denmark

In its type region, Denmark, Danian chalks and limestones are unconformably overlain by Selandian greensands and marls (e.g., Thomsen and Heilmann-Clausen, 1985). This transition to more terrestrially influenced deposition terminated a >35 m.y. period of hemipelagic carbonate deposition in the Danish basin

Stage	Formation	Lithology	CN Zone	PF Zone	Sequence stratigraphy
Selandian	Lellinge	Calcareous greensand	NP4-NP5	P3a	TA1.4
Regional unconformity					Sel 1
Danian	Danskekalk	Limestone	NP4	P1c-P2	TA1.3

Figure 1. Lithostratigraphy, biostratigraphy, and sequence stratigraphy of the Danian-Selandian transition in the type region, Denmark. Biostratigraphic terminology as adopted in Berggren et al. (2000). Sequences TA1.3/1.4 after Haq et al. (1988) and sequence boundary Sel 1 after Hardenbol et al. (1998). PF—planktic foraminifera; CN—calcareous nannofossils.

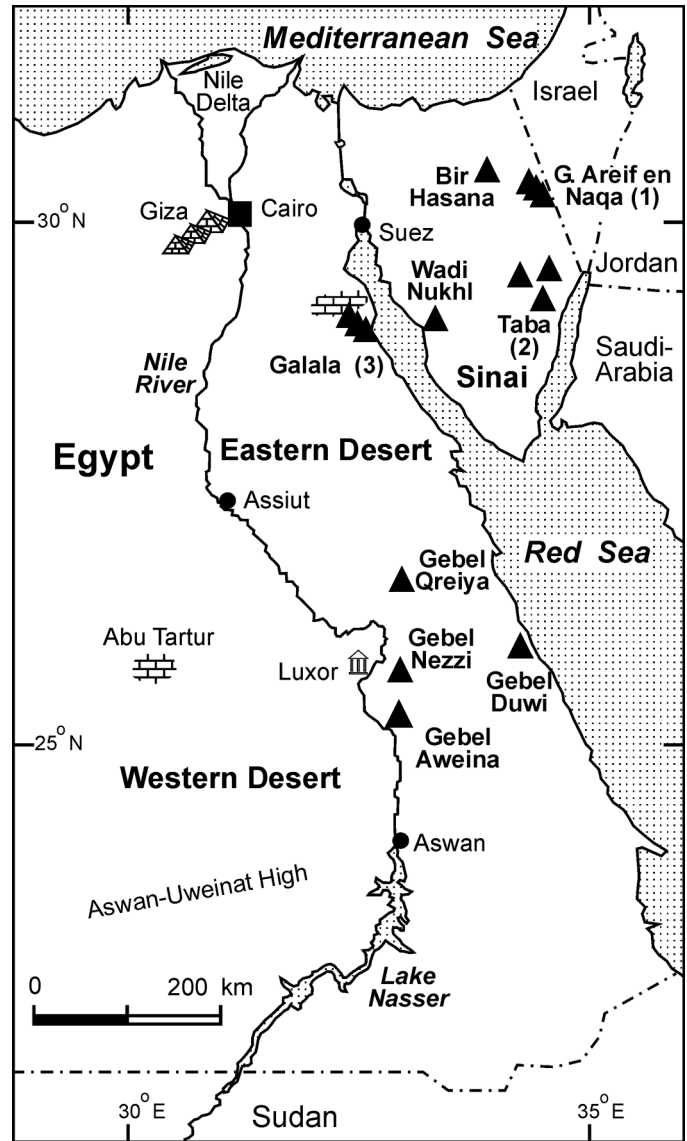


Figure 2. Location map with sections studied (triangles). Numbers refer to the following localities: (1) a transect composed of four sections across the Areif en Naqa anticline; (2) eight sections west of Taba; (3) a transect composed of five sections south of the Galala platform. See Table 1 for biostratigraphic information and references.

(Håkansson et al., 1974; Schmitz et al., 1998). This change in depositional regime between 60 and 61 Ma is related to the opening of the northeastern Atlantic and the uplift of west European landmasses (Berggren, 1994). Determining the exact biostratigraphic positions of the bounding surfaces of the unconformity marking the Danian-Selandian boundary in the type region, Denmark (Fig. 1), has proven difficult. Age and duration of the unconformity vary geographically, but there is general consensus that the top of the Danian correlates with a level within calcareous nannofossil Zone NP4 and planktic foraminiferal Subzone P1c or Zone P2 (e.g., Bignot et al., 1997). The base of the Selandian correlates with a level in the upper

half of Zone NP4 or the lower part of Zone NP5 (Thomsen and Heilmann-Clausen, 1985; Thomsen, 1994; Stouge et al., 2000). Foraminifera indicative of Subzone P3a are associated with the base of the Selandian (Stouge et al., 2000), and this subzone ought to have no stratigraphic overlap with Zone NP5 (Berggren et al., 1995, 2000), so that it is plausible that the base of the Selandian correlates with the top part of Zone NP4 and not with Zone NP5. The stratigraphic gap at the Danian-Selandian boundary in the type region thus spans an interval within Zone NP4, correlative with at least the upper part of Zone P2 to the lower part of Subzone P3a. Berggren (1994) and Berggren et al. (1995, 2000) proposed to correlate the Danian-Selandian boundary with the P2/P3 zonal boundary, with an estimated age of 60.9 Ma, whereas Hardenbol et al. (1998) estimated the age for sequence boundary Sel 1 in western Europe at 60.7 Ma (lower Subzone P3a). Awaiting formal decision of the stratigraphic position of the Danian-Selandian boundary, I refer to the sea-level fluctuation recorded at Gebel Aweina within Subzone P3a (Speijer and Schmitz, 1998), correlative with Sel 1 of Hardenbol et al. (1998), as a Danian-Selandian transition event.

Geological setting

The sections studied are located in the Eastern Desert and in Sinai (Fig. 2, Table 1). This region was part of an extensive epicontinental basin—with various subbasins—covering Egypt during the Paleocene (Fig. 3). The area is traditionally subdivided into two main structural units, the so-called stable shelf

also known as Nile Basin in the south, and the unstable shelf, also known as the Syrian Arc, in the north (Said, 1962; Shahar, 1994; Tawadros, 2001). The Nile Basin experienced little structural deformation during the early Paleogene, whereas the Syrian Arc is characterized by a fold belt that has been tectonically active since the Late Cretaceous (Shahar, 1994). During Danian-Selandian times, the southern margin of the Nile Basin was situated close to the present southern border of Egypt (Luger, 1988). Most of the area north of Aswan was characterized by hemipelagic marl and clay deposition in a generally northwest deepening basin. Uplifted areas of the Syrian Arc in northern Egypt (e.g., the Galala platform) and the local high of Abu Tatur in central Egypt interrupt this generally deepening trend. More terrestrially influenced deposition (deltaic, coastal) and phases of erosion characterized the basin's southern margin (Hendriks et al., 1985, 1987; Luger, 1985, 1988; Hewaidy, 1994). The microfossil material from hemipelagic parts of the basin studied here documents Danian-Selandian paleodepths ranging from ~70–150 m (Gebel Duwi) to ~400–600 m (Sinai).

MATERIAL AND METHODS

Samples from 23 sections in eastern Egypt (Table 1, Fig. 4) were collected during the last two decades by several teams from the Universities of Berlin, Bremen, Gothenburg and Utrecht in cooperation with partners in Egypt. In order to obtain fresh rock, the samples were generally collected from 10 to 30-cm-deep trenches or holes along the outcrop sections. Standard micropa-

TABLE 1. STRATIGRAPHIC DATA AND PALEODEPTH OF STUDIED SECTIONS

Profile	Stratigraphy	Paleodepth*	Reference to stratigraphic data
Areif en Naqa, section A1b	NP2–NP3	400–600 m	Lüning (1997)
Areif en Naqa, section A5	NP2–NP3	400–600 m	Lüning (1997)
Areif en Naqa, section A8	NP2–NP5	400–600 m	Lüning (1997)
Areif en Naqa, section W	NP3–NP6	400–600 m	Lüning (1997)
Bir Hasana	NP3–NP5	400–600 m	Lüning (1997)
Sheikh Attiya	NP1–NP6	400–600 m	Lüning (1997); Lüning et al. (1998)
Gebel Misheiti	NP1–NP6	400–600 m	Lüning (1997); Lüning et al. (1998)
West Themed	NP3–NP4	400–600 m	Lüning (1997); Lüning et al. (1998)
Taba	NP3–NP4, NP6	400–600 m	Lüning (1997); Lüning et al. (1998)
Wadi Gureis	NP1–NP3, NP6	400–600 m	Lüning (1997); Lüning et al. (1998)
Egma Plateau	NP3–NP6	400–600 m	Lüning (1997); Lüning et al. (1998)
Gebel Umm Mafrud	NP3–NP6	400–600 m	Lüning (1997); Lüning et al. (1998)
North Nuweiba	NP3–NP5	400–600 m	Lüning (1997); Lüning et al. (1998)
Wadi Nukhl	P1a–P4	400–600 m	Anan (1992); this paper
Saint Paul 9	NP1–NP5	400–600 m	Scheibner (2001); Scheibner et al. (2001)
Bir Dakhl 2	NP3–NP5	400–600 m	Scheibner (2001); Scheibner et al. (2001)
Bir Dakhl 3	NP3–NP5	400–600 m	Scheibner (2001); Scheibner et al. (2001)
Wadi Tarfa 1	NP2–NP6	400–600 m	Scheibner (2001); Scheibner et al. (2001)
Wadi Tarfa 2	NP4–NP6	400–600 m	Scheibner (2001); Scheibner et al. (2001)
Gebel Qreiya	P1a–P4	150–250 m	Luger et al. (1998); this paper
Gebel Nezzi	P1c–P4	150–250 m	This paper
Gebel Aweina	P1c–P4	150–250 m	Speijer and Schmitz (1998)
Gebel Duwi	P1b–P4	70–150 m	Faris (1984); this paper

Note: Most sections range higher into the upper Paleocene and lower Eocene.

*Paleodepth estimates in this study.

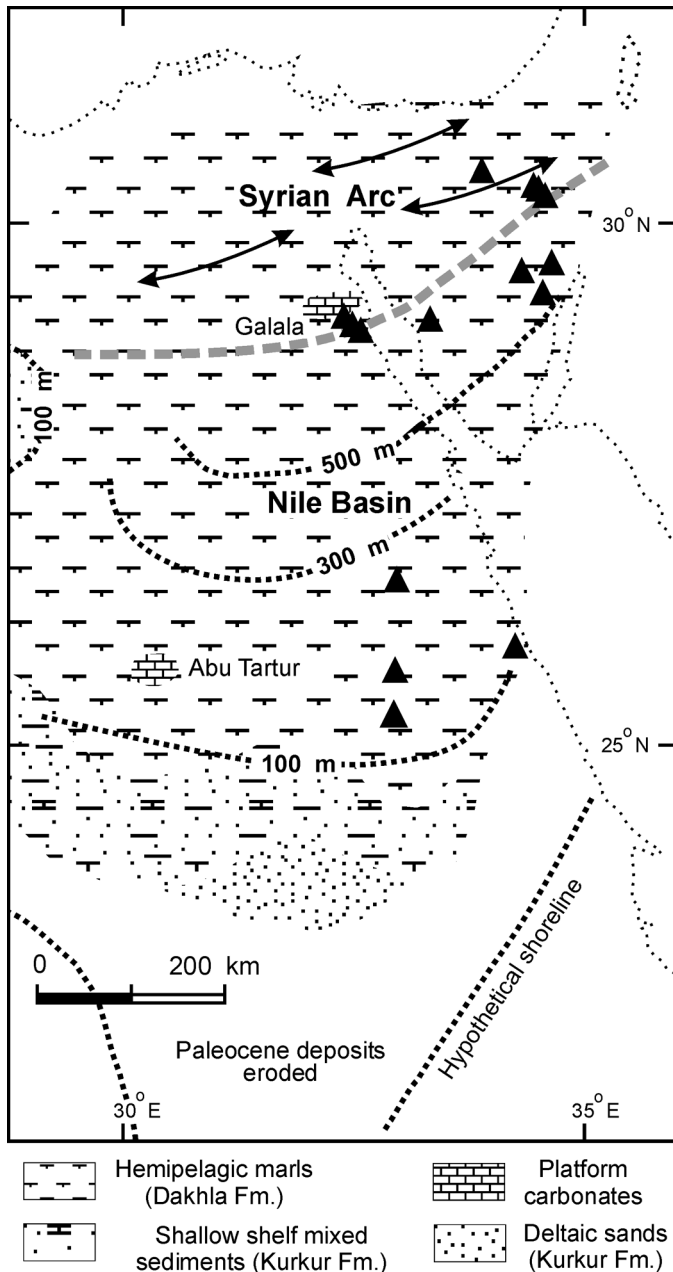


Figure 3. Reconstructed Paleocene paleogeography, lithofacies distribution and paleobathymetry (no correction for opening of Red-Sea rift). Triangles are sections studied (Fig. 2). Thick dashed grey line separates tectonically stable Nile Basin from tectonically active Syrian Arc. Arrows indicate general orientation of double-plunging anticlines (largely submarine swells; schematic) of the Syrian Arc. Isobaths are based on bio- and lithofacies distributions. Carbonate platforms (Abu Tartur and Galala) represent elevated structures on the deeper shelf. Lithofacies distribution modified from Luger (1988) with inclusion of data discussed in this study.

leontologic sample-processing procedures were employed (e.g., Speijer et al., 1996) and the size fraction larger than 125 μm was used for foraminiferal analysis. Stratigraphic distribution and compositional data of the benthic foraminiferal assemblages were determined qualitatively. Only the main biotic patterns are discussed here.

Assemblages from beds directly overlying the Cretaceous-Paleogene boundary (e.g., Subzone P1a in Gebel Qreiya and Wadi Nukhl) containing large proportions of reworked Maastrichtian foraminifera were disregarded. Planktic/benthic (P/B) ratios, expressed as percentage planktics, were determined for the southern Eastern Desert sections (Tables 2, 3). The terms 'neritic' and 'bathyal' are used as representing paleodepths less than and in excess of ~ 200 m, respectively (Van Morkhoven et al., 1986). Note however, that the continental slope was situated north of the epicontinental basin studied (Mart, 1991).

Total organic carbon (TOC) and total carbon (C_{tot}) contents were measured on homogenized samples from Gebel Nezzi and Gebel Qreiya using Leco elemental analyzer facilities at Bremen University. TOC content (precision of measurement $\pm 3\%$) was measured with a Leco CS-300 and C_{tot} with a Leco CS-200 (precision of measurement $\pm 3\%$). CaCO_3 content (Table 2) was calculated from these measurements through: $\text{CaCO}_3 = 8.3333 * (C_{\text{tot}} - \text{TOC})$.

LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

In the study area, the Danian and Selandian Stages are represented by the upper part of the Maastrichtian-Paleocene Dakhla Formation (Said, 1962, 1990) (Fig. 5). This formation consists of rather monotonous brownish to grey marls and shales with occasional intercalated thin marly limestone beds. In Sinai, age-equivalent marls and shales are sometimes referred to as Esna Formation, overlying the Maastrichtian Sudr Formation (e.g., Said, 1990; Lüning et al., 1998). The Dakhla Formation is usually overlain by Thanetian limestones and chalks of the Tarawan Formation. In the Sinai sections, however, the Tarawan Formation is usually just a few meters thick or is absent. In the latter case, there is no clear lithologic boundary between the Dakhla Formation and the Esna Formation (*s.s.*: Thanetian-Ypresian marls and shales overlying the Tarawan Formation [Scheibner et al., 2001]). Danian and Selandian marginal marine successions in the Western Desert are represented by the Kurkur Formation. South of the Abu Tartur platform, this formation interfingers with marls of the basinal Dakhla Formation.

The studied interval spans planktic foraminiferal Zone P1 to the lower part of Zone P4, corresponding to calcareous nanofossil zones NP1-NP6 (Berggren et al., 1995, 2000). In this study, because of the rarity of the P4 zonal marker *Globanomalina pseudomenardii*, the base of Zone P4 is approximated by the lowest occurrence of *Morozovella velascoensis*, a species traditionally thought to appear approximately simultaneously with *G. pseudomenardii* (e.g., Blow, 1979; Toumarkine and Luterbacher, 1985). Recent studies, however, suggest that the

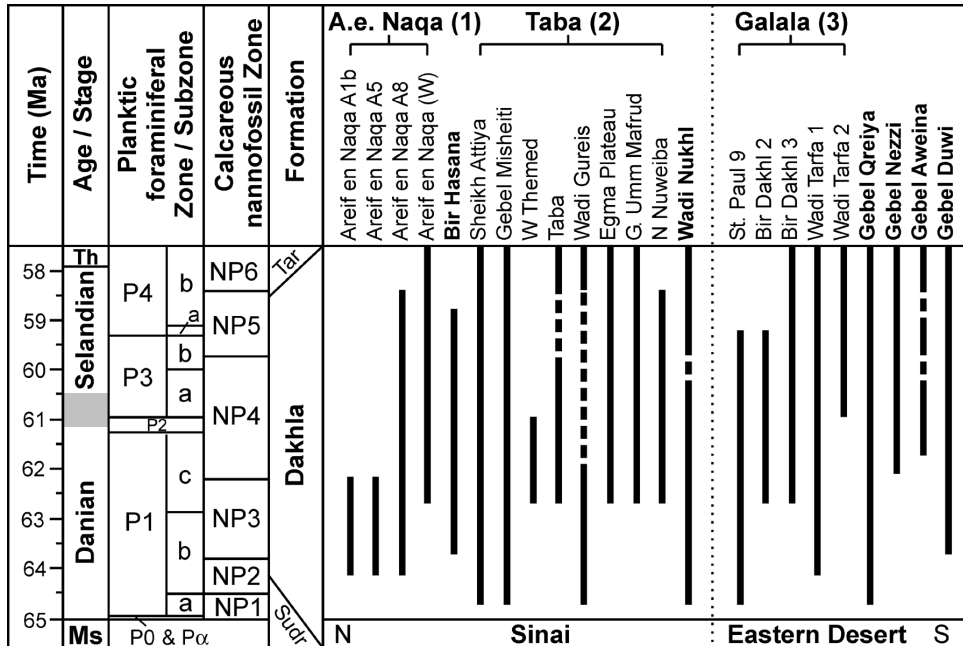


Figure 4. Biostratigraphic ranges of sections studied. Dashed lines indicate stratigraphic gaps. Ranges of the Galala transect (3) and all Sinai sections but Wadi Nukhl are based on calcareous nannofossil data (Table 1). Inconsistencies may exist with equivalent planktic foraminiferal zonal ranges (e.g., Wadi Gureis, Lüning et al., 1998). Biostratigraphic calibration of other sections is primarily based on planktic foraminifera. Bio- and chronostratigraphic scheme after Berggren et al. (2000). Grey band spanning the Danian-Selandian transition indicates the approximate extent of the stratigraphic gap between the two stages in Denmark (Fig. 1). Ms—Maastrichtian; Th—Thanetian; Tar—Tarawan; A.e. Naqa—Areif en Naqa.

lowest occurrence of *M. velascoensis* is within Subzone P3b (Olsson et al., 1999), and thus the stratigraphic range of Subzone P3b may be underestimated in the present study. Detailed biostratigraphic data of most of these sections can be found in previous reports (Table 1, Fig. 4). For Gebel Qreiya and Gebel Nezzi, new biostratigraphic data are presented in Table 2.

RESULTS

Sedimentology, CaCO₃, TOC

Sedimentary structures in the monotonous grey to grey-brown marl successions of the Dakhla Formation are rare, particularly in the successions in Sinai deposited at greater depths. In the Eastern Desert sections of Aweina, Nezzi, and Qreiya, the marls generally contain between 15 and 60% CaCO₃ (Table 2; Speijer and Schmitz, 1998). At 25–40 m above the Cretaceous-Paleogene boundary in these sections, an up to several-dm-thick dark-brown, foraminifera-rich marl bed is intercalated within Subzone P3a (Table 4). This partly laminated bed, containing abundant fish remains and planktic foraminifera, in part preserved as pyritic molds, seems to fill in an inconspicuous undulating channel-like surface in the marls. In Aweina, immediately overlying this bed common pyritic macrofossils are observed. In the Duwi section, 10 brownish more indurated beds are present in the Paleocene part of the Dakhla Formation. One of these, containing abundant secondary gypsum veins, was not sampled, but is situated in the same biostratigraphic position as the dark-brown marl beds in the other Eastern Desert sections. In the overlying interval, shark teeth, gastropods, bivalves, solitary corals and crinoid stems are common.

The TOC contents in “background marls” ranges generally between 0.1% and 0.2% in Nezzi and 0.1% and 0.3% in Qreiya (Table 2). The anomalous dark-brown bed in these sections, however, yields 0.75% and 2.0% TOC, respectively. This bed is sandwiched within shale beds with <10% CaCO₃, of which the overlying one also has slightly elevated TOC contents (0.95% in Qreiya and 0.27% in Nezzi).

Planktic/benthic (P/B) ratios and planktic foraminiferal assemblages

P/B ratios from Zone P3 (Table 3) represent the total range of P/B ratios observed in the Dakhla Formation very well. P/B ratios of the lower and upper parts of the Dakhla Formation in Nezzi and Qreiya are listed in Table 2 for comparison. Most P/B ratio values in Zone P3 fall within the range between 70% and 98% planktics. There appears to be no distinct gradient in P/B ratios from the shallower to the deeper sections. More significant are large variations within individual sections. Whereas in the Galala area P/B ratios <50% planktics are rare, these are more common in the Sinai sections and particularly in the southern Eastern Desert sections. In Qreiya and Nezzi, anomalous low P/B ratios below 20% planktics are generally associated with low-carbonate sediments. In combination with low absolute numbers of generally poorly preserved foraminifera, numerous fragments, large proportions of agglutinated and thick-shelled calcareous taxa, these low P/B ratios are an indication of postmortem dissolution. Loss of calcareous tests associated with reduced P/B ratios is observed in samples from all regions, but is particularly prominent within Zone P3 in the Aweina, Nezzi and Qreiya sections, especially in the shale beds

**TABLE 2. FORAMINIFERAL AND GEOCHEMICAL
DATA OF GEBEL QREIYA AND GEBEL NEZZI**

Profile	Sample	Level* (m)	Biozone	% Planktics	% TOC	% CaCO ₃
Gebel Qreiya	271185/30	54	P4	94.3	N.D.	N.D.
	271185/31	51	P4	98.0	0.21	81.6
	271185/32	48	P4	64.1	0.20	63.8
	271185/33	46.5	P4	48.7	0.15	42.9
	271185/34	44.5	P4	59.9	0.14	54.4
	271185/35	42	P4	63.1	0.18	50.4
	271185/36	40	P4 †	67.4	0.34	46.4
	271185/37	37.5	P3b	96.7	0.18	30.3
	271185/38	34.5	P3b	92.9	0.16	35.8
	271185/39	32	P3a	87.8	0.34	15.2
	271185/40	31.6	P3a	22.2	0.95 §	7.7
	271185/41	31.4	P3a	99.5	2.02 §	19.5
	271185/42	31	P3a	0 #	0.32 §	5.8
	271185/43	29	P3a	90.0	0.25	35.0
	271185/44	26.5	P3a	85.3	0.22	15.4
	271185/45	24	P2	93.5	0.24	24.1
	271185/46	22	P2	94.0	0.24	23.6
	281185/35	21	P2	90.9	0.12	27.4
	281185/36	19	P1c	91.2	0.07	29.7
	281185/37	17	P1c	86.9	0.07	35.2
	281185/38	14.5	P1c	92.0	0.14	55.8
	281185/26	13.5	P1c	75	0.10	58.5
	281185/25	12	P1c	86	0.08	53.2
	281185/24	10	P1b	69	0.08	52.8
	281185/23	9.5	P1b	81	0.09	54.7
	281185/22	8.0	P1b	47	N.D.	N.D.
	281185/21	5.5	P1b	65	0.02	57.2
	281185/20	3.5	P1b	10	0.10	12.3
Gebel Nezzi	51285/28	66	P4	80.3	0.06	81.9
	51285/27	61.5	N.D.	77.6	0.06	77.7
	51285/26	59.5	N.D.	63.0	0.06	72.1
	51285/25	57.5	N.D.	42.9	N.D.	N.D.
	51285/24	54	P4	92.5	0.06	78.7
	51285/23	50	P4 †	90.1	0.14	79.6
	51285/22	46	P3b	90.7	0.08	44.6
	51285/21	42	P3b	93.3	0.11 §	44.7
	51285/20	38.5	N.D.	1.9	0.27	1.9
	51285/19	38	P3a	99.7	0.75 §	20.2
	51285/18	37.5	N.D.	0 #	0.10	1.8
	51285/17	34	P3a	85.6	0.12 §	16.9
	51285/16	31.5	P2	86.5	0.08	25.5
	51285/15	29.5	P2	87.0	0.14	22.2
	51285/14	27	N.D.	92.3	0.11	30.2
	51285/13	25	N.D.	84.1	0.14	30.5
	51285/12	24.5	N.D.	90.1	0.15	44.4
	51285/11	24	N.D.	66.1	0.10	42.8
	51285/10	21.5	N.D.	85.5	0.10	49.6
	51285/9	19.5	N.D.	81.9	0.15	63.0
	51285/8	15	N.D.	25.9	0.14	46.8
	51285/7	11	N.D.	74.6	0.21	53.4
	51285/6	8.5	P1c	53.0	0.16	51.0
	51285/5	7	N.D.	12.3	0.30	37.2
	51285/4	5	N.D.	10.9	0.41	6.9
	51285/3	2.5	N.D.	7.9	N.D.	N.D.
	51285/2	1.5	N.D.	0.0	0.37	1.8

Note: Boldface data from anomalous dark-brown marl bed. N.D.—No data.

*Meters above Cretaceous-Paleogene boundary.

†The base of Zone P4 is approximated by the lowest occurrence of *M. velascoensis*.

§Average value from two sub-samples.

#Dissolution residues. Rare planktics only preserved as pyritic molds. Benthic assemblage consists of agglutinated taxa and fragments of thick-shelled calcareous taxa (Nodosarians).

TABLE 3. PERCENTAGE PLANKTICS (%P) WITHIN ZONE P3 IN STUDIED SECTIONS

Sinai *			Galala area*			Southern Eastern Desert			
Profile	Sample	%P	Profile	Sample	% P	Profile	Sample	%P	
Areif en Naqa	A8-18	97	St Paul 9	S9-58	92.1	Gebel Qreiya	271185/37	96.7	
	A8-17	94		S9-57	95.5		271185/38	92.9	
	A8-16	93		S9-56	95.4		271185/39	87.8	
Areif en Naqa	W1-11	59		S9-55	96.2		271185/40	22.2	
	W1-10	63		S9-54	96.3		271185/41	99.5	
	W1-9	89		S9-53	94.2		271185/42	0†	
	W1-8	72		S9-52	93.3		271185/43	90.0	
	W1-7	61		S9-51	94.7		271185/44	85.3	
	W1-6	98		S9-50	93.4	Gebel Nezzi	51285/23	90.1	
	W1-5	88		S9-49	96.5		51285/22	90.7	
	W1-4	77	Bir Dakhl 2	D2-48	81.6		51285/21	93.3	
	W1-3	90		D2-47	87.0	51285/20	1.9		
	W1-2	87		D2-45	93.7	51285/19	99.7		
		D2-46		93.0	51285/18	0†			
Sheikh Attiya	C1-29	73		D2-44	92.2		51285/17	85.6	
	C1-28	76		D2-43	91.0		51285/16	86.5	
	C1-27	85		D2-42	91.4	Gebel Aweina	O95 + 750 cm	87.3	
	C1-26	86		D2-41	96.6		O95 + 600 cm	92.7	
	C1-25	73		D2-40	86.1		O95 + 450 cm	96.3	
	C1-24	85		D2-39	97.3		O95 + 400 cm	94.6	
	C1-23	21		D2-38	97.9		O95 + 275 cm	91.6	
	C1-22	67		D2-37	89.0		O95 + 175 cm	81.4	
	C1-21	83		D2-36	85.8		O95 + 70-80 cm	94.2	
	C1-20	97		D2-35	90.0		O95 + 65—70 cm	87.3	
			D2-34	82.3	O95 + 55—60 cm		88.5		
			D2-32	88.9	O95 + 19—24 cm		55.4		
Gebel Misheiti	F1-43	82		D2-33	47.2		O95 + 0—2 cm	99.8	
	F1-42	88		D2-31	76.0		O95—5—8 cm	70.4	
	F1-41	78		D2-30	84.8		O95—9—15 cm	27.8	
	F1-40	95					O95—18—25 cm	68.8	
West Themed	K1-15	94	Bir Dakhl 3	D3-36	92.1		O95—30—35 cm	78.3	
				D3-35	84.6		O95—90—100 cm	44.3	
				D3-34	80.1		O95—200 cm	72.4	
Taba	M1-36	97		D3-33	94.7		O95—300 cm	76.3	
	M1-35	88		D3-32	94.9		O95—400 cm	87.6	
	M1-34	96		D3-31	96.0	Gebel Duwi	DU95D/S+41	97.6	
Wadi Gureis	P1-30	95		D3-30	93.8			DU95D/S+40.5	95.1
				D3-29	90.3			DU95D/S+40	70.0
Egma Plateau	Q1-12	98		D3-28	88.3			DU95D/S+39A	67.5
	Q1-11	53		D3-27	98.8			DU95D/S+39	86.9
				D3-26	84.3			DU95D/S+38	83.1
Gebel Umm Mafrud	R1-8	52	Wadi Tarfa 1	T1-42	98.8			DU95D/S+37	81.3
	R1-7	66		T1-41	97.3				
	R1-6	79		T1-40	95.8				
	R1-5	97		T1-39	94.0				
	R1-4	89		T1-38	94.6				
	R1-3	97		T1-37	94.8				
	R1-2	97		T1-36	96.1				
				T1-35	90.7				
North Nuweiba	T1-14	45		T1-34	68.3				
	T1-13	77		T1-33	90.3				
	T1-12	81		T1-32	92.4				
	T1-11	96		T1-31	86.9				
	T1-10	94							
	T1-9	70							
	T1-8	93	Wadi Tarfa 2	T2-11	56.6				
T1-7	89	T2-10		50.0					
		T2-9		89.4					
		T2-8		95.7					
		T2-7		88.8					
Wadi Nukhl	S718	98		T2-6	95.8				
	S716	95		T2-5	98.0				
				T2-4	94.5				
				T2-3	87.1				
				T2-2	82.7				

*Data from Sinai except for Wadi Nukhl from Lüning (1997) and data from Galala area from Scheibner (2001).

†Dissolution residues. Rare planktics only preserved as pyritic molds. Benthic assemblage consists of agglutinated taxa and fragments of thick-shelled calcareous taxa (Nodosarians).

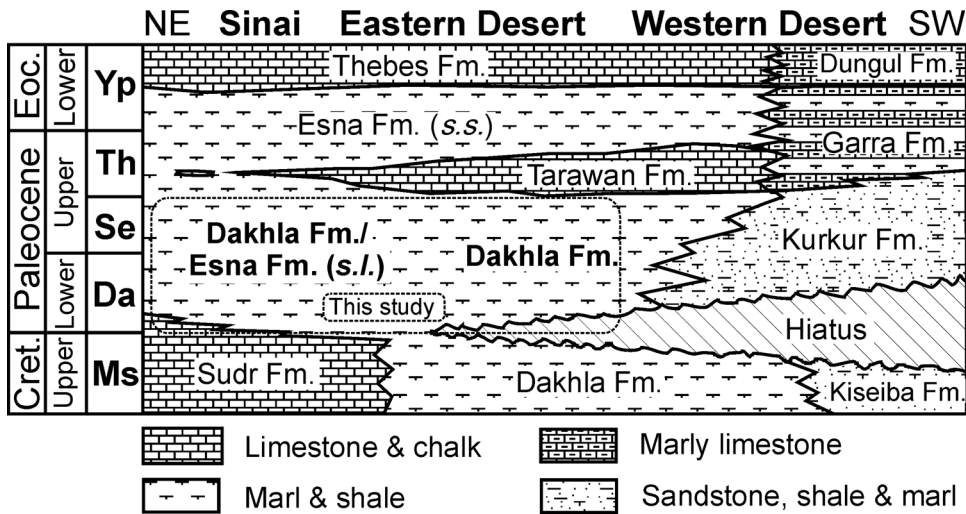


Figure 5. Schematic lithostratigraphic framework of the Paleocene in a north-east-southwest transect across Egypt. Only main lithostratigraphic units and lithologies are indicated and the lateral extent of marginal facies in southwest is exaggerated. Hiatuses other than the one spanning the Cretaceous-Paleogene boundary are not indicated. Cret.—Cretaceous; Eoc.—Eocene; Ms—Maastriichtian; Da—Danian; Se—Selandian; Th—Thanetian; Yp—Ypresian; Fm.—Formation. Drawing after Luger (1985), Hendriks et al. (1987), and Said (1990).

encompassing the anomalous dark-brown marl bed (0%–22% planktics). In contrast, the dark-brown bed itself, with >99.5% planktics, contains the highest P/B ratios, observed in all studied material.

Planktic foraminiferal assemblages in Zone P3 are diverse with most Paleocene genera like *Morozovella*, *Subbotina*, *Parasubbotina*, *Praemurica*, *Igorina*, and *Globanomalina* well represented. In contrast, samples from the dark-brown bed with P/B ratios of >99.5% planktics contain a poorly diverse planktic assemblage, largely constituted by nonkeeled genera with muricate and praemuricate tests, such as *Praemurica* and *Acarinina*. Particularly striking is the near absence of large morozovellids (*M. angulata*, *M. conicotruncata*), which are typical for planktic assemblages in Zone P3 in eastern Egypt. Samples from the

interval overlying the dark-brown bed in Aweina also lack morozovellids and contain relatively large numbers of *Igorina tadzikistanensis*.

Danian-Selandian benthic foraminiferal assemblages

Three main Danian-Selandian benthic foraminiferal assemblages characterize three bathymetric regimes from ~70–150 to ~400–600 m in the studied part of the basin (Fig. 6). The bathymetric interval between ~250 and ~400 m (situated between Gebel Qreiya and the Galala transect) is not covered in this study. Shallower assemblages, characterizing deposition at up to ~70 m depth, were described from southern Egypt (Hewaidy, 1994; Schnack, 2000).

TABLE 4. DETAILED DATA ON SAMPLES CONTAINING THE *NEOEPONIDES DUWI* ASSEMBLAGE

Profile	Sample	Subzone	% Planktics	% TOC	% CaCO ₃	Lithology	Macrofossils
Gebel Qreiya	271185/40	P3a	22.2	0.95*	7.7	Dark-grey shale	N.D.
	271185/41	P3a	99.5	2.02*	19.5	Dark-brown marl	N.D.
Gebel Nezzi	51285/20	P3a	1.9	0.27	1.9	Grey shale	N.D.
	51285/19	P3a	99.7	0.75*	20.2	Dark-brown marl	N.D.
Gebel Aweina [†]	O95 + 19–24 cm	P3a	55.4	N.D.	N.D.	Grey marl	Mollusks
	O95 + 0–2 cm	P3a	99.8	N.D.	N.D.	Dark-brown marl	No
	O95 — 5–8 cm	P3a	70.4	N.D.	N.D.	Grey marl	No
	O95 — 9–15 cm	P3a	27.8	N.D.	N.D.	Grey marl	No
	O92 + 26 m	P3a	10.9	N.D.	13	Grey shale	N.D.
Gebel Duwi	O92 + 25 m	P3a	2.9	N.D.	N.D.	Grey shale	N.D.
	DU95D/S+40	P3a	70.0	N.D.	N.D.	Grey shaley marl	No
	DU95D/S+39A	P3a	67.5	N.D.	N.D.	Grey marl	Shark teeth, mollusks, corals
	DU95D/S+18	P1b	82.5	N.D.	N.D.	Dark-grey shaley marl	No
	DU95D/S+12	P1b	92.5	N.D.	N.D.	Brown-grey marl	No

Note: N.D.—No data.

*Average value derived from two sub-samples.

[†]Data on O92 samples of Aweina from Charisi and Schmitz (1995) and Speijer and Schmitz (1998). The range of the two O92 samples corresponds to the interval from ~20 cm below to ~30 cm above the dark-brown marl bed.

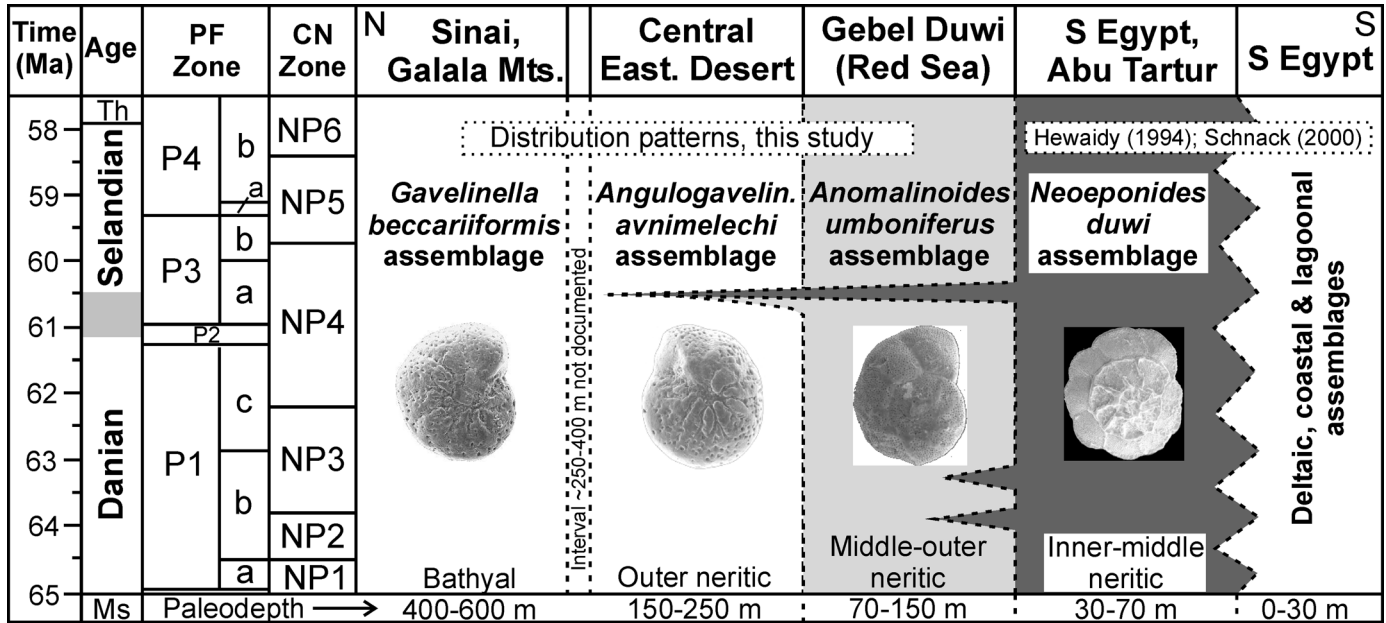


Figure 6. Schematic spatial and temporal distribution of main benthic foraminiferal assemblages in Danian to Selandian deposits of Egypt. Interfingering between the *Neoeponides duwi* and various shallower assemblages in southern Egypt (Hewaify, 1994) is more complex than indicated. Bio- and chronostratigraphy as in Figure 4. PF—planktic foraminifera; CN—calcareous nannofossils; Ms—Maastrichtian; Th—Thanetian.

Anomalinoides umboniferus assemblage. The *Anomalinoides umboniferus* assemblage in Gebel Duwi consists, besides the common nominative species, of various *Anomalinoides* spp. (*A. cf. midwayensis*, *A. praeacutus*), *Cibicidoides* spp. (*C. pseudoacutus*, *C. rigidus*), *Lenticulina* spp., *Bulimina* spp. (*B. midwayensis*, *B. strobila*), *Siphogenerinoides eleganta*, *Valvulabamina depressa*, *Oridorsalis plummerae*, *Osangularia plummerae*, *Loxostomoides applinae*, and *Gyroidinoides* spp. Deep-sea taxa such as *Gavelinella beccariiformis*, *Nuttallides truempyi*, *Gyroidinoides globosus*, and *Bulimina trinitatensis* are absent and deep outer neritic taxa such as *Angulogavelinella avnimelechi*, *Anomalinoides susanaensis*, and *Anomalinoides affinis* rarely occur in this assemblage. The absence of deeper water species in combination with fairly high P/B ratios (average ~85% planktics) suggests water depths ranging from ~70 to 150 m (middle neritic to shallow outer neritic) for this assemblage. This assemblage is also found in a 1-m-thick interval immediately underneath the incursion of the *Neoeponides duwi* assemblage (see below) at Aweina (Speijer and Schmitz, 1998).

Angulogavelinella avnimelechi assemblage. The Aweina, Nezzi, and Qreiya sections are characterized by the *Angulogavelinella avnimelechi* assemblage. This assemblage is generally composed of most species of the *Anomalinoides umboniferus* assemblage listed above, but also contains larger numbers of trochamminids and deep outer neritic taxa like *A. avnimelechi*, *A. susanaensis*, and *A. affinis*. It also includes a small percentage of bathyal marker species such as *G. beccariiformis* and *N. truempyi*, indicating deep outer neritic to upper bathyal environments (~150–250 m; Speijer and Schmitz, 1998).

Gavelinella beccariiformis assemblage. The *Gavelinella beccariiformis* assemblage is found near the Galala Mountains and all over Sinai. The nominative species is the most common in almost all samples investigated. Otherwise this assemblage is composed of *N. truempyi*, *Osangularia plummerae*, *Gyroidinoides globosus*, *A. avnimelechi*, various *Anomalinoides* (*A. affinis*, *A. rubiginosus*), *Cibicidoides* (*C. pseudoacutus*, *C. cf. hyphalus*) and numerous infrequent species. Based on upper depth limits of ~500 m for *N. truempyi* and *B. trinitatensis* (Van Morkhoven et al., 1986), Speijer (1994) suggested a water depth of 500–700 m for this assemblage. Because these taxa have been found in low numbers in the Eastern Desert sections (see also Speijer and Schmitz, 1998), the upper depth limits for these taxa appear unrealistic for the Nile Basin. Consequently, the bathymetric range of the *G. beccariiformis* assemblage, occurring in the deepest parts of the basin, is estimated somewhat shallower (~400–600 m).

These depth-related assemblages are fairly uniform through time with respect to their general composition, although some species have local lowest or highest occurrences in the Danian-Selandian interval. Compositional variations are generally subtle and in some instances appear to relate to taphonomic processes, such as dissolution (see above) rather than to primary differences.

Neoeponides duwi assemblage. Superimposed on the general biotic stability in the investigated successions are a few stratigraphic levels with a strongly deviating benthic foraminiferal composition. In the Aweina section, the *Neoeponides duwi* assemblage occurred in an ~1 m thick interval within planktic

foraminiferal Subzone P3a and calcareous nannofossil Zone NP4 (Speijer and Schmitz, 1998), and it includes the dark-brown marl bed. This same unusual assemblage occurs in short intervals in the Duwi, Nezzi and Qreiya sections. It generally consists of abundant *Neoepionides duwi*, composing up to ~60% of the benthic assemblage, *Haplophragmoides walteri*, trochamminids and small proportions of *Siphogenerinoides elegantus*, *Gyroidinoides girardanus*, *Anomalinoidea praeacutus*, *A. umboniferus*, *Cibicoides pseudoacutus*, *Bulimina strobila* and *Lenticulina* spp. This assemblage is not observed in any of the bathyal successions in the Galala area and in Sinai. In Nezzi and Qreiya, two localities similar to Aweina, the *N. duwi* assemblage is observed in the dark-brown marls and overlying shales within Subzone P3a. In the somewhat shallower Duwi succession, the assemblage occurs within Subzone P3a and further down in two Danian (Subzone P1b) horizons (Table 4). Within the present biostratigraphic constraints, the interval marked by the *N. duwi* assemblage in Subzone P3a seems to be a synchronous unit in the region.

The *N. duwi* assemblage is associated with highly variable P/B ratios. The nominative species is highly abundant (relatively and in absolute numbers) in foraminiferal assemblages with very low P/B ratios, e.g., Gebel Qreiya sample 271185/40, Gebel Nezzi sample 51285/20, and Aweina samples O92 + 25 and O92 + 26. *Neoepionides duwi* is much less abundant in absolute numbers, but similarly dominant among the benthic foraminifera in assemblages from the dark-brown beds (271185/41, 51285/19 and O95 + 0–2) characterized by >99.5% planktics and TOC enrichment. In the low-resolution successions of Nezzi and Qreiya, the appearance of the *N. duwi* assemblage seems to coincide with the extremely high P/B ratios. High-resolution data of Aweina, however, show that appearance of the *N. duwi* assemblage slightly predated the peak in the P/B ratios: A sample 9–15 cm below the dark-brown bed contains a typical *N. duwi* assemblage with abundant agglutinated taxa, suggesting that the appearance of the *N. duwi* assemblage is not directly linked to the conditions prevailing during deposition of the TOC-enriched dark-brown marl beds.

In order to understand the paleoenvironmental significance of the anomalous *N. duwi* assemblage, its stratigraphic and bathymetric distribution needs to be considered. This type of assemblage has previously been found in Danian–lower Selandian (Zones P1–P3) deposits in southern Egypt (Aswan–Uweinat high) and central Egypt, near the Abu Tartur plateau where it is associated with P/B ratios varying between 1 and 56% planktics (Hewaidy, 1994; Schnack, 2000). These areas are characterized by a carbonate-platform facies of the lower Paleocene Abu Tartur platform (Schnack, 2000) and by inner to middle neritic marls and shales (Hewaidy, 1994). Occasionally, *N. duwi* dominates the benthic foraminiferal assemblages in these shallow areas. *Haplophragmoides walteri*, another frequent component of the *N. duwi* assemblage, is a common constituent in inner neritic and restricted marine environments in the Paleocene of Tunisia and Texas (Kellough, 1965; Aubert and Berggren, 1976;

Kouwenhoven et al., 1997), but also occurs in Paleocene to Eocene flysch-type deep-water deposits (Kaminski et al., 1988). Most other taxa in this assemblage appear to have had wide bathymetric distributions in Egypt, spanning from inner neritic to upper bathyal depths (Hewaidy, 1994; Speijer, 1994; Speijer et al., 1996; Speijer and Schmitz, 1998; Schnack, 2000). In Egypt, the *N. duwi* assemblage thus seems to typify inner to middle neritic (~30–70 m) settings and the invasions into deeper shelf domains, particularly those into the outer neritic realm should be considered as anomalies.

DISCUSSION

Sea-level change during the Danian–Selandian transition

Three different sea-level scenarios for the Danian–Selandian transition in the region are considered. In the first two scenarios, the interval with the *N. duwi* assemblage, indicative of inner-to-middle neritic deposition, constitutes a relative sea-level lowstand, as suggested by Speijer and Schmitz (1998). In the third scenario it constitutes the last phase of falling sea level and the subsequent rising sea level.

Scenario one. According to the first observations on the benthic foraminiferal record of the Aweina section, the presence of the *N. duwi* assemblage (two samples) coincided with a drop in the percentage of planktic foraminifera from ~90% to ~10% (Speijer and Schmitz, 1998). This suggested that a relative sea-level fall and a decrease in paleodepth from ~150–250 m to 30–70 m forced a biofacial replacement of the deeper *A. avnimelechi* assemblage by the shallower *N. duwi* assemblage. The return of the *A. avnimelechi* assemblage marked drowning of the deeper shelf and the return to former paleodepths. The new observations indicate that this overall pattern is valid on a more regional scale.

Scenario two. In a slightly modified interpretation, the *N. duwi* assemblage is thought to have been introduced from the shallower shelf into the deeper parts through increasing current activity with falling sea level. The presence of the *N. duwi* assemblage on top of the channel-like surfaces supports this view. This interpretation also differs from scenario one in that the paleodepth for the interval of the *A. duwi* assemblage cannot be accurately assessed, since the assemblage would be largely constituted by transported elements. As in scenario one, the return of the *A. avnimelechi* assemblage marks the return to former paleodepths.

There are several problems with considering the interval marked by the *N. duwi* assemblage as an exclusively lowstand signal as in these two scenarios. The dark-brown marl beds contain large numbers of planktic foraminifera in combination with extremely high P/B ratios (>99.5% planktics). Such occurrences are not compatible with a relative sea-level lowstand for the entire interval characterized by the presence of the *N. duwi* assemblage. These sediments are also enriched in organic carbon and fish remains, pointing to oxygen deficiency at the seafloor. This cannot be reconciled with deposition under high current activity.

Scenario three. The appearance of the *A. umboniferus* assemblage prior to the appearance of the *N. duwi* assemblage in the Aweina record indicates 50–100 m shallowing (Speijer and Schmitz, 1998). The subsequent replacement by the *N. duwi* assemblage, just below the dark-brown marl bed, reflects the shallowest phase at the end of a falling relative sea level. In sequence stratigraphic terminology (Posamentier et al., 1988; Van Wagoner et al., 1988), this could represent the late highstand systems tract (HST) of a relative sea-level cycle (Fig. 7). The channel-like surface may be interpreted as a type 2 sequence boundary, marked by minor submarine erosion (Emery and Myers, 1996). The overlying sediments, marked by rich foraminiferal assemblages, and at least in Duwi and Aweina common macrofossils, seem to represent a period of condensed sedimentation during the subsequent relative sea-level rise. This interval could represent the transgressive systems tract (TST) in the relative sea-level curve. Considering the absence of sand-sized terrigenous or obviously redeposited material, there are no good indications for the presence of a lowstand systems tract or shelf-margin systems tract between the HST and TST in the southern Eastern Desert sections, suggesting that there may be a hiatus of unknown duration associated with the bottom surface of the channel.

During the early part of the rising sea level, oxygen deficiency led to restricted bottom life reflected in extremely high P/B ratios, preservation of fish remains, dark coloration and TOC-enrichment of the sediments. Simultaneously, surface ecosystems were also perturbed, as indicated by the near disappearance of the morozovellids and the predominance of non-keeled praemuricate and muricate planktic genera. As sea level rose and seafloor oxygenation improved, the *N. duwi* assem-

blages rapidly disappeared and the normal bathymetric biofacial distribution (Fig. 6) was restored.

It is intriguing that *N. duwi* remained the dominant benthic taxon during the short oxygen-deficiency phase. Its persistence in this interval could suggest an opportunistic life mode, like has been suggested for other benthic foraminiferal taxa in black shales and sapropels (e.g., Sen Gupta and Machain-Castillo, 1993). However, most of these opportunistic taxa are characterized by small and thin-shelled tests, whereas *N. duwi* is one of the largest species in the benthic assemblages and has a thick and strongly decorated test (Fig. 8). Alternatively, despite their generally good preservation, it cannot be excluded that the specimens of *N. duwi* in the dark-brown bed represent a reworked fraction from the immediately underlying sediments. High-resolution data from Aweina show that the underlying 10–20 cm of sediment contain the *N. duwi* assemblage (Table 4), but sample density of the other sections does not allow to evaluate this alternative. Irrespective of the ecologic characteristics of *N. duwi* with respect to oxygen deficiency, with the available data scenario three provides the best explanation for the sequence of events in the Danian-Selandian transition in eastern Egypt.

Regional sea-level record

If the changes in water depth and relative sea level as recorded in the Eastern Desert sections are of regional or eustatic significance, they must also have left a record in other parts of the basin. In Sinai, Lüning et al. (1998) found micropaleontologic and sedimentologic evidence for a sequence boundary, correlative with the one observed in the Eastern Desert (Fig. 7),

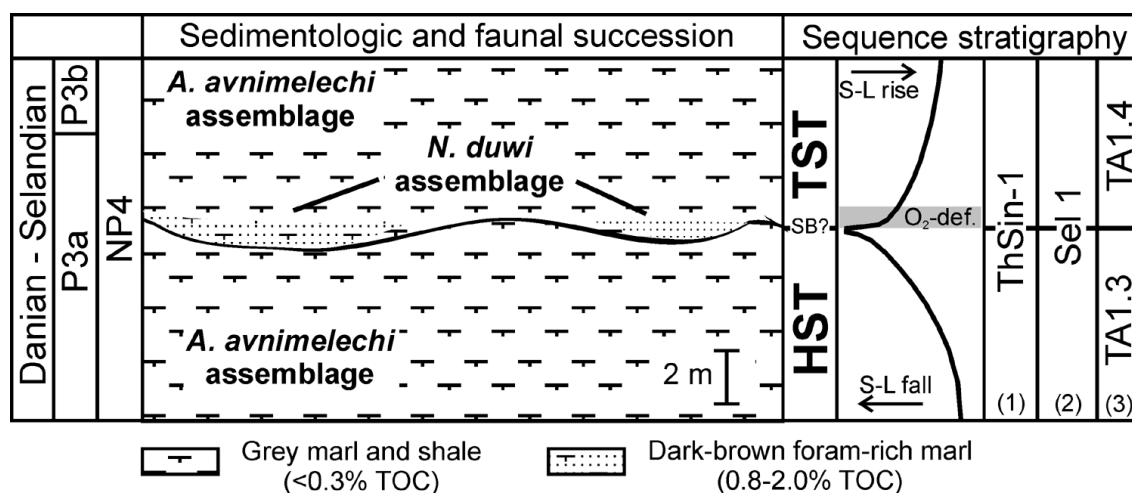


Figure 7. Schematic sedimentologic and benthic foraminiferal succession within outcrop across the Danian-Selandian transition in an outer neritic setting (e.g., Gebel Aweina). Note that in Gebel Aweina the lowest occurrence of the *N. duwi* assemblage is observed already 10–15 cm below the dark-brown foraminifera-rich marl bed. Interpreted relative sea-level history and systems tracts compared to cycle boundaries elsewhere: (1) Sinai (Lüning et al., 1998); (2) western Europe (Hardenbol et al., 1998); (3) “Global” (Haq et al., 1988). Grey band indicates oxygen deficiency at the base of the transgressive systems tract (TST). SB?—Type 2 sequence boundary?; HST—highstand systems tract; S-L—sea-level; TOC—total organic carbon.

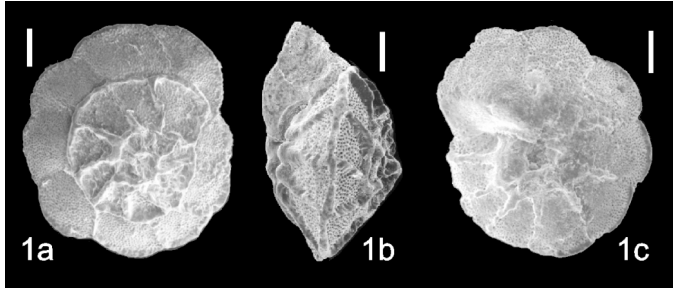


Figure 8. SEM photographs of *Neoeponides duwi* (Nakkady) from Subzone P3a in the Eastern Desert, Egypt. 1a—spiral side of specimen from Gebel Aweina (sample O95 + 19–24 cm); 1b—side view of specimen from Gebel Duwi (sample DU95DS+39A); 1c—umbilical side of another specimen from Gebel Duwi (sample DU95DS+39A). Scale bars are 100 μ m.

reflected in a reduction in P/B ratios and biostratigraphic discontinuities. A sea-level fall within Subbiochron P3a and a subsequent unconformity was observed in the Western Desert (Luger, 1985; Schnack, 2000). In southern Egypt, the late Danian sea-level fall is manifested by a regressive sequence of deltaic deposits. An erosional contact marks the transition to the overlying transgressive sequence that correlates with the lower part of Zone P4 (Hendriks et al., 1985; Luger, 1985). Except for the Galala area, where there is yet no evidence for sea-level changes within Subzone P3a (Scheibner et al., 2000), the Danian-Selandian sea-level fall and subsequent rise can be monitored in various parts of the Nile Basin. Estimating the amount of relative sea-level change awaits a detailed quantitative analysis, but Speijer and Schmitz (1998) indicate that the amount of shallowing prior to the invasion of the *N. duwi* assemblage is probably on the order of 50–100 m. Water depths before and after this sea-level fluctuation were similar, so the subsequent deepening must have been in the same order of magnitude.

Eustatic sea-level change

In order to estimate the magnitude of eustatic changes, local subsidence must be assessed. Tectonic activity in the basin appears restricted to the late Paleocene, in particular to Zones NP5 to NP9 (Strougo, 1986; Guiraud and Bosworth, 1999; Kuss et al., 2000; Scheibner et al., 2000) and thus seems to play no role in the Danian-Selandian transition in Egypt. In Aweina, 45 m of compacted sediments accumulated during the interval between the base of the Paleocene (Biochron P1c) and the top of Biochron NP6, corresponding to ~4 m.y. (Speijer and Schmitz, 1998). Paleodepths over this time interval remained overall unchanged, and assuming no tectonic activity, the average subsidence (without correction for compaction) was 11 m/myr. The total time involved in the Danian-Selandian sea-level event in Aweina (including hiatuses) is on the order of 1 m.y. or less. If the estimate of 50–100 m sea-level change and the assumption of no tectonic activity are generally correct, then the role of subsidence is neg-

ligible and the major component in the paleodepth and relative sea-level changes observed could be eustatic change.

The postulated type 2 sequence boundary in the Eastern Desert sections appears to correlate (Fig. 7) with the type 1 sequence boundary Sel 1 (Hardenbol et al., 1998) and the sequence boundary between third order cycles TA1.3 and TA1.4, for which the estimated amounts of sea-level fall and subsequent rise are 60 m and 30 m, respectively (Haq et al., 1988). The former value is within the estimated range for Aweina, but the latter value is only one half to one third of the estimate. This indicates that there is fair agreement in timing and magnitude of the Danian-Selandian sea-level fluctuation in the studied basin and globally. The magnitude of sea-level change (~50 m) suggests that glacio-eustatic processes may have been involved. Although the early Paleocene was a relatively cool period compared to the Late Cretaceous and late Paleocene (Oberhänsli and Hsü, 1986; Frakes et al., 1992; Zachos et al., 2001), independent evidence for the existence of ice sheets during the early to late Paleocene merely consists of a few records of early to “middle” Paleocene dropstones (Dalland, 1976; Leckie et al., 1995). Oxygen isotopic data, however, have been interpreted as indicating that the early Paleogene world was essentially free of ice-sheets (e.g., Zachos et al., 2001). A fairly good fit between eustatic cycles and the ice-volume record reconstructed from oxygen isotopic data currently only exists for middle Eocene and younger records (Miller et al., 1996; Abreu and Anderson, 1998). For now it remains enigmatic how this and other Paleocene large magnitude sea-level fluctuations (Haq et al., 1988) may have been eustatically controlled without good evidence for the waxing and waning of large ice-sheets.

Comparison with Paleocene-Eocene Thermal Maximum record in Egypt

In addition to indications for glacial periods within the early to early late Paleocene (Dalland, 1976; Leckie et al., 1995), it has been suggested that the first of a series of hyperthermals, short periods of extreme atmospheric and oceanic warmth, may have occurred at this time. Negative peaks in the deep-sea oxygen isotopic record suggest a total of perhaps six hyperthermals during the late Paleocene to early Eocene, of which the most prominent one was the Paleocene-Eocene Thermal Maximum (Thomas et al., 2000). Another hyperthermal may have occurred at 60.5 Ma (Thomas and Zachos, 2000), coinciding with a short-term polar-wards expansion of the distribution of the warm-water dinoflagellate genus *Apectodinium* (Bujak and Brinkhuis, 1998), at about the same time as the Danian-Selandian sea-level event. Whether or not these events truly correlate remains to be proven, but the Paleocene-Eocene Thermal Maximum appears to coincide with eustatic sea-level fluctuations (Crouch, 2001; Speijer and Morsi, 2002; Speijer and Wagner, 2002, and references therein) like the Danian-Selandian transition. The biotic and abiotic events at the Danian-Selandian transition thus warrant a comparison with those of

the Paleocene-Eocene Thermal Maximum as observed in the Nile Basin.

The Paleocene-Eocene Thermal Maximum (~55.5 Ma) represents a brief period of global warming, particularly at high latitudes, associated with an ~3‰ negative carbon isotopic excursion (Zachos et al., 1993) that was likely related to massive methane release from continental margin sediments (e.g., Kennett and Stott, 1991; Dickens et al., 1995; Katz et al., 1999; Norris and Röhl, 1999). These climatic and oceanographic changes triggered major biotic extinctions and evolutionary innovations, particularly among deep-sea benthic foraminifera (e.g., Tjalsma and Lohmann, 1983; Thomas, 1998), marine micro- and nanoplankton (e.g., Kelly et al., 1996; Aubry, 1998; Crouch et al., 2001), and terrestrial mammals (e.g., Gingerich, 2000). In the Nile Basin, many of these were identified, including the carbon isotopic excursion, anomalous planktic foraminiferal assemblages characterized by numerous *Acarinina*, and a turnover in benthic foraminiferal assemblages (Speijer, 1994; Schmitz et al., 1996; Speijer et al., 1996, 2000; Charisi and Schmitz, 1998; Bolle et al., 2000; Speijer and Wagner, 2002). Some of the local paleoenvironmental changes were related to changes in sea level (Speijer and Morsi, 2002; Speijer and Wagner, 2002).

Several aspects of the Paleocene-Eocene Thermal Maximum in the Nile Basin are of particular interest in the comparison with the Danian-Selandian transition events (Table 5). Both events are marked by the onset of oxygen deficiency on the seafloor. During the Paleocene-Eocene Thermal Maximum, this

occurred virtually basin-wide (middle neritic to bathyal), whereas during the Danian-Selandian transition apparently only the middle-outer neritic realms were affected. Both events are characterized by anomalous planktic foraminiferal assemblages. Although oxygen deficiency perturbed the seafloor biota, the otherwise common keeled *Morozovella* virtually disappeared from the surface waters and nonkeeled muricate and praemuricate taxa (*Praemurica*, *Acarinina*) became very abundant. This indicates transient environmental anomalies perturbing the ecosystems of the entire water column. Sedimentologic features of both events (minor submarine erosion, sediment starvation, omission surfaces) may have resulted from sudden sea-level rise—associated with circulation changes—after a sea-level fall. Speijer and Morsi (2002) correlated the Paleocene-Eocene Thermal Maximum with the transgressive systems tract (TST) of third order sea-level cycle TA2.3 of Haq et al. (1988). The Danian-Selandian transgressive phase appears to correlate with transgressive deposits of the Selandian transgression of cycle TA1.4.

Many details concerning the actual existence of a Danian-Selandian hyperthermal, correlations between the open ocean and the Nile Basin, the sequence-stratigraphic and oxygen-isotopic records, and ecologic changes still need to be clarified. This time interval has as yet received very little attention compared with the Paleocene-Eocene Thermal Maximum. Nevertheless, the many similarities in sedimentologic features and biotic patterns in the Nile Basin during these two time intervals

TABLE 5. BIOTIC AND SEDIMENTARY FEATURES OF DANIAN-SELANDIAN EVENT, PALEOCENE-EOCENE THERMAL MAXIMUM, AND BACKGROUND CHARACTERISTICS

Parameter	Paleocene background	Danian-Selandian transition*	PETM†
Predominant lithology	Grey to pale-brown marl	Dark-brown marl	Dark-brown marl
Discontinuities	Some paraconformities	Unconformity	Some distinct
Systems tract	Various	Transgressive	Transgressive
Fish remains	Rare	Abundant	Abundant
Peloids	Rare	Rare	Abundant
Macrofossils	Rare	Common	Rare
TOC	<0.3%	0.8–2.0%	1.5–2.7%
Foraminifera:			
% Planktics (>125 μm)	70–95% P§	2–99.8% P	~99% P
<i>Morozovella</i> #	Common to abundant	Rare	Rare
<i>Praemurica</i> and <i>Acarinina</i>	Common to abundant	Dominant	Dominant
Benthic assemblage	Diverse**	Oligotaxic	Oligotaxic
Dominant benthic taxon	Depth dependent	<i>Neoeponides duwi</i>	<i>Anomalinoidea aegyptiacus</i>
Paleobathymetry	Middle neritic to bathyal	Not applicable††	Not applicable††
Oxygenation seafloor	Good to moderate	Poor	Poor (variable?)

Note: These features may not necessarily be present in every section studied. Paleocene-Eocene thermal maximum (PETM) characteristics from Speijer and Wagner (2002).

*Compilation of observations on sections Gebel Aweina, Gebel Duwi, Gebel Nezzi, Gebel Qreiya.

†Compilation of observations on the previous 4 sections plus Wadi Nukhl, and Ben Gurion (Israel).

§Lower percentages planktics (<50%) where dissolution has strongly affected the assemblages.

#*Morozovella* first appears in Danian Zone P2.

**Diversity increases with paleodepth.

††Paleobathymetric estimates based on benthic foraminifera are not reliable because of ecologic disturbance.

are significant, and suggest that at least in this basin similar processes have taken place. It is an intriguing consideration that the Danian-Selandian transition event may have been a precursor of the Paleocene-Eocene Thermal Maximum.

CONCLUSIONS

In Egypt, a marked relative sea-level fluctuation occurred during the Danian-Selandian transition at ~60.5 Ma. A local sequence boundary appears to correlate with sequence boundaries observed on other continental margins, suggesting eustatic control. In middle to outer neritic deposits in the Eastern Desert, the sea-level fluctuation is associated with an incursion of the anomalous *Neoeponides duwi* benthic foraminiferal assemblage, which is usually restricted to Danian-Selandian inner to middle shelf regions. During the early transgressive phase, dysoxic waters spread at middle to outer neritic depths. The patterns of environmental and biotic change associated with the Danian-Selandian transition in the Nile Basin show strong similarities with the ones associated with the Paleocene-Eocene Thermal Maximum in the same basin. The question arises whether the observed patterns may be linked to a hyperthermal during the Danian-Selandian as postulated on the basis of preliminary oxygen isotopic studies.

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APPENDIX 1

Systematic part

Speijer (1994) provides taxonomic concepts and synonymies of most benthic foraminiferal taxa mentioned in the main text. A few notes on *Neoeponides duwi* are presented here. An extensive taxonomic discussion is presented.

Neoeponides duwi (Nakkady)
(Fig. 8)

Synonymy

Discorbis pseudoscopos var. *duwi*—NAKKADY 1950, p. 689, Plate 90, Figures 5–7.

Discorbis pseudoscopos duwi Nakkady—ANAN and SHARABI 1988, Plate 2, Figure 15.

Discorbis duwi Nakkady—HEWAIDY 1994, Figure 13, nos. 7, 9 (not no. 8) (without description).

Discorbis duwiensis Nakkady—SCHNACK 2000, p. 49 of appendix, Plate 7, Figures 15, 16.

Neoeponides duwi lacks the characteristic apertural openings extending along the umbilical flaps in *Discorbis* and better fits with the generic concept of *Neoeponides* as defined by Reiss (1960). Note that Loeblich and Tappan (1987) provide a different view on the generic characters of *Neoeponides* (Hottinger et al., 1990).

Nakkady (1950) named *Discorbis pseudoscopos* var. *duwi* after the locality of Gebel Duwi. Following the general practice of naming species after localities by ending with “-ensis,” Schnack (2000) proposed to change the name *Discorbis duwi* to *Discorbis duwiensis*. However, the International Code of Zoological Nomenclature (Chapter 7, Article 32) does not allow such a change (International Commission on Zoological Nomenclature, 1999).

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