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# Biostratigraphy and paleoenvironmental interpretation of Middle Eocene sequences from Darende-Balaban Basin (Eastern Anatolia, Turkey)

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**Abstract:** The Middle Eocene sequence in the Darende-Balaban Basin (Eastern Turkey) characterized by shallow and deep marine benthic and planktonic foraminiferal assemblages. *Nummulites* and other benthic foraminifers are common in its lower part (mainly in the conglomerates and sandstones) while the planktonic foraminiferal assemblages are abundant in middle and upper parts (generally fine-grained sediments). *Acarinina bulbrooki* Zone is identified within Middle Eocene strata in the study area. This biozone correlated with other Mediterranean, southern mid- to high-latitude successions where some similar species are recorded. Paleontological and sedimentological data presented in this study suggest that the Middle Eocene sequences are dominated by siliciclastic and carbonate sediments that were deposited in various environments ranging from very shallow (Korgantepe, Asartepe and Darende Formations) to deep marine (Yenice Formation) ones.

**Key words:** Middle Eocene, Turkey, paleoenvironment, biostratigraphy, Ostracoda, Foraminifera.

## Introduction

Closure of the neo-Tethys as a result of collision of the Anatolian and Arabian plates during the Middle Eocene is represented by narrow and elongated sedimentary basins located on the marginal parts of these plates, mostly on the foreland and the southern flanks of the Anatolian plate. The Darende-Balaban Basin is one of those basins, located geologically in the Eastern Taurus Mountain segment and geographically 50 km north-northwest of Malatya, around and south of Darende town, Eastern Turkey (Fig. 1).

General geological and petroleum exploration related studies about the Darende-Balaban Basin have been done since 1938 (Blumenthal 1938; Baykal 1944; Demirtaşlı & Ayan 1963; Ürgün 1963; Ayan & Bulut 1964; Wirtz 1965; Akkuş 1970, 1971; Kurtman & Akkuş 1974; Sirel 1976; Kurtman 1978). Those followed by some sedimentological and paleontological studies authored by Nazik (1993), Gürbüz & Taptık (2001), Erdoğan & Nazik (2003).

The study of this well exposed Middle Eocene sequence represented in the Darende-Balaban Basin was an important key to understand the paleoenvironmental history of this basin. Thus, this research has been done: a) to define planktonic foraminiferal zones in the Middle Eocene sequence of the Darende-Balaban Basin and b) to interpret its paleoenvironmental conditions based on the lithological features and planktonic/benthic foraminiferal features and ratios.

## Geological setting

Paleogene deposits are widespread in the Sivas-Zara-Hafik, Darende-Balaban and Muş-Hınıs-Malazgirt Basins,

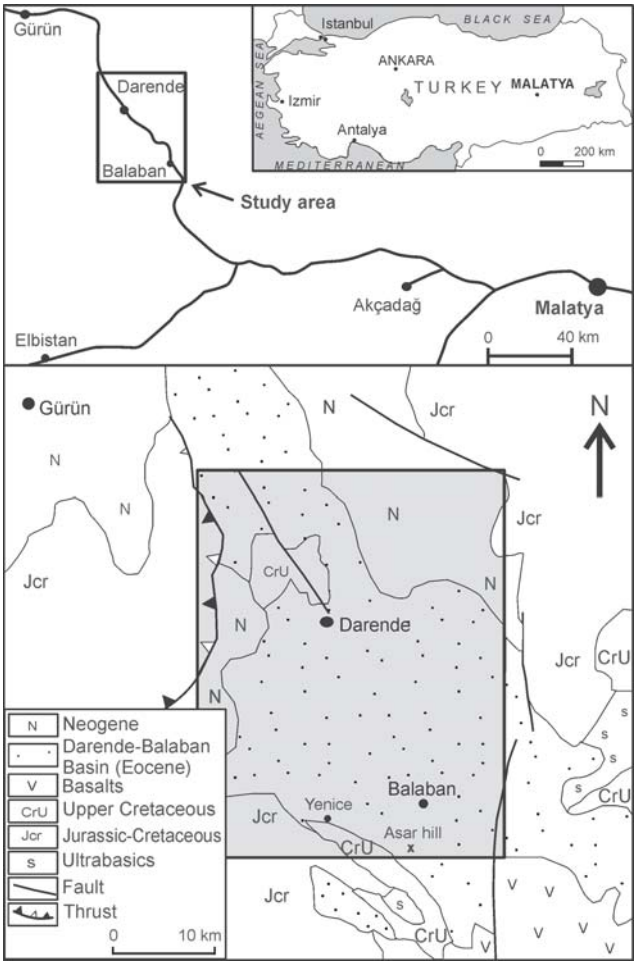


**Fig. 1.** Location map of the study area with simplified geological map (after Kurtman & Akkuş 1974).

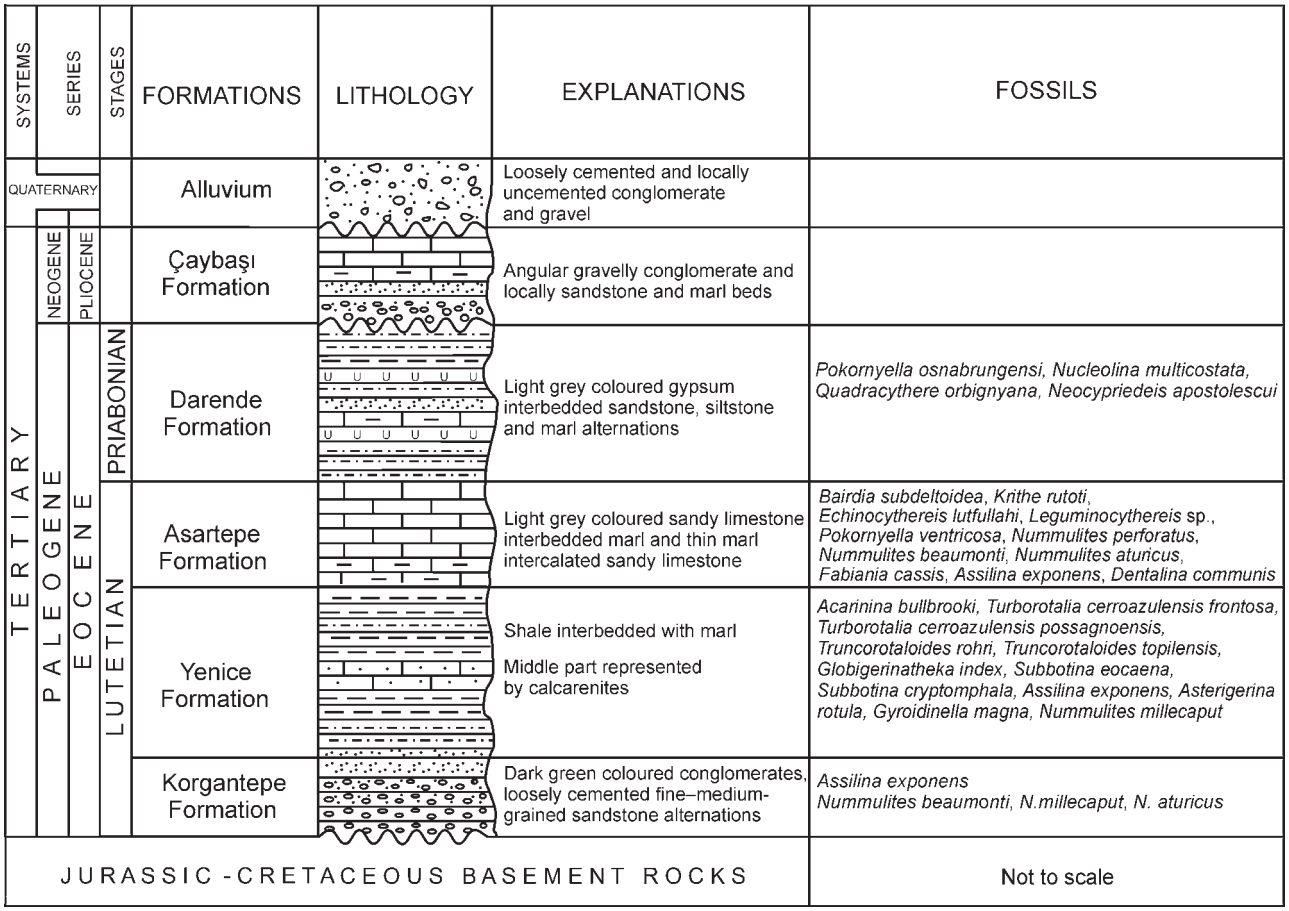


**Fig. 2.** Generalized stratigraphy of the study area (modified after Kurtman & Akkuş 1974).

in Eastern Turkey. The Darende-Balaban Basin is surounded by pre-Cretaceous and Cretaceous basement highs from the north and south (Fig. 1). The basement of the Darende-Balaban Basin is represented by Upper Jurassic–Lower Cretaceous carbonate and ophiolitic rocks forming structural highs in the north and the south of the basin. The Eocene sediments discordantly and transgressively overlie Cretaceous basement rocks (Fig. 2).

The Eocene succession consists of four lithostratigraphic units (from the base upwards), namely the Korgantepe Formation (Lutetian), the Yenice Formation (Lutetian), the Asartepe Formation (Lutetian) and the Darende Formation (Priabonian).

The Korgantepe Formation overlies Maastrichtian aged limestones and siliciclastics with an erosional unconformity (Fig. 3). The maximum thickness of this unit of 100 m was measured in the northern part of the Darende-Balaban Basin. The lower parts of the Korgantepe Formation consist of conglomerates deposited on Cretaceous fine-grained sediments. The bed thickness of conglomerates changes between 2 to 4 m. Conglomerates pass into pebbly sandstones (1–1.2 m thick), then sandstones and finally sandstones with shale intercalations.

The Korgantepe conglomerates gradually pass upwards into the Yenice Formation which is characterized by fine-grained sediments. The Yenice Formation consists of two main facies which were described previously as two members of the Yenice Formation by Akkuş (1971). These are the Yenice marls and the Yenice calcarenites. The Yenice marls are characterized by white to beige coloured, thin bedded siltstone and marl alternations. The Yenice calcarenites occur mainly in the middle parts of the Yenice Formation as lenticular geometries (Fig. 3). They consist of carbonates clasts and some fossil (corals, algae and nummulits) fragments.

The Yenice marls gradually passes upwards into Asartepe Formation (Fig. 3). The Asartepe Formation consists of white-yellow coloured, fine crystallized limestone and marly limestone in the basal parts. This part contains fossils with extrabasinal and intrabasinal clasts derived from underlying units. Higher up the sections it gradually passes into pale grey-green coloured, uniform medium- to thick-bedded limestones. This part of the formation is characterized by corals, algae, and other macro- and microfossils with less extrabasinal fragments. A 120 m of limestone thickness has been measured from this area by Akkuş (1971), but this thickness laterally decreases down to 5 m and to even less because of the lenticular geometry of the unit.

The Darende Formation is mainly composed of conglomerate, pebbly sandstone, sandstone-siltstone-marl alternations interbedded with gypsum beds. The lower part of the formation mainly consists of the coarse-grained sed-

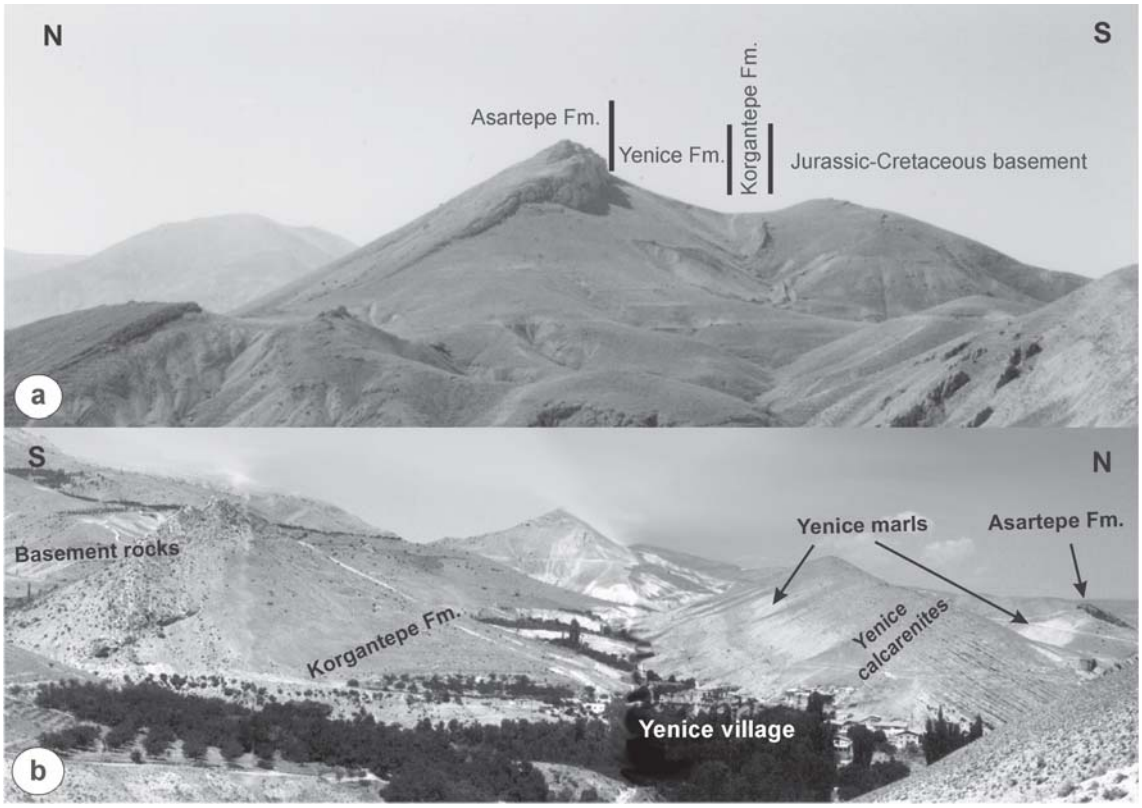


**Fig. 3.** Field photographs from the southern part of the study area showing relationships of the lithostratigraphic units. **a** — Location of the Asar hill section, looking towards to the east. **b** — Location of the Yenice section, looking towards to the west. Note the lenticular shape and total thickness changes of the Yenice and Asartepe Formations.

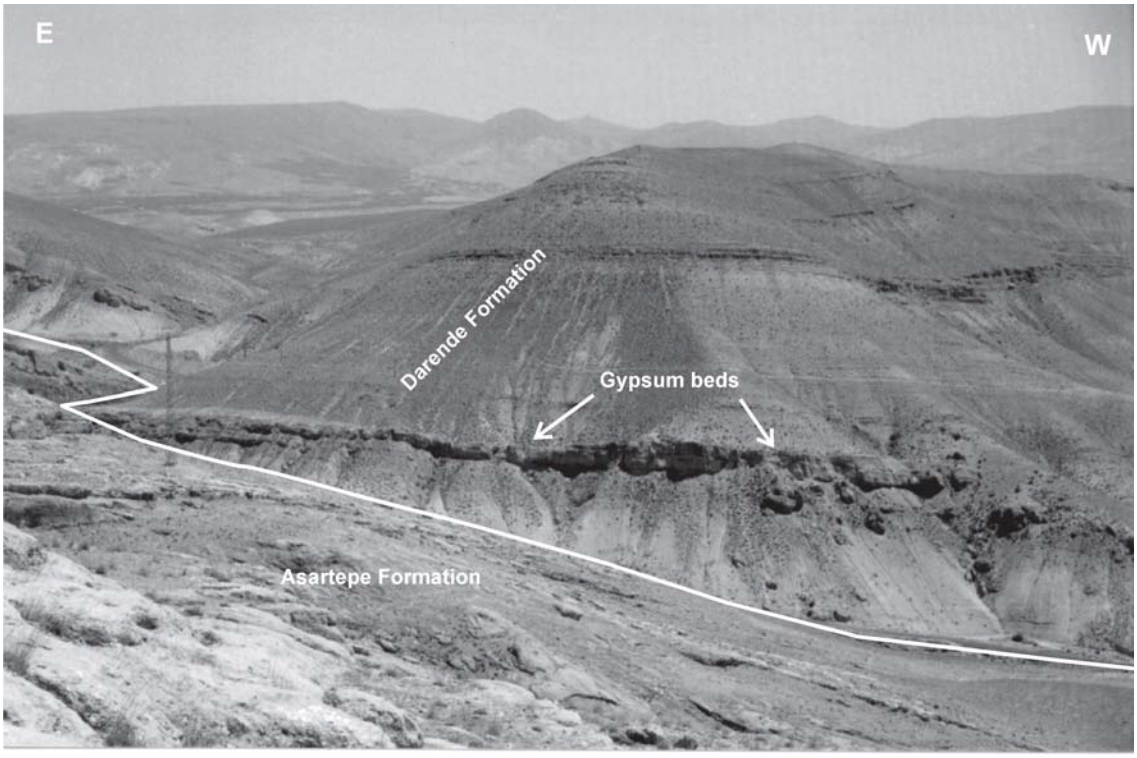


**Fig. 4.** A field photograph from the east of Darende town, showing relationships between Asartepe and Darende Formations, looking towards the south.

iments. The middle part of the sequence is characterized by, coarse- to fine-grained sandstones and marl intercalations. All the sequence then fines upward into the fine- to medium-grained sandstones with marls, then finally into the marls towards to the central parts of the basin. Gypsum beds were observed some parts of the formation (Fig. 4).

## Material and method

The data presented here is derived from three different projects done by the authors. Sections (Alidede Tepe, Mercimek Tepe, Darende, Ayvalı, Dervişbey, Boztepe and Polat) measured by Nazik (1993) around Darende town — in the northern part of the study area, Sarıcakaya, Gedik-Musu, Çatıkkaya, Haremi, Asar sections measured by Erdoğan & Nazik (2003) from the southern part of the study area were studied for foraminifers and ostracods. Two representative sections, the Yenice section measured by Gürbüz & Taptık (2001) and the Asar section measured by Erdoğan & Nazik (2003), were selected and used in this paper to show the relationships between lithostratigraphic units and foraminiferal abundance. One hundred grams of rock material was washed from 80, 130 and 270 mesh sieves for paleontological examinations. Total planktonic and benthic foraminifers were counted for each sample for all sections. Planktonic and benthic foraminiferal abundancy diagrams are prepared for Middle Eocene units. Additionally, benthic microfossil content from the thin sections of Yenice calcarenites has also been identified. Planktonic foraminiferal species identification was based mainly on Stainforth et al. (1975) and Bolli et al. (1985).

Scanning electron microscope images (Figs. 5, 6) of selected species were taken with Jeol JSM 5600 at ASSAN (Tuzla-Istanbul). The fossil materials are housed in the Department of Geology, Faculty of Engineering & Architecture, Çukurova University in Adana/Turkey.

Beside the paleontological analysis of the measured sections indicated here, the sedimentological properties of each unit were also evaluated with their field and thin section examinations from the sections measured by Gürbüz & Taptık (2001).

## Biostratigraphy

Fossil assemblages of Eocene sediments in the study area consist of planktonic/benthic foraminifers and ostracods (Figs. 7, 8).

Benthic foraminifers have been found within the Korgantepe, Yenice and Darende Formations. *Assilina exponens* (Sowerby), *Nummulites beaumonti* d'Archiac et Haime, *Nummulites millecaput* Boubée, *Nummulites aturicus* Joly et Leymerie are found in the Korgantepe Formation and calcarenite levels of Yenice Formation whereas *Asterigerina rotula* (Kaufmann), *Discocyclina* sp., *Fabiania cassis* (Openheim), *Operculina* sp., *Planorbulina* sp. occur in calcarenite levels of Yenice Formation. *Rotalia trochidiformis* Lamarck, *Sphaerogypsina globulus* (Reuss), *Halkyardia minima* Liebus, *Quinqueloculina* sp., *Cibicides* sp., *Nonion* sp., *Nodosaria* sp., *Uvigerina* sp., and *Eponides* sp. are found in the Darende Formation.

The planktonic foraminiferal assemblages from the Yenice Formation consist of *Acarinina bullbrooki* (Bolli), *Acarinina*

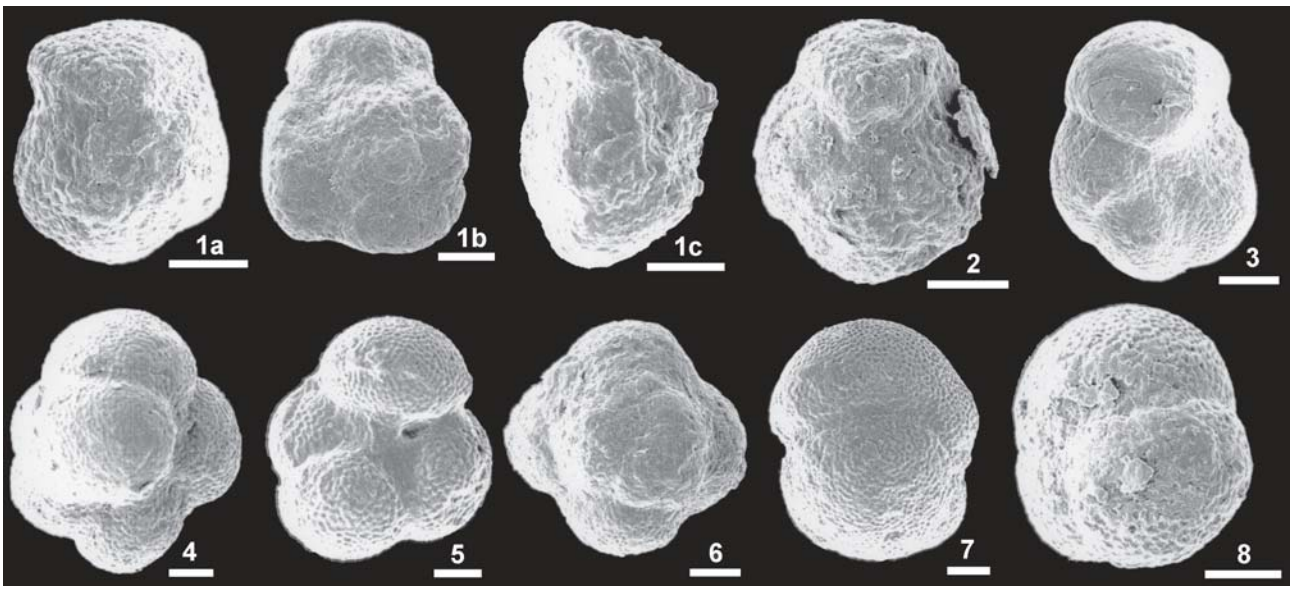


**Fig. 5. 1** — *Acarinina bullbrooki* (Bolli); a —umbilical view, b — spiral view, c — peripheral view; Sarıcakaya section, sample number 14. **2** — *Acarinina matthewsae* (Blow); umbilical view, Çatıkkaya section, sample number 9. **3** — *Acarinina spinuloinflata* (Bandy); umbilical view, Çatıkkaya section, sample number 9. **4** — *Subbotina cryptomphala* Glaessner; umbilical view, Sarıcakaya section, sample number 14. **5** — *Subbotina eocaena* Guembel; umbilical view, Sarıcakaya section, sample number 4. **6** — *Globigerina venezuelena* Hedberg; spiral view, Çatıkkaya section, sample number 5. **7** — *Globigerinatheka index* (Finlay); umbilical view, Sarıcakaya section, sample number 1. **8** — *Globigerinatheka mexicana mexicana* (Cushman); umbilical view, Sarıcakaya section, sample number 9. Note: scale bar is equal to 100 µm.

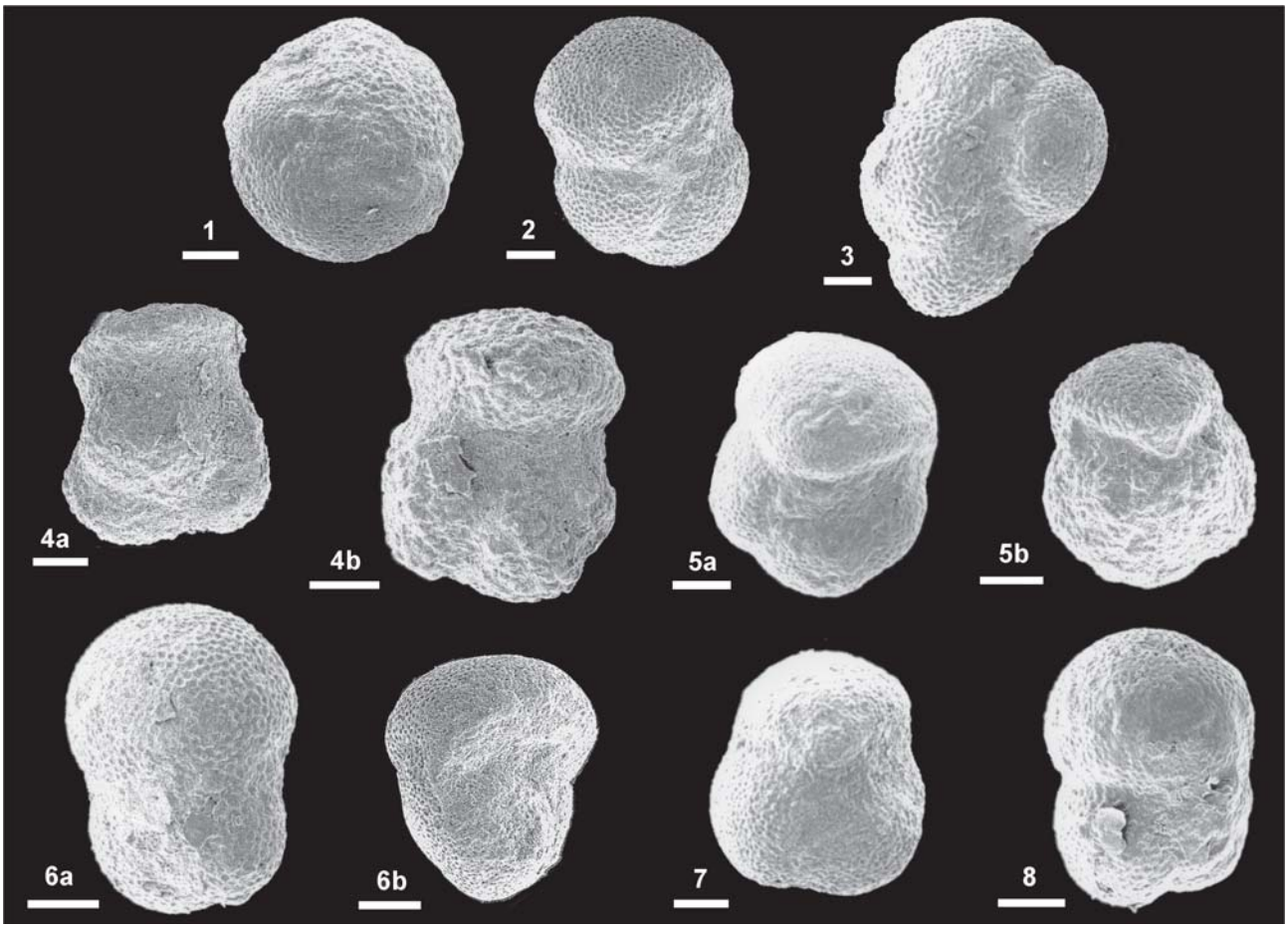


**Fig. 6. 1** — *Globigerinatheka luterbacheri* Bolli; spiral view, Sarıcakaya section, sample number 1. **2** — *Globigerinatheka subconglobata subconglobata* (Shutskaya); spiral view, Sarıcakaya section, sample number 14. **3** — *Subbotina higginsi* Bolli; spiral view, Sarıcakaya section, sample number 3. **4** — *Truncorotaloides topilensis* (Cushman); a — spiral view, b — umbilical view; Sarıcakaya section, sample number 14. **5** — *Turborotalia centralis* (Cushman et Bermüdez); a — spiral view, b — umbilical view; Sarıcakaya section, sample number 10. **6** — *Turborotalia cerroazulensis frontosa* (Subbotina); a — umbilical view, b — peripheral view; Sarıcakaya section, sample number 1. **7** — *Turborotalia cerroazulensis pomeroli* (Toumarkine et Bolli); umbilical view, Sarıcakaya section, sample number 14. **8** — *Turborotalia cerroazulensis possagnoensis* (Toumarkine et Bolli); spiral view, Sarıcakaya section, sample number 14. Note: scale bar is equal to 100 μm.

*matthewsae* (Blow), *Acarinina primitiva* (Finlay), *Acarinina spinuloinflata* (Bandy), *Subbotina cryptomphala* (Subbotina), *Subbotina eocaena* (Guembel), *Globigerina venezuelana* Hedberg, *Globigerina yeguaensis* Weinzierl et Applin, *Globigerinatheka index* (Finlay), *Globigerinatheka mexicana mexicana* (Cushman), *Globigerinatheka subconglobata curryi* (Bolli), *Globigerinatheka luterbacheri* Bolli, *Globigerinatheka subconglobata subconglobata* (Shutskaya), *Subbotina higginsi* (Bolli), *Truncorotaloides libyaensis* El-Khoudary, *Truncorotaloides rohri* Brönnimann et Bermüdez, *Truncorotaloides topilensis* (Cushman), *Turborotalia centralis* (Cushman et Bermüdez), *Turborotalia cerroazulensis cocoaensis* (Cushman), *Turborotalia cerroazulensis frontosa* (Subbotina), *Turborotalia cerroazulensis pomeroli* (Toumarkine et Bolli), *Turborotalia cerroazulensis possagnoensis* (Toumarkine et Bolli).

In addition, the ostracods *Bairdia cymbula* (Deltel), *Cytherella triestina* (Kollmann), *Cytherella ihsaniyensis* (Sönmez-Gökçen), *Krite rutoti* (Keij) are found in the Yenice Formation. The following ostracod species have been found in the Asartepe Formation: *Bairdia (Bairdiopplata) gliberti* Keij, *Echinocythereis isabenana* Oertli, *Echinocythereis scabra* (Munster), *Krite rutoti* (Keij), *Xestoleberis subglobosa* (Bosquet), *Pokornyella ventricosa* (Bosquet) and *Uroleberis striatapunctata* (Ducasse). *Quadracythere orbignyana* (Bosquet), *Nucleolina multicostata* (Deltel), *Pokornyella osnabrungensis* (Lienenklaus) and *Neocyprideis apostolescui* (Keij) occur in the Darende Formation (Nazik 1993).

The composition of the planktonic foraminiferaal assemblages allow us to distinguish the *Acarinina bullbrooki* Zone in the Middle Eocene of the Darende-Balaban Basin (Eastern Anatolia, Turkey).

Acarinina bullbrooki *Zone*

**Category:** Taxon range zone.
**Age:** Lutetian.
**Author:** Krasheninnikov, 1965a,b, 1969.
**Definition:** Range of zonal marker.

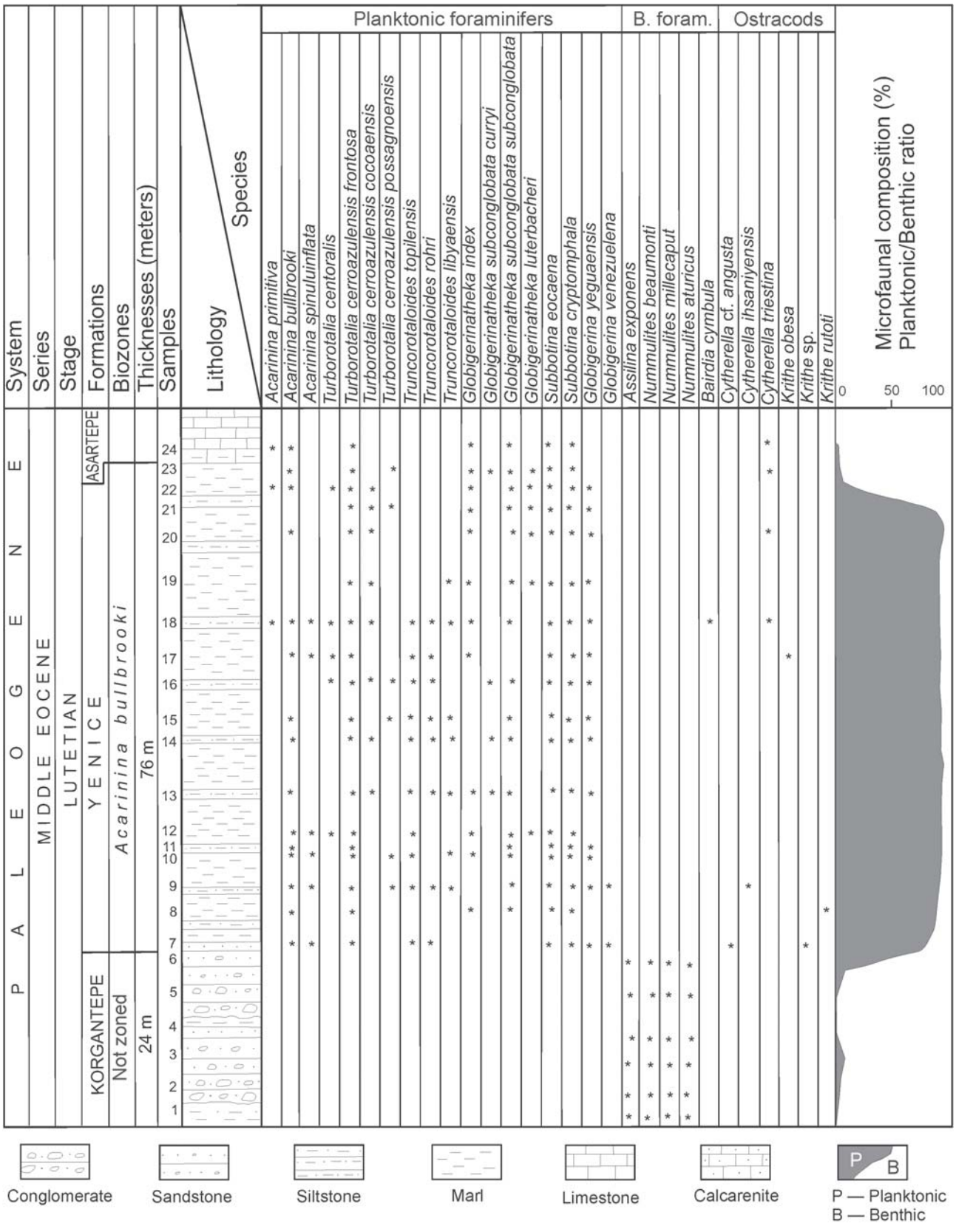


**Fig. 7.** Microfaunal composition with the planktonic/benthic foraminiferal ratio of the Korgantepe and Yenice Formations, from the Asar section.

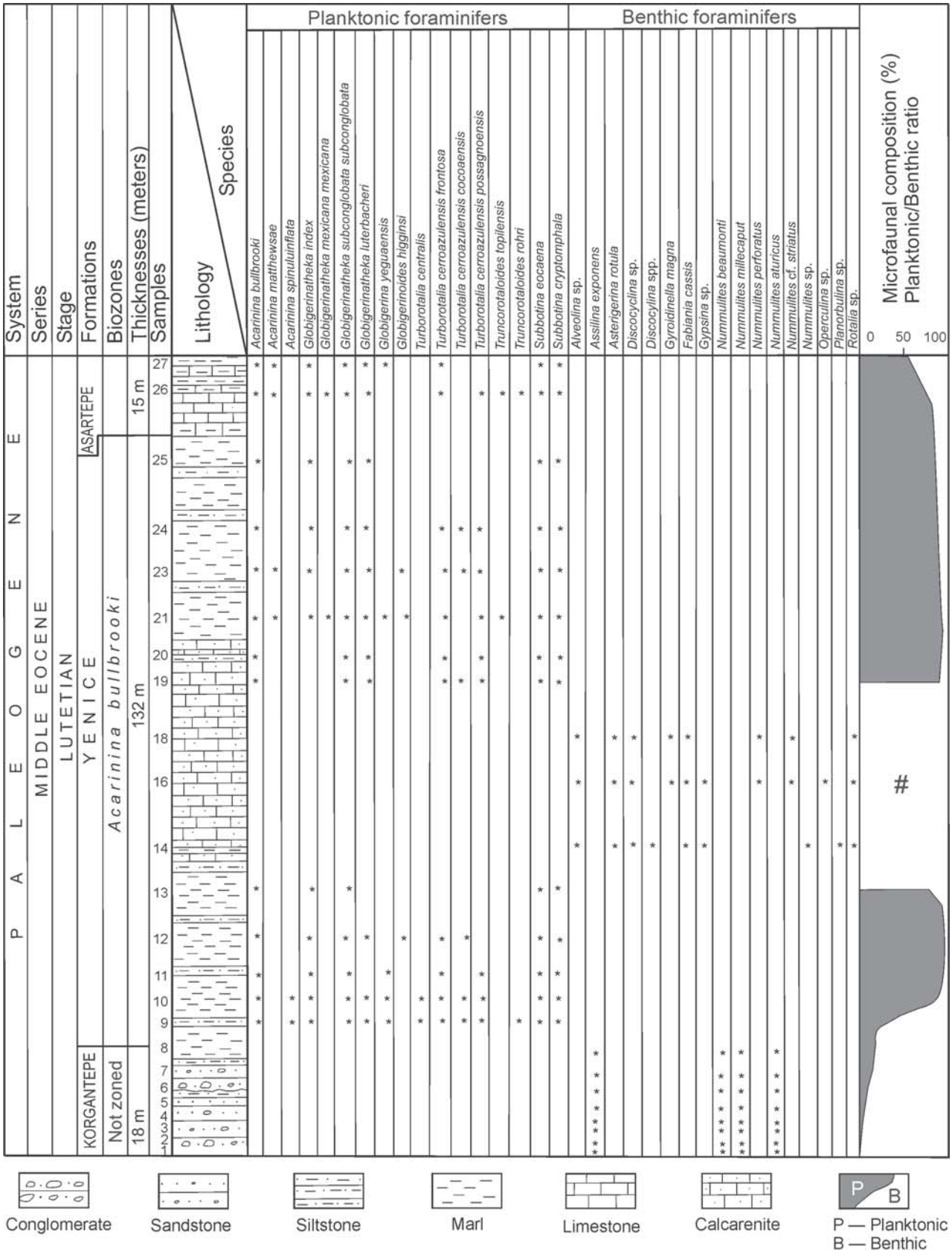


**Fig. 8.** Microfaunal composition with the planktonic/benthic foraminiferal ratio of the Korgantepe, Yenice and Asartepe Formations, from the Yenice section. # — Thin section examinations, no planktonic/benthic foraminiferal ratio study has been done from the calcarenites.

**Correlation and interpretation:** *Acarinina bullbrooki* was used as zonal marker by Krasheninnikov (1965a,b, 1969) for the base of the Middle Eocene. Bolli (1957) used *Hantkenina aragonensis* as the zonal marker of the Middle Eocene (P 10). The *Hantkenina aragonensis* Zone is renamed the *Hantkenina nuttalli* Zone by Toumarkine (1981). The characteristic taxa for the Middle Eocene and Late Eocene are *Hantkenina*, *Clavigerinella*, *Globigerinatheka* and *Turborotalia cerroazulensis* group. *Hantkenina* and *Clavigerinella* have not been found, whereas *Acarinina bullbrooki*, *Globigerinatheka* and *Turborotalia cerroazulensis* group species are abundant in the Darende-Balaban Basin. In higher latitudes, some of the Middle and Late Eocene zonal marker are often missing (Toumarkine & Luterbacher 1985). For this reason, an alternative zonal scheme from mid-latitudes based on the evolution of the *Turborotalia cerroazulensis* Lineage instead of parts of the *Hantkenina nuttalli* Zone and the *Globigerinatheka subconglobata subconglobata* Zone in the Eocene was proposed by Toumarkine & Bolli (1970). Alternative criteria for recognition of the base of the Middle Eocene are the appearance of the common and typical *Acarinina bullbrooki* according to Stainforth et al. (1975).

Therefore, *Acarinina bullbrooki* Zone is identified within the Middle Eocene sequence in the study area. *A. bullbrooki* Zone of Krasheninnikov (1965, 1969) is correlated with Zone P10-11 of Blow (1969), Berggren & van Couvering (1974) and the upper part of the *Turborotalia cerroazulensis frontosa* and *Turborotalia cerroazulensis possagnoensis* Zone of Toumarkine & Bolli (1970) emended Toumarkine (Toumarkine & Luterbacher 1985).

The *Acarinina bullbrooki* Zone has an interregional importance. It has been described in Egypt by Beckmann et al. (1969), in the Haymana Basin (Middle Anatolia) by Toker (1977) and Yıldız & Toker (1991), in the Antakya Basin (Southern Anatolia) by Yıldız & Toker (1993) and Şafak (1993) and in the Mut-Karaman Basin (Middle Taurus) by Şafak (1999) (Table 1).

## Paleoenvironmental interpretations of the Middle Eocene

The paleoenvironmental interpretations of the Middle Eocene formations described here are based on the ratio of planktonic/benthic foraminiferal associations, other fossil content, sedimentological characteristics of the sequences and examinations of thin sections from the study area. The planktonic/benthic ratio of foraminiferal associations used for environmental studies is based on Murray (1991).

### *Korgantepe Formation*

The Middle Eocene sedimentation starts with a transgressive sequence and is represented by the Korgantepe Formation which discordantly overlies the basement rocks (Fig. 3). This formation starts with an erosive basal conglomerates, passes upward into pebbly sandstones and finally sandstones. It consists of ophiolitic and carbonate rock fragments which were derived from the basement rocks.

**Fig. 9.** A close-up view to the upper parts of the Korgantepe Formation, showing abundance of *Nummulites* fossils. Lens cap for scale. From the Yenice section.

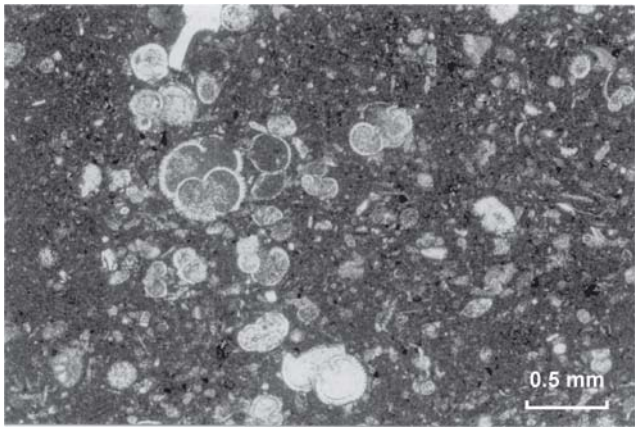


**Fig. 10.** Thin section photomicrograph from the Yenice marls. Note to the abundance of the planktonic foraminifers. From the Yenice section.

The Korgantepe Formation contains large benthic foraminifers (*Nummulites*, *Assilina*), which are abundant in some levels; specimens of the genus *Nummulites* represent up to 80–90 % of the fossil assemblages (Fig. 9). The planktonic foraminiferal ratio is very low in this formation (Figs. 7, 8).

The erosional base, lenticular geometry of whole strata, sequence characteristics of this unit and paleontological evidence derived from the Korgantepe Formation show that this unit was deposited under nearshore, shallow marine (shoreline–shore face) conditions.

### *Yenice Formation*

After the deposition of the Korgantepe Formation, transgression is continued in this area and deposition represented by Yenice Formation. The Korgantepe Formation gradually passes upward into the Yenice Formation.

**Table 1:** A comparision chart for *Acarinina bullbrooki* Zone according to different authors.

| AGE | | Standard Zonation Bolli (1957,1966) | Krasheninnikov (1965a,b,1969) | | Beckmann et al. (1969) | Toumarkine & Bolli (1970) | Blow (1969) Berggren & van Couvering (1974) | | Toumarkine & Luterbacher (1985) (Toumarkine & Bolli 1970 emended Toumarkine) | Şafak (1993, 1999) Yıldız & Toker (1991, 1993) Turkey | Berggren et al. (1995) | This study Darende-Balaban Basin Turkey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EOCENE | MIDDLE | Morozovella lehneri | A. rotundimarginata | | G. bullbrooki | G. c. possa-gnoensis | P12 | G. lehneri | T. c. possagnoensis | A. bullbrooki | M. aragonensis<br>Gb. kugleri | A. bullbrooki |
| | | Globigerinatheka subconglobata subconglobata | A. bullbrooki | G. kugleri | | | P11 | G. kugleri | | | | |
| | | Hantkenina nuttalli | | H. aragonensis | | G. c. frontosa | P10 | H. aragonensis | T. c. frontosa | | H. nuttalli | |
| | EARLY | Acarinina pentacamerata | G. arago-nensis | A. pentaca-merata | G. arago-nensis | | P9 | A. densa | | | P. palmerae | |

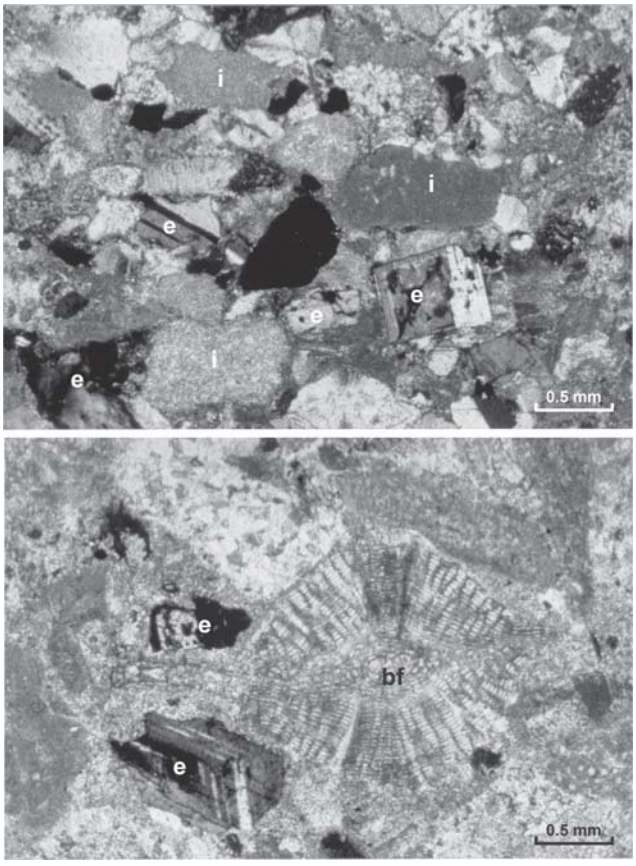


**Fig. 11.** Thin section photomicrograph from the Yenice calcarenites. Note to the intraclasts from the underlying marls with extraclasts from the basement rocks (a) and benthic foraminifers (b). From the Yenice section. **i** — intraclast, **e** — extraclast, **bf** — benthic foraminiferal (*Discocyclina* sp.).

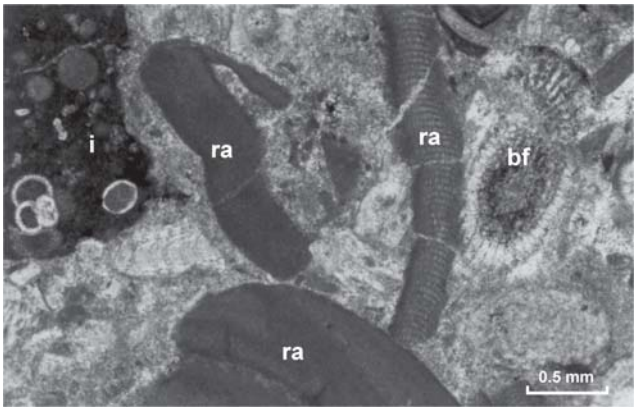


**Fig. 12.** Thin section photomicrograph from the Asartepe limestones. Note to the red Algea fragment and planktonic foraminiferal rich intraclast (seen in the upper left corner of photo) derived from the Yenice marls. From the Asar section. **i** — intraclast, **ra** — red Algea, **bf** — benthic foraminifer.

It consists of marls alternated with fine-grained sandstones and siltstones at the lower parts. This part of the sequence consists of less rock fragments and some macrofossils compared to the Korgantepe Formation. The middle and upper part of the Yenice marls represented by beige coloured marls with abundant microfossils (Fig. 10).

This marly part then passes upward into the Yenice calcarenites which are deposited as lenticular geometry within the Yenice Formation. They consist of thin- to medium- in the lower, medium- to thick- in the middle and thin- to medium-thick beds in the upper parts. Extrabasinal (ophiolitic and carbonate grains) and intrabasinal (especially reworked from underlying units, for example: from the Yenice marls) grains, *Nummulites*, coral and algea have been established from thin sections (Figs. 11, 12).

The Yenice calcarenites are overlain by the upper part of the Yenice marls. These marls again have very similar characteristics to the lower marl levels.

The fossil assemblages of the Yenice Formation generally consist of planktonic foraminifers and rare specimens of ostracods. Specimens of *Acarinina*, *Truncarotaloides*, *Globigerinatheka* and *Subbotina* are abundant in this formation. *Krithe* and *Cytherella* (marine ostracods) are found together with planktonic foraminifers. The planktonic/benthic foraminiferal ratio in the Yenice marls is the highest among all the studied lithostratigraphic units. The planktonic foraminiferal ratio is lower within the Yenice calcarenites if compared to the one in the Yenice marls (Figs. 7, 8).

All the data presented here show that the lower and upper Yenice marls were deposited under deep-marine condi-

tions. A sea-level drop that took place after the first marl level and deposition is reflected by the calcarenites. Their lenticular geometry, paleocurrent data and abundance of reworked grains from the lower part of the Yenice marls show that the Yenice calcarenites were deposited above and close to the wave base. The second phase of deepening of the sea is reflected by deposition of the upper part of the Yenice marls.

### *Asartepe Formation*

The Eocene sea started to become shallow again after the upper levels of the Yenice marls. This event is represented by the occurrences of carbonates of the Asartepe Formation. The Asartepe Formation is mainly represented by coral and algal rich lenticular reef bodies within the basin. These reef carbonates show typical characteristics of isolated platforms with their lenticular geometry.

*Bairdia subdeltoidea* (Muenster), *Krithe rutoti* (Keij), *Echinocythereis lutfullahi* Sönmez-Gokcen, *Leguminocythereis* sp., *Pokornyella ventricosa* (Bosquet) from ostracods and *Nummulites perforatus* (Monfort), *Nummulites beaumonti* d'Archiac et Haime, *Nummulites aturicus* Joly et Leymerie, *Fabiania cassis* (Openheim), *Assilina exponens* (Sowerby), *Dentalina communis* d'Orbigny from benthic foraminifers are observed within marly limestone levels of the Asartepe Formation (Nazik 1993). The planktonic/benthic foraminiferal ratio in this lithostratigraphic unit is lower than in the Yenice marls and calcarenites (Fig. 8).

The extrabasinal (less fragment compared to the Yenice calcarenites) and intrabasinal (intraclasts, corals and algae with some benthic foraminifers) grains, lenticular shape and the geometry of the formation indicate that the Asartepe Formation was deposited as reef patches (isolated platforms) in a shallow marine sea.

### *Darende Formation*

Continued lowering of the sea level is represented in this basin by the Darende Formation. The Darende Formation consists of sandstone, siltstone and marls alternations with some conglomerates. There are some evaporitic occurrences in the northern and southern parts of the basin intercalated with the clastics (Fig. 4).

*Bairdia*, *Nucleolina*, *Quadracythere*, *Pokornyella* (ostracods) and *Nodosaria*, *Sphaerogypsina*, *Halkyardia*, *Quinqueloculina* (benthic foraminifers) are found in marl and fine-grained sandstone levels. All these data suggest that this formation has been deposited under shallow marine conditions. Evaporite occurrences with shallow marine intercalations in the lower part of the formation may also suggest a possible lagoonal environment in this area.

## Conclusions

All the data presented in this study show that the Middle Eocene sequences consist of siliciclastic and carbonate sediments deposited in a range of environments from very shallow (the Korgantepe, calcarenite levels of the Yenice, Asartepe and Darende Formations) to deep marine (marl levels of the Yenice Formation).

The *Acarinina bullbrooki* Zone is identified within the Middle Eocene planktonic foraminiferal assemblages. This biozone is compared to the ones proposed by Blow (1969), Krasheninnikov (1965a,b, 1969), Beckmann et al. (1969), Toumarkine & Luterbacher (1985) and other studies from Turkey.

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