The impact of Paleocene/ Eocene (P/E) Thermal Maximum (PETM) of some sections in Sinai - Egypt, based on benthonic foraminifera

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Abstract: The present study deals with lithostratigraphy, biostratigraphy and paleoecology of paleocene – Early Eocene benthonic foraminifera northeast Sinai, Egypt; G. El Falig, G. El Qusaima, G. Holet Abu Senna and G. Um Thamalla have been collected, sampled and studied based on benthonic foraminifera. The measured sections comprises; Esna Formation and Thebes Formation. The exposed rock units contain rich and high diverse assemblage of benthonic foraminifera that are discussed. They yield 109 foraminiferal benthonic species belonging to 48 genera, 24 subfamilies, 25 families, 18 super families, 3 suborder and one order. The investigation of the foraminiferal content led to the identification of two assemblage zones; the Early - Late Paleocene *Neoflabellina* - *Spiroplectammina* - *Gavelinella* Assemblage Zone and Late Paleocene – Early Eocene *Loxostomoides* - *Cibicidoides* - *Bulimina* Assemblage Zone. During the investigated interval three biofacies with three faunal turnover events have been identified in the studied area reflecting a major sea level change. These turnovers are characterized by discontinuous distribution of species, changes of the relative abundance of species and diversification. The Esna Shale was deposited in middle neritic to upper bathyal environment and Thebes Formation was also deposited in progressively shallowing middle neritic environment.

Keywords: Benthonic foraminifera, Lithostratigraphy, Biostratigraphy, Paleoecology, Turnover, Biofacies, Paleoenvironment, PETM, BFEE, Paleocene, Eocene, Sinai, Egypt.

INTRODUCTION

For the benthonic foraminifera; the P/E boundary event has been regarded as the largest turnover in the deep-sea benthic foraminifera during the last million years (Tjalsma & Lohmann, 1983; Shahin, 2001). The event is marked by extinction of many intermediate - and deep-water species more than one third of the taxa: 33–50% per site, as well as some shallow dwelling (50- to 150-m water depths) benthic foraminifera (22%; Kaiho, 1994b**).** Although changes in deep-sea benthic foraminifera test size and an oxygen index have been established at low resolution for the past 120 m.y. (Kaiho, 1994b, 1999a), these indices have yet to be applied at high resolution to the P/E boundary. The parameters control the composition and size range of shallow-water benthic foraminiferal assemblages was the food resources and algal symbiosis (Hallock, 1985). The deep-sea benthonic foraminifera affected by factors such as dissolved oxygen levels and food supply (Phleger & Soutar, 1973; Machain 1984; Kaiho, 1994a, 1998, 1999a).

Sinai Peninsula is an important part of the southern Tethys and coincides with a belt of wind-induced upwelling (Parrish & Curtls, 1982). Several authors in Sinai have intensively worked out the P/E boundary. Among the recent studies, there are, (Marzouk & Luning, 1998; Luning et al. 1998; Obaidalla, 1999; Shahin, 1998, Ayyad, 2001; El-Nady & Shahin, 2001; El-Nady, 2002; Ayyad et al., 2003; Faris et al., 2005; El-Nady, 2005, 2008; Morsi et al., 2008).

Four sections have been measured and studied in details during the Paleocene/Eocene boundary interval in northeastern Sinai Peninsula; around El Qusaima city and namely; G.El-Falig (30°37' 30" N, 34° 10' 26" E); G.Um Thamalla (30° 38' 18" N, 33° 53' 12" E); Holet Abu Senna (30° 29' 30" N , 33° 50' 41" E), and G.El Qusaima (30° 30' 34" N, 34° 12' 21" E) sections (Fig. 1).

Out of 381 samples were collected from the studied area representing the four sections subdivision as follow, (85) samples from G.El-Falig section, (104) samples from G.Um Thamalla section, (111) samples from G.Holet Abu Sena section and (81) samples from G.El Qusaimaa section prepared for the foraminiferal .

Nearly about 110-120 gram of dried rock was impregnated with a soda solution and washed after several days and washed over a 0.063 μm sieve. This process was repeated until the residues were clean.

The samples picked up by special brush and examined using light binocular microscope. Photographs of the identified species are obtained using Scanning Electron Microscope (SEM).

LITHOSTRATIGRAPHY

The Paleocene - Lower Eocene sequences in G. El – Falig, G. Um-Thamalla, G.El Qusima, and G. Holet Abu -Senna (2), northeastern Sinai were studied in the present work. These successions classified from older to younger into Esna and Thebes formations.

The Esna Formation: in all the studied sections, can be subdivided into three main parts as follow:

The Lower part (a); the base of this part is unexposed in the studied area, it is consists of hard to moderately hard, yellowish to dark grey Shale, marl , grey marl , gypsum vienlets and calcareous clay ranging in age from the Early to Late Paleocene. This part attains a thickness of about 43m in G. Holet Abu Senna, 37m at G.Um Thamalla , 30m in G. El Qusaima and about 31m at G. El Falig .

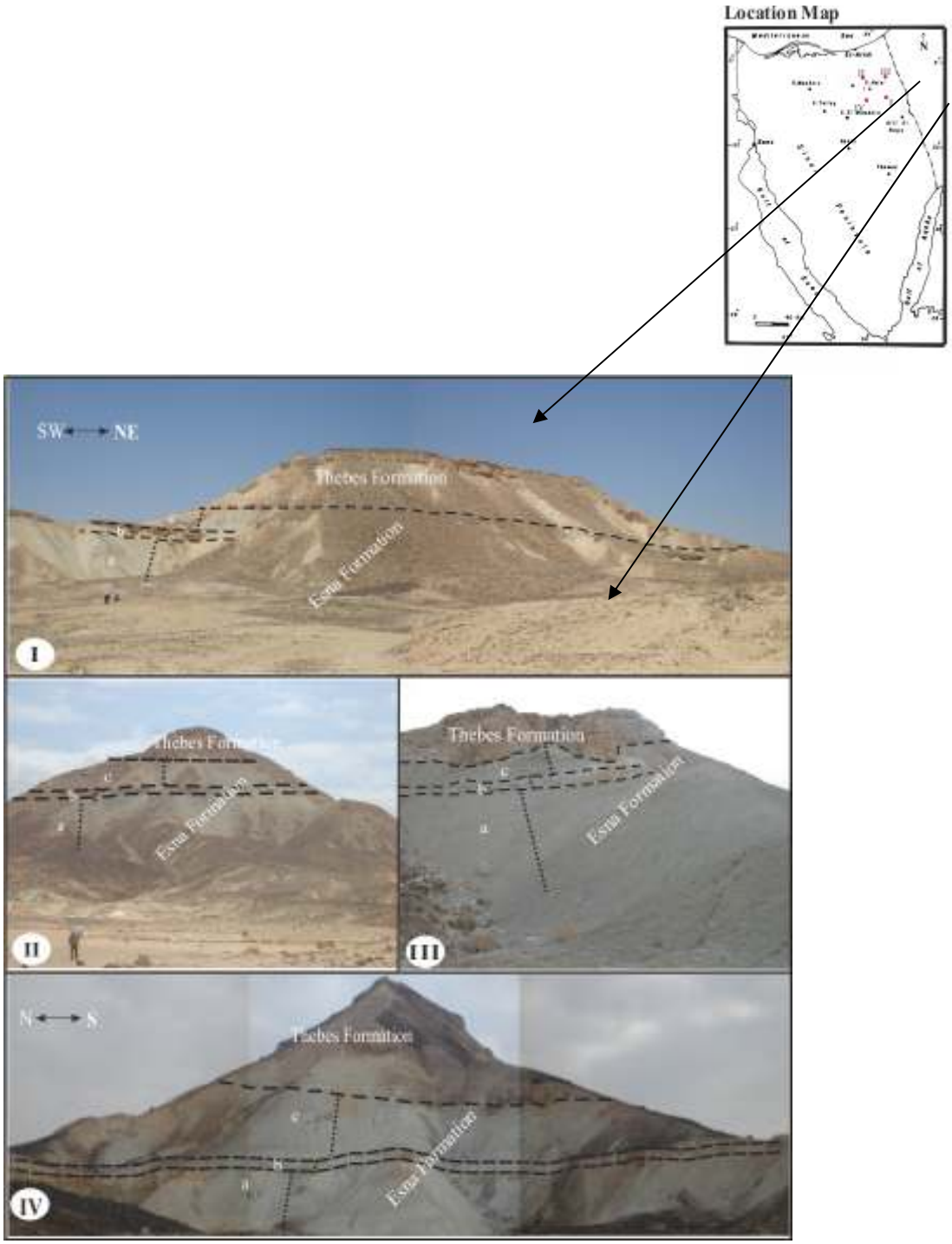


Fig (1): Location map: I- Gabal El Qusaima II- Gabal Holet Abu Senna III- Gabal El Falig IV- Gabal Um Thamalla

Middle part (b); this part represented by white chalky limestone, yellowish, and argillaceous limestone of Late Paleocene age . The thickness of this part in the studied area ranging from about, 4 m at G. Holet Abu Senna, 3.5 m at G. Um Thamalla and nearly about 3m at both G. El Falig and G. El Qusaima . This part is barren of microfossilis in all studied sections, equivalent to Tarawan Chalk (Kuss & Marzouk, 2001).

Upper part (c); It is composed of blocky to fissile , moderately hard, light grey and calcareous Shale interceded with thin beds of marl. It has a thickness of about 15m in G. Holet Abu Senna, 15.5 at G. El Qusaima, 12.5 at G. Um Thamalla and 13.5 m at G. El Falig. It overlies the Middle limestome part and underlies the Thebes Formation .

Thebes Formation: This rock unit is recorded from all the studied sections and consist mainly of yellowish to greenish marl, interbeded with chalky limestone, brownish flint nodules and concretions. The upper part of this formation is not reached in the studied sections .

It belong to the Early Eocene age and conformably overlies the Esna formation.

BIOSTRATIGRAPHY

Benthonic Foraminiferal Zonation:

In the present study, the stratigraphic distribution of the identified benthonic foraminiferal species and varities from the Paleocene - Early Eocene of the measured successions allowed to subdividing this interval into tow assemblage benthonic foraminiferal zones. Their age was determined by the equivalent planktonic foraminiferal zones. Their evolution and stratigraphic distribution were recorded from different regions in and outside Egypt by several authors ilustrated in Table (8). The proposed biostratigraphic zones with their stratigraphic position and its age briefly discussed from base to top as follows:

***Neoflabellina – Spiroplectammina - Gavelinella* Assemblage Zone:**

Contemporaneous unit: This assemblage is equivalent to the *Parasubbotina pseudobulloides, Praemurica trinidadensis, Praemurica uncinata, Morozovella angulata*, and *Igorina pusilla pusilla* zones (figure 2).

Stratigraphic Position: This assemblage zone occupies the lower and middle parts of the Esna Shale. It covers 22.4 m in G. El Falig, 25.3 m in G.El Qusaima, 26.25 m in G.Holet Abu Senna and 21m in G, Um thamalla.

Age assignement: Lower and middle Paleocene .

Assemblages: This assemblage zone is charactrized by abundances and most common taxa of *Pullenia coryelli* (White) and *Gavelinella beccariiformis* (White). In addition to the following taxa; *Spiroplectimmina kenbeli* (Le Roy), *S. spectabilis* (Grzybowski), *Spiroplectinella dentata* (Alth), *Dentelnia basiplanata* Cushman, *D. catenula* Reuss, *D. colei* Cushman & Dusenbury, *D. graacilis* D'orbigny, *D. megalopolitana* Reuss, *Verneuilina cretacea* (Karrer), *Neoflabellina jarvisi* (Cushman), *Astaculus munds* (Cushman), *Vaginulinopsis trilobata* (D'orbigny), *Hemirobulina bullata* (Reuss), *Dorothia pupa* (Reuss), *D. bulletta* (Carsey), *Gaudryina pyramidata* Cushman, *G. laevigala* Franke, *Pseudogaudryinella compacta.* (Ten Dam & Sigal), *Stilostomella paleocenica* (Cushman & Todd), *Pleurostomella clavata* (Cushman), *Coryphostoma platium* (Carsey), *Frondicularia cuspidata* (Cushman), *F. bidentata* (Cushman), *Vaginulinopsis trilobata* (D'orbigny), *Loxostomoides applinae* (Plummer), *Marssonella indentata* (Cushman & Jarvis), *M. oxycona* (Reuss), *Ammodiscus cretaceous* (Reuss), *Anomalinoides midwayensis* (Plummer), *A. rubiginosus* (Cushman), *Quadrimorphina allomorphinoides* (Reuss), *Valvulina Colei* Cushman, *Clavulinoides asper* (Cushman), *Cibicides praecursorius* (Schwager), *Cibicidoides succedens* (Brotzen), *Cibicidoides alleni* (Plummer), *Cibicides ribbingi* Brotzen, *Angulogavelinella grands* (Marssom), *Nodosarella gracillima* Cushman, *Pseudoclavulina amorpha* (Cushman), *P. globulifera* (Ten Dam & Sigal), *Ramulina globulifera* (Brady), *R. navarrona* (Cushman), *Lagena substriata* (Williamson) , *Lenticulina isidis* (Schwager), *L. midwayensis* (plummer), *Chilostomelloides cyclostoma* (Rzehak), *Ellipsopolymorphina velascoensis* (Cushman).

***Loxostomoides - Cibicidoides - Bulimina* Assemblage Zone:**

Contemporaneous unit: *Globanomalina pseudomenardii, Morozovella velascoensis, M. edgari, M. Subbotina, M. formosa formosa, M. aragonensis* and *Acranina pentacamerata* planktonic foraminiferal zones zones.

Stratigraphic position: This assemblage zone occupies the Upper part of the Esna Shale and the lower partof the Thebes Formation. The thickness of this zone attain of about 26.1 m in G. El Falig, 29.7 m in G. Um thamalla, 28.5 m in G.El Qusaima and 27.5 m in G.Holet Abu Senna.

Age assignement: Late Paleocene to Early Eocene .

Assemblages: This assemblage is charactrized by abundances and most common taxa of *Cibicidoides succedens* (Brotzen), *C. praecursorius* (Schwager), *C. alleni* (Plummer), *Bulimina midwayensis* (Cushman & Parke), *Loxostomoides applinae* (Plummer), *L. plummerae* (Cushman). In addition to the following taxa; *Lenticulina midwayensis* (Plummer), *Lenticulina isidis* (Schwager), *Gyroidinoides girardanus* (Reuss), *Dorothia pupa* (Reuss), *Anomalinoides welleri* (Plummer), *Coryphostomella telatynensis* (Gawor-Biedowa), *Dentelnia basiplanata* Cushman, *D. catenula* Reuss, *D. colei* Cushman & Dusenbury, *D. graacilis* D'orbigny, *D. megalopolitana* Reuss, *Astaculus munds* (Cushman), *Vaginulinopsis trilobata* (D'orbigny), *Hemirobulina bullata* (Reuss), *Dorothia bulletta* (Carsey), *Gaudryina pyramidata* Cushman, *G. laevigala* Franke, *G. austinana* Cushman, *Pseudogaudryinella compacta.* (Ten Dam & Sigal), *Marssonella indentata* (Cushman & Jarvis), *M. trochus* (D'orbigny), *Ammodiscus cretaceous* (Reuss), *Anomalinoides midwayensis* (Plummer), *A. rubiginosus* (Cushman), *Vulvulina colei* Cushman, *Clavulinoides asper* (Cushman), *Cibicides ribbingi* Brotzen, *Angulogavelinella grands* (Marssom), *Nodosarella gracillima* Cushman, *Pseudodavulina amorpha* (Cushman), *Pseudoclavulina globulifera* (Ten Dam & Sigal), *Ramulina globulifera* (Brady), *Ramulina navarrona* (Cushman), *Lagena substriata* (Williamson) , *Chilostomelloides cyclostoma* (Rzehak), *Ellipsopolymorphina velascoensis* (Cushman), *Stilostomella paleocenica* (Cushman & Todd), *Pleurostomella clavata* (Cushman), *Frondicularia cuspidata* (Cushman), *F. bidentata* (Cushman), *Vaginulinopsis trilobata* (D'orbigny) and *Quadrimorphina allomorphinoides* (Reuss).

PALEOECOLOGY AND PALEOBATHYMETRY ACROSS THE P/E BOUNDARY WITH SEA-LEVEL CHANGES

The reconstruction of the water depth is an important factor to elucidate the paleoecology and the paleoproductivity across the Paleocene-Eocene (P/E) boundary. For this purpose, about 0.5 gm of the residue

of each sample has been used for quantitative foraminiferal parameters at the study section (Table 1). These parameters include the P/B ratio, the Aggl. /Calc. ratio, the total foraminiferal abundance and their diversification (Fig.7). During the normal condition, the percentage of planktonic foraminifera (P/B ratio) increases with water depth and depends mainly on the relative difference of paleoproductivity of foraminiferal assemblages (Murray, 1976, Shahin, 2001; El-Nady, 2005,2008). The changes in the relative abundance of these assemblages are used to interpret the rate and nature of the foraminiferal evolution and diversification across **P/E** boundary. The productivity of benthic foraminiferal is higher in the shallow neritic environmental condition (Morkhoven et al., 1986;Kaiho et al., 2006; Shahin, 1992; 2001; El-Nady, 2005). In addition, the P/B ratio can also be used as an environmental parameter of relative paleobathymetric changes and investigate the circulation pattern and current intensities of marginal seas to open ocean (Murray, 1976). However, the global cooling episode of the early Paleocene was followed a rapid warming episode during the P/E boundary (Shackleton & Hall, 1985; Kennett & Stott, 1990; Salis *et al*., 1998; Stott et al., 1991).

Highlights several events and striking changes in abundance and composition within the assemblages that represent paleoenvironmental events performed before/after and through (PETM). These changes clearly outline a complex ecological evolution across the (PETM). Which possible confined in three biofacies as follow;

Biofacies 1(Pre-PETM):

In the studied area, the benthic foraminiferal analysis seems that during that time span (before the boundary) appearance and disappearance of the species have been affected selectively in the habitants of the open marine realm. The time interval between the Early Paleocene *Parasubbotina pseudobulloides* to the Early Middle Paleocene *Praemurica uncinata* Zone is charactrized by adeep-water Velasco-fauna type, including the genera *Gavelinella beccariiformis* , *Pullenia coryelli* , *Cibicides ribbingi* , *Spiroplectamina dentata* , *Anomalinoides rubiginosus* and others, indicating an outer neritic environment. This interval represents the maximum marine transgressive events during the Early Paleocene in Sinai. Toward the Middle Paleocene *Morozovella angulata* Zone a noticeable drop in the foraminiferal parameters, so this time interval characterized by dominance of shallow Midway type-fauna with deep Velasco type-fauna represents the middle and outer neritic condition. This position continues to th end of Middle Paleocene *Igorina pusillu pusilla* Zone. In the Late Paleocene *Globanomalina pseudomenardii* Zone, the benthonic foraminiferl assemblage represented by outerr neritic deep Velasco-fauna type as *Gavelinella beccariiformis* and *Pullenia coryelli* , Tjalsma & Lohmann (1983) and Speijer & Van der Zwaan(1994), reported the same faunal associtionfrom Upper Middle-bathyal sediments. Upward to the Late Plaeocene to the *Morozovella velascoensis* Zone, the Middle neritic environment prevailing over bathyal environment, and some species as, *Gavelinella beccariiformis* , *Pullenia coryelli* , disappear as indication for Middle neritic environment.

Biofacies 2 (during - PETM):

Coincident with PETM interval, benthonic foraminifera are on the contrary from planktonic foraminifera, where species richness reduce by approximately (30- 35%) (Thomas, 1990; Thomas & Shachleton, 1996; Oreshkina, 2003; Röhl et al., 2007; Alegret et al., 2009). In the studied sections, and during PETM, the extinition of benthonic foraminiferal taxa are charactrized this interval such as *Anomalinoides rubiginosus*, *Palmula primativa*, *Coryphostoma midwayensis*, *Dorothia pupa*, *Chrysalogonium velascoense***,** *Gyroidinoides girardanus, Marssonella oxycona*, *Neoflabellina jarvisi* and *Pullenia coryelli.* Anoxic conditions at the sea-floor may have caused some extinctions locally, but not globally (e.g., Thomas, 2007). However, there is no agreement as to whether primary productivity in surface waters increased or decreased globally at the onset of the CIE (Bains et al., 2000; Bralower, 2002; Dickens et al., 2003; Tremolada & Bralower, 2004). The extinction of deep-sea benthonic foraminifera was global (Alegret et al , 2009). Moreover, food supply, oxygen conditions or dissolution seem not to be the cause of the extinctions, warming is likely to have been the only global feature of the PETM for which there was no refugia, triggering paleoecological and paleoenvironmental instability, and eventually leading to the gradual but rapid benthic extinction event (BEE) (Monechi et al., 2000 a,b). According to Berggren and Aubert (1975), representatives of the bathyal and abyssal Velasco-type fauna such as *Cibicidoides velascoensis, Guadryina pyramidata, Dorothia bulletta, Anomalinoides rubiginosus* and *Coryphostoma midwayensis*, are common at the studied area. In additioin, the prsence of *Quadrimorphina* sp., which are most common at abyssal depths (Tjalsma & Lohmann, 1983), have been recorded. These data indicate outer neritic to Lower bathyal depth of deposition during the Late Paleocene – Early Eocene PETM in the study sections.

Biofacies 3 (after – PETM):

During the Late Paleocene interval, an important benthonic foraminifera (e.g. *Tritaxia midwayensis, Entosolenia crebera, Coryphostoma midwayensis* and *Neoflabellina jarvisi*) are completely disapeared. On the other hand, a new benthic species as (e.g. *Cibicidoides libycus, C. simplex, Anomlinoides welleir* and *Bulinina midwayensis***)** has appeared. The presence of this midway-fauna type reflect open marine with Middle to outer neritic environment, upward to *Morozovella aragonensis* and *Acarinina pentacamerata* zones, covert to inner neritic environment at the end of Thebes Formation in the studied area (Fig.7).

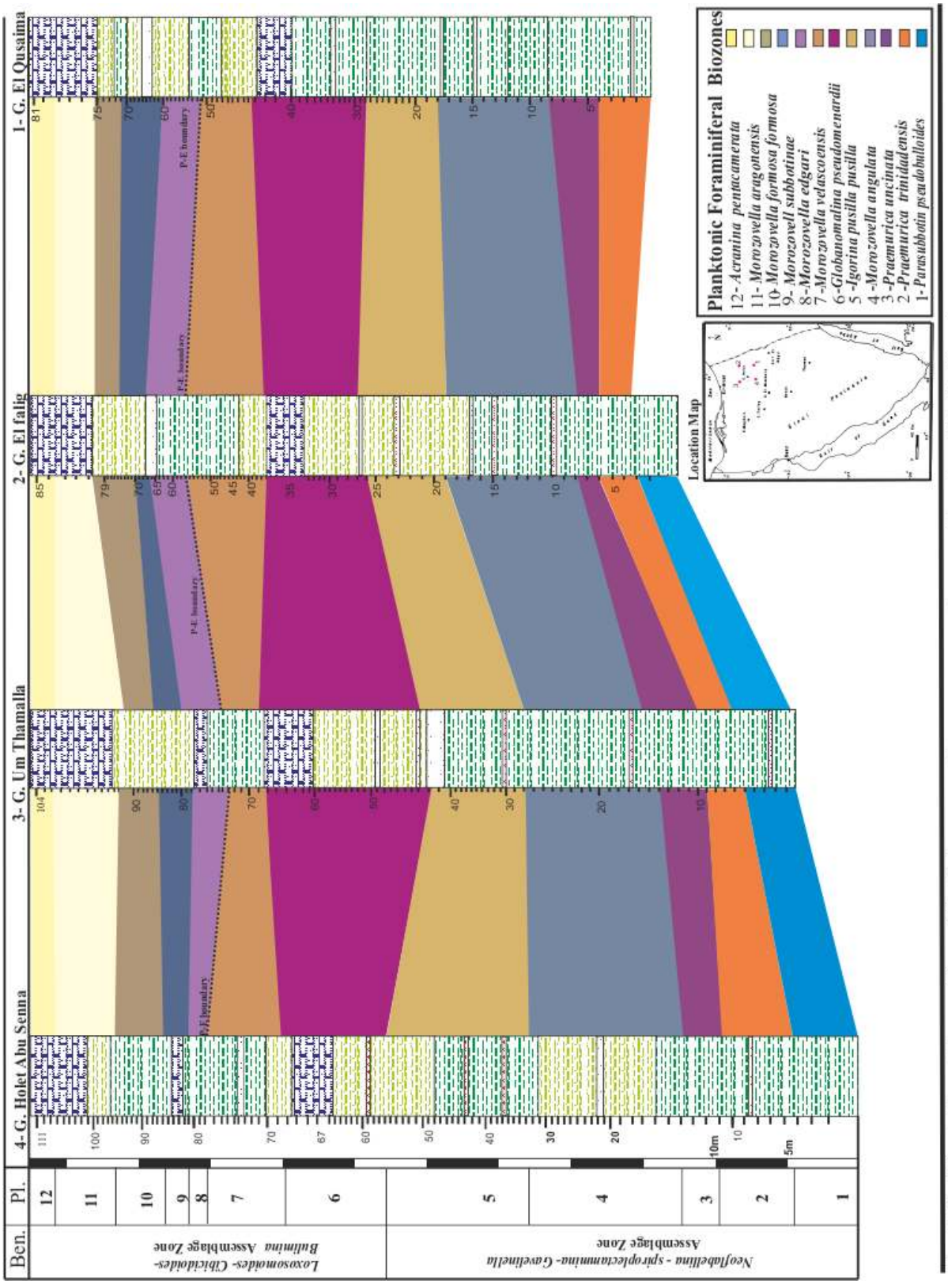


Fig. (2): Biostratigraphic zonation of the Paleocene - Eocene successions , northeastern Sinai , Egypt.

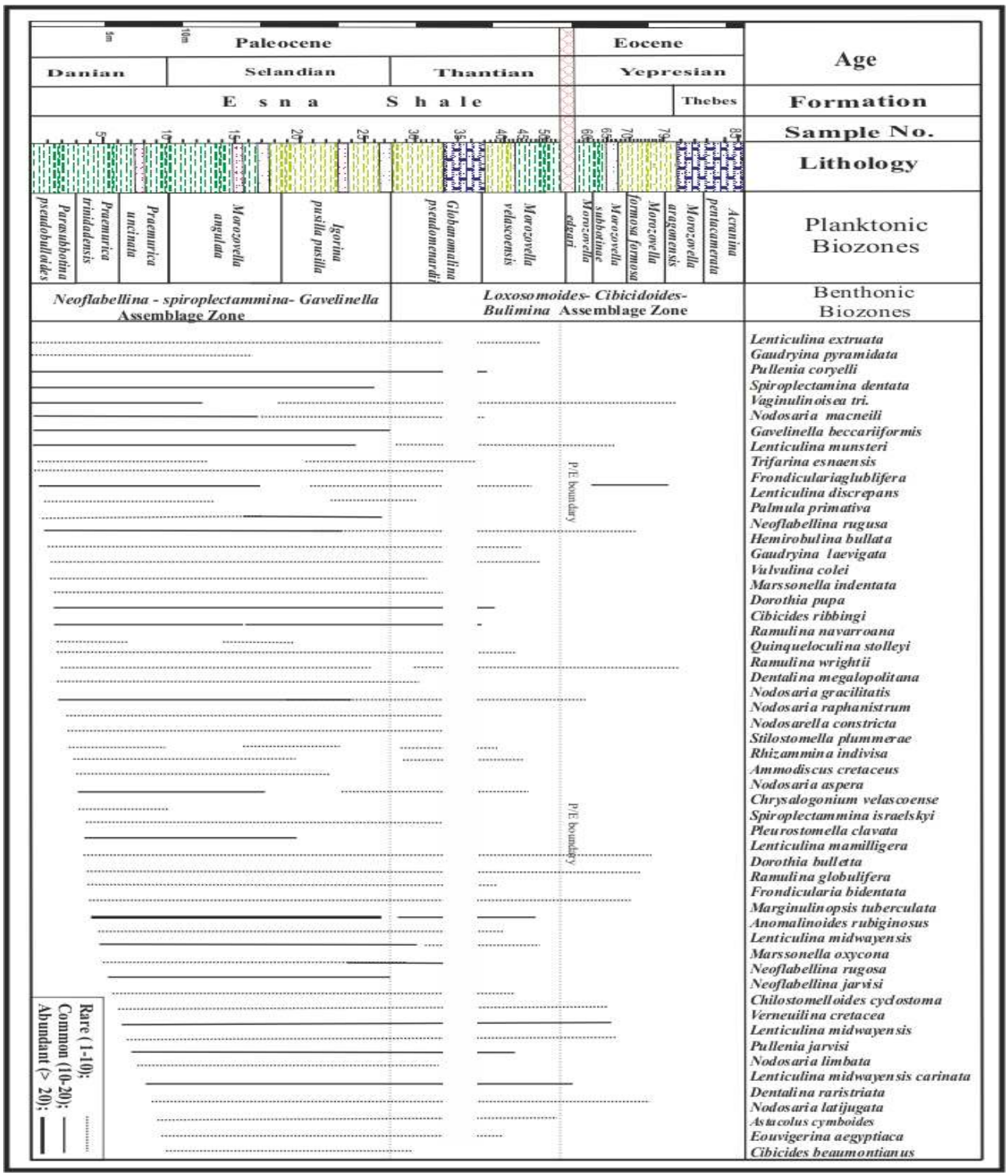


Fig. (3): Biostraigraphic chart of the benthonic foraminiferal species in G. El Falig section, northeastern Sinai, Egypt.

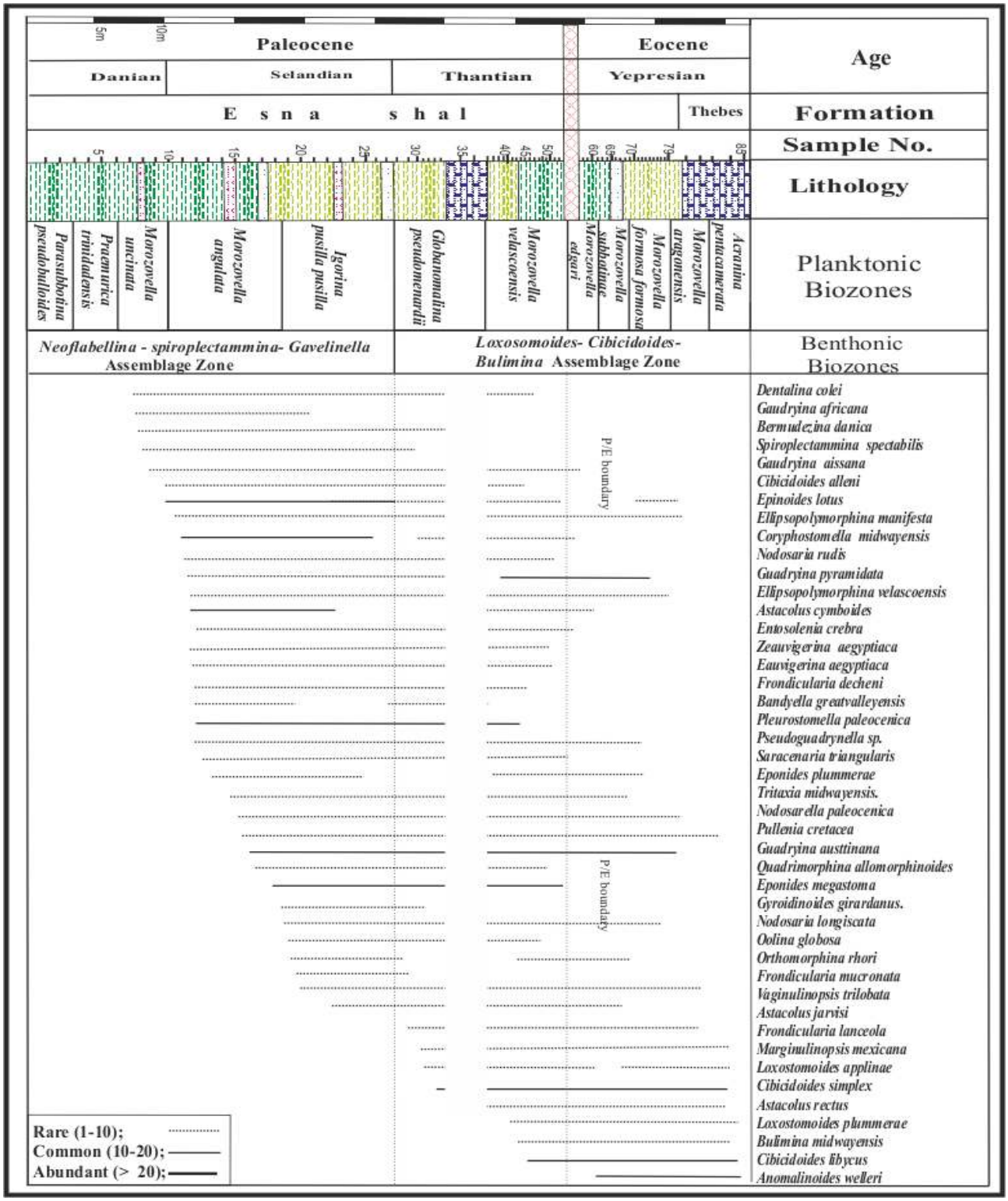


Fig. (3) ***Continued*****:** Biostraigraphic chart of the benthonic foraminiferal species in G. El Falig section, northeastern Sinai, Egypt.

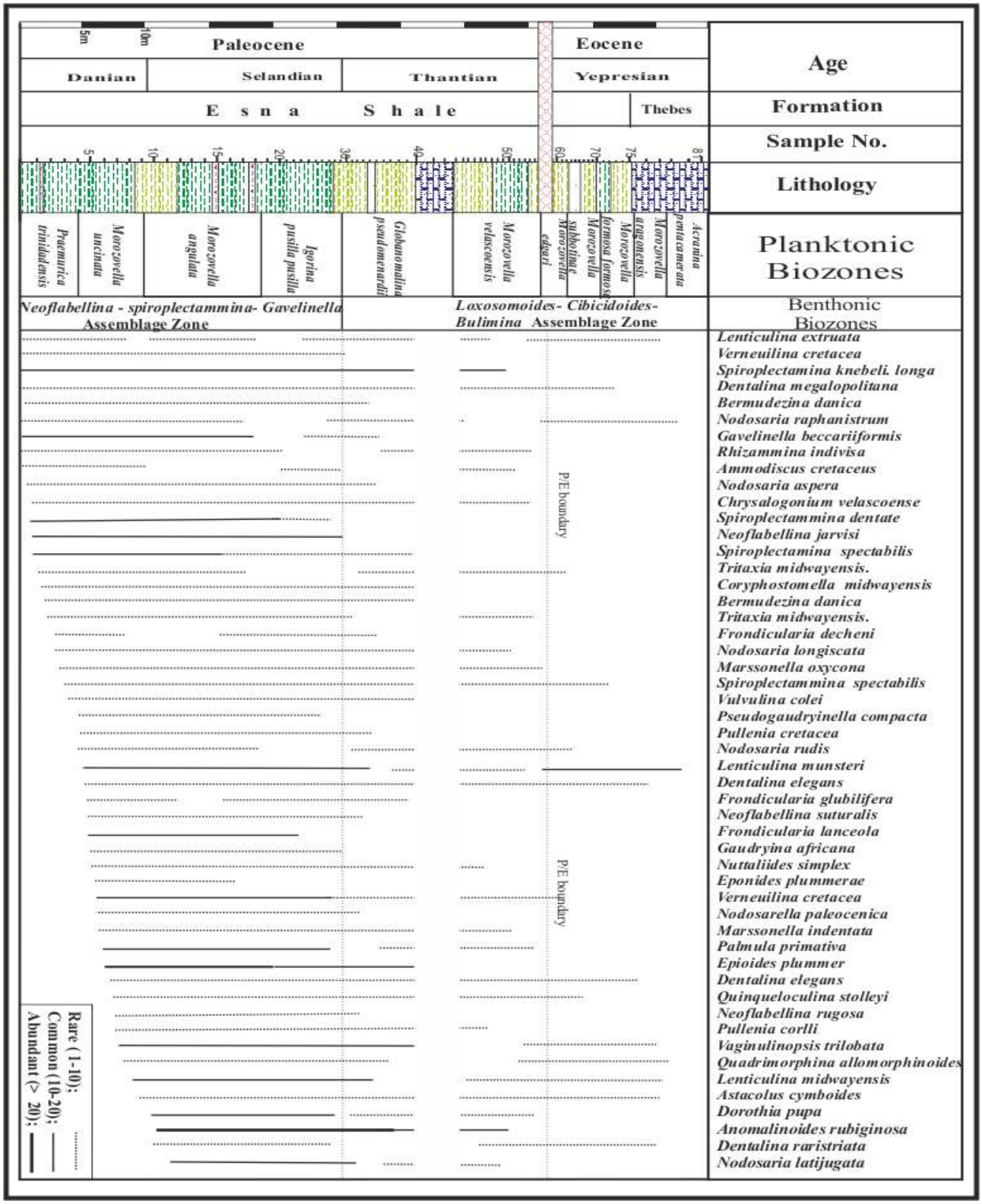


Fig. (4): Biostraigraphic chart of the benthonic foraminiferal species in G. El Qusaima section, northeastern Sinai, Egypt.

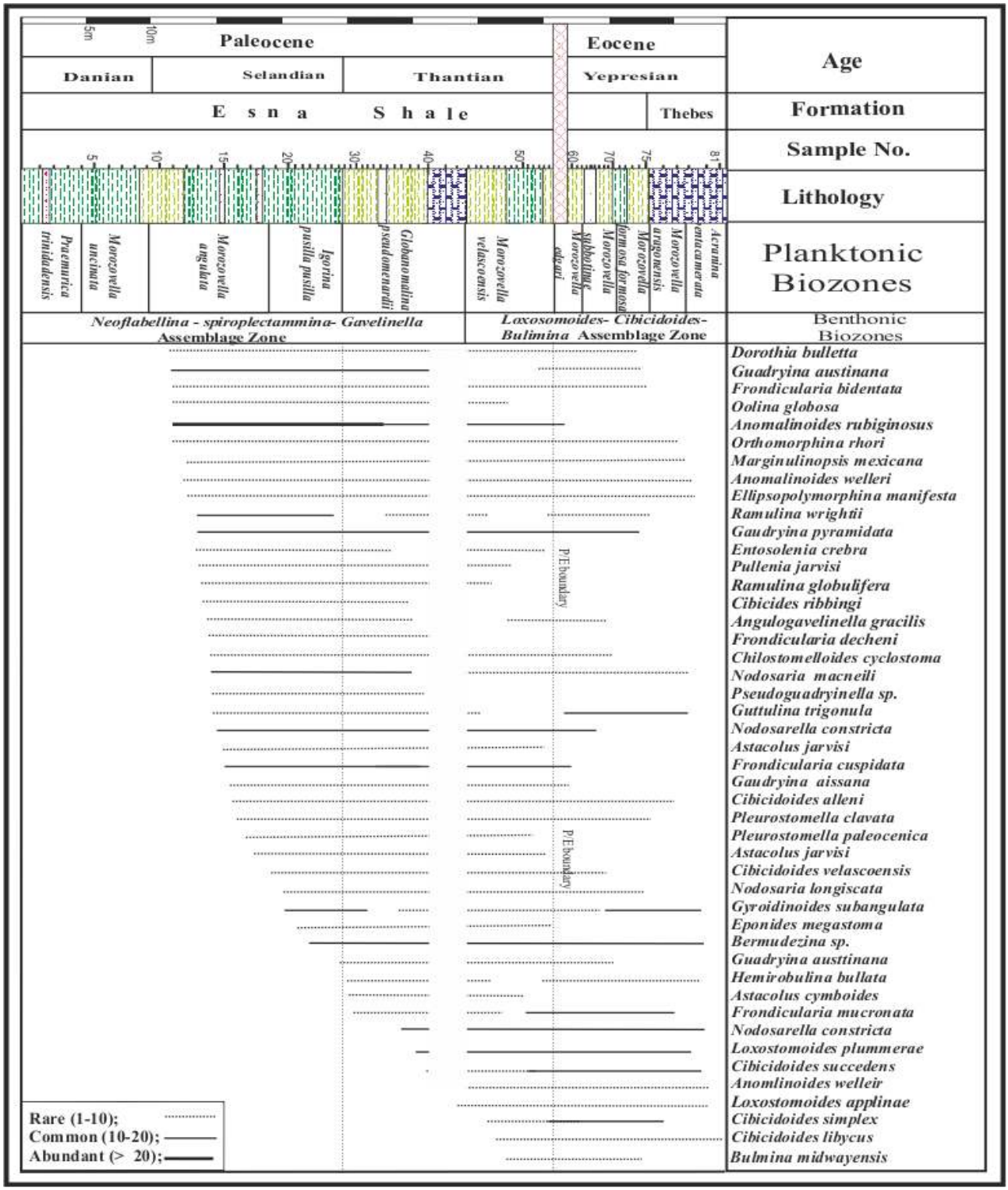


Fig. (4) ***Continue*****:** Biostraigraphic chart of the benthonic foraminiferal species in G. El Qusaima section, northeastern Sinai, Egypt.

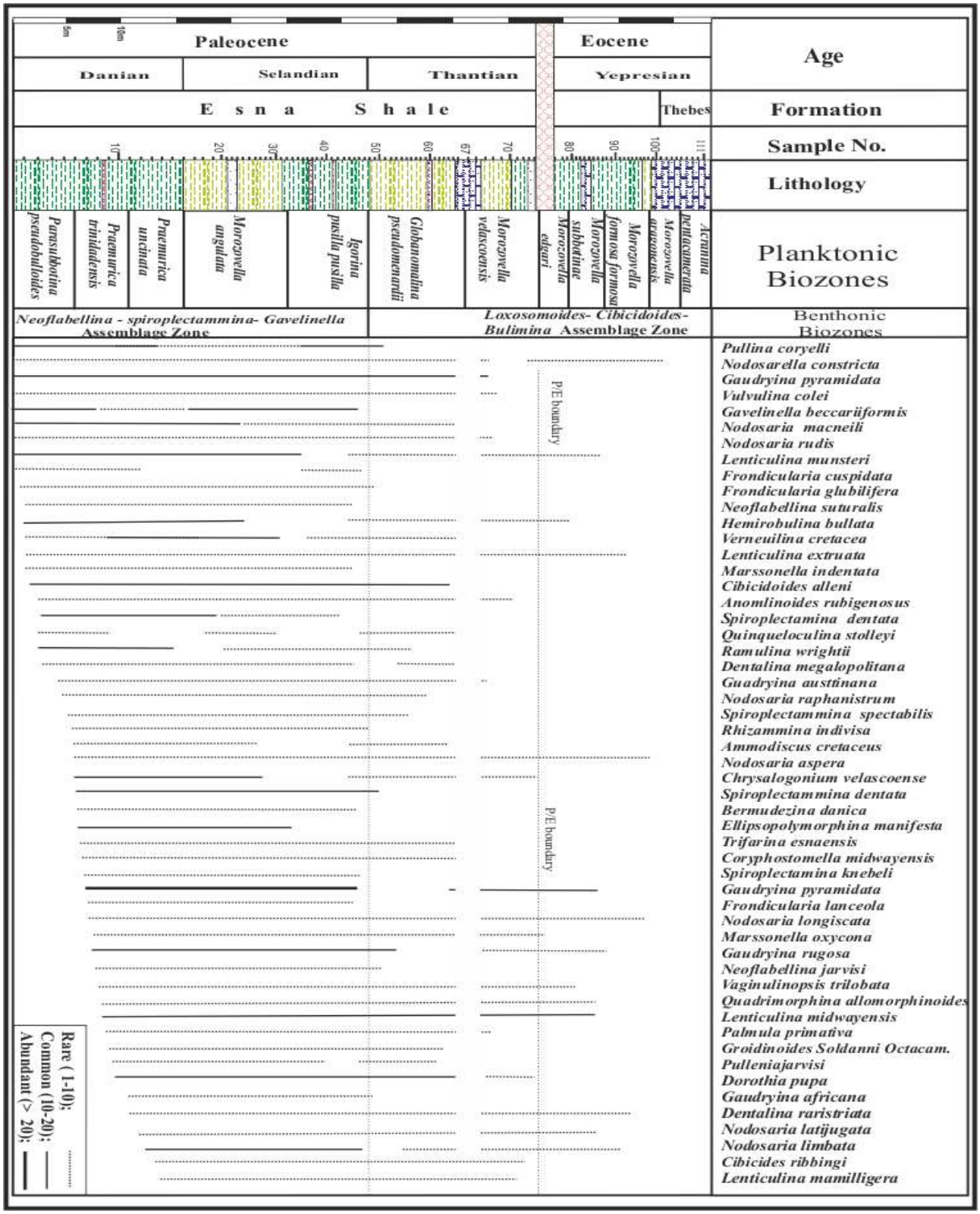


Fig. (5): Biostraigraphic chart of the benthonic foraminiferal species in G. Holet Abu Senna section, northeastern Sinai, Egypt.

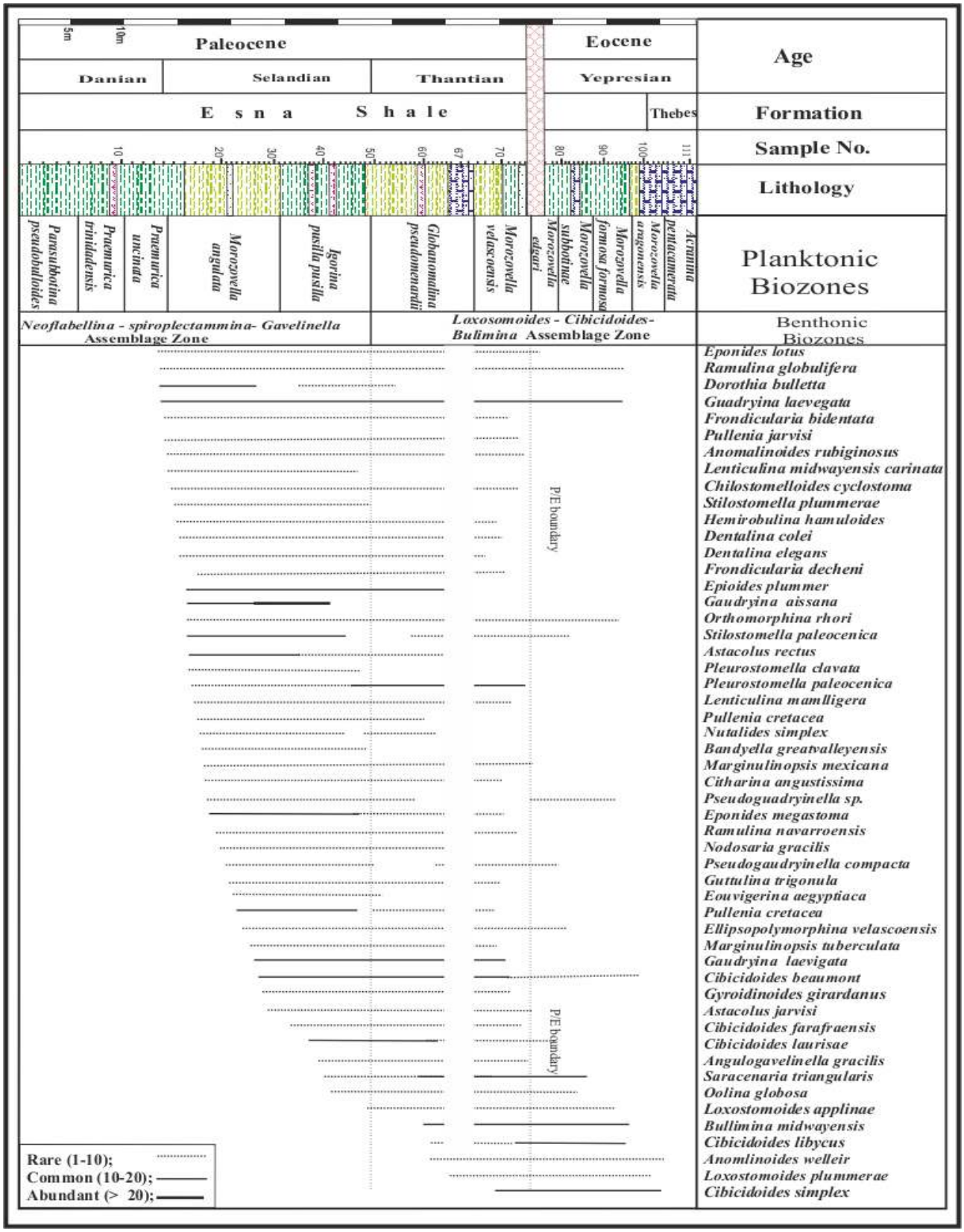


Fig. (5) ***Continued*****:** Biostraigraphic chart of the benthonic foraminiferal species in G. Holet Abu Senna section, northeastern Sinai, Egypt.

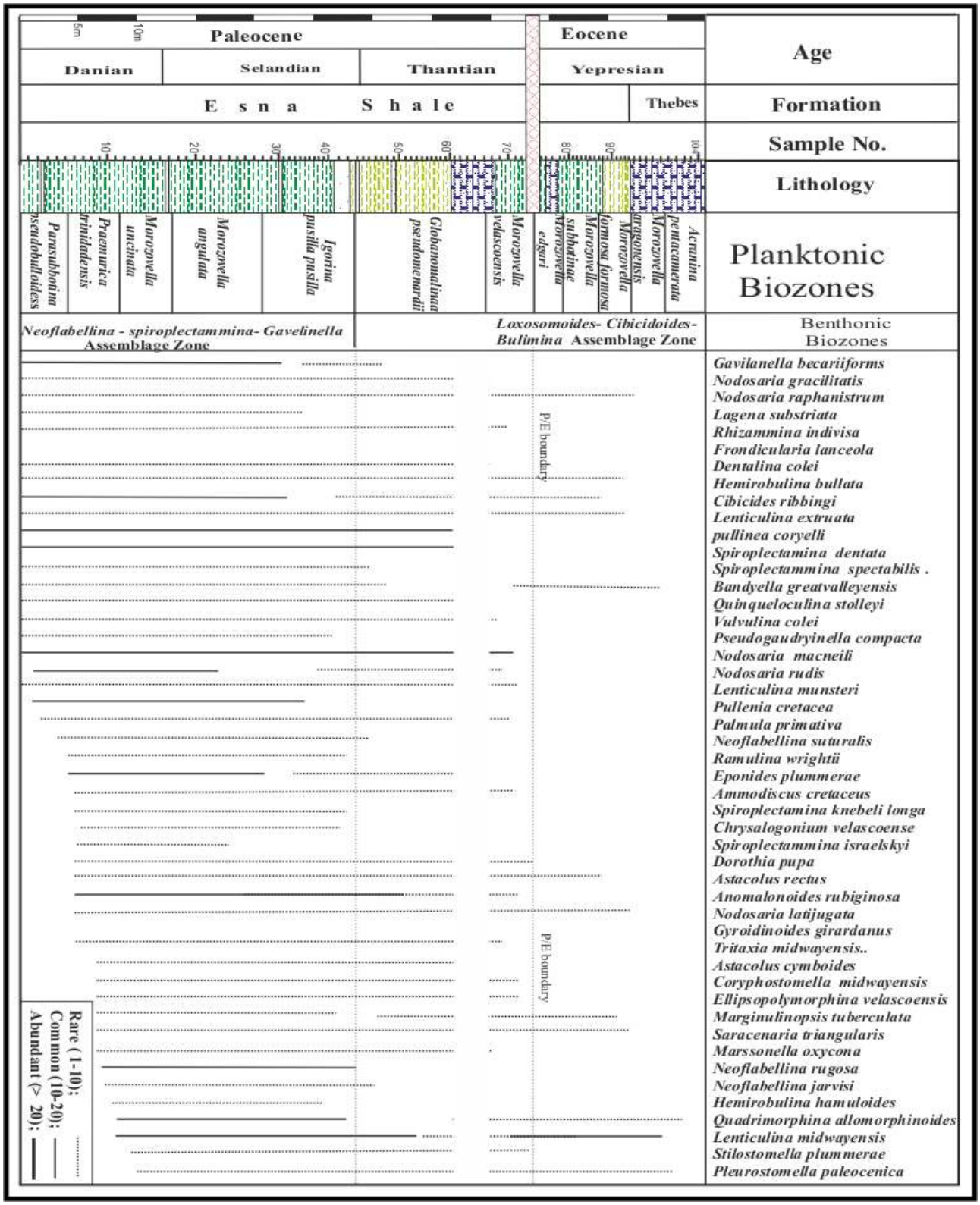


Fig. (6): Biostraigraphic chart of the benthonic foraminiferal species in G. Um Thamalla section, northeastern Sinai, Egypt.

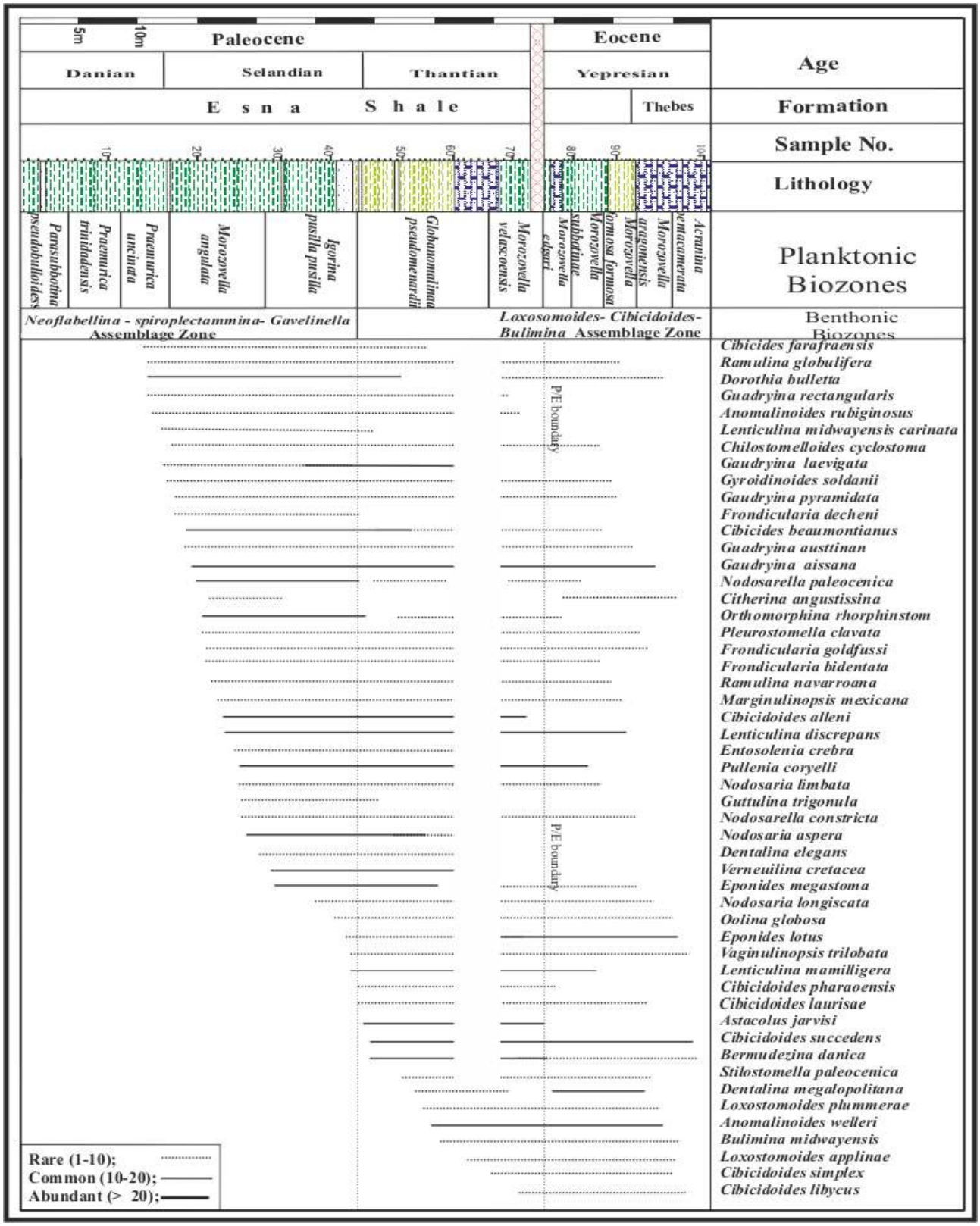


Fig. (6) ***Continued*****:** Biostraigraphic chart of the benthonic foraminiferal species in G. Um Thamalla section, northeastern Sinai, Egypt.

Table (1): Statistical analysis of the foraminifera and ostracod species in the Gabal El Qusaima section, as example

Sample no	Total No. of Foram.	Diversity	Planktonic Foram.						Benthonic Foram.						P./B. ratio	Agg. / Calc. ratio	Ostracd species	
			Plank. No.	%	Keeled		Non-keeled		Beth. No	%	Aren.		Calc.				Total No.	Diversity.
					Total No	%	Total No	%			Total No	%	Total No	%				
1	452	16	330	63	0	0	330	100	122	27	13	11	109	89	73	11	-	-
2	499	25	339	68	0	0	339	100	160	32	18	11	142	89	68	11	-	-
3	420	26	315	75	0	0	315	100	105	25	13	12	92	88	75	12	2	1
4	413	29	264	64	0	0	264	100	149	36	19	13	130	87	64	13	3	1
5	563	39	400	71	0	0	400	100	163	29	18	11	145	89	71	11	-	-
6	467	49	336	72	7	2	329	98	131	28	16	12	115	88	72	12	4	1
7	406	53	309	76	37	12	272	88	97	24	15	15	82	85	76	15	2	1
8	399	55	263	66	21	8	242	92	136	34	20	15	116	85	66	15	3	2
9	502	56	326	65	36	11	290	89	176	35	19	11	157	89	65	11	2	2
10	465	60	344	74	48	14	296	86	121	24	13	11	108	89	74	11	1	1
11	498	65	314	63	41	13	273	87	184	37	22	12	162	88	63	12	-	-
12	496	69	293	59	35	12	258	88	203	41	26	13	177	87	59	13	4	2
13	477	77	291	61	18	6	273	94	186	39	26	14	160	86	61	14	-	-
14	478	78	325	68	26	8	299	92	153	32	20	13	133	87	68	13	3	1
15	456	78	315	69	22	7	293	93	141	31	17	12	124	88	69	12	4	2
16	503	81	352	70	32	9	320	91	151	30	17	11	134	89	70	11	2	1
17	522	81	365	70	55	15	310	85	157	30	17	11	140	89	70	11	3	1
18	566	79	413	73	50	12	363	88	153	37	23	15	130	85	73	15	-	-
19	574	80	436	76	153	35	283	65	138	24	35	25	103	75	76	25	-	-
20	548	86	344	81	124	36	220	64	204	19	53	26	151	74	81	26	3	1
21	613	80	423	69	169	40	254	60	190	31	51	27	139	73	69	27	-	-
22	566	85	413	73	174	42	239	58	153	27	43	28	110	72	73	28	1	1
23	548	85	417	76	192	46	225	54	131	24	35	27	96	73	96	27	5	2
24	516	85	387	75	186	48	201	52	129	25	37	29	92	71	75	29	-	-
25	644	87	489	76	255	52	234	48	155	24	17	11	138	89	76	11	-	-
26	653	83	536	82	273	51	263	49	117	18	14	12	103	88	82	12	-	-
27	612	85	471	77	264	56	207	44	141	23	25	18	116	82	77	18	1	1
28	325	86	247	76	166	67	81	33	78	24	12	16	64	84	76	12	6	4
29	263	84	205	78	131	64	74	36	58	22	8	13	50	87	78	8	7	4
30	159	3	106	67	67	63	39	37	53	33	7	14	46	86	67	7	-	-
31	180	73	122	68	87	71	35	29	58	32	10	18	48	82	68	10	-	-
32	233	79	161	69	97	60	64	40	72	31	8	11	64	89	69	8	-	-
33	718	79	503	70	292	58	211	42	215	30	21	10	194	90	70	10	2	1
34	719	77	518	72	326	63	192	37	201	28	18	9	183	91	72	9	7	3
35	755	75	695	79	438	63	257	37	60	21	6	11	54	89	79	11	5	2
36	685	71	514	75	341	65	173	35	171	25	22	13	149	87	75	13	7	5
37	405	72	308	76	148	48	160	52	97	24	15	15	82	85	76	15	-	-
38	399	70	299	75	135	45	164	55	100	25	13	13	87	87	75	13	4	2
39	402	69	273	68	107	39	166	61	129	32	15	12	114	88	68	12	3	2
40	325	16	215	66	77	36	138	64	110	34	18	16	92	84	66	16	-	-
41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	289	66	234	81	96	41	138	59	55	19	8	14	47	86	81	14	-	-
46	365	65	277	76	133	48	144	52	88	24	14	16	74	84	67	16	7	3
47	582	62	454	78	268	59	186	41	128	22	12	9	116	91	78	9	6	3
48	648	62	486	75	330	68	156	32	162	25	13	8	149	92	75	8	5	4
49	647	63	531	82	377	71	154	29	116	18	8	7	108	93	82	7	3	1
50	689	64	572	83	339	68	233	32	117	17	7	6	110	94	83	6	2	1
51	730	61	555	76	411	74	144	26	175	24	16	9	159	91	76	9	7	5

Table (1) ***Continued*****:** Statistical analysis of the foraminifera and ostracod species in the Gabal El Qusaima section, as example

Sample no	Total No. of Foram.	Diversity	Planktonic Foram.						Benthonic Foram.						P./B. ratio	Agg. / Calc. ratio	Ostracd species	
			Plank. No.	%	Keeled		Non-keeled		Beth. No	%	Aren.		Calc.				Total No.	Diversity.
					Total No	%	Total No	%			Total No	%	Total No	%				
52	755	61	596	79	513	86	83	14	159	21	19	12	140	88	79	12	4	3
53	723	65	600	83	486	81	114	19	123	17	19	15	104	85	83	15	-	-
54	548	61	460	84	368	80	92	20	88	16	14	16	74	84	84	16	-	-
55	945	63	832	88	666	80	166	20	113	12	10	9	103	91	88	9	8	5
56	950	59	817	86	670	82	147	18	133	14	15	11	118	89	86	11	6	4
57	1012	48	840	83	722	86	118	14	172	17	24	14	148	86	83	14	3	2
58	1003	48	873	87	760	87	113	13	130	13	21	16	109	84	87	16	9	5
59	1155	50	901	78	712	79	189	21	254	22	46	18	208	82	78	18	6	3
60	1122	47	909	81	709	78	200	22	213	19	36	17	177	83	81	17	4	2
61	945	46	841	89	664	79	177	21	104	11	12	11	92	89	89	11	7	5
62	950	45	808	85	646	80	162	20	142	15	11	8	131	92	85	8	9	5
63	1012	44	840	83	722	86	118	14	172	17	15	9	157	91	83	9	5	2
64	1003	44	812	81	715	88	97	12	191	19	13	7	178	93	81	7	6	3
65	989	45	791	80	720	91	71	9	198	20	12	6	186	94	80	6	4	2
66	1012	43	850	84	782	92	68	8	162	16	11	7	151	93	84	7	7	5
67	1003	40	792	79	713	90	79	10	211	21	13	6	198	94	79	6	5	2
68	1155	40	1028	89	956	93	72	7	127	11	12	10	115	90	89	10	4	3
69	1122	42	1021	91	899	88	122	12	101	19	10	10	91	90	91	10	-	-
70	950	41	846	89	668	79	178	21	104	11	8	8	96	92	89	8	4	3
71	1045	40	910	87	737	81	173	19	135	13	14	10	121	90	87	10	5	2
72	1102	39	1014	92	811	80	203	20	88	8	11	12	77	88	92	12	8	5
73	1155	40	1109	96	954	86	155	14	46	4	7	14	39	86	96	14	10	6
74	904	41	777	86	629	81	148	19	127	14	21	16	106	84	86	16	15	13
75	950	38	827	87	496	60	331	40	123	13	16	13	107	87	87	13	5	2
76	145	42	123	85	64	52	59	48	22	15	3	12	19	88	85	12	11	8
77	125	41	105	84	50	48	55	52	20	16	4	18	16	82	84	18	-	-
78	89	38	80	90	31	39	49	61	9	10	2	19	7	81	90	19	-	-
79	112	27	99	88	39	39	60	61	13	12	3	21	10	79	88	21	5	2
80	102	24	88	86	36	41	52	59	14	14	3	20	11	80	86	20	-	-
81	113	13	98	87	37	38	61	62	15	13	4	22	11	78	87	22	-	-

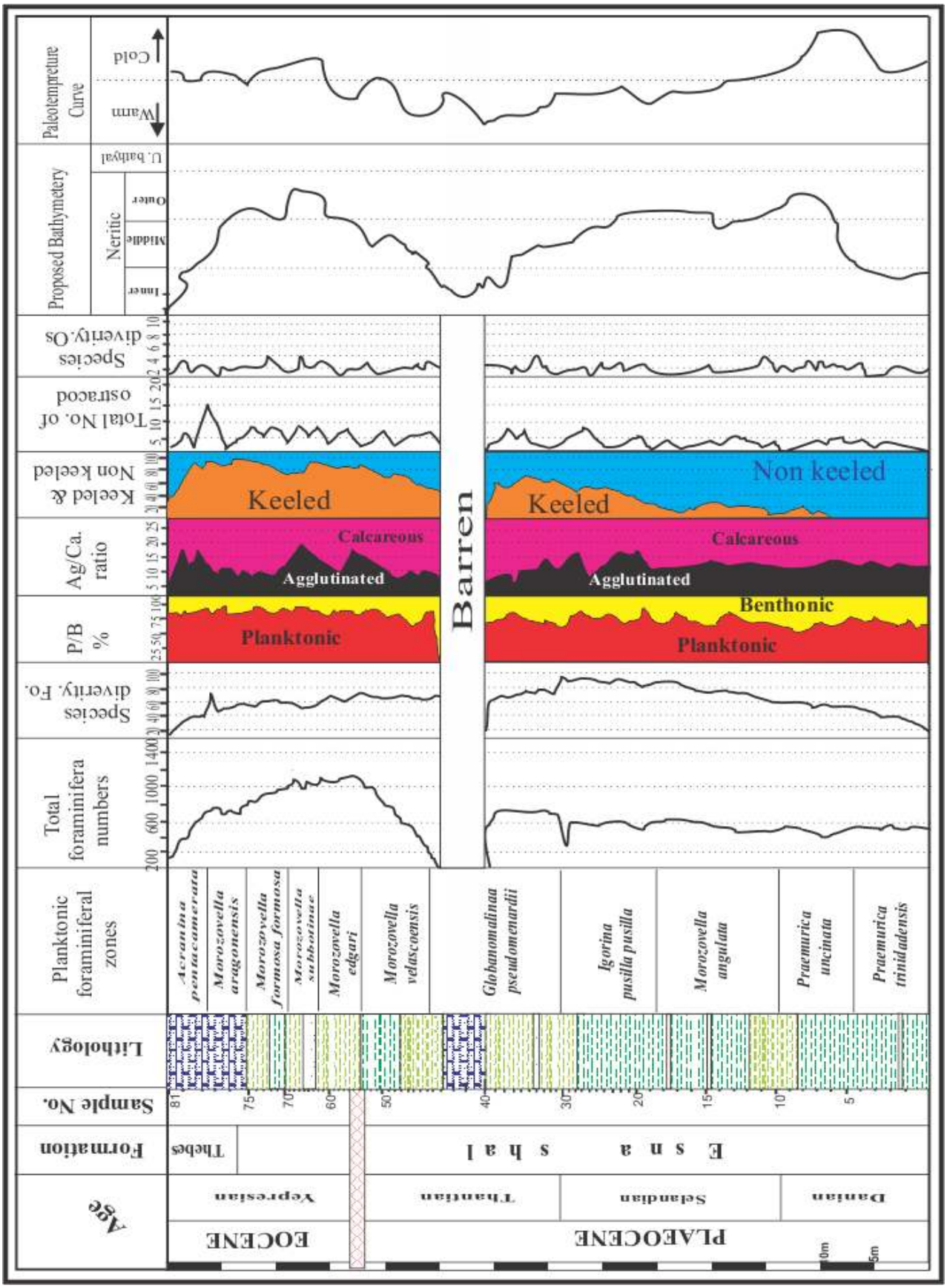
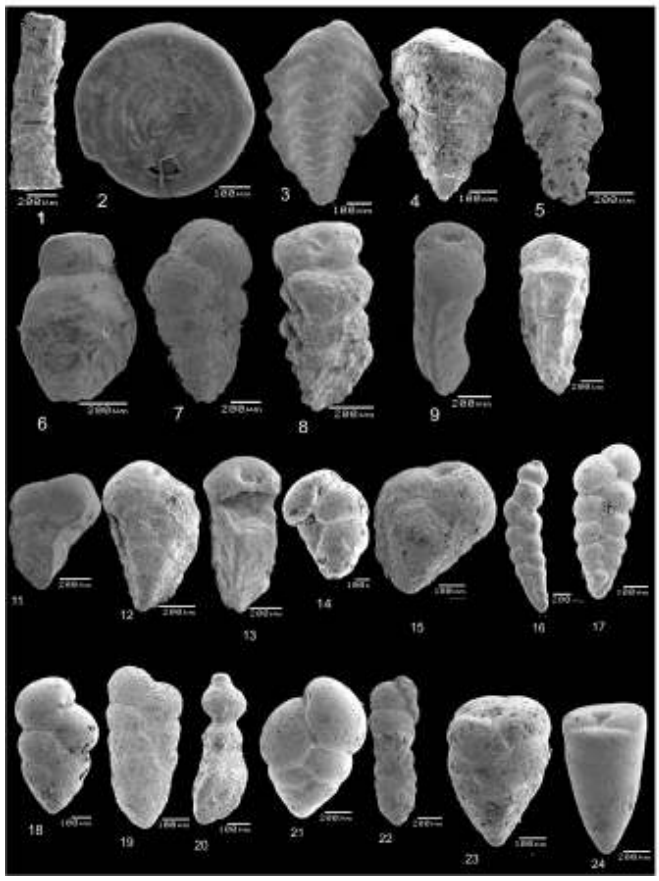


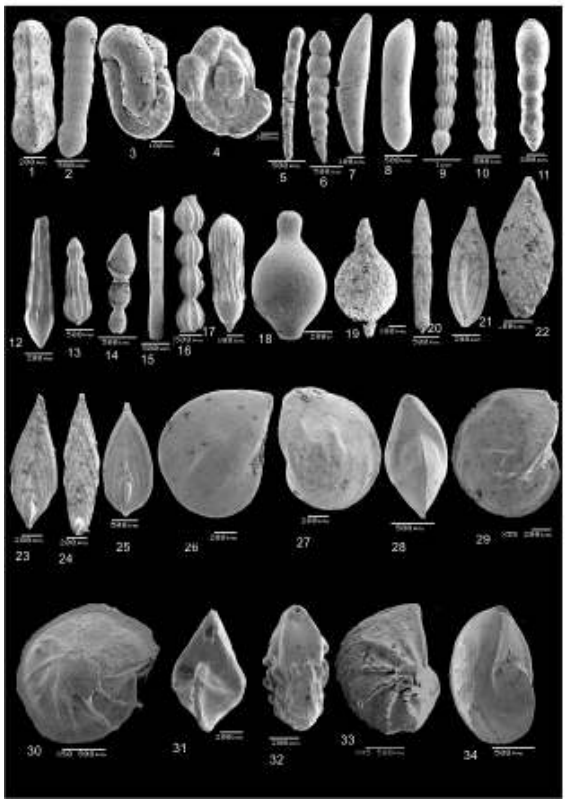
Fig. (7): Paleoecological parameters and paleoenviromental conditions in G. El Qusaima, northeastern Sinai, Egypt, as example

Plate 1



1) *Rhizammina indivisa* (Brady).
Side view, sample No.91, X60, G. Holet Abu Senna.
2) *Ammodiscus cretaceus* (Reuss) ,
Side view, sample No.16 ,X65 . G.Al Qusaima.
3) *Spiroplectamina dentata* (Alth) .
Side view, sample No.18, X90 , G. Holet Abu Senna.
4) *Spiroplectamina knebeli* (LeRoy).
Side view, sample No.91, , G. Holet Abu Senna.
5) *Spiroplectammina spectabilis* (Grzybowsk
Side view sample No.30 ,X75 . G.Al Qusaima.
6) *Valvulina colei* (Cushman).
Lateral view, sample No. 15, X95 , G. Al Qusaima.
7) *Gaudryina africana* (LeRoy).
Side view, sample No. 34, X60, G. Holet Abu Senna.
8) *Gaudryina aissana* (Ten Dam& Sigal).
Apertural view, sample No.34, X90 , G. Holet Abu Senna.
9) *Guadryina austtinana* (Cushman).
Apertural view, sample No. 88, X65, G. Holet Abu Senna.
10) *Gaudryina laevigata* (Frank).
Apertural view, sample No. 40, X75, G. El Falig.
11) *Gaudryina pyramidata* (Cushman).
Side view, sample No. 85, X75, G. Holet Abu Senna.
12) *Gaudryina rugosa* (D`Orbigny).
Apertural view, sample No. 12, X100, G. El falig.
13) *Pseudogaudryinella compacta.* (Ten Dam & Sigal).
Apertural view, sample No. 18, X110, G. El falig.
14) *Pseudogaudryinella* sp(Ten Dam & Sigal).
Apertural view, sample No. 95, X80, G. Holet Abu Senna.
15) *Verneuilina cretacea* (Karrer).
-Apertural l view, sample No.36 ,X120 . G.Al Qusaima.
16) *Bermudezina danica* (Franke)
Side view, sample No.26 , X120 . G.Al Qusaima.
17) *Bermudezina* sp.
Side view, sample No. 103, X75, G. Holet Abu Senna
18) *Tritaxia midwayensis* (Cushman).
Side View, sample No. 60, X110, G. El Falig.
19) *Dorothia bulletta* (Carsey).
Side view, sample No. 10, X130, G.Um Thamalla.
20) *Pseudoclavulina clavata* (Cushman).
Side view, sample No. 41, X65, G. Holet Abu Senna.
22) *Marsonella ellisorae* (Cushman).
Side view, sample No. 19, X65, G.Um Thamalla.
23) *Marssonella indentata* (Cushman & Jarvis).
Apertural view, sample No. 18, X130, G.Um Thamalla
24) *Marssonella oxycona* (Reuss).
Apertural view, sample No. 18, X65, G. Holet Abu Senna.

Plate 2

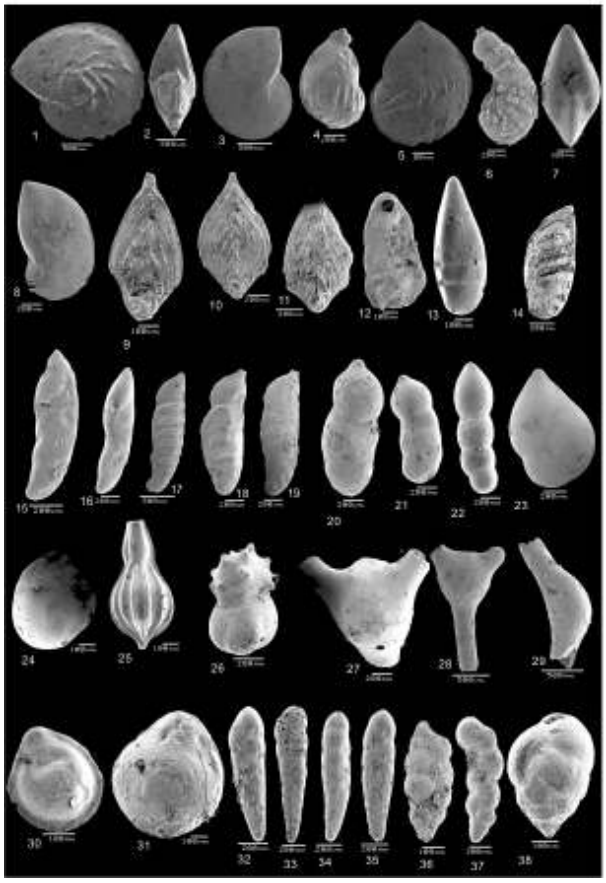


1) ***Pseudoclavulina globulifera*** **(Ten Dam & Sigal).**
Side view, sample No. 91, X40, G. Holet Abu Senna
2) ***Clavulinoides aspera*** **(Cushman).**
Side view, sample No.66 ,X65 . G.Al Qusaima.
3,4) ***Quinqueloculina stolleyi*** **(Brotzen).**
3-Dorsal view , sample No. 17, X 140 . G. Holet Abu Senna
4-Ventral view, sample No. 8, X140, G. El Falig.
5) ***Chrysalogonium velascoense*** **(Cushman).**
Side view , sample No. 66, X 65 . G. Holet Abu Senna
6) ***Dentalina colei*** **(Cushman & Dusenbury).**
Side view, sample No. 73, X40, G. El Falig.
7) ***Dentalina elegans*** **(D`Orbigny).**
Side view, sample No. 12, X60, G. El Falig.
8) ***Dentalina megalopolitana*** **(Reuss).**
Side view, sample No. 75, X40, G.Um Thamalla.
9,10) ***Dentalina raristriata*** **(Chapman).**
9-Side view , sample No. 3, X 30 . G. Holet Abu Senna.
10-Side view , sample No. 61, X 30 . G. Holet Abu Senna.
11) ***Nodosaria aspera*** **(Reuss).**
Side view, sample No. 55, X100, G.Um Thamalla
12) ***Nodosaria gracilitatis*** **(Cushman)**
Side view, sample No.3 , X27 . G.Al Qusaima.
13) ***Nodosaria latejugata*** **(Guembel).**
Side view , sample No. 71, X 45 . G. Holet Abu Senna
14) ***Nodosaria limbata*** **(D'Orbigny).**
Side view , sample No. 13, X 45 . G. Holet Abu Senna.
15) ***Nodosaria longiscata*** **(D'Orbigny).**
Side view, sample No.28 , X33 . G.Al Qusaima.
16) ***Nodosaria macneili*** **(Cushman).**
Side view , sample No. 13, X 37 . G. Holet Abu Senna
17) ***Nodosaria raphanistrum*** **(Linne).**
Side view , sample No. 55, X 95 . G. Holet Abu Senna

18,19) ***Nodosaria rudis*** **(D'Orbigny).**
18- Side view, sample No. 76, X95, G. El Falig
19- Side view , sample No.82, X 100 . G. Holet Abu Senna.
20) ***Frondicularia bidentata*** **(Cushman)**
Side view, sample No. 20, X30, G.Um Thamalla
21) ***Frondicularia cuspidata*** **(Cushman).**
Side view, sample No. 50, X85, G.Um Thamalla.
22) ***Frondicularia decheni*** **(Reuss).**
Side view, sample No. 32, X45, G. El Falig.
23) ***Frondicularia goldfussi*** **(Reuss).**
Side view, sample No. 71, X60, G. El Falig.
24) ***Frondicularia lanceola*** **(Reuss).**
Side view , sample No.53, X60 . G. Holet Abu Senna.

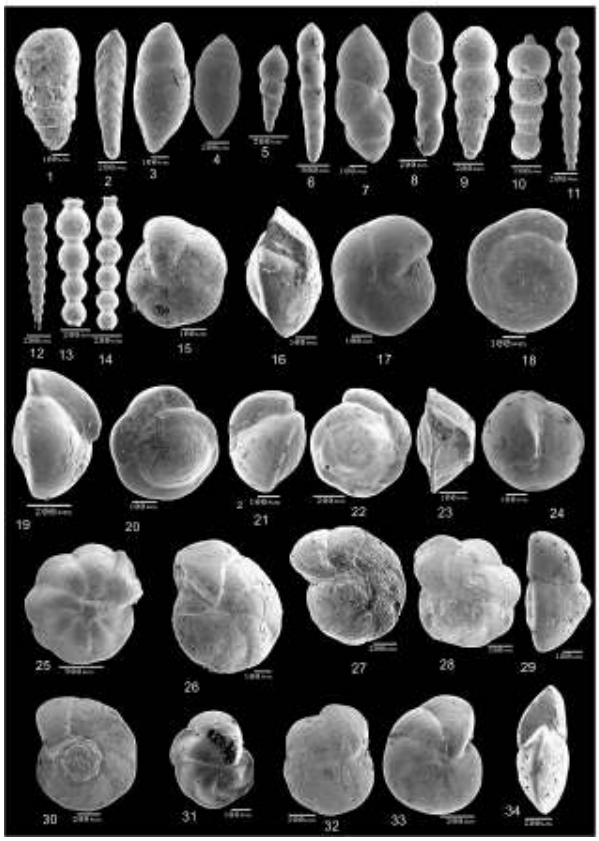
25) ***Frondicularia mucronata*** **(Reuss).**
Side view, sample No. 50, X37, G.Um Thamalla.
26-29) ***Lenticulina discrepans*** **(Reuss).**
Side view , sample No. 18, X65 . G. Holet Abu Senna.
Side view , sample No. 18, X60 . G. Holet Abu Senna.
Apertural view , sample No. 10, X50 . G. Holet Abu Senna.
Side view view sample No.19 , X55. G.Al Qusaima.
30,31) ***Lenticulina extruata*** **(Cushman).**
Side view , sample No.10, X50 . G. Holet Abu Senna.
Apertural view , sample No. 10, X65 . G. Holet Abu Senna.
32,33) ***Lenticulina mamilligera*** **(Karre).**
Apertural view view sampleNo.36 , X45. G.Al Qusaima.
Peripheral view view sample No.36 , X85. G.Al Qusaima.
34) ***Lenticulina midwayensis*** **(Plummer).**
Peripheral view, sample No. 71, X50, G. El Falig.

Plate 3



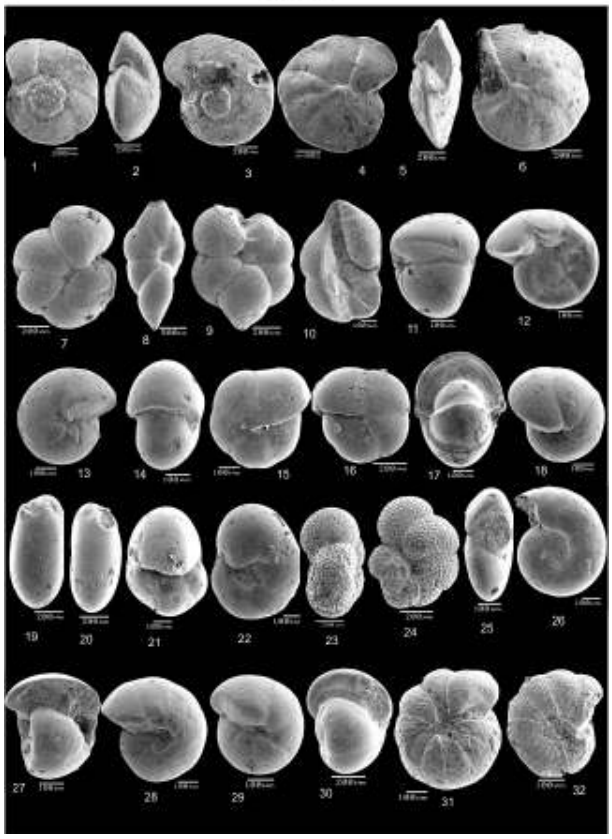
1) ***Lenticulina midwayensis carinata*** **(Plummer).**
1- Side view sample No.19, X43. G.Al Qusaima
2-3) ***Lenticulina muensteri*** **(Roemer).**
2- Peripheral view view sample No.19 , X37. G.Al Qusaima.
3- Side view, sample No. 70, X45, G. El Falig.
4,5) ***Marginulinopsis mexicana alticostata*** **(Cushman & Barksdale).**
4- Side view , sample No.102, X65 . G. Holet Abu Senna.
5- Side view , sample No.102, X85 . G. Holet Abu Senna.
6) ***Marginulinopsis tuberculata*** **(Plummer).**
6- Side view , sample No.66, X60 . G. Holet Abu Senna.
7,8) ***Saracenaria triangularis*** **(D'Orbigny)**
7- Apertural view, sample No. 83, X110, G.Um Thamalla.
8- Side view, sample No. 83, X110, G.Um Thamalla.
9) ***Neoflabellina jarvisi*** **(Cushman).**
9- peripheral view sample No.17 , X110. G.Al Qusaima.
10) ***Neoflabellina rugosa*** **(D'Orbigny).**
10- Side view, sample No. 83, X65, G.Um Thamalla.
11) ***Neoflabellina suturalis*** **(Cushman).**
11- Side view, sample No. 18, X85, G. El Falig.
12) ***Palmula primativa*** **(Cushman)**
12- Apertural view sample No.60 , X100. G.Al Qusaima
13- ***Astacolus cymboides*** **(D'Orbigny).**
13- Side view , sample No.14, X100 . G. Holet Abu Senna.
14- ***Astacolus jarvisi*** **(Cushman).**
14- Side view , sample No.80, X44 . G. Holet Abu Senna.
15,16) ***Astacolus rectus*** **(D'Orbigny).**
15- Side view, sample No. 45, X90, G. El Falig.
16- Side view, sample No. 45, X60, G. El Falig.
17-19)*Vaginulinopsis trilobata* **(D'Orbigny).**
17- Side view, sample No. 88, X45, G. El Falig.
18- Side view, sample No. 88, X65, G. El Falig.
19- Side view, sample No. 88, X60, G. El Falig.
20-22) ***Hemirobulina bullata*** **(Reuss)**
20- Side view sample No.66 , X60. G.Al Qusaima.
21- Side view , sample No.60, X65 . G. Holet Abu Senna.
22- Side view , sample No.10, X65 . G. Holet Abu Senna.
23) ***Hemirobulina hamuloides*** **(Brotzen).**
23- Side view, sample U.M. 25, X70, G.Um Thamalla.
24) ***Citharina angustissima*** **(Reuss).**
24- Side view, sample No. 100, X24, G.Um Thamalla.
25- ***Lagena substriata*** **(Williamson)**
25- Side view sample No.16 , X100. G.Al Qusaima.
26) ***Guttulina trigonula*** **(Reuss).**
26-Ventral view, sample No. 23, X90, G. Holet Abu Senna.
27) ***Ramulina globulifera*** **(Brady).**
27- Side view, sample No. 49, X45, G.Um Thamalla.
28)*Ramulina navarroana* **(Cushman).**
28- Side view sample No.34 , X60. G.Al Qusaima.
29) ***Ramulina wrightii*** **(Barnard).**
29- Side view , sample No. 36, X50 . G. Holet Abu Senna.
30) ***Entosolenia crebra*** **(Matthes).**
30- Side view , sample No. 25, X190 , G. Al Qusaima
31) ***Oolina globosa*** **(Montagu).**
31- Side view, sample No.72, X100, G. Holet abu Senna.
32,33) ***Loxostomoides applinae*** **(Plummer).**
32- Side view, sample No. 76, X90, G. El Falig
33- Side view, sample No. 76, X70, G. El Falig.
34,35) ***Loxostomoides plummerae*** **(Cushman).**
34- Side view, sample No.82 , X80 . G.Al Qusaima.
35- Side view, sample No.85 , X80 . G.Al Qusaima.
36,37) ***Eouvigerina aegyptiaca*** **(Nakkady).**
36- Side view, sample No.21, X130 . G. Holet abu Senna.
37- Side view, sample No.26 , X130 . G. Holet abu Senna.
38) ***Bulimina midwayensis*** **(Cushman & Parker).**
38- Apertural view sample No.52 , X160 . G.Al Qusaima

Plate 4



1) *Trifarina esnaensis* (LeRoy).
1- Side view, sample No. 3, X100, G. El Falig.
2) *Coryphostomella telatynensis* (Gawor-Biedowa).
2- Lateral view view, sample No. 46, X80, G. El Falig.
3,4) *Ellipsopolymorphina velascoensis* (Cushman).
3-Side view , sample No.95, X 80 . G. Holet Abu Senna.
5) *Nodosarella constricta* (Cushman & Bermudez).
5- Side view , sample No. 16, X 45 . G. Holet Abu Senna.
6) *Nodosarella paleocenica* (Cushman & Todd).
6- Side view, sample No. 55, X40, G.Um Thamalla .
7) *Pleurostomella clavata* (Cushman) .
7-Peripheral view sample No. 18 , X100 . G.Al Qusaima.
8) *Pleurostomella paleocenica* (Cushman).
8- Peripheral view, sample No. 41, X80, G. El Falig
9) *Bandyella greatvalleyensis* (Trujillo).
9- Side view, sample No. 56, X45, G.Um Thamall
10) *Orthomorphina rhori* (Cushman& Stainforth).
10- Side view, sample No. 43, X60, G. El Falig.
11,12) *Stilostomella paleocenica* (Cushman & Todd).
11- Side view , sample No. 62, X 60, G. Holet Abu Senna
12- Side view , sample No. 68, X 70 ,G. Holet Abu Senna
13,14) *Stilostomella plummerae* (Cushman).
13- Side view, sample No. 22, X60, G. El Falig.
14- Side view, sample No. 23, X60, G. El Falig.
15-17) *Eponides megastoma* (Grzybowski).
15- Umbilical view, sample No.23, X110, G. El Falig.
16- Peripheral view, sample No. 53, X140, G. Holet abu Senna.
17- Umbilical view, sample No. 38, X120, G.Um Thamalla.
18,19) *Eponides lotus* (Schwager).
18- Spiral view, sample No. 70, X100, G. El Falig.
19- Peripheral view, sample No. 16, X95, G. El Falig.
20) *Eponides lotus* (Schwager).
20- Spiral view , sample No. 22, X140, G. Al Qusaima.
21,22) *Eponides plummerae* (Cushman).
21- Peripheral view, sample No. 23, X140, G. Holet abu Senna
22- Spiral view, sample No. 23, X90, G. Holet abu Senna.
23,24) *Nuttallides simplex* (Nuttall).
23- Peripheral view, sample No. 22,X160, G. Holet Abu Senna.
24- Umbilical view, sample No. 22,X120, G. Holet Abu Senna.
25-28) *Cibicidoides alleni* (Plummer).
25- Umbilical view , sample No. 15, X50 . G. Holet Abu Senna.
26- Umbilical view , sample No. 16, X50 . G. Holet Abu Senna.
27- Spiral view sample No.19 , X65. G.Al Qusaima.
28- Umbilical view, sample No. 36, X88 . G. Holet Abu Senna.
29,30) *Cibicidoides libycus* (LeRoy).
29- Peripheral view , sample No. 88, X50 . G. Holet Abu Senna.
30- Dorsal Spiral view , sample No. 88, X50 . G. Holet Abu Senna.
31) *Cibicidoides pharaonis* (LeRoy).
31- Umbilical view, sample No. 86, X110, G.Um Thamalla.
32-34) *Cibicidoides simplex* (Brotzen).
32- Umbilical view, sample No. 79, X75, G. Holet Abu Senna.
33- Umbilical view, sample No. 82, X95, G. Holet Abu Senna.
34-Peripheral view, sample No. 88, X75, G. Holet Abu Senna.

Plate 5



1-3) ***Cibicidoides succedens*** **(Brotzen).**
1- Spiral view, sample No. 78 X80, G.Um Thamalla.
2- Peripheral view, sample No. 78, X85, G.Um Thamalla.
3- Spiral view, sample No. 75, X75, G.Um Thamalla.
4-6) ***Cibicidoides laurisae*** **(Mallory).**
4- Umbilical view, sample No. 44, X110, G. Al Qusaima.
5- Peripheral view, sample No. 49, X45, G.Um Thamalla
6- Umbilical view, sample No. 49, X45, G.Um Thamalla
7) ***Cibicides beaumontianus*** **(D'orbigny)**
7- Umbilical view, sample No. 36, X90, G. El Falig.
8-10) ***Cibicides ribbingi*** **(Brotzen).**
8- Ventral view, sample No. 22, X45, G. El Falig.
9- Ventral view view sample No.30 , X80. G.Al Qusaima
10- Dorsal view, sample No. 24, X100, G. El Falig.
11-13) ***Pullenia coryelli*** **(White).**
11- Peripherall view, sample No. 23, X150, G. Um Thamalla.
12- Spiral view, sample No. 23, X150, G. Um Thamalla.
13- Umbilical view , sample No. 14, X120, G. Al Qusaima.
14-16) ***Pullenia cretacea*** **(Cushman).**
14- Peripheral view , sample No. 18, X95, G. Al Qusaima
15- Ventral view , sample No. 18, X95, G. Al Qusaima
16- Ventral view, sample No. 23, X120, G. Holet abu Senna
17,18) ***Pullenia jarvisi*** **(Cushman).**
17- Peripheral view, sample No. 28, X140, G. Holet abu Senna.
18- Ventral view, sample No. 23, X120, G. Holet abu Senna
19,20) ***Chilostomelloides cyclostoma*** **(Rzehak).**
19- Side view sample No.18 , X85. G.Al Qusaima
20- Side view sample No.18 , X85. G.Al Qusaima.
21,22) ***Quadrimorphina allomorphinoides*** **(Reuss).**
21- Ventral view, sample No. 18, X100, G. Holet Abu Senna.
22- Ventral view, sample No. 18, X120, G. Holet Abu Senna.
23-24) ***Anomalinoides rubiginosus*** **(Cushman).**
23- Peripheral view, sample No. 44, X110, G. Al Qusaima.
24- Ventral view, sample No. 36, X90, G. Holet Abu Senna.
25,26) ***Anomalinoides welleri*** **(Plummer).**
25- Peripheral view, sample No. 13, X110, G.Um Thamalla.
26- Spiral view, sample No. 13, X130, G.Um Thamalla.
27,28) ***Gyroidinoides girardanus*** **(Reuss).**
27- Side view , sample No. 22, X130 , G. Holet Abu Senna
28- Ventral view, sample No. 16, X150, G. El Falig.
29,30) ***Gyroidinoides soldanii octocameratus*** **(Cushman & Hanna).**
29- Ventral view , sample No. 55, X140 , G. Holet Abu Senna.
30- Peripheral view , sample No. 55, X90 , G. Holet Abu Senna.
31) ***Angulogavelinella gracilis*** **(Marsson).**
31- Ventral view, sample No. 54, X110, G. Al Qusaima.
32) ***Gavelinella beccariiformis*** **(White).**
32- Ventral view , sample No. 35, X70 , G. Holet Abu Senna

CONCLUSION

More than 109 benthonic foraminifera species are recorded from the exposed rock unites (Esna and Thebes formations).in the studied sections . Their vertical distribution are shown and most of them are photographed with SEM and illustrated in 5 plates . The investigation of the foraminiferal content has led to the recognition of two assemblage zone . Their age determination depend mainly on the equivalent planktonic foraminifera content. The statistical analysis is carried out in details to determine the paleoenviromental parameters , base on P/B Ratio, Agg./Calc. Ratio. Could be divided paleoenvironmental events of the studied sections into three biofacies Biofacies 1 (before PETM), Biofacies 2 (during PETM) and Biofacies 3 (After PETM). The Esna Shale was deposited in a middle neritic to upper bathyal environment and Thebes Formation was also deposited in progressively shallowing middle neritic environment.

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