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Review of the Early/Middle Eocene biostratigraphy and paleoenvironment of the Rus Formation and Wadi Al Nahayan Member of the Dammam Formation, western limb of Jabal Hafit, United Arab Emirates

Haidar Anan

Emeritus, Former Vice President for Academic Affairs, Al Azhar University-Gaza

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Abstract

The present study presents an amended two planktic foraminiferal biozones using the modified ranges of *Acarinina cuneicamerata* and *Turborotalia frontosa* index species from sixteen species of six genera throughout E7a,b biozone, and revised calibration datum of the Early/Middle Eocene (EME) bioevent in the western limb of Jabal Hafit, Al Ain area, United Arab Emirates (UAE). Sixteen planktic foraminiferal diagnostic species are recorded and illustrated from the upper part of the Rus Formation (late Early Eocene = late Ypresian, E7a) and the lower part of the Wadi Al Nahayan Member of the Dammam Formation (early Middle Eocene = early Lutetian, E7b).

Keywords: Eocene, Biostratigraphy, Paleoenvironment, Rus Formation, Dammam Formation, Jabal Hafit, UAE.

1. Introduction

The present paper is a continuation of the studies concerned with the complete record of the foraminiferal content of the Paleogene rocks in the Al Ain area of the United Arab Emirates (UAE), particularly Jabal Hafit which located to the southwest of Al Ain city, and represents the third part of the sequence outcropping in the western limb in Jabal Hafit: the top Early Eocene (Anan, 1996) and the Early/Middle Eocene (EME) sequence (Anan, 2015a). Jabal Hafit is located to the southeast of Al Ain city, Emirate of Abu Dhabi, UAE (Figure 1).

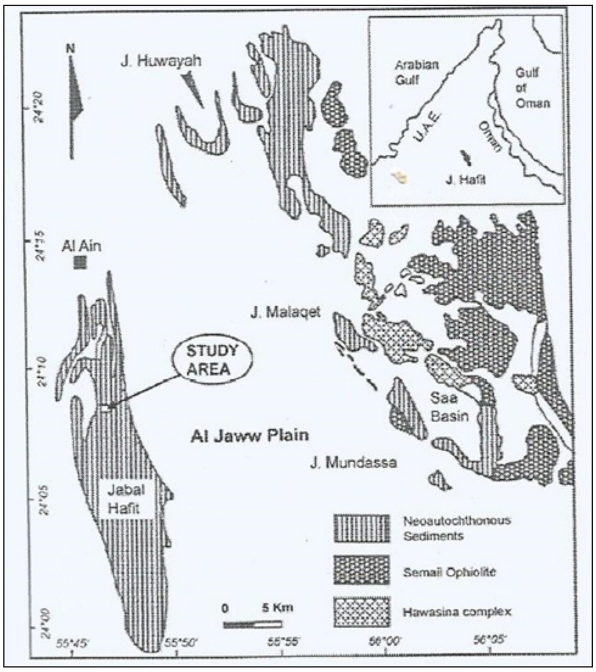

Figure 1. Location map of Al Ain area , UAE including Jabal Hafit (west of Al Jaww Plain), J. Malaqet and J. Mundassa, east Al Jaww Plain (after Anan, 2015a).

The base Middle Eocene succession (about 17 m thick) is located about 5m above the upper Early Eocene intraformational conglomeratic bed in K4 (about 50 m thick), along the asphalted road climbing to the top of the Jabal at the western limb of Jabal Hafit anticline (Figure 2). The previous studies of Cherif et al. (1992), Anan et al. (1992), Anan (1996, 2015a, b), Boukhary et al. (2006) on the planktic, nummulitic foraminifera and nannoplankton content around the EME boundary in Jabal Hafit are pertinent to the present study. The paleontology, stratigraphy, paleoenvironment and also the lacuna around the EME boundary in UAE and some other parts in the Tethys are presented.

2. Material of study

Eighteen soft marl and gypsiferous shale samples alternated with other hard and Nummulitic and Alvelinid large benthic foraminiferal beds were collected from the inclined succession of the Early-Middle Eocene rocks of the western limb of Jabal Hafit (Lat. 24° 4’ 40’’ N, Long. 55° 46’ 54’’ E), which is located to the south of Al Ain city, and exposed along the asphalted road climbing to the top of the Jabal with about 70 m thick in K4 (Figure 3). The study gypsiferous shale and marl samples yield well-preserved and diverse planktic foraminiferal assemblage and have supplied the morphotype of the illustrated sixteen species of six genera.

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* Corresponding author e-mail: profanan@gmail.com

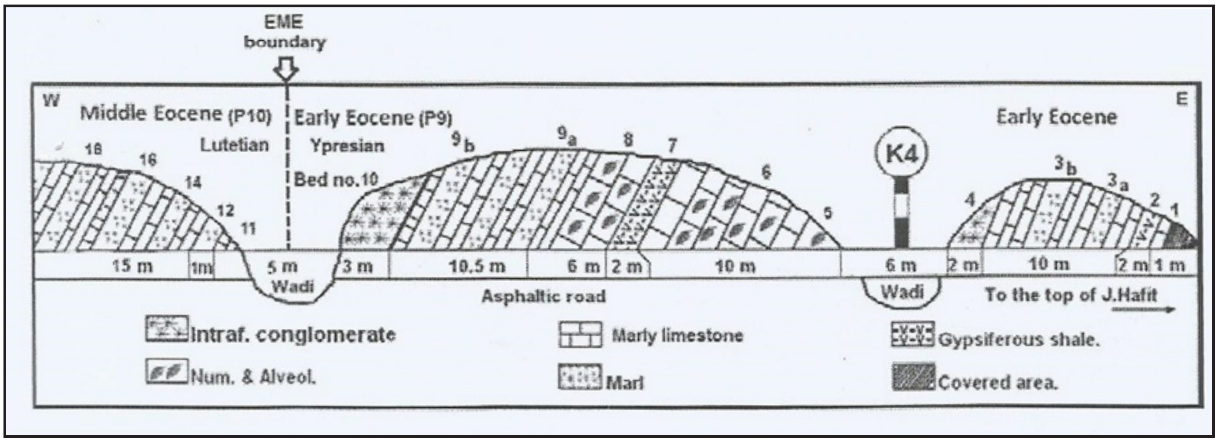

Figure 2. Schematic section of the Early/Middle Eocene succession at K4 of J. Hafit (after Anan, 2015a).

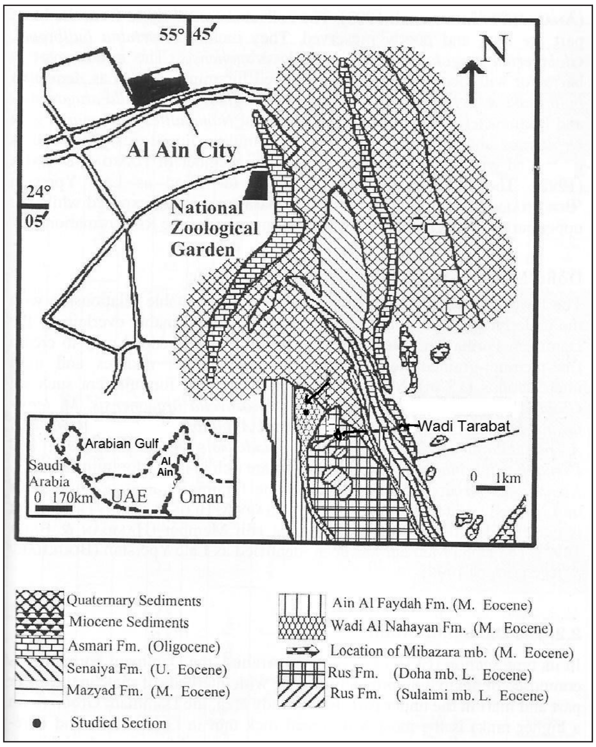

Figure 3. Geologic map of Jabal Hafit (UAE) including the study section of the Middle Eocene Wadi Al Nahayan Member of the Dammam Formation (after Hamdan and Bahr, 1992) outcropping at the western limb of Jabal Hafit (after Boukhary et al., 2006).

3. Stratigraphy

According to Payros et al. (2007), an attempt is made at a new Ypresian/Lutetian boundary biomagneto chronology based on data from the Gorrondatxe section, which shows that the boundary between Zones P9 (=E7, approximately) and P10 (=E8, approximately) is 3.1 Myr younger than hitherto considered, and the duration of the Early Eocene, most commonly defined according to this planktic foraminiferal zonal boundary, has generally been underestimated over the last four decades. After that, Molina et al. (2011) noted that it was conceptually agreed that the Lutetian GSSP should be placed somewhere in the interval between the top of the historical Ypresian Stage defined in Belgium and the bottom of the historical Lutetian Stage stratotype defined in Paris. A major problem to this end is the scarcity of continuous sections at the Ypresian/Lutetian transition due to the large offlap/sea level fall event that cuts out part or all of the NP13/14 calcareous nannofossil interval in many sections. Consequently, the Ypresian/Lutetian boundary interval is represented by a hiatus in most sections worldwide (see Anan, 2015b).

The stratigraphic succession exposed in the northern part of Jabal Hafit (UAE) ranges from Early Eocene to Miocene (Figure 3). The basal Middle Eocene succession (Wadi Al Nahayan Member of the Dammam Formation) is represented by a thick sequence of limestone, marl and shale intercalation. The lower Eocene rocks (Ypresian) belong to Hili Member of the Rus Formation (after Hamdan and Bahr, 1992). It is represented by a thick sequence of bedded limestone with flint in the lower part and marl intercalation in the upper part (about 50m), which ends by an intraformational conglomeratic bed (Figure 4).

Figure 4. The late Early Eocene intraformational conglomeratic bed at EME boundary in K4, western limb of J. Hafit, UAE.

On the other hand, Boukhary et al. (2006) noted that the diagnostic conglomeratic bed (around the Ypresian and Lutetian) yields large benthic foraminiferal assemblage as *Assilina spira, Somalina praestefaninii* and *Nummulites perplxus* similar to the basal Lutetian assemblage of Italy and regarded this conglomeratic bed as a new member (Mibazara Member) in the Middle Eocene Wadi Al Nahayan Formation of the Dammam Group (Figure 5). The lower Eocene rocks (Ypresian) belong to Hili Member of the Rus Formation (after Hamdan and Bahr, 1992).

Figure 5. The early Middle Eocene Mibazara Member of the Dammam Formation overly the late Early Eocene Rus Formation, according to Boukhary et al. (2006).

Based on the stratigraphic distribution of the planktic foraminiferal species of the Early/Middle Eocene (EME)(= Ypresian/Lutetian, Y/L) boundary in K4, two biozones are recognized, from base to top (after Anan, 1966, 2015a): the late Early Eocene *Acarinina pentacamerata* Zone (P9 of Blow, 1969 = E7 of Berggren and Pearson, 2006), and early Middle Eocene *Hantkenina nuttalli* Zone (P10=E8), or *Acarinina bullbrooki* Zone, or *Subbotina frontosa* Zone as treated in UAE (Anan, 2015a). The planktic foraminifera zonation around EME boundary is adapted here to accommodate the modern studies of some authors, i. e. Wade et al. (2011) and Karoui-Yaakoub et al. (2015) for the late Ypresian to become: *Acarinina pentacamerata* (E6), *Acarinina cuneicamerata* (E7a) and the lowest part of *Turborotalia frontosa* (E7b) biozones, while the early Lutetian biozones are: the upper part of *Turborotalia frontosa* (E7b) and *Guembelitrioides nuttalli* (E8).

4. Planktic foraminiferal biostratigraphy

Amendment to the planktic foraminiferal assemblages around the EME biozones in the present study are diversified and enable the biozones of *Acarinina cuneicamerata* (E7a) and *Turborotalia frontosa* (E7b):

E7a: *Acarinina cuneicamerata* Lowest-occurrence Subzone (top Early Eocene), which definedasinterval between the LO (lowest occurrence) of the nominate taxon *Acarinina cuneicamerata* and the LO *Guembelitrioides nuttalli*. According to Karoui-Yaakoub et al. (2015) the upper boundary is detected also by the LO of *Turborotalia frontosa* and *Acarinina bullbrooki*.

E7b: *Turborotalia frontosa* Lowest-occurrence Subzone (topmost Early Eocene to lowest Middle Eocene), which defined as the interval between the LO of the nominate taxon *Turborotalia frontosa* and the *LO Guembelitrioides nuttalli*.

5. Taxonomy and systematic description

The taxonomy followed here is that of Pearson et al. (2006). The stratigraphic distribution of the planktic foraminiferal species around the EME of Jabal Hafit is presented in Table 1. Two species of *Morozovella (M. caucasica and M. crater)* are restricted in the top Ypresian and don't cross the EME boundary. The other nine species *(Morozovella aragonensis, Parasubbotina inaequispira, Subbotina linaperta, S. yeguaensis, Acarinina bullbrooki, A. cuneicamerata, A. pentacamerata, A. praetopilensis and Pseudohastigerina micra)* are recorded in the top Ypresian and continue in the base Lutetian. Five species *(Subbotina eocaena, S. hagni, S. patagonica, Acarinina berwaliana and Turborotalia frontosa)* appear only in the base Lutetian (illustrated in Plate 1).

Table 1. The planktic foraminiferal distribution in the Early-Middle Eocene transition of the western limb of J. Hafit, Al Ain area, UAE. The neglected samples (see Figure 2) are related to hard limestone or nummulitic limestone beds (don't yields planktic foraminifer), - = not recorded, x= recorded species. Θ = illustrated species.

no	Early-Middle Eocene Planktic foraminiferal Species		Western Limb of Jabal Hafit														
		Bed no.	1					2					3				
		Sample no.	2	3a	3b	4	5	6	7	8	9a	9b	10	12	14	16	18
1	Parasubbotina	inaequispira	x	x	x	-	-	-	x	-	x	x	-	Θ	x	x	x
2	Subbotina	eocaena	-	-	-	-	-	-	-	-	-	-	-	Θ	x	x	x
3		hagni	-	-	-	-	-	-	-	-	-	-	-	Θ	x	x	x
4		linaperta	x	x	Θ	-	-	-	x	-	x	x	-	x	x	x	x
5		patagonica	-	-	-	-	-	-	-	-	-	-	-	x	Θ	x	x
6		yeguaensis	x	x	x	-	-	-	x	-	-	-	-	x	Θ	x	x
7	Acarinina	berwaliana	-	-	-	-	-	-	-	-	-	-	-	Θ	x	x	x
8		bullbrooki	x	x	x	-	-	-	x	-	x	x	-	Θ	x	x	x
9		cuneicamerata	x	x	x	-	-	-	x	-	x	Θ	-	-	x	x	x
10		pentacamerata	x	x	x	-	-	-	x	-	-	Θ	-	x	x	x	x
11		praetopilensis	x	x	x	-	-	-	x	-	x	Θ	-	-	-	-	-
12	Morozovella	aragonensis	x	x	x	-	-	-	x	-	x	x	-	x	x	Θ	x
13		crater	x	Θ	x	-	-	-	x	-	x	x	-	-	-	-	-
14		caucasica	x	x	x	-	-	-	x	-	Θ	x	-	-	-	-	-
15	Turborotalia	frontosa	-	-	-	-	-	-	-	-	-	-	-	Θ	x	x	x
16	Pseudohastigerina	micra	Θ	x	x	-	-	-	x	-	x	x	-	x	x	x	x

Genus Parasubbotina Olsson et al., 1992

Type species *Globigerina pseudobulloides* Plummer, 1926

***Parasubbotina inaequispira* (Subbotina, 1953)**

Pl. 1, fig. 1

1953 *Globigerina inaequispira* Subbotina, p. 84, pl. 6, fig. 1.

2006b *Parasubbotina inaequispira* (Subbotina) - Olsson et al., p. 101, pl. 5.11, figs. 1-15.

2017 *Parasubbotina inaequispira* (Subbotina) - Seferinov, p. 79, pl. 1, figs. 5-6.

This species has low trochospiral test with 4-4½ globular well separated chambers in the final whorl, umbilical aperture with lip. It is recorded around the EME boundary of J. Hafit, UAE.

Genus *Subbotina* Brotzen and Požaryska, 1961

Type species: *Globigerina triloculinoides* Plummer, 1927

***Subbotina eocaena* (Gümbel, 1868)**

Pl. 1, fig. 2

1868 *Globigerina eocaena* Gümbel, p. 662, pl. 2, fig. 109.

1992 *Subbotina eocaena* (Gümbel) - Cherif et al., p. 46, pl. 1, fig. 36.

1995 *Globigerina eocaena* Gümbel - Anan, p. 8, pl. 1, fig. 10.

2006a *Globigerina eocaena* Gümbel - Olsson et al., p. 134, pl. 6.9, figs. 1-16.

2018 *Subbotina eocaena* (Gümbel) - Wade et al., p. 315, pl. 10. 3, figs. 1-16.

This species was originally described from the MLE rocks in Texas, and later found in some localities of the Tethys (Italy, Egypt, UAE, India, Australia). Berggren, 1965 (after Subbotina, 1960) considered that the Early-Late Eocene S. eocaena has evolved from the Early Eocene *S. pseudoeocaena* (Subbotina). Olsson et al. (2006a) noted that *S. eocaena* is closely related Eocene large-sized subbotinids, which includes *S. hagni* (Gohrbandt, 1967) and S. corpulenta (Subbotina, 1953). It is recorded from the early Middle Eocene (EME) of Jabal Hafit.

***Subbotina hagni* (Gohrbandt, 1967)**

Pl. 1, fig. 3

1967 *Globigerina hagni* Gohrbandt, p. 324, pl. 1, figs 1-3.

2002 *Subbotina hagni* (Gohrbandt) - Hancock et al., p. 40.

2006a *Subbotina hagni* (Gohrbandt) - Olsson et al., p. 142, pl. 6.11, figs. 1-17.

2020 *Subbotina hagni* (Gohrbandt) - Anan, p. 10, pl. 1, fig. 3.

This species was originally described from the Middle Eocene of Austria, and later found in some parts of the Tethys (Austria, Bulgaria, Egypt, UAE, Australia). It is recorded herein from the EME of Jabal Hafit.

***Subbotina linaperta* (Finlay, 1939)**

Pl. 1, fig. 4

1939 *Globigerina linaperta* Finlay, p. 125, pl. 13, figs. 54-57.

1976 *Globigerina* (Eoglobigerina) linaperta Finlay - Hillebrandt, p. 331, pl. 1, figs. 14-15.

1980 *Subbotina linaperta* (Finlay) - Barr and Berggren, p. 185, pl. 2, fig. 19.

2006a *Subbotina linaperta* (Finlay) - Olsson et al., p. 149, pl. 6.14, figs. 1-16.

2020 *Subbotina linaperta* (Finlay) - Anan, p. 10, pl. 1, fig. 5.

This species was originally described from the Paleocene-Middle Eocene rocks in Trinidad, and later in other localities of the Tethys (Spain, Italy, Egypt, UAE, Qatar, India, Indian Ocean, New Zealand). It is considered as a basic stock for all Eocene Globigerinids by some authors (Stainforth et al., 1975; Haggag and Luterbacher, 1991 and Anan, 1995). Olsson et al. (2006a) considered this species belongs to a tightly coiled subbotinids, which includes *S. angiporoides* (Hornibrook, 1965) and *S. patagonica* (Todd and Kniker, 1952), which may be derived from the latter species. It is recorded around the EME rocks of Jabal Hafit.

***Subbotina patagonica* (Todd and Kniker, 1952)**

Pl. 1, fig. 5

1952 *Globigerina patagonica* Todd and Kniker, p. 26, pl. 4, fig. 32.

2006a *Subbotina patagonica* (Todd and Kniker) - Olsson et al., p. 154, pl. 6.15, figs. 1-16.

2019 *Subbotina patagonica* (Todd and Kniker) - Solé et al., p. 1047, figs. 4-5.

This species was originally recorded from the Early Eocene of Chile, and later of London clay and the Indian Ocean as noted by Olsson et al. (2006a). It is characterized by its compact low trochospiral test, the final chamber making up about ½ the test and semicircular aperture. It is recorded here, for the first time, from the EME rocks of Jabal Hafit.

***Subbotina yeguaensis* (Weinzierl and Applin, 1929)**

Pl. 1, fig. 6

1929 *Globigerina yeguaensis* Weinzierl and Applin, p. 409, pl. 43, fig. 1.

2006b *Subbotina yeguaensis* (Weinzierl and Applin) - Olsson et al., p. 162, pl. 6.18, figs. 1-16.

2017 *Subbotina yeguaensis* (Weinzierl and Applin) - Seferinov, p. 90, pl. 3, figs. 6-7.

This species was originally recorded from the Middle Eocene of Yegua Formation, USA. Olsson et al. (2006b) considered the figured form of G. p. pseudoeocaena Subbotina (1953) as a junior synonym of *Subbotina yeguaensis* Krasheninnikov and Hoskins (1973) include two other subspecies *G. pseudoeocaena compacta* and *G. pseudoeocaena trilobata* in the species concept of G. p. pseudoeocaena Subbotina. It is recorded around the EME rocksof J. Hafit.

Genus *Acarinina* Subbotina, 1953

Type species: *Acarinina acarinata* Subbotina, 1953

***Acarinina berwaliana* (Mohan and Soodan, 1969)**

Pl. 1, fig. 7

1969 *Globorotalia berwaliana* Mohan and Soodan, p. 9, text-fig. 1 A-F.

2015a *Acarinina berwaliana* (Mohan and Soodan) - Anan, p. 13, pl. 1, fig. 2.

This species was originally recorded in the early Middle Eocene *Hantkenina aragonensis* Zone (=*H. nuttalli* Zone, P10) in the Kutch, India and continue in the younger zone. Berggren et al. (2006) treated this species as a doubtful species of *Acarinina cuneicamerata* (Blow). It is regarded here as a separate species, and recorded from the EMEof Jabal Hafit.

***Acarinina bullbrooki* (Bolli, 1957)**

Pl. 1, fig. 8

1957 *Globorotalia bullbrooki* (Bolli), p. 167, pl. 38, fig. 5.

1996 *Acarinina bullbrooki* (Bolli) - Anan, p. 158, fig. 6.9.

2006 *Acarinina bullbrooki* (Bolli) - Berggren et al., p. 269, pl. 9.6, figs. 1-16.

2020 *Acarinina bullbrooki* (Bolli) - Alhejoj et al., p. 5, fig. 2.Z.

This species was originally described from the Early-Middle

Eocene (EME) succession of Trinidad, and found later in some localities of the Tethys (Tunisia, Egypt, Jordan, UAE). Berggren et al. (2006, p. 271) treated *Acarinina spinuloinflata* (Bandy) as a junior synonym of *A. bullbrooki*. It is recorded around the EME rocks of Jabal Hafit.

Acarinina cuneicamerata **(Blow, 1979)**

Pl. 1, fig. 9

1979 *Globorotalia (Acarinina) cuneicamerata* Blow, p. 924, pl. 146, figs. 6-8.

2006 *Acarinina cuneicamerata* Blow - Berggren et al., p. 280, pl. 9.9, figs. 1-16.

2019 *Morozovella cuneicamerata* (Bolli) - Solé et al., p. 1047, fig. 4. 4.

This EME species is characterized by its 5-6 subtriangular to wedge-shaped cuneiform chambers in the last whorl than 4-4½-5 subangular chambers in Early Eocene *A. angulosa.* Berggren et al. (2006) noted that *A. cuneicamerata* probably evolved from *A. angulosa*. The illustrated forms of the latter species by Anan (2015a) and Karoui-Yaakoub et al. (2015) are closely related to *A. cuneicamerata*.

Acarinina pentacamerata **(Subbotina, 1947)**

Pl. 1, fig. 10

1947 *Globorotalia pentacamerata* Subbotina, p. 128, pl. 7, figs. 12-17, pl. 9, figs. 24-26.

1953 *Acarinina pentacamerata* (Subbotina) - Subbotina, p. 233, pl. 23, fig. 8, pl. 24, fig. 6.

2015a *Acarinina pentacamerata* (Subbotina) - Anan, p. 14, pl. 1, fig. 5.

This species was originally described from the Middle Eocene in Caucasus, and found later in many localities of the Tethys (UAE, Egypt, Tunisia, Spain, Mexico). A. pentacamerata Zone (P9) represents the top EarlyEocene zone in Jabal Hafit (after Blow, 1969), and represents the pre-top Early Eocene zone (E7) for Berggren et al. (2006). It is recorded in samples around the EME boundary of Jabal Hafit.

Acarinina praetopilensis **(Blow, 1979)**

Pl. 1, fig. 11

1979 *Globorotalia (Truncorotaloides) topilensis praetopilensis* Blow, p. 1043, pl. 155, fig. 9.

2006 *Acarinina praetopilensis* Blow - Berggren and Pearson, p. 300, pl. 9.16, figs. 1-16.

2020 *Acarinina praetopilensis* Blow - Alhejoj et al., p. 5, fig. 2. AC.

This species was recorded in the South Atlantic and Southern Tethys (Egypt, Jordan, UAE) from E7-E12 Zones. The figured specimens from Egypt (Youssef et al., 1983) and UAE of Anan (1996, 2015a) as *Acarinina triplex* is closely related to *A. praetopilensis.* It is recorded around the EME rocks of Jabal Hafit.

Genus Morozovella McGowran, 1968

Type species: *Pulvinulina velascoensis* Cushman, 1925

Morozovella aragonensis **(Nuttall, 1930)**

Pl. 1, fig. 12

1930 *Globorotalia aragonensis* Nuttall, p. 288, pl. 24, figs. 6-11.

1976 *Globorotalia (Morozovella) aragonensis* Nuttall - Hillebrandt, p. 348, pl. 4, figs. 2- 5.

1980 *Morozovella aragonensis* (Nuttall) - Barr and Berggren, p. 185, pl. 2, fig. 6.

2006 *Morozovella aragonensis* (Nuttall) - Berggren and Pearson, p. 349, pl. 11.3, figs. 1-16.

2020 *Morozovella aragonensis* (Nuttall) - Alhejoj et al., p. 5, fig. 2.W.

This species was originally described from the EME rocks in Mexico and found later in some localities of the Tethys (Spain, Tunisia, Egypt, UAE, Australia). Toumarkine and Luterbacher (1985) noted that one branch of *Morozovella subbotinae* lineage develops to a series of species starting with *M. lensiformis*, evolving towards *M. aragonensis*. Berggren and Pearson (2006) regarded that this species evolved from *M. lensiformis* and does not appear to have left any descendants. This species is recorded around the EME boundary of Jabal Hafit.

Morozovella crater **(Hornibrook, 1958)**

Pl. 1, fig. 13

1958 *Globorotalia crater* Hornibrook, p. 33, pl. 1, figs. 3-5.

1996 The transitional form between *M. lensiformis and M. caucasica* - Anan, p. 154, fig. 5.11.

2006 *Morozovella crater* Hornibrook - Berggren and Pearson, p. 358, pl. 11.5, figs. 1-16.

2015a *Morozovella* sp. 2 - Anan, p. 24, pl. 1, fig. 9.

2019 *Morozovella* crater Hornibrook - Sharma et al., p. 2, pl. 1, figs. 4-5.

This species has plano-convex test, 4½-5 chambers in the last whorl, thickened circumumbilical rim of elevated chamber shoulders. It evolved from *M. lensiformis* and evolved into *M. caucasica* as noted earlier by Anan (1996) and later Berggren and Pearson (2006). It is recorded in the top Early Eocene of Jabal Hafit.

Morozovella caucasica **(Glaessner, 1937)**

Pl. 1, fig. 14

1937 *Globorotaliaaragonensis* Nuttall var. caucasica Glaessner, p. 31, pl. 1, fig. 6.

1996 *Morozovella caucasica* Glaessner - Anan, p. 154, fig. 5. 9,10.

2006 *Morozovella caucasica* Glaessner - Berggren and Pearson, p. 354, pl. 11.4, figs. 1-16.

2018 *Morozovella caucasica* Glaessner - Seferinov, p. 41, pl. 2, figs. 11-13.

This species was described originally from the Early Eocene of Caucasus, but around EME boundary in some localities in the Tethys (i. e. Mexico, Spain, Qatar, Australia). Stainforth et al. (1975), Hillebrandt (1976), Haggag and Luterbacher (1991), Anan (1996, 2015a) and Molina et al. (2000) noted that this species restricted only in the Early Eocene, while it was found also in the early Middle Eocene in some localities in the Tethys by some authors, i. e.: Blow (1969), Toumarkine and Luterbacher (1985), Pearson (1993). As noted by Anan (2015b) its absence in many localities in the Tethys (Australia, New Zealand, India, Turkey, Arabia, Egypt, Libya, France, Bulgaria, Spain, USA, Argentina, Chile) most probably due to a lacuna (*pentacamerata* event of Anan, 2015b) around the EME boundary. It is recorded in the top Early Eocene of Jabal Hafit.

Genus *Turborotalia* Cushman and Bermúdez, 1949

Type species: *Globorotalia centralis* Cushman and Bermúdez, 1937

Turborotalia frontosa **(Subbotina, 1953)**

Pl. 1, fig. 15

1953 *Globigerina frontosa Subbotina*, p. 84, pl. 12, fig. 3.

1980 *Subbotina frontosa* (Subbotina) - Barr and Berggren, p. 185, pl. 2, fig. 18, pl. 5, fig. 16.

1985 *Turborotalia cerroazulensis frontosa* (Subbotina) -

Toumarkine and Luterbacher, p. 136, fig. 34. 11.
2005 T*urborotalia frontosa* (Subbotina) - Mukhopadhyay, p. 37, pl. 1, figs. 1-7, pl. 3, fig. 20.
2020 *Turborotalia frontosa* (Subbotina) - Alhejoj et al., p. 5, figs. 2. AF, AG.

This species was originally described from the EME rocks in Caucasus, and later found in some localities of the Tethys (Italy, Libya, Egypt, UAE, India, Australia). Toumarkine and Luterbacher (1985) treated it as the first member of the *Turborotalia cerroazulensis* lineage *(Subbotina frontosa-Turborotalia cerroazulensis cunialensis lineage).* It is recorded here from the EME rocks of Jabal Hafit.

Genus *Pseudohastigerina* Banner and Blow, 1959
Type species: Nonion micrus Cole, 1927
Pseudohastigerina micra **(Cole, 1927)**
Pl. 1, fig. 16

1927 *Nonion micrus* Cole, p. 22, pl. 5, fig. 12.
1953 *Globigerinella micra* (Cole) - Subbotina, p. 122, pl. 13, figs. 16-17.
1956 *Globanomalina ovalis* Haque, p. 147, pl. 14, fig. 3.
1959 *Pseudohastigerina micra* (Cole) - Banner and Blow, p. 19, pl. 3, fig. 6, text-figs. 4 g—i.
2018 *Pseudohastigerina micra* (Cole) - Seferinov, p. 46, pl. 3, figs. 7-8.

This species was originally described from the Early Eocene-Early Oligocene succession in Mexico, and later from some localities of the Tethys (Spain, Bulgaria, Libya, Egypt, UAE, Pakistan, India). Loeblich and Tappan (1988) noted that the illustrated topotype specimens of *Globanomalina ovalis* Haque (1956) as well as the topotype of *Nonion micrus* Cole (1927) show no appreciated differences and are regarded as congeneric. It is recorded around the EME rocks of Jabal Hafit.

6. The Ypresian/Lutetian (Y/L) boundary in the UAE

1. Anan (1996) suggested that the intraformational conglomeratic bed at the top Lower Eocene succession of Jabal Hafit (Fig. 4) is likely an indicator of a hiatus between the Lower Eocene and Middle Eocene succession at Jabal Hafit. This tectonic event which synchronous with the active tectonic and eustatic sea-level changes at the end of the Ypresian (Vail et al., 1977; Haq et al., 1987). This bed was deposited as submarine debris flows in the basin, not as subaerial denudation, which and has a homogenous thickness, about 3 m. Moreover, Anan (1996) studied in detail the foraminiferal assemblage of the Lower Eocene section at K4 which consists of about twenty alternating soft and hard beds of about seventy m thick. The intraformational conglomeratic bed (which consists of angular to subangular limestone detritus of different sizes with fine-grained marl matrix) ends the Lower Eocene rocks in this section (=Mibazara Member of Boukhary et al., 2006), and represents the lithological indicator for the EME lacuna which associated with the major sea-level lowering of Vail et al., 1977 (Figure 6), besides the faunal gap of some diagnostic planktic species, especially the existence of *Morozovella caucasica* only in the Lower Eocene rocks, but its absence in the younger Middle Eocene horizon.

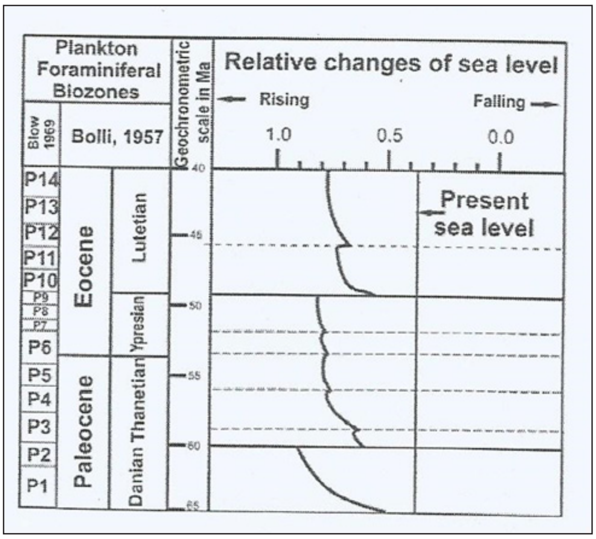

Figure 6. The Ypresian/Lutetian boundary relative to the global sea level fluctuation of Vail et al. (1977).

2. Boukhary et al. (2006) found rich large benthic foraminiferal species in the fine reddish matrix of marly limestone carbonates which cements the conglomerate clastic in the intraformational conglomeratic bed. These taxa are *Assilina spira abrardi, Somalina praestefaninii and Nummulites perplxus,* which are similar to the basal Lutetian assemblage of Italy. Consequently, these authors considered this conglomeratic bed as representing the basal part of the Middle Eocene, and considered it as a basal Lutetian with a new member (the Mibazara Member) in the Dammam Formation. According to these authors, the nannofossil assemblage at the EME boundary coincides with the NP13/NP14 boundary which lies within the top Lower Eocene of Jabal Hafit.

3. Anan (2014, 2015a,b) noted that the core of Jabal Hafit in Al Ain area (UAE) contains late Ypresian sediments (about 55 m) ends by an intraformational conglomeratic bed (about 3 m). The upper Early Eocene succession is separated from the early Middle Eocene by erosional wadi (about 5 m), which stratigraphically is located above the upper Early Eocene intraformational conglomeratic bed. This conglomeratic bed was most probably controlled by active tectonic and eustatic sea-level changes, at the end of the Ypresian. It represents a major, but short-lived regression in Jabal Hafit, and the lacuna at the EME boundary is associated with the major sea-level lowering (Vail et al., 1977 and Haq et al., 1987), just before the end of the Early Eocene, at 49 Ma. Moreover, the '*pentacamerata* event' of Anan (2015b) most probably synchronous with the early/middle Eocene spreading system of the Indian Ocean, and coincident with the reactivation movement of the Syrian Arc folding.

7. The Ypresian/Lutetian (Y/L) boundary in the Tethys

Vrielynck et al. (1995) noted that for 260 Ma, the Tethys Ocean covered much of the face of the earth, from the Caribbean domain to the west to the Indonesian domain to the east. From the Late Cretaceous to the present, the Tethys has been closing, with sediments in the Caribbean, Alpine-Himalayan, and Indonesian belts. Before that, Tethys had spread and cut Pangaea as early as the Permian. Remnants of this ocean are found only in the Central Atlantic and the Mediterranean Sea.

1. Mohan and Soodan (1970) noted that the Middle Eocene (Lutetian) sediments disconformably overlie the Early Eocene (Ypresian) sediments in western Kutch, India.
2. Malumián and Caramés (1997) presented a correlation chart that shows an irregular stratigraphic lacuna around the EME boundary, and also at the Cretaceous/Paleogene and Paleocene/Eocene boundaries at Argentina and Chile
3. Moore et al. (1978) noted that a lacuna occurs near the base of the Middle Eocene (48-50 Ma) and it is seen only as a shoulder in the hiatus abundance curves of the World Ocean.
4. Haq and Aubry (1980) noted that North Africa and Middle East formed important parts of the Tethyan link between the Atlantic and the Pacific Oceans during the early Cenozoic.
5. Al-Hashimi (1980) noted that the lower-middle Eocene contact in Wadi Hauran (west of Iraq) is marked by a one-meter thick bed of conglomerate (it consists of nodular phosphate, glauconite and fish teeth), and this deposition indicates a break in sedimentation before the Middle Eocene transgression. He also added that similar lower-middle Eocene unconformity of the Dammam Formation is encountered throughout south and southwestern Iraq.
6. Berggren and Miller (1988) noted that the global sea level lowering (and associated hiatus/unconformity) characteristics of the EME interval, may place in apparent juxtaposition or overlap, biostratigraphic events which are normally separated in space and time.
7. Haggag (1992) detected an unconformity in Wadi Ed Dakhl (Eastern Desert of Egypt) which represents a gap across the EME boundary.
8. Janin et al. (1993) evidenced a well-known hiatus between the Cuisian (Early Eocene) and Lutetian (Middle Eocene) in the French type localities.
9. Browning et al. (1996) suggested that the major unconformity at the EME boundary (in New Jersey coastal plain, USA) is associated with major facies changes and sea-level lowering at the top of C22n (49 Ma, at P9/P10 boundary, within NP14a).
10. Molina et al. (2000) noted that the base of *Hantkenina nuttalli* Zone (P 10), at an exposed section near Agost (Southern Spain), which is often used to set the boundary between the Lower and the Middle Eocene (Y/L) falls facies changes from a limestone bank to marls just below the first occurrence of *H. nuttalli* implies a short hiatus at the lithological boundary.
11. Orue-Etxebarria et al. (2006) presented a comparison of all traditionally events used to place the EME boundary (by planktic foraminifera, calcareous nannofossil, large benthic foraminifera) which have been identified in the Gorrondatxe section (northern Spain) give evidence that all these events (previously considered as simultaneous) occur at very different levels. Accordingly, the stratigraphical position of the Ypresian-Lutetian (Y/L) boundary is still a matter of controversy between the calcareous nannoplankton, planktic foraminiferal and large benthic foraminifera faunal biostratigraphic schemes (Figure 7).

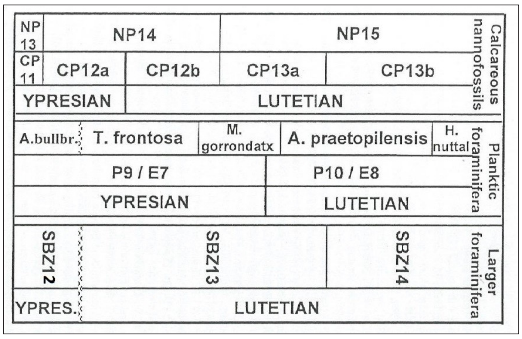

Figure 7. The position of the boundary between the Ypresian and Lutetian based on different biostratigraphic zones of calcareous nannoplankton, planktic foraminifera and larger foraminifera in Gorrondatxe beach section, Basque Country, W. Pyrenees, northern Spain (after Orue-Etxebarria et al., 2006).

12. Ortiz et al. (2008) noted that the Ypresian–Lutetian (Y–L; early-middle Eocene) transition at the continuous Agost section, southeastern Spain (115-m-thick) shows such markers and characterize palaeoenvironmental turnovers, which consists of hemipelagic marls intercalated with hemipelagic limestones and turbidity sandstones, spans from planktic foraminiferal Zones P9 to P12 (E7 to E10) and found that the most abundant planktic species belong to the genera *Acarinina, Morozovella, Subbotina,* and *Pseudohastigerina*. They also distinguished several mineralogical boundaries at the Agost section, each associated with lithological facies changes suggesting a change in provenance rather than changes in weathering conditions. Benthic foraminiferal and trace fossil assemblages also suggest an associated relative fall of sea level from upper-middle bathyal to sublittoral depths.
13. Payros et al. (2009) noted that the Global Stratotype Section and Point of the Lutetian Stage, which is still pending definition, should be placed at a globally correlatable event included within that unrepresented interval. This common evolution can be readily interpreted in terms of a sea-level driven depositional sequence whose low stand and transgressive systems tracts are included within the Ypresian/Lutetian boundary interval.
14. Molina et al. (2011) noted that the Ypresian/Lutetian boundary stratotype has to be defined at a level equivalent with the base of the Lutetian, which is the lowermost standard stage of the middle Eocene. The boundary stratotype must be defined by a lithostratigraphic level coinciding with an easily correlatable event that allows correlation, in a suitable marine continuous section, preferably out of the Paris basin where the Lutetian stage was defined since the Lutetian in the Paris basin is a sedimentary sequence between two hiatuses. Consequently, the GSSP has to be located in a deep-water section with minimal evidence of disturbance, transport and erosion. The LO of *Hantkenina nuttalli*, frequently used by planktic foraminiferal specialists to mark this boundary is younger than the base of the Lutetian in the Paris Basin, according to the new data from the Agost section.

15. Wade et al. (2011) noted that the early-middle Eocene First Appearance Datum of Turborotalia frontosa has resulted in large changes in the duration of Biochrons E7a,b.
16. Karoui-Yaakoub et al. (2015) noted that the Y/L transition at Sejnen section of Tunisia allowed tracing a precise correlation with the Global Stratotype Section and Point (GSSP) for the Y/L boundary recently defined at Gorrondtxe of Spain. The planktic foraminifera assemblages are diversified and enable the biozones of *Acarinina pentacamerata* (E6), *Acarinina cuneicamerata* (E7a), *Turborotalia frontosa* (E7b), and *Guembelitrioides nuttalli* (E8) to be identified.
17. Anan (2015b) noted that the fossil assemblage around the EME boundary (equivalent to Y/L boundary) provides a good database for biostratigraphic subdivisions, and the time-interval corresponding to the late Early Eocene planktic foraminiferal *Acarinina pentacamerata* Zone (P9) and early Middle Eocene *Hantkenina nuttalli* Zone (or *Acarinina bullbrooki* Zone, P10) around the boundary and this interval is called ‘pentacamerata event’. This event is marked by important changes of the depositional setting and stratigraphic lacuna mainly due to tectonic activity in combination with lowering sea-level in many localities in the Tethys, i.e., New Zealand, Australia, India, Pakistan, Iraq, Qatar, UAE, Saidi Arabia, Kuwait, Jordan, Palestine, Egypt, Libya, Turkey, Ireland, Spain, France, USA, Argentina and Chile.
18. Alqudah et al. (2019) noted that the Y/L boundary could be correlated with angular unconformity at Bekaa Valley, Lebanon.
19. Alhejoj et al. (2020) noted that the Y/L boundary at Jabal Ghuzayma in central Jordan is placed near the base of the planktic foraminiferal E7b Subzone (lower occurrence of the Turborotalia frontosa) at the transition from the massive argillaceous limestone and the overlaying bedded limestone with flint bands.

8. Paleoenvironment

In the study section, the planktic foraminiferal species are numerous in the gypsiferous shale and marl samples around the EME boundary which represent the middle-upper neritic environment. The nummulitic and alveolinid limestone samples represent a shallow inner neritic environment. The intraformational beds of the top Early Eocene horizon and limestone samples around the EME boundary are barren. Anan (1996) suggested that the intraformational conglomeratic bed around EME boundary in Jabal Hafit (Figure 4) was deposited as submarine debris flows in the basin with a short distance of transportation on a slightly deepening pale slope from the positive localized source area, not as subaerial denudation, which consists of angular to subangular limestone detritus of different sizes with fine-grained marl matrix and has a homogenous thickness, about 3 m. Strougo and Haggag (1983) noted that the occurrence of deposits of an intraformational conglomeratic bed suggests a minimal reworking and accumulation in a low-energy environment with a short distance of transportation on a slightly deepening pale slope from the positive localized source area during the time of active tectonics. Browning et al. (1996) suggested that the EME boundary in the New Jersey coastal plain (USA) is associated with major facies changes and sea-level lowering at the top of the P9/P10 boundary (49 Ma). Molina et al. (2000) noted that the boundary between theY/L falls a facies changes from a limestone bank to marls just below the first occurrence of H. nuttalli implies a short hiatus at the lithological boundary. Jauhri and Agarwal (2001) noted that the Early Paleogene succession of the sedimentary facies in the south Shillong Plateau in NE India seems to be the result of sea-level and climate changes controlled by major tectonic reshuffling. Ortiz et al. (2008) noted that the Y–L(early-middle Eocene) transition at the continuous Agost section, southeastern Spain (115-m-thick) shows such markers and characterize palaeoenvironmental turnovers, which consists of hemipelagic marls intercalated with hemipelagic limestones and turbidity sandstones. Payros et al. (2009) noted that the Early/Middle Eocene (=Ypresian/Lutetian) transition is represented by a hiatus in many North European sections, including those in which the classic stratotypes were originally defined. Anan (2015b) noted that the fossil assemblage around the EME boundary in UAE is marked by important changes of the depositional setting and stratigraphic lacuna mainly due to tectonic activity in combination with lowering sea-level in many other localities in the Tethys. Khawaj et al. (2018) noted that the Eocene is an important Epoch for carbonate depositions, and it was the time of marine transgression.

9. Conclusions

The analysis of the EME planktic foraminiferal species in the western limb of Jabal Hafit, Al Ain area, United Arab Emirates (UAE)led to the following conclusions:

1. The paleontology, biostratigraphy and paleoenvironmental remarks are presented to sixteen planktic foraminiferal species from six genera have been recorded and illustrated.
2. Two modern planktic foraminiferal biozones are amended using the modified ranges of *Acarinina cuneicamerata* and *Turborotalia frontosa* index species throughout E7a,b biozone, and revised calibration datum of the EME bioevent in this study.
3. The lower Eocene rocks (Ypresian) belong to Hili Member of the Rus Formation and represented by a thick sequence of bedded limestone with flint in the lower part and marl intercalation in the upper part (about 50m), which ends by an intraformational conglomeratic bed, which was deposited as submarine debris flows in the basin, not as subaerial denudation, during the time of active tectonics and synchronous with the eustatic sea-level changes at the end of the Ypresian.
4. The basal Middle Eocene succession (Wadi Al Nahayan Member of the Dammam Formation) is represented by a thick sequence of limestone, marl and shale intercalation.
5. The planktic foraminiferal analysis around the EME boundary is unconformable, which emphasized by the existence of an intraformational conglomeratic bed at the end of the Ypresian.
6. The lacuna around EME boundary has been reported from different parts of the world, which named as global “ *pentacamerata* event” by Anan (2015b).

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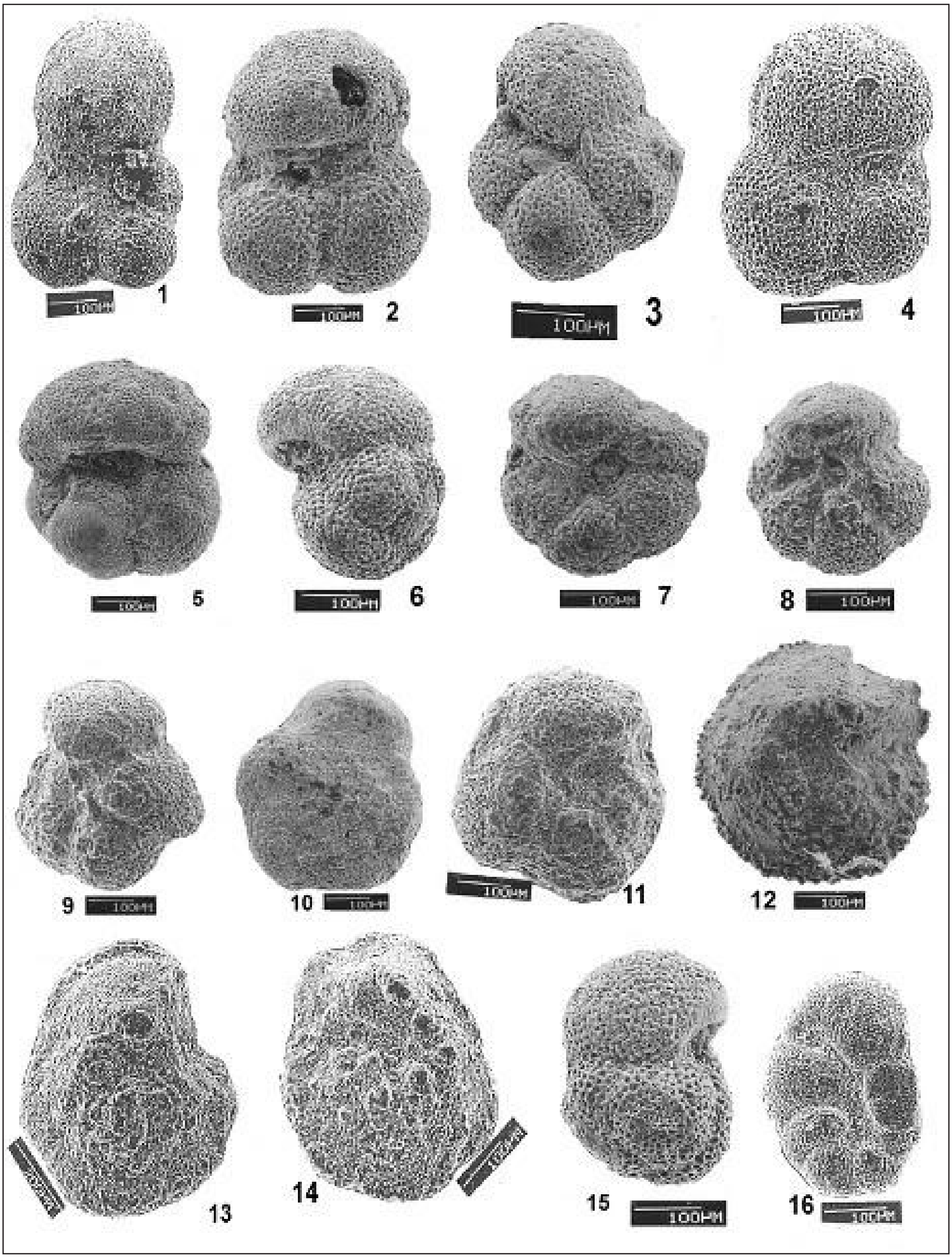

Plate 1.

1. Parasubbotina inaequispira (Subbotina, 1953), sample 12.
2. Subbotina eocaena (Gümbel, 1868), sample 12.
3. S. hagni (Gohrbandt, 1967), sample 12.
4. S. linaperta (Finlay, 1939), sample 3.
5. S. patagonica (Todd and Kniker, 1952), sample 16.
6. S. yeguaensis (Weinzierl and Applin, 1929), sample 14.
7. Acarinina berwaliana (Mohan and Soodan, 1969), sample 12.
8. A. bullbrooki (Bolli, 1957), sample 12
9. A. cuneicamerata (Blow, 1979), sample 9a.
10. A. pentacamerata (Subbotina, 1947), sample 9b.
11. A.praetopilensis (Blow, 1979), sample 9b.
12. Morozovella aragonensis (Nuttall, 1930), sample 16.
13. M. crater (Hornibrook, 1958), sample 3.
14. M. caucasica (Glaessner, 1937), sample 9a.
15. Turborotalia frontosa (Subbotina, 1953), sample 12,
16. Pseudohastigerina micra (Cole, 1927), sample 2.