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Maastrichtian-Early Eocene litho-biostratigraphy and palæogeography of the northern Gulf of Suez region, Egypt

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ABSTRACT—The Maastrichtian-Lower Eocene sediments on both sides of the northern Gulf of Suez can be subdivided into eight formal formations (including one group) and one informal formation that are described in detail. These lithostratigraphic units reflect three different environmental regimes of deposition or non-deposition. The first regime is characterised by uplift and erosion or non-deposition resulting mostly from the uplift of the Northern Galala/Wadi Araba structure, a branch of the Syrian Arc Foldbelt. The shallow water carbonate platform and slope deposits of the Late Campanian-Maastrichtian St Anthony Formation and the Paleocene-Lower Eocene Southern Galala and Garra Formations represent the second regime and are found north and south of the Northern Galala/Wadi Araba High. The third regime is represented by basinal chalks, marls and shales of the Maastrichtian Sudr Formation and of the Paleocene-Eocene Dakhla, Tarawan and Esna Formations, the Dakhla/Tarawan/Esna informal formation and the Thebes Group. The distribution and lateral interfingering of the above mentioned environmental regimes reflect different vertical movements, changing basin morphology, sea level changes and progradation of shallow water sediments and is illustrated on 11 palæogeographic maps. © 2001 Elsevier Science Limited. All rights reserved.

RÉSUMÉ—Les sédiments du Maastrichtien et Eocène inférieur, affleurant de part et d'autre au nord du Golfe de Suez, peuvent être subdivisés en huit unités bien définies (incluant un groupe) et une unité plus informelle qui sont décrites en détail. Ces unités lithostratigraphiques témoignent de trois environnements sédimentaires différents. Le premier est caractérisé par une surrection et une érosion ou une absence de dépots qui résulte pour l'essentiel de la surrection de la structure du Northern Galala/Wadi Arabia, une branche de la ceinture plissée de l'arc Syrien. Un environnement de plateforme carbonatée peu profond, avec des dépots de pentes, correspondant à la formation de St Anthony du Campanien supérieur-Maastrichtien, et aux formations Paléocène-Eocène inférieur du Southern Galala et du Garra, représente le second régîme de dépôt; il est observé au Nord et au Sud du Northern Galala/Wadi Arabia High. Le troisième régîme est constitué par des craies de bassin, des marnes et des shales de la formation maastrichtienne de Sudr, des formations Paléocène-Eocène de Dakla, Tarawan et Esna, la formation informelle de Dakla/Tarawan/Esna et le groupe Thebes. La distribution des milieux de dépots précédents et leurs passages latéraux, témoignent de mouvements verticaux, de variations de la morphologie des bassins et du niveau marin, et de la progradation de sédiments d'eaux peu profondes. Ils sont illustrés par 11 cartes paléogéographiques. © 2001 Elsevier Science Limited. All rights reserved.

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INTRODUCTION

During the last decades, many authors investigated the stratigraphic subdivision of the Upper Cretaceous-Palæogene strata in the Galala Mountains and west central Sinai (Fig. 1). Most of these studies were focused on the bio- and lithostratigraphical interpretation of isolated sections. Only a few authors, such as Masters (1984) and Said (1990), concentrated on regional comparisons.

In this work, the stratigraphic results from the Galala Mountains and neighbouring areas are combined with literature data from numerous isolated sections (especially in west central Sinai). The authors concentrated on questions of lateral facies transitions and their stratigraphical synchroneity or diachroneity. Special emphasis is put on the interfingering of shallow water limestones over swells and tectonically induced uplifts, and basinal marls and shales. The results of the facies investigation, in combination with the different types of hiatuses observed in the area, led to a detailed palæogeography of the Maastrichtian to Early Eocene that is documented in 11 maps.

GEOLOGICAL SETTING

The investigated area represents a segment of the northern passive margin of the Afro-Arabian Plate. This passive margin formed during the Late Triassic/ Jurassic opening of the Neotethys. The extensional tectonic processes resulted in the formation of east-west-striking northward-deepening half-grabens that were mostly covered by the Late Triassic-Early Cretaceous seas, depending on, among others, sea level fluctuations. Beginning with the initial stages of the collision between the African and European Plates during Turonian times, a dextral transpressive reactivating of the half-grabens took place along the North African-Arabian Plate boundary (e.g. Moustafa and Khalil, 1995). As a consequence, a system of inverted, uplifted and folded grabens was formed along the Syrian Arc System (Fig. 1). This area is also known in Egypt as the 'unstable shelf' (Krenkel, 1925; Said, 1960). It contrasts with the tectonically unaffected area further south ('stable shelf'). While the latter is characterised by lithologically uniform marine strata, formed on a gently north-dipping shelf, small-scaled facies variations are obvious within the basin-swell-morphologies of the unstable shelf area (Kuss *et al.*, 2000). The Galala Mountains in the Eastern Desert, together with areas in western Sinai, represent a southern branch of the Syrian Arc called the Northern Galala/Wadi Araba (NGWA) High (Kuss *et al.*, 2000) (Fig. 2). The Upper Cretaceous-Palæogene carbonate dominated successions of a south- and north-dipping carbonate ramp prograde from the Northern Galala/Wadi Araba High. Facies transitions between the Paleocene shallow water ramp carbonates and deeper water intrashelf marls of the Southern Galala Sub-basin (Fig. 2) farther south have been studied in sections along the dip direction. Mass transport deposits like slides, slumps and debris flows occur (Scheibner *et al.*, 2000).

METHODS

The study area is exposed around the northern parts of the Gulf of Suez. Eight Upper Cretaceous-Palæogene sections of the Northern and Southern Galala on the western side of the Gulf of Suez were investigated in detail (Fig. 3), including the northern and southern forelands of the Galalas. Additionally, data of west central Sinai, opposite to the working area, was reviewed.

Facies interpretations are based on fine-scale logging of stratigraphic sections in and along the Northern Galala/Wadi Araba High. Studies of 169 thin sections of the Maastrichtian-Early Eocene interval are supplemented by 479 marl samples that formed the base for a high-resolution biostratigraphic frame based on planktic and benthic foraminifers and calcareous nannoplankton.

BIOSTRATIGRAPHY

For the Maastrichtian, the biostratigraphic scheme given by Perch-Nielsen (1985) and Norris *et al.* (1998) (Fig. 4) was followed. The biostratigraphic schemes of Berggren *et al.* (1995) for planktic foraminifers (P-zones), of Martini (1971) for calcareous nannolankton (NP-zones) and of Serra-Kiel *et al.* (1998) for shallow benthic foraminifers (SB-zones) are used for the Paleocene and Early Eocene. The calibration of planktic foraminifers and calcareous nannoplankton is from Norris *et al.* (1998) for the Cretaceous and from Berggren *et al.* (1995) for the Palæogene (Fig. 4). In section T2 (Fig. 4a), NP10 could be divided into four sub-zones, named NP10a, NP10b, NP10c and NP10d, following Aubry (1995). In sections T1, D2 and D3 (Fig. 4a), NP10 can only be subdivided into two sub-zones (NP10a–c and NP10d) because *T. digitalis* could not be found. Faris and Strougo (1998) and Aubry *et al.* (1999) also used this subdivision in their description of the Esna Shales of Egypt. In addition to Berggren *et al.* (1995), Speijer *et al.* (2000) was followed in subdividing the planktic foraminiferal biozone P5 into P5a, P5b and P5c. The very short sub-zone P5b is characterised by the total range of *M. allisonensis* marking the Late Paleocene thermal maximum.

All sections presented in Fig. 4 were recalibrated to the above mentioned schemes. If planktic foraminifers,

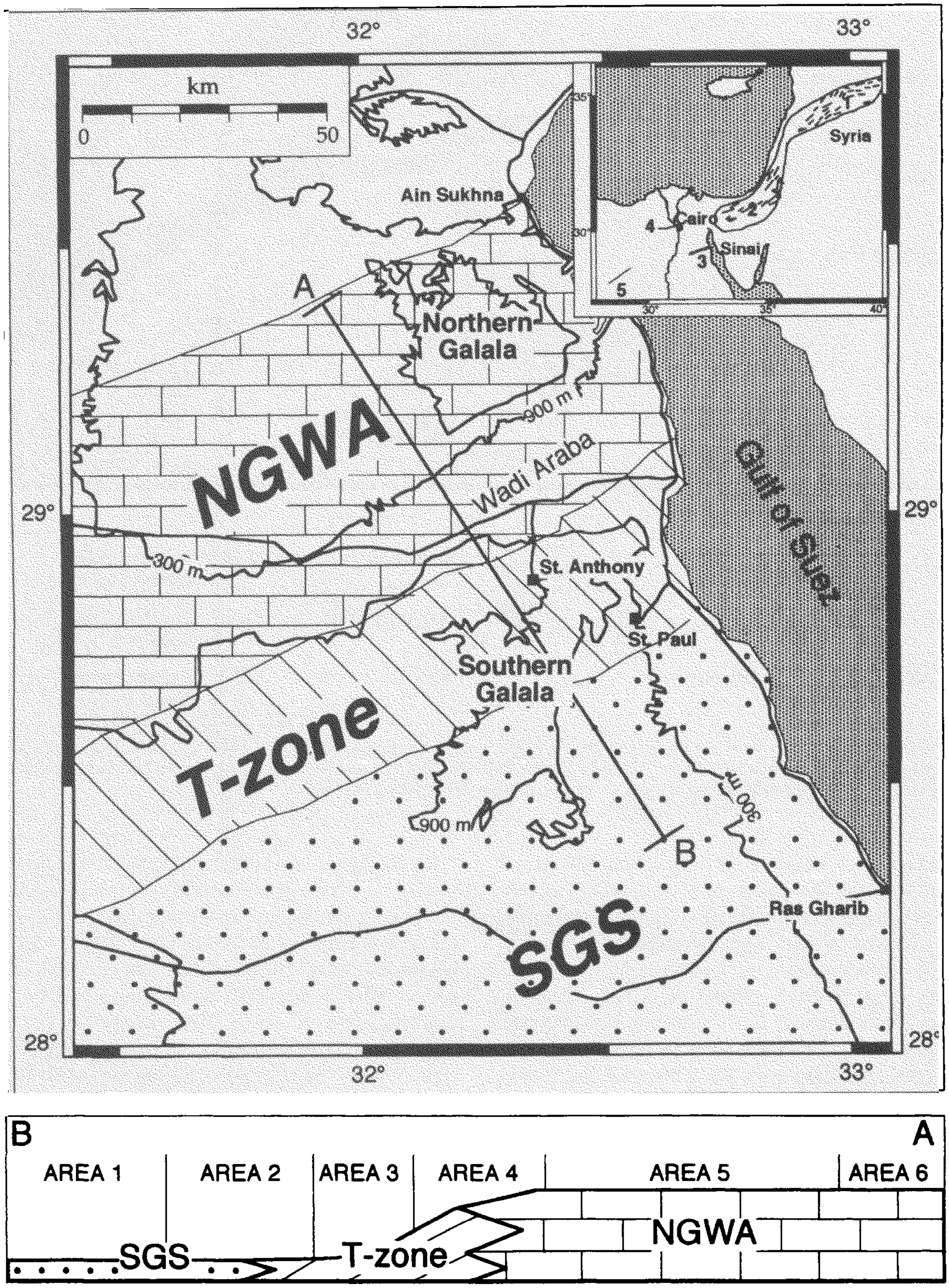


Figure 1. The two Galala Plateaus at the western Gulf of Suez forming part of a Syrian Arc Fold in the Eastern Desert (see inset). 1: Palmyrid Fold Belt; 2: Negev-Sinai Fold; 3: Northern Galala/Wadi Araba High; 4: Abu Roash; 5: Bahariya Uplift/Western Desert. During Late Cretaceous-Palæogene times, the platform (NGWA) to basin (SGS) transitions (T-zone) were formed roughly parallel with the strike of the Galalas. In transect A–B (bottom of the figure), the boundaries of areas 1–6 are indicated.

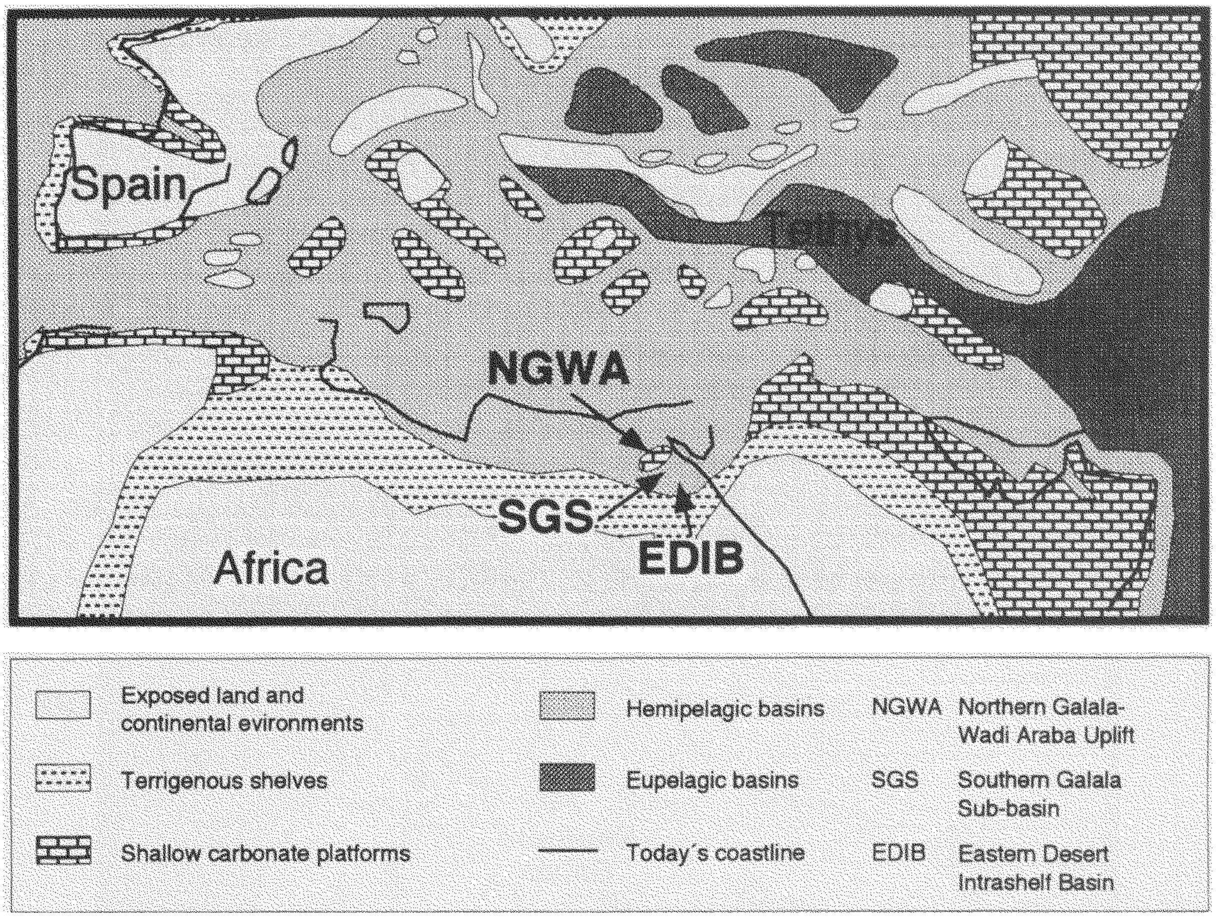


Figure 2. *Latest Maastrichtian palæogeographic map of the circum-tethyan realm (modified after Camoin* et al., *1993). The area of investigation is around the Northern Galala/Wadi Araba and reaches to the Southern Galala Sub-basin in the south. The Southern Galala Sub-basin is part of the Eastern Desert Intrashelf Basin.*

as well as calcareous nannofossils, were used for bio-stratigraphy. The calcareous nannoplankton was given priority. The biostratigraphic scheme which is used (planktic foraminifers or calcareous nannoplankton) is indicated in the figures.

Luger *et al.* (1998) presented a new planktic foraminiferal biozonation for the Maastrichtian for those areas in which the Late Maastrichtian index fossil *A. mayaroensis* is very rare or absent. Marzouk and Lüning (1998) described a strong variability of planktic foraminifers and calcareous nannoplankton correlations on Sinai, especially in the lower Paleocene, whereas in the upper Paleocene the different zonal correlations are in good agreement. Boukhary and Abdelmalik (1983) and El-Dawoody (1992) reviewed the biostratigraphy of the Late Paleocene-Eocene succession in Egypt.

LITHOSTRATIGRAPHY OF MAASTRICHTIAN-EARLY EOCENE STRATA

Ever since the first description of the Maastrichtian to Eocene sediments in the Western Desert by Zittel (1883) (Fig. 5), the lithostratigraphic subdivision of the Upper Cretaceous-Eocene successions in Egypt has been the subject of many discussions, especially during the 1950s–1960s (Nakkady, 1950, 1957; El-Naggar, 1966a, 1966b, 1968; Sabry 1968). Even today, lithostratigraphic terminology is used non-uniformly (Issawi *et al.*, 1999), especially the Esna Formation (Hermina and Lindenberg, 1989). For terminology, the authors used Hermina *et al.* (1989) as a basis, especially with respect to usage of litho-stratigraphic subdivision. In accordance with recommendations of the International Stratigraphic Guide (Salvador, 1994), they describe lithostratigraphic units by a geographic term combined with a unit term instead of a geographic term combined with a lithological term to allow for lithological variability (e.g. Esna Formation instead of Esna Shale, as has been used frequently in the past).

In the following paragraph, a short summary of the commonly used formations and their regional distribution of the Upper Cretaceous-Palæogene litho-stratigraphic units for northern Egypt and Sinai is given,

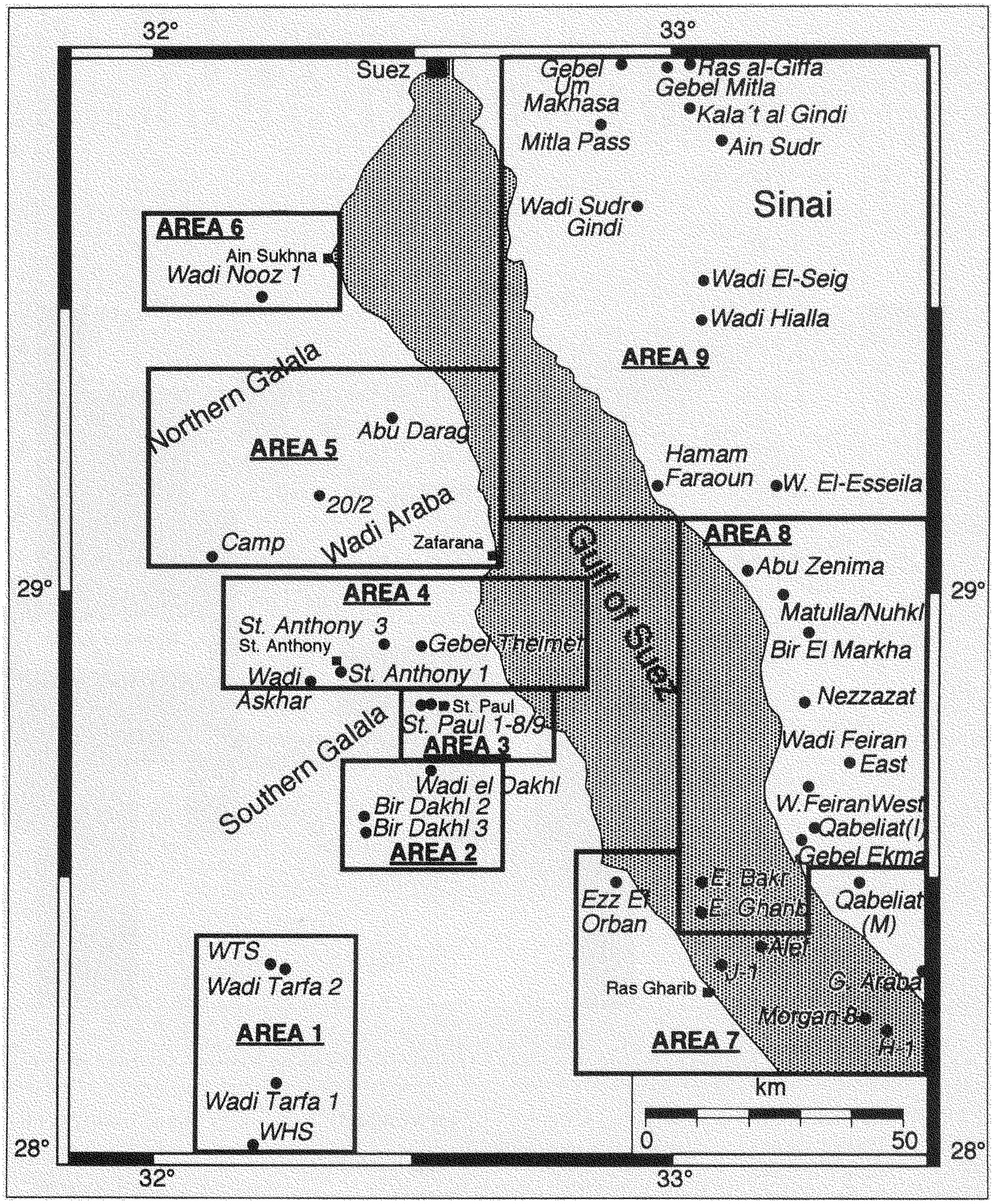


Figure 3. Section map of the northern part of the Gulf of Suez. The nine rectangles represent areas of different depositional history. The sections in areas 1–6, on the western side of the Gulf of Suez (Galala Mountains), are based on new and literature data; whereas the sections of areas 7–9, on the eastern side of the Gulf of Suez (Sinai), are based on literature data only.

including some additional suggestions (Fig. 5). A detailed historical overview can be found in El-Naggar (1966a, 1966b) and Issawi (1972).

According to the description of Zittel (1883) of the Upper Cretaceous to Lower Eocene sediments in the Western Desert (Farafra, Dakhla and Kharga) (Fig. 5), the following lithostratigraphic units occur from bottom to top: *Overwegi* layers; ash-grey shales ('aschgraue Blätterthone'); snow-white layered limestone or chalk with *Ananchytes ovata*; green shales ('grünliche Blätterthone'); and *Operculina* limestone (Unterlibysche Stufe). Near Esna, Zittel (1883), miscorrelated the green shales underlying the *Operculina* limestone with the Danian 'ash-grey shales' of the Western Desert. With this miscorrelation, a long confusion of lithostratigraphic terminology started.

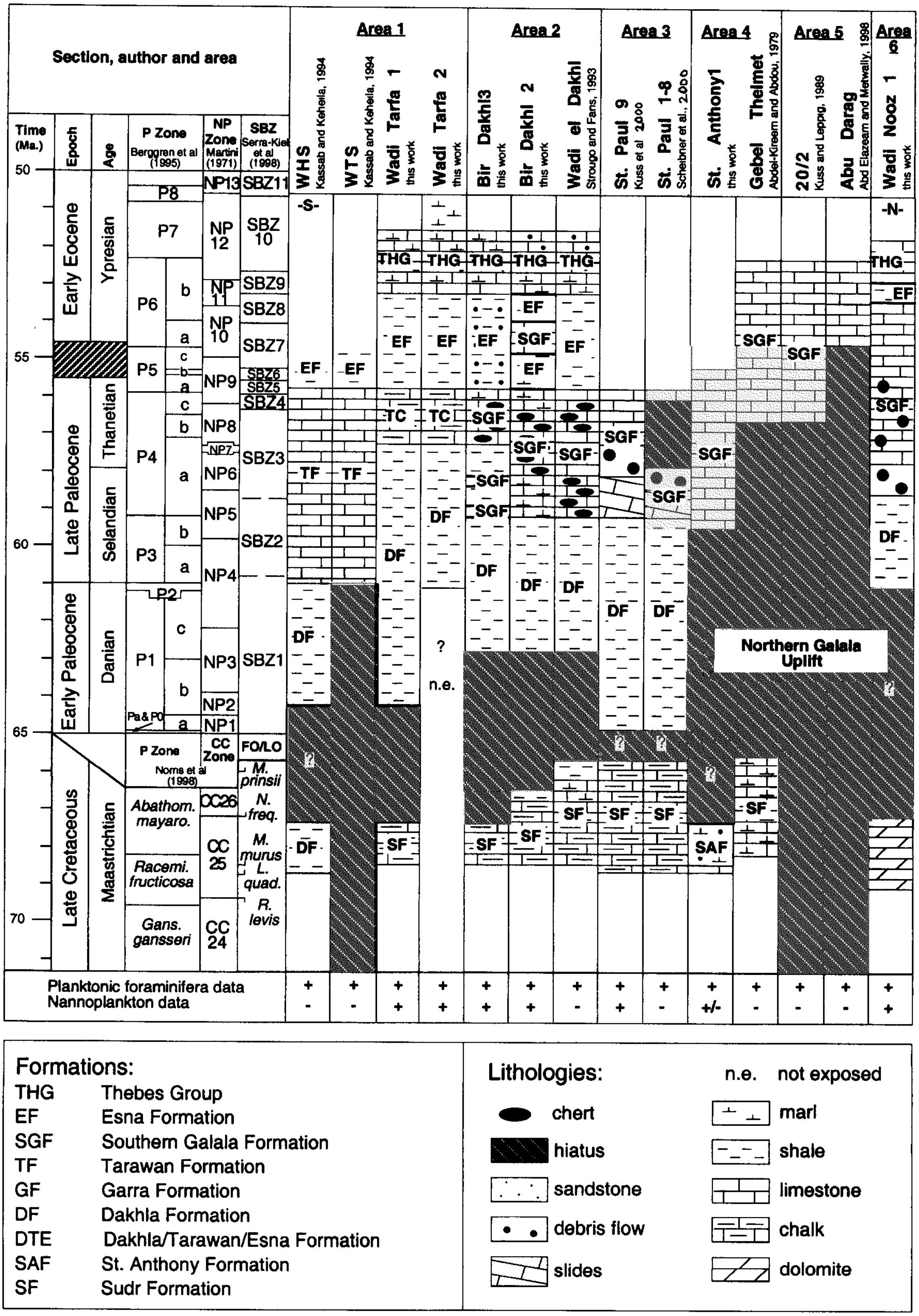


Figure 4. The biostratigraphy and lithology of newly measured Maastrichtian-Palæogene sections, including sections taken from literature. The broad grey band reflects the current opinion on the position of the Paleocene-Eocene boundary. The biozonations of planktonic foraminifers (P zones), calcareous nannoplankton (NP zones for Palæogene and CC zones for Maastrichtian) and shallow benthic foraminifers (SBZ) are listed. In the Maastrichtian, the first and last occurences of calcareous nannoplankton index forms are indicated. The different biozonal schemes used are indicated with + (used) and - (not used). Other biozonal schemes such as shallow benthic foraminifers, macrofossils and ammonites are rarely used here and are not listed. The black areas indicate hiatuses, due to erosion or non-deposition. Question marks indicate uncertain stratigraphical ranges. (a) Sections of areas 1–6, on the western side of the Gulf of Suez (Galala Mountains), are mostly newly measured sections together with sections from literature.

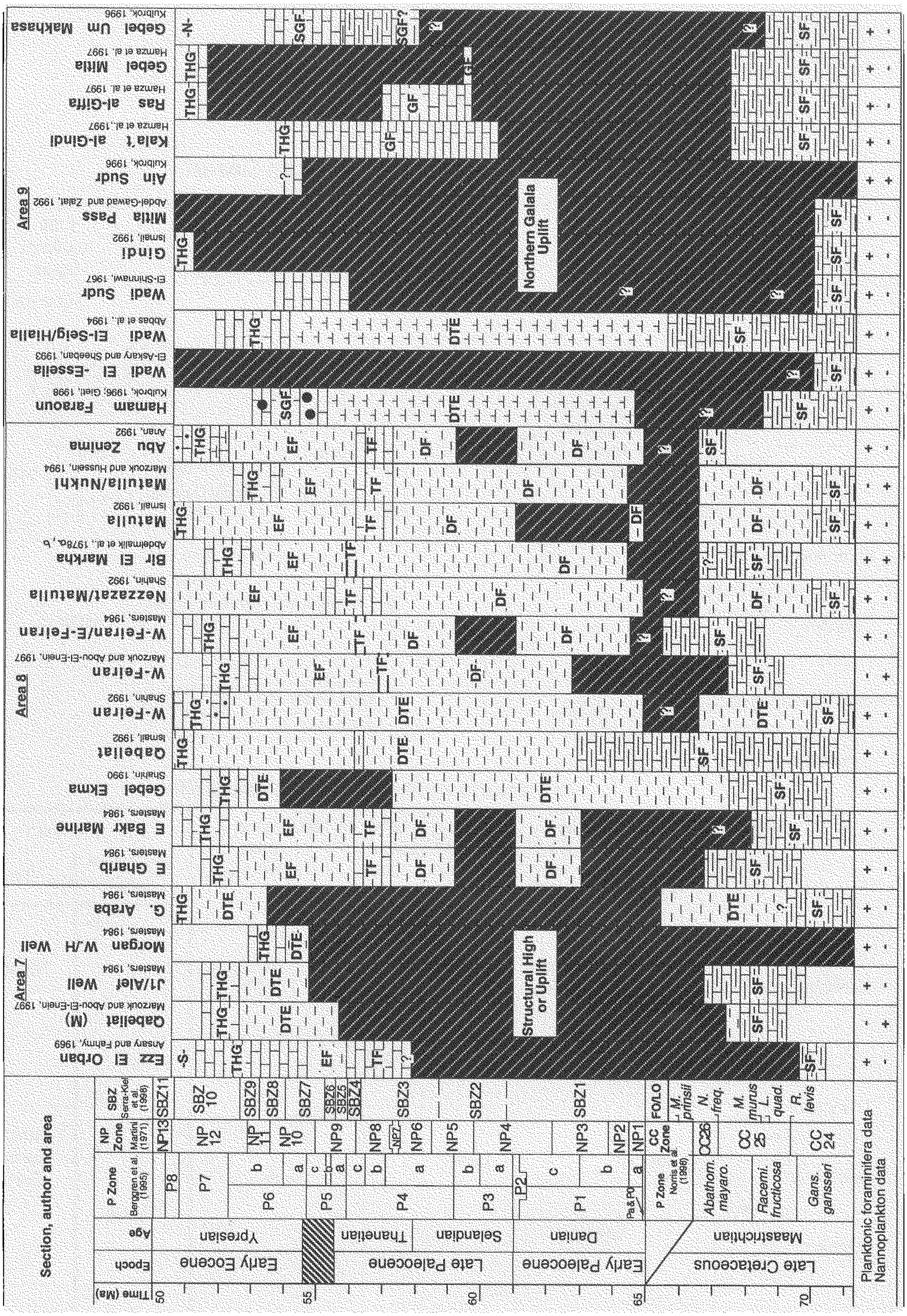


Figure 4. *continued. The biostratigraphy and lithology of newly measured Maastrichtian-Palæogene sections, including sections taken from literature. The broad grey band reflects the current opinion on the position of the Paleocene-Eocene boundary. The biozonations of planktonic foraminifers (P zones), calcareous nannoplankton (NP zones for Palæogene and CC zones for Maastrichtian) and shallow benthic foraminifers (SBZ) are listed. In the Maastrichtian, the first and last occurences of calcareous nannoplankton index forms are indicated. The different biozonal schemes used are indicated with + (used) and - (not used). Other biozonal schemes such as shallow benthic foraminifers, macrofossils and ammonites are rarely used here and are not listed. The black areas indicate hiatuses, due to erosion or non-deposition. Question marks indicate uncertain stratigraphical ranges. (b) Sections of areas 7–9, on the eastern side of the Gulf of Suez (Sinai), are entirely from literature. Unfortunately, it is not clear from which part of Gebel Qabeliat Marzouk and Abou-El-Enein (1997) took their section. Because of the hiatus, this section was attributed to area 8, whereas section Gebel Qabeliat of Ismail (1992) belongs to area 7.*

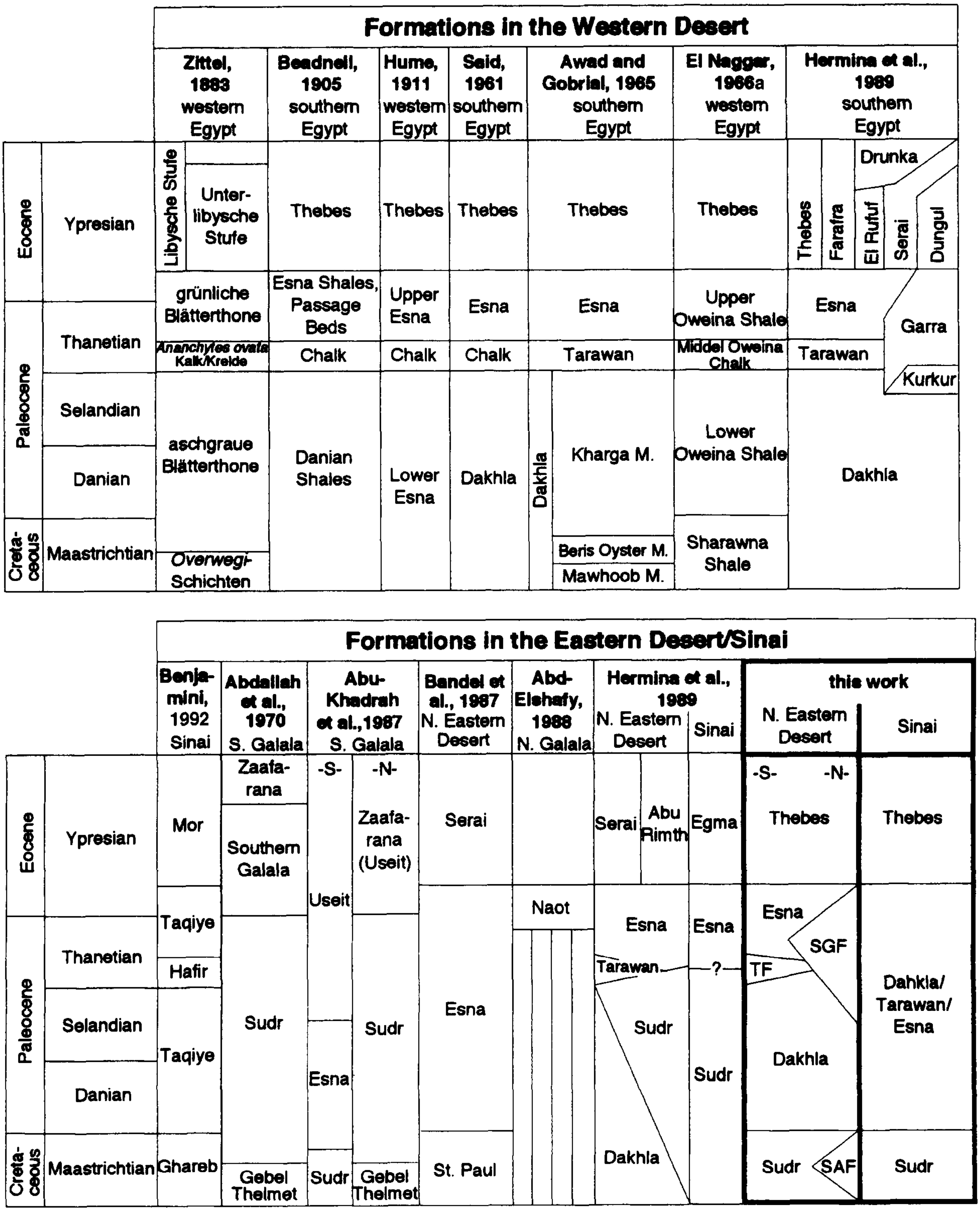


Figure 5. Lithostratigraphical schemes in the Western Desert and in the Eastern Desert/Sinai. Today, in southern Egypt, the lithological subdivison of Said (1961) is accepted. In northern Egypt, this subdivision is not applicable due to the thin or even absent Tarawan Formation (TF). Most authors ignore that fact and just expand the Esna Formation down to the Maastrichtian, but this leads to misinterpretations. Therefore, in this study, the informal Dahkla/Tarawan/Esna Formation was introduced. SAF: St Anthony Formation; SGF: Southern Galala Formation.

Beadnell (1905) described, for the first time, an 'Esna Shale' unit above the chalk (Tarawan) and the Danian shales as passage beds between the Cretaceous and the Eocene. Hume (1912) mentioned the Lower and the Upper Esna Shales below and above the chalk (Tarawan), respectively. Later, Said (1961) introduced the Dakhla Shale as a new formation, replacing the Danian shales of Beadnell (1905) and the Lower Esna of Hume (1912). The chalk between the Dakhla and Esna Formations was named the Tarawan Chalk by Awad and Ghobrial (1965). Since then, the terms Dakhla Formation (DF), Tarawan Formation (TF) and Esna Formation (EF) have been generally accepted for the lithostratigraphic subdivision in southern and western Egypt (Hermina and Lindenberg, 1989). El-Naggar (1966a, 1966b) introduced the terms Lower Oweina Shale, Middle Oweina Chalk and Upper Oweina Shale for the Tertiary part of the Dakhla, Tarawan and Esna Formations, but this lithostratigraphic scheme found little acceptance in the scientific community.

The subdivision of Awad and Ghobrial (1965) cannot be applied to the Late Cretaceous-Palæogene strata of northern Egypt and Sinai, however, because the Tarawan Formation is partly absent or very thin. Although Hermina and Lindenberg (1989) attributed a Late Paleocene to Early Eocene age to the Esna Formation, they mentioned *that "the upper part of the Dakhla, the Tarawan and the Esna which range from Paleocene to Early Eocene age in southern Egypt are represented in northern Wadi Qena and on Sinai by the Esna Formation which overlies the Maastrichtian-Paleocene Sudr Formation, and underlies the Lower Eocene limestone (Thebes).*" This usage has lead to a stratigraphic miscorrelation of the Esna Formation that ranges in southern and western Egypt only from Upper Paleocene to Lower Eocene, whereas in northern Egypt and Sinai it starts as early as the latest Maastrichtian (e.g. Said, 1990; Lüning *et al.*, 1998a). Therefore, the authors propose the Dakhla/Tarawan/Esna Formation (DTE) as an informal lithostratigraphic unit for Upper Maastrichtian-Lower Eocene shales and marls in those parts of northern Egypt and Sinai where the Tarawan Formation cannot be differentiated (Fig. 5).

The Dakhla, Tarawan and Esna Formations and their earlier denotations are widely used in Egypt. On Sinai, however, the Maastrichtian-Eocene successions were also subdivided according to the schemes for southern Israel. There, the synonyms for the Sudr, Tarawan and Esna Formations and Thebes Group are Ghareb Formation, Hafir Member, Taqiye Formation and Mor Formation (Bartov and Steinitz, 1977; Romein, 1979; Benjamini, 1992), respectively. Where the chalky Tarawan Formation (Hafir Member) is missing on Sinai, the entire shaley to marly formation, ranging from Paleocene to Early Eocene times is referred to as Esna Formation (Said, 1990) or Taqiye Formation (e.g. Bartov and Steinitz, 1977).

FORMATIONS AND THEIR DISTRIBUTION WITHIN THE STUDY AREA

Discussed below are the eight formal formations (including one group) and one informal formation and their distributions within the nine areas west (areas 1–6) and east (areas 7–9) of the Gulf of Suez (Fig. 3). The sections within the single areas are grouped together because of their stratigraphical and lithological similarities. The stratigraphic intervals range from Maastrichtian to Lower Eocene. Areas 1–6 are located in the Eastern Desert west of the Gulf of Suez, oriented from south (area 1) to north (area 6) (Figs 1, 3, 4a and 6). On the eastern side of the Gulf of Suez (west central Sinai), the areas 7–9 are also orientated from the south (area 7) to the north (area 9) (Fig. 4b). The transition of the Early Eocene shallow water Southern Galala Formation (SGF) to the deeper water Thebes Group (THG) in the working area is not a subject of the study. Therefore, the attribution of these sediments to one or the other formation is less certain. All sections studied (and additional literature) are listed in Table 1, the biostratigraphical and lithostratigraphical correlations of most sections are given in Fig. 4a, b. To illustrate the changing distribution of the various lithologies with time, palæogeographic maps of the investigated area are presented for 11 Maastrichtian to Early Eocene time slices.

Sudr Formation (SF) (Figs 4a, b and 7c, e)

Author and type section: Ghorab (1961); Wadi Sudr (west central Sinai)

Stratigraphical range: Campanian-Maastrichtian (Lower Paleocene?)

The contact of the Sudr Formation to the overlying Dakhla Formation is either sharp, in which case it usually coincides with the Cretaceous/Palæogene boundary, or is more gradual, in which case (areas 2, 7, 8) the Sudr Formation terminates within late or latest Maastrichtian biozone CC25 or CC26 (Fig. 4a, b).

Lithology: Massive white and cream chalk and chalky limestone beds with thin intercalations of light grey calcareous shales and argillaceous crystalline limestones. The Sudr Formation was studied in areas 1, 2 and 3 (sections T1, D2, D3 and S1–9) where it is composed of alternating beds of white chalk (up to 1.20 m) and thin grey marls (up to 0.10 m). In St Paul (area 3), a 1.3 m thick shaley unit is intercalated in the upper part of biozone CC25c, which is also typical for transitional beds on Sinai.

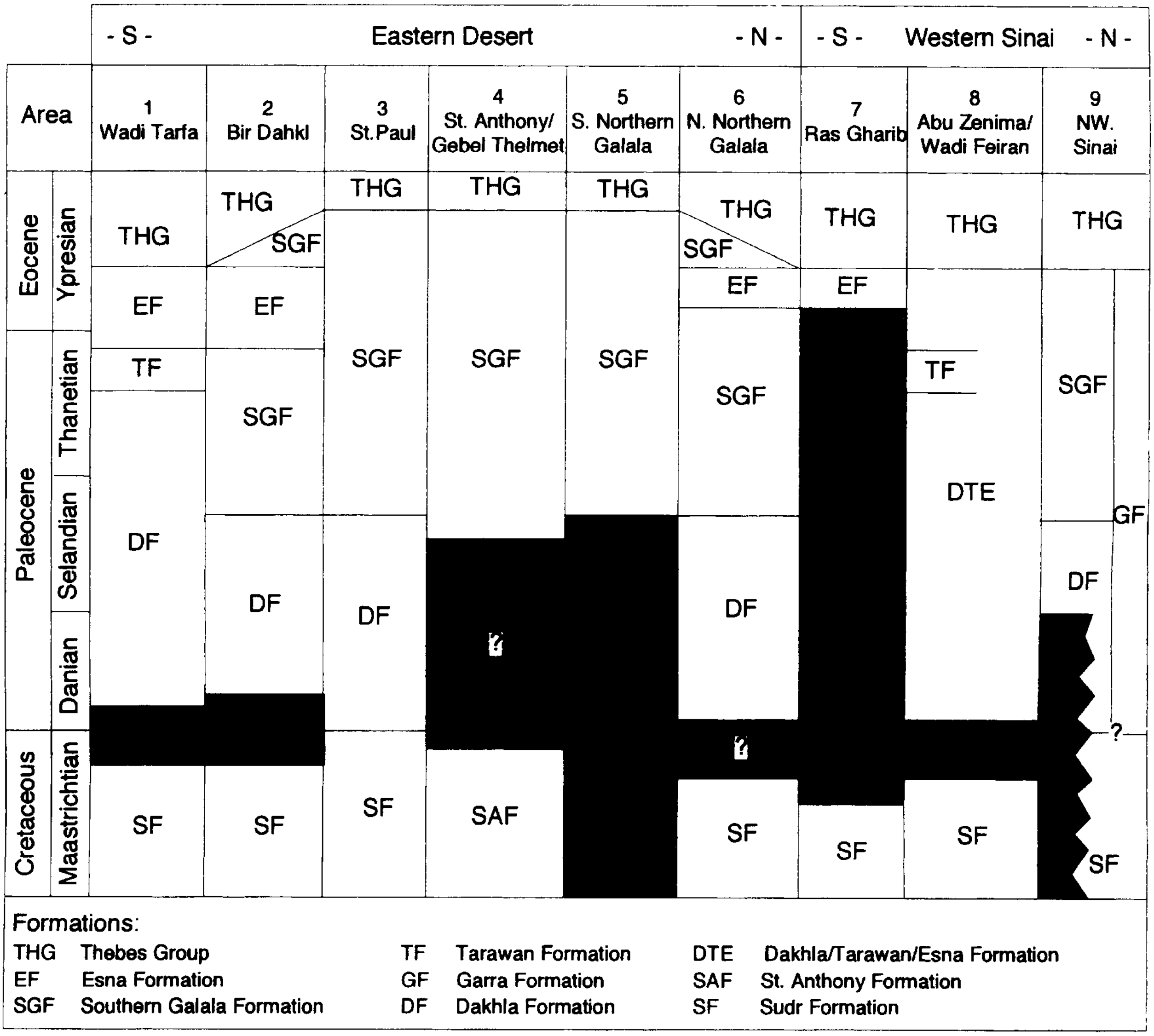


Figure 6. Distribution and age of formations in the nine investigated areas. The black units are hiatuses due to erosion or non-deposition. In area 9, on northwestern Sinai, the stratigraphical range is uncertain because of varying stratigraphical ranges of the rock units within this area.

Table 1. Sections that were newly measured or taken from literature

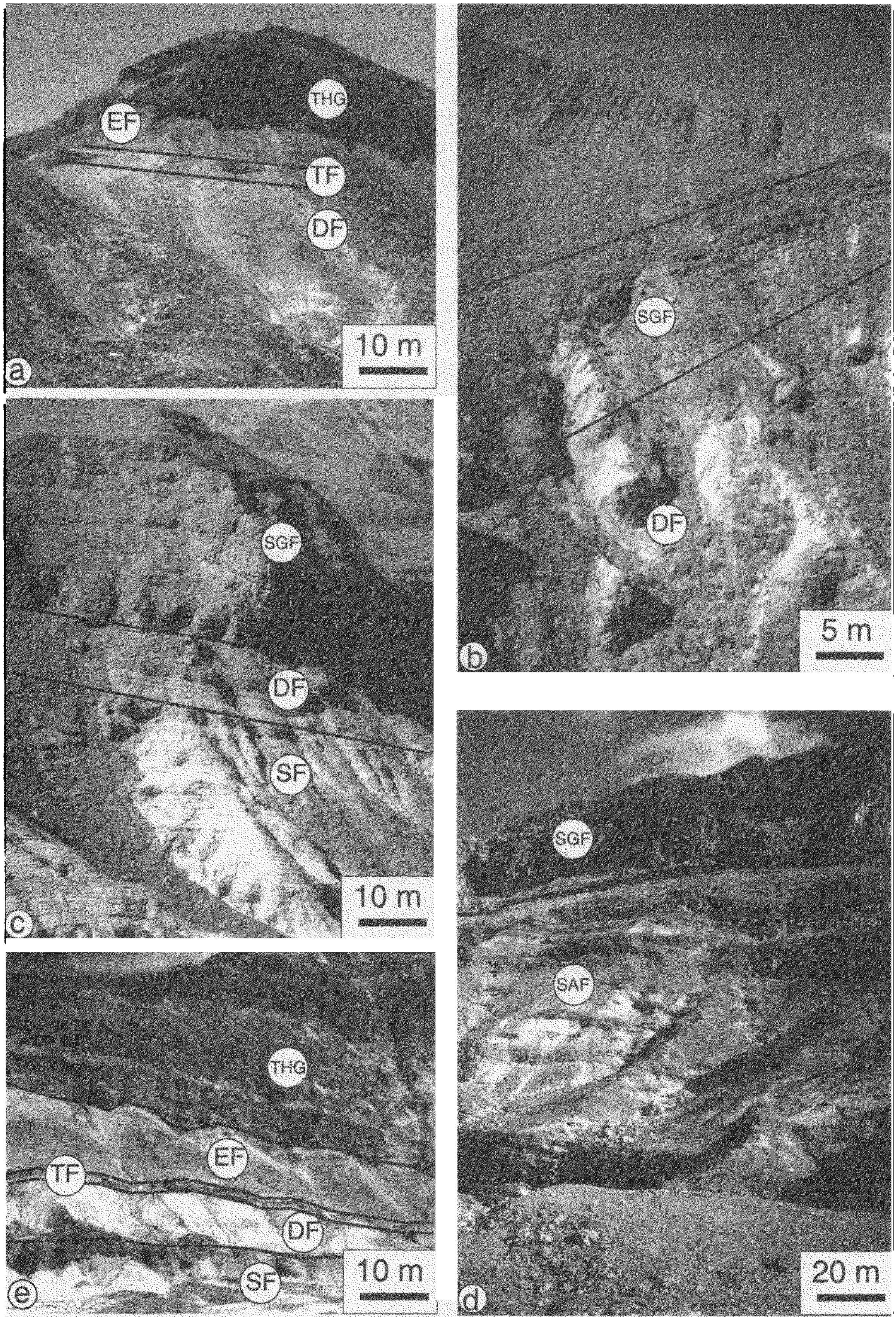
Area	Profile/Location	Coordinates	Author
1	WHS/Wadi Hawashiya	without exact location	Kassab and Keheila, 1994
	WTS/Wadi Tarfa	without exact location	Kassab and Keheila, 1994
	O/Wadi Hawashiya	140 km east of El Sheikh fadl	El-Dawy, 1999
	S/Wadi Hawashiya	151 km east of El Sheikh fadl	El-Dawy, 1999
	T1/Wadi Hawashiya	N28°13,52′; E32°13,64′	This work
	T2/Wadi Tarfa	N28°27,31′, E32°13,73′	This work
	Section 11/Wadi Tarfa	without exact location	Nishi *et al.*, 1994
	Section U/Wadi Tarfa	without exact location	Bandel *et al.*, 1987
	Wadi Tarfa	without exact location	Tantawy *et al.*, 2000
2	D3/Bir Dakhl	N28°36,43′; E32°23,77′	This work
	D2/Bir Dakhl	N28°39,61′; E32°23,59′	This work
	WD/Wadi Dakhl	without exact location	Strougo and Faris, 1993
	Abu Rimth 1-3	N28°43′; E32°,30′	Gietl, 1998
	Bir Dakhl	without exact location	Metwally and Abd El Azeam, 1997

If coordinates are given in the literature, then they are mentioned here. Coordinates with a star do not indicate geographical points, but rather geographical ranges given by the authors.

Table 1. continued.

Area	Profile/Location	Coordinates	Author
3	S9/St. Paul	N28°50,37´; E32°31,53´	Kuss *et al* , 2000
	S1–S8/St. Paul	N28°50,72´; E32°31,29´	Scheibner *et a* l., 2000
	St. Paul	N28°50,63´; E32°32,62´	Strougo *et al*., 1992
	St. Paul	N28°50,63´; E32°32,62´	Haggag (1991)
	St. Paul	without exact location	Ismail and Abdallah, 1966; Abdou *et al*., 1969; Mazhar *et al*., 1979; Strougo, 1986; Bandel and Kuss, 1987, Girgis, 1987; Kuss and Leppig, 1989; Faris, 1997; Kulbrok, 1996; Boukhary *et al*., 1998
4	A1/St. Anthony	N28°54,95´; E32°21,21´	Kuss and Leppig, 1989; Kulbrok, 1996; this work
	A3/E of St. Anthony	N28°56,72´; E32°25,14´	this work
	Wadi Askhar	without exact location	Selima and Askalany, 1996
	St. Anthony	without exact location	Zittel, 1883; Awad and Abdallah, 1966; Kuss, 1986; Bandel and Kuss, 1987; Kuss and Malchus, 1989; Malchus, 1990; Kuss *et al.* , 2000
	GT/Gebel Thelmet	without exact location	Abdel-Kireem and Abdou, 1979
	Gebel Thelmet	without exact location	Hottinger, 1960; Abdallah *et al*., 1970; Abdallah and Eissa, 1970; Abdel-Kireem, 1971; Mazhar *et al*., 1979; Kulbrok, 1996
5	20/2/S North Galala	without exact location	Kuss and Leppig, 1989; Malchus, 1990
	AD/Abu Darag	without exact location	Abd-Elazeam and Metwally, 1998
	Camp/S North Galala	without exact location	Gietl, 1998
	Several/S North Galala	without exact location	Abd-Elshafy and Atta, 1993
6	N1/Wadi Nooz	N29°31,86´; E32°11,24´	This work
	Wadi Nooz	without exact location	Gietl, 1998
	Wadi Noat/Wadi Nooz	without exact location	Abd-Elshafy and Atta, 1993
7	EEO/Ezz El-Orban	without exact location	Ansary and Fahmy, 1969 Barakat and Fahmy, 1969
	Qabeliat	without exact location	Marzouk and Abou-El-Enein, 1997
	J1/Gulf of Suez	without exact location	Masters, 1984 (Kerdany and Abdel Salam, 1970)
	Alef Well/Gulf of Suez	without exact location	Masters, 1984 (Kerdany and Abdel Salam, 1970)
	Morgan 8/Gulf of Suez	without exact location	Masters, 1984 (Kerdany and Abdel Salam, 1970)
	H-1 Well/Gulf of Suez	without exact location	Masters, 1984 (Kerdany and Abdel Salam, 1970)
	G. Araba/Gebel Araba	without exact location	Masters, 1984
8	AZ/Abu Zenima	without exact location	Anan, 1992
	Matulla	without exact location	Shahin, 1992; Ismail, 1992, 1996; Marzouk and Hussein, 1994; IObaidalla, 1999
	Nezzazat	without exact location	Shahin, 1992
	Nuhkl	without exact location	Marzouk and Hussein, 1994
	BEM/Bir El-Markha	without exact location	Abdelmalik, 1978a, 1978b
	Qabeliat	without exact location	Ismail, 1992
	Wadi Feiran	without exact location	Shahin, 1992
	Wadi Feiran	without exact location	Marzouk and Abou-El-Enein, 1997
	Wadi Feiran	without exact location	Masters, 1984
	Gebel Ekma	without exact location	Shahin, 1990
	E-Bakr Marine 1/Gulf of Suez	without exact location	Masters, 1984 (Kerdany and Abdel Salam, 1970)
	E-Feiran	without exact location	Masters, 1984
	Wadi Feiran	without exact location	Masters, 1984
	E. Gharib/Gulf of Suez	without exact location	Masters, 1984 (Kerdany and Abdel Salam, 1970)
	Gebel Qabeliat	without exact location	Faris *et al*., 1986; Allam and Khalil, 1989
	4 Sections/Abu Rudeis	without exact location	Cherif *et al*., 1989
	Gebel Nezzazat	without exact location	Arafa 1991
	SE Nezzazat/Wadi Feiran	without exact location	El Sheikh and El Beshtawy, 1992
	some sections/Wadi Feiran	without exact location	El-Deeb and El-Gammal, 1997
	Wadi Nukhl	without exact location	Monechi *et al*., 1999
	Wadi Feiran	*N28°40´–50´; E33°20´–30´	Eweda and El-Sorogy, 1999
9	Gindi/Gebel Gindi	without exact location	Ismail, 1992; Ismail, 1996
	Gebel Um Makhasa	without exact location	Kulbrok, 1996
	Gebel Gindi	without exact location	Kulbrok, 1996
	Wadi Sudr	N29°50,34´; E33°05,08´	Gietl, 1998
	Wadi Sudr	without exact location	Youssef and Shinnawi, 1954; El-Shinnawi, 1967

If coordinates are given in the literature, then they are mentioned here. Coordinates with a star do not indicate geographical points, but rather geographical ranges given by the authors.


a
EF
THG
TF
DF
10 m
b
SGF
DF
5 m
c
SGF
DF
SF
10 m
d
SGF
SAF
20 m
e
THG
EF
TF
DF
SF
10 m

Synonymy: Synonymous with the St Paul Formation of Kuss (1986), Bandel *et al.* (1987) and Bandel and Kuss (1987) (Fig. 5).

Regional distribution: The Sudr Formation is only found in northern Egypt and Sinai.

At St Anthony (area 4), the chalks of the Sudr Formation have a Late Campanian age. They are disconformably overlain with an erosional surface by the units of the St Anthony Formation (SAF) (Fig. 7d).

The stratigraphical range of the Sudr Formation at Abu Zenima/Wadi Feiran (area 8) is not clear. Most authors agree that it terminates in the Upper Maastrichtian; however, some authors indicate that the Sudr Formation continues up to the Cretaceous/Palæogene boundary (Fig. 4b). Only Ismail (1992) extended its stratigraphical range at Gebel Qabeliat to the Lower Paleocene, which seems to depend on how transitional beds are classified.

The chalks Kulbrok (1996) described at Ain Sudr (area 9) are of Upper Campanian age (*Globotruncana aegyptiaca* Zone) and those of Gebel Gindi and Hamam Faraoun are of Maastrichtian age (*Gansserina gansseri* Zone).

Both sections in Wadi Nooz (area 6) start with 25 m massive thick bedded dolomites, which may be attributed to the Sudr Formation. However, dolomitisation has prohibited a conclusive stratigraphical assignment. Similar lithologies were described from the Sudr Formation of Sinai (Youssef and Shinnawi, 1954; El-Shinnawi, 1967). Alternatively, these dolomites may be attributed to the underlying Turonian Strata (Abd-Elshafy and Atta, 1993).

In northwestern Sinai (area 9), Youssef and Shinnawi (1954) and El-Shinnawi (1967) described 175 m of pinkish-white bedded chalks and chalky limestones that change to yellowish-white hard dolomitic limestone in its upper part. Samples of the upper part were thought to contain rare Maastrichtian foraminifers and *Subbotina triloculinoides* of Paleocene age (El-Shinnawi, 1967). The scarcity and the poor preservation of the foraminifers strongly puts the latter assignment into doubt, although reworking may be a possible explanation. Forty-five metres below the base of the Sudr Formation, Youssef and Shinnawi (1954) and El-Shinnawi (1967) found *Exogyra* cf. *overwegi*, which correlate in area 4 (St Anthony) to the Middle/Late Maastrichtian St Anthony Formation.

Depositional setting: The Sudr Formation was deposited as basinal chalks with no shallow water influences. Lüning *et al.* (1998b) discussed the depositional environment of the chalks of the Sudr Formation on eastern Sinai in greater detail.

Discussion: Other authors, such as Abdallah and Eissa (1970), Abdallah *et al.* (1970) and Abu Khadrah *et al.* (1987), erroneously included dolomitic limestones of the white cliff (sediments of the Southern Galala Formation) above the cave of St Anthony. Kuss and Leppig (1989) indicated a Late Paleocene age by means of planktic and benthic foraminifers for these strata and attributed them to the Southern Galala Formation.

St Anthony Formation (SAF) (section A1 in Fig. 4a and Fig. 7d)

Authors and type section: Bandel and Kuss (1987); Monastery of St Anthony (Eastern Desert)

Stratigraphical range: Upper Campanian-Upper Maastrichtian

The mainly carbonate lithologies of the St Anthony Formation in the Southern Galala disconformably overlie chalks of the Sudr Formation and underlie the carbonates of the Southern Galala Formation. In the upper part of the St Anthony Formation, *Exogyra overwegi* is present. Age-equivalent sediments with *Exogyra overwegi* were first described in the Western Desert in the '*Overwegi* Layers' (Zittel, 1883), now known as the Beris Oyster Mudstone Member of the Dakhla Formation (Awad and Ghobrial, 1965; Luger, 1985). The base of the St Anthony Formation is of Late Campanian age (Kuss, 1986; Kulbrok, 1996; Selima and Askalany, 1996). Although only poor biostratigraphic data is available from the mainly sandy-dolomitic upper units, a Maastrichtian age is indicated by thin sections. Abdel-Kireem and Abdou (1979) described Upper Maastrichtian planktic foraminifers of the *Abathomphalus mayaroensis* Zone at

Figure 7. The Late Cretaceous-Palæogene sediments of the western (a–d) and eastern (e) side of the Gulf of Suez. (a) Section T1, the southernmost section in area 1: the chalks of the Tarawan Formation (TF) are intercalated between the marls and shales of the Dakhla Formation (DF) below and the Esna Formation (EF) above. The cliff at the top is built of chalky limestones of the Serai Formation of the Thebes Group (THG). (b) Section D2 in area 2: the marls and shales of the Dakhla Formation are overlain by the limestones of the Southern Galala Formation (SGF) with a gradual contact. The fault at the top is of younger age and was the result of Red Sea graben tectonics. The section continues left of the picture with the rest of the sediments of the Southern Galala and the Esna Formations and the Thebes Group. (c) Section S9 (Kuss et al.*, 2000) in area 3: the marls and shales of the Dakhla Formation are sandwiched between chalks of the Sudr Formation (SF) below and shallow water influenced sediments of the Southern Galala Formation above. (d) Section A1 in area 4: the marls and sandy marls of the St Anthony Formation (SAF) are overlain by the shallow water limestones of the Southern Galala Formation. The Southern Galala Formation forms a steep white cliff along the northern rim of the Southern Galala. (e) Wadi Nukhl on Sinai: similar to section T1 (a), the thin Tarawan Formation is sandwiched between the Dakhla and the Esna Formations (picture courtesy of R.P. Speijer). The scales are only approximations due to a distorted perspective.*

Gebel Thelmet (GT; Fig. 4a). A possible hiatus between the Late Cretaceous and the Early Tertiary sediments in section A1 is assumed but could not be substantiated in the studied sections by means of planktic foraminifers or calcareous nannoplankton.

Lithology: Chalky limestones, marls and sandstones

Synonymy: The St Anthony Formation corresponds to the Gebel Thelmet Formation of Abdallah and Eissa (1970) (Fig. 5). Although their term is older, the authors followed Bandel and Kuss (1987) because Abdallah and Eissa (1970) and Abdallah *et al.* (1970) were apparently confused by the Cretaceous-Eocene lithologies (see the discussion of the Sudr Formation). Other reasons for using the term St Anthony Formation are the accessibility and the thickness differences of the type sections. Whereas the section in Gebel Thelmet is dangerous to access (due to possible mine occurrences) and has a reduced section thickness, the section at monastery of St Anthony is easily accessible and has a much larger thickness.

Regional distribution: The shallow water influenced deposits of St Anthony Formation are mapped only along the northern rim of the Southern Galala. A time equivalent formation in northern Egypt and Sinai is the Sudr Formation (Fig. 6).

Depositional setting: The sediments of the St Anthony Formation are slope sediments of a shallow water carbonate platform. In the lower part of the St Anthony Formation, large slumping structures occur and are well exposed. In the middle part, limestones with slumping and reworked shallow water biota, such as *Orbitoides* and *Omphalocyclus*, occur. In the upper part of section A3 (7 km east of St Anthony; Fig. 1), the shallow water bivalve *Pinna* and teeth of bony fishes were found that thrived in calm water zones of reefs (C. Werner, *pers. comm.*). Kulbrok (1996) assigned the deposits of the St Anthony Formation to a distally steepened ramp, and Selima and Kerdany (1996) assigned them to shallow marine environments.

Dakhla Formation (DF) (Figs 4a, b and 7a–c, e)

Author and type section: Said (1961); Dakhla, north of Mut (Western Desert)

Stratigraphical range: Maastrichtian to Upper Paleocene

The lowermost occurrence of the Dakhla Formation in the Paleocene is at St Paul (area 3), within the middle to upper foraminiferal *Parvularugoglobigerina eugubina* Zone (Pα) (Strougo *et al.*, 1992) and, respectively, the middle NP 1 calcareous nannofossil zone (Girgis, 1987; Faris, 1997). The top of the Dakhla Formation lies in Bir Dakhl (area 2), St Paul (area 3) and northern Northern Galala (area 6) within NP5, where it underlies the Southern Galala Formation. At Wadi Tarfa (area 1) and in western Sinai (areas 8, 9), it occurs within NP7/8, where the Dakhla Formation underlies the Tarawan Formation. The latter is thin or even absent in northern Egypt and Sinai.

Lithology: In the studied area, the Dakhla Formation consists of chalky marls in the uppermost Maastrichtian and of softer shaley grey-green marls in the Paleocene (Fig. 8). The thickness of the Dakhla Formation varies from 6.5 m (D3) to 23.5 m (T1).

Synonymy: The Dakhla Formation is synonymous with the 'aschgraue Blätterthone' of Zittel (1883), the Lower Esna of Hume (1912) and the Lower Oweina Shale of El-Naggar (1966a) (Fig. 5).

Regional distribution: The Dakhla Formation is present in all areas except areas 4, 5 and 7, where a stratigraphical gap occurs (Fig. 6). In contrast to the results of this study in Bir Dakhl (area 2), Strougo and Faris (1993) attributed the whole succession, which is sandwiched between the top of the Sudr Formation and the base of the Thebes Group, to the Southern Galala Formation. However, they subdivided the Southern Galala Formation into three main units: a lower light green argillaceous limestone; a middle prominent harder bioclastic limestone with large foraminifers and thick chert bands; and an upper green-grey calcareous shale. In the present study, the authors correlated this tripartition, which is evident also in neighbouring sections, to the Dakhla, Southern Galala and Esna Formations (from base to top) (Fig. 8).

In the Northern Galala (area 6), the Dakhla Formation has a thickness of 10 m and is composed of paper-shales and marly limestones, the latter with abundant planktic foraminifers (morozovellids) in thin sections, indicating an age of P3 or younger (section N1; Fig. 4a). In the present study, the authors attributed these sediments to the Dakhla Formation because of their lithological and stratigraphical similarities.

Depositional setting: The Dakhla Formation was deposited as basinal marls with no shallow water influences. Speijer and Schmitz (1998) reported from Gebel Aweina (300 km to the south), for most of the Dakhla Formation, a palæowater depth of 200 m. The palæowater depth decreases to lower than 100 m only within the planktic foraminifer zone P3. Shahin (1990) described bathyal environments for the shales of the Dakhla Formation.

Discussion: In the Western Desert, the Dakhla Formation was subdivided by Awad and Ghobrial (1965) into three members: the Mawhoob Shale Member; the Beris Oyster Mudstone Member; and the Kharga Shale Member. The Cretaceous/Palæogene boundary lies within the upper part of the Kharga Shale Member (Awad and Ghobrial, 1965). In contrast to southern and western Egypt where the base of the Dakhla Formation lies in the Lower Maastrichtian and exhibits

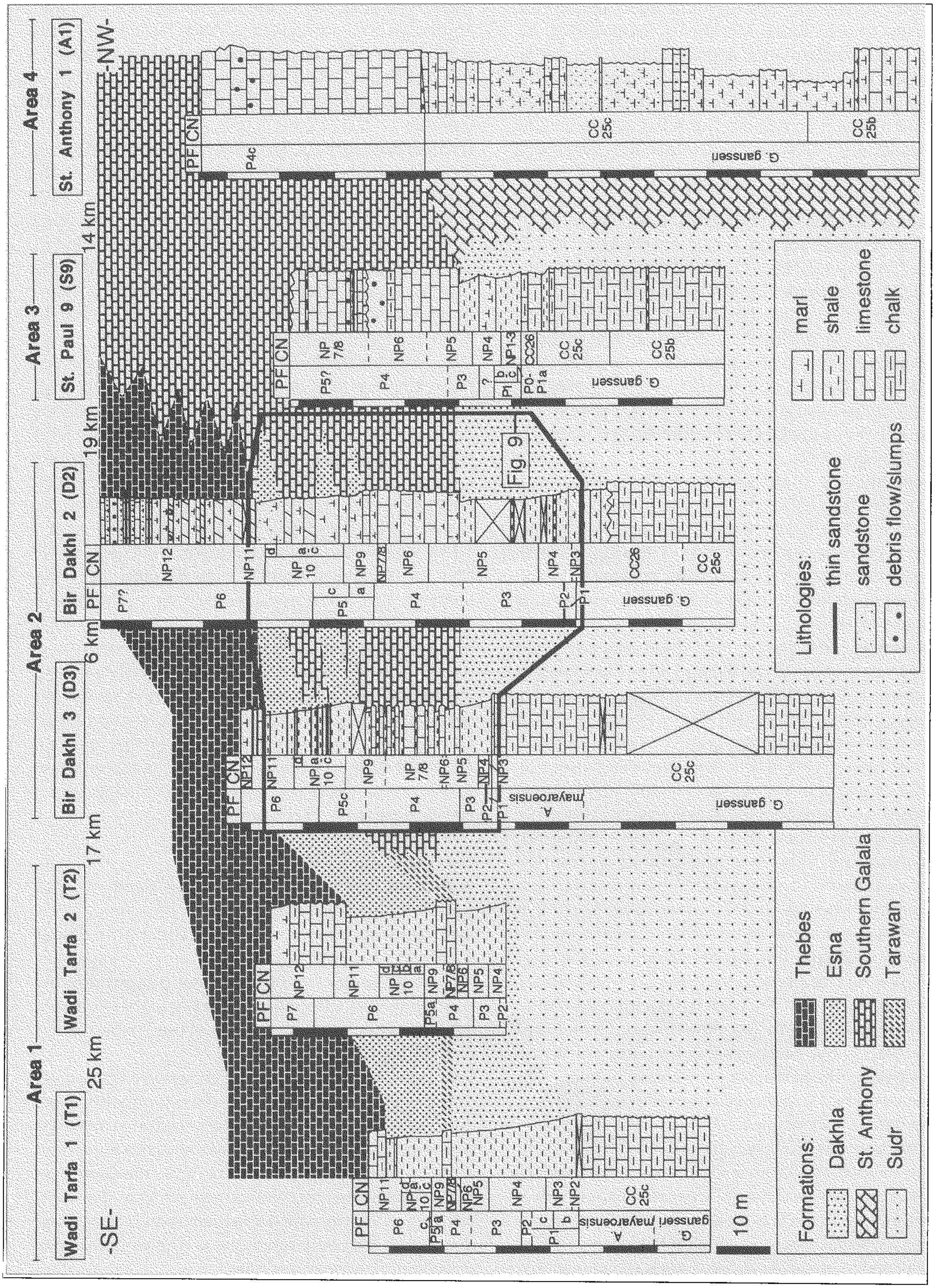


Figure 8. *Bio- and lithostratigraphic correlation of six sections from areas 1–4 on the western side of the Gulf of Suez (Eastern Desert). Best visible is the progradation of the shallow water sediments of the St Anthony Formation in the Maastrichtian-Paleocene and of the Southern Galala Formation in the Paleocene-Eocene. The black rectangle in sections D3 and D2 indicates the range of the detailed correlation of Fig. 9.*

the complete succession of all three members, in northern Egypt and Sinai only the equivalent of the younger Kharga Shale Member is present (Fig. 5). Here, the Sudr Formation and St Anthony Formation correlate with the Mawhoob Shale Member and the Beris Oyster Mudstone Member, respectively. In northern Egypt and Sinai, the base of the Dakhla Formation lies usually at the Cretaceous/Palæogene boundary and the top within P4/NP6 (Fig. 4a, b).

Tarawan Formation (TF) (Figs 4a, b and 7a, e)
Authors and type section: Awad and Ghobrial (1965); Gebel Tarawan, Kharga Oasis (Western Desert).
Stratigraphical range: Upper Paleocene

The base lies within NP7/8/(P4) and the top lies within lower NP9/(P5). The stratigraphical range of the Tarawan Formation comprises biozones P4/NP6 to P5/NP9. Kassab and Keheila (1994), however, gave a range from zones P3/mid-NP4 to P4c/lower NP9. It overlies the Dakhla Formation and underlies the Esna Formation.

Lithology: In the study area, the Tarawan Formation is characterised by a 1.80 m (area 1, section T1) to 2.10 m (section T2) thick chalk bed with flint, similar to the underlying Sudr Formation. In the Kharga area, it is represented by a 3–45 m thick chalk unit, which in places changes into chalky limestone, limestone or siliceous limestone.

Synonymy: The Tarawan Formation was described by earlier authors as Chalk (Zittel, 1883), Danian Chalk (Beadnell, 1905) or Middle Oweina Chalk Member (El-Naggar, 1966a, 1966b) (Fig. 5).

Regional distribution: In area 1, sections Wadi Hawashiya section (WHS) and Wadi Tarfa section (WTS) of Kassab and Keheila (1994) exhibit discrepancies with respect to lithology and stratigraphy. In section WHS (near to section T1 in this study), these authors described the Dakhla Formation extending down to the Maastrichtian and no Sudr Formation, whereas in WTS (near to section T2 in this study) the Tarawan Formation rests unconformably over Late Campanian sediments (Fig. 4a). Moreover, its thickness of 30–50 m and stratigraphical range with the base lying within P3 (NP4–NP 5) differs markedly from the observations (from this study) in the neighbouring sections. Similar to the hiatuses, these discrepancies may be the result of very local highs and lows controlling deposition of these different lithologies.

In section Ezz El-Orban (area 7) of Ansary and Fahmy (1969), the Tarawan Formation is represented by a 43 m layer of mainly argillaceous limestone, which is partly chalky in its lower part (Fig. 4b). The authors named it Middle Oweina Chalk after El-Naggar (1966a, 1966b) and assigned its stratigraphical range to within P4. The Tarawan Formation in Ezz El-Orban is very thick in comparison to the sections of the Tarawan Formation on Sinai and in the Wadi Tarfa area. These sediments may, more appropriately, be assigned to the Southern Galala Formation, which reaches a thickness of more than 20 m in the nearby northwestern Bir Dakhl area.

Depositional setting: The Tarawan Formation in the study area was deposited as basinal chalks/limestones with no shallow water influences. Anan (1992) and Lüning *et al.* (1998a) concluded that the Tarawan Formation on Sinai was deposited during a period of low sea levels. Luger (1985) and Speijer and Schmitz (1998), on the other hand, reported from southern Egypt that the sediments of the Tarawan Formation were deposited during sea level highstands.

Discussion: In northern Egypt and Sinai, the Tarawan Formation has a reduced thickness or is absent (Fig. 5). However, even where the Tarawan Formation is present (thin chalks or limestones at the NP6-NP9 interval), it was often not discussed by various authors, although it is visible within the respective profiles (northeastern Sinai: Hewaidy, 1987; Matulla: Ismail, 1992; Wadi Nukhl: Marzouk and Hussein, 1994; Wadi Feiran: Marzouk and Abou-El-Enein, 1997; Matulla: Obaidalla, 1999; Figs 4b and 7e). The absence of the Tarawan Formation misled some authors. Consequently, they wrongly attributed even Maastrichtian chalks to the Tarawan Formation (e.g. Shafik and Stradner, 1971). Selima and Askalany (1996) attributed chalky limestones in Wadi Askhar (area 4) to the Tarawan Formation. In section A1 (7 km east of Wadi Askhar), these chalks contain abundant shallow water biota (corals, coralline algae) and are attributed in the present study to the Southern Galala Formation (Figs 5 and 6).

Garra Formation (GF) (Fig. 4b)
Author and type locality: Issawi, 1969; South of Gebel Garra, south Western Desert
Stratigraphical range: Upper Paleocene to Lower Eocene

In northwestern Sinai, its base disconformably overlies the Sudr Formation and lies within P3a. It is overlain by the Egma Formation of the Thebes Group within P6a.

Lithology: In area 9, the Garra Formation is composed of a basal white argillaceous limestone with chert near its top, overlain by massive limestones and thus shows similarities with the Southern Galala Formation at Bir Dakhl (area 2). In Kala´t al-Gindi, the Garra Formation has a maximum thickness of 49 m (Fig. 4b). At the type locality, the Garra Formation is composed of well-bedded white limestone and chalk with minor shale and marl intercalations.

Regional distribution: The Garra Formation was described only by Hamza *et al.* (1997) from northwestern and north central Sinai.

Depositional setting: In southern Egypt, the Garra Formation was deposited in the middle to inner shelf (Luger, 1985), whereas on Sinai deeper marine settings are assumed (see the discussion of the Southern Galala Formation below).

Discussion: In northwestern Sinai (area 9), Hamza *et al.*, (1997) described limestones of the Garra Formation (mid-P3b–mid-P6a), sandwiched between the chalks of the Sudr Formation and the limestones of the Thebes Group (Fig. 4b). Said and Kenawy (1956) identified a bathyal fauna in the chalky sediments. Whether these deposits are synonym with the Southern Galala Formation remains uncertain. However, at least the introduction of the Garra Formation in this part of Egypt may explain earlier discrepancies in lithological description and dating of the Sudr Formation and Thebes Group.

Hermina and Lindenberg (1989) described the Garra Formation from the southern Western Desert. It disconformably overlies the Kurkur Formation and underlies the Dungul Formation. The Garra Formation, in southern Egypt, is a lateral equivalent of the upper parts of the Dakhla, Tarawan and Esna Formations (Fig. 5).

Southern Galala Formation (SGF) (Figs 4a, b and 7b, c, d)

Authors and locality: Abdallah *et al.* (1970); redefined by Kuss and Leppig (1989)

The reference section 18/2 (Kuss and Leppig, 1989) is situated in a north-south-trending wadi, 6 km west of monastery of St Anthony

Stratigraphical range: Upper Paleocene-Lower Eocene

Data from this study indicate that the base of the Southern Galala Formation lies within the *Glomalveolina levis* Zone (Upper Thanetian, P4c/NP8) and the top lies within the *Alveolina dainelli* Zone (Cuisian, P9/NP13). In Bir Dakhl and St Paul, the Southern Galala Formation is overlying the Paleocene Dakhla Formation (Fig. 4a) with a stratigraphical range from mid-NP5/(P3/4) to mid-NP9/(P4/5). In section D2, the Southern Galala Formation interfingers with the Esna Formation, and the top lies within NP10/P6 (Figs 6, 8 and 9). At St Paul, the top of the Southern Galala Formation lies within SBZ10 (NP12/P7) (Gietl, 1998). In St Anthony, the Southern Galala Formation overlies the Late Campanian-Maastrichtian St Anthony Formation, while farther north it is unconformably underlain by Turonian strata in section 20/2 (Kuss and Leppig, 1989) and other parts of the Northern Galala (Abd-Elshafy and Atta, 1993), and by Campanian limestones of the Matulla Formation in Abu Darag (Abd-Elazeam and Metwally, 1998). Malchus (1990) described a hiatus ranging from Late Cenomanian to Maastrichtian in section 20/2. In the northern areas of the Northern Galala, the Southern Galala Formation overlies the Paleocene Dakhla Formation (section N1 of Fig. 4a) and underlies the Thebes Group.

Lithology: Massive sandy fossiliferous (alveolina, numulitids, coralline algae) limestones and limestone/sandstone intercalations often conglomeratic with a thickness of about 250 m. In the southern parts, it is limestones with flint.

Synonymy: Abu Khadrah *et al.* (1987) introduced the Useit Formation as a junior synonym of the Southern Galala Formation. The whole Palæogene part (P5/6; NP9/10) of section Wadi Naot (limestones and clayey siltstones) in the Northern Galala was attributed by Abd-Elshafy and Atta (1993) to the Naot Formation, which was introduced by Abd-Elshafy (1988) in Wadi Naot (Wadi Naot is a synonym of Wadi Nooz used by the authors). The authors did not employ the term Naot Formation in this study because it is possible to differentiate the Dakhla Formation and Southern Galala Formation (Fig. 5).

Regional distribution: In sections D2 and D3 (area 2), the Southern Galala Formation starts with the first hard limestone bed and is characterised by alternating limestones (up to 1 m thick) with abundant chert layers or nodules and shaley marls (up to 0.7 m thick). The hard limestones are partly composed of bioclastic wackestones, and chalky and dolomitic limestones. Figure 9 shows the interfingering of the Southern Galala Formation and the partly overlying Esna Formation in detail (sections D2 and D3). In section D2, three limestone beds show abundant bioturbation of *Zoophycos* and *Thalassinoides*. The main part of the Southern Galala Formation unit A in sections D2 and D3 (Fig. 9) has a thickness of 17 m and 20 m, respectively. Although the Southern Galala Formation has more or less the same thickness in these sections, the thickness of the different biozones varies (e.g. NP6 and NP7/8; Fig. 9).

At St Paul (area 3), the Southern Galala Formation is composed of limestones with locally abundant quartz grains that were deposited as gravity flows, such as glides, slumps and debris flows. A few thin (maximum 20 cm) marl beds are intercalated in the lower part (Scheibner *et al.*, 2000).

The steep white cliff at St Anthony and Gebel Thelmet (area 4) is composed of dolomitic limestones of the Southern Galala Formation (Fig. 7d). Because of its white colour and its chalky appearance, which is due to diagenetic alternations, several authors (Abdallah and Eissa, 1970; Abdallah *et al.*, 1970; Abu

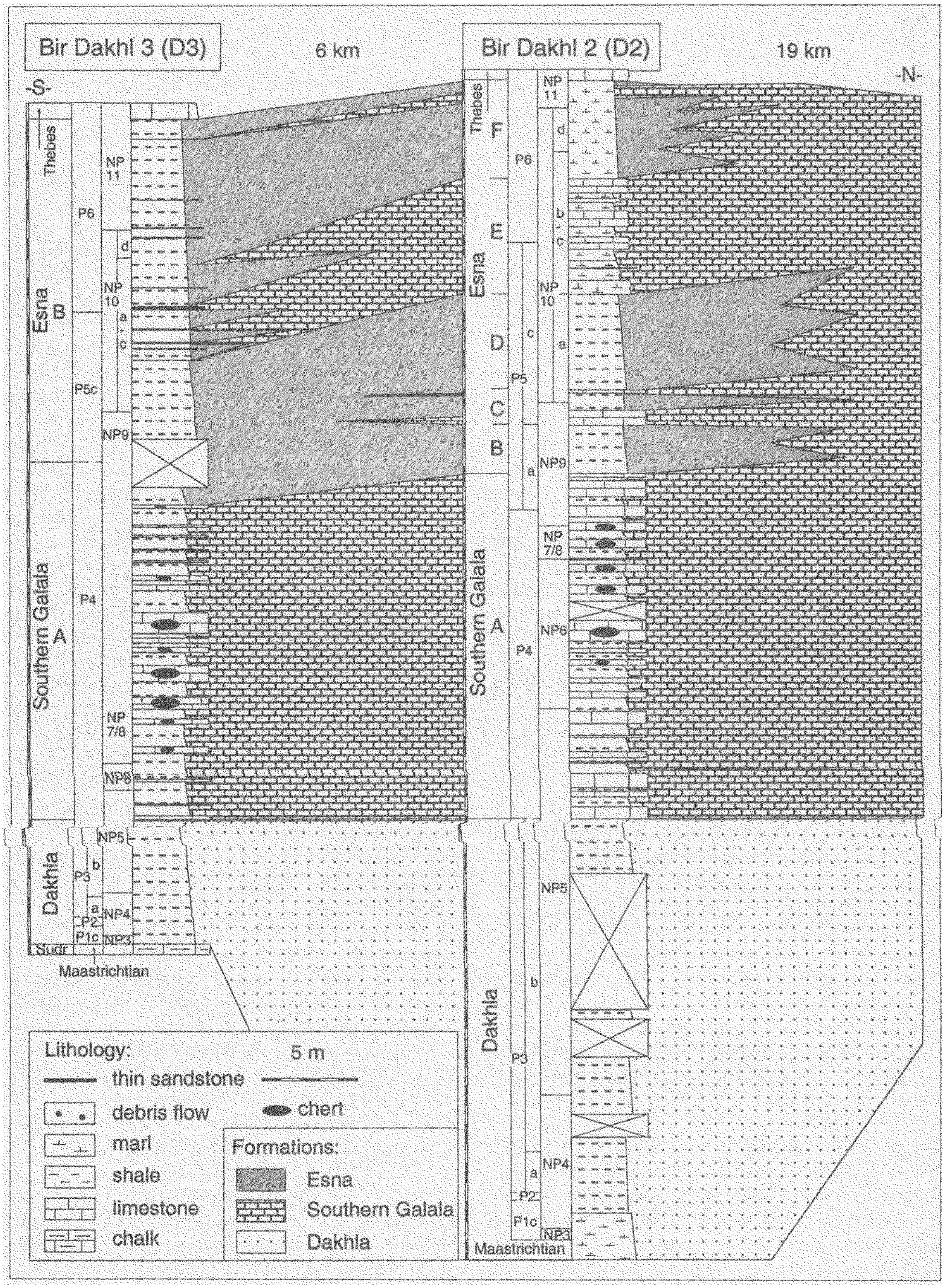


***Figure 9**. Detailed bio- and lithostratigraphic correlation of sections D3 and D2 in area 2. The letters A–F indicate different units described in the text.*

Khadrah *et al.*, 1987) previously misinterpreted these strata as chalks of the Sudr Formation (Fig. 5) or of the Tarawan Formation (Selima and Askalany, 1996). However, the basal conglomeratic debris flow type deposits of 0–2 m thickness are overlain by white diagenetically overprinted limestones with abundant corals in the lower 15 m. In the middle part of the nearly 70 m high cliff, *Hottingerina lukasi* (SBZ4/P4c) was found, indicating a latest Paleocene age.

In section 20/2 (area 5) (Kuss and Leppig, 1989), the Late Paleocene-Early Eocene Southern Galala Formation is build of massive sandy limestones, limestone-sandstone intercalations and debris flows. In Wadi Nooz (area 6), it is formed of debris flows and chaotically bedded limestones. Because of lithologic similarities to the Southern Galala Formation of area 3 (St Paul), this unit is attributed to the Southern Galala Formation. As in the underlying Dakhla Formation, only morozovellids were found, indicating again an age of P3 or younger. In Hamam Faraoun in the very south of area 9, Gietl (1998) described debris flows up to 6 m thick with siliciclastic sand and larger foraminifers and shallow water limestones with larger foraminifers of Early Eocene age (SBZ7-9, NP10-12). In the north of area 9 (Wadi Sudr), Gietl (1998) found limestone/marl beds with slumps, debris flows and larger foraminifers. In Gebel Um Makhasa, Kulbrok (1996) described chalky limestones of SBZ4-6 (NP8/9) with larger foraminifers and corals, which may be attributed to the Southern Galala Formation.

Depositional setting: The sediments of the Southern Galala Formation are sediments of a carbonate platform and slope, which were deposited on and around the Northern Galala/Wadi Araba High. They interfinger with basinal sediments of the Southern Galala Subbasin in area 2 (Bir Dakhl). Kulbrok (1996), Gietl (1998) and Scheibner *et al.* (2000) described the carbonate platform and slope deposits of the Southern Galala Formation in more detail.

Discussion: In this study, the classification of Abu Khadrah *et al.* (1987) and Selima and Askalany (1996) are not followed. The Useit Formation described by Abu Khadrah *et al.* (1987) was thought to overlie a unit termed Esna Formation in St Paul; which, however, is of Early Paleocene age and, therefore, should be regarded as Dakhla Formation (see the discussion of the Abu Rimth Formation below). Moreover, the same authors correlated the Zaafarana Formation with the Useit Formation, although the first was originally described to overlie the Southern Galala Formation and is of middle Eocene age (Abdallah *et al.*, 1970). It is not clear by the above whether the Zaafarana Formation should be attributed to the Useit Formation and, hence, represent part of the Southern Galala Formation, or whether it forms part of the overlying Thebes Group (Fig. 5).

Esna Formation (EF) (Figs ba, b and 7a, e)

Author and type section: Beadnell (1905); Gebel Aweina near Esna

Stratigraphical range: Late Paleocene to Early Eocene

Its stratigraphical range has been discussed intensively (El-Naggar, 1966a, 1966b, 1968; Sabry, 1968; Issawi, 1972). Today, it is accepted in Egypt, except Sinai, that the Esna Formation is intercalated between two, more or less, chalky limestone units. These units are, the Tarawan Formation below and the Thebes Group above, and thus represent Late Thanetian to Early Ypresian (P4c/lower NP9 to mid-P7/NP12; Fig. 6). On Sinai, however, the term Esna Formation is quite often used to describe the whole Paleocene shales sandwiched between the Sudr Formation below and the Thebes Group above (Lüning *et al.*, 1998a; Marzouk and Lüning, 1998; see discussion below).

Lithology: The Esna Formation is composed of green-grey shales and marls with planktic foraminifers and calcareous nannoplankton.

Synonymy: The Esna Formation is synonymous with the 'grünliche Blätterthone' of Zittel (1883), the upper Esna of Hume (1912) and the Upper Oweina Shale of El-Naggar (1966a, 1966b) (Fig. 5).

Regional distribution: In Wadi Tarfa (area 1), the Esna Formation is 10.50 m (T1) to 17.10 m (T2) thick and is composed of the same lithology as the Dakhla Formation. Nishi *et al.* (1994) described a section south of the Ras Gharib to El-Sheikh Fadl Road with only 5 m of the Esna Formation overlain by chalks of the Thebes Group, whereas El-Dawy (1999) reported 21 m of Esna Formation in a section south of the Ras Gharib to El-Sheikh Fadl Road.

Strougo and Faris (1993), in their Wadi El-Dakhl section (area 2), described green-grey calcareous shales and cream to light grey laminated argillaceous limestones. In section D3 (area 2), the Esna Formation is characterised by green-grey shaley marls with abundant thin (up to 0.22 m thick) sandstone layers. These sandstones are partly cross-laminated and have rip-up clasts. The sicliciclastic intercalations were interpreted as distal fan lobes, of which more proximal parts at St Paul were discussed in Scheibner *et al.* (2000). In Bir Dakhl (area 2), the Southern Galala Formation grades laterally into shales of the Esna Formation, best visible in section D2 and less clear in section D3 (Fig. 9). In section D2, the intimate interfingering of the Esna Formation with the Southern Galala Formation is evident (Figs 8 and 9). As a consequence, this part of the section can be subdivided into five units. From the bottom to the top, the following five units can be distinguished (Fig. 9) as follows:

i) A: alternating limestones with abundant chert layers (see Southern Galala Formation above);

ii) B: 2.5 m grey-green marl;

iii) C:1.9 m alternation of silty marls and dolomitic limestone with laminations and channel structures;

iv) D: 4.4 m grey-green marl at the base silty;

v) E: 6 m alternation of shaley, partly silty, marls and dolomitic limestones with laminations, channel structures and rip-up layers; and

vi) F: 5.2 m of silty marls.

Within this profile, units (A), (C) and (E) exhibit characteristics of the Southern Galala Formation, whereas units (B), (D) and (F) could be attributed to the Esna Formation (Fig. 9).

In northern Northern Galala (area 6), the 15 m of the Esna Formation are of Lower Eocene age (NP11/12/P6), indicated by presence of calcareous nannofossils and planktic foraminifers. In contrast, Gietl (1998) described alveolinids of SBZ5 (NP9/P5) from limestones overlying the Esna Formation; which, however, may have been reworked from older carbonates.

Depositional setting: The Esna Formation was deposited as basinal marls with no shallow water influences. Shallow water deposits were found only in areas that interfinger with the Southern Galala Formation. Speijer and Schmitz (1998) gave a palæodepth curve from Gebel Aweina (*ca* 300 km to the south) and reported palæowater depths of about 200 m for most of the Esna Formation. The palæowater depth decreases to 100 m only in the uppermost part of the Esna Formation. According to Shahin (1990), the shales of the Esna Formation were deposited on Sinai in bathyal environments.

Discussion: The credit for the introduction of the Esna Formation was given to Beadnell (1905), although shales in the vicinity of Esna were mentioned earlier by Zittel (1883) and others (see El-Naggar, 1966a, 1966b).

In northern Egypt and on Sinai, the whole Paleocene shales and marls are often attributed to the Esna Formation in areas where no Tarawan Formation exists (Said, 1990) and thus have a stratigraphical range from Upper Maastrichtian to Lower Ypresian (see the discussion of the Dakhla/Tarawan/Esna Formation below). Even if only the lower part of the Paleocene shales are exposed (e.g. Abu Khadrah *et al.*, 1987), they were quite often referred to as Esna Formation, which makes lithostratigraphic correlation very confusing (Abu Khadrah *et al.*, 1987; Hewaidy, 1987; Said, 1990; Cherif and Ismail, 1991; Marzouk and Hussein, 1994) (Fig. 5). The authors, therefore, suggest attributing only Upper Paleocene shales to the Esna Formation, whereas Lower Paleocene shales would belong to the Dakhla Formation. This bipartition is only possible in areas where either only Upper Paleocene shales or only Lower Paleocene shales were exposed or where they were separated by the Tarawan Formation. If the shales range from the Lower to the Upper Paleocene, the authors suggest the usage of the Dakhla/Tarawan/Esna Formation (Figs 5 and 6).

Snavely *et al.* (1979) stated that most authors agree with the upper portion of the Esna Formation being assigned to the Ypresian *Morozovella subbotinae* Zone (P6/NP10/11 of Berggren *et al.*, 1995), the transitional marly beds typical of the conformable Esna-Thebes contact were assigned to the *Morozovella aragonensis* Subzone (P7/NP12 of Berggren *et al.*, 1995). However, in this study, it was found that the Esna-Thebes contact in the Eastern Desert was usually within NP11. In the upper part of the Esna Formation as well as in the Thebes Group, *Nummulites deserti* was found (LeRoy, 1953; Hermina and Lindenberg, 1989), indicating an Ypresian age (NP11–NP12), which contrasts with the stratigraphical range of that species mentioned by Serra-Kiel *et al.* (1998) as SBZ4 and SBZ5 and which corresponds to NP9. This discrepancy led to some confusion of the stratigra-phical range of the Thebes Group. For example, Gietl (1998) correlated the lower part of the Thebes Group to the *Alveolina cucumiformis* Zone (SBZ5 or NP9), which would be in disagreement with the strati-graphical range of our samples.

Dakhla/Tarawan/Esna Formation (DTE) (Fig. 4b)

Stratigraphy: The stratigraphical range of this informal formation is Upper Maastrichtian to Lower Eocene. Because of the gradual transition from the Maastrichtian chalk to the Paleocene shales, the onset of the Dakhla/Tarawan/Esna Formation in Abu Zenima/Wadi Feiran (area 8) is not clearly fixed lithologically. It varies from a level within the Upper Maastrichtian to one at the Cretaceous/Palæogene (K/Pg) boundary. A small hiatus at the K/Pg boundary is probable (Shahin, 1992). As with the lower stratigraphic boundary, the upper boundary is not well constrained. The transition from the Dakhla/Tarawan/Esna Formation to the Thebes Group lies around P6/7, NP11/12. It overlies the Sudr Formation and underlies the Thebes Group.

Lithology: Green-grey shales and marls, similar to the Esna Formation

Regional distribution: The Dakhla/Tarawan/Esna Formation is only present on Sinai.

Depositional setting: The Dakhla/Tarawan/Esna Formation was deposited as basinal marls similar to the Esna Formation (Shahin, 1990).

Discussion: The Dakhla/Tarawan/Esna Formation is an informal formation for the latest Cretaceous-Palæogene grey-green shales in northern Egypt and Sinai, where the Tarawan Formation cannot be identified. In most sections within the Dakhla/Tarawan/Esna Formation at around upper P4/5, one or more limestones might be attributed to the Tarawan Formation. Masters (1984) indicated two limestone beds in Wadi Feiran East, which could be attributed to the Tarawan Formation and probably represent a tectonic duplication (R.P. Speijer, *pers. comm.*). Because of the reduced thickness of the beds, probably not all authors indicated these layers as Tarawan Formation. The varying ages of the top of the Dakhla/Tarawan/Esna Formation are due not to transitional lithologies but to the different biozonations used. Authors who have worked with the calcareous nannoplankton bio-zonation gave older (NP11 = P6) ages than authors who used the planktic foraminifer zonation (P6/7). This discrepancy probably results from the variability in the planktic foraminifers-calcareous nannoplankton correlation (Marzouk and Lüning, 1998). Another explanation may be the usage of different planktic foraminifer biozonations, which were revised in time or different taxonomic concepts of the authors.

Thebes Group (THG) (Figs 4a, b and 7a, e)
Authors: Hermina and Lindenberg (1989)
Stratigraphical range: Lower Eocene (see different formations below)
Lithology: (see different formations below)
Synonymy: (see different formations below)
Regional distribution: At Wadi Tarfa, the base of the Thebes Group lies within NP11/P6. It is composed of chalky limestones alternating with chalky marls. Some of the chalks have layers or nodules of flint incorporated.

In Bir Dakhl (area 2), the Thebes Group is formed by chalky limestones with abundant chert layers or nodules, marly intercalations and sandstones with cross-bedding, lamination and rip-ups. They may contain alternations of harder and softer marls. In the lower part of section D2, the marls are partly rich in quartz grains and *Nummulitids*. In the upper part of section D2, slumping and first *Alveolina*-rich sandstones occur that could belong to the Southern Galala Formation as well, but this transition was not investigated in detail.

Bandel *et al.* (1987) described the Serai Formation overlying the Esna Shale from the western escarpment of Wadi Tarfa. Within the upper third of the 110 m thick succession of bedded marly to platy chalks with flint intercalations, a 17 m thick unit of alveolinid-nummulitid-bearing limestones aged SBZ11–14 occurs that indicate an Early Eocene age. The Thebes Group of northern Northern Galala (area 6) is composed of well-bedded dolomitic limestones partly with nummulitids, deformed alveolinids, few debris flows and quartz grains. The base lies in lower NP12. These sediments may belong to the Southern Galala Formation as well but, again, were not subject of this study. The Thebes Group in area 8 is composed of a sequence of well-bedded chalky limestones with intercalated chert bands (El Sheikh and El Beshtawy, 1992) or of yellowish sandy limestones followed by limestones with chert bands (Shahin, 1990, 1992). In Wadi Feiran (area 8), Eweda and El-Sorogy (1999) divided the Thebes Formation into a lower 180–190 m thick cherty chalky limestone member and an upper 50–60 m thick calcareous claystone member.
Depositional setting: Only the lower part of the Thebes Group in area 1 (Wadi Tarfa) was studied. Here, the sediments were deposited in a basinal setting without any shallow water influences. In areas 2–6, the transition from the Southern Galala Formation to the above lying Thebes Group was not investigated. Shahin (1990) and Lüning *et al.* (1998a) suggested that the Thebes Group on Sinai was deposited during a time of a lowered sea level. Snavely *et al.* (1979) proposed the following three-stage depositional history for the Thebes Group:

i) basin-wide pelagic carbonate deposition with thin shallow water facies near the basin margins;

ii) gradual shallowing; and

iii) abrupt lowering of sea level.

Discussion: The Thebes Group was introduced by Hermina and Lindenberg (1989). It replaces the Thebes Formation of Said (1960) and is equivalent to the 'Libysche Stufe' of Zittel (1883), excluding the Esna Shales (Fig. 5). The Thebes Group includes the following formations (Fig. 5):

i) Farafra Formation, El-Rufuf Formation, Serai Formation, Drunka Formation and Dungul Formation in the scarps and plateau areas south of Minia;

ii) Abu Rimth Formation in the Southern Galala; and

iii) Egma Formation on Sinai.

Here, the focus is only on the Serai, Egma and Abu Rimth Formations since they have been described in the study area of the northern part of the Gulf of Suez. In this contribution, the authors refer to the Thebes Group when 'speaking' of Lower Eocene strata that overly the Esna or Dakhla/Tarawan/Esna Formations (except the Galala Mountains, where the Thebes Group overlies the Southern Galala Formation) and underlie the Minia Formation. In the contribution, no subdivision of the different formations is done.

Serai Formation
Authors and type section: Barron and Hume (1902); redefined by Lindenberg *et al.* (in Hermina and Lindenberg, 1989) as facies variation of the Thebes Group; Gebel Serai, south Wadi Qena, Eastern Desert
Stratigraphical range: Early Eocene

Synonymy: Synonymous with the lower and middle members of the Thebes Formation by Said (1960) and the lower member of the Thebes Formation of Snavely *et al.* (1979).
Lithology: Fine-grained thinly-bedded micritic limestones, chalky and cherty with rare shales, grading upward into massive bioturbated beds with few allochthonous layers
Discussion: The Serai Formation is widely developed throughout the Stable Shelf, at the plateau surface between the Nile and Kharga Oasis, Wadi Qena, and the Quseir-Safaga region. A special slump facies of mixed autochthonous and allochthonous sediments is defined separately as Abu Rimth Formation in the Southern Galala (see below). The Serai Formation was described by Bandel *et al.* (1987) in the Wadi Tarfa area.

Egma Formation
Author and type section: Beadnell (1927) and Hermina and Lindenberg (1989) mention no type section, only the type area (Egma Plateau on Sinai).
Stratigraphical range: Early Eocene
Lithology: Shallow platform deposits of medium-bedded to massive limestones with tabular chert bands, chalky frequent turbidite layers with reworked fossils.
Discussion: The Egma Formation is present in the southern and northern Sinai. It overlies the Esna Formation whereas the top is uncovered.

Abu Rimth Formation
The following description is taken from Phillobbos, Lindenberg and Schmitz (in Hermina and Lindenberg, 1989):
Author and type section: Phillobbos, Lindenberg and Schmitz (in Hermina and Lindenberg, 1989)

The type area is the Wadi Abu Rimth in the Southern Galala, south-southwest of the monastery of St Paul.
Stratigraphical range: Early Eocene
Lithology: It is composed of "*well-bedded open marine to shelf limestones and marls with intercalated thin turbidite and thick olistostrome layers containing abundant larger foraminifers, clasts of shallow water carbonates, including reefal limestones, Alveolina limestones and displaced sand.*" They may have conspicuous slump structures.
Synonymy: It is synonymous with the lower and middle members of the Thebes Formation by Said (1960) and the Thebes Formation of Bandel and Kuss (1987).
Discussion: The stratigraphical range of the Abu Rimth Formation (Philobbos *et al.*, in Hermina and Lindenberg, 1989) collides with the stratigraphical range of the above mentioned Southern Galala Formation. Philobbos *et al.* (in Hermina and Lindenberg, 1989) mentioned that the Abu Rimth Formation overlies the Esna Formation in the southern parts. However, in St Paul no Upper Paleocene shales of the Esna Formation occur, only the Lower Paleocene shales of the Dakhla Formation. As documented before, the term Esna Formation is loosely used and sometimes covers the Lower Paleocene Dakhla Formation as well. Therefore, the strata overlying in the Dakhla Formation St Paul could not belong to the Abu Rimth Formation but should be correctly attributed to the Southern Galala Formation. As a consequence, the Abu Rimth Formation in the Galalas is represented by the conglomeratic sandy lithologies of the Southern Galala Formation and, hence, has to be attributed as a synonym of the latter. The Abu Rimth Formation is present only in the Southern Galala (Philobbos *et al.*, in Hermina and Lindenberg, 1989), which corresponds to the areal extension of the Southern Galala Formation according to the authors' results. Therefore, the term Abu Rimth Formation should be abandoned.

LATERAL TRANSITIONS OF FORMATIONS

St Anthony Formation (shallow water) and Sudr-/ Dakhla Formations (deep water)
Shallow water carbonates and siliciclastics of the St Anthony Formation were deposited from the Late Campanian to the Late Maastrichtian and are exposed only in an east-west-trending belt at the northern rim of the Southern Galala. At these times, no such sediments arrived 14 km to the south at St Paul (Figs 1 and 3), where only sediments of the deeper water Sudr and Dakhla Formations accumulated. Interfingerings with the basinal Sudr and Dakhla Formations are not exposed. In St Paul, shallow water carbonates of the Southern Galala Formation were deposited only during Late Paleocene to Early Eocene times. The authors interpret that this facies change in St Anthony is due to the proximal position of St Anthony to the Wadi Araba High (NGWA) in the north that shed shallow water sediments from a carbonate platform as early as the Campanian/Maastrichtian (Kuss *et al.*, 2000).

In area 9, shallow water sediments were deposited during the Campanian-Maastrichtian (*Exogyra* cf. *overwegi*) (Youssef and Shinnawi, 1954; El-Shinnawi, 1967) and were possibly equivalent to the St Anthony Formation. In contrast to area 4 (St Anthony) where the shallow water Upper Cretaceous St Anthony Formation was overlain by the shallow water Paleocene-Eocene Southern Galala Formation on Sinai, sediments with *Exogyra* cf. *overwegi* were overlain by the deeper water chalks of the Sudr Formation. This contrast of depositional facies could be explained by differences in the vertical movements. While the Northern Galala/Wadi Araba area represents the centre of the Northern Galala/Wadi Araba High, north-western Sinai (area 9) was less affected by this local high.

Southern Galala Formation (shallow water) and Dakhla-/Esna Formations (deep water)

Similar to the St Anthony Formation, the Southern Galala Formation is deposited in an east-west-trending area in the Galalas and parts of Sinai (Hamam Faraoun). However, its areal extension is far larger than that of the St Anthony Formation. Interfingering between the deeper water deposits of the Dakhla and Esna Formations and the shallow water limestones of the Southern Galala Formation and the lateral variations within the Dakhla and Esna Formations are best exposed at the two Bir Dakhl sections D2 and D3 (area 2) that are 6 km apart (Figs 8 and 9). In both sections, the Southern Galala Formation starts in mid-NP5. While the Southern Galala Formation of the southern D3 section is represented by thin-bedded bioclastic wackestones, chalky-dolomitic limestones and thicker 'Dakhla Formation' type shales, the northerly D2 section shows thicker limestones and thinner shales. It is assumed that this lithological contrast in the two sections is a result of the closer position of the Northern Galala/Wadi Araba carbonate platform to section D2 (Kuss *et al.*, 2000) and the contemporary increase of platform-derived carbonates (Figs 8 and 9). An even more pronounced lithological contrast is evident in the Upper Paleocene to Lower Eocene succession. In the southern D3 section, distal equivalents of the Southern Galala Formation are represented only by thin siliciclastic intercalations within the Esna Formation, whereas in the northern D2 section massive siliciclastic limestones with internally reworked clasts have been deposited (units B and D) (Figs 8 and 9).

Area 3 (St Paul) is a fine example of a ramp-to-basin transition. Three phases of ramp progradation were observed that are indicated by mass transport deposits of glides, slumps and debris flows. Microfacies analysis provided evidence of a change in the origin of the debris flow deposits that reflect a transition from a basinal-to-outer-ramp setting to a middle-to-inner-ramp setting including a change in the distribution of biota (Scheibner *et al.*, 2000).

The lithologies of the succession of the northern area of the Northern Galala (area 6) are very similar to those of areas 2 (Bir Dakhl) and 3 (St Paul) of the Southern Galala. Allochthonous shallow water carbonates intercalated with hemipelagic marls show the interfingering of limestones derived from the nearby shallow water platform of the Northern Galala/Wadi Araba. On both sides, south and north of the Northern Galala/Wadi Araba, similar lithologies with slides, slumps and debris flows are present. The only biostratigraphic data from the sections of area 6 studied here are obtained from marls of the Esna Formation.

On Sinai (area 9), Gietl (1998) described similar carbonate dominated successions with debris flows, slumps, intercalated siliciclastics and larger foraminifers of the Late Paleocene-Early Eocene shallow water Southern Galala Formation. These sedimentary textures occur in Wadi Sudr (north) and Hamam Faraoun (south) and evidence the existence of a palæotopographic high between both areas.

Southern Galala Formation (shallow water) and Thebes Group (deep water)

The sediments attributed at Bir Dakhl (area 2) and at the northern Northern Galala (area 6) to the lower Serai Formation (THG) may also be classified as Southern Galala Formation because of basic facies similarities between both, which was not studied within the present contribution (Fig. 6). In that case, again, an interfingering of the deeper water Thebes Group with the shallow water-derived sediments of the Southern Galala Formation may be deduced from detailed studies on their contacts with the Thebes Group. Snavely *et al.* (1979) mentioned that the sediments of the lower Thebes Group were deposited as basin-wide pelagic carbonates with thin shallow water facies near the basin margins.

HIATUSES AND SYNSEDIMENTARY TECTONICS

In the study area, four types of hiatuses can be distinguished, characterised by variable duration and/or different trigger mechanisms.

Major hiatus from Late Cretaceous to Late Paleocene

Together with the nowadays eroded Wadi Araba, the southern Northern Galala (area 5) represents an area affected by the Syrian Arc deformation and hence is part of Said´s (1961) Unstable Shelf. In the Northern Galala, compressional deformation resulted in uplift, erosion and non-deposition during the Late Cretaceous to Late Paleocene. In the Shabraweet area ~70 km north of the Northern Galala/Wadi Araba, Mohammed and Omran (1991) described a hiatus from the Campanian-Early Eocene similar to the hiatus observed in the Northern Galala. On Sinai, area 7 shows similarities to area 5 (middle to south Northern Galala) where a large hiatus is evident across the Cretaceous/Palæogene boundary as well (Fig. 4a, b). Except for section Ezz El-Orban, only latest Paleocene sediments occur above the K/Pg boundary. According to Said (1960) and Moustafa and Khalil (1995), the boundary between the stable/unstable shelf lies at Wadi Araba and north of area 8 (north of Abu Zenima). Thus, this area shouldn't be affected by the Syrian Arc deformation. However, if it was also affected, the boundary between the stable/unstable shelf should be shifted on Sinai south of the area 7.

Another possibility is the presence of a local high with non-deposition for which there is no other evidence yet. Bosworth *et al.* (1999) demonstrated that the Syrian Arc deformation also affected regions in stable intraplate settings, at least as far south as the southern part of the Gulf of Suez (Esh El-Mellaha Range and Gebel Zeit), due to far-field compressional stress.

In contrast to all other areas described, north-western Sinai (area 9) has the most complex and inhomogeneous tectonic and depositional history. Probably, it could be subdivided into more areas: into areas with larger hiatuses across the K/Pg boundary; and areas with continuous sedimentation. Together with the two southern areas, areas 7 and 8, the depositional history of central western Sinai would be even more complex. The reason for these different depositional histories may lie in the fact that these areas were differently affected by the Syrian Arc deformation. In contrast to the uplift of the Northern Galala/Wadi Araba High that lead to erosion and non-deposition during the Late Cretaceous-Late Paleocene in the Northern Galala, the northwestern Sinai was less affected by the tectonic processes of the Northern Galala/Wadi Araba High (Youssef and Shinnawi, 1954; El-Shinnawi, 1967; Kulbrok, 1996; Gietl, 1998).

Hiatus across the Maastrichtian/Paleocene boundary

A hiatus across the Maastrichtian/Paleocene boundary is evident or inferred in most sections. An exception is St Paul with the presence of the Upper Maastrichtian nannoplankton *Micula prinsii* Zone and the Lower Paleocene plankton foraminifer Pα zone. The sections in St Paul are considered one of the most complete across the K/Pg boundary in Egypt, although they are very condensed. Lüning *et al.* (1998a) also documented a very complete section ranging across the K/Pg boundary on eastern Sinai.

Comparable lithologies, probably of the same stratigraphical range as area 3 (St Paul) (Scheibner *et al.*, 2000), are found on Sinai in area 9 (Hamam Faraoun: Kulbrok, 1996; Gietl, 1998). Moreover, the sections Wadi El-Seig/Wadi Hialla (Abbass *et al.*, 1994) evidenced a Late Cretaceous-Palæogene succession with a stratigraphical range similar to the St Paul section of area 3. Elsewhere, a hiatus is present at the K/Pg boundary in most of Egypt and probably resulted from a combination of low sedimentation rates, reworking, changing circulation patterns and sea level changes (Lüning *et al.*, 1998a).

Hiatus within the Late Paleocene (P3) of Sinai

Some sections of Wadi Feiran/Abu Zenima (area 8) show a hiatus around P3. The authors assume similar reasons for this hiatus as described for that of the Maastrichtian/Palæogene boundary. Furthermore, a submarine topographic high may have influenced, in combination with some of the above mentioned reasons, the Late Paleocene sedimentation processes and finally resulted in the P3 hiatus.

Minor hiatuses

Short-ranging hiatuses within single biozones are possibly present in all sections. However, these short hiatuses become evident only in sections with exact biostratigraphic controls based on planktic foraminifers and calcareous nannoplankton. In sections T1 and T2 (area 1), short hiatuses between P5 and P6 occur where parts of upper P5 and lower P6 are missing. These short hiatuses are interpreted, in this study, as resulting from times of non-deposition/erosion or very reduced depositional rates that could not be mapped in detail due to larger sample spacing.

MAASTRICHTIAN TO PALÆOGENE PALÆOGEOGRAPHIC EVOLUTION OF THE NORTHERN GULF OF SUEZ

Figure 10a–k illustrates the regional evolution of the depositional settings summarised for 11 time slices and defined for calcareous nannoplankton biozones. These time slices were chosen because they best characterise the changing of the depositional environments through time. The CC biozones represent two Maastrichtian time slices, NP1–NP9 represent the Paleocene and NP10–NP12 represent the Lower Eocene (compare Fig. 4 and the Paleocene-Eocene boundary herein).

In areas of non-deposition or eroded areas, the palæogeographic maps illustrate only the absence of time-equivalent sediments today. Whether deposition occurred, or not, is not indicated because the time of erosion cannot be pinpointed accurately. For comparison of palæogeographic maps and stratigraphy of areas of major uplift, see Fig. 4. Within this stratigraphic/palæogeographic framework, the Wadi El-Esseila succession (El-Askary and Shaaban, 1993) remains questionable because the stratigraphic subdivision here is in no concordance with the stratigraphic subdivision of the surrounding sections.

CC25 (Fig. 10a)

During the middle Maastrichtian biozone CC25, the areas west and north of the northern parts of the Gulf of Suez are characterised by non-deposition

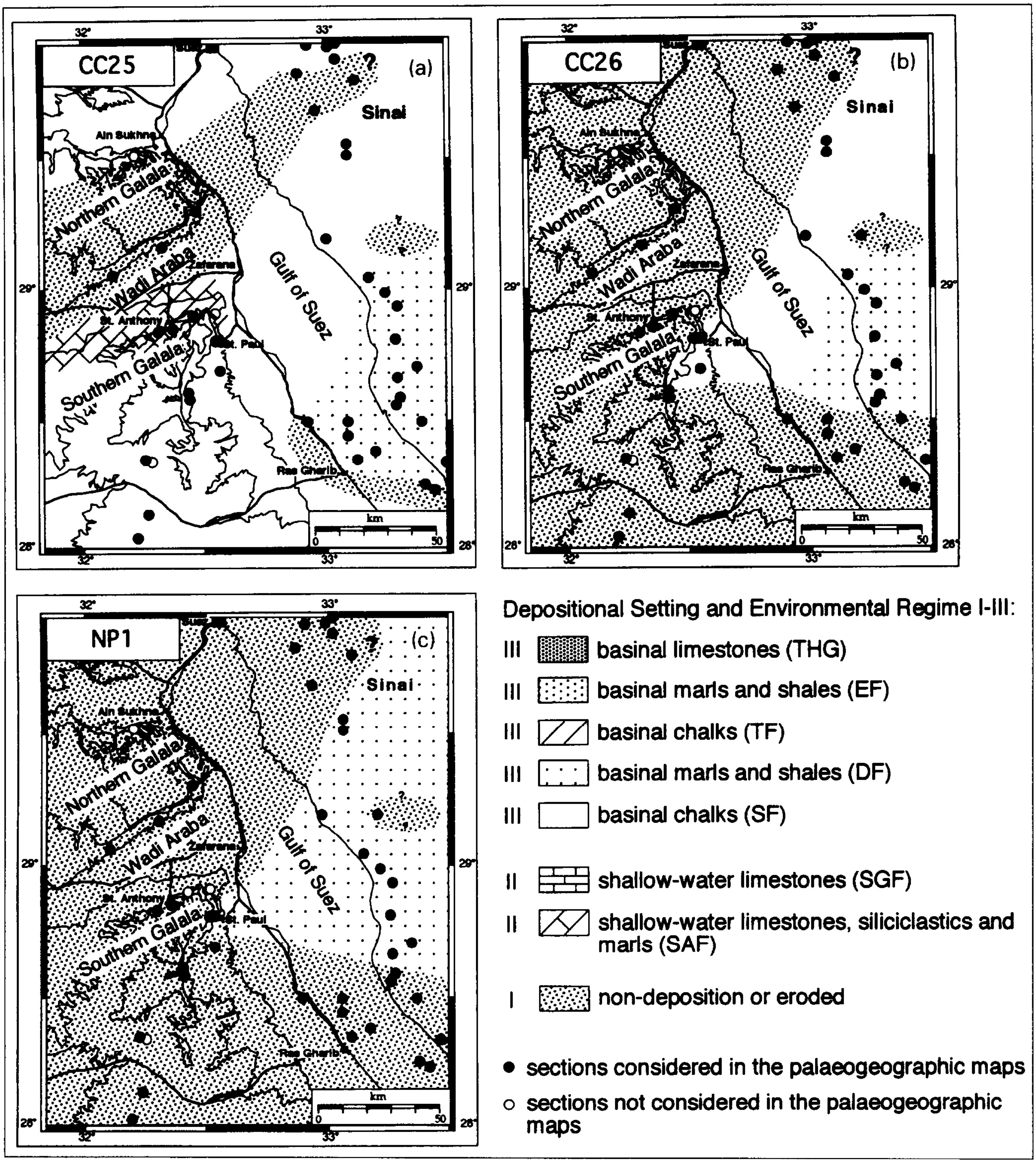


Figure 10. Regional palæogeographic maps of 11 time slices from the Maastrichtian-Early Eocene (continued on the following two pages). In the Maastrichtian, the two calcareous nannoplankton biozones of CC25 and CC26 (a and b); and in the Paleocene, the calcareous nannoplankton biozones of NP1–N10 (c); were chosen. Three different environmental regimes can be distingushed (I–III). The first regime with hiatuses reflects uplift and erosion or non-depositon (I). The shallow water influenced shelf and slope deposits of the Late Campanian-Maastrichtian St Anthony Formation and the Paleocene-Eocene Southern Galala Formation are the second environmental regime (II). The third regime is represented by the Maastrichtian Sudr Formation and the Paleocene-Eocene Dakhla, Tarawan and Esna Formations and Thebes Group reflecting basinal lithologies (III). The topographic base-map and the location of sections (with ● and ○) refer to Fig. 1. ●: sections with stratigraphical information; ○: sections with no stratigraphical information, due to non-exposure.

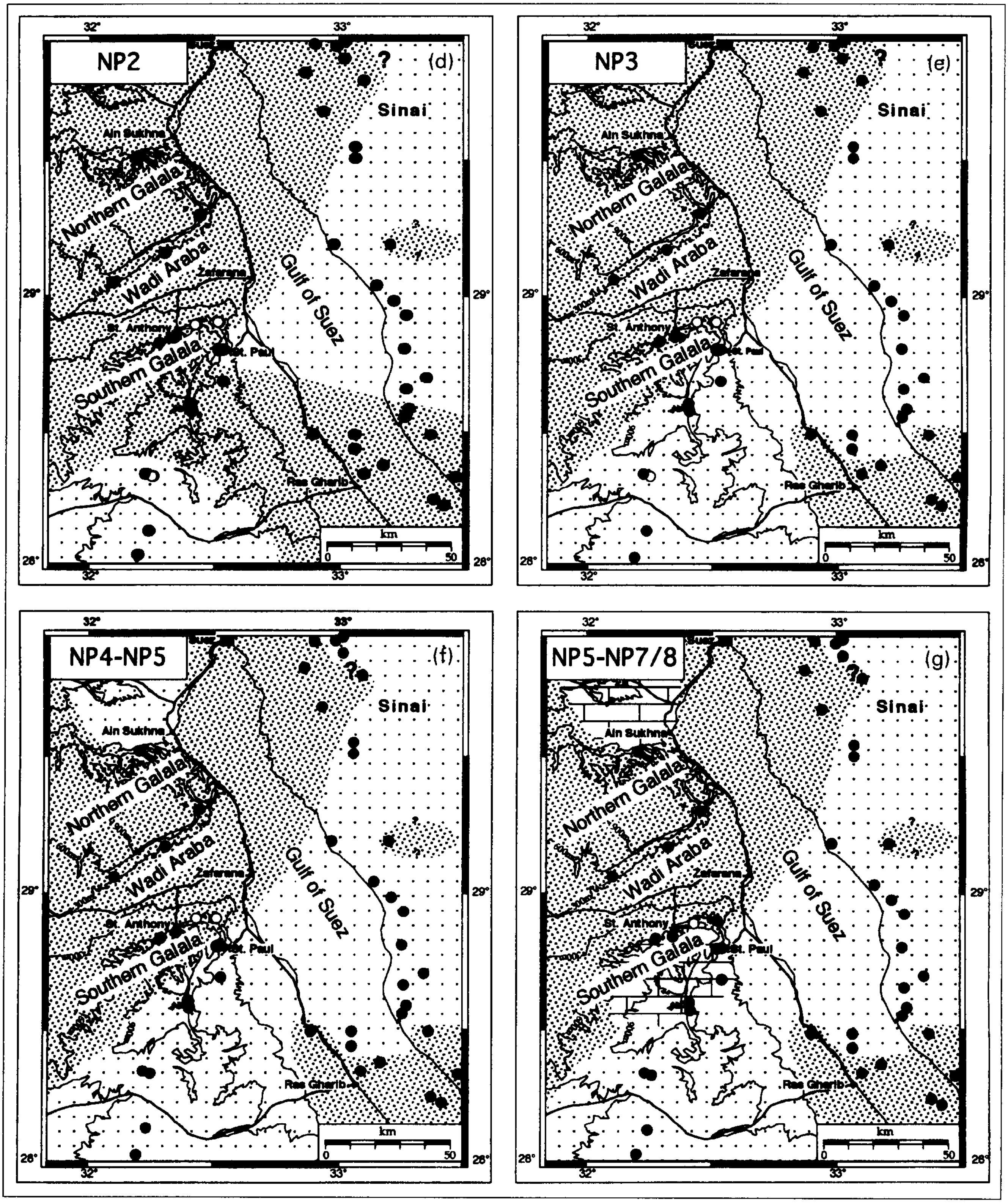


Figure 10. continued. Regional palæogeographic maps of 4 out of 11 time slices from the Maastrichtian-Early Eocene. In the Paleocene, the calcareous nannoplankton biozones of NP1–N10 (d–g) were chosen. *See p. 247 for legend and symbol explanations.*

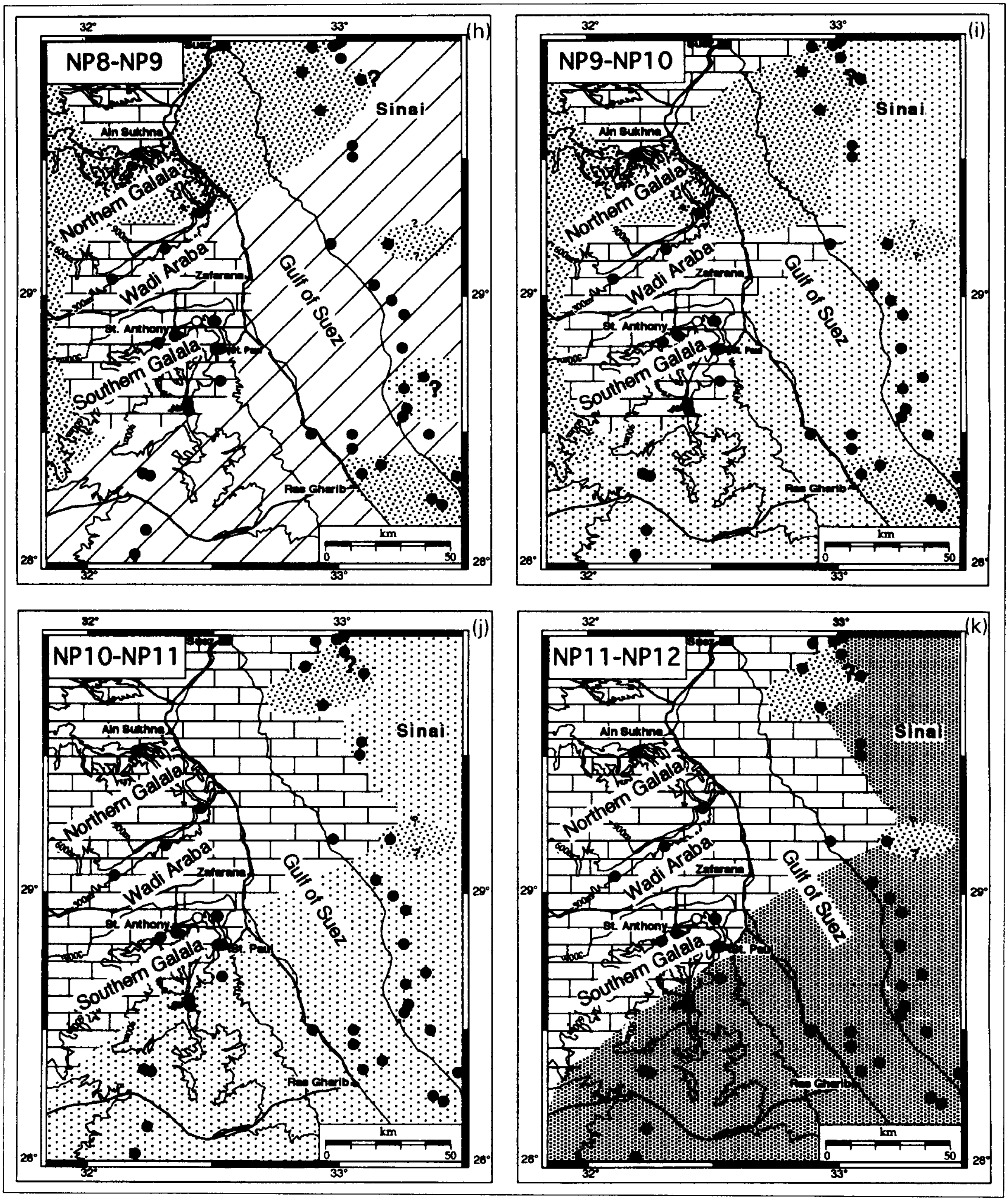


Figure 10. continued. Regional palæogeographic maps of 4 out of 11 time slices from the Maastrichtian-Early Eocene. In the Paleocene, the calcareous nannoplankton biozones of NP1–NP10 (h and i); and in the Eocene, NP10–NP12 (j and k) were chosen. *See p. 247 for legend and symbol explanations.*

that may reflect subaerial exposures or submarine swells. At the western Gulf of Suez, these areas coincide with the Northern Galala/Wadi Araba High. The stratigraphical range of the Northern Galala/ Wadi Araba hiatuses may reach Turonian-Early Paleocene (Kuss and Leppig, 1989; Abd-Elshafy and Atta, 1993). The eroded sediments derived from this area were mainly transported southward, where they were deposited as chalky limestones, marls and sandstones of the St Anthony Formation in the northern parts of the Southern Galala (St Anthony and Gebel Thelmet sections in Fig. 4a). North of the Northern Galala/Wadi Araba, no sediments of the St Anthony Formation are present, only the deeper water chalks of the Sudr Formation (Wadi Nooz: this work; Gebel Um Makhasa: Kulbrok, 1996). The Northern Galala/Wadi Araba formed an isolated island surrounded by shallow water sediments that interfinger with chalks, marly chalks and marls of the deeper water Sudr Formation and Dakhla Formation. In addition to the uplifted area of the Northern Galala/Wadi Araba, two local areas of non-deposition occur on Sinai (Wadi El-Esseila of El-Askary and Shaaban, 1993) and in the south of the investigated area (Ezz El-Orban, Morgan 8 and H1 of Masters, 1984). It is not clear, whether these two areas were truly exposed islands, local highs with non-deposition or only the result of later erosion.

CC26 (Fig. 10b)

The regional distribution of the depositional settings is least clear within this time slice because of the poor biostratigraphic data. On western Sinai, the calcareous nannoplankton data of Abdelmalik *et al.* (1978a, 1978b) and Marzouk and Hussein (1994) were mainly relied upon. The planktic foraminifers do not offer a better biostratigraphic solution, as the *A. mayaroensis* Zone covers also part of CC25, and the index fossil *A. mayaroensis* is very rare in southern Egypt (Luger *et al.*, 1998). In most sections in this area, as well as in most of Egypt, the time interval ranging from the upper part of CC26 to the Early Paeocene is probably a time of non-deposition and/or exposure. During the latest Maastrichtian, chalks, marly chalks and marls of the deeper water Sudr and Dakhla Formations were deposited within a basin that extends from the St Paul/Bir Dakhl area in the west to the west central Sinai in the east (e.g. St Paul area: see this work; Wadi El-Seig/Hialla: Abbass *et al.*, 1994; Matulla and Nuhkl: Marzouk and Hussein, 1994). It is not clear whether the shallow water sediments of the St Anthony Formation were deposited in the Southern Galala or not.

NP1 (Fig. 10c)

The early part of NP1 is, similar to the late part of CC26, a time of non-deposition or erosion in the area of investigation (Strougo *et al.*, 1992; Faris, 1997). The basin configuration of the Southern Galala Sub-basin is very similar to that of CC26. It encompasses the St Paul area in the west to the west central Sinai in the east, but the prevailing lithologies changed in time. Instead of chalks of the Maastrichtian Sudr Formation, marls and shales of the Dakhla and Dakhla/Tarawan/Esna Formations were deposited in the Early Paleocene.

NP2 (Fig. 10d)

During NP2 times, the established basin (Southern Galala Sub-basin) with the marls and shales of the Dakhla and Dakhla/Tarawan/Esna Formations from St Paul to the western Sinai remains in the same configuration. Additionally, marls of the Dakhla Formation were deposited in the Wadi Tarfa area. All other areas in the northwest (NGWA) and in the southeast (Ezz El-Orban area) are still exposed or areas of non-deposition.

NP3 (Fig. 10e)

In NP3, the two isolated basins, both parts of the Southern Galala Sub-basin with marls of the Dakhla Formation, were connected through the Bir Dakhl area. Similar to NP2, the Northern Galala/Wadi Araba and the Ezz El-Orban areas remain areas of non-deposition.

NP4–lower NP5 (Fig. 10f)

The configuration of the Southern Galala Sub-basin remains the same. Additionally, north of the Northern Galala/Wadi Araba in the Wadi Nooz area (this work) marly sediments of the Dakhla and Dakhla/Tarawan/ Esna Formations prevail.

Upper NP5–lower NP7/8 (Fig. 10g)

During this interval, shallow water deposits of the Southern Galala Formation prograded (Scheibner *et al.*, 2000). Slumps and debris flows evidence the south-ward progradation, starting from the Southern Galala, extending towards the south to the area of Bir Dakhl and progressing towards the north to the area of Wadi Nooz. This ramp progradation was initiated by a main sea level drop at the base of P4 (within NP5), as Scheibner *et al.* (2000) demonstrated in the area of St Paul (area 3) and Lüning *et al.* (1998a) on Sinai. Speijer and Schmitz (1998) reconstructed a palæodepth curve of that interval based on studies of benthic foraminifers from Gebel Aweina (*ca* 300 km to the south). These authors also concluded that a sea level drop occurred during lower P4. In the Southern Galala Sub-basin, the marls and shales of the Dakhla or Dakhla/Tarawan/Esna Formations were deposited.

Upper NP 7/8–lower NP9 (Fig. 10h)

During these biozones, the chalks of the Tarawan Formation were deposited in the south and east of the Northern Galala/Wadi Araba, although on Sinai, the Tarawan Formation is very thin or even missing. Here, the marly sediments of the Dakhla/Tarawan/Esna Formation were deposited. The shallow water sediments of the Southern Galala Formation were deposited now on parts of the Northern Galala, and in the south (Ras Gharib) the area of non-deposition becomes smaller. Anan (1992) and Lüning *et al.* (1998a) concluded that the Tarawan Formation on Sinai was deposited during a series of low sea levels. Luger (1985) and Speijer and Schmitz (1998), on the other hand, reported from southern Egypt that the sediments of the Tarawan Formation were deposited during sea level highstands.

Upper NP 9–lower NP10 (Fig. 10i)

The basin configuration of the Southern Galala Sub-basin stays the same, but the lithological character changes again. Now, the marls and shales of the Esna and the Dakhla/Tarawan/Esna Formations were deposited. North of the Northern Galala/Wadi Araba, the sediments of the Southern Galala Formation reach as far east as Gebel Um Makhasa (Kulbrok, 1996).

Upper NP 10–lower NP11 (Fig. 10j)

During this interval, sediments of the Southern Galala Formation dominate the areas of the Northern Galala/Wadi Araba. The only area of non-deposition is on the northwestern Sinai (Wadi Sudr: Gietl, 1998; Ain Sudr: Kulbrok, 1996; Mitla Pass: Abdel Gawad and Zalat, 1992). For the first time, sediments of the Dakhla and Dakhla/Tarawan/Esna Formations were deposited in the area of Ras Gharib, which could be part of a basin Said (1990) described in the Early Eocene around Abu Zenima.

Upper NP 11–NP12 (Fig. 10k)

The difference from this to the previous time slice is the deposition of the limestones of the Thebes Group in the Southern Galala Sub-basin instead of the marls and shales of the Esna and Dakhla/Tarawan/Esna Formations. Shahin (1990) and Lüning *et al.* (1998a) suggested that the Thebes Group was deposited during a time of a lowered sea level.

CONCLUSIONS

Palæogeographic changes are evident in the Maastrichtian to Early Eocene deposits in the surrounding of the northern Gulf of Suez based on three environmental regimes: basinal sediments; platform slope sediments; and non-deposition. The basinal sediments include chalks of the Sudr Formation in the Maastrichtian, shaley-marly sediments of the Dakhla, Esna and Dakhla/Tarawan/Esna Formations (a newly introduced informal formation), and chalks and limestones of the Tarawan Formation in the Paleocene to Early Eocene.

The basinal sediments of the Sudr, Dakhla and Esna Formations interfinger near the structural high of the Northern Galala/Wadi Araba High. This high was subaerially exposed during the Late Cretaceous to Early Eocene. The shallow water slope deposits of the St Anthony and Southern Galala Formations were deposited south of this high, whereas north of the high only the sediments of the Southern Galala Formation came to deposition.

Other local highs that led to non-deposition or erosion are present on northwest and southwest Sinai. In particular, the high around Ras Gharib could indicate that the boundary between the stable and unstable shelf on the Sinai lies farther south.

Four different types of hiatuses could be distinguished, characterised by varying duration and/or different mechanisms (e.g. sea level changes). At least the palæogeographical change within calcareous nannozone NP5 resulted from a main sea level drop.

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