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Planktic foraminifera around the Early/Middle Eocene boundary in the United Arab Emirates and other Tethyan localities

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Abstract

Thirty diagnostic planktic foraminiferal species are identified around the Early/Middle Eocene boundary (EME) in Jabal Hafit, Al Ain area, United Arab Emirates (UAE). Six Early Eocene and nine Middle Eocene species are illustrated in this paper. The identified species provide a good database for identification of the faunal changes around the EME in J. Hafit, UAE, Arabia and to construct the planktic foraminiferal biostratigraphic zonation. The EME boundary in J. Hafit, UAE and in other Tethyan localities is also discussed.

Keywords

Eocene, stratigraphy, planktic foraminifera, lacuna, United Arab Emirates, Arabia, Tethys.

1. INTRODUCTION

This study is one of a series studying planktic and benthic foraminiferal assemblages of the Paleogene succession of some outcrops in Al Ain area, UAE. Jabal Hafit comprise a part of this succession (Fig. 1). Twenty one late Early Eocene planktic foraminiferal species were illustrated by Anan, 1996. In this study, another six illustrated Early Eocene species and nine early Middle Eocene planktic foraminiferal species are added. The early Middle Eocene succession is located about 5 m above the upper Early Eocene intraformational conglomeratic bed (bed no. 10, Figs. 2, 3). The previous studies of Anan *et al.*, 1992; Anan, 1996 and Boukhary *et al.*, 2006 on the foraminiferal content around EME boundary in J. Hafit are pertinent to the present study. The paleontology, stratigraphy, paleogeography and the lacuna around the EME boundary and its influence on the distribution of the identified species are presented and discussed.

2. STRATIGRAPHY

Based on the stratigraphic distribution of the planktic foraminiferal species, two zones (after Blow, 1969) from the late Early Eocene (P9) and early Middle Eocene (P10) are recognized around the EME boundary in kilometer 4 (K4, along the asphalted road climbing to the top of the Jabal) in the western limb of J. Hafit anticline (Figs. 2, 3). These two zones are, from top to base: *Hantkenina nuttalli* Zone (or *Acarinina bullbrooki* Zone, P10), the *Acarinina pentacamerata* Zone (P9), and an Intraformational conglomeratic bed is located between them. According to the stratigraphic ranges of the relevant index fossils *Morozovella caucasica* and *H. nuttalli,* the EME boundary in the studied section (Fig. 2), can be treated as follows (Table 1):

1. The diagnostic planktic foraminiferal species *M. caucasica* (Plate I, fig. 7) has been recorded around the EME boundary (P9 and P10) in some regional studies (Blow, 1969; Toumarkine & Luterbacher, 1985 and Pearson, 1993), while it has been found only in the late Early Eocene horizon (P9) by other authors (Stainforth *et al.,* 1975; Anan, 1996; Molina *et al.,* 2000 and this study).
2. The base of the Middle Eocene is usually placed at the first appearance of the Middle Eocene marker species *H. nuttalli* (P10), but this species, unfortunately, has not been found in P10 of J. Hafit as noted by Anan *et al.*, 1992 and Anan, 1996 as well as in the earliest Middle Eocene of some studied sections in Egypt (i.e.: Haggag & Luterbacher, 1991; Haggag, 1992 and Marzouk & Soliman, 2004). This species appears only in younger level in some regional studies worldwide (i.e.: Blow, 1969; Toumarkine & Luterbacher, 1985 and Pearson, 1993). These authors also noted that the absence of *H. nuttalli* in the earliest Middle Eocene horizon prevents the direct recognition of the Middle Eocene (*H. nuttalli* Zone, P10). This stratigraphic situation is most probably due to a local lacuna or a regional diastem. On the other hand, the corresponding interval (P10, instead

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of *H. nuttalli* Zone) was recognized and named as *Turborotalia cerroazulensis frontosa* (= *Subbotina frontosa*) Zone by Toumarkine & Bolli, 1970 in Italy or as *Acarinina bullbrooki* Zone (related to the characteristic species *A. bullbrooki*), which is the oldest biozone of the Middle Eocene in Egypt (Haggag & Luterbacher,1991) as well as in the UAE (Anan *et al.,*1992; Anan, 1996) and in this study.

3. TAXONOMY AND STRATIGRAPHY

In this study, thirty planktic foraminiferal species are recorded in the Early/Middle Eocene succession (below and above the late Early Eocene intraformational conglomeratic bed no. 10, Figs. 2 and 3). Among them, 15 species are illustrated (Plate I). The distribution of the planktic foraminiferal around the Early/Middle Eocene (EME) boundary of the Jabal Hafit section in Al Ain area, UAE is presented in Table 2. The taxonomy of Loeblich & Tappan, 1988 is followed in this study.

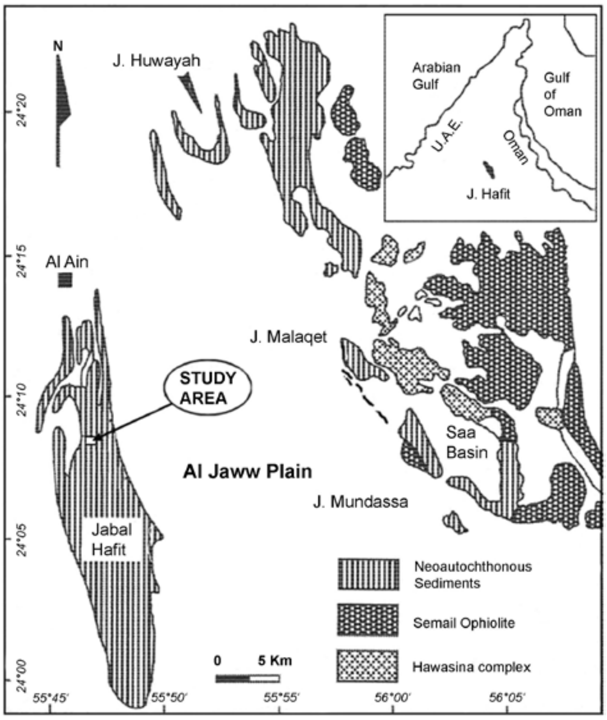


Fig. 1: Location map of the study area at kilometer 4 (K4) in the western limb of J. Hafit anticline (UAE) along the asphalted road climbing to the top of the Jabal.

Fig. 3: View of the late Early Eocene intraformational conglomeratic bed (no. 10, *) at EME boundary in K4, western limb of J. Hafit (about 3 m thick). This bed is composed of highly compacted and oriented limestone, pebbles and cobbles conglomerate clasts in different sizes which are highly cemented by a fine reddish matrix of marly nummulitic carbonates (after Anan, 1996 and Boukhary *et al*., 2006).

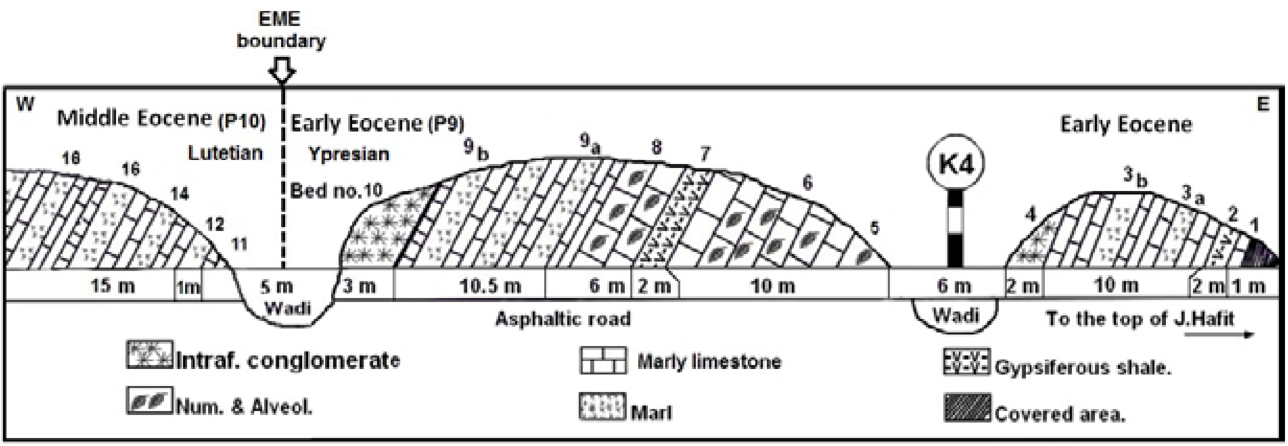
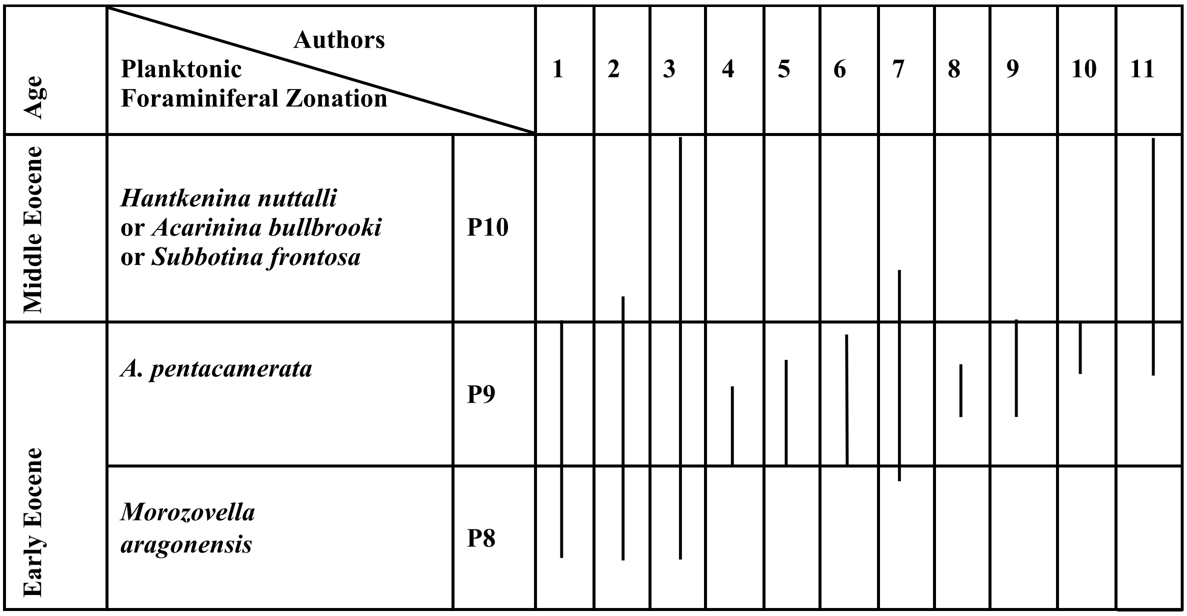


Fig. 2: Schematic section of the EME succession at K4 of J. Hafit.

Table 1: Stratigraphic ranges of *Morozovella caucasica* (Glaessner) as recorded by some authors: 1. Stainforth *et al*., 1975; 2. Toumarkine & Luterbacher, 1985; 3. Krasheninnikov & Pflaumann, 1977; 4. Hillebrandt, 1976; 5. Benjamini, 1980; 6. Toumarkine, 1978; 7. Blow, 1969; 8. Molina *et al.,* 2000; 9. Anan *et al.*, 1992; Anan, 1996 and this study; 10. Haggag & Luterbacher, 1991; 11. Pearson, 1993. *M. caucasica* ranges from the uppermost Early Eocene (*A. pentacamerata* - P9) through early Middle Eocene (P10) in the some regional studies (Authors: 2, 3, 7, 11), while this species by other authors (1, 4, 5, 6, 8, 9, 10 and this study) has been reported up to the top Early Eocene, but not in the Middle Eocene. Its absence in the Middle Eocene most probably is indicated to a diastem around EME boundary of J. Hafit.



Order Foraminiferida Eichwald, 1830
Suborder Globigerinina Delage & Hérouard, 1896
Superfamily Globorotaliacea Cushman, 1927
Family Truncorotaloididae Loeblich & Tappan, 1961
Genus *Acarinina* Subbotina, 1953
Type species: *Acarinina acarinata* Subbotina, 1953

***Acarinina angulosa* (Bolli, 1957)**
Pl. I, fig. 1

1957. *Globigerina soldadoensis angulosa* Bolli, p. 71, pl. 16, figs. 4-6.
1976. *Acarinina soldadoensis angulosa* (Bolli).– Hillebrandt, p. 345, pl. 5, fig. 11.
1996. *Acarinina soldadoensis angulosa* (Bolli).– Anan, p. 158, fig. 6.4.

Acarinina angulosa was originally described from the Early Eocene rocks in Trinidad, and found later in some Tethyan localities (Spain, UAE). It is characterized by its axially elongated chambers, and its test longer than *A. soldadoensis* (Brönnimann) allows distinction between these two resembling species. *A. angulosa* is recorded in Early Eocene rocks (marl, marly limestone and gypsiferous shale beds) of J. Hafit (samples 2, 3a, b, 7, 9a, b – see Table 2).

***Acarinina berwaliana* (Mohan & Soodan, 1969)**
Pl. I, fig. 2

1969. *Globorotalia berwaliana* Mohan & Soodan, p. 9, text-fig. 1 A-F.
1970. *Globorotalia berwaliana* Mohan & Soodan.– Mohan & Soodan, p. 41, pl. 1, fig. 12.

This species was originally recorded in the Middle Eocene *Hantkenina aragonensis* Zone (=*H. nuttalli* Zone) in the Kutch of India and continue in the younger zone. It is recorded here, for the first time in Arabia, from the early Middle Eocene of J. Hafit (sample 12, Table 2).

Acarinina broedermanni
(Cushman & Bermudez, 1949)

1949. *Globorotalia* (*Truncorotalia*) *broedermanni* Cushman & Bermudez, p. 40, pl. 7, figs. 22-24.
1973. *Acarinina broedermanni* (Cushman & Bermudez).– Krasheninnikov & Hoskins, p. 120, pl. 1, figs. 4-6.
1992. *Globorotalia* (*Acarinina*) *broedermanni* Cushman & Bermudez. – Cherif *et al.*, p. 48, pl. 2, fig. 8.
2002. *Igorina broedermanni* (Cushman & Bermudez).– Hancock *et al.,* p. 40.
2004. *Igorina broedermanni* (Cushman & Bermudez).– Pearson *et al.,* p. 37, pl. 2, fig. 2.
2010. *Acarinina broedermanni* (Cushman & Bermudez).– Haggag *et al.,* p. 179, fig. 17. 21.

This species was originally described from the EME succession in Cuba, and found later in some localities in the Tethys (Atlantic Ocean, Trinidad, Tanzania, Egypt, UAE, Australia). It is recorded in the EME succession of J. Hafit.

Acarinina bullbrooki (Bolli, 1957)
Pl. I, fig. 3

1957. *Globorotalia bullbrooki* Bolli, p. 167, pl. 38, fig. 5.
1982. *Globorotalia bullbrooki* Bolli.– Bassiouni *et al.*, p. 46, pl. 2, fig. 10.
1992. *Globorotalia* (*Acarinina*) *bullbrooki* Bolli.– Cherif *et al.,* p. 48, pl. 2, fig. 9.
1996. *Acarinina bullbrooki* (Bolli).– Anan, p. 158, fig. 6.9.
2008. *Acarinina bullbrooki* (Bolli).– Abd El-Aziz, p. 18, pl. 1, fig. 9.

This species was originally described from the EME succession of Trinidad, and found later in some localities of the Tethys (Egypt, UAE). It is recorded in the EME rocks of J. Hafit.

Acarinina interposita Subbotina, 1953
Pl. I, fig. 4

1953. *Acarinina interposita* Subbotina, pl. 23, figs. 6, 7.
1965. *Acarinina interposita* Subbotina.– Berggren, p. 287, text-fig. 6.
1991. *Acarinina interposita* Subbotina.– Haggag & Luterbacher, p. 328, fig. 7.15.
1993. *Acarinina interposita* Subbotina.– Hewaidy & Al-Hitmi, p. 505, pl. 2, figs. 19-21.

This species was originally described from the EME succession in Caucasus, and found later in some localities of the Tethys (Egypt, Qatar). It is recorded here, for the first time, in the early Middle Eocene of J. Hafit (sample 12, Table 2).

Acarinina nitida (Martin, 1943)

1943. *Globigerina nitida* Martin, p. 115, pl. 7, fig. 1.
1985. *Acarinina nitida* (Martin).– Toumarkine & Luterbacher, p. 116, fig. 18.1-2.
1996. *Acarinina nitida* (Martin).– Anan, p. 158, fig. 6. 2.
2010. *Acarinina nitida* (Martin).– Haggag *et al.,* p. 179, fig. 17.14.

This species was originally described from the Early Eocene of USA, and found later in some localities of the Tethys (Egypt, UAE). Some authors: Stainforth *et al.*, 1975; Toumarkine & Luterbacher, 1985; Berggren & Norris, 1997 treated *A. nitida* as a senior synonym of *A. acarinata* Subbotina. It is recorded in the Early Eocene succession of J. Hafit.

Acarinina pentacamerata (Subbotina, 1947)
Pl. I, fig. 5

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.
1996. *Acarinina pentacamerata* (Subbotina).– Anan, p. 158, fig. 6. 7.
2000. *Acarinina pentacamerata* (Subbotina).– Carreño *et al.*, p. 188, pl. 2, fig. 7.
2011. *Acarinina pentacamerata* (Subbotina).– Karoui-Yaakoub *et al.,* p. 110, fig. 5. 8.

This species was originally described from the Middle Eocene in Caucasus, and found later in many localities of the Tethys (UAE, Qatar, Egypt, Tunisia, Spain, Mexico). *A. pentacamerata* Zone (P9) represents the top Early Eocene zone in J. Hafit (after Blow, 1969), but represents the pre-top Early Eocene zone (E6) for Berggren & Pearson, 2005. It is recorded in samples (2, 3a, b, 7, 9a, b, 12, Table 2) around the EME boundary of J. Hafit.

Acarinina pseudotopilensis Subbotina, 1953

1953. *Acarinina pseudotopilensis* Subbotina, p. 227, pl. 21, figs. 8-9, pl. 22, figs. 1-2.
1973. *Acarinina pseudotopilensis* Subbotina.– Krasheninnikov & Hoskins, p. 120, pl. 3, figs. 7-9.
1993. *Acarinina pseudotopilensis* Subbotina.– Hewaidy & Al-Hitmi, p. 505, pl. 3, figs. 7-9.
1996. *Acarinina pseudotopilensis* Subbotina.– Anan, p. 158, fig. 6.6.
2004. *Acarinina pseudotopilensis* Subbotina.– Pearson *et al.,* p. 37, pl. 2, fig. 7.
2010. *Acarinina pseudotopilensis* Subbotina.– Haggag *et al.,* p. 179, fig. 17.25.

This species was originally described from the EME rocks in Caucasus, and found later in some parts of the Tethys (Atlantic Ocean, Tanzania, Egypt, UAE, Qatar). It is recorded in the EME rocks of J. Hafit.

Acarinina quetra (Bolli, 1957)

1957. *Globorotalia quetra* Bolli, p. 79, pl. 19, figs. 1-6.
1993. *Morozovella quetra* (Bolli).– Hewaidy & Al-Hitmi, p. 507, pl. 4, figs. 4-6.
1996. *Globorotalia quetra* Bolli.– Anan, p. 158, fig. 6.8.
2002. *Acarinina quetra* (Bolli).– Hancock *et al.,* p. 40.
2010. *Morozovella quetra* (Bolli).– Haggag *et al.,* p. 181, fig. 18.8.

This species was originally described from the Early Eocene in Trinidad, and found later in some localities of the Tethys (Atlantic Ocean, Egypt, UAE, Qatar, Australia). Toumarkine & Luterbacher, 1985 considered *A. quetra* has been evolved from the Paleocene *A. aequa* (Cushman & Renz). It is recorded in the Early Eocene succession of J. Hafit.

Table 2: The planktic foraminiferal distribution around the Early/Middle Eocene (EME) boundary of the study section in Jabal Hafit, Al Ain area, UAE throughout the succession (bed/sample numbers 1-12), - = barren, x = recorded species, Θ = illustrated species).

Sp.	Planktic foraminiferal species around EME in J. Hafit, UAE 1		Early Eocene bed/samples											M. Eocene	
No.			2	3a	3b	4	5	6	7	8	9a	9b	10	11	12
1	*Acarinina*	*angulosa*	-	x	x	x	-	-	-	x	-	Θ	x	-	-
2		*nitida*	-	x	x	x	-	-	-	x	-	x	x	-	-
3		*quetra*	-	x	x	x	-	-	-	x	-	x	x	-	-
4		*soldadoensis*	-	x	x	x	-	-	-	x	-	x	x	-	-
5		*triplex*	-	x	x	x	-	-	-	x	-	x	Θ	-	-
6	*Morozovella*	*caucasica*	-	x	x	x	-	-	-	x	-	Θ	x	-	-
7		sp. 1	-	x	x	x	-	-	-	x	-	x	Θ	-	-
8		sp. 2	-	x	Θ	x	-	-	-	x	-	x	x	-	-
9	*Subbotina*	*cryptomphala*	-	x	x	x	-	-	-	x	-	x	x	-	-
10		*turgida*	-	x	x	x	-	-	-	x	-	x	x	-	-
11	*Acarinina*	*broedermanni*	-	x	x	x	-	-	-	x	-	x	x	-	x
12		*bullbrooki*	-	x	x	x	-	-	-	x	-	x	x	-	Θ
13		*pentacamerata*	-	x	x	x	-	-	-	x	-	x	Θ	-	x
14		*pseudotopilensis*	-	x	x	x	-	-	-	x	-	x	x	-	x
15		*spinuloinflata*	-	x	x	x	-	-	-	x	-	x	x	-	x
16	*Morozovella*	*aragonensis*	-	x	x	x	-	-	-	x	-	x	x	-	x
17		*lensiformis*	-	x	x	x	-	-	-	x	-	x	x	-	x
18	*Truncorotaloides*	*topilensis*	-	x	x	x	-	-	-	x	-	x	x	-	x
19	*Subbotina*	*compacta*	-	x	x	x	-	-	-	x	-	x	x	-	x
20		*inaequispira*	-	x	x	x	-	-	-	x	-	x	x	-	Θ
21		*linaperta*	-	x	x	x	-	-	-	x	-	x	x	-	x
22		*pseudoeocaena*	-	x	x	x	-	-	-	x	-	x	x	-	x
23	*Globanomalina*	*micra*	-	x	x	x	-	-	-	x	-	x	x	-	x
24	*Acarinina*	*berwaliana*	-	-	-	-	-	-	-	-	-	-	-	-	Θ
25		*interposita*	-	-	-	-	-	-	-	-	-	-	-	-	Θ
26	*Subbotina*	*eocaena*	-	-	-	-	-	-	-	-	-	-	-	-	Θ
27		*eocaenica*	-	-	-	-	-	-	-	-	-	-	-	-	Θ
28		*frontosa*	-	-	-	-	-	-	-	-	-	-	-	-	Θ
29		*hagni*	-	-	-	-	-	-	-	-	-	-	-	-	Θ
30		*trilobata*	-	-	-	-	-	-	-	-	-	-	-	-	Θ

Acarinina soldadoensis (Brönnimann, 1952)

1952. *Globigerina soldadoensis* Brönnimann, p. 7, pl. 1, figs. 1-9.
1980. *Acarinina soldadoensis* (Brönnimann).– Barr & Berggren, p. 185, pl. 2, fig. 4.
1985. *Acarinina soldadoensis soldadoensis* (Brönnimann).– Toumarkine & Luterbacher, p. 115, fig. 17.1-2.
1993. *Muricoglobigerina soldadoensis* (Brönnimann).– Hewaidy & Al-Hitmi, p. 506, pl. 3, figs. 10-12.
2002. *Acarinina soldadoensis* (Brönnimann).– Hancock *et al.,* p. 40, pl. 1, figs. 13-15.
2010. *Acarinina soldadoensis* (Brönnimann).– Haggag *et al.,* p. 179, fig. 17.16-17.

This species was originally described from the Early Eocene rocks in Trinidad, and found later in some localities of the Tethys (Libya, Egypt, UAE, Qatar, Australia). It is recorded in the Early Eocene rocks of J. Hafit (Table 2).

Acarinina spinuloinflata (Bandy, 1949)

1949. *Globigerina spinuloinflata* Bandy, p. 122, pl. 23, fig. 1.

1969. *Globorotalia spinuloinflata* (Bandy).– Samanta, p. 335, pl. 2, fig. 5.
1985. *Acarinina spinuloinflata* (Bandy).– Toumarkine & Luterbacher, p. 130, fig. 29.2-3.
2000. *Acarinina spinuloinflata* (Bandy).– Ben Ismail-Lattrache, p. 10, pl. 3, fig. 7.
2008. *Acarinina spinuloinflata* (Bandy).– Abd El-Aziz, p. 21, pl. 1, fig. 13.

This species was originally described from the EME rocks in USA, and found later in some localities of the Tethys (Trinidad, Tunisia, Egypt, UAE, India). It is recorded in the EME succession of J. Hafit.

Acarinina triplex Subbotina, 1953
Pl. I, fig. 6

1953. *Acarinina triplex* Subbotina, p. 230, pl. 23, figs 1-5.
1973. *Acarinina triplex* Subbotina.– Krasheninnikov & Hoskins, p. 121, pl. 4, figs. 1-3.
1983. *Globorotalia triplex* (Subbotina).– Youssef *et al.,* p. 143, pl. 3, fig. 18.
1996. *Acarinina triplex* Subbotina.– Anan, p. 158, fig. 6.5.

This species was originally described from the Paleocene-Early Eocene rocks in Caucasus, and found later in some localities in the Tethys (Atlantic Ocean, Egypt, UAE). It is recorded in the Early Eocene rocks of J. Hafit.

Genus _Morozovella_ McGowran, 1968
Type species: *Pulvinulina velascoensis* Cushman, 1925

Morozovella aragonensis (Nuttall, 1930)

1930. *Globorotalia aragonensis* Nuttall, p. 288, pl. 24, figs. 6-11.
1976. *Globorotalia* (*Morozovella*) *aragonensis* Nuttall.– Hillebrandt, p. 348, pl. 4, figs. 2, 3, 5.
1980. *Morozovella aragonensis* (Nuttall).– Barr & Berggren, p. 185, pl. 2, fig. 6.
1985. *Morozovella aragonensis* (Nuttall).– Toumarkine & Luterbacher, p. 112, fig. 16. 4-6.
2002. *Morozovella aragonensis* (Nuttall).– Hancock *et al.,* p. 40, pl. 2, figs. 5-7.
2004. *Morozovella aragonensis* (Nuttall).– Pearson *et al.,* p. 37, pl. 2, fig. 12.
2011. *Morozovella aragonensis* (Nuttall).– Karoui-Yaakoub *et al.,* p. 109, fig. 4.11, 12.

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 & Luterbacher, 1985 noted that the Early Eocene *Morozovella subbotinae* comprises several lineage branches that can be traced into the Middle-Late Paleocene to ancestral forms which are probably close to *M. aequa.* One branch of *M. subbotinae* lineage develops to a series of species starting with *M. lensiformis*, evolving towards *M. aragonensis*, and the end-forms *M. caucasica* and *M. aragonensis* are recorded in the EME succession of J. Hafit.

Morozovella caucasica (Glaessner, 1937)
Pl. I, fig. 7

1937. *Globorotalia aragonensis* Nuttall var. *caucasica* Glaessner, p. 31, pl. 1, fig. 6.
1976. *Globorotalia* (*Morozovella*) *caucasica* (Glaessner).– Hillebrandt, p. 348, pl. 4, figs. 2, 3, 5.
1985. *Morozovella caucasica* (Glaessner).– Toumarkine & Luterbacher, p. 114, fig. 16.2-3.
1996. *Morozovella caucasica* (Glaessner).– Anan, p. 158, fig. 5.9, 10.
2000. *Morozovella caucasica* (Glaessner).– Carreño *et al.*, p. 188, pl. 2, figs. 5, 6.

This species was described from the Early Eocene rocks in Caucasus, and later found from the EME rocks in some localities of the Tethys (Mexico, Spain, UAE, Qatar, Australia). Stainforth *et al.,* 1975 noted that this species exists only in the Early Eocene *M. aragonensis* Zone (P8) and *A. pentacamerata* (P9) Zone. No record is confirmed in the Middle Eocene (as in J. Hafit), while it is found also in the base of the Middle Eocene by other authors (Table 1). It is recorded only in the Early Eocene succession of J. Hafit.

Morozovella lensiformis (Subbotina, 1953)

1953. *Globorotalia lensiformis* Subbotina, p. 214, pl. 18, figs. 4-5.
1985. *Morozovella lensiformis* (Subbotina).– Toumarkine & Luterbacher, p. 112, fig. 16.1.
1992. *Morozovella lensiformis* (Subbotina).– Anan *et al.,* p. 228, fig. 8.11.
2002. *Morozovella lensiformis* (Subbotina).– Hancock *et al.,* p. 40, pl. 2, figs. 2-4.
2010. *Morozovella lensiformis* (Subbotina).– Haggag *et al.,* p. 181, fig. 18.24.

This species was originally described from the EME rocks in Caucasus, and later found in some localities of the Tethys (Atlantic Ocean, Egypt, UAE, Australia). It is recorded in the EME rocks of J. Hafit.

Morozovella sp. 1
Pl. I, fig. 8

1996. Transitional form between *M. aragonensis* and *M. caucasica.*– Anan, p. 154, fig. 6.1.
2010. *Morozovella* aff. *aragonensis* (Nuttall).– Haggag *et al.,* p. 181, fig. 18.25-26.

The Early Eocene *Morozovella* sp. 1 is treated here as a separate species. It is located between *Morozovella lensiformis* and *M. aragonensis* in the *M. subbotinae – M. lensiformis – M. aragonensis – M. caucasica* lineage (for Toumarkine & Luterbacher, 1985). Anan, 1996 treated this Early Eocene form J. Hafit (sample 9b, see Fig. 2 and Pl. I) as a transitional form between *M. aragonensis* and *M. caucasica*. It seems that the Early Eocene illustrated form *Morozovella* aff. *aragonensis* of Haggag *et al.* (2010, fig. 18. 25, 26) from the Farafra Oasis (Egypt) should be regarded as the species concept of *Morozovella* sp. 1. It is recorded only in the Early Eocene succession of J. Hafit.

Morozovella sp. 2
Pl. I, fig. 9

1996. Transitional form between *M. lensiformis* and *M. caucasica*.– Anan, p. 154, fig.5.11.

The Early Eocene *Morozovella* sp. 2 is treated here as a separate species. It is located between *Morozovella aragonensis* and *M. caucasica* in the *M. subbotinae* – *M. lensiformis* – *M. aragonensis* – *M. caucasica* lineage (of Toumarkine & Luterbacher, 1985). It is not a transitional form between *M. lensiformis* and *M. caucasica* as noted by Anan, 1996. It is recorded only in the Early Eocene rocks of J. Hafit.

Genus _Truncorotaloides_ Blow, 1979
Type species: *Truncorotaloides rohri* Brönnimann & Bermùdez, 1953

Truncorotaloides topilensis (Cushman, 1925)

1925. *Globigerina topilensis* Cushman, p. 7, pl. 1, fig. 9.
1969. *Truncorotaloides topilensis* (Cushman).– Samanta, p. 336, pl. 2, fig. 8.
1996. *Truncorotaloides topilensis* (Cushman).– Anan, p. 158, fig. 6.12.
2000. *Truncorotaloides topilensis* (Cushman).– Ben Ismail-Lattrache, p. 10, pl. 3, fig. 4.
2008. *Truncorotaloides topilensis* (Cushman).– Abd El-Aziz, p. 22, pl. 1, fig. 18.

This species was originally described from the EME rocks in Mexico, and later found in some localities of the Tethys (Atlantic Ocean, Tunisia, Egypt, UAE, India). It is recorded in the EME succession of J. Hafit (Table 2).

Superfamily Globigerinacea Carpenter, Parker & Jones, 1862
Family Catapsydracidae Bolli, Loeblich & Tappan, 1957
Genus _Subbotina_ Brotzen & Požaryska, 1961
Type species: *Globigerina triloculinoides* Plummer, 1927

Subbotina compacta (Subbotina, 1953)

1953. *Globigerina pseudoeocaena* Subbotina var. *compacta* Subbotina, p. 82, pl. 5, figs. 3, 4.
1983. *Globigerina pseudoeocaena compacta* Subbotina.– Youssef *et al.*, p. 273, pl. 4, fig. 27.
1996. *Globigerina pseudoeocaena compacta* Subbotina.– Anan, p. 157, fig. 5.6.

This species was originally described from Middle-Late Eocene (MLE) rocks in Caucasus, and later found in some localities of the Tethys (Egypt, UAE). It is recorded in the EME rocks of J. Hafit.

Subbotina cryptomphala (Glaessner, 1937)

1937. *Globigerina bulloides* d'Orbigny var. *cryptomphala* Glaessner, p. 29, pl. 1, fig. 1.
1975. *Globigerina cryptomphala* Glaessner.– Toumarkine & Bolli, p. 76, pl. 4, figs. 9-11.
1996. *Globigerina cryptomphala* Glaessner.– Anan, p. 157, fig. 5.9.
2002. *Subbotina cryptomphala* (Glaessner).– Hancock *et al.,* p. 40.

This species was originally found in the Early Eocene rocks in Caucasus, and later found in some localities of the Tethys (Italy, UAE, Australia). It is recorded only in the Early Eocene rocks of J. Hafit.

Subbotina eocaena (Gümbel, 1868)
Pl. I, fig. 10

1868. *Globigerina eocaena* Gümbel, p. 662, pl. 2, fig. 109.
1969. *Globigerina eocaena* Gümbel.– Samanta, p. 330, text-fig. 1.
1975. *Globigerina eocaena* Gümbel.– Toumarkine & Bolli, p. 76, pl. 4, figs. 1-2.
1993. *Subbotina eocaena* (Gümbel).– Pearson, p. 222, text-fig. 25e.
1995. *Globigerina eocaena* Gümbel.– Anan, p. 8, pl. 1, fig. 10.
2008. *Subbotina eocaena* (Gümbel).– Abd El-Aziz, p. 24, pl. 2, fig. 3.

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 *S. eocaena* has evolved from the Early Eocene *S. pseudoeocaena* (Subbotina). It is recorded from the early Middle Eocene rocks of J. Hafit (sample 12, Table 2).

Subbotina eocaenica (Terquem, 1882)
Pl. I, fig. 11

1882. *Globigerina eocaenica* Terquem var. *eocaenica* Terquem, p. 86, pl. 9, fig. 4.
1965. *Globigerina eocaenica* Terquem.– Berggren, p. 284, text-figure 4.
1983. *Globigerina eocaenica eocaenica* Terquem.– Youssef *et al.*, p. 271, pl. 4, fig. 10.

This species was described from the Paleocene-Early Eocene of Caucasus, and found later in the EME rocks in some localities of the Tethys (Egypt, UAE). Berggren, 1965 (after Subbotina, 1960) consider that *S. eocaenica* has evolved into the Early Eocene *S. pseudoeocaena* (Subbotina). It is recorded here, for the first time, from the early Middle Eocene rocks of J. Hafit.

Subbotina frontosa (Subbotina, 1953)
Pl. I, fig. 12

1953. *Globigerina frontosa* Subbotina, p. 84, pl. 12, fig. 3.
1975. *Globorotalia cerroazulensis frontosa* (Subbotina).– Toumarkine & Bolli, p. 80, pl. 2, figs. 1-3.
1980. *Subbotina frontosa* (Subbotina).– Barr & Berggren, p. 185, pl. 2, fig. 18, pl. 5, fig. 16.
1985. *Turborotalia cerroazulensis frontosa* (Subbotina).– Toumarkine & Luterbacher, p. 136, fig. 34. 11.
1993. *Subbotina frontosa* (Subbotina).– Pearson, p. 222, text-fig. 25e.
2002. *Subbotina frontosa* (Subbotina).– Hancock *et al.,* p. 40.
2005. *Turborotalia frontosa* (Subbotina).– Mukhopadhyay, p. 37, pl. 1, figs. 1-7, pl. 3, fig. 20.

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 & 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 early Middle Eocene rocks of J. Hafit.

Subbotina hagni (Gohrbandt, 1967)
Pl. I, fig. 13

1967. *Globigerina hagni* Gohrbandt, p. 324, pl. 1, figs 1-3.
2002. *Subbotina hagni* (Gohrbandt).– Hancock *et al.,* p. 40.
2002. *Subbotina hagni* (Gohrbandt).– Abdelghany, p. 216, pl. 1, fig. 9.
2008. *Subbotina hagni* (Gohrbandt).– Abd El-Aziz, p. 25, pl. 2, fig. 4.

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

Subbotina inaequispira (Subbotina, 1953)
Pl. I, fig. 14

1953. *Globigerina inaequispira* Subbotina, p. 69, pl. 6, figs. 1-4.
1976. *Globigerina* (*Eoglobigerina*) *inaequispira* Subbotina.– Hillebrandt, p. 331, pl. 1, figs. 1-6, 8, 11, 13.
1980. *Subbotina inaequispira* (Subbotina).– Barr & Berggren, p. 191, pl. 5, figs. 13-15.
1993. *Subbotina inaequispira* (Subbotina).– Pearson, p. 222, text-fig. 25e.
1996. *Globigerina inaequispira* Subbotina.– Anan, p. 154, fig. 5.2.
2008. *Subbotina inaequispira* (Subbotina).– Abd El-Aziz, p. 25, pl. 2, fig. 5.

This species was originally described from the EME rocks in Caucasus, and later found in some localities of the Tethys (Spain, Libya, Egypt, UAE). It is recorded in the EME rocks of J. Hafit.

Subbotina linaperta (Finlay, 1939)

1939. *Globigerina linaperta* Finlay, p. 125, pl. 13, figs. 54-57.
1970. *Globigerina linaperta* Finlay.– Samanta, p. 33, pl. 6, figs. 19, 20.
1976. *Globigerina* (*Eoglobigerina) linaperta* Finlay. – Hillebrandt, p. 331, pl. 1, figs. 14, 15.
1980. *Subbotina linaperta* (Finlay).– Barr & Berggren, p. 185, pl. 2, fig. 19.
1990. *Subbotina linaperta* (Finlay).– Premoli Silva & Spezzaferri, p. 312, pl. 2, fig. 2.
1993. *Globigerina linaperta* (Finlay).– Anan & Hamdan, p. 40, fig. 4.9.
2010. *Subbotina linaperta* (Finlay).– Haggag *et al.,* p. 179, fig. 17. 29.

This species was originally described from the Paleocene-Middle Eocene rocks in Trinidad, and later found in some 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 & Luterbacher, 1991 and Anan, 1995). It is recorded in the EME succession of J. Hafit.

Subbotina pseudoeocaena (Subbotina, 1953)

1953. *Globigerina pseudoeocaena* Subbotina var. *pseudoeocaena* Subbotina, p. 81, pl. 4, fig. 9, pl. 5, figs. 1, 2.
1973. *Globigerina pseudoeocaena* Subbotina.– Krasheninnikov & Hoskins, p. 122, pl. 10, figs. 4-6.
1983. *Globigerina pseudoeocaena pseudoeocaena* Subbotina.– Youssef *et al.*, p. 273, pl. 4, fig. 28.
1996. *Globigerina pseudoeocaena pseudoeocaena* Subbotina.– Anan, p. 157, fig. 5.5.

This species was originally described from the EME rocks in Caucasus, and later found in some localities of the Tethys (Atlantic Ocean, Egypt, UAE). Krasheninnikov & Hoskins, 1973 includes two other subspecies *G. pseudoeocaena compacta* and *G. pseudoeocaena trilobata* in the species concept of *G. pseudoeocaena pseudoeocaena* Subbotina. These three subspecies are considered here as a separate forms like in the original description of Subbotina, 1953. It is recorded in the EME rocks of J. Hafit.

Subbotina trilobata (Subbotina, 1953)
Pl. I, fig.15

1953. *Globigerina pseudoeocaena* Subbotina var. *trilobata* Subbotina, p. 83, pl. 5, fig. 5.
1983. *Globigerina pseudoeocaena* Subbotina var. *trilobata* Subbotina.– Youssef *et al.*, p. 273, pl. 4, fig. 29.

This species was originally described from the MLE rocks in Caucasus, and later found in Egypt. It is recorded here, from the first time, in the early Middle Eocene horizon of J. Hafit.

***Subbotina turgida* (Finlay, 1939)**

1957. *Globigerina turgida* Finlay, 1939, p. 125.
1957. *Globigerina turgida* Finlay.– Bolli, p. 73, pl. 15, figs 3-5.
1983. *Globigerina turgida* Finlay.– Youssef *et al.*, p. 275, pl. 5, fig. 5.
1996. *Globigerina turgida* Finlay.- Anan, p. 157, fig. 5.4.

This species was described from Early Eocene rocks in New Zealand, and later found in some localities of the Tethys (Trinidad, Egypt, UAE). It is recorded only in the Early Eocene succession of J. Hafit.

Superfamily Hantkeninacea Cushman, 1927
Family Globanomalinidae Loeblich & Tappan, 1984
Genus *Globanomalina* Haque, 1956
Type species: *Globanomalina ovalis* Haque, 1956

***Globanomalina micra* (Cole, 1927)**

1927. *Nonion micrus* Cole, p. 22, pl. 5, fig. 12.
1953. *Globigerinella micra* (Cole).– Subbotina, p. 122, pl. 13, figs. 16, 17.
1961. *Globigerinella micra* (Cole).– Gohrbandt, p. 142, pl. 7, fig. 7.
1968. *Globanomalina micra* (Cole).– Srinivasan, p. 145, pl. 13, figs. 3, 4.
1969. *Pseudohastigerina micra* (Cole).– Samanta, p. 342, pl. 1, fig. 6.
1971. *Globanomalina micra* (Cole).– Jenkins, p. 78, pl. 2, figs. 50-54.
1980. *Pseudohastigerina micra* (Cole).– Barr & Berggren, p. 191, pl. 5, fig. 11.
1993. *Pseudohastigerina micra* (Cole).– Pearson, p. 219, text-fig. 25b.
1995. *Pseudohastigerina micra* (Cole).– Anan, p. 8, pl. 1, fig. 9.
2008. *Pseudohastigerina micra* (Cole).– Abd El-Aziz, p. 28, pl. 2, fig. 10.

This species was originally described from the Early Eocene-Early Oligocene succession in Mexico, and later found in some localities of the Tethys (Spain, Libya, Egypt, UAE, Pakistan, India, New Zealand). On the other hand, the *Cassigerinella chipolensis – Pseudohastigerina micra* Zone represents the earliest Oligocene zone for Stainforth *et al.*, 1975; Youssef *et al.*,1983 and Anan *et al.*, 1992. It is recorded in the EME succession of J. Hafit (Table 2).

4. UAE FAUNAL STRATIGRAPHY AROUND EME BOUNDARY

Thirty planktic foraminiferal species are considered as markers around EME boundary in J. Hafit, UAE:

1. 10 species (33.3%) are restricted in the top Early Eocene and do not cross the EME boundary in the studied section. These species are: *Acarinina angulosa, A. nitida, A. quetra, A. soldadoensis, A. triplex, Morozovella caucasica, M.* sp. 1, *M.* sp. 2, *Subbotina compacta* and *S. turgida* (bed/sample nos. 1-10).
2. 13 species (43.3%) are recorded in the top Early Eocene and continue in the base of Middle Eocene, crossing the EME boundary: *Acarinina broedermanni, A. bullbrooki, A. pentacamerata, A. pseudotopilensis, A. spinuloinflata, Morozovella aragonensis, M. lensiformis, Subbotina cryptomphala, S. inaequispira, S. linaperta, S. pseudoeocaena, Truncorotaloides topilensis* and *Globanomalina micra* (bed/sample nos. 1-12).
3. 7 species (23.3%) appear only in the Middle Eocene: *Acarinina berwaliana, A. interposita, Subbotina eocaena, S. eocaenica, S. frontosa, S. hagni* and *S. trilobata* in the studied section (bed/sample no. 12).

5. THE LACUNA AROUND THE EME BOUNDARY IN THE TETHYS

1. Mohan & Soodan, 1970 noted that the Middle Eocene (Lutetian) sediments disconformably overlie the Early Eocene (Ypresian) sediments in western Kutch, India.
2. 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.
3. Haq & Aubry, 1980 noted that the North Africa and Middle East formed important parts of the Tethyan link between the Atlantic and the Pacific Oceans during the early Cenozoic.
4. 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 prior to the Middle Eocene transgression. He also added that similar lower-middle Eocene unconformity of the Dammam Formation is encountered throughout the south and southwestern Iraq.
5. Warrak, 1987, 1996 has pointed out that the deformation of the neoautochthonous Maastrichtian and Tertiary sediments in the southern part of the Northern Oman Mountains was synchronous and developed contemporaneously with sedimentation. He also concluded that J. Hafit and other foreland folds in the Northern Oman Mountains were formed prior to the main Zagaros deformation which started in very late Miocene and culminated in the late Plio-Pleistocene.
6. Berggren & 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. Anan, 1996 suggested that the intraformational conglomeratic bed around EME boundary in J. Hafit was deposited as submarine debris flows in the basin, not as subaerial denudation. It consists of angular to subangular limestone detritus of different sizes with fine grained marl matrix and has an homogenous thickness (about 3 m). This intraformational conglomeratic bed (bed no. 10, Figs. 2, 3) suggests a minimal reworking and accumulation in a low-energy environment with a short distance of transportation on a slightly deepening paleoslope from the positive localized source area during the time of active tectonics (Strougo & Haggag, 1983).
10. Boukhary *et al.,* 2006 found rich large benthic foraminiferal species in the fine reddish matrix of marly limestone carbonates which cements the conglomerate clasts in the conglomeratic bed (bed no. 10, Fig. 2). These are *Assilina spira abrardi, Somalina praestefaninii* and *Nummulites perplexus,* 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. 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 J. Hafit.
11. Accordingly to Orue-Etxebarria *et al.,* 2006 the stratigraphical position of the Ypresian-Lutetian boundary is still a matter of controversy between the calcareous nannoplankton, planktic foraminiferal and larger foraminifera faunal biostratigraphic schemes.

6. SUMMARY AND CONCLUSIONS

1. The core of Jabal Hafit in Al Ain area (UAE) contains late Ypresian sediments (beds no.1-10, about 55 m). This Ypresian succession ends by an intraformational conglomeratic bed (bed no. 10, about 3 m).
2. The early Middle Eocene succession is located about 5 m stratigraphically above the upper Early Eocene intraformational conglomeratic bed (bed no. 10, Figs. 2, 3).
3. Thirty diagnostic planktic foraminiferal species are identified around the Early/Middle Eocene (EME) boundary in Jabal Hafit. Ten species (33.3%) are restricted in the top Early Eocene (Ypresian) and do not cross the EME boundary in the studied section, 13 species (43.3%) are recorded in the top and continue in the base of Middle Eocene crossing the EME boundary, while 7 species (23.3%) appear only in the base Lutetian (Table 2).
4. The planktic foraminiferal analysis of the Ypresian-Lutetian (Y/L) transition exposed in J. Hafit indicates that the Y/L boundary is unconformable (represented by intraformational conglomeratic bed, bed no. 10, Figs. 2, 3).
5. The deposition of this conglomeratic bed was most probably controlled by active tectonic and eustatic sea-level changes, at the end of the Ypresian (Vail *et al.,* 1977 and Haq *et al.,* 1987). It represents a major, but short-lived regression in J. Hafit. I suggest that 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 (Fig. 4).
6. After the Ypresian, a rapid tectonic subsidence, followed by a rapid transgression submerged Al Ain area. Then during the Lutetian, the sediments were deposited.
7. The lacuna around EME boundary has been reported from different parts of the Middle East, as a response of the global sea level drop, following: Benjamini, 1980; Abul-Nasr & Thunell, 1987; Strougo *et al.,* 1990 and Anan, 1996.
8. The EME (P9/P10) boundary doesn't have the same ages for all different authors around the world: 49 Ma following Berggren, 1972; Vail *et al.*, 1977; Moore *et al.,* 1978; Vail & Hardenbol, 1979; Haq *et al.*, 1987; Browning *et al.*, 1996; Serra-Kiel *et al.,* 1998; Meulenkamp & Sissingh, 2003, but 50 Ma following Hrbek *et al.,* 2004; 52 Ma for Berggren *et al.*, 1985; Pearson, 1993, but 52.6 Ma for Martini & Müller, 1986.

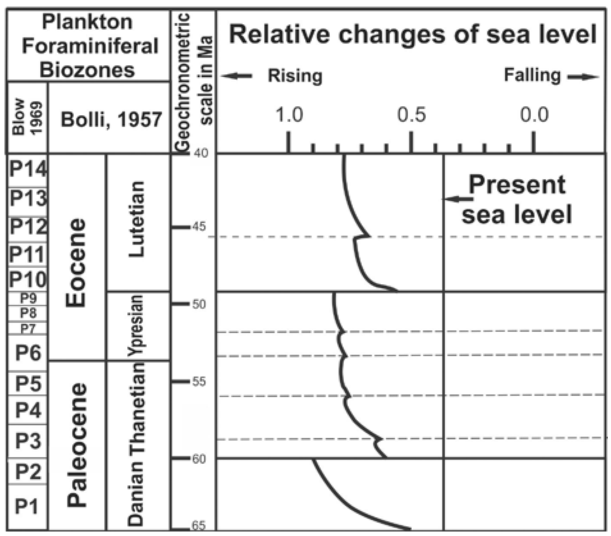


Fig. 4: The time around the EME boundary (= the Ypresian-Lutetian boundary) relative to the global sea level fluctuation of Vail *et al.* (1977).

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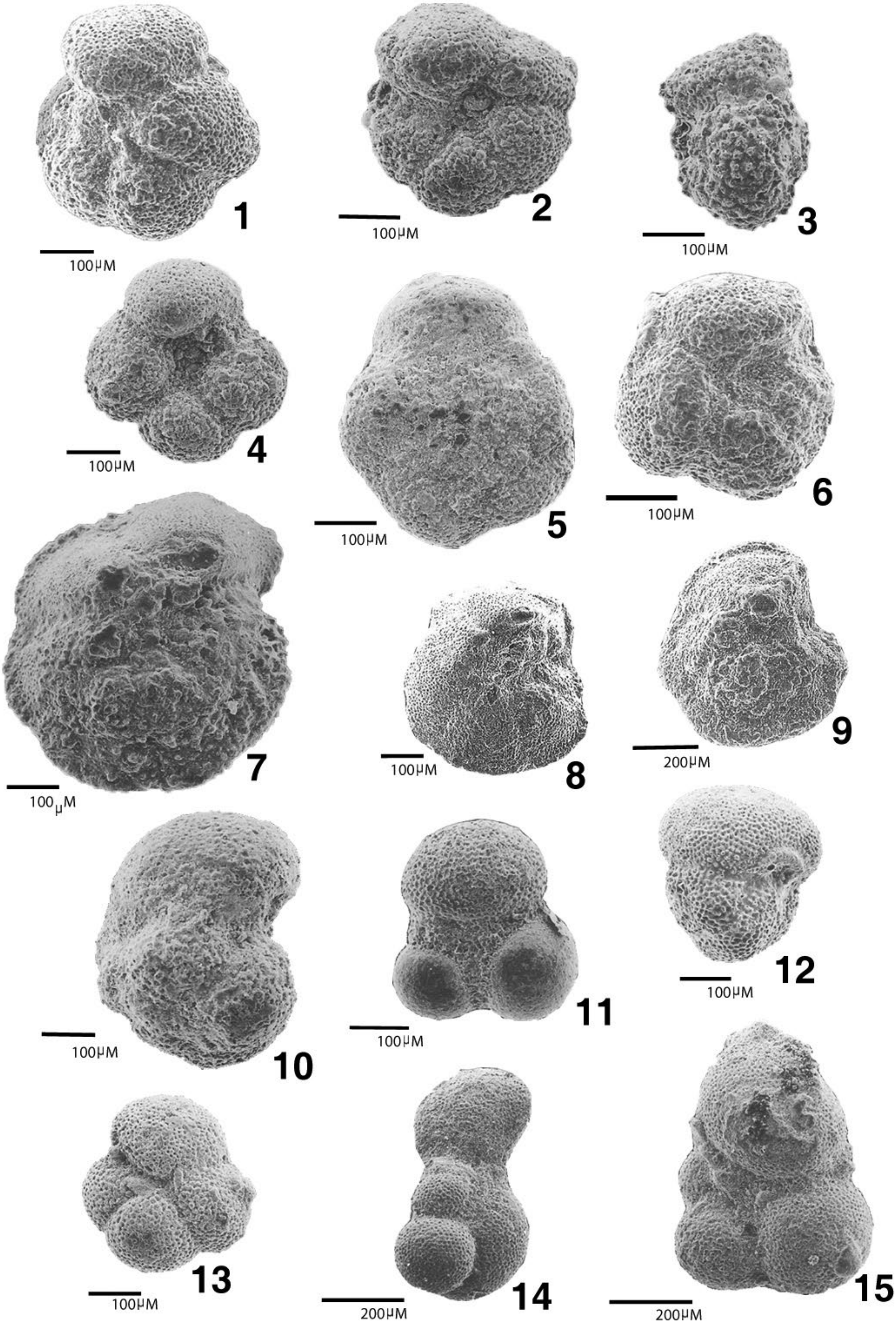
Plate I

Fig. 1: *Acarinina angulosa* (Bolli, 1957), Sample 9a, Early Eocene of Jabal Hafit, UAE.
Fig. 2: *Acarinina berwaliana* (Mohan & Soodan, 1969), S. 12, Middle Eocene.
Fig. 3: *Acarinina bullbrooki* (Bolli, 1957), S. 12, Middle Eocene.
Fig. 4: *Acarinina interposita* Subbotina, 1953, S. 12, Middle Eocene.
Fig. 5: *Acarinina pentacamerata* (Subbotina, 1947), S. 9b, Early Eocene.
Fig. 6: *Acarinina triplex* Subbotina, 1953, S. 9b, Early Eocene.
Fig. 7: *Acarinina caucasica* (Glaessner, 1937), S. 9a, Early Eocene.
Fig. 8: *Morozovella* sp. 1, transitional form between *Morozovella lensiformis* (Subbotina) and *M. aragonensis* (Nuttall), S. 9b, Early Eocene (after Anan, 1996).
Fig. 9: *Morozovella* sp. 2, transitional form between *Morozovella aragonensis* (Nuttall) and *M. caucasica* (Glaessner), S. 3a, Early Eocene (after Anan, 1996).
Fig. 10: *Subbotina eocaena* (Gümbel, 1868), S. 12, Middle Eocene.
Fig. 11: *Subbotina eocaenica* (Terquem, 1882), S. 12, Middle Eocene.
Fig. 12: *Subbotina frontosa* (Subbotina, 1953), S. 12, Middle Eocene.
Fig. 13: *Subbotina hagni* (Gohrbandt, 1967), S. 12, Middle Eocene.
Fig. 14: *Subbotina inaequispira* (Subbotina, 1953), S. 12, Middle Eocene.
Fig. 15: *Subbotina trilobata* (Subbotina, 1953), S. 12, Middle Eocene.

Plate I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