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ORIGINAL PAPER

The first record and paleoenvironmental analysis of ^{13}C,^{18}O isotopes of the Middle Eocene foraminifera around Orduzu, Malatya Basin, Eastern Türkiye

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Abstract

Several foraminiferal assemblages were recorded around the Orduzu-Pınarbaşı, Battalgazi district of the Malatya province. The studied foraminiferal assemblages yield the middle Eocene (Lutetian-Bartonian) age for the Suludere and Gedik formations in the study area. Benthic foraminiferal genera are *Anomalinoides*, *Bulimina*, *Cibicides*, *Cibicidoides*, *Elphidiella*, *Gavelinella*, *Karreriella*, *Lagena*, *Lenticulina*, *Nodosaria*, *Planularia*, *Planulina*, *Robulus*, *Siphonina*, *Spirillina*, *Uvigerina*, and *Vulvulina*, and planktonic foraminiferal species include *Acarinina*, *Catapsydrax*, *Globigerinatheka*, *Hantkenina*, *Hastigerina*, *Igorina*, *Morozovella*, *Orbulinoides*, *Pseudohastigerina*, *Subbotina*, *Truncorotaloides*, and *Turborotalia*. The carbon isotope provides information on sea-level changes during the middle Eocene period. The $\delta^{18}O$ (VPDB) foraminiferal shells vary between − 5.40 and − 1.22‰, and $\delta^{13}C$ (VPDB) values range from − 5.50 and + 1.78‰. The seawater temperatures calculated from the oxygen isotope fractionation between calcite and water are between 19.2 and 39.7 °C. Isotope and fossil data show that the salinity of seawater is normal, that is, 33–34‰ of it. Benthic and planktonic species indicated that the deposition occurred within subtropical and tropical sea waters in environments varying from inner shelf to slope.

Keywords Foraminifera · Isotopic data · Paleoenvironmental analysis · Middle Eocene · Malatya Basin · Eastern Türkiye

Introduction

The studied Eocene sequence is located that we conducted around Orduzu-Pınarbaşı (Eastern Malatya, eastern Türkiye) and is widely exposed in the Malatya Basin, which is a part of the southern branch of the Neotethyans Ocean. The sequence that unconformably overlies the Çamurlu Granitoid is composed of sandstone, nummulite-bearing conglomerate and mudstone (the Karakayatepe Formation) at the base and continues upward with reefal limestone and flysch (the Suludere Formation) and passes into nummulitic limestones (Gedik Limestone). The Gedik Limestone consists of beige-grey-bluish, grey-dark grey, thick-very thick-bedded limestone with abundant nummulite and carbonate conglomerate, sandstone, siltstone, and carbonate mudstone interbeds (Fig. 1).

Several studies were carried out regarding stratigraphy, tectonics, paleontology, sedimentology, and petroleum geology of the Malatya region (Yazgan et al. 1987; Karaman 1993; Perinçek and Kozlu 1984; Yazgan 1983; Demir 1997; Eren and Önal 2003; Önal et al. 2003; Önal and Kaya 2007; Çağlar (Kaya) 2009). Önal et al. (2003) identified *Asterigerina rotula* (Kaufmann), *Nummulites* sp., *Discocyclina* sp., *Spiroclypeus albapustula* Bolli, *Globigerinoides pseudodubia* Bandy, *Acarinina* sp., *Discocyclina* sp., *Nodasaria* spp., algae, and bryozoan fossils in the samples taken from the claystone and sandstone levels of the Suludere Formation. According to these fossil findings, the flysch sequence is of the middle Eocene age. Micro–macro fossils collected

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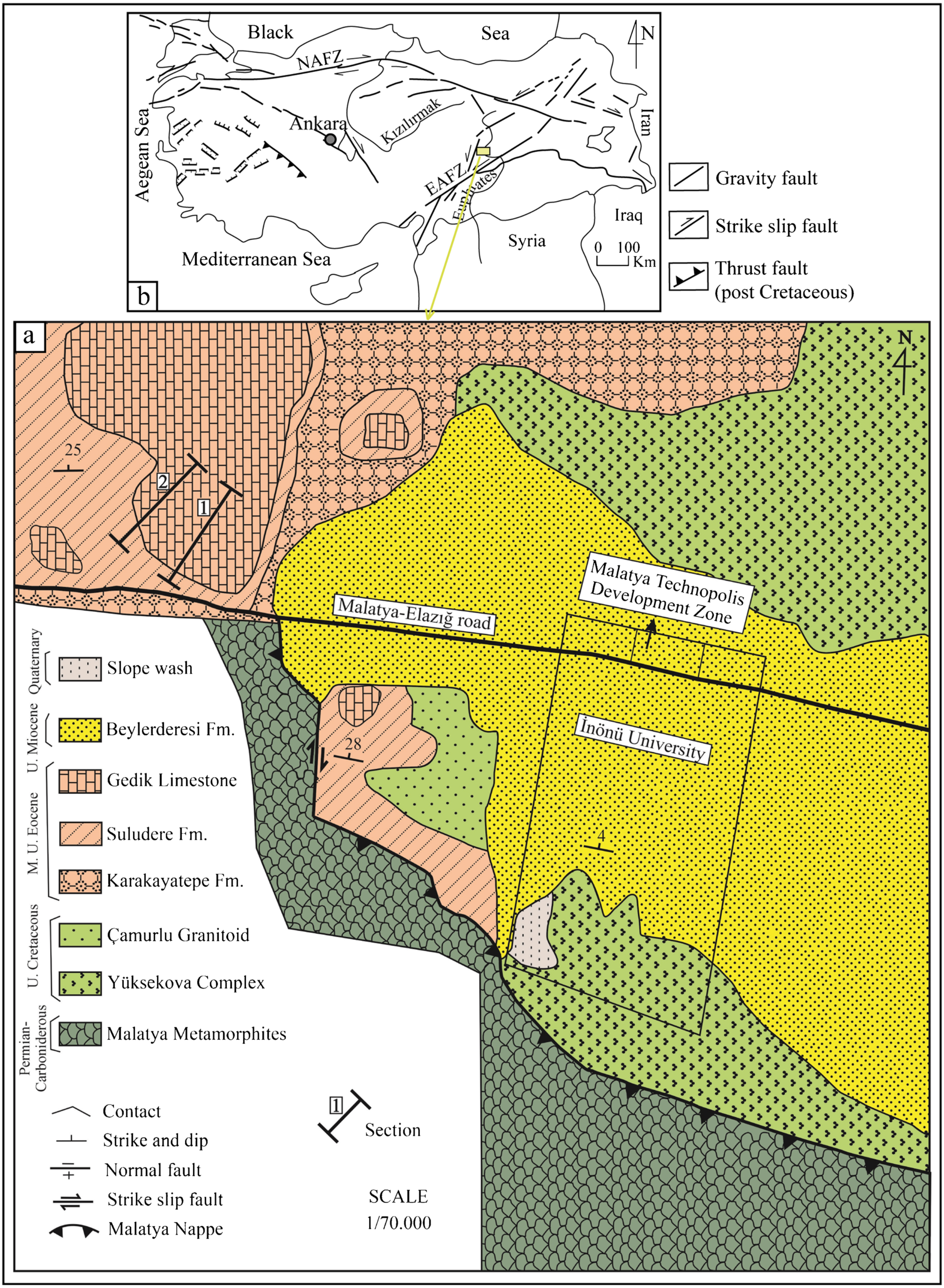
Black
Sea
NAFZ
N
Aegean Sea
Ankara
Kızılırmak
Iran
EAFZ
Euphrates
Iraq
Syria
Mediterranean Sea
0 100 Km
b
Gravity fault
Strike slip fault
Thrust fault
(post Cretaceous)
a
N
25
2
1
28
4
Malatya-Elazığ road
Malatya Technopolis Development Zone
İnönü University
Quaternary
Slope wash
U. Miocene
Beylerderesi Fm.
Gedik Limestone
Suludere Fm.
M. U. Eocene
Karakayatepe Fm.
U. Cretaceous
Çamurlu Granitoid
Yüksekova Complex
Permian-Carboniderous
Malatya Metamorphites
Contact
Strike and dip
Normal fault
Strike slip fault
Malatya Nappe
Section
SCALE
1/70.000

◂**Fig. 1** **a** Simplified geological map of the study area (modified from Demir 1997) **b** Tectonic settings of Turkey (modified from Şengör and Yılmaz 1981)

from the samples taken from Gedik limestone in the south of Malatya imply the unit was of the middle-upper Eocene age. According to Önal and Kaya (2007) and Çağlar (Kaya) (2009), the Suludere Formation and Gedik limestone around the Yeşilyurt area are middle Eocene in age.

The aim of this study is to examine the deposition conditions of the benthic and planktonic foraminiferal assemblage of the Orduzu-Pınarbaşı (E Malatya) Eocene sequence. A stable isotope study on the fossil taxa had not been previously performed in the region. Therefore, this study attempts to obtain information on the paleoenvironmental conditions during the Eocene period based on the stable isotope composition of foraminiferal shells.

A direct comparison between fossil foraminifera and the ecological environment is very important for paleoenvironmental interpretations, and especially, benthic foraminifera are an excellent paleoenvironmental indicator (e.g., Nebelsick et al. 2013). Because of their high fossilization potential, worldwide availability, high abundance, and quick response to environmental changes, benthic foraminifera are used in numerous studies in biostratigraphy and reconstruction of past climate and ocean changes (Horton et al. 1999; Murray 2006; Schönfeld et al. 2012; Haynert et al. 2012; Dolven et al. 2013; Sinanoglu and Sasmaz 2019). Many researchers have also demonstrated the usefulness of the Eocene planktonic foraminifera as a paleoecological index (e.g., Boersma and Premoli Silva 1991).

Materials and methods

Two stratigraphic sections from the Suludere Formation and Gedik Limestone were measured. Sixty-three soft and hard rock samples were systematically taken. Soft rock samples were kept in a 17% hydrogen peroxide solution for 24 h. Then they were washed with pressurized water and dried.

Foraminiferas were examined under a binocular microscope as dry samples by sieving them through 0.125–0.250 mesh size.

The $\delta^{18}O$ ‰ PDB and $\delta^{13}C$ ‰ PDB isotope compositions of the selected foraminifer species were sent to the Iso-Analytical Lab (UK). Operations are done in the lab: samples were weighed into clean Exetainer™ tubes (then crushed in situ), and the tubes were placed in a drying oven for 24 h to remove moisture. Once the samples were dry, septum caps were fitted to the tubes. The tubes were then flushed with 99.995% helium. Acid was added to the samples, and they were allowed to react in the acid overnight and then heated to 60 °C for 2 h to allow complete carbonate conversion to CO_2. Carbon dioxide was sampled from the Exetainer™ tubes into a continuously flowing He stream using a double-holed needle. The CO_2 gas liberated from samples was then analyzed by continuous flow-isotope ratio mass spectrometry (CF-IRMS). Gas species of different masses are separated in a magnetic field and then simultaneously measured using a Faraday cup collector array to measure the isotopomers of CO_2 at m/z 44, 45, and 46. The CO_2 was resolved on a packed column gas chromatograph, and the resultant chromatographic peak was carried forward into the ion source of Europa Scientific 20–20 IRMS, where it is ionized and accelerated. The phosphoric acid used for digestion had been prepared for isotopic analysis by Coplen et al. (1983) and was injected through the septum into the vials.

The temperature of the water was calculated using the following equation of Shackleton (1974):

$$T = 16.9 - 4.38(\delta^{18}O_c - \delta^{18}O_w) + 0.1(\delta^{18}O_c - \delta^{18}O_w)^2$$

We determined $\delta^{18}O$ of water according to Douglas and Savin (1978). Since $\delta^{18}O_w$ also depends on salinity changes, Craig and Gordon (1965) established a relationship between the salinity and oxygen isotope composition of ocean water:

$$\delta^{18}O_w = 0.66S - 23.5$$

After this pioneering work, several other methods were established for the estimation of $\delta^{18}O_w$ with respect to paleosalinity (e.g., Railsback and Anderson 1989; Wolff et al. 1999; Malaizé and Caley 2009).

The benthic and planktonic foraminiferal species were mainly identified based on the Ellis and Messina 1940 Catalogue of Micropaleontology (from 1940 to the present day) and a few studies indicating and discussing foraminifera (e.g., Bolli 1966; Van Morkhoven et al. 1986; Loeblich and Tappan 1988; Berggren et al. 1995; Kaminski and Gradstein 2005; Ortiz and Thomas 2006). The foraminiferal species selected were photographed with a scanning electron microscope.

Geological settings and stratigraphy

The basement of Malatya Basin, located in the Southern Taurus-Anatolian Platform belt, is formed by the Yüksekova Group serpentinites, Malatya Metamorphics (Malatya Massif) (Permo-Carboniferous) and Triassic-Jurassic-Cretaceous Tectonic Segments, which are the product of late Cretaceous-early Eocene island-arc volcanism (Yilmaz et al. 1993).

The geologic units in the study area are composed of magmatic, metamorphic, and sedimentary rocks. In the study area, the rock units, from oldest to the youngest, are the upper Triassic Malatya Metamorphites, the upper Cretaceous Yüksekova Complex and Çamurlu Granitoid, the middle-upper Eocene Karakayatepe Formation, Suludere Formation and Gedik Limestone, the upper Miocene Beylerderesi Formation, and the Quaternary slope debris (Fig. 1) (Demir 1997).

The geological features of Suludere Formation and Gedik Limestone, which are the subject of this study, are briefly described.

Suludere (Pınarbaşı) Formation

The Suludere Formation outcropping in the western part of the study area was named by Demir (1997). It is widely exposed toward the eastern and southern parts of the area, particularly around the Yeşilyurt district (Önal and Kaya 2007). The formation consists of a marl unit with a greyish-greenish fresh surface, dark green-blackish, thin-thick bedded, alternating with sandstone, siltstone, and claystone. The base of the formation is not exposed in the study area. The sandstone interlayers are repeated more frequently in the lower sections. Claystones and marls are partly colored laminated, and sandstone layers are greenish-grey colored and partly coarse-grained. The exposures to the east of Yılancık Hill in the south of the study area (outside the map area) contain hard, and carbonate cemented sandstone and sandy limestone levels.

Benthic (*Eorupertia* sp. and *Linderina* sp.) and planktonic foraminifera (*Acarinina bullbrooki* (Bolli), *Globigerina eocaena* Gümbel, *Turborotalia cerroazulensis pessagnoensis* (Toumarkine) and *Turborotalia cerroazulensis cerroazulensis* (Cole)) indicate that the Suludere Formation is of the middle to upper Eocene age (Gözübol and Önal 1986; Demir 1997). In the Suludere Formation around Yeşilyurt in the southwest of the area, Çağlar (Kaya) (2009) described several benthic foraminifera including *Nummulites bayhariensis*, *N.* sp., *Assilina* sp., *Asterigerina* sp., *Sphaerogypsina globula*, *Orbitolites* sp., *Discocyclina* sp., and *Fabiania* sp., and planktonic foraminifera including *Acarinina brodermani*, *A. bullbrooki*, *Globigerina eocaena*, *G. inaequispira*, *Turborotalia cerroazulensis brotherman*, *T. Cerroazulensis frontosa*, and *T. Cerroazulensis pessagnoensis.* The age of formation was reported middle Eocene. Sedimentary features and fossil assemblages indicate that formation was deposited in the fore-slope neritic shelf (carbonates) and deep shelf edge environments (Önal and Kaya 2007).

Gedik Limestone

The unit was first named as Gedik Limestone by Gözübol and Önal (1986) because of its typical type section around Gedik (Yeşilyurt). The unit is thickly bedded and covers a large area around Yeşilyurt but it is thinly layered and has a limited exposure in the south and north of Hekimhan and Muşardağı and around the Bacalı district (Önal and Kaya 2007).

The Gedik Limestone starts with red-brown conglomerate, sandstone, siltstone, and carbonate mudstone at the bottom and continues with limestone layers with abundant *Nummulites*. With the increase in the carbonate content toward the top, it turns into light–dark grey, hard, thin-thickly layered, oolitic, oncoid, pisolitic, algal, and nummulitic limestone (Fig. 2). The unit is laterally thinned and thickened and shows frequent facies changes. The reference sections of the unit were measured at the Yeşilyurt-Adıyaman road cut and Çöşnük-Pınarbaşı (Demir 1997). Gedik Limestone overlies the Malatya Metamorphites, Yüksekova Complex, and the Sarıkız Formation with an angular unconformity and gradually passes into the Oligocene Balçay Formation to the top. The unit displays a regressive character and is in vertical and lateral transition to the Suludere Formation. Based on benthic foraminifera (*Eorupertia* sp. and *Fabiania cassis* (Oppenheim)), it is suggested to be middle-upper Eocene in age (Önal and Gözübol 1992; Demir 1997). Çağlar (Kaya) (2009) determined benthic foraminifera of *Nummulites perforatus* zone according to *Bulimina alazaensis*, *B. jacksonensis*, *Uvigerina eocaena*, *U. spinicostata*, *Fabiania cassis*, *Eorupertia magna*, *Asterigerina rotula*, *Baculogypsinoides tetraedra*, *Nummulites aturicus*, *N. perforatus*, *N. striatus*, *Discocyclina umbilicata*, and *D.* cf. *stellata stellaris* and planktic foraminifera of *Turborotalia cerroazulensis frontosa*, *Hantkenina* cf. *alabamensis*, *Globigerina eocaena*, and *G. venezuelena*, which indicated Bartonian age for the Limestone.

Fig. 2 A view from the Gedik Limestones of the SW of Yassı Tepe around Orduzu-Pınarbaşı (E Malatya) (Or-1)

According to the fossil assemblage (such as benthic foraminifera *Alveolina* sp. and Miliolidae) and facies characteristics, Önal and Kaya (2007) suggested that Gedik Limestone was deposited in buildups or platform margin and open platform (shelf lagoon) (the presence of Miliolids confirms a shelf lagoon environment).

Biostratigraphy

Detailed biostratigraphic studies on the foraminifera of samples systematically collected from two measured stratigraphic sections (Or-1 and Or-2) in the Suludere Formation and Gedik Limestone yielded three planktonic biozones of Lutetian-Bartonian age. Planktonic foraminiferal zones are given below, from oldest to youngest:

P12 *Morozovella lehneri* Partial Range Zone (P11 Zone of Bolli 1957, 1966; Berggren and Miller 1988, P12 of Berggren et al. 1995) (Or-1) (Fig. 3).

Age: 43.6–40.5 My; middle Eocene (Lutetian-early Bartonian) (Berggren et al. 1995).

P13 *Orbulinoides beckmanni* Taxon Range Zone (P13 of Bolli 1957, 1966; Blow 1979; Berggren and Miller 1988 and Berggren et al. 1995) (Or-2) (Fig. 4).

Age: 40.5–40.1 My; late-middle Eocene (Bartonian) (Berggren et al. 1995).

P14 *Truncorotaloides rohri-Morozovella spinulosa* Partial Range Zone (P14 Zone of Berggren and Miller 1988 and Berggren et al. 1995) (Or-2).

Age: 40.1–38.4 My; late-middle Eocene (late Bartonian) (Berggren et al. 1995).

The benthic foraminiferal zones corresponding to these planktonic foraminiferal zones are SBZ 13–18 (Figs. 3 and 4).

Measured stratigraphical section Or-1 (NE Pınarbaşı)

This section on the 1/70.000 scaled Malatya L40-b3 quadrangle has a length of 136.5 m. The layers are approximately horizontal. The sequence is exposed northeast of the Pınarbaşı district, and it starts at coordinates of N 42°0.45′1.27″-E 54°0.46′24.7″ and ends at the coordinates of N 42°0.45′26.1″-E 54°0.46′33.7″ (Fig. 3).

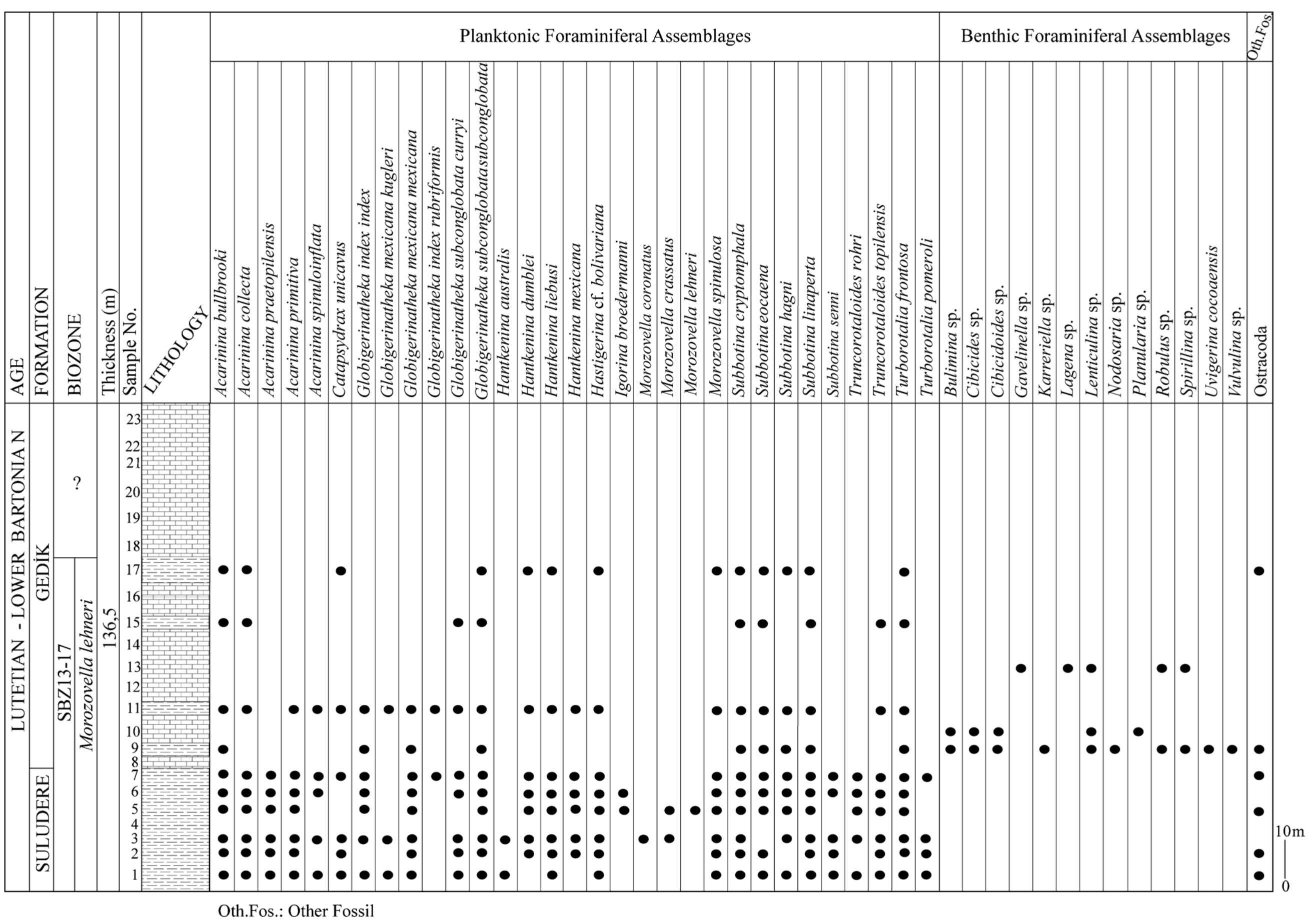

Fig. 3 Orduzu-Pınarbaşı (Malatya) measured stratigraphical section Or-1

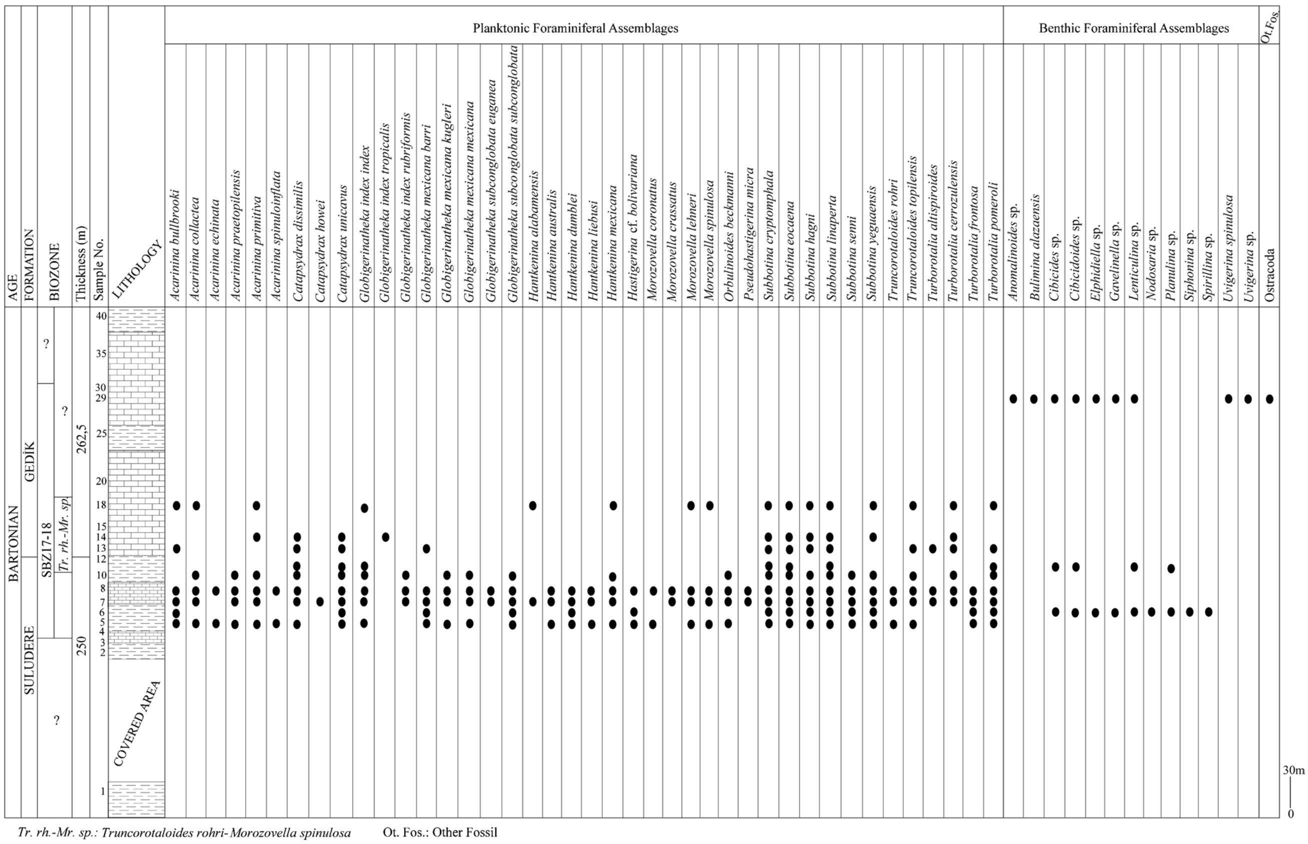

Fig. 4 Orduzu-Pınarbaşı (Malatya) measured stratigraphical section Or-2

Measured stratigraphical section Or-2 (NE Pınarbaşı)

This section on the 1/70.000 scaled Malatya L40-b3 quadrangle has a length of 512.5 m. The sequence consisting of horizontal layers is located northeast of the Pınarbaşı district. The section starts at coordinates of N 42°0.45′5.41″-E 54°0.45′9.49″ and ends at the coordinates of N 42°0.46′02.1″-E 54°0.46′7.45″ (Fig. 4).

Results and discussion

Paleoenvironmental analysis

Paleoenvironmental interpretations of the middle Eocene-aged formations described here are based on benthic and planktonic foraminiferal assemblages and stable isotope analysis evaluations of foraminiferal shells.

Stable isotope

We created the paleoenvironmental framework of the region during the Lutetian-Bartonian period based on the $\delta^{18}O$ ‰ (PDB) and $\delta^{13}C$ ‰ (PDB) records of the foraminiferal shells;

According to the $\delta^{18}O$ ‰ and $\delta^{13}C$ ‰ (PDB) values of the samples consisting of 4 benthic foraminifera and 14 planktonic foraminifera, while $\delta^{18}O$ presents high negative values between − 1.22 and − 5.40‰, $\delta^{13}C$ values vary between − 5.50 and + 1.78‰. During the middle Eocene, seawater temperature calculated according to $\delta^{18}O$ ‰ (PDB) values was between 19.2 and 39.7 °C (Figs. 5, 6, 7, and 8). Although the isotopic deviations observed in the ^{18}O and ^{13}C curves in both sections were probably due to changes in the degree of seasonality affected by local climatic changes, an increase in temperature was detected at some levels of the sections (Figs. 7, 8).

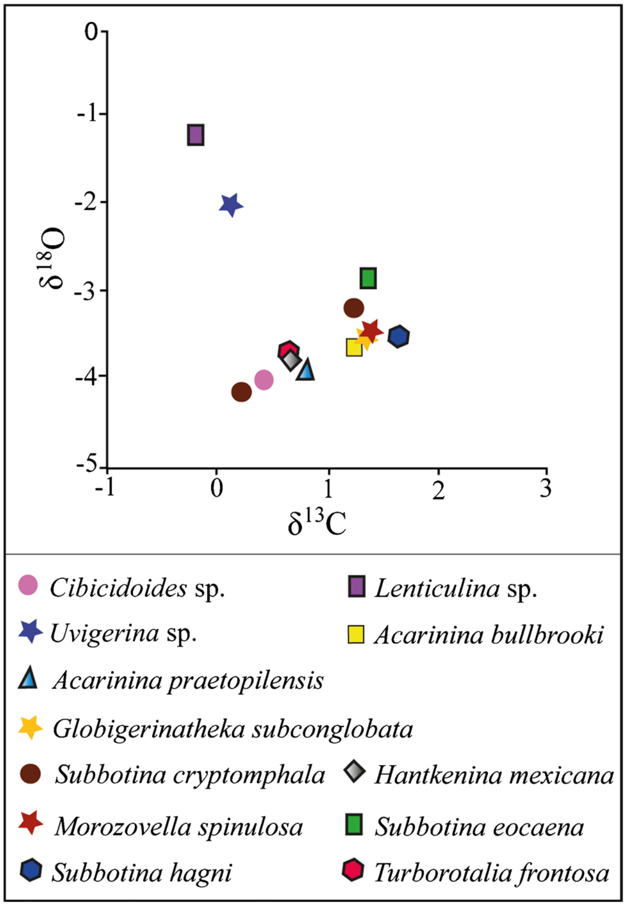

Fig. 5 Cross-plot $\delta^{13}C$ versus $\delta^{18}O_w$ compositions of foraminifera of the Or-1 section

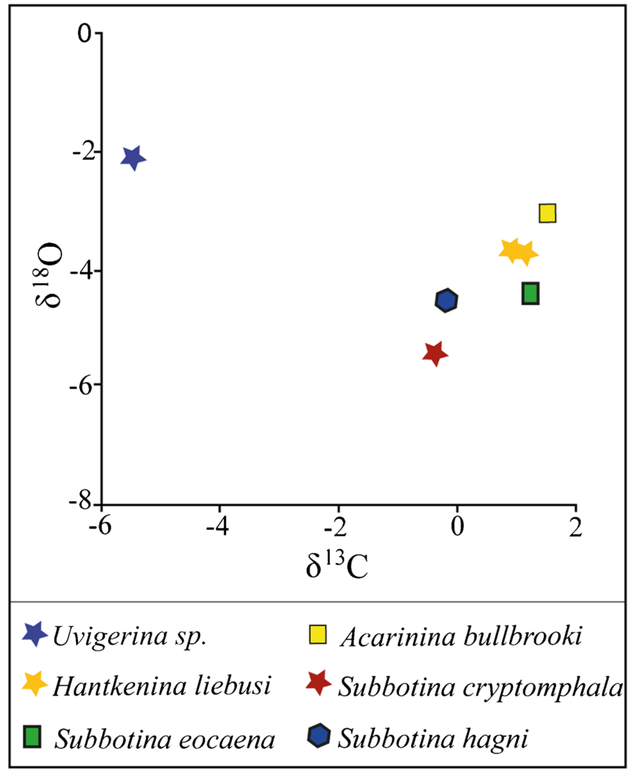

Fig. 6 Cross-plot $\delta^{13}C$ versus $\delta^{18}O_w$ compositions of foraminifera of the Or-2 section

Various researchers have argued that a warm, humid climate during the Eocene was global in some parts of the European, Asian, and African continents (e.g., Parrish et al. 1982; Murray and Wright 1974). Shackleton and Boersma (1981) suggested that a maximum vertical temperature gradient of 10–15 °C was predicted during the Eocene and Oligocene, even in the open ocean. Zachos et al. (1994) indicated that climatic warming would gradually impact seawater, causing an increase in the density and salinity of the water. Matter (1974) and Schlanger and Douglas (1974) stated that the $\delta^{18}O$ and $\delta^{13}C$ values obtained from the samples analyzed in their studies were affected by biogenic carbon residues, changes in the lithological properties of the carbonate material due to burial and diagenesis, melting and regrowth events, and alteration. They indicated that the fact that the studied material was affected by any or a few of these factors caused the obtained isotope results and, therefore, paleotemperature and paleosalinity values of seawater to be above or below normal values.

Berlin et al. (1976) suggested temperatures of 21.4 to 25 °C for the growth of *Nummulites perforatus* from the Hungarian Eocene. In their stable isotope study on *Nummulites*, Bartholdy et al. (2000) considered it appropriate to correct the measured oxygen isotope values by a factor of 2.5‰, which produces reliable results, as a first approach, according to their estimates and taking into account this view of the seawater paleotemperature data. The maximum seawater temperature they calculated was 30 °C, according to this correction. Pearson et al. (2001) suggested that the tropical sea surface temperatures of foraminiferal shells, which were extremely well preserved during the Eocene, were at least 28–32 °C.

According to the $\delta^{18}O$ isotope results of benthic and planktonic foraminifera we obtained from our study area, the maximum seawater temperature of 39.7 °C belonged to the *Subbotina cryptomphala* planktonic foraminifera, and the temperatures above 30 °C were during the Bartonian period. The fact that some seawater paleotemperature values were very high than normal probably indicated that the samples were under the effects mentioned by Matter (1974) and Schlanger and Douglas (1974) (Figs. 7, 8). We can say that the assumed warming trend is consistent with

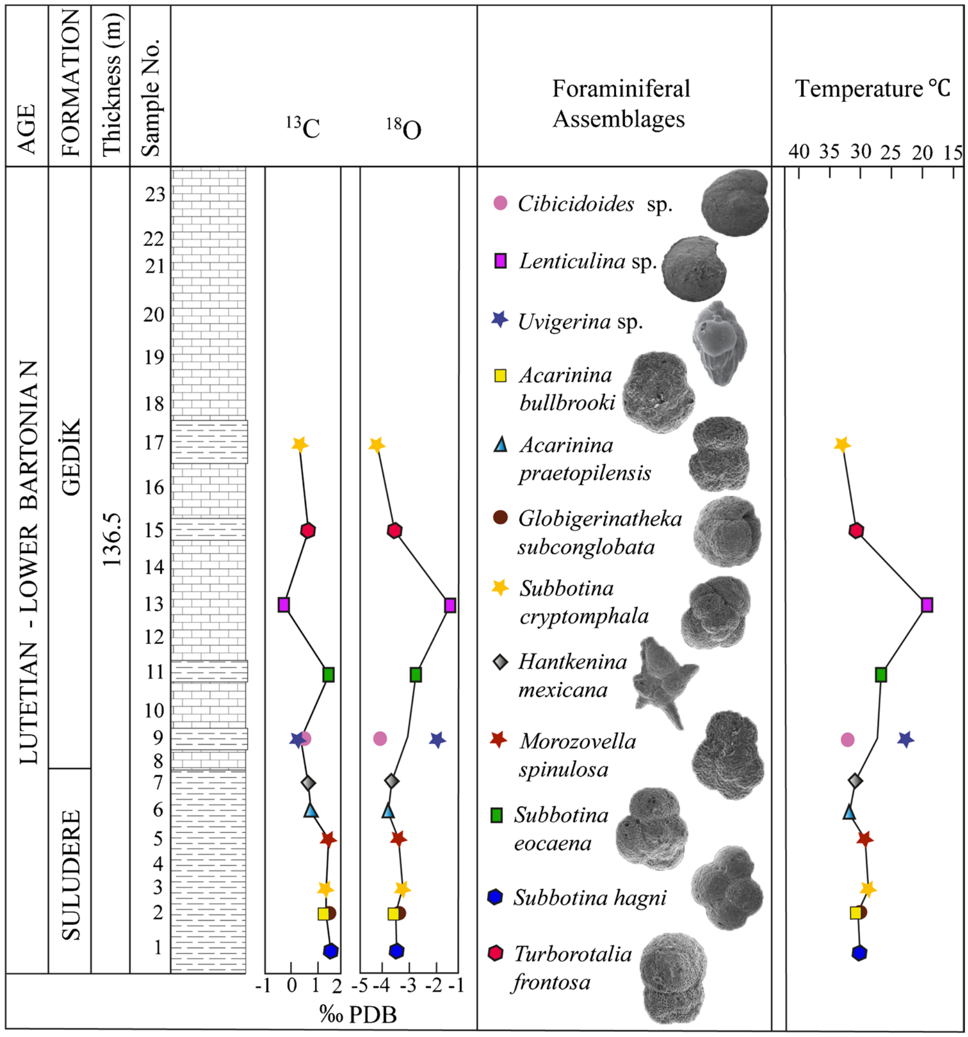

Fig. 7 $\delta^{18}O_w$ ‰ (PDB) values and paleotemperature (°C) through the Lutetian-L. Bartonian in the Or-1 section, E Malatya

some authors' data published for the middle Eocene (cf. Oberhänsli 1996).

Most stable isotope signals were interpreted in terms of seawater temperatures. However, Craig and Gordon (1965) first established the salinity-water isotope relationship regarding seawater paleosalinity. In the following years, many researchers developed various formulae and methods according to $\delta^{18}O_{sw}$ to determine paleosalinity (e.g., Railsback and Anderson1989; Wolff et al. 1999; Malaizé and Caley 2009). We obtained results close to each other when we calculated the seawater paleosalinity according to these methods and formulae. According to these results and the fossil content we determined, we thought seawater's salinity was within normal values during the middle Eocene.

According to the analysis results, the $\delta^{13}C$ values are between − 5.50 and + 1.78, and the $\delta^{13}C$ curve provides information on the changes in the sea level. In this region, rapid positive changes in ^{13}C values during the Lutetian-Bartonian period are evidence of a relatively rapid increase in the sea level, and negative changes are evidence of decreases in the sea level (Figs. 7, 8).

Foraminifera

Foraminiferal assemblages in the deposits of Suludere Formation and Gedik Limestone are well preserved. Therefore, they provide a basic knowledge of the paleoenvironment. It is known that many taxa favor cold, temperate, or warm bottom water. The bottom water temperature is closely related to the water depth. For example, if the water depth exceeds 100 m, temperate bottom waters are formed even in tropical regions. *Lenticulina* prefers cold bottom water, and in

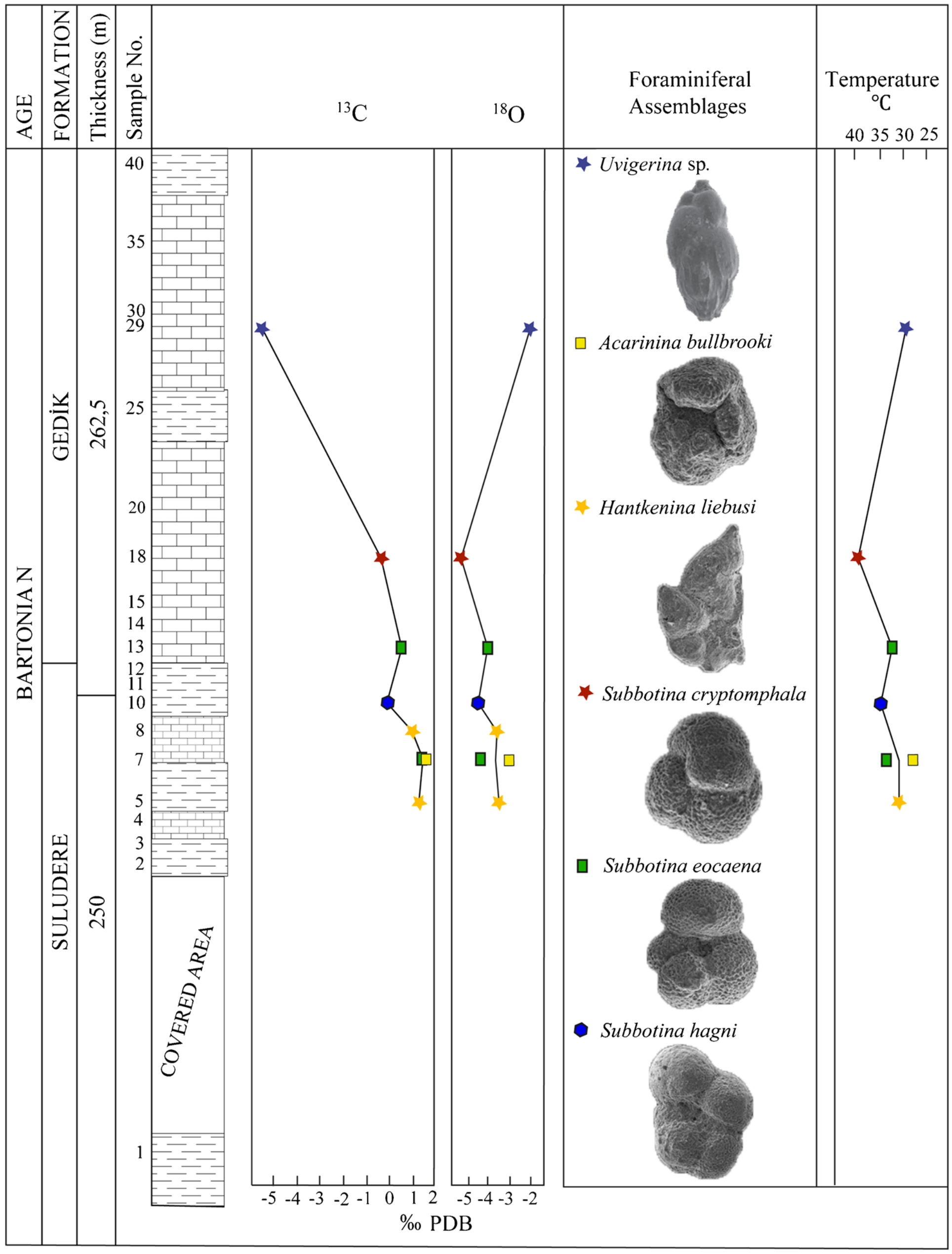

Fig. 8 δ[18]O_w ‰ (PDB) values and paleotemperature (°C) through the Bartonian in the Or-2 section, E Malatya

current marine assemblages, *Lenticulina* is epifaunal and known as a typical organism in the outer shelf of bathyal environments. *Uvigerina* sp. prefers shelf-abyssal, epifaunal-infaunal, and infaunal habitats between 100 and > 4500 m, rarely shallower than 100 m. However, *Cibicidoides* is infaunal and prefers habitats at depths between 30 and 3500 m (Sen Gupta 1999; Murray 2006). *Bulimina alazaensis* Cushman lives between 42 and 3640 m (Sen Gupta et al. 2009). Sinanoglu and Sasmaz (2019) determined that *Nummulites* have formation and deposition conditions such as a decrease in temperature or an increase in *f*O2 and pH and high oxygen fugacity in a shallow sea (10 and 60 m depths) environment.

Planktonic foraminifera indicate the offshore environment, and their relative abundance increases toward the basin (cf. Geel 2000). The abundance of planktonic foraminifera in the lower-middle levels of the Or-1, 2 stratigraphic sections and well-preserved deep-water benthic taxa (e.g., *Lenticulina*) indicate depositions in the outer shelf environment. The presence of shallow water forms and scarcity or absence of deep-sea representatives suggest that the formations were deposited in a shallow inner shelf (neritic) environment. In brief, the biotic assemblages of the formations indicate that the deposition took place in the inner shelf-bathyal marine environment in the warm waters of tropical and subtropical regions.

It is accepted that the highest foraminiferal diversity occurs under normal sea conditions, with salinity rates varying between 32‰ and 37‰. It is known that fewer species are observed with an increase in salinity rates (Sen Gupta 1999; Murray 2006). The diversity of foraminifera recorded in the studied sections shows that the salinity is at the normal level (33–34‰).

Conclusion

Benthic and planktonic foraminifera content recognized in the Suludere Formation and Gedik Limestone in the Malatya province yielded the presence of Zones SBZ 13–18 and P12-14 that are Lutetian-Bartonian in age.

The $\delta^{18}O$ and $\delta^{13}C$ values of the foraminiferal species in two measured stratigraphic sections indicated that seawater temperatures varied between 19.2 and 39.7 °C implying that there were short-term cooling and overheating phases. The isotopic deviations observed in the $\delta^{18}O$ and $\delta^{13}C$ curves in the same sections were probably due to local climatic changes. The extreme temperature increase was derived from geochemical and/or lithological effects. Furthermore, the warming trend is also compatible with the data proposed for the middle Eocene.$\delta^{13}C$ values are between − 5.50 and + 1.78‰ and provide information on the highly variable sea level during the middle Eocene. The stable isotope analysis and the fossil coverage indicate that the seawater salinity was normal during the Lutetian-Bartonian period. Sedimentary features and fossil content indicate that the Suludere Formation and Gedik Limestone were deposited in environments from the inner shelf to the slope. Foraminiferal assemblage and stable isotope results yield that the units were deposited in tropical and subtropical warm waters.

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Data availability All data used to support the findings of this study is contained in the article.

Declarations

Conflict of interest The authors declare no competing interests.

References

Bartholdy J, Bellas SM, Keupp H, Rusu A, Hosu A (2000) Oxygen and carbon isotope paleontology and paleoecological conditions in nummulitic banks: first results from the Transylvanian Eocene. GFF 122:21–22. https://doi.org/10.1080/11035890001221021

Berggren WA, Miller KG (1988) Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology. Micropaleontology 34:362–380. https://doi.org/10.2307/1485604

Berggren WA, Kent DV, Swisher CCI, Aubry MP (1995) A revised Cenozoic geochronology and chronostratigraphy. In: Geochronology, Time Scales and Stratigraphic Correlations: Framework for an Historical Geology. SEPM Spec Publ 54:129–212. https://doi.org/10.2110/pec.95.04.0129

Berlin TS, Barhatova NN, Habakov AV (1976) A calcium/magnesium method of obtaining data on palaeotemperature in the Eocene sea in Hungary and Slovakia. Annu Rep Hungarian Geol Inst 1974:477–485

Blow WH (1979) The Cainozoic Globigerinida: a study of the morphology, taxonomy, evolutionary relationships and the stratigraphical distribution of some Globigerinida (mainly Globigerinacea). Brill Publishers, Leiden

Boersma A, Premoli Silva I (1991) Distribution of Paleogene planktonic foraminifera: analogies with the Recent? Palaeogeogr Palaeoclimatol Palaeoecol 83(1–3):29–47. https://doi.org/10.1016/0031-0182(91)90074-2

Bolli HM (1957) Planktonic foraminifera from the Eocene Naver and San Fernando formations of Trinidadc BpWpI. Bull US Natl Mus 215:155–172

Bolli HM (1966) Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera. Boletin Informativo Asociacion Venezolana de Geologia, Mineria y Petroleo 9:3–32

Çağlar Kaya M (2009) Benthic foraminiferal biostratigraphy of the tertiary sediments from the Elazig and Malatya Basins, Eastern Turkey. J Geol Soc India 74:209–222. https://doi.org/10.1007/s12594-009-0123-8

Coplen TB, Hopple J, Kendall C (1983) Comparison of stable isotope reference samples. Nature 302:236–238

Craig H, Gordon LI (1965) Deuterium and oxygen 18 variations in the ocean and the marine atmosphere. In: Stable Isotopes in Oceanographic Studies and Paleotemperatures. Consiglio nazionale delle richerche, Laboratorio de geologia nucleare, Pisa, Italy

Demir O (1997) Malatya-İsmetpaşa-Akçadağ-Kürecik-Hekimhan-Arguvan-Karakaya baraj gölü arasındaki alanın jeolojisi ve hidrokarbon olanakları. Rapor No. 3781, 31 s, TPAO Arama Grubu Dokümantasyon Merkezi

Dolven J, Alve E, Rygg B, Magnusson J (2013) Defining past ecological status and in situ reference conditions using benthic foraminifera: a case study from Oslofjord, Norway. Ecol Ind 29:219–223. https://doi.org/10.1016/j.ecolind.2012.12.031

Douglas RG, Savin SM (1978) Oxygen isotopic evidence for the depth stratification of Tertiary and Cretaceous planktonic foraminifera. Mar Micropaleontol 3:175–196. https://doi.org/10.1016/0377-8398(78)90004-X

Ellis BF, Messina A (1940) Catalogue of foraminifera. American Museum of Natural History, New York, USA

Eren D, Önal M (2003) Eosen yaşlı Gedik Kireçtaşı'nın (Malatya Güneyi) mermer olarak kullanılabilirliği. Türkiye IV. Mermer Sempozyumu (Mersem'2003) Bildiriler Kitabı 18-19 Aralık Afyon, Türkiye, pp 27–36

Geel T (2000) Recognition of stratigraphic sequences in carbonate platform and slope deposits: empirical models based on microfacies analysis of Palaeogene deposits in southeastern Spain. Palaeogeogr Palaeoclimatol Palaeoecol 155:2118. https://doi.org/10.1016/S0031-0182(99)00117-0

Gözübol A, Önal M (1986) Çat barajı isale tünelinin mühendislik jeolojisi ve kaya mekaniği incelemesi ve Malatya Çelikhan alanının jeolojisi. TÜBİTAK TBAG-647 No'lu Proje Ankara, Türkiye

Haynert K, Schönfeld J, Polovodova AI, Thomsen J (2012) The benthic foraminiferal community in a naturally CO_2-rich coastal habitat of the Southwestern Baltic Sea. Biogeosciences 9:4421–4440. https://doi.org/10.5194/bg-9-4421-2012

Horton B, Edwards RJ, Lloyd JM (1999) UK intertidal foraminiferal distributions: implications for sea-level studies. Mar Micropaleontol 36:205–223. https://doi.org/10.1016/S0377-8398(99)00003-1

Kaminski MA, Gradstein FM (2005) Atlas of Paleogene cosmopolitan deep-water agglutinated foraminifera.- Grzybowski Foundation. Spec Publ 10:547

Karaman T (1993) Malatya doğu ve güneydoğusunun jeolojisi ve petrografisi. Doktora Tezi, Selçuk Üniversitesi Fen Bilimleri Enstitüsü, 198 s

Loeblich AR, Tappan H (1988) Foraminiferal genera and their classification. Van Nostrand Reinhold Company, New York, p 970. https://doi.org/10.1007/978-1-4899-5760-3

Malaizé B, Caley T (2009) Sea surface salinity reconstruction as seen with foraminifera shells: methods and cases studies. Eur Phys J Conf 1:177–188. https://doi.org/10.1140/epjconf/e2009-00919-6

Matter A (1974) Burial Diagenesis of Pelitic and Carbonate Deep-Sea Sediments from the Arabian Sea. In:Whitmarsh RB, Ross DA (eds) Initial reports of the Deep Sea Drilling Project, vol 23. National Science Foundation, pp 421–469. https://doi.org/10.2973/dsdp.proc.23.109.1974

Murray JW (2006) Ecology and applications of benthic foraminifera. Cambridge University Press, Cambridge UK, pp 1–438

Murray JW, Wright CA (1974) Palaeogene Foraminiferida and Palaeoecology Hampshire and Paris Basins and the English Channel. Spec Pap Palaeontol 14:1–177

Nebelsick JH, Kroh A, Roth-Nebelsick A (2013) The legacy of ocean climate and chemistry change in the echinoderm fossil record. In: Johnson C (ed) Echinoderms in a changing World. Proceedings of the 13th International Echinoderm Conference, Tasmania. CRC Press, London and New York, pp 1–22

Oberhänsli H (1996) Klimatische und ozeanographische Veränderungen im Eozän. Zeitschrift Der Deutschen Geologischen Gesellschaft 147:303–413. https://doi.org/10.1127/zdgg/147/1996/30

Önal A, Eren D, Depci T, Önal A (2003) Orduzu (Malatya) Volkanitleri'nin petrografik – petrolojik özellikleri ve yapıtaşı olabilirliği. İnönü Üniversitesi Rapor No. 2001/26 Malatya, Türkiye

Önal M, Gözübol AM (1992) Malatya metamorfikleri üstündeki örtü birimlerinin stratigrafisi, yaşı, sedimanter fasiyesleri, depolanma ortamları ve tektonik evrimi. Türkiye Petrol Jeologları Derneği Bülteni 4:119–127

Önal M, Kaya M (2007) Stratigraphy and tectono-sedimentary evolution of the Upper Cretaceous-Tertiary sequence in the southern part of the Malatya Basin, East Anatolia, Turkey. J Asian Earth Sci 29:878–890. https://doi.org/10.1016/j.jseaes.2006.06.004

Ortiz S, Thomas E (2006) Lower-middle Eocene benthic foraminifera from the Fortuna Section (Betic Cordillera, southeastern Spain). Micropaleontology 52(2):97–150. https://doi.org/10.2113/gsmicropal.52.2.97

Parrish JT, Ziegler AM, Scotese CR (1982) Rainfall patterns and the distribution of coals and evaporites in the Mesozoic and Cenozoic. Palaeogeogr Palaeoclimatol Palaeoecol 40:67–101

Pearson PN, Ditchfield PW, Singano J, Harcourt-Brown KG, Nicholas CJ, Olsson RK, Shackleton NJ, Hall MA (2001) Warm tropical sea surface temperatures in the Late Cretaceous and Eocene epochs. Nature 413:481–487. https://doi.org/10.1038/35097000

Perinçek D, Kozlu H (1984) Stratigraphy and structural relations of the units in the Afşin-Elbistan –Doğanşehir region (Eastern Taurus). Proceedings of International Symposium on the Geology of the Taurus Belt Ankara, Turkey, pp 181–198

Railsback LB, Anderson TF (1989) Paleoceanographic modeling of temperature-salinity profiles from stable isotopic data. Paleoceanography 4(5):585–591. https://doi.org/10.1029/PA004i005p00585

Schlanger SO, Douglas RG (1974) The pelagic ooze-chalk-limestone transition and its implications for marine stratigraphy. Spec Publ Int Assoc Sedimentol 1:117–148

Schönfeld J, Alve E, Geslin E, Jorissen F, Korsun S, Spezzaferri S (2012) Members of the Fobimo. The Fobimo (Foraminiferal Bio-Monitoring) initiative—towards a standardized protocol for soft-bottom benthic foraminiferal monitoring studies. Mar Micropaleontol 94–95:1–13. https://doi.org/10.1016/j.marmicro.2012.06.001

Sen Gupta BK (1999) Systematics to modern foraminifera. In: Sen Gupta BK (ed) modern foraminifera. Kluwer Academic Publishers, Dordrecht, pp 7–36. https://doi.org/10.1007/0-306-48104-9_2

Sen Gupta BK, Smith LE, Machain-Castillo ML (2009) Foraminifera of the Gulf of Mexico. In: Felder DL, Camp DK (eds) Gulf of Mexico–origins, waters, and biota biodiversity. Texas A&M Press, College Station, Texas, pp 87–129

Şengör AMC, Yılmaz Y (1981) Tethyan Evolution of Turkey: a plate tectonic approach. Tectonophysics 75:181–241

Shackleton NJ (1974) Attainment of isotopic equilibrium between ocean water and benthonic foraminifera genus *Uvigerina;* isotopic changes in the ocean during the last glacial", colloque international. Centre National De La Recherche Scientifique 219:203–210

Shackleton NJ, Boersma A (1981) The climate of the Eocene ocean. J Geol Soc London 138:153–158. https://doi.org/10.1144/gsjgs.138.2.0153

Sinanoglu D, Sasmaz A (2019) Geochemical evidence on the depositional environment of *Nummulites* accumulations around Elazig, Sivas, and Eskişehir (Turkey) in the middle Eocene sub-epoch. Arab J Geosci 12:759. https://doi.org/10.1007/s12517-019-4920-0

Van Morkhoven FPCM, Berggren WA, Edwards AS (1986) Cenozoic cosmopolitan deep-water benthic foraminifera. Bulletin Des Centres De Recherches Exploration-Production Elf-Aquitaine 11:1–421

Wolff T, Grieger B, Haie W, Dürkoop A, Mulitza S, Pätzold J, Wefer G (1999) On the reconstruction of paleosalinities, use of proxies in paleoceanography: Eexamples from the South Atlantic. Springer-Verlag, Berlin Heidelberg, pp 207–228

Yazgan E, Asutay HJ (1987) Malatya güneydoğusunun jeolojisi ve Doğu Toroslar'ın jeodinamik evrimi. Ankara, Maden Tetkik ve Arama Raporu No. 8272, Ankara, Türkiye

Yazgan E (1983) A geotraverse between the Arabian platform and the Munzur nappes. In: International Symposium on the Geology of the Taurus Belt. Guide book for excursion, Ankara, Turkey

Yilmaz Y, Yigitbas E, Genc CS (1993) Ophiolitic and metamorphic assemblages of Southeast Anatolia and their significance in the geological evolution of the orogenic belt. Tectonics 12(5):1280–1297. https://doi.org/10.1029/93TC00597

Zachos JC, Stott LD, Lohmann KC (1994) Evolution of marine temperatures during the Paleogene. Paleoceanography 9(2):353–387. https://doi.org/10.1029/93PA03266