Upper Eocene larger foraminifera from the Dammam Formation in the border region of United Arab Emirates and Oman

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ABSTRACT: An Upper Eocene diagnostic larger foraminiferal assemblage is described and illustrated from carbonates of the uppermost Dammam Formation, on the western side of the Northern Oman Mountains, along the United Arab Emirates and Oman borders. This assemblage comprises *Fabiania cassis* (Oppenheim, 1896), *Silvestriella tetraedra* (Gümbel, 1870), *Pellatispira madaraszi* Hantken, 1876, *Nummulites fabianii* (Prever, 1905), *N. ptukhiani* Kacharava, 1969 and *N. retiatus* (Roveda, 1959). The presence of *Nummulites ptukhiani* and *N. fabianii* within the same horizon of *Pellatispira madaraszi* places both species in the Priabonian stage, confirming a Late Eocene age for the uppermost part of the Dammam Formation. The studied carbonates were deposited in an inner shelf environment, which may be related to the eustatic fall of sea level at the end of the Late Eocene.

INTRODUCTION

The Dammam Formation and the partly equivalent Seeb Limestone Formation were deposited in a shallow marine environment (Racey,1994). The Upper Eocene part of the Dammam Formation consists of fossiliferous shallow-marine carbonates and covers a large part of the eastern Arabian Peninsula. Upper Eocene sequences along the United Arab Emirates and Oman border, (text-fig.1) have been studied previously by Hunting (1979), Cherif and El-Deeb (1984), Hamdan and Bahr (1992), Anan et al. (1992), Racey (1994), White (1994), Jones and Racey (1994), Anan (1995), Whittle et al. (1996) and Abdelghany (2002).

The first lithostratigraphic and chronostratigraphic subdivision of the Paleogene strata in the Al-Ain area, southeastern United Arab Emirates was erected by Hunting (1979), who defined eleven coded rock units (text-fig.2) and assigned ages to these rock units based mainly on the micropaleontologic data of Terratest (1973).

In their study of the Eocene of the Al-Ain area, Cherif and El-Deeb (1984) introduced the Hafit, Senaiya and Al Jaww formations (text-fig.2) and subdivided them into members similar to the lithostratigraphic units described by Hunting (1979). The Eocene-Oligocene sequence in the Jabal Hafit area was later divided into three formations and eight members (text-fig.2) based on lithology, defined planktonic foraminifera and *Nummulites* (Hamdan and Bahr, 1992). They defined the Rus Formation (Lower Eocene), comprising the Hilli and Wadi Tarabat members; the Dammam Formation (Middle to Upper Eocene), comprising the Middle Eocene Wadi Al Nahyan Member and Ain Al-Faydah Member (on the eastern limb of Jabal Hafit anticline only), and the Mazyad Member (Upper Eocene); and the Asmari Formation (Lower to Middle Oligocene) consisting of the Muwaiji, Mutaredh and Zakher members (text-fig.2).

Anan et al. (1992) identified twelve planktonic foraminiferal zones (P9-P21) at Jabal Hafit spanning the late Early Eocene to Oligocene. Cherif et al. (1992) recognized four bathymetrically significant types of shallow and deep inner neritic; middle and outer neritic of calcareous algae, bryozoa and foraminiferal assemblages represented in the Eocene and Oligocene sequences at Jabal Hafit. This study enabled Cherif et al. (1992) to establish a bathymetric curve for the studied sections which fits with their results and this can be also correlated with the Eustatic curve of Haq et al. (1987) for global changes in sea levels.

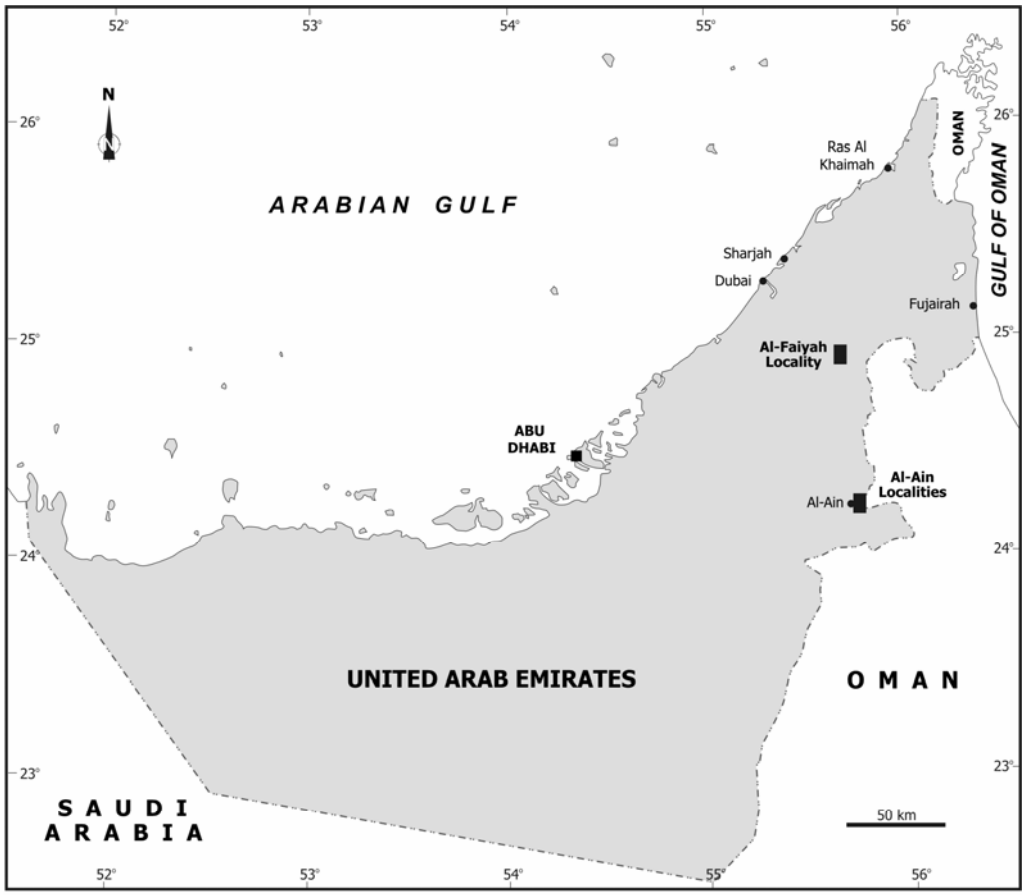
Anan (1995) recorded *Cribrohantkenina inflata* (Howe) in the Mazyad Member of the uppermost part of the Dammam Formation from the northwestern limb of Jabal Malaqet anticline (text-fig.1). Whittle et al. (1996) described the Dammam Formation in Jabal Hafit as representing a continuous sequence from the Early Eocene Rus Formation to the Oligocene Asmari Formation.

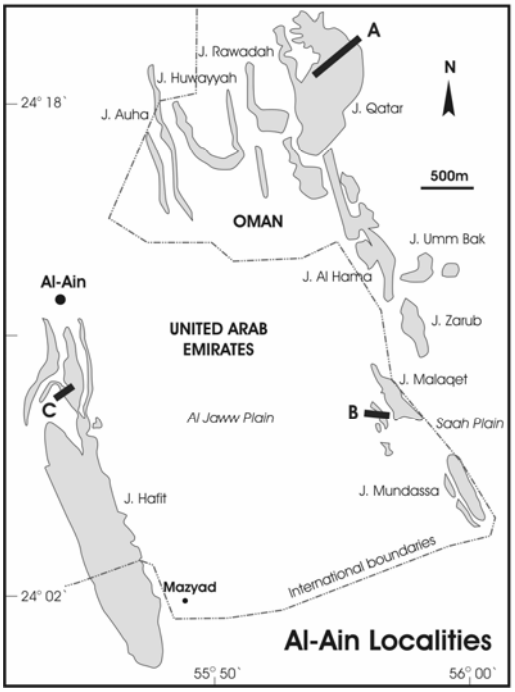
The present study aims dates and illustrates Upper Eocene larger foraminifera from the uppermost part of the Dammam Formation in Jabal Qatar, Jabal Malaqet, Jabal Hafit and the western limb of Jabal Buhays in the Al Faiyah Range Mountains.

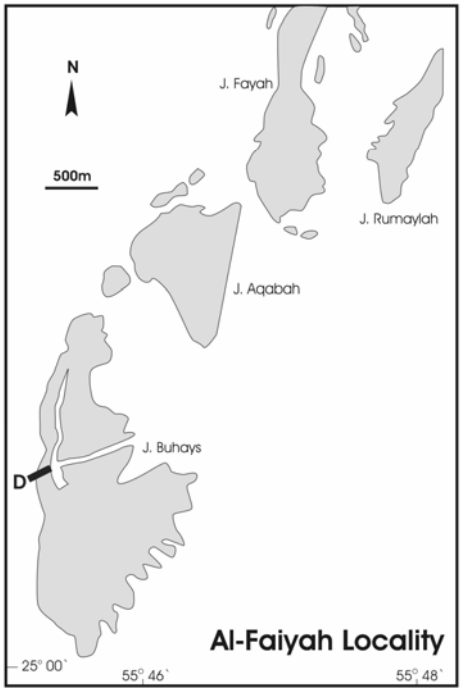
This interval consists of a thick, well exposed sequence of rhythmically alternating limestone and marl beds that is rich in smaller and larger foraminifera, and therefore well suited for the present micropaleontologic study.

MATERIAL AND STUDY LOCATIONS

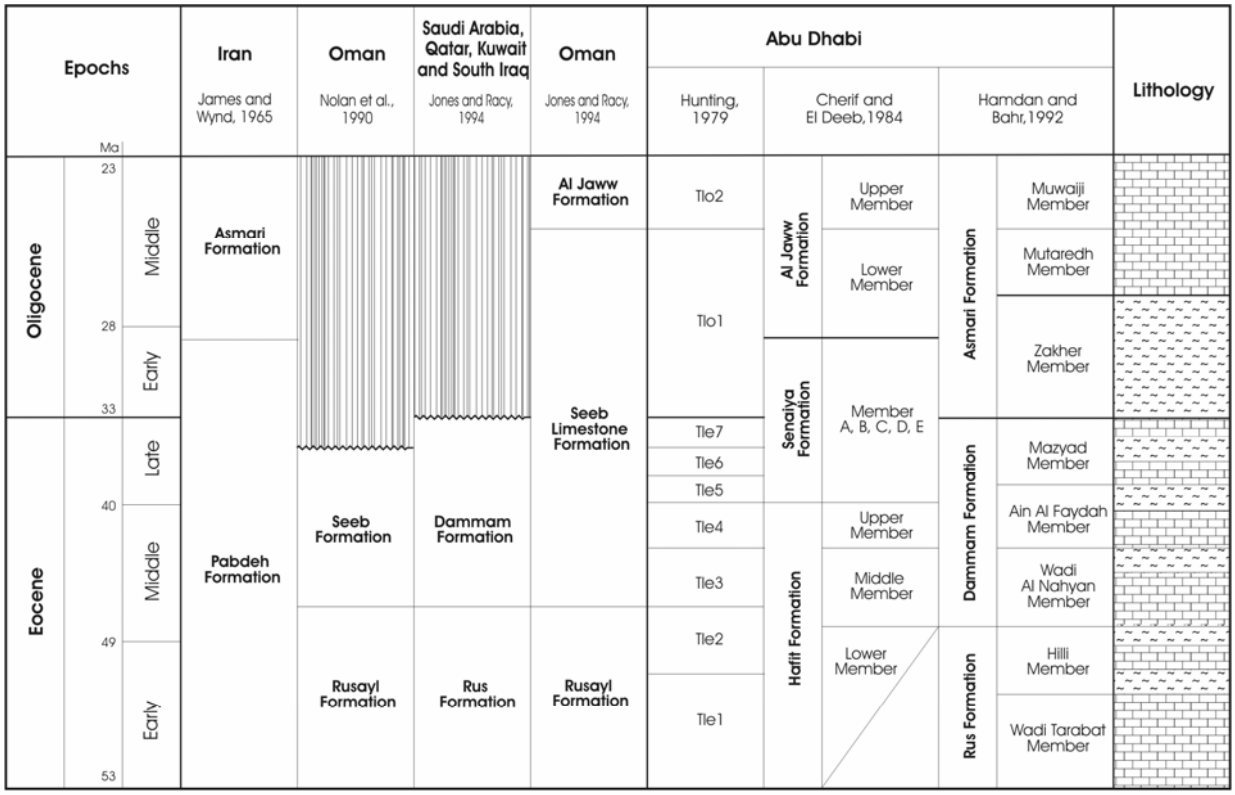
Four stratigraphic sections representing the Upper Eocene part of the Dammam Formation were measured and sampled in the area along the border between the United Arab Emirates and Oman (text-figs.1, 3 and plate 7). Stratigraphic section (A), located 24km northeast of Al-Ain city, is 194m thick and forms a limb of the Jabal Qatar syncline at latitude 24°19'30"N and longitude 55°54'0"E.







TEXT-FIGURE 1
Location map of the study area and the measured sections.



TEXT-FIGURE 2
Lithostratigraphic correlation chart of Abu Dhabi (UAE), and neighbouring countries (based on Hamdan and Bahr, 1992).

The poorly-exposed basal beds consist of a thick marl sequence containing thin (0.5m thick) erosion-resistant layers of limestone. These are followed by a one-metre limestone bed rich in larger foraminifera and then another thick succession of marl capped by another thin limestone.

Stratigraphic section (B), was measured on the northwestern limb of the Jabal Malaqet anticline, about 22km east of Al-Ain city, at latitude 24°9'24"N and longitude 55°56'47"E. It is estimated to be 94m thick, although the base is unexposed. It consists of yellow, gypsiferous marls alternating with brown, nummulitic limestone beds near the top of the section.

Stratigraphic section (C) is 64m thick and was examined from a site near the hinge zone of the Hafit anticline, south of the city of Al-Ain. The base of the section is located at latitude 24°08'57"N and longitude 55°44'47"E. The lowermost part of this section consists of hard, thick-bedded, bioturbated, nummulitic limestones. These are followed by a thick sequence of intercalated limestones and marls topped by another hard, thick bedded nummulitic limestone.

Stratigraphic section (D) is 18m thick and located on the lower slopes of the western side of Jabal Buhays, in the Al Faiyah Range Mountains. It consists of a pale green, highly fractured marl with calcite veins at its base. This is followed by a thick sequence of limestone, which is highly fossiliferous and very rich in larger foraminifera especially *Nummulites* spp.

LITHOSTRATIGRAPHY

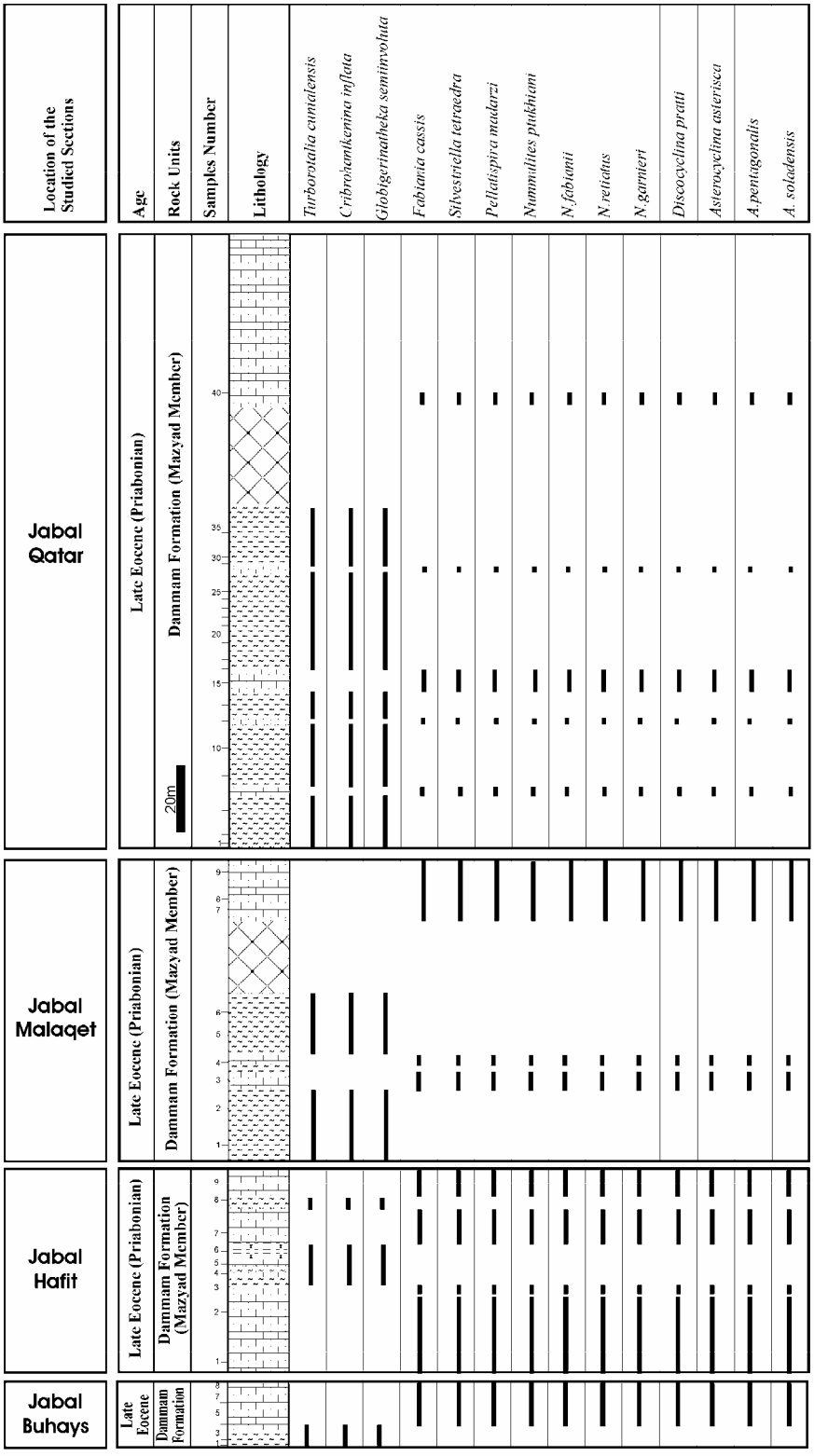
Dammam Formation (partly equivalent to the Seeb Limestone Formation and the Pabdeh Formation)

The name Dammam Formation was introduced by Bramkamp (1941) in an unpublished Aramco report from a type section located along the Dhahran Al'Alah road in eastern Saudi Arabia, at latitude 26°19'26"N, and longitude 50°4'5"E, beginning at the point where this road intersects the margin of the Dammam Dome (Powers et al. 1966; Powers 1968). However, in Oman it is referred to as a part the Seeb Limestone Formation and Pabdeh Marl Formation (Jones and Racey, 1994).

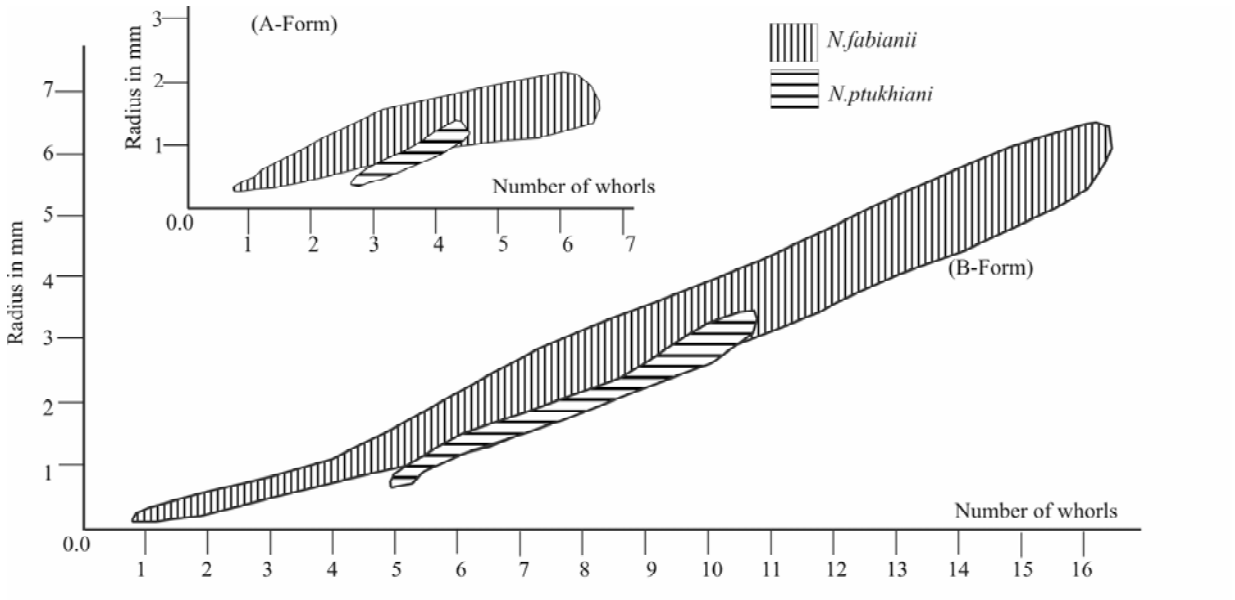
It is widely exposed throughout large areas of southern Iraq, Kuwait, Saudi Arabia, Qatar, UAE and Oman (Jones and Racey, 1994). The Dammam Formation consists of a sequence of shallow water shelf carbonates interbedded with marls.

While the lower part of the Dammam Formation is usually unfossiliferous, the middle and upper parts of all studied sections in the region show Middle to Late Eocene age, based mainly on larger benthonic and planktonic foraminifera.

In Kuwait and Saudi Arabia, the Dammam Formation is divided into five members from base to top as follows: the Midra and Saila members, the Alveolina Limestone Member, the Khobar Limestone Member and the Alat Limestone Member. In the Western Desert of southern Iraq the middle part of the Dammam contains Middle



TEXT-FIGURE 3
Lithostratigraphy of the studied sections showing the distribution of the identified foraminiferal species (Based on Abdelghany, 2002).



TEXT-FIGURE 4
Spiral diagram showing the relationship between *Nummulites ptukhiani* and *N. fabianii* in the study area and other localities based on table 1.

Eocene larger foraminifera, while the upper part has age-diagnostic larger benthonic fauna of Middle-Late Eocene age. In the UAE (offshore Abu Dhabi) the Dammam Formation has been dated to the Middle to Late Eocene. In the present study area it consists of three members, from base to top as follows: the Wadi Al Nahyan and Ain Al Faydah members, both of Middle Eocene age, and the Mazyad Member of Late Eocene age as in (text-fig. 2).

The Mazyad Member of the Dammam Formation in the UAE–Oman border area is the topic of this contribution. The base of the Mazyad Member is unexposed in any of the studied stratigraphic sections. The top of the member is characterized by hard, thin-bedded, bioclastic nummulitic limestones, rich in larger foraminifera (plate 7). The exposed thicknesses of the Mazyad Member in the studied sections are as follows: 194m thick in the Jabal Qatar section, 94m thick in the Jabal Malaqet section, 64m thick in the Jabal Hafit section and 18m thick at the base of slope of the western limb of Jabal Buhays Anticline, in the Al Faiyah Range Mountains. The Mazyad Member is recognized for the first time at Jabal Buhays. The biostratigraphic distribution of the identified smaller and larger foraminifera the studied sections is shown in (text-fig.3).

Faunal Content of the Dammam Formation

Marl layers in the studied sections are rich in planktonic foraminifera whereas the limestones are rich in larger foraminifera.

The *Nummulites fabianii* group is important for defining the Middle/Upper Eocene boundary in the Tethyan province. The evolutionary lineage of this group according to (Herb and Hekel, 1973; 1975; Schaub, 1981; Racey, 1995; Papazzoni, 1998; and Papazzoni and Sirotti, 1995) comprises from (older to younger) *Nummulites ptukhiani, N. fabianii fabianii, N. fabianii retiatus*.

The present investigations indicates that *N. ptukhiani* co-occurs with *N. fabianii* and that *N. fabianii* extends stratigraphically above *N. retiatus*. We also, note that the rest size of *N. ptukhiani* is larger than that of *N. fabianii*, whereas the size of the protoconch of *N. ptukhiani* overlaps with that of *N. fabianii* (table 1 and text-fig.4).

N. ptukhiani occurs with the association of *Pellatispira madaraszi, Fabiania cassis* and *Silvestriella* species, placing *N. ptukhiani* at the base of the Priabonian stage. On the basis of the biometric data presented herein *N. ptukhiani* should be regarded as the direct ancestor of *N. retiatus*. *N. ptukhiani* is found in a sequence yielding *the planktonic foraminifera Globigerinatheka semiinvoluta and Turborotalia cunialensis/Cribrohantkenina inflata* (Anan et al., 1992 and Abdelghany, 2002). The identified larger foraminifera enable a subdivision of the sections into two larger foraminiferal zones currently used by different workers (text-figs.5, 6):

a-) *Nummulites fabianii, N. ptukhiani, N. retiatus* and *N. garnieri* and

b-) *Fabiania cassis, Silvestriella tetraedra, Pellatispira madaraszi, Discocyclina pratti, Asterocyclina asterisca A. pentagonalis* and *A. soladensis.*

The proposed biozones in the present study are isochronous with the well defined P15 and P16 planktonic foraminiferal Zones noted by Anan et al. (1992) and Abdelghany (2002) from the same stratigraphic sections.

The taxonomy followed here is based on that adopted by Loeblich and Tappan (1988). Eleven foraminiferal species were recovered with the stratigraphically important taxa illustrated in (text-fig.3 and plates 1-6). The stratigraphic relationships between the identified planktonic and larger foraminiferal species for the sections studied are shown in (text-fig.6).

DISCUSSION

Geological age of the Dammam Formation

Most previous workers have assigned the Dammam Formation to the Early to Middle Eocene (Powers et al., 1966; Powers, 1968; and Boukhary, 1985). But some have said it extends into the Upper Eocene.

TABLE 1
Measurements of *N. ptukhiani* and *N. fabianii* Megalospheric generation (A-Form) and Microspheric generation (B-Form) according to different authors and the study area.

Species name	*N. ptukhiani*	*N. fabianii*
Characters	Kacharava, 1969	(Prever, 1905)
B-Form		
Diameter and Thickness	3.0-3.4 mm and 1.0-1.2 mm	2.87-5.25 mm and 1.33-1.68 mm
Form of the test	Lenticular with central boss	Lenticular with central boss
Number of Whorls/radius	6 whorls in a radius of 1.3- 1.6 mm	2 whorls in a radius of 0.3-0.41mm; 4 whorls in a radius of 0.87-0.96 mm; 6 whorls in a radius of 1.33-1.63 mm
A-Form		
Diameter and Thickness	2.7-2.9 mm and 1.25-1.4 mm	2.17-2.94 mm and 0.95-1.33 mm
Form of the test	Lenticular with central boss	Lenticular with central boss
Septal filaments	Radial	Radial
Number of Whorls/radius	3 whorls in a radius of 0.35- 0.45 mm 3 whorls in a radius of 0.57-0.63 mm 4 whorls in a radius of 1.32 mm	2 whorls in a radius of 0.37-0.4 mm 4 whorls in a radius of 0.93-1.1 mm
Size of protoconch	0.1-0.15 mm	0.12-0.19 mm
Age	Priabonian	Priabonian

Species characters	Schaub, 1981		Herb and Hekel, 1973	Present study	
	N. ptukhiani	*N. fabianii*	*N. fabianii fabianii*	*N. ptukhiani*	*N. fabianii*
B-Form					
Diameter and Thickness	4.5-6mm and 1.8-2.2mm	8-12mm and 2-3mm	-	3.0-3.4 mm and 1.0-1.2 mm	2.78-5.25 mm and 1.33-1.68 mm
Form of the test	Lenticular	Lenticular	Lenticular	Lenticular with central boss	Lenticular with central boss
Number of whorls/radius	9 whorls in a radius of 2.6mm 10 whorls in a radius of 3-3.3mm	12 whorls in a radius of 3.8-5.0mm 13 whorls in a radius of 4.2-5.3mm 14 whorls in a radius of 4.6-5.9mm 15 whorls in a radius of 6.2mm	1 whorl in a radius of 0.4mm 2 whorls in a radius of 0.68mm 3 whorls in a radius of 0.92mm 4 whorls in a radius of 1.25mm 5 whorls in a radius of 1.68mm	6 whorls in a radius of 1.3-1.6 mm	2 whorls in a radius of 0.3-0.41 mm 4 whorls in a radius of 0.87-0.96 mm 6 whorls in a radius of 1.33-1.63 mm 8 whorls in a radius of 2.07mm

Species characters	Schaub, 1981		Herb and Hekel, 1973	Present study	
	N. ptukhiani	*N. fabianii*	*N. fabianii fabianii*	*N. ptukhiani*	*N. fabianii*
A-Form Diameter and Thickness	2.8-4mm 1-1.8mm	2-4.5mm 1-2mm	-	2.7-2.9 mm 1.25-1.4 mm	2.17-2.94 mm 0.95-1.33 mm
Form of the test	Lenticular	Lenticular	Lenticular	Lenticular with central boss	Lenticular with central boss
Number of whorls/radius	-	4 whorls in a radius of 1-1.6mm 5 whorls in a radius of 1.2-1.9mm 6 whorls in a radius of 2.2mm	1 whorl in a radius of 0.35mm 2 whorls in a radius of 0.52mm 3 whorls in a radius of 0.8mm 4 whorls in a radius of 1.0mm	3 whorls in a radius of 0.35-0.45 mm 3 whorls in a radius of 0.57-0.63 mm 4 whorls in a radius of 1.32 mm	4 whorls in a radius of 0.97-1.8 mm 6 whorls in a radius of 1.33-1.44mm 6 whorls in a radius of 1.48mm
Size of protoconch	0.15-0.22mm	0.17-0.36mm	Mean value 0.14mm	0.1-0.15mm	0.15-.22 mm
Age	Bartonian	Priabonian	Priabonian	Priabonian	Priabonian

El-Nakhal (1988) assigned a Middle-Late Eocene age to the Dammam Formation on the basis of the occurrence of Early Eocene planktonic foraminifera in the lower part of the Umm er Radhuma Formation from some wells of the Rub'al Khali described by (Hasson 1985), and the estimates of sedimentation rates of shallow water carbonates for the area. The extension of the Dammam into the Late Eocene was confirmed by the presence of Late Eocene planktonic and benthonic foraminifera in the western Desert of Iraq (Al–Hashimi 1980).

As reported by Cherif and El Deeb (1984), Anan et al. (1992), Anan (1995) and Abdelghany (2002), the Upper Eocene Mazyad Member consists of an open marine highly fossiliferous marl alternating with thin-bedded limestone. It is dated as early to middle Late Eocene (Priabonian) on the basis of the *Globigerinatheka semiinvoluta*, P15 and *Turborotalia cunialensis*/*Cribrohantkenina inflata* Concurrent Range Zone, P16 (text-fig.6).

Paleoenvironments

Larger foraminifera occur in warm waters within the photic zone (Bearington-Penney and Racey, 2004). Hohenegger et al.(1999) reported larger foraminifera living in the upper 50m in front of the fringing coral reef northwest of Sesoko Island, Japan and recent nummulites species living between 20 and 70m depth of the water.

A pronounced eustatic sea level fall occurred at the close of Chron C13r (mid) to Chron C13r (late) (the end of Zone P17, *T. cerroazulensis*) (Haq et al. 1987, Keller et al.1987). This occurred at about 34.0-33.8 Ma, i.e. latest Eocene (Berggren et al., 1995). This global regression may have been expressed in the study area by sea level fluctuations partly associated with tectonic disturbances (uplifting and subsidence or responsible for the mountains building). A drop in sea level is consistent with this research, reflecting the deposition of shallow marine limestones rich in echinoids, calcareous algae, miliolids and nummulitids (plates 2-7). This conclusion is in accordance with Cherif et al. (1992) who interpreted a hiatus between the Priabonian and the Lower Oligocene at Jabal Hafit.

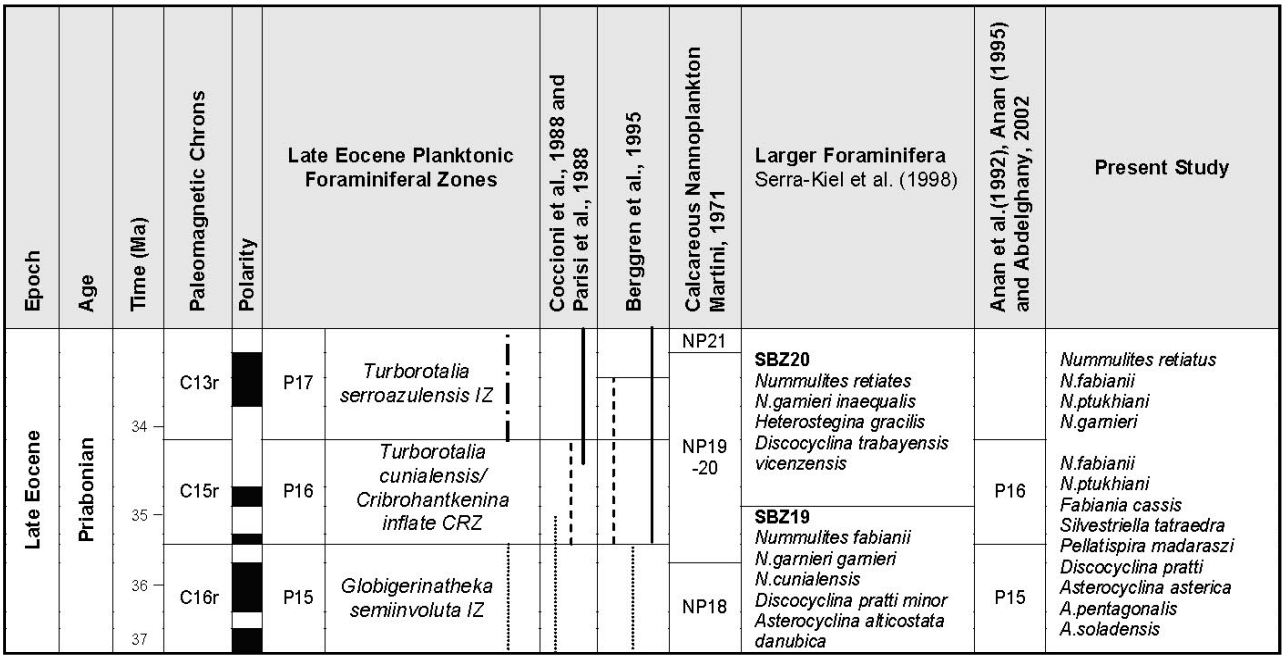
CONCLUSION

Larger foraminifera recovered from the uppermost part of the Dammam Formation in the United Arab Emirates-Oman border area include assemblages of *Fabiania cassis*, *Silvestriella tetraedra*, *Pellatispira madaraszi*, *Nummulites fabianii*, *N. ptukhiani*, *N. retiatus*, *N. garnieri*, *Discocyclina pratti*, *Asterocyclina asterisca*, *A. pentagonalis* and *A. soladensis*. Most of these species are reported in these strata for the first time especially at Jabal Qatar and the western limb of Jabal Buhays in the Al Faiyah Range Mountains.

These occurrences indicate deposition in warm shallow marine inner shelf environments. Similar conlusions have been reported by Cherif et al.(1992), Anan (1995) Abdelghany (2002) in the United Arab Emirates and by Racey (1992, 1994, 1995, 2001), White (1994), Jones and Racey (1994) and Bearington-Penney and Racey (2004) in Oman. The expansion of shallow-water depositional settings indicated by these occurrences reflect the eustatic sea-level fall at the end of *Turborotalia cerroazulensis*, Zone P17, i.e. about 33.8Ma (Berggren et al. 1995).

Age	Southern France Boussac, 1911 and Douville, 1919	Egypt Cuvillier, 1930	Syria Cizancourt, 1934	Italy Roveda, 1961	Iran Sampo, 1969	Iraq Al-Hashimi, 1980	Oman Adams and Racey, 1992	Northern Oman White, 1994	Northern Oman Racey, 1995	Turkey Sirel, 2003	Present Study
Late Priabonain	*N. bouillei* *N. fabianii* *N. rosai*	*N. striatus*	*Nummulites bouillei* *N. cf. incrassatus*	*N .cf. bouillei* *N. chavannesi* *N. incrassatus* *Operculina alpina*	*N. fabianii*	*Nummulites bouillei* *N. incrassatus*			*N. fabianii* *N. striatus* *Heterostegina* cf. *H. nuda* *Spiroclypeus granulosus*	*N. bouillei* *N. incrassatus* *N. garnieri* *N. fabianii* *Silvestriella tetraedra*	*N. retiatus* *N. fabianii* *N. fabianii* *N. garnieri, N. ptukhiani* *Fabiania cassis* *Silvestriella tetraedra* *Pellatispira madaraszi* *Discocyclina pratti* *Asterocyclina asterisca* *A. pentagonalis* *A. soladensis*
Early Priabonain	*N. striatus* *N. perforatus*			*N. incrassatus* *N. fabianii* *N. garnieri* *Operculina alpina*		*N. striatus* *N. praefabianii*	*Borelis vonderschmitti*, *Calcarina* sp., *Fabiania cassis*, *Silvestriella tetraedra* and *Spiroclypeus granulosus*	*Biplanispira absurda*, *Asterocyclina* spp., *Discocyclina* spp., *Gypsina globulus*, *Nummulites* spp., *Rhapydionina urensis*, and *Silvestriella tetraedra*			

TEXT-FIGURE 5
Correlation between the study area and other localities (based on Al-Hashimi, 1980).



TEXT-FIGURE 6
Stratigraphic ranges of the Late Eocene foraminiferal index species according to different authors: *Globigerinatheka semiinvoluta* (·····), *Cribrohantkenina inflata* (- - - -), *Turborotalia cunialensis* (———) and *T. cerroazulensis* (– · –).

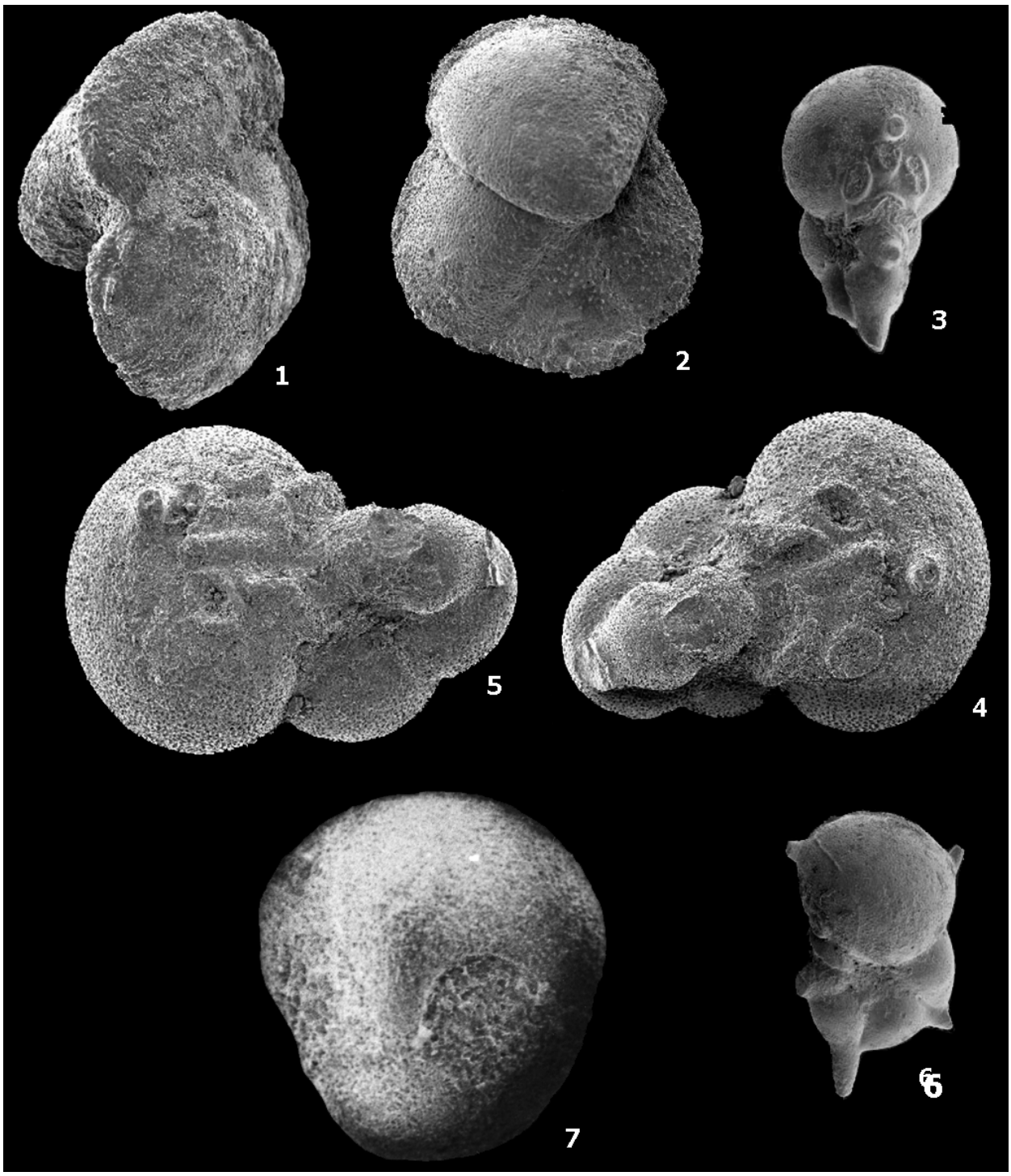


PLATE 1

1-2 *Turborotalia cunialensis* (Toumarkine and Bolli, 1970), Jabal Qatar section, sample 8; 1 dorsal view, x107; 2, ventral view, x98, (from Abdelghany, 2002).
3-6 *Cribrohantkenina inflata* (Howe, 1928), Jabal Qatar section, sample 8; 3-5, apertural views; 3, x79; 4, x114;5, x107; 6, dorsal view, x74, (from Abdelghany, 2002).
7 *Globigerinatheka semiinvoluta (*Keijzer, 1945), Jabal Hafit section, eastern limb, sample 5, x60 (from Anan et al., 1992).

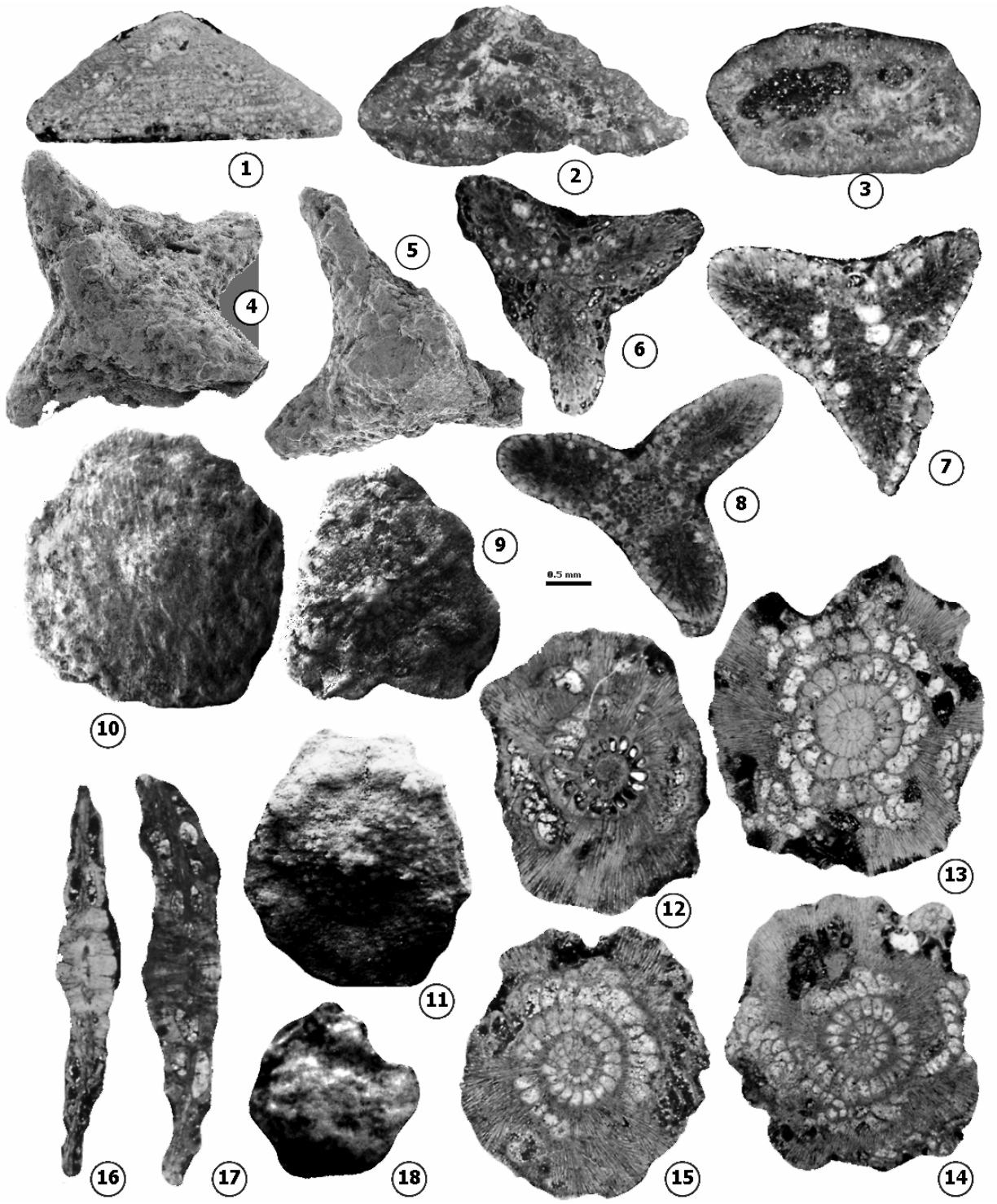


PLATE 2

1-3 *Fabiania cassis* (Oppenheim, 1896).
4-8 *Silvestriella tetraedra* (Gümbel, 1870).
9-18 *Pellatispira madaraszi* Hantken, 1876.

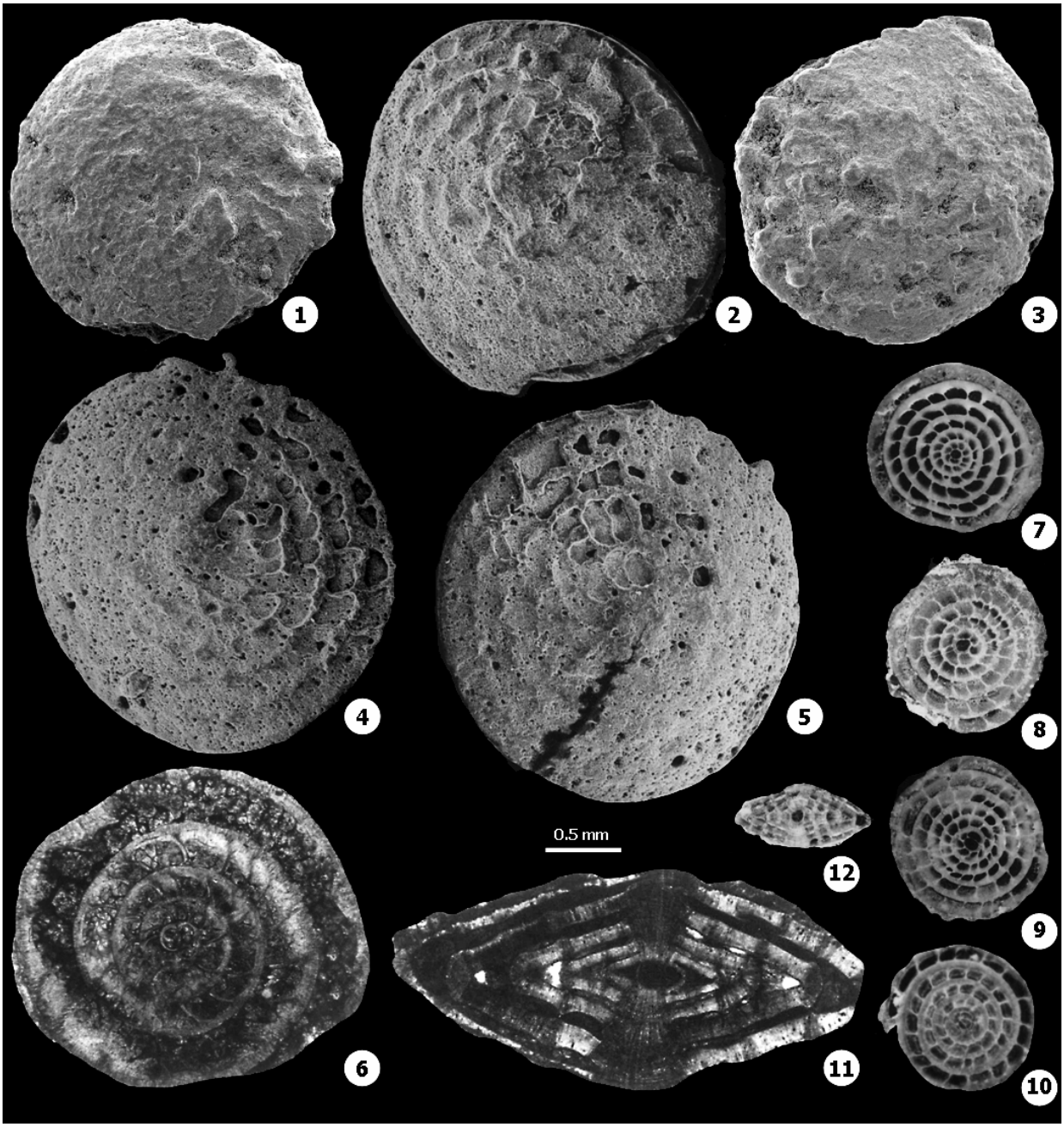


PLATE 3

1-5 *Nummulites fabianii* (Prever, 1905); external view, (A-Form).
6-10 *Nummulites fabianii* (Prever, 1905); equatorial section, (A-Form).
11-12 *Nummulites fabianii* (Prever, 1905); axial section, (A-Form).

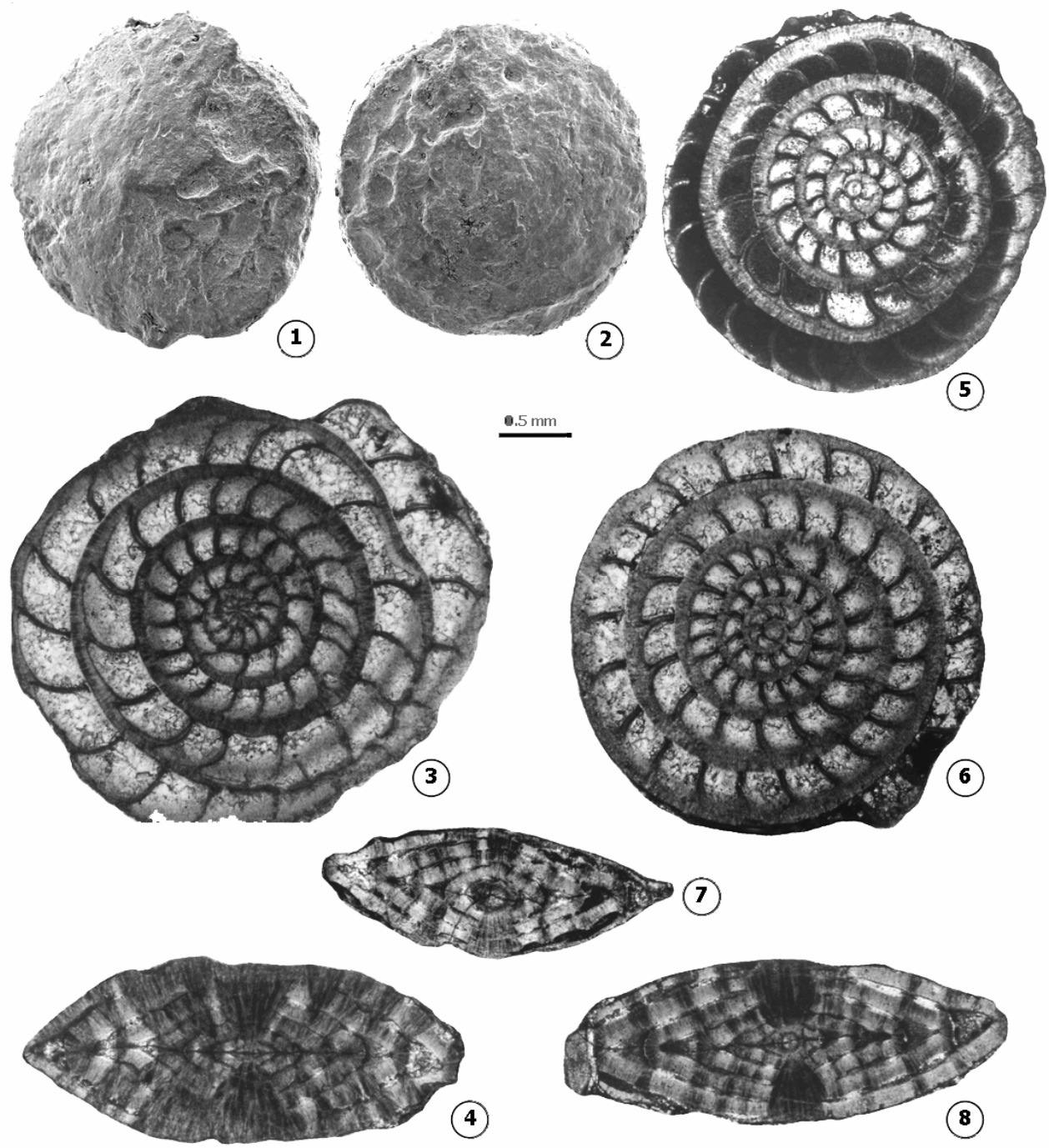


PLATE 4

1-2 *Nummulites ptukhiani* Z.D. KACHARAVA, 1969; external view, (A-Form).
3-4 *Nummulites ptukhiani* Z.D. KACHARAVA, 1969; 3-equatorial view; 4- axial view, (B-Form).
5-6 *Nummulites ptukhiani* Z.D. KACHARAVA, 1969; equatorial section, (A-Form).
7-8 *Nummulites ptukhiani* Z.D. KACHARAVA, 1969; axial section, (A-Form).

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REFERENCES

ABDELGHANY, O. (2002): Biostratigraphy (*Turborotalia cunialensis*/ *Cribrohantkenina inflata* Concurrent-Range Zone, P16) of the Late Eocene Dammam Formation, west of the Northern Oman Mountains.- Micropaleontology, 48: 209-221.

ADAMS, C.G. and RACEY, A. (1992): THE OCCURRENCE AND PALEOBIOGEOGRAPHICAL SIGNIFICANCE OF THE FORAMINIFERID YABERINELLA FROM THE EOCENE OF OMAN. Palaeontology, 35 part 1, 237-245.

AL-HASHIMI, H.A.J. (1980): Biostratigraphy of Eocene-Lower Oligocene of western desert, Iraq. Actes du VI Colloque Africain de Micropaléontologie, Tunis 1974, Annals des Mines et de la Géologie, Tunis, 3: 209-229.

ANAN, H.S. (1995): Late Eocene Biostratigraphy of Jabals Malaqet and Mundassa of Al Ain region, United Arab Emirates. Revue de Micropaleontologie, 38: 3-14 .

ANAN, H.S., BAHR, S.A., BASSIOUNI, M.A., BOUKHARY, M.A. and HAMDAN, A. (1992): Contribution to Early Eocene-Oligocene biostratigraphy of Jabal Hafit succession, United Arab Emirates.- Middle East Research Center, Ain Shams University, Earth Science Series, 6: 225-247.

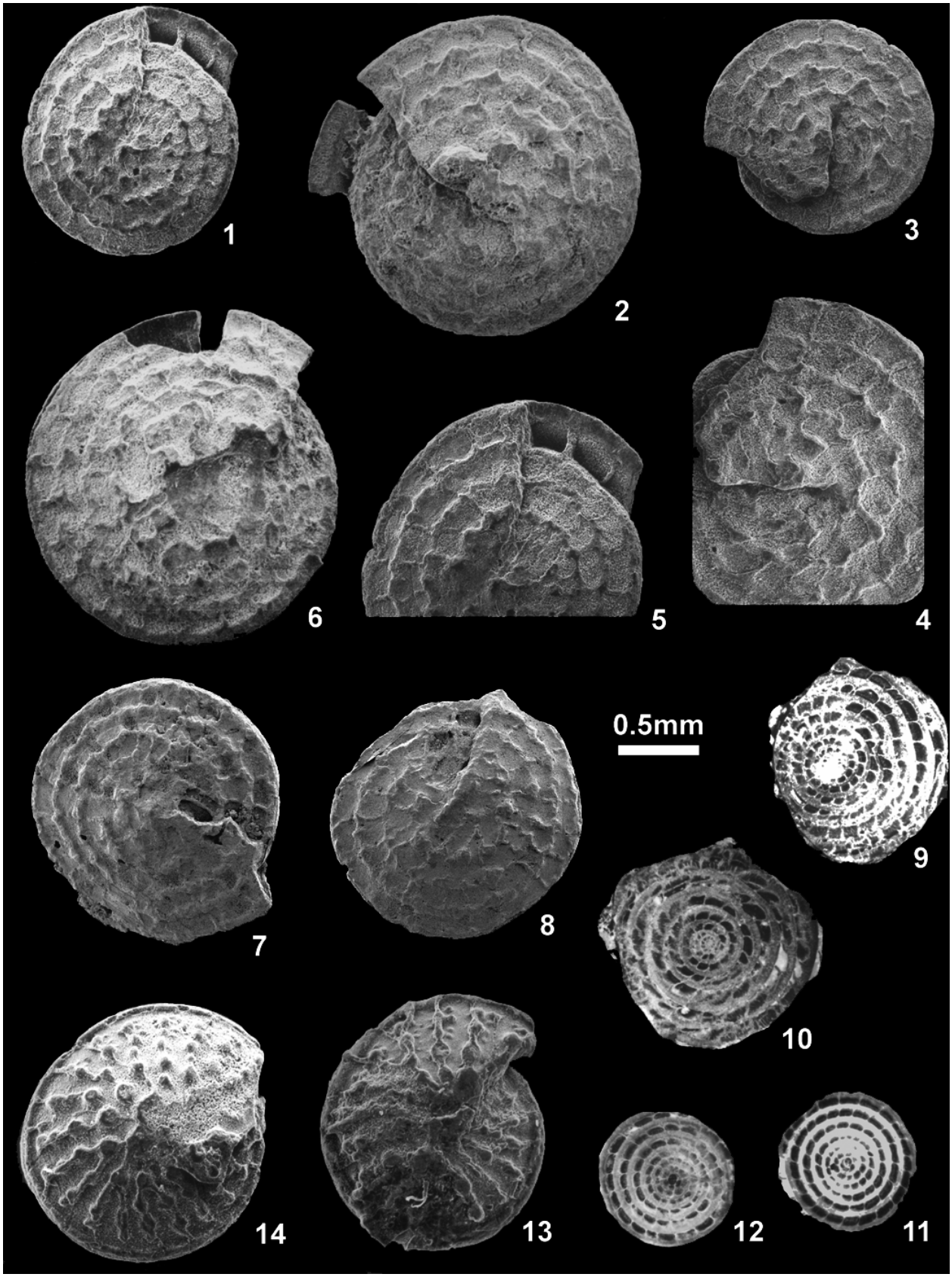
BEAVINGTON-PENNEY, S.J. and RACEY, A. (2004): Ecology of extant nummulitids and other larger benthic foraminifera; applications in palaeoenvironmental analysis. Earth Science Reviews, p.1-47.

BERGGREN, W.A., KENT, D.V., SWISHER III, C.C. and AUBRY, M.-P. (1995): A revised Cenozoic geochronology and chronostratigraphy. In BERGGREN, W.A., KENT, D.V., SWISHER III, C.C. AUBRY, M.-P. and HARDENBOL, J. (eds.). Geochronology, time scales and global stratigraphic correlation. SEPM, Special Publication 54: 129-212.

BOUKHARY, M. (1985): Paleontological studies on the Eocene Successionon western Qatar, Arabian Gulf. Revue Paleobiologie, vol.2 (4), p.183-202.

PLATE 5

1-8 *Nummulites retiatus* (ROVEDA, 1959); external view.
9-10 *Nummulites retiatus* (ROVEDA, 1959); equatorial section (B-Form).
11-12 *Nummulites retiatus* (ROVEDA, 1959); equatorial section, (A-Form).
13-14 *Nummulites garnieri* De la Harpe in Boussac, 1911 ; external view.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BOUSSAC, J. (1911): Etudes paleontologique sur le Nummulites Alpin. Mem. Carte Geol.de France, Paris, 17, pp.1-440, 22pls.

BRAMKAMP, R.A. (1941): Unpublished report: in Cavelier, C.: Geological description of the Qatar Peninsula. Department of Petroleum Affairs, Qatar, 39: 1970.

CHERIF, O.H. and EL-DEEB, W.M.Z. (1984): The Middle Eocene-Oligocene of the northern Hafit area, south of Al Ain City (United Arab Emirates).- Geology Mediterranean, 11/2: 207-217.

CHERIF, O. H., AL-RIFAIY, I. A. and EL-DEEB, W. Z. M. (1992): "Post-Nappes" early Tertiary foraminiferal paleoecology of the northern Hafit area, south of Al-Ain City (United Arab Emirates). Micropaleontology, 38: 37-56.

CIZANCOURT, T.De (1934): Materiaux pour la stratigraphie du Nummulitique sans le desert de Syrie. Bulletin Societe Geologie France, Series 54, pp.737-758, 3pls.

COCCIONI, R., MONACO, P., MONECHI, S., NOCCHI, M. and PARISI, G. (1988): Biostratigraphy of the Eocene-Oligoccne boundary at Massignano (Ancona, Italy). International Subcommittee Paleogene Stratigraphy, E/O Meeting, Ancona, Special Publication 2: 59-80.

CUVILLIER, J. (1930): Revision du Nummulitique Egyptien. Memoires de l' Institut Egypte, 16, pp.1-372, 25pls.

EL-NAKHAL, H, A. (1988): New observations on the geological age of the Dammam Formation in Arabia.- Micropaleontology, 34: 284-285.

HAMDAN, A.R.A. and BAHR, S. (1992): Lithostratigraphy of the Paleogene succession of northern Jabal Hafit, Al Ain area, United Arab Emirates.- Middle East Research Center, Ain Shams University, Earth Science Series, 6: 201-224.

HAQ, B.U., HARDENBOL, J. and VAIL, P.R. (1987): Chronology of fluctuating sea levels since the Triassic. Science, New York, vol. 235, p. 1156-1167.

HASSON, P. (1985): New observations on the biostratigraphy of the Saudi Arabian Umm er Radhuma Formation (paleogene) and its correlation with neighboring regions. Micropaleontology, 3:335-364.

HERB, R. and HEKEL, H. (1973): Nummuliten aus dem Obereocaen von Possagno. Schweizerische Paleontologische Abhandlungen 97: 113-135.

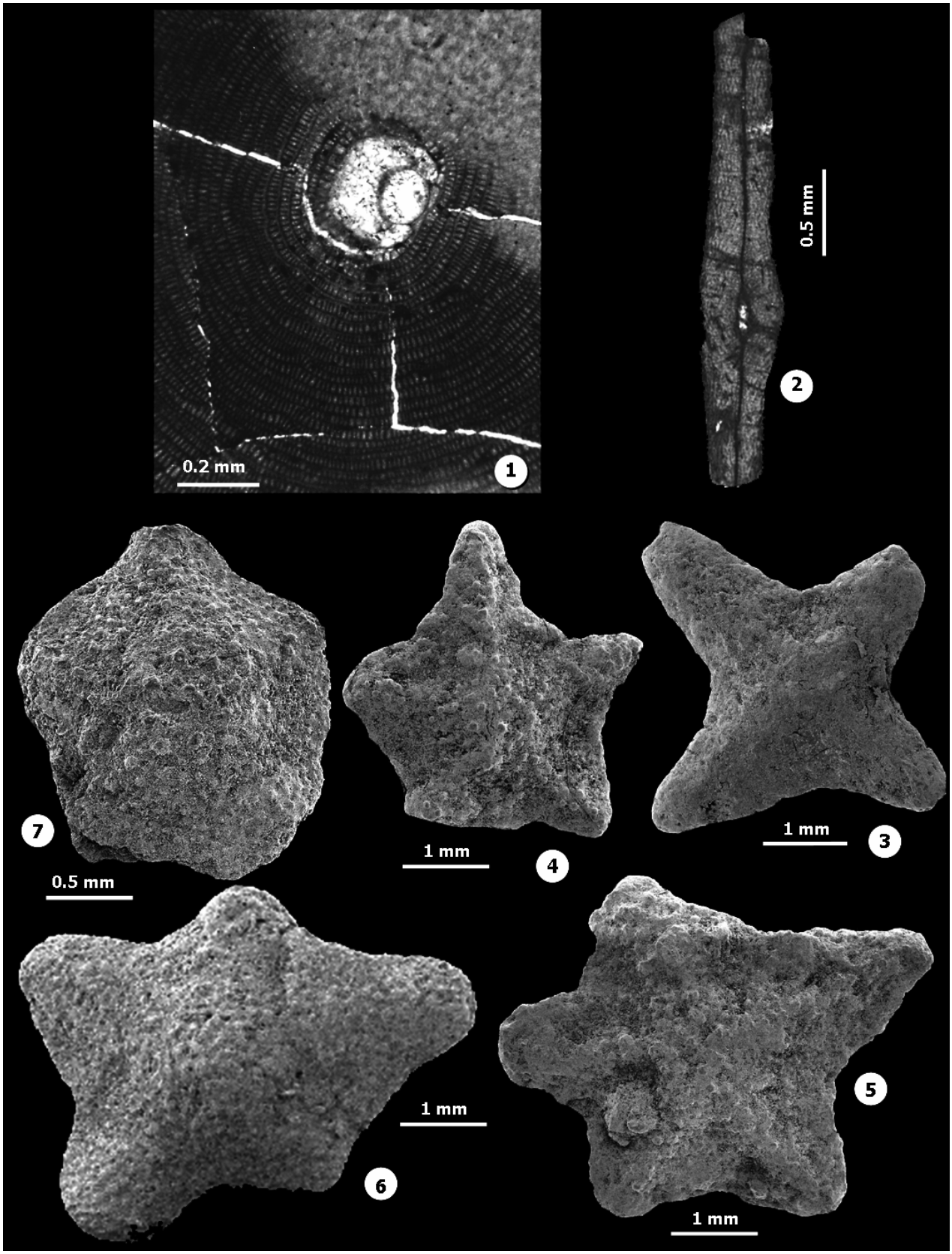
HERB, R. and HEKEL, H. (1975): Biostratigraphy, Variability and Facies Relations of some Upper Eocene Nummulites from Northern Italy.- Ecologae Geologicae Helvetiae, 66(2): 419-445.

HOHENEGGER, J., YORDANOVA, E., NAKANO, Y., and TATZREITER, F.(1999): Habitats of larger foraminifera on the upper reef slope of Sesoko Island, Okinawa, Japan. Marine Micropaleontology 36: 109-168.

HUNTING GEOLOGY and GEOPHYSICS LIMITED (1979): Report on a Mineral Survey of the U.A.E., Al-Ain Area. Ministry of Petroleum and Mineral Resources, Abu Dhabi, 9: 1-29.

PLATE 6

1-2 *Discocyclina pratti* (MICHELIN); 1-equatorial section; 2- axial section.
3-4 *Asterocyclina asterisca* (GUPPY); external view.
5, 6 *Asterocyclina pentagonalis* (SCHAFHÄUT); external views.
7 *Asterocyclina soladensis* CAUDRI, 1975 ; external view.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JONES, R.W. and RACEY, A. (1994): Cenozoic stratigraphy of the Arabian Peninsula and Gulf, Micropalaeontology and Hydrocarbon Exploration in the Middle East (M.D.Simmons, Ed.), 273-307, Chapman and Hall.

KELLER, G., HERBERT, T., DORSEY, R., D'HONDT, S., JOHNSSON, M. and CHI, W.R. (1987): Global distribution of late Paleogene hiatus. Geology, Boulder, 15: 199-203.

LOEBLICH, A. R. and TAPPAN, H. (1988): Foraminiferal genera and their classification.- pl., New York (Van Nostrand Reinhold Comp. Inc.). vol. 1:XII + 970 pp.; vol. 2X+

MARTINI, E. (1971): Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: A. FARINACCI (ed.), Proceedings II Planktonic Conference, Roma, 1970, 2, 739-85.

NOLAN, S. C., SKELTON, P. W., CLISSOLD, B. P. and SMEWING, J.D. (1990): Maastrichtian to early Tertiary stratigraphy and palaeogeography of the Central and Northern Oman Mountains.- In: ROBERTSON, A.H.F., SEARLE, M.P. and RIES, A.C. (Ed), The Geology and Tectonics of the Oman Region. Geological Society of London, Special Publication 49, 495-519.

PAPAZZONI, C.A. (1998): Biometric analyses of Nummulites "*ptukhiani*"Z.D.KACHARAVA, 1969 and Nummulites fabianii (PRAVER in FABIANI, 1905). Journal of Foraminiferal Research, 28 (3): 161-176.

PAPAZZONI, C.A. and A. SIROTTI (1995): Nummulites biostratigraphy at the Middle/Upper Eocene boundary in the Northern Mediterranean area. Rivista Italiana di Paleontologia e Stratigrafia , 101 (1): 63-80.

PARISI, G., GUERRERA, F., MADILE, M., MAGNONI, G., MONACO, P., MONECHI, S. and NOCCHI, M. (1988): Middle Eocene to Early Oligocene calcareous nannofossil and foraminiferal biostratigraphy in the Monte Cagnero section. Piobbico (Italy). International Subcommittee of Paleogene Stratigraphy, E/O Meeting, Ancona, Italy, Special Publication, 2: 119-135.

POWERS, R.W. (1968): Lexique Stratigraphique International Asie, Saudi Arabia (CNRS Paris), III (10): 177p.

POWERS, R.W., RAMIREZ, L.F., REDMOND, C.D. and BERG JR., E.L. (1966): Geology of the Arabian Peninsula.- Sedimentary Geology of Saudi Arabia. US Geological Survey, Prof. Paper 560 D. UD Government Printing Office, Washington: 147p.

RACEY, A. (1992): New nummulite (Foraminiferida) species from the Eocene of Northern Oman. Journal of Micropalaeontology, 11, 189-195.

RACEY, A. (1992): The relative taxonomic value of morphological characters in the genus *Nummulites* (Foraminiferida). Journal of Micropalaeontology, 11, 199-209.

RACEY, A. (1994): Biostratigraphy and palaeobiogeographic significance of Tertiary Nummulitids (Foraminifera) from Northern Oman. Micropalaeontology and Hydrocarbon Exploration in the Middle East (M.D.SIMMONS, Ed.), 343-370, Chapman and Hall.

RACEY, A. (1994): Palaeoenvironmental Significance of Larger Foraminiferal Biofabrics: Implications for Petroleum Exploration. AL-HUSSEINI, M.I.(ed.) Selected Middle East Papers from AAPG GEO'94, Bahrain, Vol.2, 793-810.

RACEY, A. (1995): Lithostratigraphy and larger foraminiferal (nummulitid) biostratigraphy of the Tertiary of Northern Oman.- Micropaleontology, vol. 41, supplement, pp.1-123, text-figures 1-93, plates 1-11, appendix 1.

RACEY, A. (2001): A review of Eocene Nummulite accumulations: structure, formation and reservoir potential. Journal of Petroleum Geology, 24 (1), 79-100.

PLATE 7

Field photographs showing the stratigraphic relations and characters of the Dammam Formation in the study area.

1- Interlayer larger foraminiferal limestone and marl of the Dammam Formation, Jabal Qatar.

2-4 Interlayer larger foraminiferal limestone and marl of the Dammam Formation, Jabal Malaqet.

5-6 Interlayer larger foraminiferal limestone and marl of the Dammam Formation, Jabal Hafit.

7- Interlayer larger foraminiferal limestone and marl of the Dammam Formation, western limb of Jabal Buhays Anticline, Al Faiyah Range Mountains.


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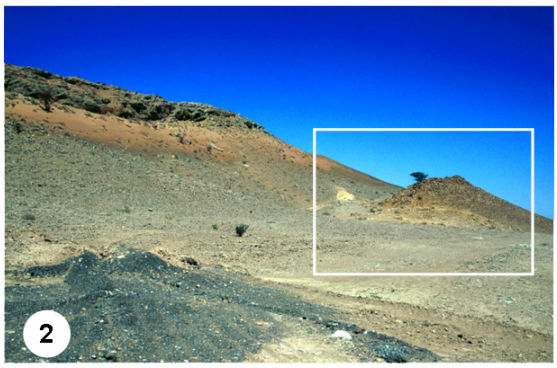
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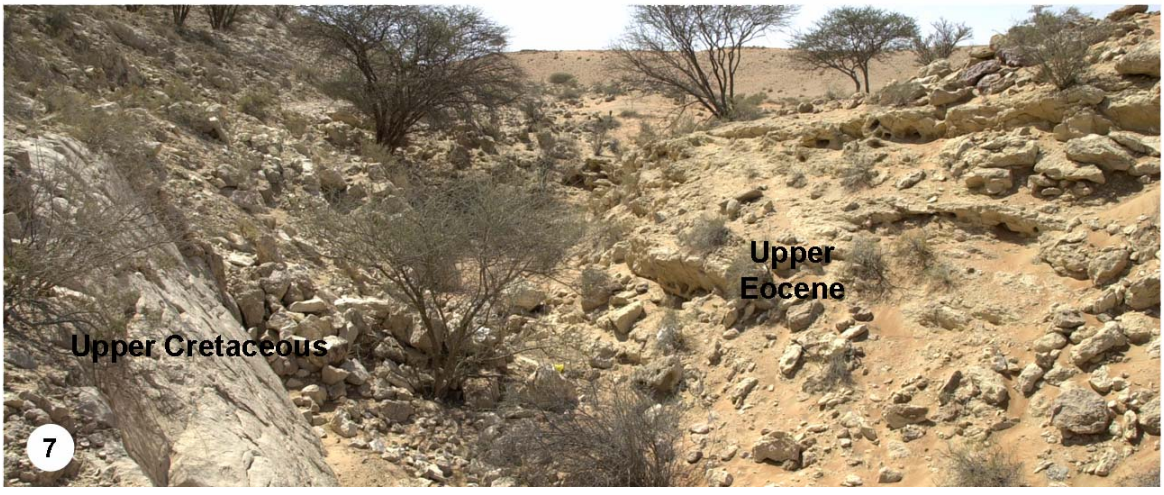
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SCHAUB, H. (1981): *Nummulites* et *Assilines* de la Tethys Paleogene. Taxinomie, Phylogenese et Biostratigraphie. Memoires Suisses de Paleontologie, vol.104:236p., vol.105 (Atlas I) and vol.106 (Atlas II).

SERRA-KIEL, J. L. HOTTINGER, E.CAUS, K.DROBNE, C.FERRANDEZ, A.K.JAUHRI, R. PAVLOVEC, J.PIGNATTI, J.M. SAMSO, H. SCHAUB, E. SIREL, A.STROUGO, Y.TAMBAREAU, J..TOSQUELLA and E.ZAKREVSKAYA (1998): Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. Bulletin Societe geologie France, 169 (2): 281-299.

SIREL, E. (2003): Foraminiferal description and biostratigraphy of the Bartonian, Priabonian and Oligocene shallow-water sediments of the southern and Eastern Turkey. Revue de Paléobiologie, Genève, 22 : 269-339.

TERRATEST, LTD. (1973): Abu Dhabi Mineral Survey: Final Report (Unpublished).

WHITE, M.R. (1994): Foraminiferal biozonation of the northern Oman Tertiary carbonate succession. In Micropaleontology and Hydrocarbon Exploration in the Middle East book Edited by SIMONS, M.D., 309-342.

WHITTLE, G.L, ALSHARHAN, A.S. and EL-DEEB, W.M.Z. (1996): Facies analysis and early diagenesis of the Middle-Late Eocene Dammam Formation, Abu Dhabi, United Arab Emirates.- Carbonates and Evaporites, 11: 32-41.