Chapter III
Biostratigraphy

III. Biostratigraphy

This chapter deals with the biostratigraphic classification of the Upper Cretaceous-Lower Eocene succession crops out in the Farafra Oasis. Most of the rock samples from the fourteen measured stratigraphic sections yield rich and diverse planktic and benthic foraminiferal assemblages.

In the present study, 191 foraminiferal species are identified, of these 91 planktics and 100 benthics. In general, the preservation of the specimens is good except for the Early Paleocene specimens. The most important foraminiferal species are photographed in the laboratories of the Egyptian Mineral Resources Authority (E.M.R.A.) by using the Scanning Electron Microscope (SEM). They are depicted in 9 plates. In addition, the most important macrofauna recognized in the studied Upper Cretaceous-Lower Eocene succession are identified, photographed, and depicted in two plates (plates 10-11).

The taxonomy of the Late Cretaceous and Early Paleogene planktic foraminifers adopted herein is that of Loeblich and Tappan (1988) for the planktic foraminiferal species with some modification given by Olsson *et al.* (1992, 1999) and Berggren and Norris (1997) for the Paleocene age (Table 3.1). The systematic description of the benthic foraminifers is beyond the scope of the present work. Benthic foraminiferas encountered in the studied succession are only counted to obtain the Planktic/Benthic (P/B) ratio, which is used with other depth indicators in paleoenvironmental interpretation.

The following table discusses briefly the arrangement of the identified planktic foraminiferal species according to their systematic position as.

Table 3.1 The arrangement of the identified planktic species according to their systematic position.

Planktic foraminifera

Order: Foraminiferida Eichwald, 1830

Suborder: Globigerinina Delage & Herouard, 1896

Superfamily: Heterohelicacea Cushman, 1927

S. No.	Family	Genus	Species	Pl.	Fig.
1	Guembelitriidae Montanaro Gallitelli, 1957	*Guembelitria*	*cretacea*	1	-
2		*Globoconusa*	*daubjergensis*		1
3	Chiloguembelinidae	*Chilogumbelina*	*morsei*		-
5			*midwayensis*		-
6	Heterohelicidae	*Heterohelix*	*globulosa*		2
7			*navarroensis*		3
8			*reussi*		
9			*striata*		4
10		*Planoglobulina*	*carseyae*		5
11			*glabrata*		6
12		*Pseudotextularia*	*elegans*		7
13		*Racemiguembelina*	*fructicosa*		8
14			*bowelli*		9a-d
15		*Pseudoguembelina*	*costulata*		10
16			*excolata*		11
17			*hariaensis*		-
18			*palpebra*		12

Superfamily: Planomalinacea Boli, Loeblich & Tappan, 1957

S. No.	Family	Genus	Species	Pl.	Fig.
19	**Globigerinelloididae Longoria, 1974**	***Globigerinelloides***	*prairiehillensis*	1	13a-b

Superfamily: Rotaliporacea Sigal, 1958

S. No.	Family	Genus	Species	Pl.	Fig.
20	**Hedbergellidae Loeblich & Tappan, 1961**	***Hedbergella***	*holmdelensis*	1	14a-b
21			*monmouthensis*	-	-
22		***Globanomalina***	*chapmani*	-	-
23			*compresa*	1	15a-b
24			*planoconica*	-	-
25			*pseudomenardii*	1	16a-c
26		***Pseudohastigerina***	*micra*	2	1a-b
27			*wilcoxensis*		2a-b

Superfamily: Globotruncanacea Brotzen, 1942

S. No.	Family	Genus	Species	Pl.	Fig.
28	Globotruncanidae Brotzen, 1942	*Contusotruncana*	*contusa*	2	3a-b
29			*fornicata*		4a-c
30			*plicata*	-	-
31		*Gansserina*	*gansseri*	2	5a-c
32			*widenmayeri*	-	-
33		*Globotruncana*	*aegyptiaca*	2	6a-c
34			*arca*		7a-c
35			*bulloides*		8a-b
36			*duwi*		9a-b
37			*linneiana*	-	-
38			*mariei*	-	-
39			*orientalis*	2	10a-b
40			*rosetta*	3	1a-b
41	Globotruncanidae Brotzen, 1942	*Globotruncanita*	*conica*	-	-
42			*stuarti*	3	4a-b
43			*stuartiformis*		3a-c
44			*pettersi*		2a-b
45		*Rugotruncana*	*subcircumnodifer*	-	-
46		*Globotruncanella*	*havanensis*	3	5
47			*petaloidea*		6

Superfamily: Globorotaliacea Cushman, 1927

S. No.	Family	Genus	Species	Pl.	Fig.
48	Rugoglobigerinidae Subbotina, 1960	*Rugoglobigerina*	*hexacamerata*	3	7
49			*macrocephala*		8a-b
50			*reicheli*		9a-b
51			*rugosa*		10a-b
52			*scotti*		11a-b

S. No.	Family	Genus	Species	Pl.	Fig.
53	Truncorotaloididae Loeblich & Tappan 1961	*Praemurica*	*inconstants*	4	1a-b
54			*trinidadensis*		2a-b
55			*uncinata*		3a-b
56		*Igorina*	*albeari*		4a-b
57			*pusilla*		5a-b
58		*Acarinina*	*africana*	-	-
59			*angulosa*	4	7a-b
60			*convexa*	-	-
61			*inaequispira*	-	-
62			*intermadia*	-	-
63			*mckannai*	4	8a-b
64			*nitida*		9
65			*pentacamerata*		11
66			*primitiva*		10
67			*sibaiyaensis*		12a-c
68			*soldadoensis*		14a-b
69			*strabocella*		13a-c
70			*wilcoxensis*		15a-b

S. No.	Family	Genus	Species	Pl.	Fig.
71	Truncorotaloididae Loeblich & Tappan 1961	*Morozovella*	*Acuta*	5	1a-c
72			*aequa*		2a-c
73			*angulata*		3a-c
74			*apanthesma*		4a-b
74			*aragonesis*	-	-
75			*caucasica*	5	5a-b
76			*conicotruncata*		4a-b
77			*formosa*		6a-c
78			*gracilis*		7a-b
79			*marginodentata*		9a-b
80			*lensiformis*		8a-b
81			*occlusa*		10a-b
82			*prava*	6	1
83			*subbotinae*		2a-c
84			*velascoensis*		3a-c

Superfamily: Globigerinacea Carpenter, Parker & Jones, 1862

S. No.	Family	Genus	Species	Pl.	Fig.
85	Globigerinidae Carpenter, Parker & Jones, 1862	*parasubbotina*	*pseudobulloides*	6	4a-c
86			*varianta*		5a-c
87		*Subbotina*	*eocaena*	-	-
88			*linberata*	6	7a-b
89			*triangularis*		8a-b
90			*triloculinoides*		9a-b
91			*velascoensis*		10

The identified planktic foraminiferal zones are compared with their equivalents in neighboring areas and in the world (Figs. 3.1 & 3.2). The vertical distribution of the planktic species is essentially used to establish a biostratigraphic classification for the Upper Cretaceous-Lower Eocene succession of the Farafra Oasis.

The Maastrichtian rocks in the studied stratigraphic sections of the Farafra Oasis are classified according to the schemes of Li and Keller (1998a, b) and Li *et al.* (1999). Their biozonations are similar to the biozonations of Caron (1985), except for the interval encompassed by the two Late Maastrichtian biozones: *Gansserina gansseri* Zone and *Abathomphalus mayaroensis* Zone, which are subdivided into seven biozones (Fig. 3.1). Each biozones has been labeled CF for Cretaceous foraminiferal zones and numbered from younger to older (CF1-CF8).

For the Paleocene-Early Eocene interval, Berggern *et al.* (1995) and Berggren and Norris (1997) planktic zonations are used in the present study. These zonal schemes are emended by Pardo *et al.* (1999); Berggren *et al.* (2000) and Berggren and Ouda (2003a). Eleven planktic foraminiferal zones are distinguished in the Upper Cretaceous-Lower Eocene succession of the Farafra Oasis. These are three in the Late Cretaceous bottomed by a barren interval. The Danian is subdivided into two biozones; bottomed by a hiatus in the K/T boundary. The Late Paleocene is divided into two zones, while the Early Eocene includes three zones (Fig. 3.2).

The following is the description of the established planktic foraminiferal biozones arranged from older to younger:

III.1 Late Cretaceous biozones

Barren interval

The exposed part of El-Hefhuf Formation in the Farafra Oasis is found barren of any foraminiferal tests. This part attains

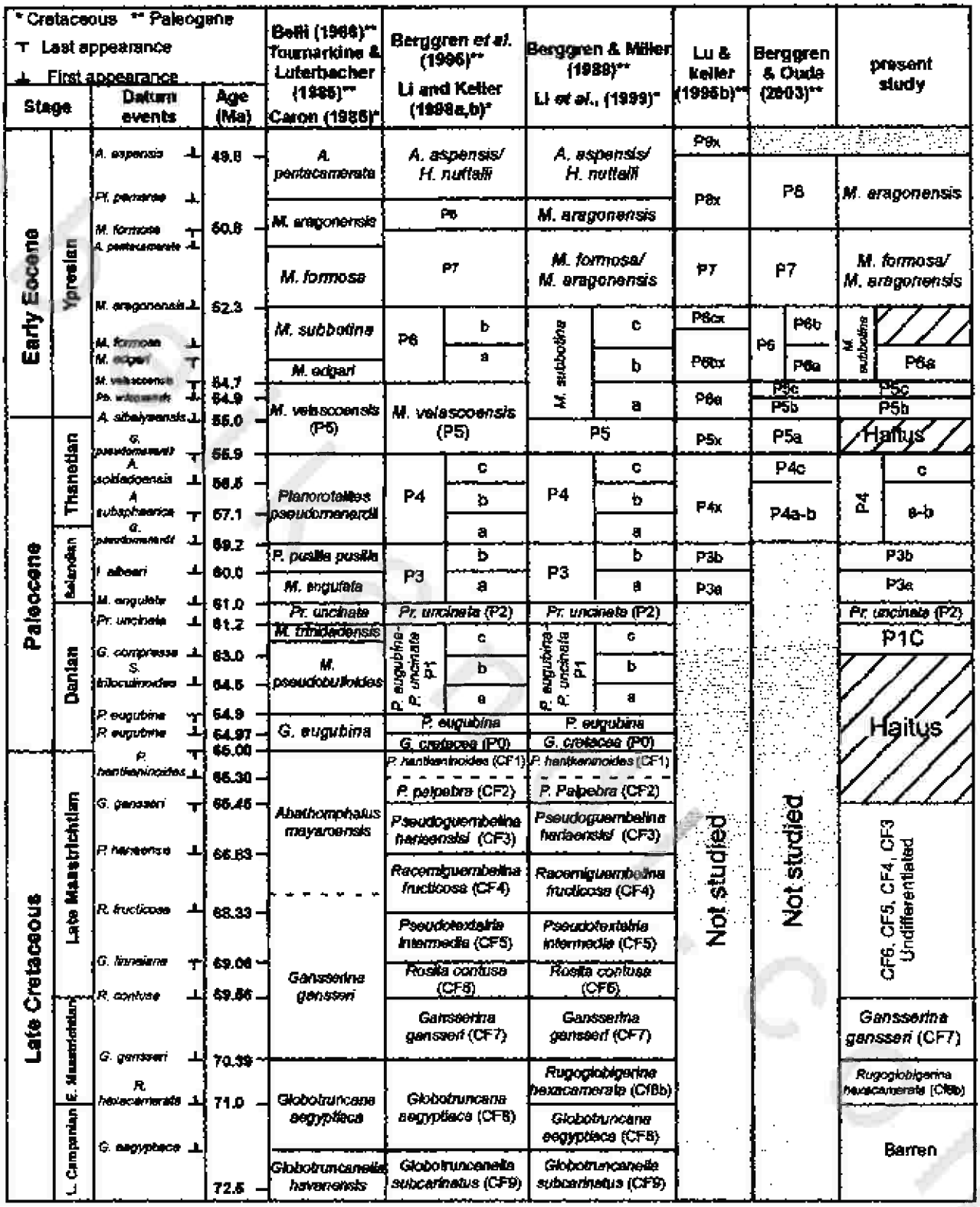


Fig. 3.1 Summary of the commonly used planktic foraminiferal zonal schemes, age estimates and their coeval in the Farafra Oasis. The estimated ages and datum events are based on Li and Keller 1999 for the Late Cretaceous and Berggren *et al.*, 1995 for the Early Paleogene.

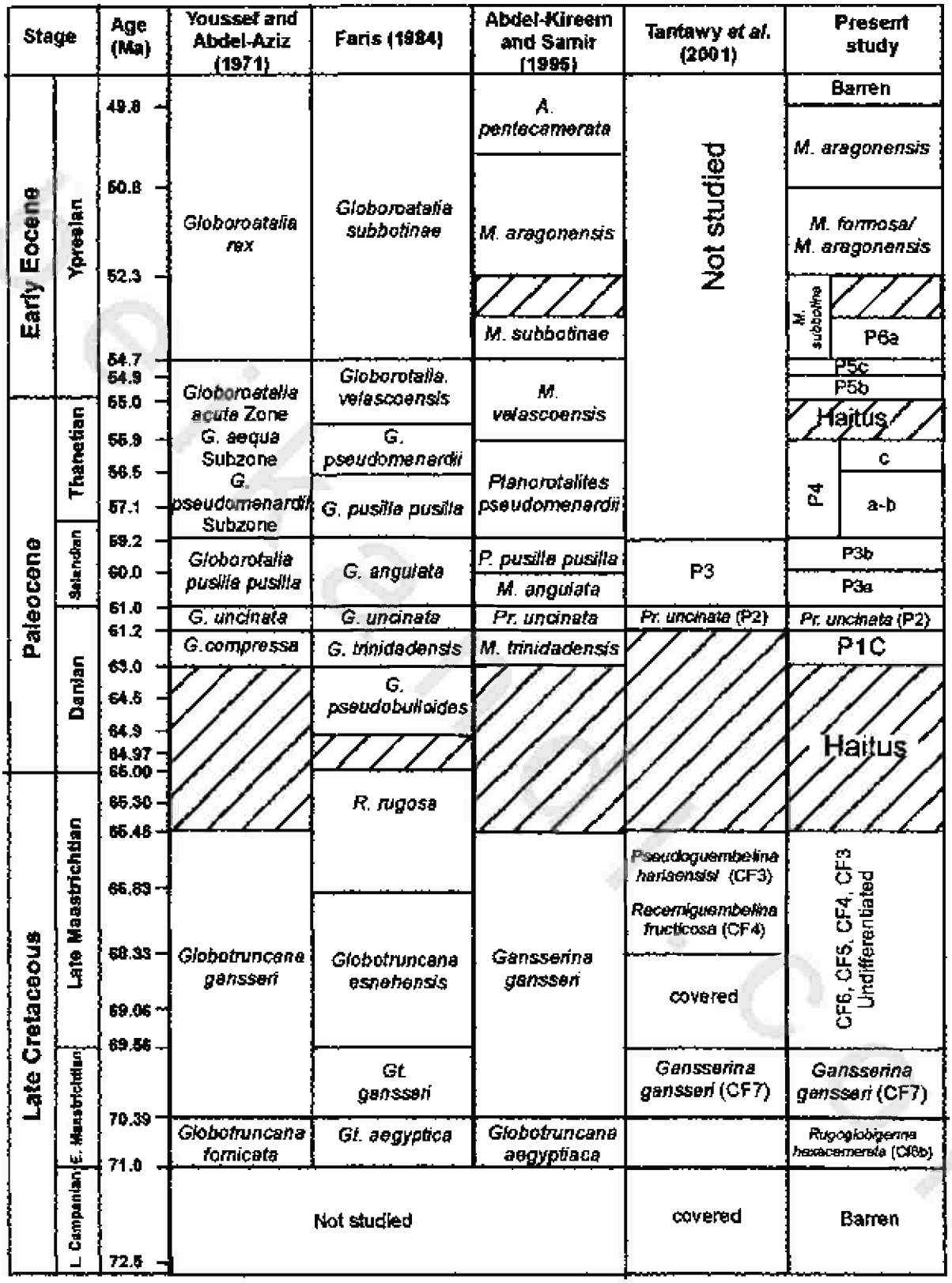


Fig. 3.2 Correlation of the Late Cretaceous–Early Eocene zones in the present study and those previously established in the Farafra and Dakhla oases.

about 34m thick at south Wadi Hennis and 11m thick at east Shakhs El-Obeiyid. The clastic sediments of El-Hefhuf Formation are considered to be of Santonian age according to their stratigraphic position and to the previous palynological investigation of Ibrahim and Abdel-Kireem (1997) and Abdel Mohsen (2002). While, its upper carbonate sediments are dated to be of Campanian age based on their stratigraphic position. In addition to, the presence of the larger *Pycnodonte vesicularis* (Lamarck) and *Neithea coquandi* (Péron) as well as shark teeth and fragments of fish bones. In Sinai, Khalil and Mashaly (2004) defined the Santonian-Campanian boundary by the first appearance of *Pycnodonte vesicularis* (Lamarck) at the contact between the Matulla Formation and the snow white chalk of the Sudr Formation.

The Campanian-Maastrichtian boundary in the Farafra Oasis is defined at the contact between El-Hefhuf Formation and the overlying Khoman Formation. The latter ascribes to the *Rugoglobigerina hexacamerata* (CF8b) Zone. This contact corresponds to the upper portion of the Duwi Formation of Late Campanian-Early Maastrichtian age in the Nile Valley (Faris, 1984).

1. *Rugoglobigerina hexacamerata* Interval Zone (= CF8b)

Author: Li *et al.* (1999).

Estimated age: 71.0-70.39 Ma (Early Maastrichtian).

Definition: This interval zone starts from the first appearance (FA) of the *Rugoglobigerina hexacamerata* (Brönnimann) at the

base to the first occurrence of the *Gansserina gansseri* (Bolli) at the top.

Stratigraphic position: This zone is recorded from the basal part of the Khoman Formation. It attains about 28m thick (samples 1-30) in northwest Ain Maqfi section (Fig. 3.3).

Planktic faunal content: This zone is found rich in its planktic foraminiferal tests (Fig. 3.3). The most dominant species recorded in this zone include: *Globotruncana arca* (Cushman), *G. aegyptiaca* Nakkady *G. orientalis* El-Naggar, *G. duwi* (Nakkady), *G. bulloides* Vogler, *G. linneiana* (d'Orbigny), *Globotruncanita stuartiformis* (Dalbiez), *G. stuarti* (de Lapparent), *Contusotruncana fornicate* (Plummer), *Rugoglobigerina rugosa* Plummer, *R. macrocephala* Brönnimann, *Heterohelix globulosa* (Ehrenberg), *H. navaroensis* Loeblich, *H. reussi* (Cushman) and *H. striata* (Ehrenberg).

Benthic faunal content: The most important benthic species recorded in the *Rugoglobigerina hexacamerata* Zone include: *Bolivinoides draco* (Marsson), *B. decoratus* (Jones), *Nodosaria semispinosa* LeRoy, *Pseudoclavulina maqfiensis* (LeRoy), *Gaudryina pyramidata* Cushman, *Bolivinopsis minuta* (Said & Kenawy), *Praebulimina carseyae* (Plummer), *Sitella cushmani* (Sandidge) and *Neoflabllina rugosa* (d'Orbigny).

Remarks: Li *et al.* (1999) divided the Maastrichtian Stage into two substages (Early and Late). The planktic foraminiferal specialists considered the first appearance of the *Globotruncana aegyptiaca* (CF8) of Li and Keller (1998a, b) as marker for the Latest Campanian–Earliest Maastrichtian age. Recently, Li *et al.*

(1999) subdivided the *Globotruncana aegyptiaca* (CF8) into two subzones; CF8a and CF8b (Fig 3.1).

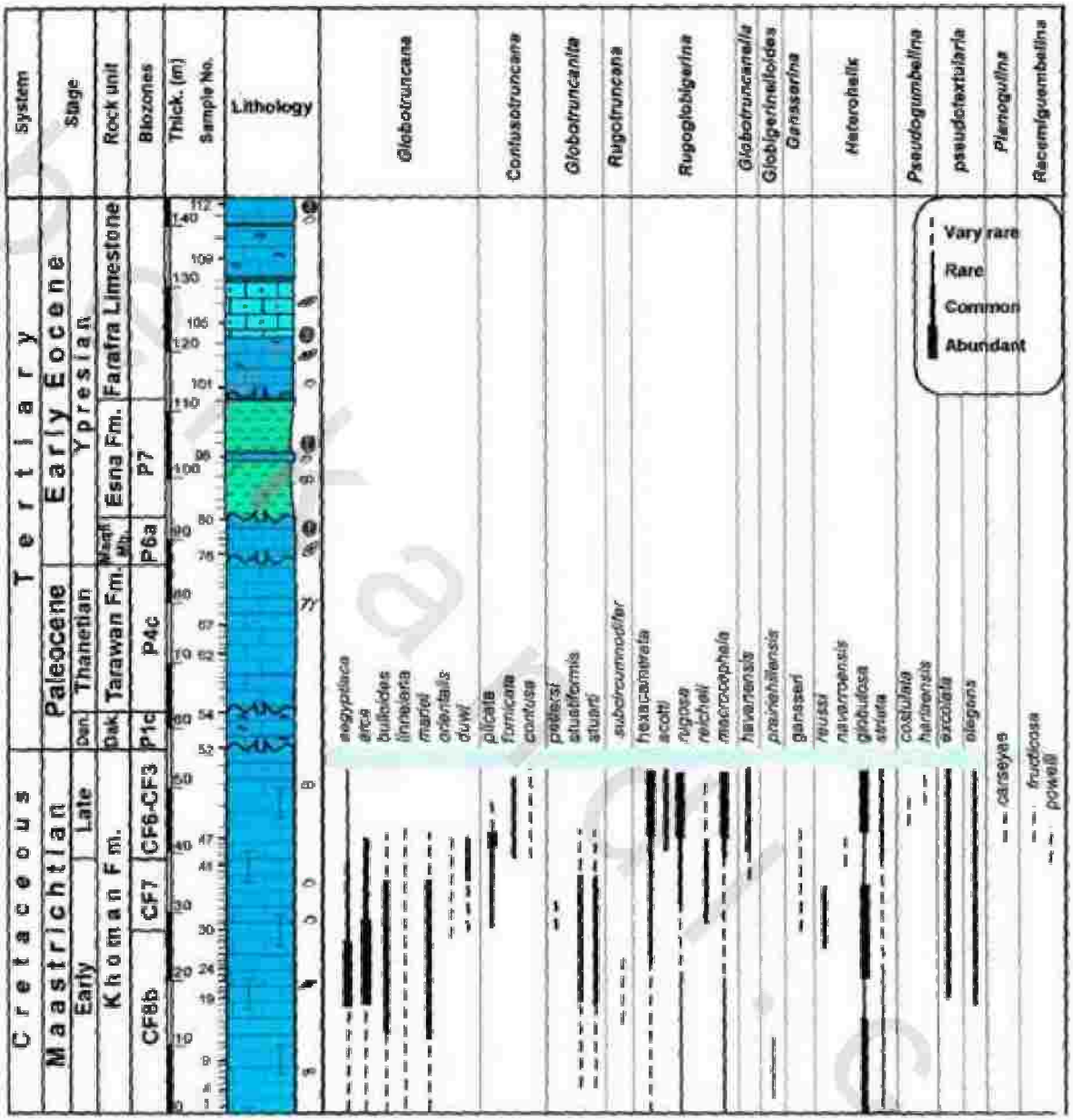
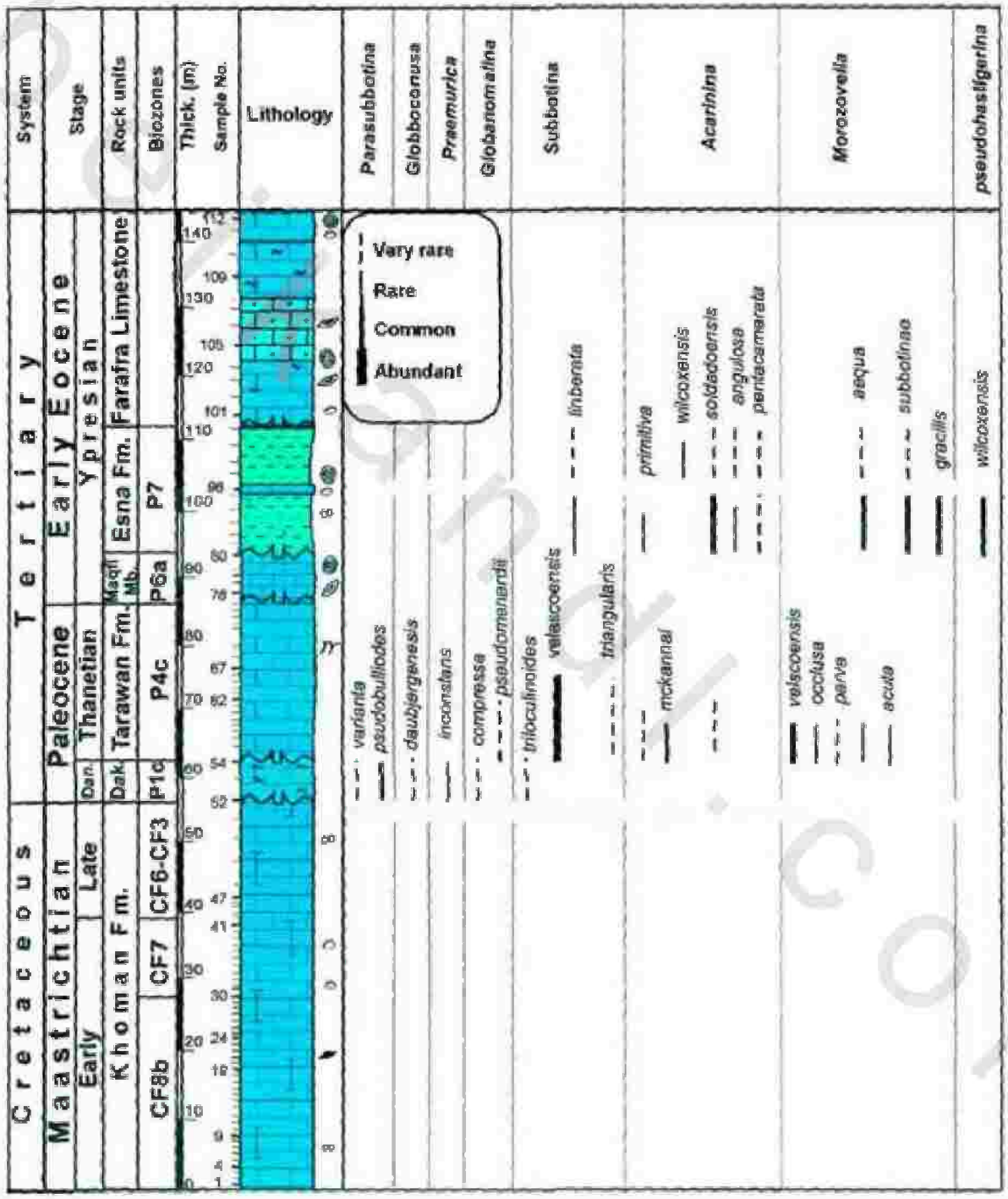


Fig. 3.3 Frequency distribution of the planktic foraminiferal species of the Maastrichtian rocks exposed in northwest Ain Maqfi area, northeast Farafra Oasis.

The present *Rugoglobigerina hexacamerata* Zone could be correlated with other zones described from Egypt such as *Globotruncana fornicata* Zone of El-Naggar (1966) and Ansary and Tewfik (1966) and *Globotruncana falsostuarti* Zone of Abdel Kireem *et al.* (1995). This zone is also equivalent to the upper

part of the *Globotruncana aegyptiaca* Zone which recorded by many authors such as Samir (1994) in the area between Bahariya and Farafra, El-Nady and Shain (2001) from northeast Sinai and Khalil and Mashaly (2004) from the Lower Maastrichtian sediments in Gabal Musaba Salama, southwest Sinai.



Cont. Fig. 3.3 Frequency distribution of the planktic foraminiferal species of the Paleocene-Lower Eocene rocks exposed in northwest Ain Maqfi area, northeast Farafra Oasis.

Outside Egypt, the *Rugoglobigerina hexacamerata* Zone is equivalent to the top part of the *Globotruncana tricarinata* Zone of Barr (1972) from Libya. This zone is also equivalent to the upper part of the *Globotruncana falsostuarti* Zone, which was recorded by several authors such as Robaszynski *et al.* (1984) in Europe.

In the Farafra Oasis, the *Rugoglobigerina hexacamerata* Zone is equivalent to the *Globotruncana fornicate* Zone of Youssef and Abdel-Aziz (1971) and the *Globotruncana aegyptiaca* Zone of Abdel-Kireem and Samir (1995) from Gunna North. Recently, this zone is recorded by Tantawy *et al.* (2001) in the Western Desert of Egypt.

2. *Gansserina gansseri* Partial Range Zone (= CF7)

Author: Brönnimann (1952) introduced this zone for the first time as *Globotruncana gansseri* from the Early Maastrichtian of Trinidad. Since then it is recognized worldwide.

Estimated age: 70.4-69.6 Ma (Early Maastrichtian).

Definition: This zone covers the interval from the first occurrence of the *Gansserina gansseri* (Bolli) at the base to the first occurrence of the *Contusotruncana contusa* (Cushman)

Stratigraphic position: The *Gansserina gansseri* Zone is recorded from the middle part of the Khoman Formation. It attains about 11m thick in northwest Ain Maqfi (Fig. 3.3).

Planktic faunal content: The *Gansserina gansseri* Zone is very rich in its planktic foraminiferal species (Fig. 3.3). The most common species which were recorded in this zone and extended from the underlying zone are: *Globotruncana aegyptiaca*

Nakkady, *G. orientalis* El-Naggar, *G. linneiana* d'Orbigny, *Globotruncanita stuartiformis* (Dalbiez), *G. stuarti* (de Lapparent), *Contusotruncana fornicata* (Plummer), *Rugoglobigerina rugosa* Plummer, *R. macrocephala* (Brönnimann), *R. scotti* Brönnimann, *Heterohelix globulosa* (Ehrenberg) and *H. reussi* (Cushman). The distinctive planktic species which start it occurrence with this zone are *Globotruncanita pettersi* (Gandolfi), *Gansserina wiedenmayeri* (Gandolfi), *Pseudoguembelina costulata* (Cushman), *Pseudoguembelina excolata* (Cushman), *Pseudotextularia elegans* (Rzehak), *Planoglobulina carseyae* (Plummer), *Rugoglobigerina scotti* Brönnimann and *Globotruncanella havanensis* (Voorwijk).

Benthic faunal content: The common benthic species recorded in the *Gansserina gansseri* Zone are generally those found in the underlying zone.

Remarks: The planktic foraminiferal specialists considered the first appearance of the *Gansserina gansseri* (Robaszynski *et al.*, 1984, Caron, 1985 and Li and Keller, 1998a, b) to define the Late Maastrichtian substage. The FA of the *Abthomphalus mayaroensis* Bolli was adopted by Boersma (1981) to delineate the Early/Late Maastrichtian boundary. They considered the *A. mayaroensis* Bolli as a not reliable index species. However, it has been found that *Abathomphalus mayaroensis* Bolli is very rare or absent in the high latitude regions and is relatively shallow water fauna due to its deeper dwelling habitat (Dupuis *et al.*, 2001 and Master, 1984). Bralower *et al.* (1995) proposed that the Early/Late Maastrichtian boundary can be placed at the base of Chron C30n, which corresponds to the middle of the *Racemiguembelina fructicosa* Zone (=CF4) of Li and Keller (1998a). Li *et al.* (1999) used the base of CF4 Zone to define the

Early/Late Maastrichtian boundary. In this study, the present author follows Gradstein *et al.* (1995) and Li and Keller (1998a, b) by using the FA of the *Contusotruncana contusa* (Cushman) at 69.56 Ma as a marker species for the Early/Late Maastrichtian boundary.

The *Gansserina gansseri* Zone is synonymous with the same recorded zone by Wonders (1980), Li and Keller (1998 a, b), Li *et al.* (1999) and Tantawy *et al.* (2001), and also with the lower part of the *Gansserina gansseri* Zone of Bolli (1966), Robaszynski *et al.* (1984) and Caron (1985). In the Farafra Oasis, this zone is equated with the lower part of the *Gansserina gansseri* Zone which recorded by Youssef and Abdel-Aziz (1971), Samir (1994) and Abdel-Kireem and Samir (1995). It is also equivalent to the lower part of the *Gansserina gansseri* Zone of El-Nady and Shain (2001), El-Bassiouni *et al.* (2003) and Khalil and Mashaly (2004).

3. *Contusotruncana contusa/ Pseudotextularia intermedia/ Racemiguembelina fructicosa/ Pseudoguembelina hariaensis* Interval Zone (= CF6-CF5-CF4-CF3 Undifferentiated)

Author: Dalbeiez (1955) introduced the *Globotruncana contusa* Zone for the first time from the Late Maastrichtian of Tunisia, while the CF5-CF4-CF3 zones are emended by Li and Keller (1998a).

Estimated age: 69.56-65.45Ma (Late Maastrichtian).

Definition: This zone covers the interval from the first occurrence of the *Contusotruncana contusa* (Cushman) at the base to the appearance of the Paleogene taxa.

Stratigraphic position: The *Contusotruncana contusa/ Pseudotextularia intermedia/ Racemiguembelina fructicosa/*

Pseudoguembelina hariaensis Zone (CF6-CF3) Zone is recorded from the upper part of the Khoman Formation exposed in the Farafra Oasis. It attains about 5m thick at Shakhs El-Obeiyid section, 28m thick at northeast Bir Bidni and 17m thick at northwest Ain Maqfi section (Figs. 3.4).

Planktic faunal content: The most dominant planktic species recorded in this zone are those extending from the underlying zone such as *Contusotruncana fornicata* (Plummer), *C. plicata* (White), *Racemiguembelina fructicosa* (Egger), *Pseudoguembelina hariaensis* Nederbagt, *Heterohelix globulosa* (Ehrenberg), *H. reussi* (Cushman), *Pseudoguembelina palpebra* (Brönnimann and Brown), *P. excolata* (Cushman), *P. costulata* (Cushman), *Pseudotextularia elegans* (Rzehak), *Planoglobulina glabrata* (Cushman), *Globotruncana aegyptiaca* Nakkady, *Globotruncanella havanensis* (Loeblich), *Rugoglobigerina rugosa* Plummer, *Rugoglobigerina macrocephala* Brönnimann, *Globigerinelloides prairiehillensis* (Passagno), *Hedbergella holmdelensis* (Olsson) and *Rugoglobigerina scotti* (Brönnimann) in addition to *Contusotruncana contusa* (Cushman) (Fig 3.4).

Benthic faunal content: The most diagnostic species that recorded in this zone are those recognized in the underlying two zones in addition to *Saracenaria triangulars* (d'Orbigny), *Lagena sulcata* (Walker & Jacob), *Anomalinoides sinaensis* Said & Kenawy, *A. grandis* (LeRoy), *Neoflabellina jarvisi* (Cushman), *Clavulinoides trilaterus* (Cushman) and *Tritaxia barakai* Said & Kenawy. The end of the Maastrichtian is marked by the disappearance of several forms; the most important of them are *Bolivinoides draco* (Marsson), *Bolivinoides decoratus* (Jones), *Neoflabellina rugosa* (d'Orbigny), *Verneuilina aegyptiaca* (Cushman) and *Vaginulinopsis austinanai* (Cushman).

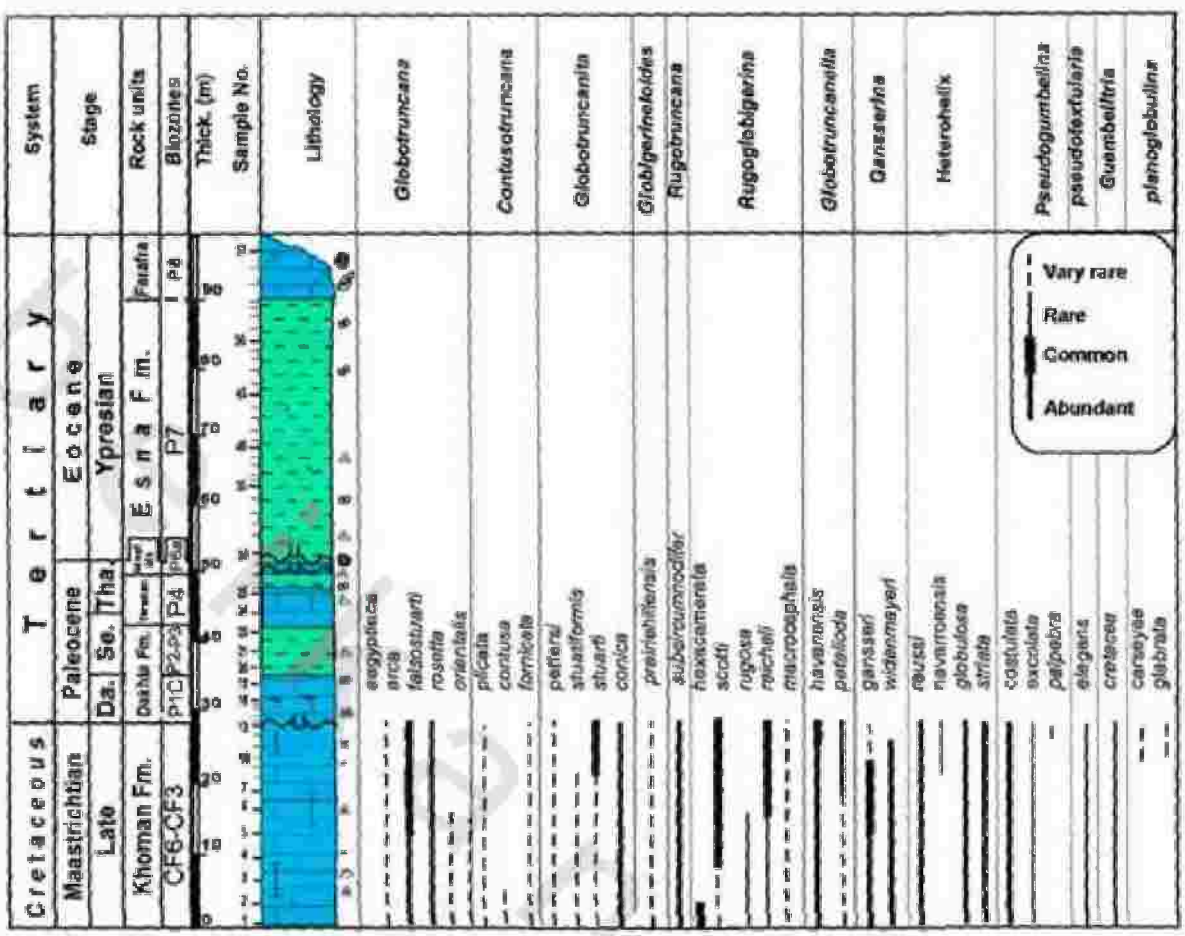
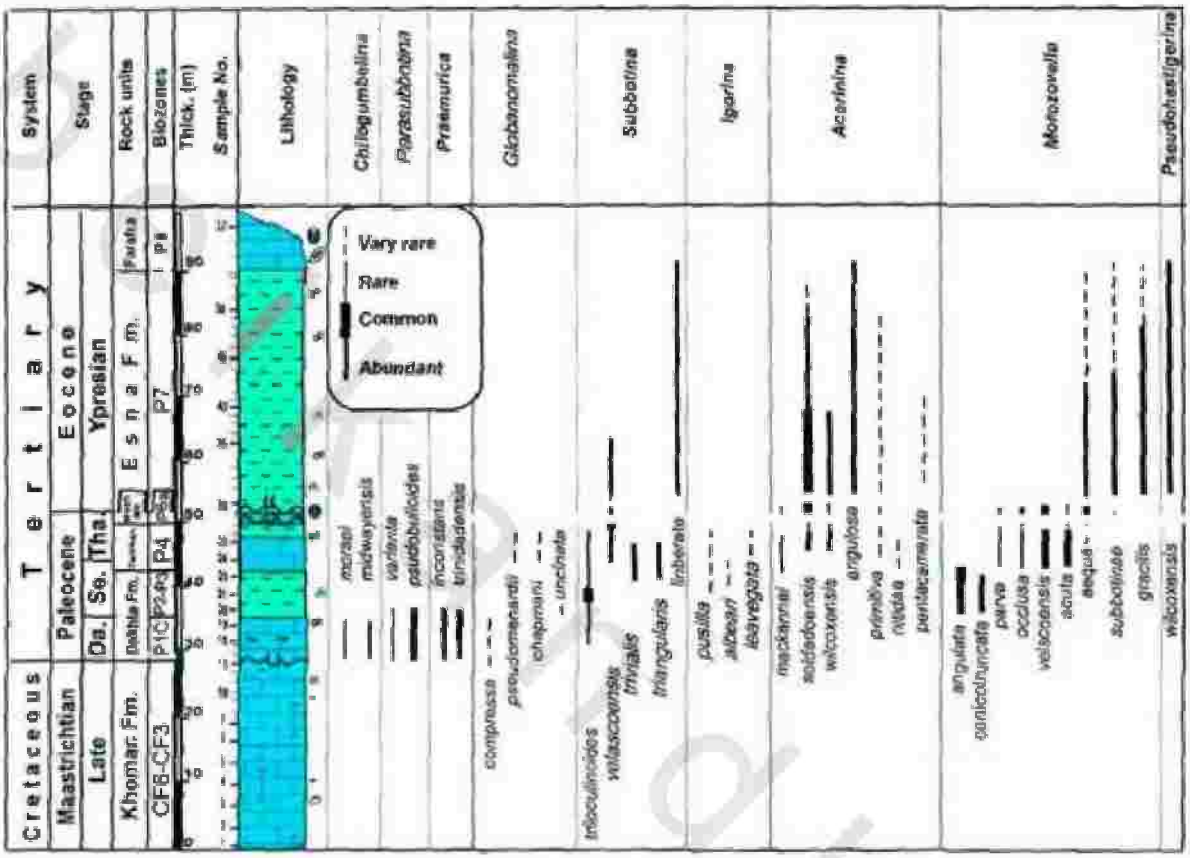


Fig. 3.4 Frequency distribution of the planktic foraminiferal species of the Maastrichtian rocks exposed in northwest Bir Bidni area, northwest Farafra Oasis.

Macrofossil content: The top part of the Khoman Formation that belongs to the *Gansserina gansseri* and *Contusotruncana contusa/ Pseudotextularia intermedia/ Racemiguembelina fructicosa/ Pseudoguembelina hariaensis* Zones include the following macrofossils: *Lyropecten* (*Aequipecten*) *mayeremari* (Newton), *Spondylus dutempleanus* d'Orbigny and *Agerostrea ungulata* (Schlotheim) among the bivalves as well as the *Burtinella solarioides* Wanner and *Terebratulina gracilis* Schlotheim among the gastropods and brachiopods respectively.

Remarks: This Zone is considered herein as the youngest Cretaceous zone recorded in the Farafra Oasis. At the Maastrichtian/Danian boundary of the Farafra Oasis, several

remarks on the planktic foraminifers are observed such as the extinction of all Cretaceous species (tropical-subtropical and cosmopolitan), the first appearance of the Danian species and the abrupt change in species richness.



Cont. Fig. 3.4 Frequency distribution of the planktic foraminiferal species of the Paleocene-Lower Eocene rocks exposed in northwest Bir Bidni area, northwest Farafra Oasis.

At Qur Hadida area, the lowest exposed chalk is marked by the occurrence of diverse CF3 foraminiferal assemblages and the disappearance of the *Gansserina gansseri* (Bolli) that marks the top of CF3 (Fig. 3.5). The Latest Maastrichtian-Early Danian is absent due to the K/T hiatus in the northern part of Egypt. The interval of the *Pseudoguembelina palpebra* (CF2) Zone and *Plummerita hantkeninoides* (CF1) Zone in the Cretaceous Period as well as the *Parvularugoglobigerina eugubina* (P0) Zone, *Parvularugoglobigerina eugubina-Subbotina triloculinoides*

(P1a) Subzone and *Subbotina triloculinoides-Globanomalina compressa* (P1b) Subzone in the Early Paleocene period are missing. This hiatus is also recorded by many authors (e.g. Youssef and Abdel-Aziz, 1971; Hermina, 1990 and Abdel-Kireem and Samir 1995) in the Farafra Oasis due to regional tectonic activity. Abdel-Kireem *et al.* (1995) also recorded this hiatus in two deep wells from the northern part of the Western Desert.

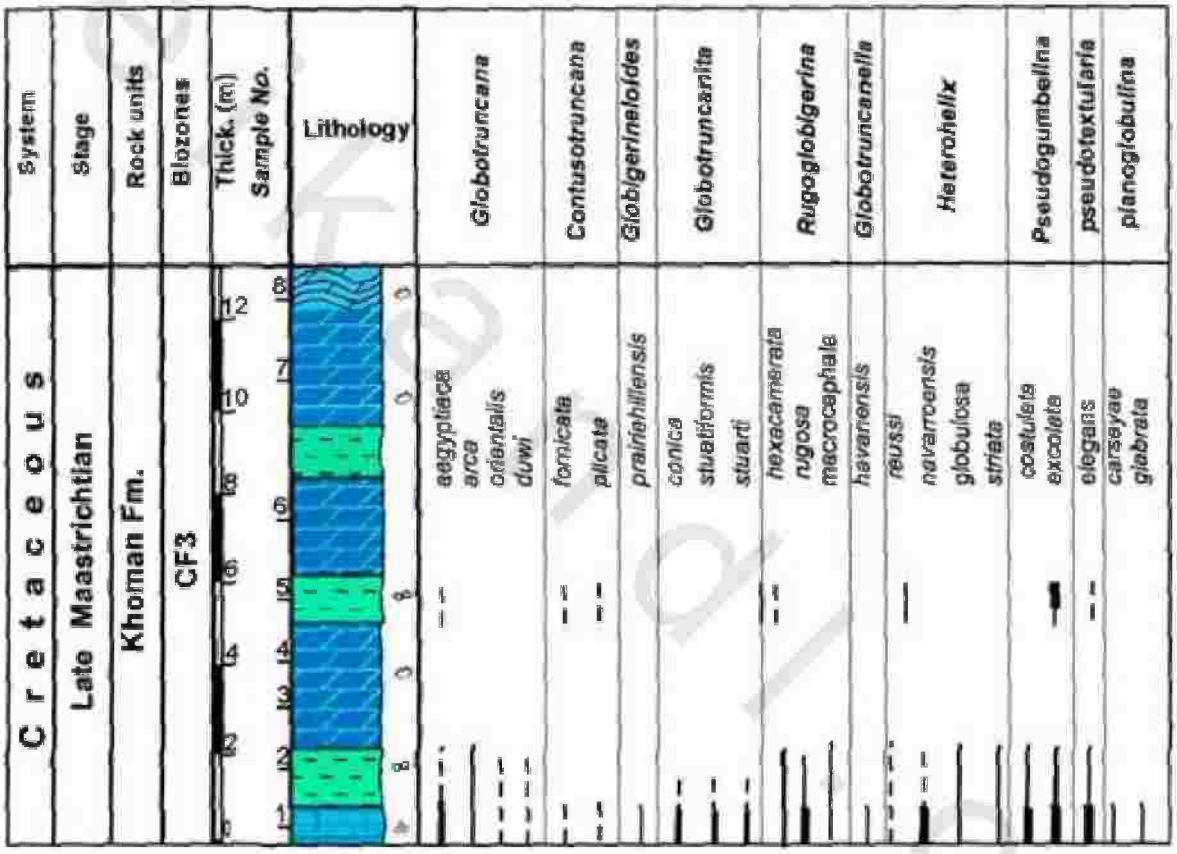


Fig. 3.5 Frequency distribution of the planktic foraminiferal species of the Upper Maastrichtian rocks exposed in Our Hadida area, east Farafra Oasis.

The present (CF6-CF3) Zone is correlatable with the *Pseudoguembelina hariaensis* Zone (CF3), *Racemiguembelina fructicosa* Zone (CF4), *Pseudotextularia intermedia* Zone (CF5) and *Contusotruncana contusa* Zone (CF6) recorded by Li and Keller (1998a, b), Li *et al.* (1999) and Tantway *et al.* (2001). It corresponds to the *Globotruncana contusa* Zone and middle part of

the *Abathomphalus mayaroensis* Zone recorded in the Caribbean (Premoli Silva and Bolli, 1973), in the western Mediterranean (Wonders, 1980) and the upper part of the *Gansserina gansseri* Zone and lower part of the *Abathomphalus mayaroensis* Zone of Caron (1985) and Bolli (1966). Abdel-Kireem (1986) recorded the *Globotruncana contusa* Subzone from the latest Middle Maastrichtian of the Tanjero Formation, northeast Iraq as a part of the *Globotruncana aegyptiaca-lapperenti-stuarti* Assemblage Zone and mentioned that the lower boundary of his subzone is characterized by the first appearance of *Globotruncana contusa* and *G. conica*, while its upper boundary is characterized by the first occurrence of the *Abathomphalus mayaroensis* Bolli. In the Farafra Oasis and according to the faunal similarities, the present (CF6-CF3) Zone could be correlated with the upper part of the *Gansserina gansseri* Zone of Youssef and Abdel-Aziz (1971), Hermina (1990) and Abdel-Kireem and Samir (1995) (Fig. 3.2).

In fact, the zonal scheme of Li and Keller (1998a, b) can not be applied in the present study because the *Globotruncana linneiana* (d'Orbigny), *Pseudoguembelina hariaensis* Nederbagt and *Racemiguembelina fructicosa* (Egger) are sporadically and rarely recorded in the studied sections.

Samir (2002) subdivided the *Racemiguembelina fructicosa* (CF4) Zone of Li and Keller (1998a) into subzones: *Racemiguembelina fructicosa* Subzone (which is defined from first appearance of the nominate taxon to the FA of the *Abathomphalus mayaroensis* Bolli) and the *Abathomphalus mayaroensis* Subzone (which extends from FA of the *Abathomphalus mayaroensis* to FA of the *Pseudoguembelina hariaensis* Nederbagt). As previously mentioned, the

Abathomphalus mayaroensis Bolli is considered as unreliable index species in the low latitude sections.

III.2 Paleocene biozones

4. *Parvularugoglobigerina eugubina-Praemurica uncinata* Zone (= P1)

Author: Berggren and Miller (1988). This zone is emended by Berggren *et al.* (1995).

Estimated age: 64.9-61.2Ma (Danian).

Definition: The *Parvularugoglobigerina eugubina-Praemurica uncinata* Zone is defined as the biostratigraphic interval between the LA of the *Parvularugoglobigerina eugubina* and the FA of *Praemurica uncinata*.

Remarks: The *Parvularugoglobigerina eugubina-Praemurica uncinata* Zone is subdivided by Berggren *et al.* (1995) into three subzones labeled P1a, P1b, and P1c. Arenillas *et al.* (2000) called this subzone as *Parasubbotina pseudobulloides* Zone. Keller and Von Salis (1995) divided the Early Danian into two zones: P0 and P1 (equivalent to P0, Pα and P1 of Berggren *et al.*, 1995). They subdivided their P1 Zone into four subzones labeled P1a, P1b, P1c and P1d (Fig. 3.6). In the Farafra Oasis, the P1c Subzone lies directly on the Cretaceous planktic taxa.

- *Globanomalina compressa/Praemurica inconstans-Praemurica uncinata* Interval Subzone (=P1c)

Author: The *Globanomalina compressa/ Praemurica inconstans-P. uncinata* Interval Subzone is defined by Berggren *et al.* (1995) which is equivalent to subzone P1c in Berggren and Miller (1988).

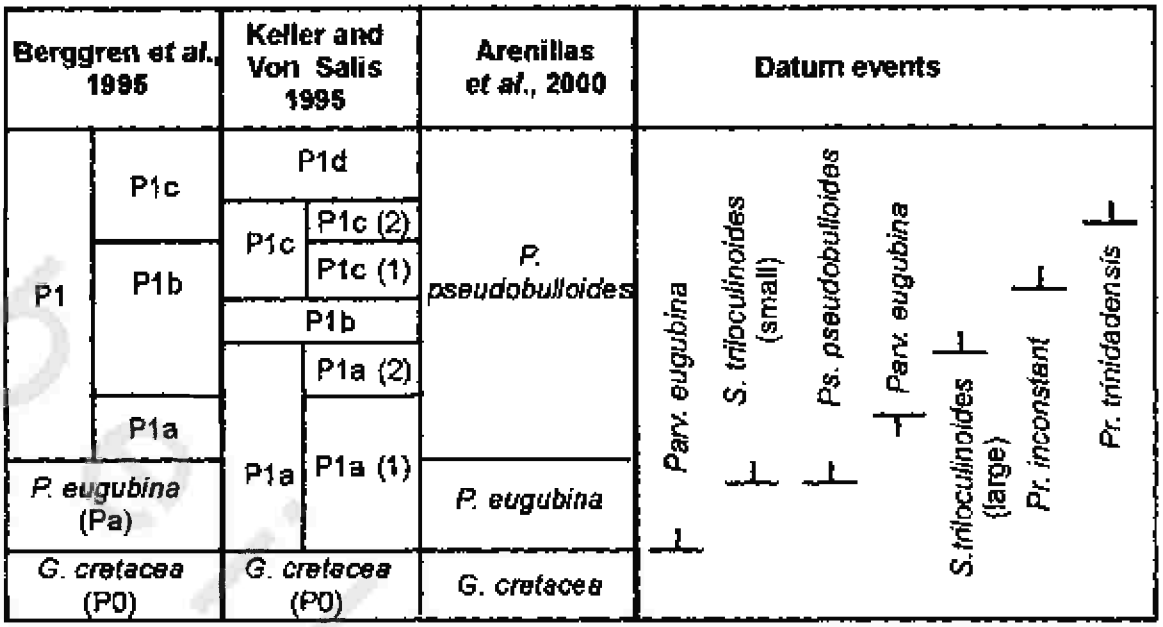


Fig. 3.6 Correlation between biozonal schemes of Berggern *et al.* (1995), Keller *et al.* (1995), Arenillas *et al.* (2000) for the Early Danian age.

Estimated age: 63.0-61.2Ma (Late Danian).

Definition: This biozone covers the biostratigraphic interval between the FA of the *Globanomalina compressa* (Plummer) and/or *Praemurica inconstans* (Subbotina) at the base and the FA of the *Praemurica uncinata* (Bolli) at the top.

Stratigraphic position: The *Globanomalina compressa-Praemurica uncinata* Subzone is recorded from the lower part of the Kharga Shale Member of the Dakhla Formation in the Farafra Oasis. It attains 12m at Shakhs El-Obeiyid section, 7m thick at northwest Bir Bidni section, 5m thick at northwest Ain Maqfi and Ain Maqfi and 4m thick at Bir Murr.

Planktic faunal content: The *Globanomalina compressa/ Praemurica inconstans- P. uncinata* Subzone is very rich in its faunal content (Fig. 3.7). The most dominant planktic species recorded in this zone include: *Globoconusa daubjergensis* (Brönnimann), *Globanomalina compressa* (Plummer),

Parasubbotina pseudobulloides (Plummer), *Parasubbotina varianta* (Subbotina), *Subbotina triloculinoides* (Plummer), *Praemurica inconstans* (Subbotina), *Praemurica trinidadensis* (Bolli) and *Chiloguembelina midwayensis* (Cushman).

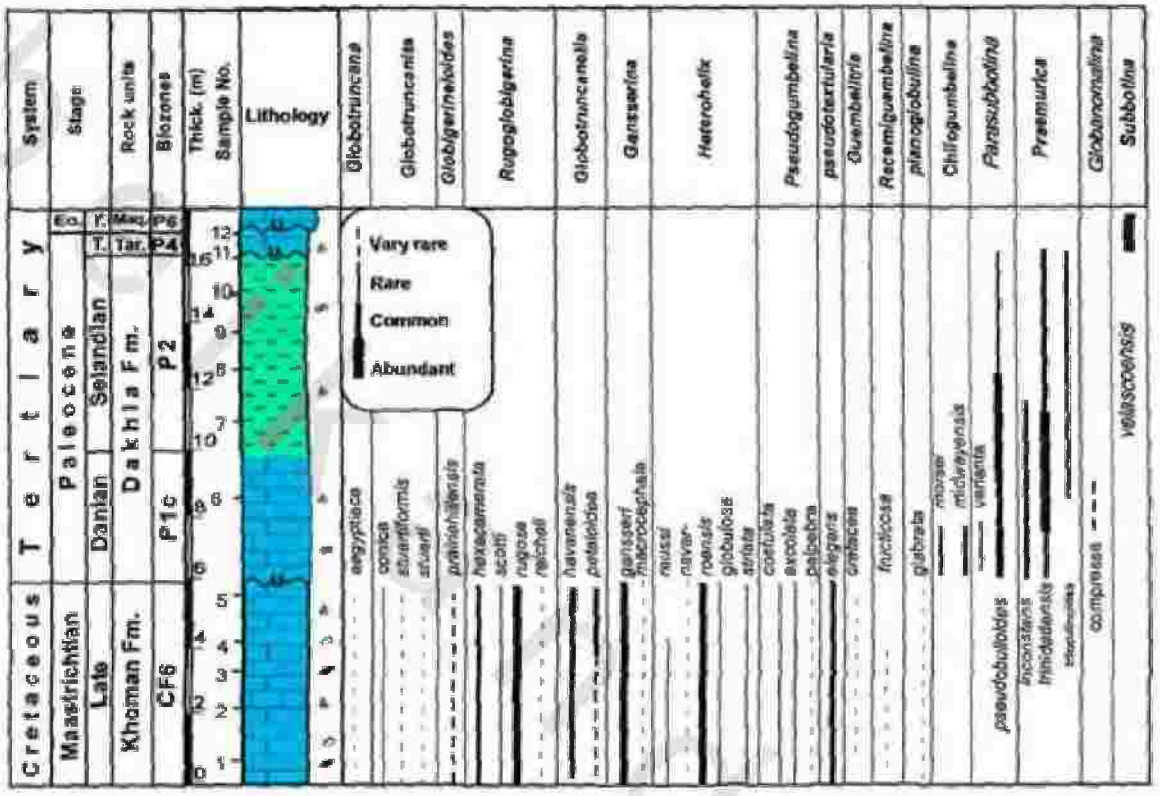


Fig. 3.7 Frequency distribution of the planktic foraminiferal species of the Upper Cretaceous-Lower Eocene rocks exposed in Bir Murr area, east Farafra Oasis.

Benthic faunal content: The most abundant benthic species recorded in the *Globanomalina compressa-Praemurica uncinata* Subzone are: *Cibicidoides farafraensis* (LeRoy), *Spiroplectinella dentata* (Alth), *Lenticulina midwayensis* (Plummer), *L. obesa* (Nakkady), *Pseudoclavulina maqfiensis* (LeRoy) and *P. farafraensis* (LeRoy).

Macrofossils content: The predominant macrofaunal species in the *Globanomalina compressa/Praemurica inconstans-Praemurica uncinata* Subzone is the *Terebratula libyca* Wanner that marks the Cretaceous/Tertiary boundary in the Farafra Oasis.

Remarks: Berggren and Norris (1997) proposed the *Globanomalina compressa-Praemurica uncinata* Subzone as emendation of the Subzone P1c (*Morozovella inconstans-Planorotalites compressa*) of Berggren and Miller (1988). The present P1c Subzone is equivalent to the *Morozovella trinidadensis* Zone of Stainforth *et al.* (1975) and Toumarkine and Luterbacher (1985), the P1b Subzone (*Globorotalia* (*T.*) *Compressa/Eogobigerina eobulloides simplissima*) of Blow (1979), the P1c Subzone of Berggren and Miller (1988), the *Praemurica trinidadensis* (P1d) Subzone of El Dawy (2005) and Berggren and Norris (1997). This subzone is also corresponding to the basal part of the *Globorotalia compressa-Globigerina daubjergensis* Zone of El-Nagger (1966), the upper part of the *Globoconusa daubjergensis/Globorotalia pseudobulloides* Zone of Abdel Kireem (1971), the basal part of the *Globorotalia compressa* Zone of Youssef and Abdel-Aziz (1971) and the *Morozovella trinidadensis* Zone of Abdel-kireem and Samir (1995), El-Nady and Shahin (2001), El-Bassiouni *et al.* (2003) and Khalil and Mashaly (2004). This zone is also correlatable with the same zone recorded by Galal (2005); the *Globanomalina compressa/Praemurica inconstans-Praemurica uncinata* Subzone and the equivalent *chiloguembelina midwayensis* Zone from west central Sinai.

Tantawy *et al.* (2001) pointed out that the strong erosion during the Danian is also evidenced at Gunna North where the P2 planktic foraminiferal assemblage and the lower zone NP4 calcareous nannofossil assemblage overlie directly the Late Maastrichtian CF4-3 and CC25b assemblages. In the present study, the oldest recorded Danian biozone is the *Globanomalina compressa-Praemurica uncinata* (=P1c).

5. *Praemurica uncinata–Morozovella angulata* Interval Zone (=P2)

Author: Berggren *et al.* (1995).

Estimated age: 61.2-61.0Ma (Latest Danian).

Definition: The *Praemurica uncinata–Morozovella angulata* Zone marks the biostratigraphic interval between the FA of the *Praemurica uncinata* (Bolli) at the base and the FA of the *Morozovella angulata* (White) at the top.

Stratigraphic position: This biozone is recorded from the middle part of the Kharga Shale Member of the Dakhla Formation in the Farafra Oasis. It attains about 5m thick at Shakhs El-Obeiyid, about 10m thick at Ain Maqfi and 6m thick at Bir Murr (Fig 3.6).

Planktic faunal content: The *Praemurica uncinata–Morozovella angulata* Zone is found rich in its faunal content. The most dominant planktic species recorded in this zone include: *Globoconusa daubjergensis* (Brönnimann), *Globanomalina compressa* (Plummer), *Parasubbotina pseudobulloides* (Plummer), *Parasubbotina varianta* (Subbotina), *Subbotina triloculinoides* (Plummer), *Praemurica inconstans* (Subbotina), *Praemurica trinidadensis* (Bolli), *Morozovella praeangulata* (Blow), *M. praecursoria* (Morozova) and *Parasubbotina variospira* (Belford).

Benthic faunal content: *Clavulinoides trilaterus* (Cushman), *Gaudryina aissana* Dam & Sigal, *Loxostomoides applinae* (Plummer), *Paralabamina reussi* (Morrw), *Vulvulina colei* Cushman, *Dorothia bulletta* (Carsey) among many others are the most common benthic species present in the *Praemurica*

uncinata–Morozovella angulata Zone.

Remarks: This zone corresponds to the *Globorotalia uncinata* Zone of Bolli (1957 & 1966), the *Globorotalia* (*Acarinina*) *praecursoria* Zone of Blow (1979), the *Morozovella uncinata* Zone of Toumarkine and Luterbacher (1985) and Khalil and Mashaly (2004) and the *Praemurica uncinata* Zone (P2) of Berggren and Miller (1988), Berggren *et al.* (1995) and Berggren and Norris (1997). A Middle Paleocene age is suggested to the *Globorotalia uncinata* Zone by El-Naggar (1966) from Nile Valley and by Abdel-Kireem and Samir (1994) from the Farafra Oasis. Recently, Samir (2002) and Galal (2005) recorded the *Praemurica uncinata–Morozovella angulata* Zone from the Latest Danian in Sinai.

6. *Morozovella angulata-Globanomalina pseudomenardii* Interval Zone (= P3)

Author: Berggren *et al.* (1995).

Estimated age: 61.0-59.4Ma (Earliest Selandian).

Definition: The *Morozovella angulata-Globanomalina pseudomenardii* biostratigraphic interval between the FA of the *Morozovella angulata* (White) at the base and the FA of the *Globanomalina pseudomenardii* (Bolli) at the top.

Stratigraphic position: This zone is recorded from the top part of the Kharga Shale Member of the Dakhla Formation in the Farafra Oasis. It has a total thickness of about 10m in northwest Bir Bidni and 1m in Ain Maqfi area.

Remarks: This biostratigraphic interval is handled in different ways by various authors. For instance, Blow (1979, p. 263)

mentioned that the *Globorotalia* (*T*) *pusilla* appears before the *Globorotalia angulata*. This differs from the subdivision proposed by Stainforth *et al.* (1975) and Toumarkine and Luterbacher (1985) which is based on the sequential FA of the *Morozovella angulata* and *Igorina pusilla*. Berggren and Miller (1988) subdivided this zone relying on the FA of the *Igorina pusilla* in the lower third of the *Morozovella angulata* Zone into two subzones: P3a (which is defined from the FA of the *Morozovella angulata* to the FA of the *Igorina pusilla*) and P3b (which marks the biostratigraphic interval from the FA of the *Igorina pusilla* to the FA of the *Globanomalina pseudomenardii*). Several authors applied this zonal scheme such as Berggren and Norris (1993), Li and Keller (1998a, b) as well as Tantawy (1998) and Obaidalla (2000) in Egypt. The *Morozovella angulata-Globanomalina pseudomenardii* Zone is equivalent to the *Globorotalia angulata* Zone described by Faris (1985) in Ain Amur, Kharga area and to the *Morozovella angulata* Zone of Hewaidy (1987) in El-Quseima, north Sinai and of Khalil and Mashaly (2004) in Gabal Musaba Salama, west central Sinai. Recently, Tantawy *et al.* (2001) recorded the P3 Zone from the Western Desert, while Samir (2002), Galal and Kamel (2003) and Ayyad *et al* (2003) identified this zone from Sinai.

Berggren *et al.* (1995), Berggren and Norris (1997) and Olsson *et al.* (1999) re-subdivided P3 Zone into two subzones: *Morozovella angulata-Igorina albeari* Interval Subzone (P3a) and *Igorina albeari–Globanomalina pseudomenardii* Interval Subzone (P3b). Based on this subdivision, the present P3 Zone is divided into two subzones in the Farafra Oasis.

- ***Morozovella angulata-Igorina albeari* Interval Subzone (P3a)**

Author: Berggren *et al.* (1995).

Estimated age: 61-60Ma (Earliest Selandian).

Definition: Biostratigraphic interval from the FA of the *Morozovella angulata* (White) at the base to the FA of the *Igorina albeari* (Cushman and Bermudez) at the top.

Planktic faunal content: The planktic assemblage of this subzone is dominated by morozovelliods with angular conical chambers throughout their youngest whorl such as *Morozovella conicotruncata* (Subbotina), *M. Praeangulata* (Blow), *M. angulata* (White), *M. praecursoria* (Morozova) in addition to *Subbotina triloculinoides* (Plummer), *Globanomalina compressa* (Plummer) and *Praemurica uncinata* (Bolli) (Fig 3.4).

Remarks: It is preferable to use the *Morozovella angulata* rather than the *Igorina pusilla* to delineate the lower boundary of the P3a Subzone. This is due to the rarity or sporadic occurrence of the *Igorina pusilla* as outlined by many authors (e.g. Beckmann *et al.*, 1969; Toumarkine and Luterbacher, 1985; Abdel-Kireem and Samir, 1995; Berggren and Norris, 1997). Based on faunal similarities, the present P3a Subzone could be equivalent to the upper part of the *Morozovella uncinata* Zone of Stainforth *et al.* (1975) and Toumarkine and Luterbacher (1985) and to the lower part of P3 Zone of Blow (1979). The *Morozovella angulata* Zone is recorded in Egypt by Abdel-Kireem and Samir (1995), Marzouk and Lüning (1998) and El-Nady and Shahin (2001). Recently, the *Morozovella angulata-Igorina albeari* Interval

Subzone is also recorded by Samir (2002) and Galal and Kamel (2003) in south Sinai.

- ***Igorina albeari/Globanomalina pseudomenardii* Interval Subzone (P3b)**

Estimated age: 60.0-59.2Ma (Selandian).

Definition: Biostratigraphic interval between the FA of the *Igorina albeari* (Cushman and Bermudez) at the base and the FA of the *Globanomalina pseudomenardii* (Bolli) at the top.

Planktic faunal content: *Morozovella angulata* (White), *M. conicotruncata* (Subbotina), *M. acuta* (Toulmin), *Parasubbotina varianta* (Subbotina), *P. variospira* (Belford), *Subbotina triloculinoides* (Plummer), *Acarinina mckannai* (White) and *A. primitiva* (Finlay) are the dominant planktic species in the P3b subzone.

Macrofossil content: No macrofossils were recorded in P1-P3 zones in the Farafra Oasis.

Remarks: Until few years, the Paleocene was subdivided by several authors into two stages: Danian and Thanetian. The Danian/Thanetian boundary was placed at the *Praemurica uncinata-Morozovella angulata/Morozovella angulata-Globanomalina pseudomenardii* (P2/P3) zonal boundary of the planktic foraminifera. Recently, the tripartite solution (Danian, Selandian and Thanetian) was voted as a proposal by the International Subcommission on Paleogene Stratigraphy (ISPS) (Jenkins and Luterbacher, 1992). Berggren *et al.* (1995) and Scheibner *et al.* (2001) placed arbitrarily the Danian/Selandian boundary at the base of the *Morozovella angulata-*

Globanomalina pseudomenardii (P3) zonal boundary. The lower boundaries of these three stages at their historical type localities are corresponding to three major sequence boundaries in the relative coastal onlap cycle charts of Haq *et al.* (1988) and can be denoted by several significant biostratigraphic events (Berggren *et al.*, 1995). In the present study, the Danian/Selandian boundary is placed at the top middle of the upper informal unit (i.e Kharga Shale Member) of the Dakhla Formation.

Based on faunal similarities and the FA of both the *Igorina pusilla* and *Morozovella angulata* being coincident, the present P3b Subzone could be equivalent to the latest part of the *Globorotalia* (*M.*) *angulata* Zone of Blow (1979), Berggren and Norris (1997) and Khalil and Mashaly (2004). This subzone is also equivalent to the *Morozovella pusilla* Zone proposed by many workers in Egypt, such as Youssef and Abdel-Aziz (1971), Abdel-Kireem and Samir (1995) and El-Nady and Shahin (2001). Recently, the *Igorina albeari*/*Globanomalina pseudomenardii* Subzone is also recorded by Samir (2002) and Galal and Kamel (2003) in the south Sinai.

7. *Globanomalina pseudomenardii* Total Range Zone (= P4)

Author: Bolli (1957).

Estimated age: 59.4-55.9 Ma (Late Selandian-Middle Thanetian).

Definition: This zone is defined as the biostratigraphic interval of the total range of the nominate taxon *Globanomalina pseudomenardii* (Bolli). Recently, Berggren and Norris (1997) subdivided the P4 Zone into three subzones based on total range

of the *Acarinina subsphaerica* (Subbotina) and the partial range of the *A. soldadoensis*. In the present study, the *A. subsphaerica* is absent. So, it is difficult to define precisely the P4a/P4b boundary. The present author considers the interval from the FA of the *Globanomalina pseudomenardii* (Bolli) to the FA of the *Acarinina soldadoensis* (Brönnimann) and *Morozovella aequa* (Cushman and Renz) as representing the P4a-b Subzone. While the biostratigraphic interval from the FA of the *A. soldadoensis* (Brönnimann) to the LA of the *G. pseudomenardii* (Bolli) is defines the P4c Subzone. The later is characterized by several abundant morozovelliods such as *Morozovella velascoensis* (Cushman), *M. acuta* (Toulmin), *M. aequa* (Cushman and Renz) and *M. subbotinae* (Morozova).

Stratigraphic position: Abdel-Kireem and Samir (1995) mentioned that the *Globanomalina pseudomenardii* Zone covers the topmost part of the Tarawan Formation and the basal part of the Esna Formation. In the present study, this zone occupies the sediments of the Tarawan Formation in the Farafra Oasis. It attains about 34m thick at Shakhs El-Obeiyid, about 9m thick in northwest Bir Bidni section, 6.5m thick in south Qaret Sheikh Abd Alla, about 23m thick in northwest Ain Maqfi, about 1m thick in Ain Maqfi, about 2m thick in northern slope of El Quss Abu Said and 0.5m thick in the southern slope of El Quss Abu Said and about 1m thick in Bir Murr.

Planktic faunal content: *Morozovella acuta* (Toulmin), *M. aequa* (Cushman and Renz), *M. velascoensis* (Cushman), *M. occlusa* (Loeblich and Tappan), *Acarinina nitida* (Martin), *A. primitiva* (Finlay), *A. mckannai* (White), *A. strabocella* (Loeblich & Tappan) and *Subbotina velascoensis* (Cushman) are the

dominant planktic species recorded in the P4 Zone (Fig. 3.7, 3.8 & 3.9).

Macrofossil content: The Tarawan Formation that belongs to the P4 Zone in the Farafra Oasis locally includes very small amounts of limonitic macroinvertebrate fossils. These dwarfed fossils were first noticed in the Kharga Oasis by Awad and Ghobrial (1965). The most important dwarf fossils are the bivalve *Nucula* (*Nucula*) *tremolatestriata*, *N.* (*Lamellinucula*) *edwardsi*, *Nuculana* (*Saccella*) *leia* and *Thyasira cretacea*, the porifera *schizorhabdus libycus* and *ventriculites poculum*, the coelentrata *Caryosmilia granosa*, the cephalopod *Eutrephoceras desertorum*, the gastropod *Drepanocheilus unicarinatus* and the brachiopod *Terebratulina gracilis*.

Remarks: The Selandian/Thanetian boundary is located at the base of Chron 26n which lies within the NP6 Zone (International Subcommission on Paleogene Stratigraphy, ISPS, 2002. Berggren *et al.* (1995) and Scheibner *et al.* (2001) placed the Selandian/Thanetian (S/Th) boundary at the base of Chron 26n with an estimated age of about 57.9 Ma. This boundary was recorded within the *Globanomalina pseudomenardii-Acarinina subsphaerica* Subzone (P4a; the lower part of the *Globanomalina pseudomenardii* Zone). In Egypt, the present P4 Zone is equivalent to the *Globanomalina pseudomenardii* Zone proposed by many authors (e.g. Beckmann *et al.*, 1969; Youssef and Abdel Malik, 1969; Hewaidy, 1987; El-Nady and Shahin, 2001; Samir 2002; Galal and Kamel, 2003 and Khalil and Mashaly, 2004).

In the Farafra Oasis, Youssef and Abdel-Aziz (1971) attributed the Late Paleocene sediments to the *Globorotalia acuta* Zone, which in turn is subdivided into a lower *G. pseudomenardii*

Subzone and an upper *G. aequa* Subzone. The Late Paleocene P4 Zone is also equivalent to the *Planorotalites pseudomenardii* Zone of Abdel-Kireem and Samir (1995) (Fig 3.2). In contrary to the present study, Hermina (1990) stated that the Upper Paleocene *Globanomalina pseudomenardii* Zone of the Maqfi area lies directly over the Late Cretaceous *Gansserina gansseri* Zone with unconformity surface.

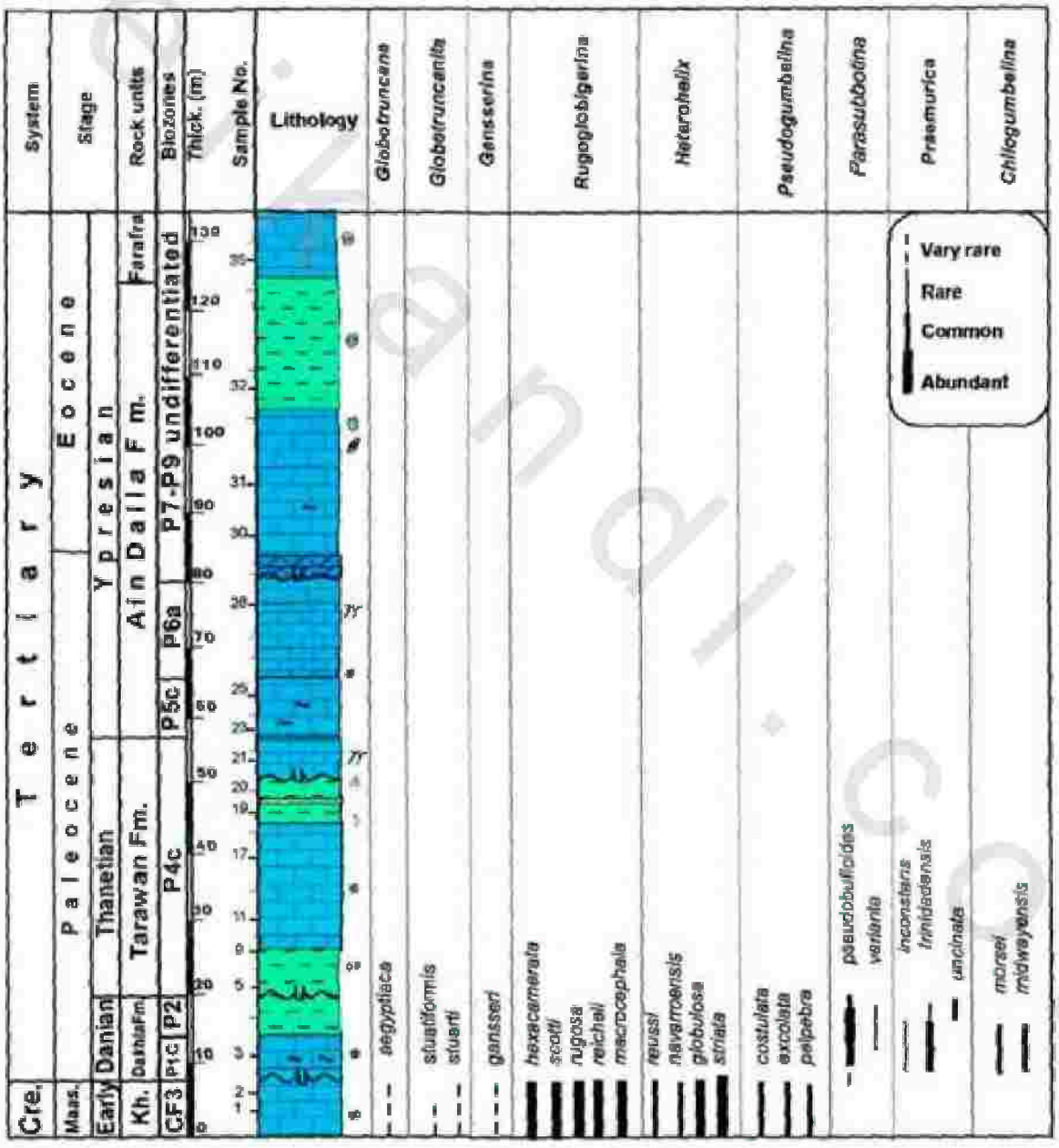
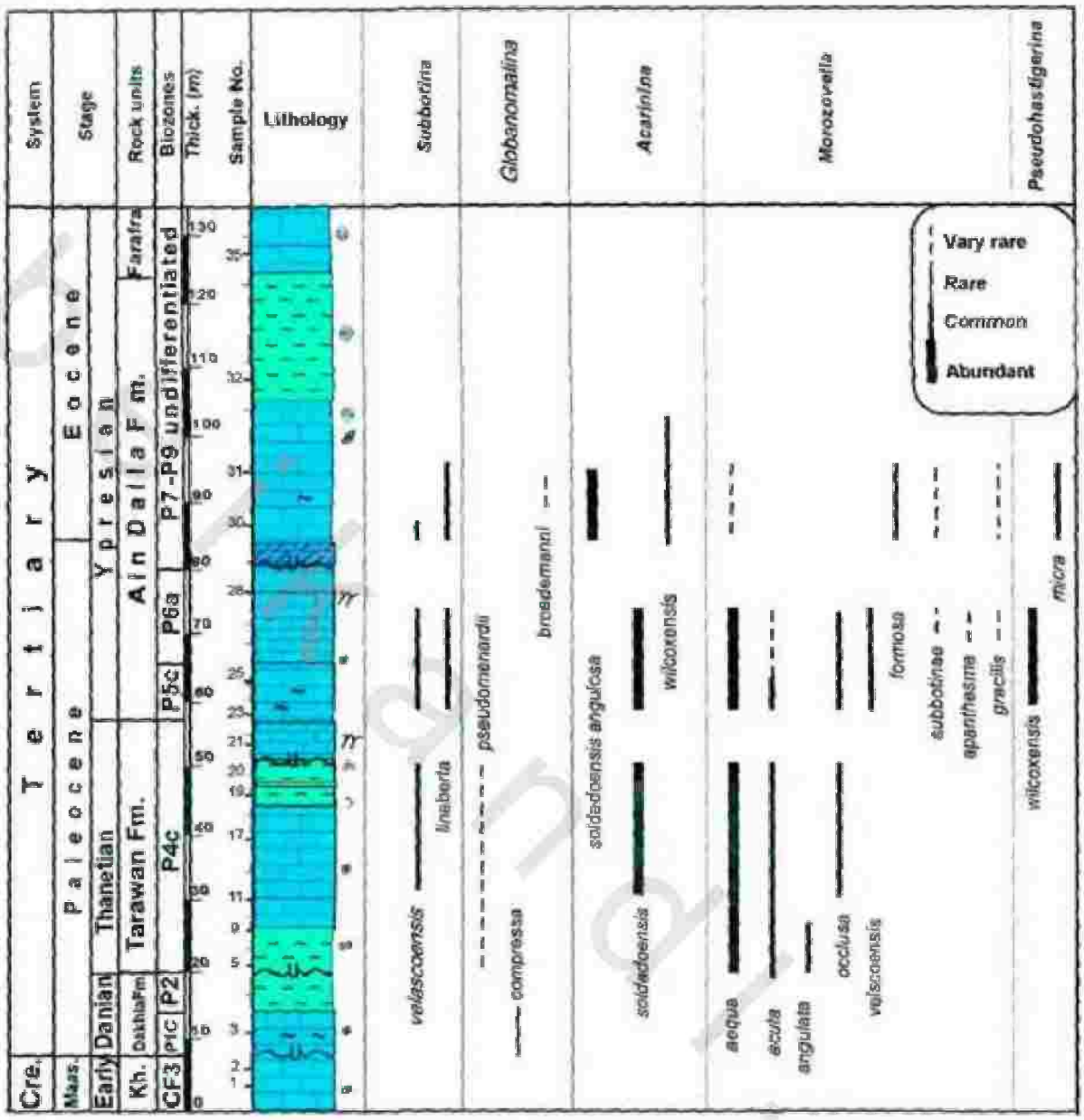


Fig. 3.8 Frequency distribution of the planktic foraminiferal species of the Upper Maastrichtian-Paleocene rocks exposed in Shakhs El-Obeiyid area, west Farafra Oasis.



Cont. Fig. 3.8 Frequency distribution of the planktic foraminiferal species of the Paleocne-Lower Eocene rocks exposed in Shakhs El-Obeivid area, west Farafra Oasis.

The *Globanomalina pseudomenardii* P4 Zone lies directly over the late Danian *Globanomalina compressa/Praemurica inconstans-Praemurica uncinata* P1c Subzone in northwest Ain Maqfi (Fig. 3.3) or over the Latest Danian *Praemurica uncinata* P2 Zone in Bir Murr and Shakhs El-Obeiyid areas (Figs. 3.7 & 3.8) or over the *Morozovella angulata-Igorina albeari* P3a Subzone of Earliest Selandian in Ain Maqfi with a clear

unconformity surface between the Dakhla and Tarawan formations (Fig 3. 14).

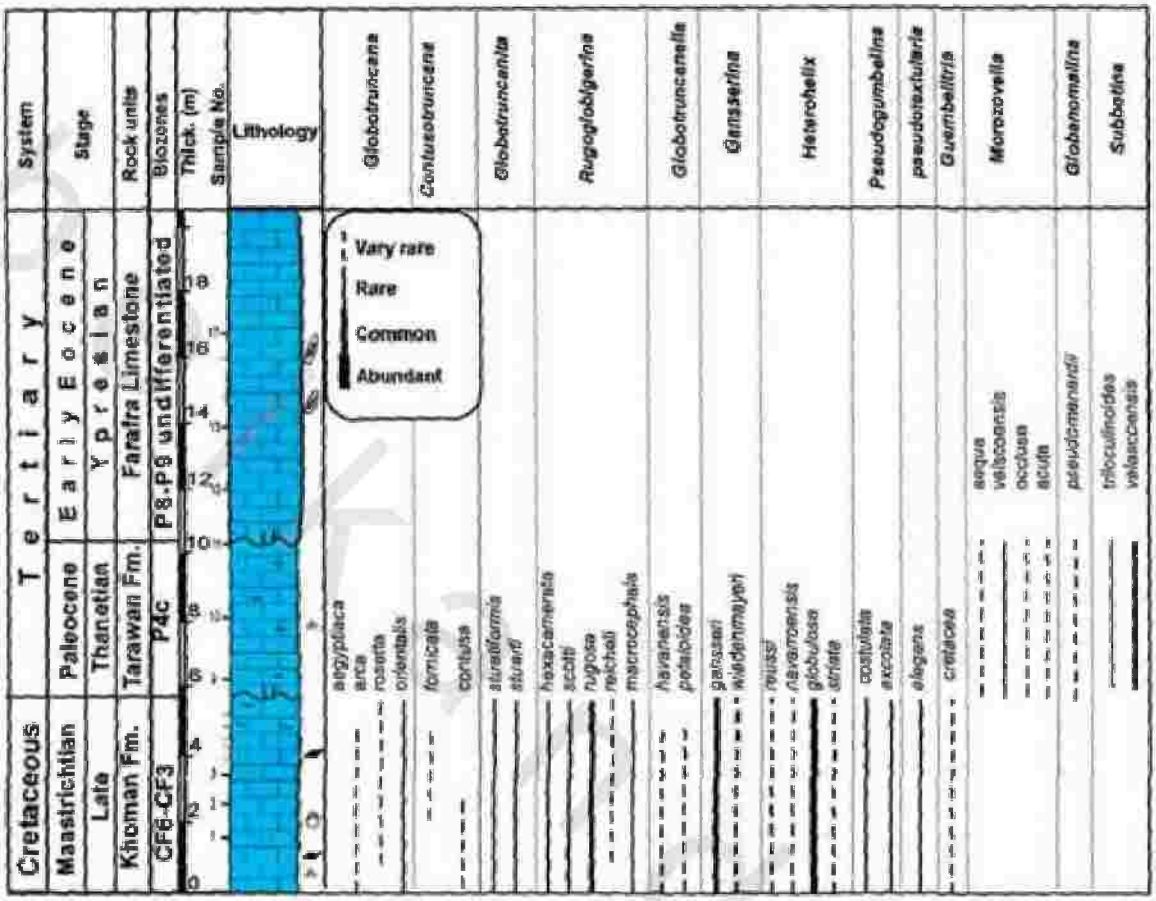


Fig. 3.9 Frequency distribution of the planktic foraminiferal species of the Upper Maastrichtian-Lower Eocene rocks exposed in south Qaret Sheikh Abd Alla area, west Farafra Oasis.

III.3 Early Eocene biozones

8. *Morozovella velascoensis* Zone (= P5)

Author: Bolli (1957) and emended by Berggren *et al.* (1995).

Estimated age: 55.9-54.7Ma (Late Thanetian-Earliest Ypresian).

Definition: The *Morozovella velascoensis* Zone marks the biostratigraphic interval between the LA of the *Globanomalina pseudomenardii* (Bolli) at the base and the LA of the *Morozovella velascoensis* (Cushman) at the top.

Stratigraphic position: This zone is recorded from the lower part of the Esna Formation in the Farafra Oasis. It has a total thickness of about 5m in Shakhs El-Obeiyid and about 5m thick in El Quss Abu Said (Figs. 3.8 & 3.10).

Remarks: The P/E boundary is located between the top of the Thanetian Stage s.s. (Sensu Stricto, as defined in its type area) at a level closely correlative with Chron C25r which is equivalent to 56.6 Ma and the base of the Ypresian Stage (base of Ieper Clay Formation) with an estimated age of 57.37 Ma. Berggren and Ouda (2003a, b) subdivided the P5 Zone into three subzones, arranged from base to top as follows: (a) *Globanomalina pseudomenardii/Acarinina sibaiyaensis* P5a Subzone the biostratigraphic interval from the LA of the *G. pseudomenardii* to the FA of the *A. sibaiyaensis*, (b) *Acarinina sibaiyaensis/Pseudohastigerina wilcoxensis* P5b Subzone; the biostratigraphic interval from the FA of the *Acarinina sibaiyaensis* to the FA of the *Pseudohastigerina wilcoxensis* and (c) *Pseudohastigerina wilcoxensis/Morozovella velascoensis* P5c Subzone.

During the last ten years, the WG (Working Group) on the Paleocene/Eocene boundary studied more than twenty three stratigraphic sections of marine deposits (from neritic to bathyal). Ultimately, two sections were supported as the Global Standard Stratotype-section (GSSP) for the P/E boundary; one in Spain (Zumaya section) and the other in Egypt (Dababiya section). Finally, the WG voted in favor of placing the GSSP for the base of the Eocene Series in the abandoned quarry of the Dababiya section, Luxor, Egypt (Ouda and Aubry, 2003). The boundary is placed at the base of a thin dark gray clay bed underlying a 2.0 m phosphatic bed. The International Subcommission on Paleogene Stratigraphy (ISPS) has voted in favor the Dababiya section. The

WG considered the Paleocene/Eocene boundary at the top of the *G. pseudomenardii/A. sibaiyaensis* P5a Subzone.

The Working Group on the Paleocene/Eocene boundary directed by Aubry *et al.* (1999) selected the Carbon Isotope Excursion (CIE) which has an estimate age of 55.5Ma as the most important event which can be used to define the base of the Ypresian age (base of Eocene Epoch). The CIE has been accepted by the International Subcommission on Paleogene Stratigraphy (ISPS) as best criterion for delineate the P/E boundary.

Berggren and Miller (1988) defined the *Morozovella velascoensis* Zone as a partial range of the *Morozovella velascoensis* between the LA of the *Globanomalina pseudomenardii* and the FA of the *Morozovella subbotinae.* A similar stratigraphic interval between both bioevents has also been recorded by Canudo and Molina (1992); Lu and Keller (1995a, b), Ayyad (1996), Obaidalla (2000) and Samir (2002). On the other hand, Lu and Keller (1993), Berggren *et al.* (1995, 2000) and Pardo *et al.* (1999) recorded juxtaposition between the LA of the *Globanomalina pseudomenardii* and the FA of the *Morozovella subbotinae* in numerous deep sea sites and outcrop sections. Blow (1979), Canudo *et al.* (1995), Tantawy (1998), Molina *et al.* (1999) and Berggren and Ouda (2003a, b) recorded an overlap between these two taxa in several localities of the Tethyan Ocean.

Speijer *et al.* (2000) proposed a threefold subdivision for the P5 Zone as follows, from bottom to top: *Globanomalina chapmani* P5a Subzone (interval from the LA of the *G. pseudomenardii* and to the FA of the *Morozovella allisonensis*), *Morozovella allisoensis* P5b Total Range Subzone and *Globanomalina luxorensis* P5c Subzone (interval from the LA of

Stratigraphic position: The *Acarinina sibaiyaensis/Pseudohastigerina wilcoxensis* Subzone is recorded locally at the basal part of the Esna Formation in the Farafra Oasis. It is only observed in El Quss Abu Said area (Fig. 3.10).

Planktic faunal content: The most abundant planktic foraminiferal species in this zone are: *Acarinina sibaiyaensis* (El-Naggar), *A. mckannai* (White), *A. soldadoensis* (Brönnimann), *Morozovella velascoensis* (Cushman), *M. subbotinae* (Morozova), *M. gracilis* (Bolli), *M. occlusa* (Loeblich and Tappan), *M parva* (Rey), *Subbotina velascoensis* (Cushman), *S. triangularis* (White), *Acarinina wilcoxensis* (Cushman and Ponton) and *A. soldadoensis* (Brönnimann) (Fig 3.10).

Remarks: Pardo *et al.* (1999) were the first authors used the FA of the *Acarinina sibaiyaensis* (El-Naggar) and *Morozovella africana* (El-Naggar) as good markers for delineating the Paleocene/Eocene boundary. These two taxa are easy to identify and have a short-range; their lowest occurrences coincide with the onset of the Carbon Isotope Excursion (CIE) and benthic foraminiferal Extinction Event (BFEE). Thus, Pardo *et al.* (op. cit.) subdivided P5 Zone into two subzones: P5a and P5b based on the FA of the *A. sibaiyaensis* (El-Naggar).

Molina *et al.* (1999) proposed a five-fold subdivision of the P5 Zone. This zonal scheme is based on the FA of the *Morozovella aequa* (Cushman and Renz), *M. gracilis* (Bolli), *M. berggreni* (El-Naggar), *Acarinina sibaiyaensis* (El-Naggar) and *Pseudohastigerina wilcoxensis* (Cushman and Ponton). This scheme was neglected by Molina *et al.* (2003) because the *M. berggreni* and *Ph. wilcoxensis* have been found in older levels. The *M. berggreni* (El-Naggar) is recorded by Berggren and Ouda (2003a) slightly below the P5 Zone. The base of the *Acarinina sibaiyaensis/Pseudohastigerina wilcoxensis* Subzone considered

as the lower boundary of the Eocene Epoch according to the Working Group on the Paleocene/Eocene boundary. Based on faunal similarities, the *Acarinina sibaiyaensis/Pseudohastigerina wilcoxensis* Subzone corresponds to the *Acarinina sibaiyaensis* Subzone of Galal and Kamel (2003).

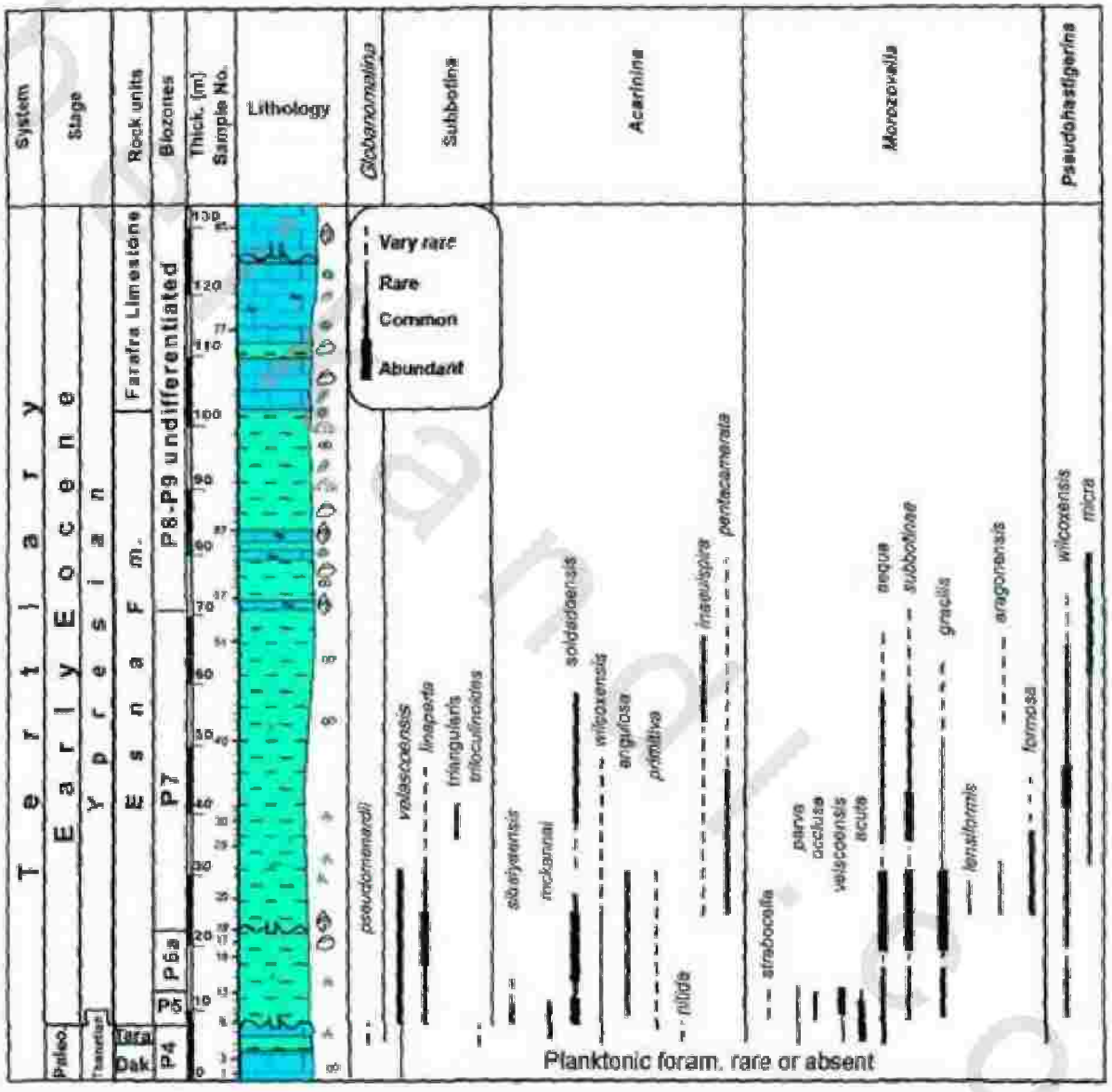


Fig. 3.10 Frequency distribution of the planktic foraminiferal species of the Upper Paleocene-Lower Eocene rocks exposed in the northern slope of El Quss, Farafra Oasis.

- ***Pseudohastigerina wilcoxensis/Morozovella velascoensis* Concurrent-range Subzone (P5c)**

Author: Berggren (1971) and emended by Molina *et al* (1999).

Definition: Biostratigraphic interval from the FA of the *Pseudohastigerina wilcoxensis* (Cushman and Ponton) to the LA of the *Morozovella velascoensis* (Cushman).

Stratigraphic position: This zone is also recorded locally from the lower part of the Esna Formation in the Farafra Oasis. It attains a total thickness of 3m at Gabal Sofra, 4m at El Quss Abu Said and about 15m at Shakhs El-Obeiyid area above directly of *Globanomalina pseudomenardii* P4 Zone (Fig. 3.8 & 3.11).

Planktic faunal content: The most common planktic species recorded in the *Pseudohastigerina wilcoxensis/Morozovella velascoensis* Subzone are generally those present in the underlying zone in addition to the *Pseudohastigerina wilcoxensis* (Cushman and Ponton) (Figs. 3.8, 3.10 & 3.11).

Benthic faunal content: The most common benthic foraminiferal assemblage in the P3-P5 zones are *Marginulinopsis tuberculata* (Plummer), *Pseudoclavulina farafraensis* LeRoy, *Loxostomoides applinae* (Plummer), *Angulogavelinella abudurbensis* (Nakkady), *Cibicides rigidus* (Schwager), *Quadrimorphina alabamensis* Cushman , *Gaudryina africana* LeRoy, *Spiroplectammina knebeli* LeRoy, *Verneuilina aegyptiaca* Said & Kenawy, *Dorothia bulletta* (Carsey), *D. pupa* (Reuss), *Spiroloculina proboscidea* Schwager, *Ammodiscus cretaceous* (Reuss), *Bulimina midwayensis* Cushman & Parker and others.

Remarks: According to the faunal similarities, the present *Pseudohastigerina wilcoxensis/Morozovella velascoensis* Subzone could be correlated with the top part of the

Globanomalina luxorensis Zone described by Tantawy (1998) and the *Globanomalina luxorensis* Subzone of Speijer *et al.* (2000). Recently, Saad (2001) recorded the *Pseudohastigerina wilcoxensis/Morozovella velascoensis* Subzone in south Egypt from the Latest Paleocene and Galal and Kamel (2003) described it from the Early Eocene in west central Sinai.

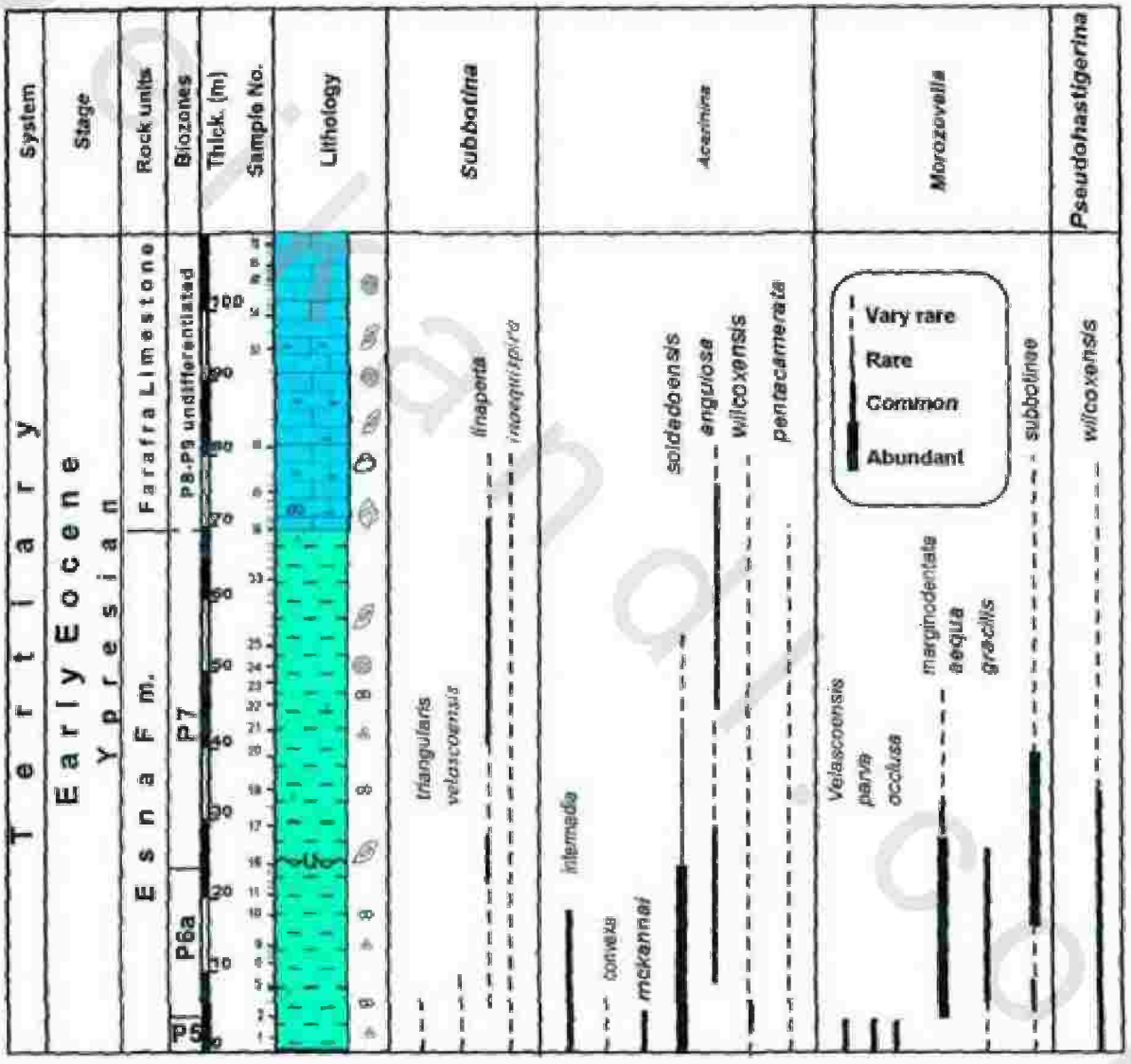


Fig. 3.11 Frequency distribution of the planktic foraminiferal species of Lower Eocene rocks exposed in Gabal Sofra, west Ain Dalla area.

9. *Morozovella subbotinae* Zone (= P6)

Author: Toumarkine and Luterbacher (1985); emended and redefined by Berggren *et al.* (1995).

Estimated age: 54.7-52.3 Ma (Early Ypresian).

Stratigraphic position: The *Morozovella subbotinae* Zone is recorded from the lower part of the Esna Formation in the Farafra Oasis. It attains 8m thick in Gabal Sofra, about 20m thick in Ain Dalla, 8m thick in northwest Bir Bidni, 10m thick in the northern slope of El Quss Abu Said, 7m thick in the southern slope of El Quss Abu Said and 18m thick in southeast Qur Hadida.

Definition: The *Morozovella subbotinae* Zone covers the interval between the LA of the *Morozovella velascoensis* (Cushman) to the FA of the *Morozovella aragonensis* (Nuttall). Berggren and Norris (1997) subdivided P6 Zone into two subzones: a lower *Morozovella formosa formosa* and/or *Morozovella lensiformis* interval Subzone P6a (which is defined from the LA of the *Morozovella velascoensis* at the base to the FA of the *Morozovella formosa* or *M. lensiformis* at the top) and an upper *Morozovella formosa/M. lensiformis-M. aragonensis* interval Subzone P6b (which marks the biostratigraphic interval from the FA of the *Morozovella formosa* (Bolli) and/or *Morozovella lensiformis* (Subbotina) at the base to the FA of the *Morozovella aragonensis* (Nuttall) at the top. In the present study, the *Morozovella formosa/M. lensiformis-M. aragonensis* Subzone P6b is not recorded in all the studied sections.

Planktic faunal content: The *Morozovella subbotinae* Zone is marked by a relative high abundance of *Morozovella subbotinae* (Morozova), *M. gracilis* (Boli), *M. marginodentata* (Subbotina), *M. aequa* (Cushman and Renz), *Pseudohastigerina wilcoxensis*

(Cushman and Ponton), *Acarinina soldadoensis* (Brönnimann), *A. angulosa* (Bolli) and *Subbotina linaperta* (Finlay) (Figs. 3.12 & 3.13).

Benthic faunal content: *Marginulina wetherellii* Jones, *Loxostomoides applinae* (Plummer), *Stilostomella paleocenica* (Cushman & Todd), *Frondicularia wanneri* Nakkady, *Bulimina farafraensis* LeRoy, *B. quadrata* Plummer, *Pseudonodosaria manifesta* (Reuss), *Chilostomella czizeki* Reuss and *Dentalina gracilis* d'Orbigny are the most popular benthic species in P6 Zone.

Macrofossils content: The P6 Zone includes dwarf fossils that occur at about 20m above the base of the Esna Formation in southeast Qur Hadida and El Quss Abu Said. The recorded species in this zone are similar to those found in P4 Zone, in addition to some echinoids.

Remarks: The *Morozovella subbotinae* Zone was originally defined by Bolli (1957) as *Globorotalia rex* Zone. He defined this zone as the interval, with the zonal marker *Globorotalia rex* from its first occurrence to the first occurrence of *Globorotalia formosa* and *G. aragonensis* (Bolli, 1966, p. 14). According to the definition of P6 Zone and the associated planktic assemblage it could be equated with P6 Zone of Berggren *et al.* (1995) and Bolli *et al.* (1998). In Molina *et al.* (1994, 1999), Li and Keller (1995a, b) and Lu *et al.* (1998), the *Morozovella formosa formosa* and *Morozovella lensiformis* were recorded in different levels. Lu and Keller (1995b) subdivided their P6 Zone into three subzones: P6a; P6bx and P6cx based on the LA of the *Morozovella velascoensis* and *Igorina lodoensis*. The P6 Zone of Berggren *et al.* (1995) is also correlative to the P6b and P6c Subzone of

Berggren and Miller (1988) and to P6bx and P6cx Subzone of Lu and Keller (1995b).

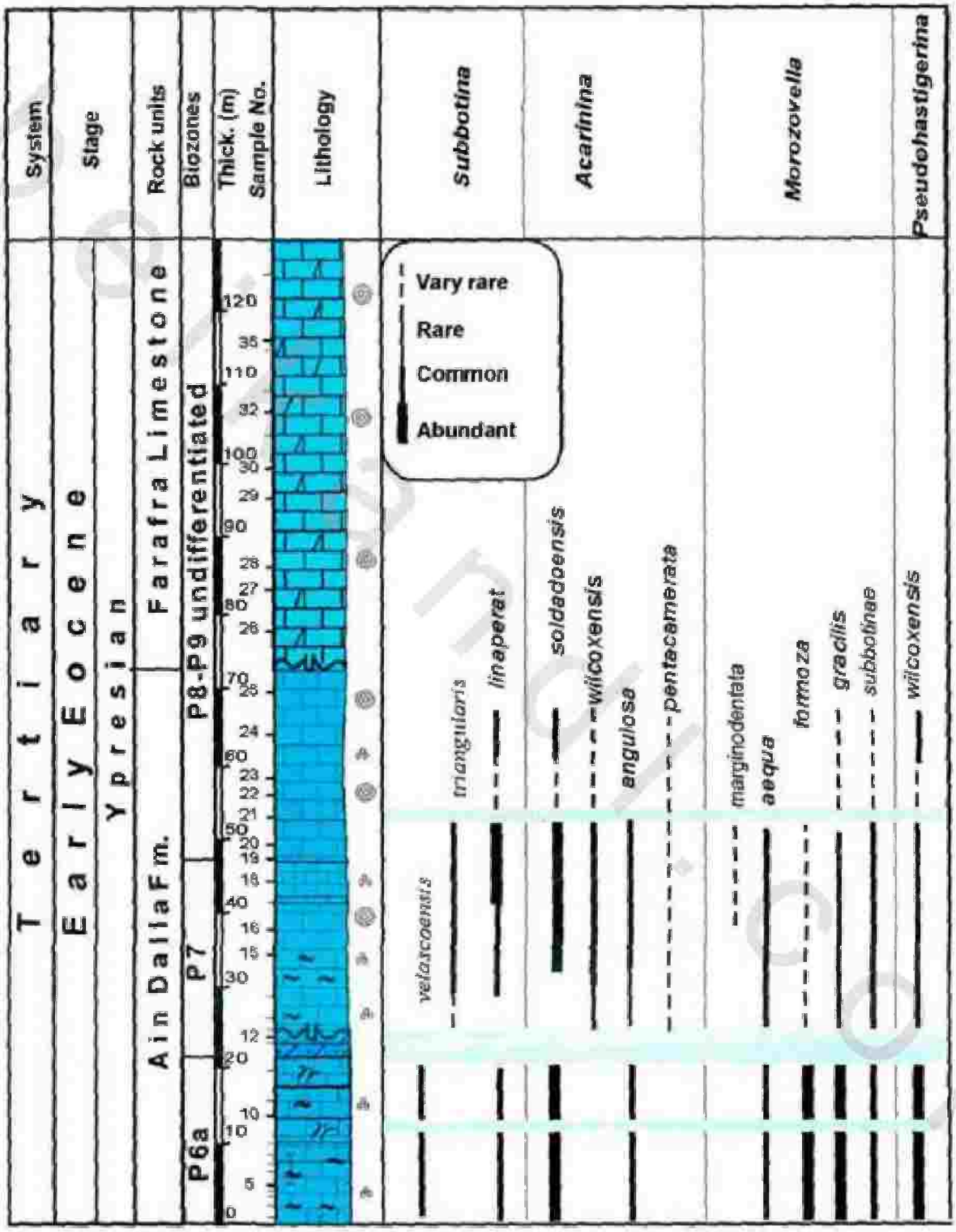


Fig. 3.12 Frequency distribution of the planktic foraminiferal species of Lower Eocene rocks exposed in northeast Ain Dalla, northwest Farafra Oasis.

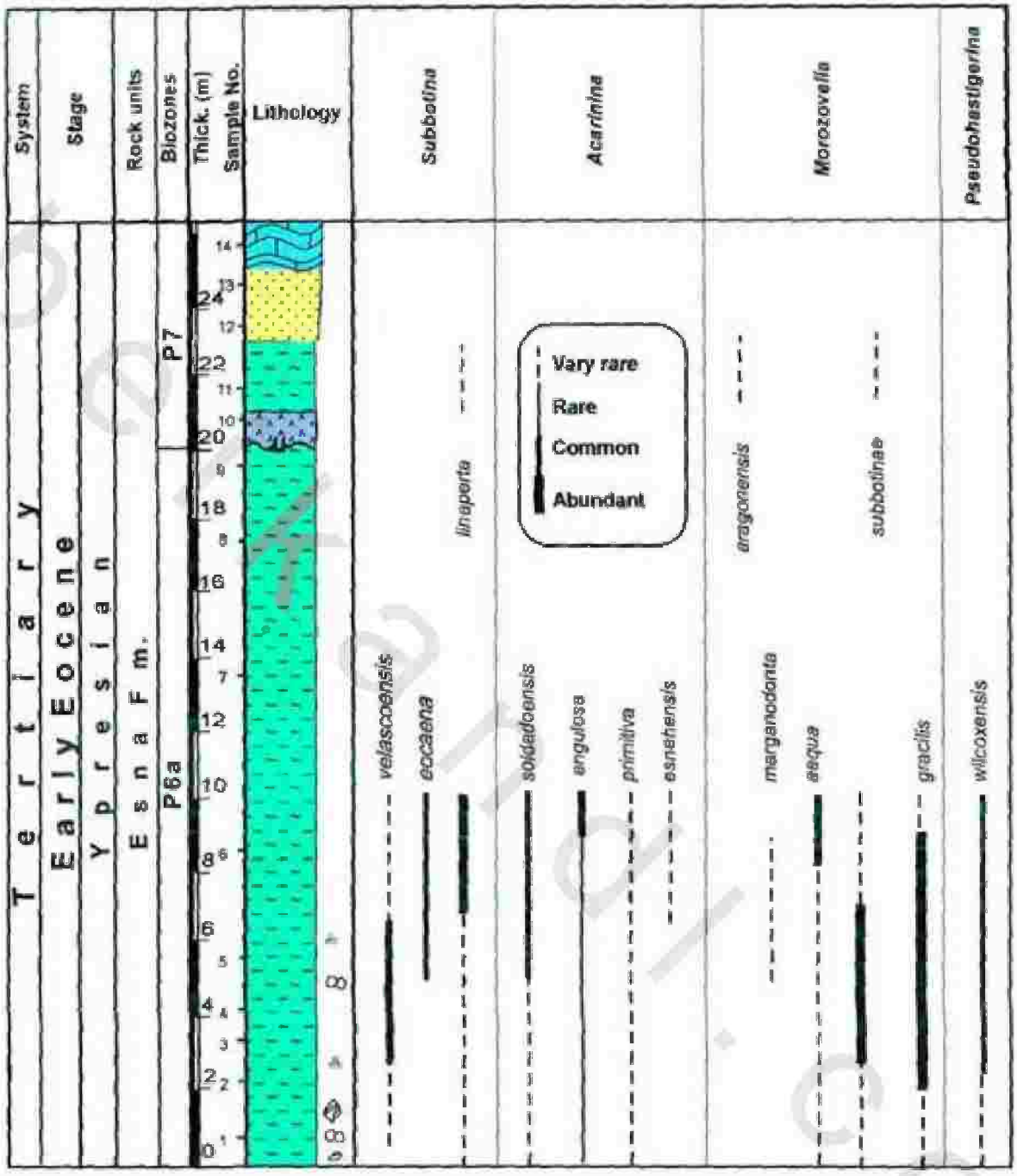


Fig. 3.13 Frequency distribution of the planktic foraminiferal species of the Lower Eocene rocks exposed in southeast Our Hadida, east Farafra Oasis.

The *Morozovella formosa* and/or *Morozovella lensiformis* Subzone corresponds to the *Morozovella edgari* Zone of Luger (1985), Marzouk and Lüning (1998), El-Nady and Shahin (2001), and Khalil and Mashaly (2004) and to the *Morozovella*

subbotinae Zone of Abdel-Kireem and Samir (1995). This *Morozovella formosa* and/or *Morozovella lensiformis* Subzone are correlatable with the same zone recorded by Samir (2002) and Dupuis *et al.* (2003) and with the *Morozovella edgari* and *M. edgari-M. formosa/M. lensiformis* Subzones of Galal and Kamel (2003).

10. *Morozovella aragonesis/M. formosa* Concurrent Range Zone (= P7)

Author: Bolli (1957) and emended by Berggren (1969), Blow (1979) and Berggren and Miller (1988).

Estimated age: 52.3-50.8 Ma (Middle Ypresian).

Definition: This zone comprises the interval between the FA of the *Morozovella aragonensis* (Nuttall) to the LA of the *Morozovella formosa* (Bolli).

Stratigraphic position: The *Morozovella aragonesis/M. formosa* Zone forms the middle part of the Esna Formation in the Farafra Oasis.

Planktic faunal content: The *Morozovella aragonesis/M. formosa* Zone yields a relative high abundance of *Morozovella lensiformis* (Subbotina), *M. subbotinae* (Morozova), *M. formosa*, (Bolli), *M. aragonensis* (Nuttall), *Acarinina pentacamerata* (Subbotina), *A. angulosa* (Bolli), *Subbotina linaperta* (Finlay), *S. inaequispira* (Subbotina) and *Pseudohastigerina micra* (Cole) (Figs. 3.14 & 3.15).

Benthic faunal content: The common recorded benthic species in the *Morozovella aragonesis/M. formosa* Zone are *Spiroplectammina carinata* Subbotina, *Gaudryina pyramidata*

Cushman, *Textularia farafraensis* LeRoy, *Nodosaria semispinosa* LeRoy, *Pseudonodosaria manifesta* (Reuss) and *P. laevigata* (d'Orbigny).

Remarks: This zone is equivalent to the *M. formosa* Zone and the lower part of the *M. aragonensis* Zone of Bolli (1966) and Toumarkine and Luterbacher (1985) and to the lower part of P8b Subzone of Blow (1979). It coincides with the P7 Zone of Berggren *et al.* (1995), Berggren and Miller (1988) and Galal and Kamel (2003).

11. *Morozovella aragonesis/Acarinina aspensis-Hantkenina nuttalli* Partial Range Zone (= P8-P9 undifferentiated)

Author: Bolli (1957) and emended by Berggren (1969) and Berggren and Miller (1988).

Estimated age: 52.3-49.0 Ma (Late Ypresian).

Stratigraphic position: The *Morozovella aragonesis/Acarinina aspensis-Hantkenina nuttalli* Zone forms the middle-upper part of the Esna Formation and the Farafra Limestone in the Farafra Oasis.

Planktic faunal content: The *Morozovella subbotinae* (Morozova), *M. caucasica* (Glaessner), *M. aragonensis* (Nuttall), *Globanomalina planoconica* (Subbotina) and *Acarinina pentacamerata* (Subbotina) are the dominant planktic species in the *Morozovella aragonesis/Acarinina aspensis-Hantkenina nuttalli* Zone.

Benthic faunal content: The *Eponides lotus* (Schwager), *Biopertorbis aegyptiaca* (LeRoy), *Cibicides libycus* (LeRoy), *Stilostomella paleocenica* (Cushman & Todd), *Rotalia*

calcariformis (Schwager), *Discocyclina nudimargo* (Schwager), *Dentalina gracilis* d'Orbigny and *Ornatanomalina* sp. are the most common species in the P7 Zone. In addition, large amounts of larger foraminiferal are present which mark the upper part of the studied Esna Formation.

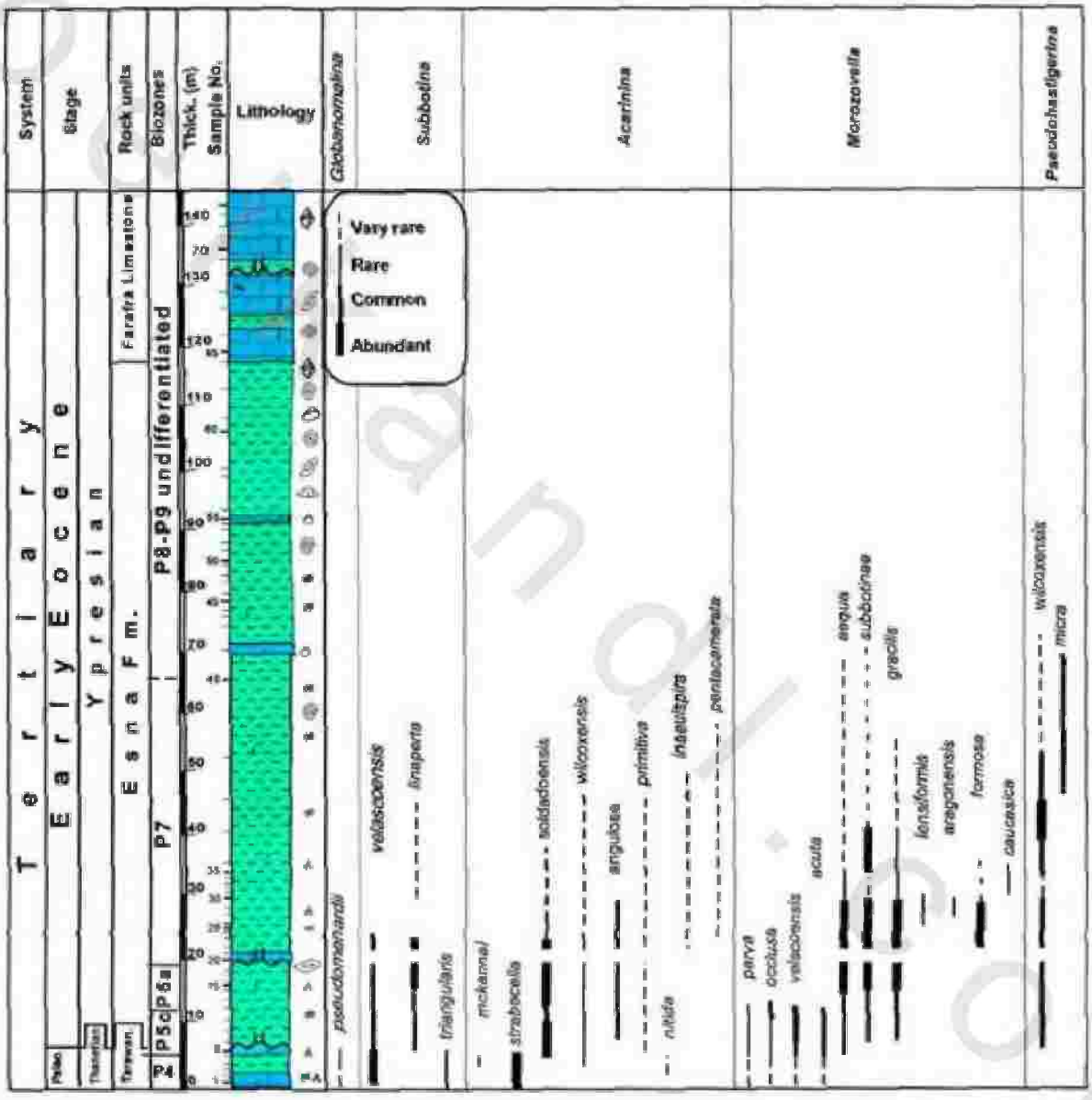


Fig. 3.14 Frequency distribution of the planktic foraminiferal species of the Upper Paleocene-Lower Eocene rocks exposed in the southern slope of El Quss Abu Said, Farafra Oasis.

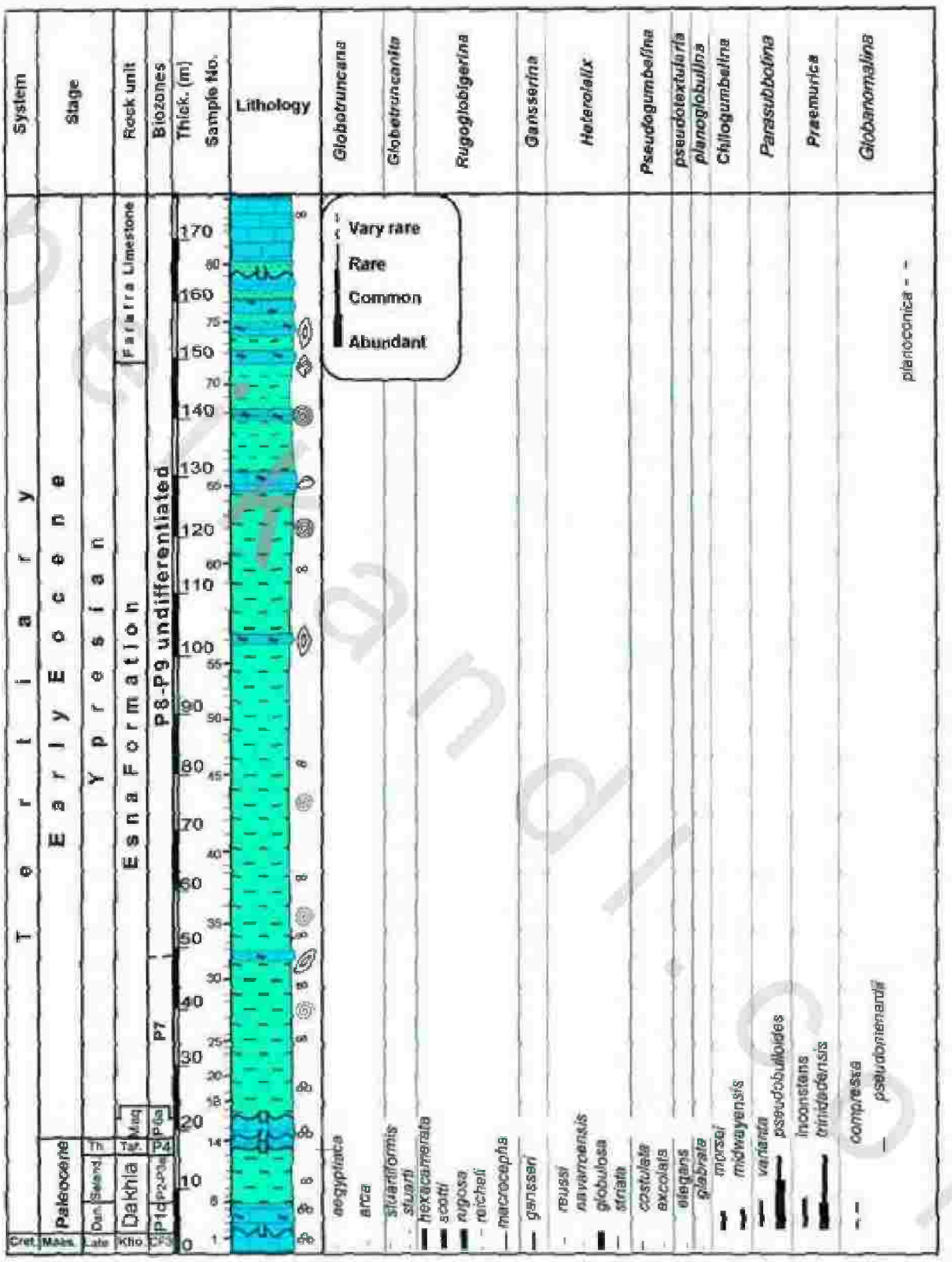
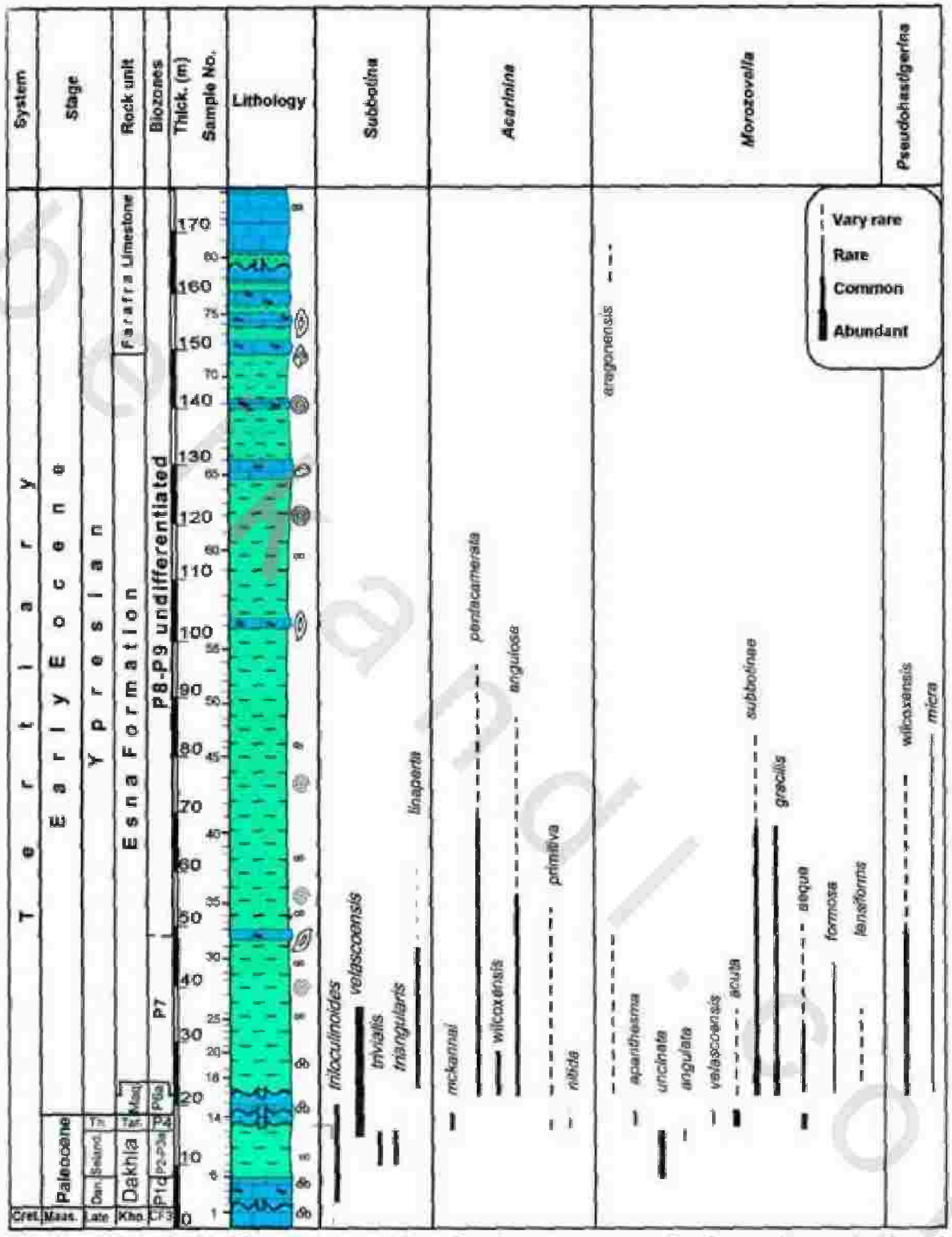


Fig. 3.15 Frequency distribution of the planktic foraminiferal species of the Upper Maastrichtian-Paleocene rocks exposed in Ain Maqfi area, east Farafra Oasis.



Cont. Fig. 3.15 Frequency distribution of the planktic foraminiferal species of Paleocene- Lower Eocene rocks exposed in Ain Maqfi area, east Farafra Oasis.

Remarks: Due to the fine crystalline nature and the shallow depositional environment under which the upper part of the Esna

Formation as well as the Farafra Limestone have been deposited only a few planktic foraminiferal species are found which do not provide clear dating resolution or zonations for such interval. Correlation of the macrofossils present in the Farafra Limestone with those of the Thebes Formation in the Kharga Oasis given by Omara and Kenawy (1975) indicate that the Farafra Limestone in the Farafra Oasis is coeval with the upper stratigraphic member of the Thebes Formation. While, Strougo (1996) proved that the Farafra Formation is younger than the Thebes Formation of the Nile Valley. He correlated it with the upper Libyan rocks described by Zittle (1883). The Farafra Limestone could be correlative with the P9 Zone of BKSA95. The upper part of the Esna Formation, however, is characterized by the explosive development of nummulites, operculines, alveolines and Discocyclines. The most important macrofossils in this part are *Euphenax zitteli* (Mayer-Eymar), *Spondylus aegyptiacus* Newton, *Gryphaeostrea eversa* (Melleville), *Pycnodonte aviculina* (Oppenheim), *Ostrea (Ostrea) aviola* Newton, *"Limea" delanouei* Oppenheim and *Glyptoactis (Claibornicardia) aff. Corpulenta* Strougo, in addition to the gastropod *Mesalia farafrensis* Oppenheim and the echinoid *Palaeostoma zitteli* De Loriol and *Porocidaris farafraensis* Youssef.

The most important macrofossils in the Farafra Limestone on the other hand, are *Anodontia thebaica* (Oppenheim) and *Pseudomiltha nokbaensis* (Oppenheim) in addition to the gastropod *Gisortia gigantean* (Munster) and *Rostellaria mokattamensis* Cuvillier. Said and Kerdany (1961) introduced the *Alveolina decipiens* Zone for the Farafra Limestone in the Farafra Oasis and assigned it to the Ypresian age.