Turkish Journal of Earth Sciences

Volume 32 | Number 4 Article 5

1-1-2023

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Turkish Journal of Earth Sciences
http://journals.tubitak.gov.tr/earth/
Research Article
Turkish J Earth Sci
(2023) 32: 487-509
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doi:10.55730/1300-0985.1857

Foraminiferal micropaleontology of the Harami Formation (Elazığ, Eastern Turkey), and reassessment of its age based on larger benthic foraminifera

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Received: 01.12.2022 • **Accepted/Published Online:** 15.04.2023 • **Final Version:** 29.05.2023

Abstract: The age and depositional environment of the Harami Formation were reevaluated based on the new larger benthic foraminiferal (LBF) data. LBF assemblage including *Orbitoides medius* (d'Archiac), *O. megaloformis* Papp and Küpper, *O. gruenbachensis* Papp, *Pseudomphalocyclus blumenthali* Meriç, *Omphalocyclus macroporus* (Lamarck), *Sirtina* cf. *orbitoidiformis* Brönnimann and Wirz, *Hellenocyclina beotica* Reichel, *Lepidorbitoides campaniensis* Van Gorsel, *L. bisambergensis* (Jaeger), *L.* cf. *minor* (Schlumberger), *Pseudosiderolites vidali* (Douville), and *Siderolites* gr. *calcitrapoides* Lamarck were determined in the formation. Based on this LBF assemblage data, the late Campanian-Maastrichtian age was assigned to the formation. The paleontological and sedimentological data indicate that the Harami Formation was deposited on a shallow ramp environment.

Key words: Harami Formation, late Campanian-Maastrichtian, eastern Turkey, Elazığ

1. Introduction

The late Cretaceous is one of the most important epoch in the geological history of the Eastern Taurid Region because of the significant tectonic events in the Neotethys Ocean (Şengör et al., 2003; Robertson et al., 2016). Orbitoidal larger benthic foraminifera such as *Orbitoides*, *Omphalocyclus,* and *Lepidorbitoides*, late Cretaceous in age indicate Tethyan platforms' relatively tropical and subtropical marine carbonate platforms and ramps (Van Gorsel, 1978; Loeblich and Tappan, 1987; Goldbeck and Langer, 2009). They are significant foraminiferal fauna to note for reliable dating and detailed interpretations of upper Cretaceous sediments.

The study area is located northeast and southwest of Elazığ in the Eastern Anatolian region, Turkey (Figures 1A, 1B). In the foraminiferal literature, in the Arabian platform (Meriç, 1967; Özcan, 1993, 1995; Görmüş et al., 1995; Özcan and Özkan Altıner, 1999a, 1999b; Özcan, 2007; Özer et al., 2009; Özcan et al., 2021), in the Anatolid-Taurid platform (Görmüş, 1992, 1994, 1997; Matsumaru, 1997; Görmüş and Meriç, 2000; Özcan and Özkan Altıner, 2001; Görmüş et al., 2003; Görmüş, 2015; Görmüş and Akoraller, 2019; Görmüş et al., 2019), and in the Pontid (Özcan and Özkan Altıner, 1999a, 1999b; Özcan, 2007; Özer et al., 2009; Consorti and Köroğlu, 2019; Özcan et al., 2019; Erdem et al., 2021; Özcan et al., 2021) systematics of the late Cretaceous orbitoidal forms were recorded. There are also many micropaleontologic studies on the orbitoidal forms worldwide (Caus et al., 2016; Malarkodi et al., 2017; Kayğılı et al., 2021; Özcan et al., 2021, 2022). Although the Harami Formation has already been studied in the vicinity of Elazığ, there are very limited studies in the northeast and southwest of Elazığ (Özgen et al., 1993; İnceöz, 1996; Aksoy et al., 1999; Kaya and İnceöz, 2001) (Table), dating of the formation in these areas is controversial, and systematics of orbitoidal foraminifers are not well documented. The Harami Formation, in the vicinity of Elazığ, was previously recorded as the late Maastrichtian-Tanetian Harabekayış Formation (Özgen et al., 1993) based on its LBF and rudist content. Later was named as the Harami Formation by İnceöz (1996) and Kaya and İnceöz (2001). In the last two studies, it is dated as late Maastrichtian and middle-late Maastrichtian, respectively. The late Campanian-early Maastrichtian aged was also attributed to Harami Formation (Aksoy et al., 1999) (Table). The purpose of this study is to reevaluate the Harami Formation's age and depositional environment based on its LBF content.

2. Geological setting

Sedimentary, magmatic, and metamorphic units of Devonian-Jurassic to Quaternary in age crop out in the study area (Figures 2–5). These units are, from bottom to top, the Devonian-Jurassic Keban Metamorphics,

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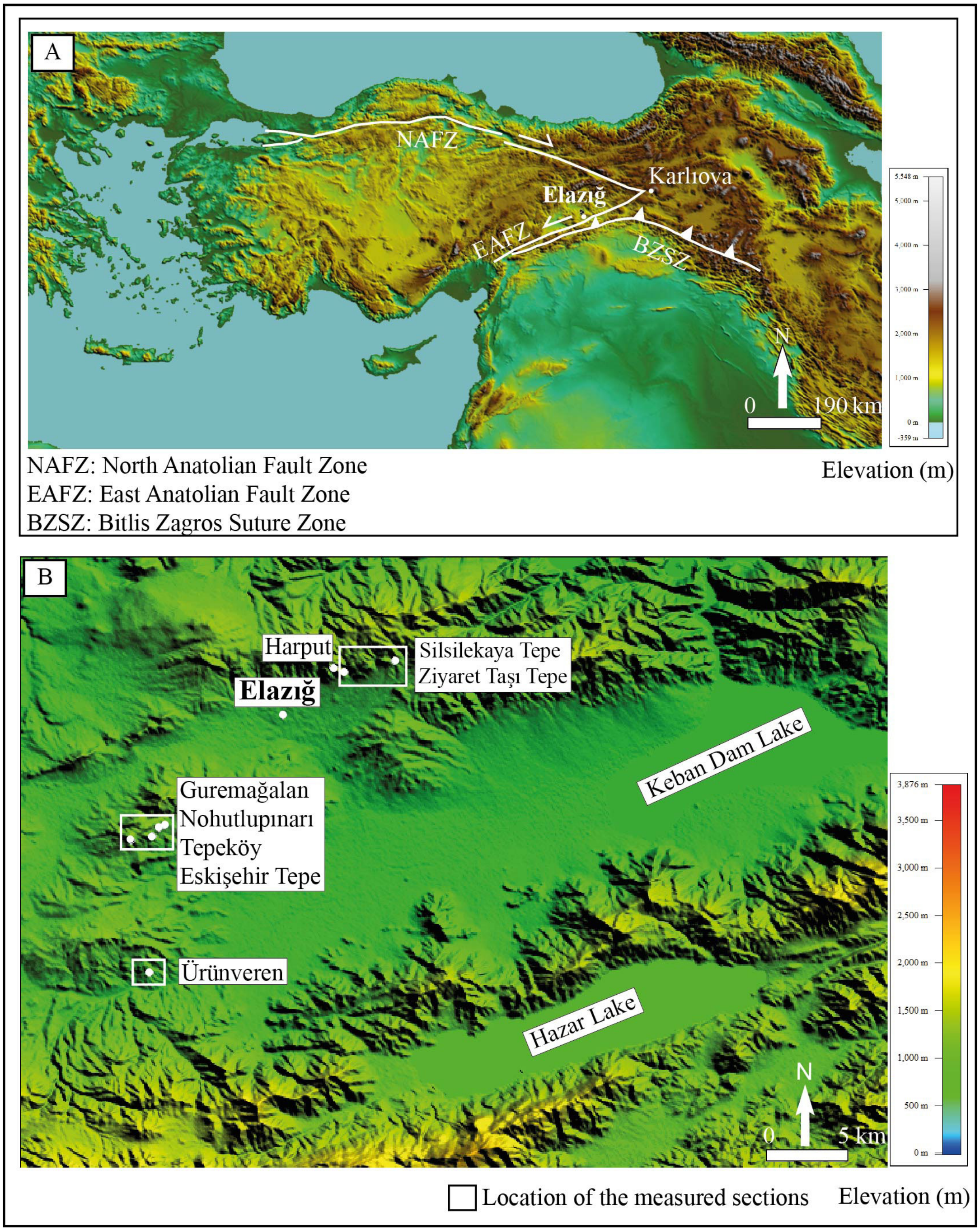

Figure 1. A) Main tectonic outline of Turkey and the location of the study area (Elazığ). B) Location of the measured sections belonging to Harami Formation.

the upper Cretaceous Elazığ Magmatics, the upper Campanian-Maastrichtian Harami Formation, the middle Eocene-Oligocene Kırkgeçit Formation, the Neogene-Quaternary Karabakır Formation, and the Quaternary Palu Formation (Figures 2–5).

The Harami Formation, first described by Erdoğan (1975) around Harami village in the north of Gölbaşı district of Adıyaman province, crops out in very limited areas in the eastern Taurus Orogenic Belt.

The Harami Formation in the vicinity of Elazığ overlies the Elazığ Magmatics/Yüksekova Complex (Tekin et al., 2015; Beyarslan and Bingöl, 2018; Ural and Kaya Sarı, 2019) consisting of island arc product. The formation begins with red-colored conglomerates and sandstones and

Table. Benthic foraminifera content and age correlation of the upper Cretaceous units in the previous studies and this study in the Elazığ.

Author	Study Area	Formation	Benthic Foraminifera Assemblages	Age
Özgen et al., 1993	SW, NE, and W of Elazığ	Harabekayış Formation	**I:** *Orbitoides medius, O. apiculatus, Omphalocyclus macroporus, Hellenocyclina beotica, Lepidorbitoides minor, Siderolites calcitrapoides, Smoutina cruysi, Planorbulina* aff. *antiqua, Sulcoperculina* sp., miliolidae, textulariidae. **II:** *Rotalia perovalis, Scandonea* aff. *samnitica, Rotalia* sp., *Anomalina* sp., *Eponides* sp., *Mississipina* sp., miliolidae, textulariidae. **III:** *Idalina sinjarica, Mississipina binkhorsti, Daviesina danieli, Cuvillierina sireli, Rotalia trocidiformis, Rotalia perovalis, Kathina selveri, Miscellanea miscella, Orbitoclypeus seunesi, Anomalina* sp., *Eponides* sp., *Linderina* sp., *Operculina* sp., miliolidae, textulariidae.	late Maastrichtian-Tanetian **I:** late Maastrichtian **II:** Danian **III:** Tanetian
İnceöz, 1996	NE Elazığ	Harami Formation	*Orbitoides medius, O. apiculatus, Orbitoides* spp., *Omphalocyclus macroporus, Sirtina orbitoidiformis, Hellenocyclina beotica, Lepidorbitoides* spp., *Siderolites calcitrapoides, Smoutina cruysi, Scandonea samnitica, Triloculina* sp., *Quinqueloculina* sp., rotaliidae, textulariidae.	late Maastrichtian
Aksoy et al., 1999	SW Elazığ	Harami Formation	*Orbitoides* cf. *medius, Orbitoides* sp., *Lepidorbitoides* spp., *Pseudosiderolites vidali, Pseudosiderolites* sp., *Praesiderolites dordoniensis.*	late Campanian-early Maastrichtian
Kaya and İnceöz, 2001	NE, SW, and W of Elazığ	Harami Formation	*Orbitoides medius, O. apiculatus, Omphalocyclus macroporus, Sirtina orbitoidiformis, Hellenocyclina beotica, Lepidorbitoides minor, L.* cf. *socialis, Lepidorbitoides* sp., *Pseudorbitoides trechmanni, Siderolites calcitrapoides, Smoutina* sp.	middle-late Maastrichtian
This Study	NE and SW Elazığ	Harami Formation	*Orbitoides medius, O. megaloformis, O. gruenbachensis, Orbitoides* sp., *Pseudomphalocyclus blumenthali, Omphalocyclus macroporus, Sirtina* cf. *orbitoidiformis, Hellenocyclina beotica, Lepidorbitoides campaniensis, L. bisambergensis, L.* cf. *minor, Pseudosiderolites vidali, Siderolites* gr. *calcitrapoides, Siderolites* sp., *Sulcoperculina* sp., miliolidae, textulariids, rotaliids.	late Campanian-Maastrichtian

grades upward to sandy limestone and massive limestone (Aksoy, 1993; İnceöz, 1996). Some researchers (Aksoy, 1993; İnceöz, 1996) state that the Harami Formation unconformably rests on the Elazığ Magmatics, while some (Aksoy et al., 1999) argued that it conformably overlies it.

3. Materials and methods

The LBF samples of the Harami Formation were collected while measuring sections at seven localities in the northeastern and southwestern of Elazığ (Figure 1B). These measured sections were named as Silsilekaya Tepe, Ziyaret Taşı Tepe, Nohutlupınarı, Guremağalan, Eskişehir Tepe, Tepeköy, and Ürünveren. Following the preliminary examination, 612 oriented thin sections were prepared from the loose samples (*Orbitoides*, *Lepidorbitoides*, *Pseudosiderolites*) and 170 thin sections from the rock samples. The determination of the LBF content of the Harami Formation was conducted by utilizing equatorial and axial sections in these thin sections. All specimens have been stored in the paleontological collections at the Geology Department of Fırat University. The determination of carbonates was done by following Dunham (1962).

4. Foraminiferal micropaleontology of the Harami Formation

4.1. Silsilekaya Tepe Section

This section was measured in Harput, located 4.2 km northeast of Elazığ (38° 42' 2. 35" N, 39° 15' 32. 93" E; 38° 42' 07. 44" N, 39° 15' 40. 00" E) (Figure 1B). The Harami Formation overlying conformably the upper Cretaceous Elazığ Magmatics comprises, from bottom to top, reddish conglomerate, reddish sandy limestone, grey-white limestone, and grey-white massive limestone (Figures 2A–2C). Samples S1–S13 were collected from this measured section (Figure 2C). The thickness of the

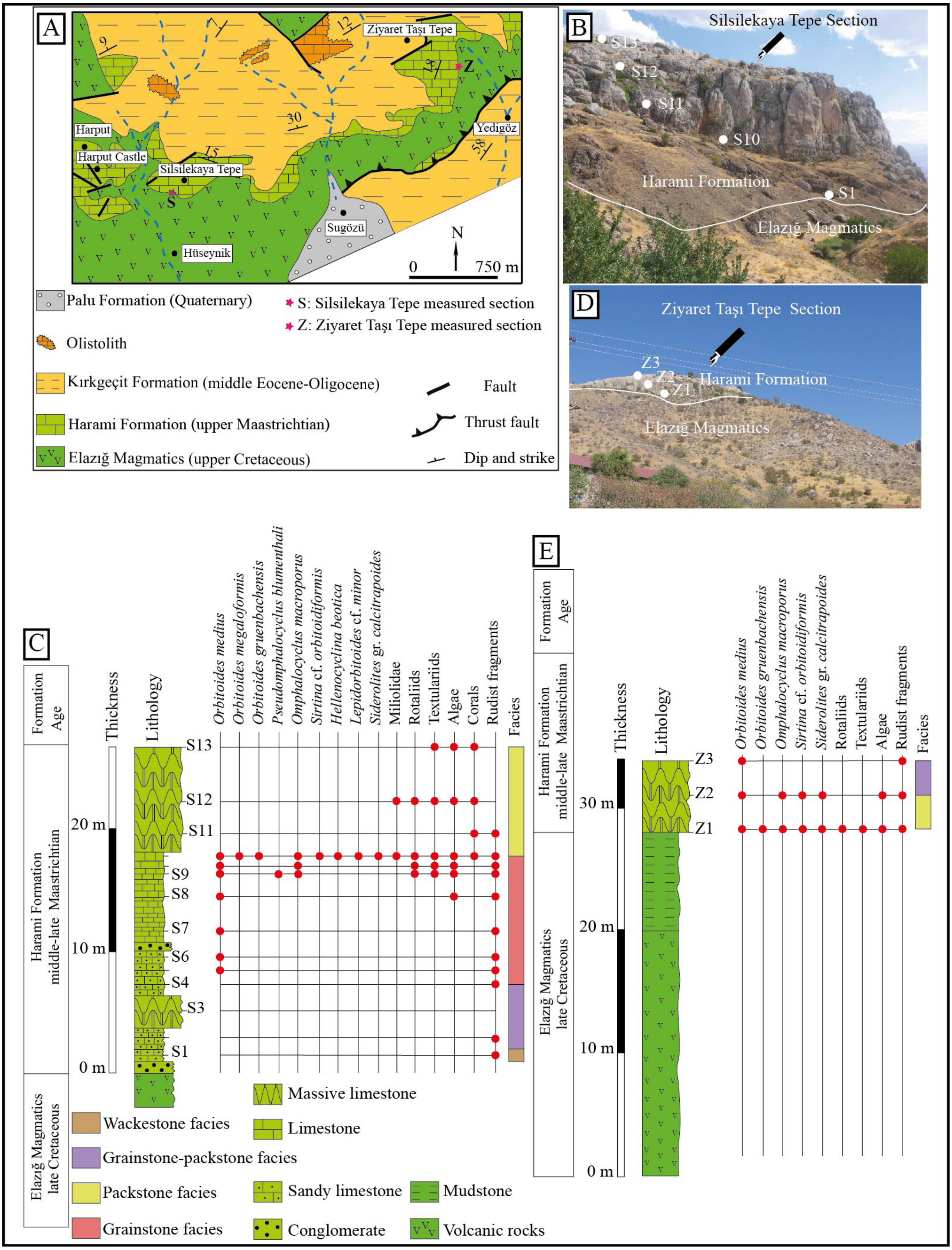

Figure 2. A) The geological map of the Harput area (İnceöz, 1996). B) Field photograph of the Silsilekaya Tepe Section. C) Silsilekaya Tepe measured columnar section. D) Field photograph of the Ziyaret Taşı Tepe Section. E) Ziyaret Taşı Tepe measured columnar section.

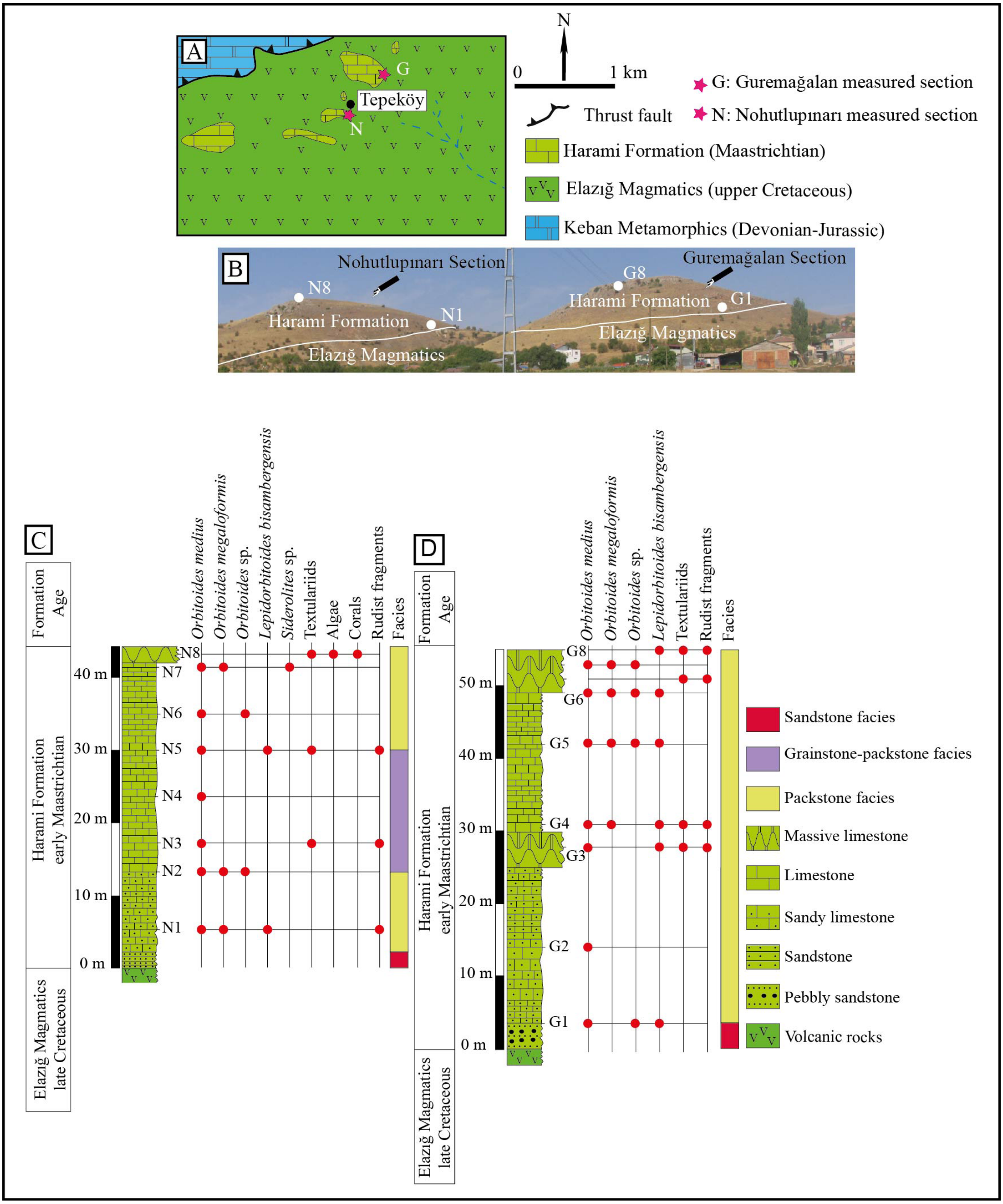

Figure 3. A) The geological map of the Nohutlupınarı and Guremağalan areas (Aksoy, 1993). B) Field photographs of the Nohutlupınarı and Guremağalan sections. C) Nohutlupınarı measured columnar section. D) Guremağalan measured columnar section.

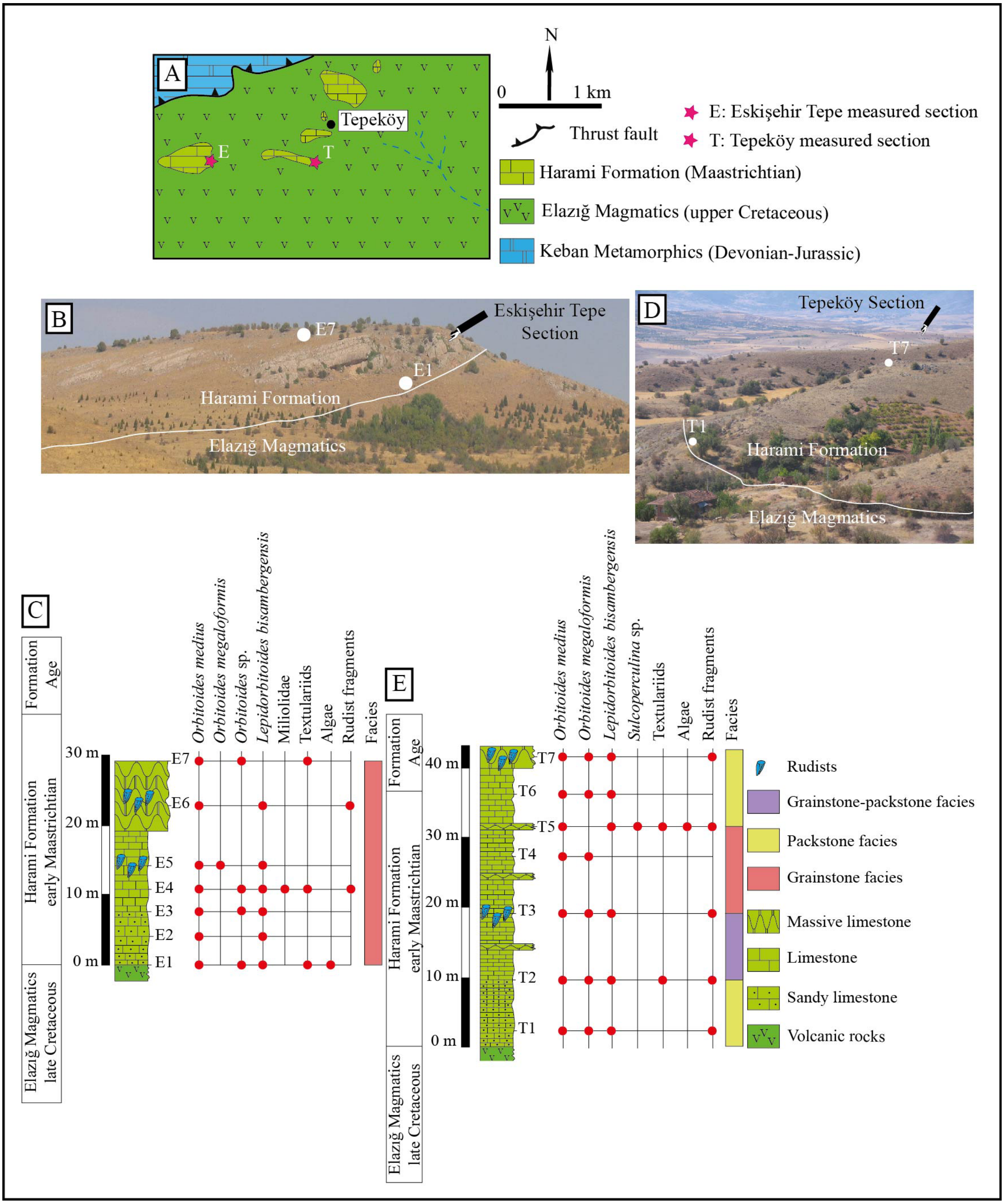

Figure 4. A) The geological map of the Eskişehir Tepe and Tepeköy areas (Aksoy, 1993). B) Field photograph of the Eskişehir Tepe Section. C) Eskişehir Tepe measured columnar section. D) Field photograph of the Tepeköy Section. E) Tepeköy measured columnar section.

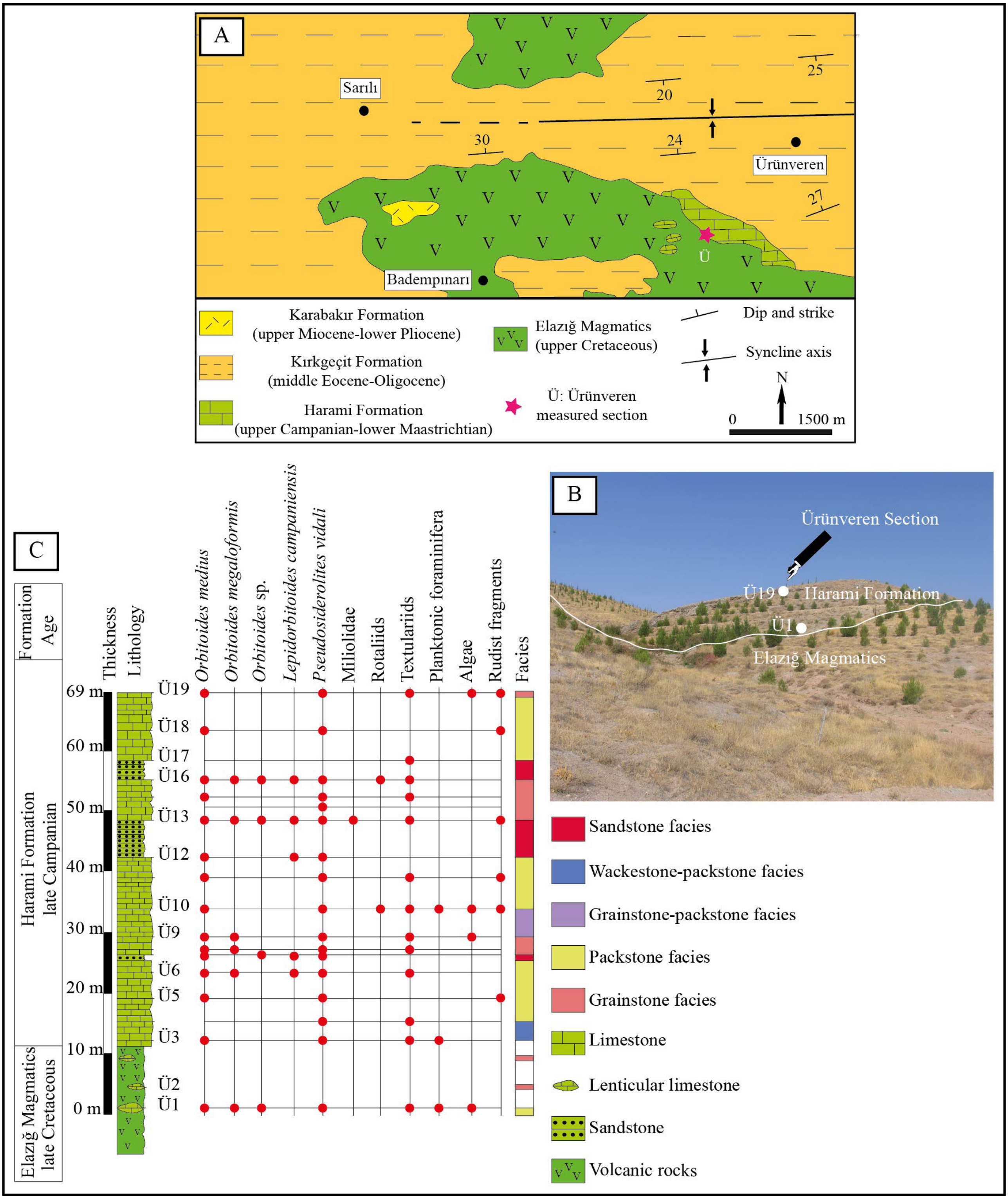

Figure 5. A) The geological map of the Ürünveren area (Aksoy et al., 1999). B) Field photograph of the Ürünveren Section. C) Ürünveren measured columnar section.

unit is 30 m. Loose samples are scarce. *Orbitoides medius*, *O. megaloformis*, *O. gruenbachensis*, *Pseudomphalocyclus blumenthali*, *Omphalocyclus macroporus*, *Sirtina* cf. *orbitoidiformis*, *Hellenocyclina beotica*, *Lepidorbitoides* cf. *minor*, *Siderolites* gr. *calcitrapoides*, miliolidae, rotaliids, textulariids, algae, corals, and rudist fragments represent the fossil content of this section (Figure 2C). The limestone of this section is represented by grainstone, packstone, grainstone-packstone, and wackestone facies (Figures 2C, 6A–6H).

4.2. Ziyaret Taşı Tepe Section

This section was measured at the northeast of Elazığ (38° 42' 23. 24" N, 39° 17' 46. 83" E; 38° 42' 27. 83" N, 39° 17' 21. 41" E) (Figure 1B). Overlying conformably the upper Cretaceous Elazığ Magmatics, the Harami Formation consists of grey-white massive limestone (Figures 2A, 2D, 2E). Z1–Z3 samples were collected from this section (Figure 2E). The unit has a thickness of 34 m. No loose specimens were available. *Orbitoides medius*, *O. gruenbachensis*, *Omphalocyclus macroporus*, *Sirtina* cf. *orbitoidiformis*, *Siderolites* gr. *calcitrapoides*, rotaliids, textulariids, algae, and rudist fragments were determined in thin sections prepared from hard rocks (Figure 2E). The limestone of this section is represented by packstone and grainstone-packstone facies (Figures 2E, 6D–6G).

4.3. Nohutlupınarı Section

Samples N1–N8 were collected from this measured section at the southwest of Elazığ (38° 36' 26. 02" N, 39° 8' 55. 30" E; 38° 36' 23. 57" N, 39° 8' 50. 10" E) (Figure 1B). The 44-m thick formation is represented by reddish sandstone, reddish sandy limestone, grey-white limestone, and grey-white massive limestone (Figures 3A–3C). The unit contains dominantly *Orbitoides medius*, *O. megaloformis*, *Orbitoides* sp., also *Lepidorbitoides bisambergensis*, *Siderolites* sp., textulariids, algae, corals, and rudist fragments (Figure 3C). The limestone of this section is represented by packstone and grainstone-packstone facies (Figures 3C, 6D–6G).

4.4. Guremağalan Section

Samples G1–G8 were collected from the 55-m thick Harami Formation at the southwest of Elazığ (38° 36' 32. 64" N, 39° 9' 5. 81" E; 38° 36' 30. 81" N, 39° 9' 2. 08" E) (Figures 1B, 3D). The formation consists of reddish pebbly sandstone, reddish sandy limestone, grey-white limestone, and grey-white massive limestone (Figures 3A, 3B, 3D). The unit contains dominantly *Orbitoides medius*, *O. megaloformis*, *Orbitoides* sp., also *Lepidorbitoides bisambergensis*, textulariids, and rudist fragments were determined (Figure 3D). The limestone of this section is represented by packstone facies (Figures 3D, 6D–6G).

4.5. Eskişehir Tepe Section

E1–E7 samples were collected from this measured section at the southwest of Elazığ (38° 35' 59. 6" N, 39° 7' 54. 39" E; 38° 36' 1. 93" N, 39° 7' 51. 31" E) (Figure 1B). The formation comprises reddish sandy limestone, grey-white limestone, and grey-white massive limestone (Figures 4A–4C). The sequence has a thickness of 29 m. The unit contains dominantly *Orbitoides medius*, *O. megaloformis*, *Orbitoides* sp., also *Lebidorbitoides bisambergensis*, miliolidae, textulariids, algae, and rudist fragments were determined (Figure 4C). The limestone of this section is represented by grainstone facies (Figures 4C, 6A–6C).

4.6. Tepeköy Section

Samples T1–T7 were collected from the 43-m thick Harami Formation at the southwest of Elazığ (38° 36' 9. 74" N, 39° 8' 40. 51" E; 38° 36' 8. 53" N, 39° 8' 36. 25" E) (Figures 1B, 4E). The formation consists of reddish sandy limestone, grey-white limestone, and grey-white massive limestone (Figures 4A, 4D, 4E). The formation contains dominantly *Orbitoides medius*, *O. megaloformis*, also *Lepidorbitoides bisambergensis*, *Sulcoperculina* sp., textulariids, algae, and rudist fragments were determined (Figure 4E). The limestone of this section is represented by grainstone, packstone, and grainstone-packstone facies (Figures 4E, 6A–6G).

4.7. Ürünveren Section

Samples Ü1–Ü19 were collected from the Harami Formation at the southwest of Elazığ (38° 31' 14. 16" N, 39° 8' 33. 34" E; 38° 31' 19. 29" N, 39° 8' 29. 42" E) (Figure 1B). At the lower part of this section, the volcanic rocks of the upper Cretaceous Elazığ Magmatics are laterally and vertically transitional with grey limestone with lenticular beds of the Harami Formation. This level grades upwards into a limestone sequence which contains sandstone intercalations (Figures 5A–5C). In this 69-m thick section, *Orbitoides medius*, *O. megaloformis*, *Orbitoides* sp., *Lepidorbitoides campaniensis*, *Pseudosiderolites vidali* are the dominant species, but miliolidae, rotaliids, textulariids, planktonic foraminifera, algae, and rudist fragments were also determined (Figure 5C). The limestone of this section is represented by grainstone, packstone, grainstone-packstone and wackestone-packstone facies (Figures 5C, 6A–6G, 6I).

5. Systematic paleontology

In this paper, the classification scheme is based on Loeblich and Tappan (1987) and the reviewed classification of Boudagher-Fadel (2018) (Figures 7–14). The systematic descriptions of Van Hinte (1976), Van Gorsel (1975, 1978), and Robles-Salcedo et al. (2018) were also taken into consideration.

Order: Rotaliida Delage and Hérouard, 1896
Superfamily: Orbitoidoidea, Schwager, 1876
Family: Orbitoididae Schwager, 1876
Subfamily: Orbitoidinae Schwager, 1876
Genus: *Orbitoides* d'Orbigny, 1848
Type species: *Lycophris faujasii* Defrance 1823, p. 271.

***Orbitoides medius* (d'Archiac, 1837)**
Figures 7A, 7B, 8, 9A–9F
1837 *Orbitolites media* d'Archiac, p. 178.
1852 *Orbitoides media* (d'Archiac) d'Orbigny, p. 852.
Samples no: Three hundred and ninety-nine specimens from samples E1–E7, G1–G7a, N1–N7, S5–S10, S10a, T1–T7, Ü1, Ü3, Ü5–Ü13, Ü15, Ü16, Ü18, Ü19, and Z1–Z3.
Description: The shape of the test varies, but it is generally lenticular with a circular outline (Figures 7A, 7B). It is generally symmetric with respect to the equatorial plane, but asymmetry is seen in some specimens (Figures 8D, 8E). The test diameter ranges from 2.03 mm to 6.61 mm, with sample averages of 4.03 mm. The test thickness ranges from 0.40 mm to 3.33 mm, with sample averages of 1.60 mm. The coarse granules covering the test surface and fused into the ridges are common in the axial part of the test. Consisting of a protoconch, a deuteroconch, and two tritoconch, the embryo forms configurations with three or four chambers in its equatorial sections, depending on the sectioning level on the equatorial plane (Figures 8A, 8B, 9A–9F). Based on its outline, the embryo is commonly semispherical. The embryo ranges in size (Li+li) from 279 µm to 839 µm, with an average of 454–600 µm (seven measured sections, samples from 53 different levels, 399 specimens). This embryo followed by orbitoidal cycles of arc-shaped equatorial chamberlets, and primary and

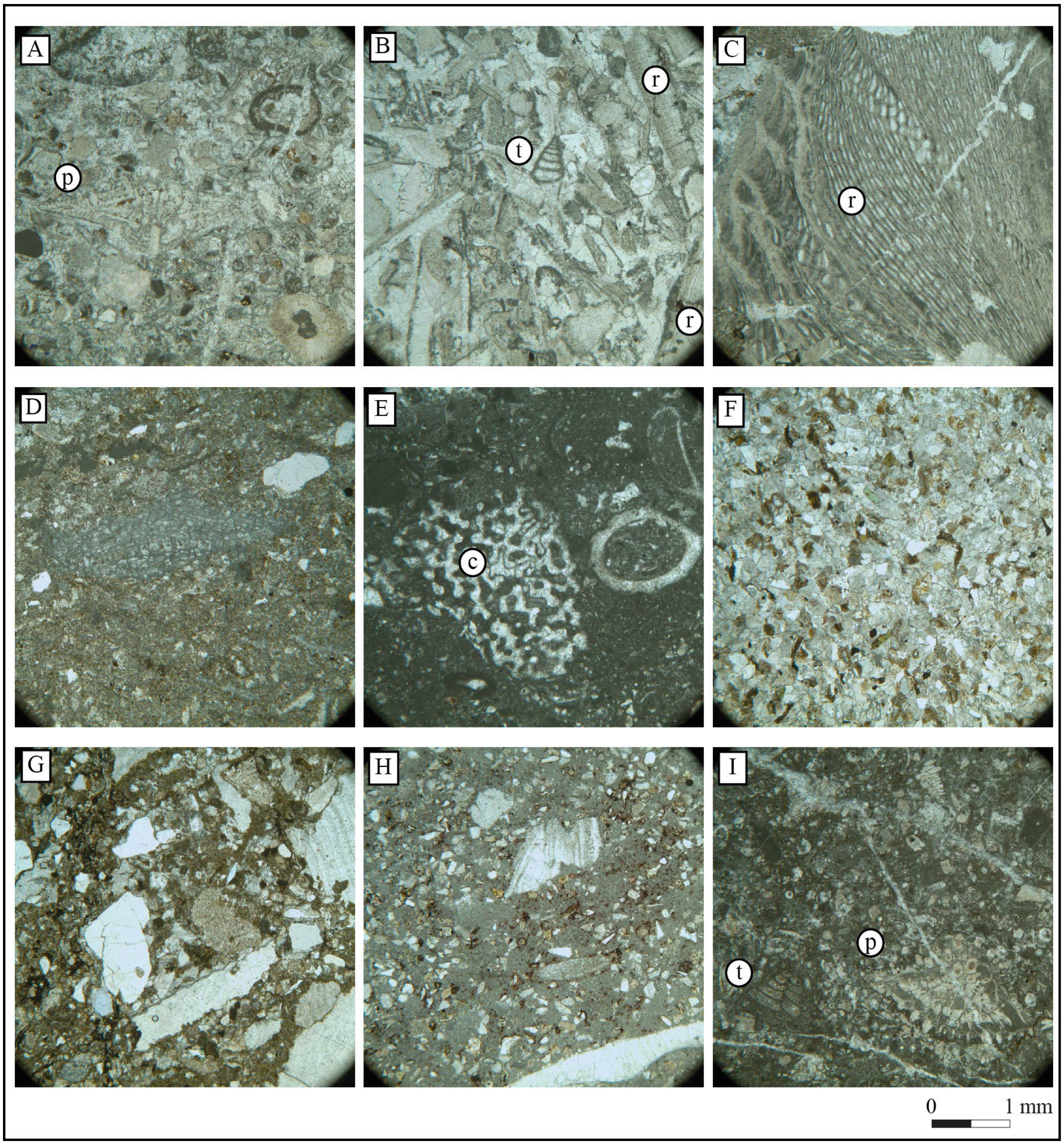

Figure 6. A–I) Photomicrographs of the microfacies views. A–C) Grainstone, samples Ü7-3, E4-1, E6-9. D–G) Packstone, samples G4-1, N8-3, G1-4, T1-2. H) Wackestone, sample S1-1. I) Wackestone-packstone, sample Ü3-5. c: corals, p: *Pseudosiderolites vidali*, t: textulariid, r: rudist fragment.

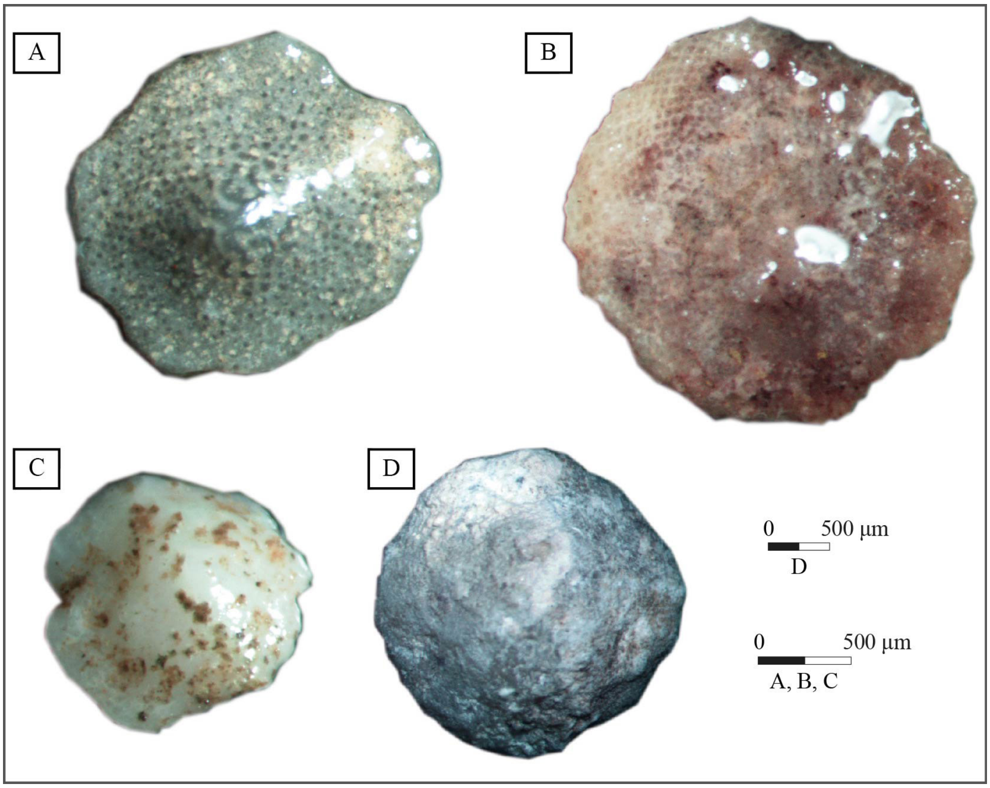

Figure 7. A–D) External views of *Orbitoides medius, O. megaloformis*, and *O. gruenbachensis.* A–B) *O. medius*, samples Ü3-1, T3-17. C) *O. megaloformis*, sample G8-2. D) *O. gruenbachensis*, sample S10-9.

accessory epi-embryonic chamberlets. The number of epi-embryonic chamberlets ranges from 4 to 8, with a mean of 4.00–5.33. The average of the stolons connecting the equatorial chamberlets in the late stages of ontogenetic development is about 31–49 µm in diameter (Figure 8C).

Remarks: Using different species concepts (typological vs. morphometric), the *O. hottingeri-O. douvillei-O. tissoti-O. medius-O. megaloformis-O. gruenbachensis-O. apiculatus-O. gensacicus* species succession is considered to be a single evolutionary series (Van Hinte, 1976; Van Gorsel, 1978; Caus et al., 1996). Based on the previous literature data, the morphometric species concept was also used for the species assignment in this study. *Orbitoides* specimens were assigned to *O. medius* based on the limits of the internal parameters as follows: 454 µm < $(Li+ li)_{mean}$ < 600 µm and 4 < E_{mean} < 5.33.

Age: Despite uncertainty about the distribution of the aforementioned species along the Campanian-Maastrichtian boundary, *O. medius* is accepted as late Campanian species (Van Hinte, 1966, 1976; Van Gorsel, 1978; Baumfalk, 1986; Caus et al., 1996). While *O. medius* is known from the Oman Campanian Qahalah Formation (Kayğılı et al., 2021), it is also stated to exist from the Maastrichtian Simsima Formation overlying it (Özcan et al., 2021, 2022). *O. medius* were also reported from early-late Campanian (Özcan et al., 2019), late Campanian (Kayğılı et al., 2021), and Maastrichtian (Meriç, 1980; Özgen et al., 1993; Görmüş, 1994, 1997; İnceöz, 1996; Aksoy et al., 1999; Abdelghany, 2006; Consorti and Köroğlu, 2019; Özcan et al., 2021, 2022). It indicates the late Campanian-Maastrichtian in age.

***Orbitoides megaloformis* Papp and Küpper, 1953**

Figures 7C, 9G–9I

1953 *Orbitoides media megaloformis* n. sp., Papp and Küpper, p. 74, pl. 1, figs. 8A, 8B, and 9.

Samples no: Eighty-three specimens from samples E5, G4–G7a, N1, N2, N7, S10, T1–T4, T6, T7, Ü1, Ü6, Ü8, Ü9, Ü13, and Ü16.

Description: The test has a lenticular outline and a densely granulated outer surface (Figure 7C). The test diameter ranges from 1.72 mm to 6.13 mm, with sample averages of 3.69 mm. The test thickness ranges from 0.87 mm to 2.60 mm, with 1.52 mm sample averages. The embryo is composed of a protoconch, a deuteroconch, and a tritoconch, resulting in four chambered configurations in the equatorial sections (Figures 9G–9I). The embryo is typically semispherical in shape. The embryo size (Li+li) ranges from 332 µm to 934 µm, with sample averages ranging from 633 µm to 714 µm (six measured sections, samples from 21 different levels, 83 specimens). Principal and accessory epi-embryonic chamberlets and orbitoidal cycles of arc-shaped equatorial chamberlets follow the embryo. Epi-embryonic chamberlets' number ranges between 6 and 9. The average number of epi-embryonic chamberlets is between 6 and 8.50.

Remarks: For the species assignment, the morphometric species concept has been used, and *Orbitoides* specimens were assigned to *O. megaloformis* based on species limits of 633 µm < $(Li+li)_{mean}$ < 714 µm and 6 < E_{mean} < 8.50.

Age: *O. megaloformis* has often been reported from Campanian (Erdem et al., 2021) and Maastrichtian (Gunter et al., 2002; Özcan et al., 2021). It indicates the late Campanian-Maastrichtian in age.

***Orbitoides gruenbachensis* Papp, 1955**

Figures 7D, 9J–9L

1955 *Orbitoides apiculata gruenbachensis* n. sp., Papp, p. 305, pl. 2, figs. 1–8, 9a–9b, 10, 12, pl. 3 fig. 2.

Samples no: Twelve specimens from samples S10 and Z1.

Description: The embryo size (Li+li) ranges between 752 µm and 1417 µm, with sample averages between 956 µm and 982 µm (two measured sections, samples from 2 different levels, 12 specimens). Following the embryo are primary and accessory epi-embryonic chamberlets. Epi-embryonic chamberlets number ranges between 10 and 14. There are 11–12 epi-embryonic chamberlets on average.

Remarks: *O. gruenbachensis* is characterized by a large

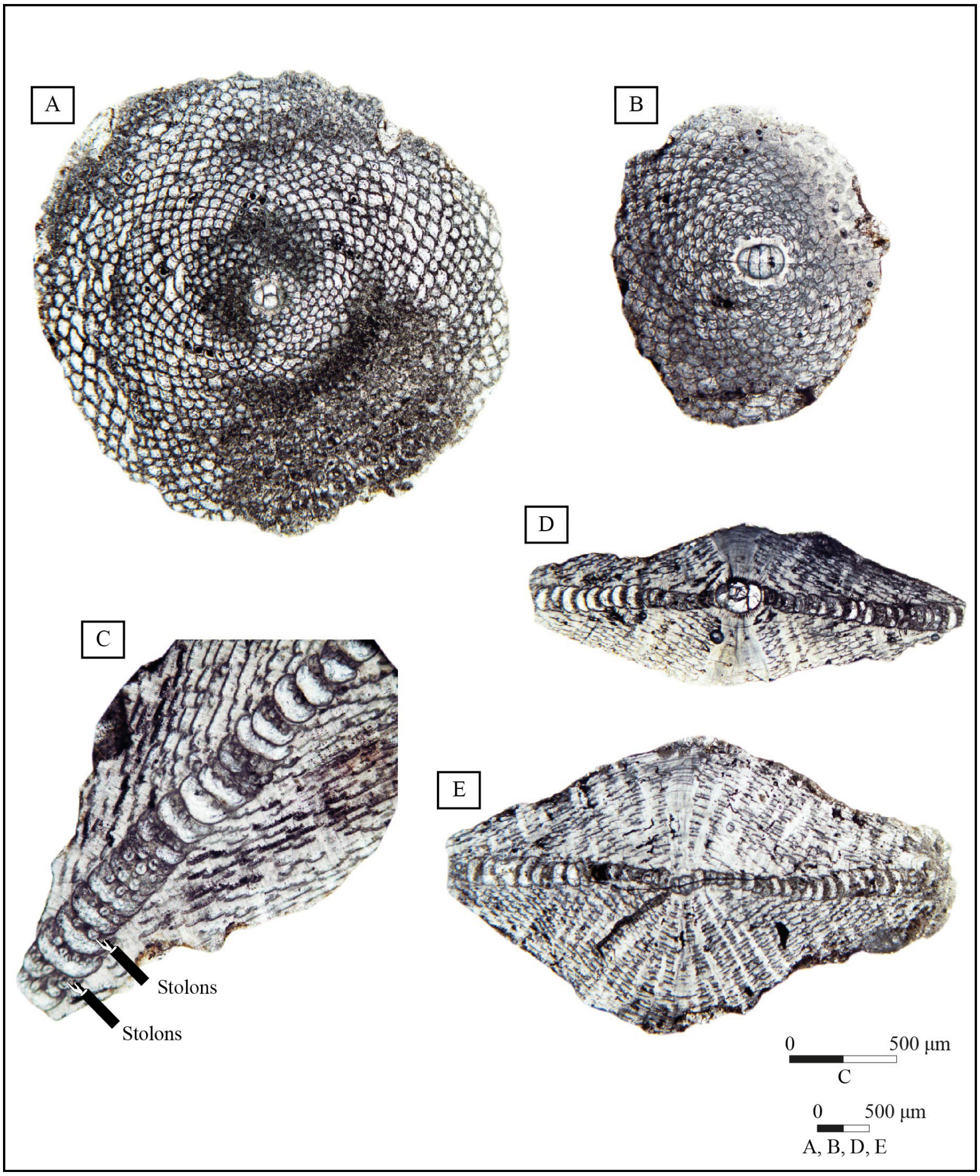

Figure 8. A–E) Photomicrographs showing *Orbitoides medius.* A–B) Equatorial sections, samples T3-9, G4-8. C) Stolons in axial section, sample G5-10. D–E) Axial sections, T3-21, T2-7.

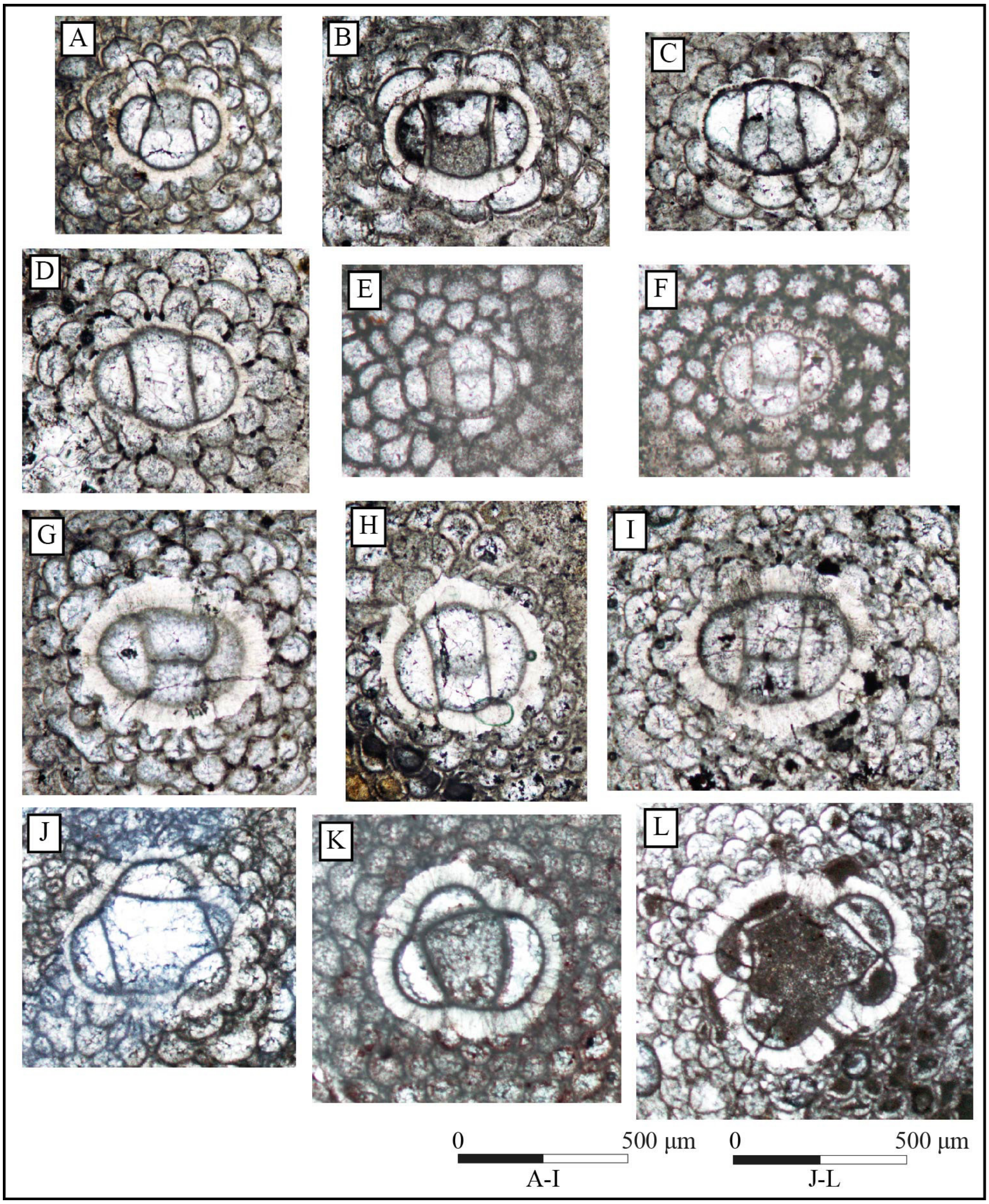

Figure 9. A–L) Photomicrographs showing equatorial sections of various embryonic views in *Orbitoides medius*, *O. megaloformis*, and *O. gruenbachensis*. A–F) *O. medius,* samples Ü3-1, G4-2, N2-10, G5-2, Ü8-4, Ü8-7. G–I) *O. megaloformis,* samples N2-14, Ü8-12, T2-9. J-L) *O. gruenbachensis,* samples S10-8, S10-9, S10-10. A–L: Equatorial sections.

bilocular embryonic apparatus, that is like the embryonic chamber configuration extensively observed in *O. apiculatus* (Figures 9J–9L) (Özcan et al., 2021). For the species assignment, the morphometric species concept was used in this study, and *Orbitoides* specimens were assigned to *O. gruenbachensis* based on species limits of 956 µm < $(Li+li)_{mean}$ < 982 µm and 11 < E_{mean} <12.

Age: *O. gruenbachensis* Papp was defined as early Maastrichtian in Austria (Papp, 1955); in Turkey, it was defined in the middle-late Maastrichtian (Meriç, 1967; Görmüş, 1997; Meriç and Görmüş, 1999). It indicates the middle-late Maastrichtian age.

Genus: *Pseudomphalocyclus* Meriç, 1980

Type species: *Pseudomphalocyclus blumenthali* Meriç, 1980, p. 85.

Pseudomphalocyclus blumenthali **Meriç, 1980**

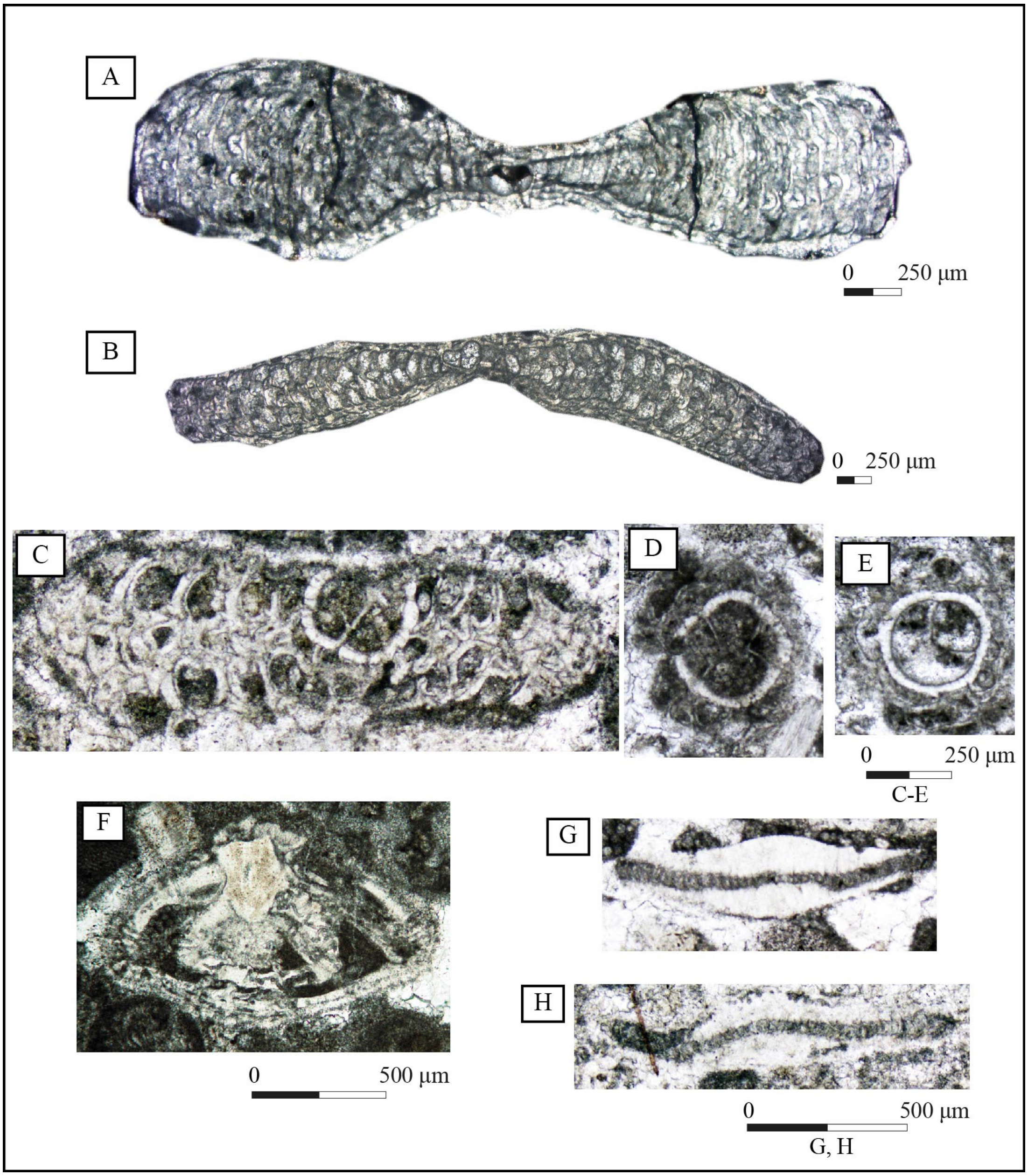

Figure 10. A–H) Photomicrographs showing *Pseudomphalocyclus blumenthali, Omphalocyclus macroporus, Sirtina* cf. *orbitoidiformis*, and *Hellenocyclina beotica*. A-B) *Pseudomphalocyclus blumenthali*, samples S9-6, S9-1. C–E) *Omphalocyclus macroporus,* samples S10-3, S10-2, S10-6. F) *Sirtina* cf. *orbitoidiformis*, sample S10-3. G–H) *Hellenocyclina beotica*, samples S10-2, S10-3. A, B, C, F, G, H: Axial and near axial sections. D, E: Equatorial and near equatorial sections.

Figures 10A, 10B
1980 *Pseudomphalocyclus blumenthali* n. sp., Meriç, p. 87, pl. 1, p. 89, pl. 2.
Samples no: Two specimens from sample S9.
Description: Because no free specimens were available, no direct observation of the nature of the test surface was possible. The macrospheric embryo can be observed as bilocular, trilocular, and quadrilocular (Figures 10A, 10B) (Meriç, 1980). The test diameter varies from 3536 µm to 5102 µm, and the peripheral thickness ranges from 540 µm to 710 µm. The centre thickness ranges from 268 µm to 442 µm. The embryo size (Li+li) ranges between 342 µm and 461 µm, with a sample average of 402 µm.
Remarks: This form shows great similarity to the genus

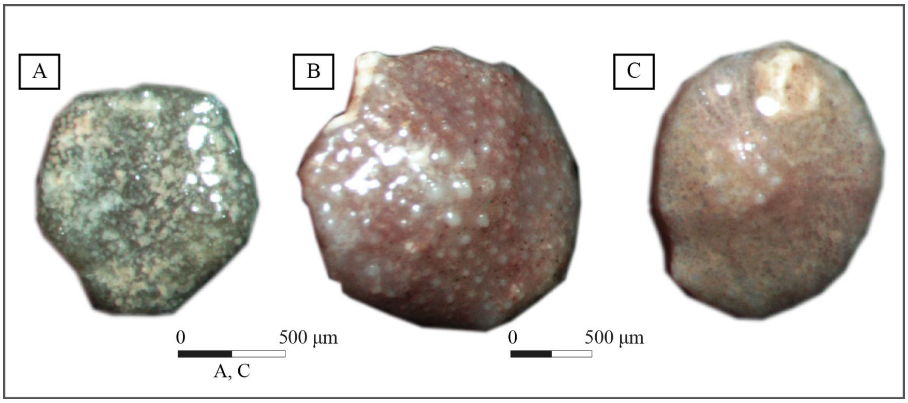

Figure 11. A–C) External views of *Lepidorbitoides campaniensis, L. bisambergensis*, and *Pseudosiderolites vidali*. A) *L. campaniensis*, sample Ü7-9. B) *L. bisambergensis*, sample N1-5. C) *P. vidali*, sample Ü13-1.

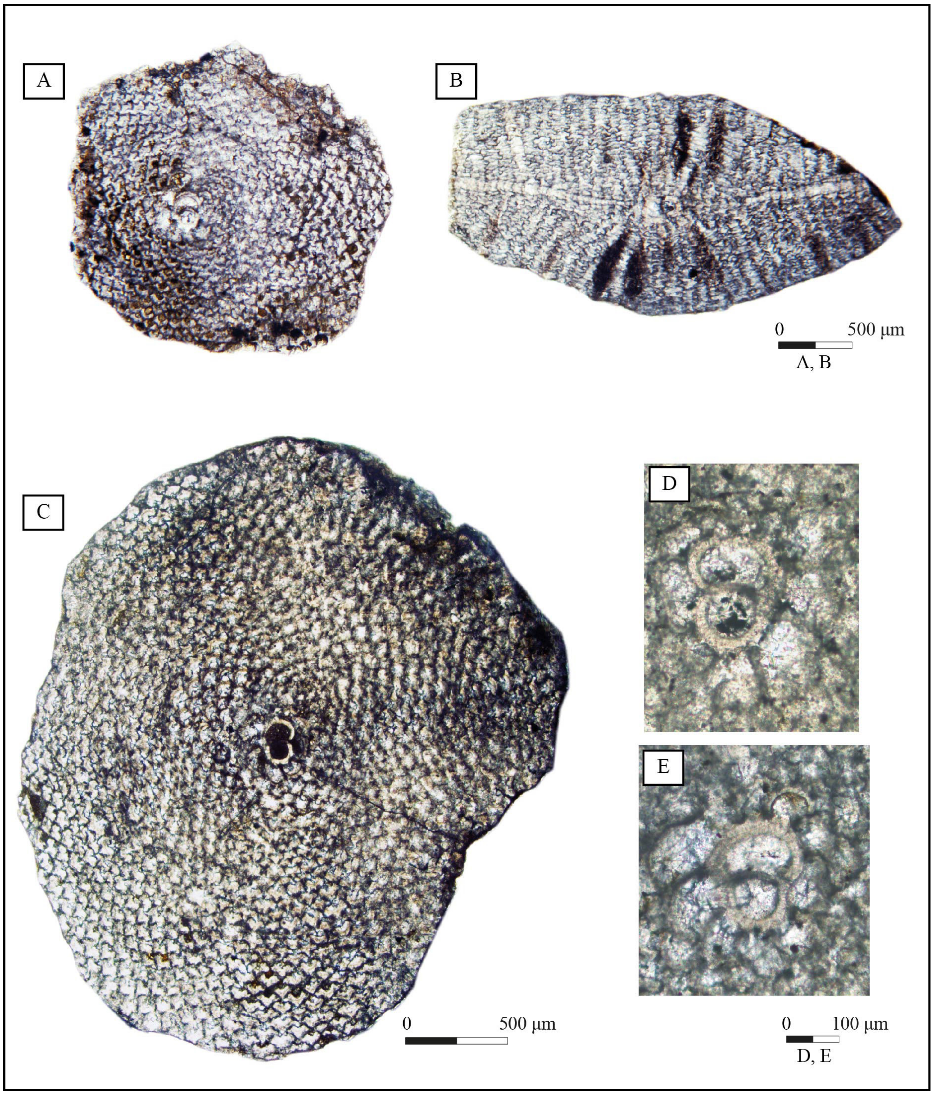

Figure 12. A–E) Photomicrographs showing *Lepidorbitoides campaniensis*, samples Ü7-9, Ü13-11, Ü16-18, Ü7-18, Ü6-15. A, C, D, E: Equatorial sections. B: Axial section.

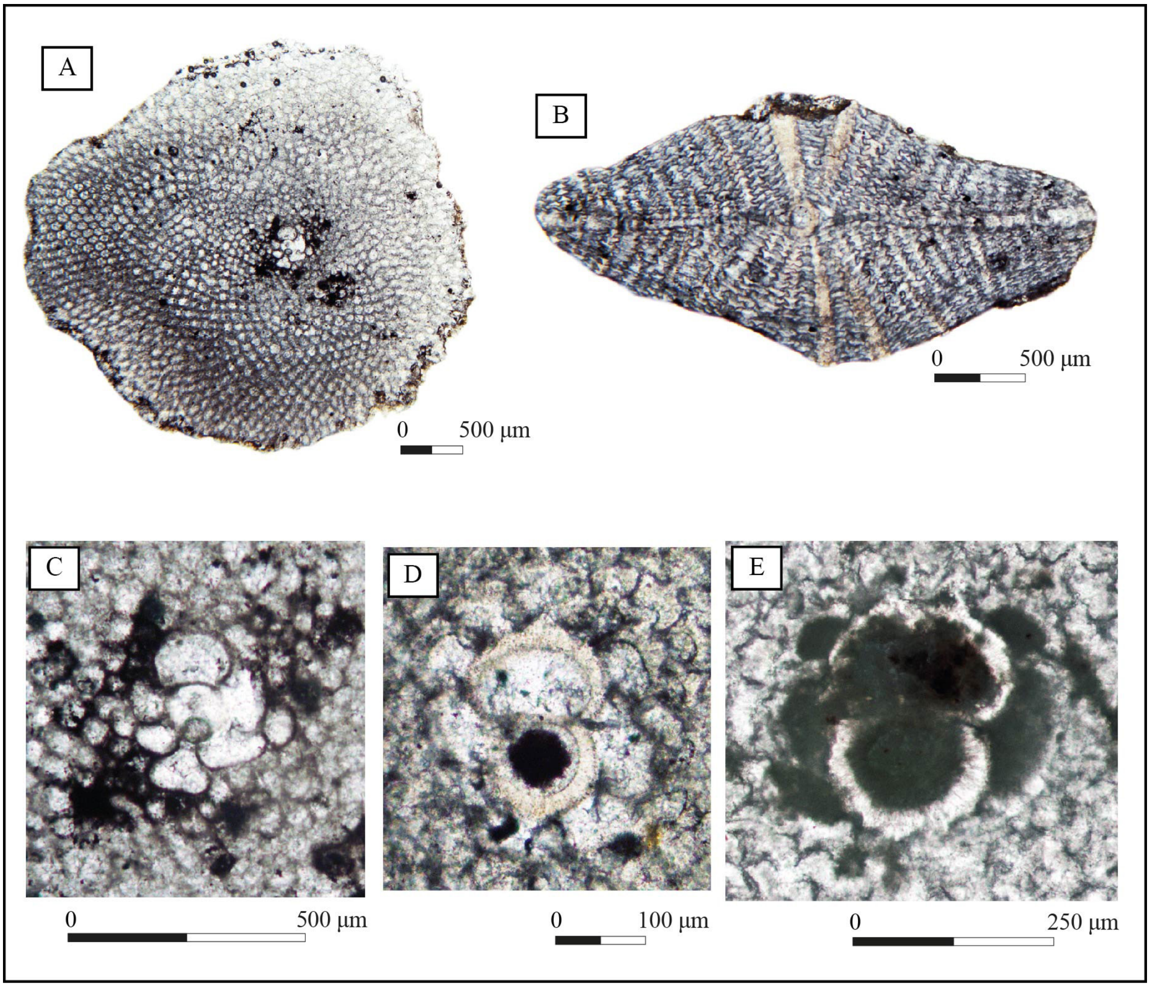

Figure 13. A–E) Photomicrographs showing *Lepidorbitoides bisambergensis* and *Lepidorbitoides* cf. *minor*. A–D) *L. bisambergensis*, samples T3-12, T5-14, N5-6. E) *L.* cf. *minor*, sample S10-2. A, C, D, E: Equatorial sections. B: Axial section.

Omphalocyclus Bronn in its test shape and the general characteristics observed in axial and equatorial sections of the type species. However, it is clearly differentiated from *Omphalocyclus* by the presence of lateral chambers and pillars in axial sections. The height of equatorial chambers also increases toward the periphery giving a general papilion-shape to the test (Figures 10A, 10B) (Meriç, 1980).

Age: *P. blumenthali* is definitely to be regarded as an index fossil of the Maastrichtian (Meriç, 1980; Özcan, 1993; Matsumaru, 1997; Özer et al., 2009; Meriç et al., 2010). In this study, *P. blumenthali* was determined in the middle-late Maastrichtian in the Silsilekaya Tepe Section is associated with *O. gruenbachensis*, *O. macroporus*, *S.* cf. *orbitoidiformis, H. beotica*, *L.* cf. *minor*, and *S.* gr. *calcitrapoides*.

Subfamily: Omphalocyclinae Vaughan, 1928

Genus: *Omphalocyclus* Bronn, 1853

Type species: *Orbulites macropora* Lamarck, p. 197.

***Omphalocyclus macroporus* (Lamarck, 1816)**

Figures 10C–10E

1853 *Omphalocyclus* Bronn, in Bronn and Roemer, p. 95.

Samples no: Fourteen specimens from samples S9, S9a, S10, Z1, and Z2.

Description: No free specimens were available; therefore, no direct observation was possible on the nature of the test surface. The test diameter ranges from 1742 µm to 3818 µm, with sample averages of 2295 µm. The test thickness ranges from 403 µm to 667 µm, with sample average 514 µm. The centre and peripheral thickness are 264 µm and 420 µm, respectively. The embryo size (Li+li) ranges between 440 µm and 1054 µm, with sample averages of 650 µm.

Remarks: The most widespread species in this genus is *O. macroporus*, which has a comparatively large four-chambered embryon and a discoidal, bilaterally depressed test (Figure 10D). During its ontogenic development, this test consists of a number of annular equatorial chamberlets

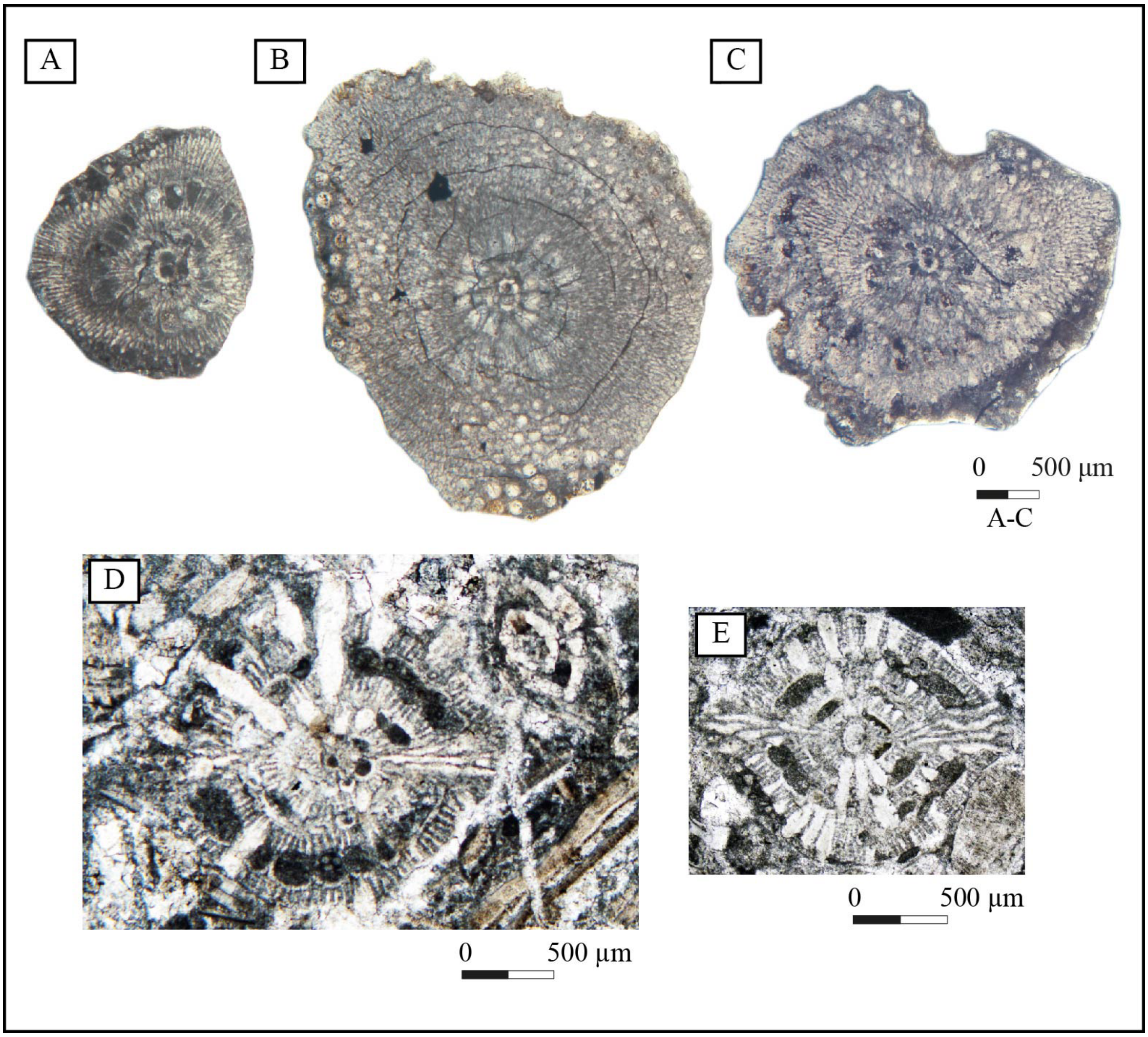

Figure 14. A–E) Photomicrographs showing *Pseudosiderolites vidali* and *Siderolites* gr. *calcitrapoides*. A–C) *P. vidali*, samples Ü3-7, Ü4-1, Ü8-10. D–E) *Siderolites* gr. *calcitrapoides*, samples Z1-1, S10-3. A–E: Equatorial and near equatorial sections.

that double or treble in axial directions (Küpper, 1954; Papp, 1954; Neumann, 1958; MacGillavry, 1963; Meriç, 1967; Van Gorsel, 1978). The genus is characterized by the absence of lateral chamberlets layers (Figure 10C).

Age: *Omphalocyclus* occurrences of several stratigraphic levels from Campanian to late Maastrichtian have been documented by Özcan (2007) and Kayğılı et al. (2021). *O. macroporus* has often been reported from Maastrichtian (Meriç, 1967, 1980; Özcan, 1993; Özgen et al., 1993; İnceöz, 1996; Matsumaru, 1997; Abdelghany, 2006; Özcan, 2007; Caus et al., 2016; Kayğılı et al., 2021; Özcan et al., 2022). In this study, *O. macroporus* which was determined in the middle-late Maastrichtian in the Silsilekaya Tepe and Ziyaret Taşı Tepe sections is associated with *O. gruenbachensis*, *P. blumenthali*, *S.* cf. *orbitoidiformis*, *H. beotica*, *L.* cf. *minor*, and *S.* gr. *calcitrapoides*.

Family: Lepidorbitoididae Vaughan, 1933

Subfamily: Clypeorbinae Sigal, 1952

Genus: *Sirtina* Brönnimann and Wirz, 1962

Type species: *Sirtina orbitoidiformis* Brönnimann and Wirz, 1962.

***Sirtina* cf. *orbitoidiformis* Brönnimann and Wirz, 1962**

Figure 10F

1962 *Sirtina orbitoidiformis* Brönnimann and Wirz, p. 520–526, figs. 1–6.

Samples no: Ten specimens from samples S10, Z1, and Z2.

Description: No loose specimens were available; therefore, no direct observation was possible on the nature of the test surface. The diameter of the test ranges from 572 µm to 1024 µm, with an average of 794 µm. The thickness of the test ranges from 310 µm to 649 µm, with an average of 527 µm.

Remarks: *S. orbitoidiformis* is a rotaliid form with well-developed ventral umbilical pillars and with orbitoidal lateral chambers on the dorsal side (Figure 10F) (Van

Gorsel, 1978). Test is lenticular with pustulate umbos and acute margin (Van Gorsel, 1978). Young individuals have clearly differentiated dorsal and ventral sides (Van Gorsel, 1978). In adult specimens, the final whorls tend to become involute and the dorsal and ventral sides are similar (Van Gorsel, 1978).

Age: *Sirtina* reported from the early Maastrichtian in the Persian Gulf, Iran (Van Gorsel, 1978). *S. orbitoidiformis* was recorded in the late Campanian in some studies (Özcan, 1993; Erdem et al., 2021), while it was recorded in the late Maastrichtian (İnceöz, 1996; Consorti and Köroğlu, 2019) and Maastrichtian (but not the latest) (Özcan et al., 2022). In this study, *S.* cf. *orbitoidiformis* reported from the middle-late Maastrichtian in the Silsilekaya Tepe and Ziyaret Taşı Tepe sections is associated with *O. gruenbachensis*, *P. blumenthali, O. macroporus*, *S.* cf. *orbitoidiformis, H. beotica, L.* cf. *minor*, and *S.* gr. *calcitrapoides*.

Subfamily: Lepidorbitoidinae Vaughan, 1933

Genus: *Hellenocyclina* Reichel, 1949

Type species: *Hellenocyclina beotica* Reichel, 1949, p. 140.

***Hellenocyclina beotica* Reichel, 1949**

Figures 10G, 10H

1949 *Hellenocyclina beotica* n. sp., Reichel, p. 140.

Samples no: Four specimens from sample S10.

Description: Lateral sides of the equatorial layer thickened with hyaline calcareous material, thickest in the central part (Figures 10G, 10H). No loose specimens were available; therefore, no direct observation was possible of the nature of the test surface. The test diameter ranges from 519 µm to 1021 µm, with an average of 835 µm. The thickness of the test ranges from 175 µm to 319 µm, with an average of 250 µm. Proloculus (?) is small and about 164 µm in diameter.

Remarks: *H. beotica* was introduced for small, flat, or slightly conical, discoidal orbitoidal foraminifer without lateral chambers from Greece (Van Gorsel, 1978). Diameter of up to 1.7 mm, usually less than 1 mm, thickness of 0.2–0.42 mm (Van Gorsel, 1978). The diameter of the protoconch (?) is 45 µm (Van Gorsel, 1978).

Age: *H. beotica* is definitely to be regarded as an index fossil of the late Maastrichtian (Özgen et al., 1993; İnceöz, 1996; Matsumaru, 1997; Consorti and Köroğlu, 2019). In this study, *H. beotica* determined in the middle-late Maastrichtian in the Silsilekaya Tepe Section is associated with *O. gruenbachensis*, *P. blumenthali, O. macroporus*, *S.* cf. *orbitoidiformis*, *L.* cf. *minor*, and *S.* gr. *calcitrapoides*.

Genus: *Lepidorbitoides* Silvestri, 1907

Type species: *Orbitoides socialis* Leymerie, 1851, p. 191.

***Lepidorbitoides campaniensis* Van Gorsel, 1973**

Figures 11A, 12A–12E

1973 *Lepidorbitoides campaniensis* n. sp., Van Gorsel, p. 263–271, pl. 1, figs. 1–6, pl. 2, figs. 1–4, pl. 3, figs. 1–4, pl. 4, figs. 1–3, fig. 3.

Samples no: Fifteen specimens from samples Ü6, Ü7, Ü12, Ü13, and Ü16.

Description: Megalospheric specimens' diameters range from 1.27 mm to 3.57 mm, with sample averages of 2.70 mm. Megalospheric specimens' thickness ranges from 0.52 mm to 1.43 mm, with averages of 1.03 mm. Protoconch and deuteroconch average diameters vary between 85 µm–97 µm and 124 µm–132 µm, respectively (one measured section, samples from 5 different levels, 15 specimens). The average deuteroconch to protoconch ratio ranges from 1.33 to 1.58. The embryo is characterized by following with an auxiliary chamber, which results in the formation of two spirals that terminate in a closing chamber (Figures 12A, 12C–12E) (biserial nepionic arrangement of Van Gorsel, 1975). In contrast, some specimens have almost never two auxiliary chambers, giving rise in a quadriserial nepionic arrangement of short spirals. The embryons in these specimens appear to be larger than those in specimens with a single auxiliary chamber.

Remarks: The biserial peri-embryonic arrangement is the diagnostic feature for this species (Van Gorsel, 1975). The outline of the test is lenticular, circular-discoidal, and densely granulated (Figure 11A) (Van Gorsel, 1975). Equatorial chambers are open arcuate (Van Gorsel, 1975).

Age: *L. campaniensis* has often been reported from late Campanian (Erdem et al., 2021) and late Campanian-early Maastrichtian (Van Gorsel, 1978). In this study, late Campanian age is proposed for *L. campaniensis* determined in the Ürünveren Section.

***Lepidorbitoides bisambergensis* (Jaeger, 1914)**

Figures 11B, 13A–13D

1914 *Orbitoides* (*Lepidorbitoides) socialis* var. *bisambergensis*, Jaeger, p. 146, 147, 158–160.

Samples no: Fifty-eight specimens from samples E1-E6, G1, G3-G6, G8, N1, N5, T1-T3, and T5-T7.

Description: The megalospheric specimens' test diameters range from 2.00 mm to 4.30 mm, with sample averages of 3.03 mm. The test thickness of the megalospheric specimens ranges between 0.74 mm and 2.24 mm, with sample averages of 1.40 mm. The protoconch and deuteroconch average diameters are 82–108 µm and 101–151 µm, respectively (four measured sections, samples from 20 different levels, 58 specimens). The average deuteroconch to protoconch ratio ranges from 1.20 to 1.70.

Remarks: A quadriserial nepionic arrangement, without adauxiliary chambers, is a distinctive feature of this species (Figures 13A, 13C, 13D) (Van Gorsel, 1975). Primitive specimens have an asymmetric nepiont (asymmetric deuteroconch and a little small second principal auxiliary chamber, from which only a few and small subsequent chambers are formed) (Van Gorsel, 1975). The majority of equatorial chambers are arcuate, with ogival chambers appearing around the edges of larger specimens (Van

Gorsel, 1975).

Age: *L. bisambergensis* has often been reported from early Maastrichtian (Van Gorsel, 1978; Özcan, 1995; Özcan and Özkan Altıner 1999a, 1999b, 2001). In this study, early Maastrichtian *L. bisambergensis* was determined in the Guremağalan, Nohutlupınarı, Eskişehir Tepe, and Tepeköy sections.

***Lepidorbitoides* cf. *minor* (Schlumberger, 1901)**

Figure 13E

1901 *Orbitoides minor*, Schlumberger, p. 466, pl. VIII, figs. 2, 3, 5, pl. IX, figs. 2–3.

Samples no: One specimen from sample S10.

Description: The test diameter of the only megalospheric specimen determined is 3 mm. The megalospheric specimen has a test thickness of 1.2 mm. The diameters of the protoconch and deuteroconch are 149 µm and 204 µm, respectively (one measured section, sample from 1 level, 1 specimen). The deuteroconch to protoconch ratio is 1.4.

Remarks: The quadriserial arrangement and a small number of adauxiliary chambers distinguish this species from others (Figure 13E) (Van Gorsel, 1975). The appearance of the ontogenetically early equatorial chambers in the horizontal section is arcuate, with ogival and spatulate equatorial chambers commonly occupy the outer half of the horizontal section (Van Gorsel, 1975).

Age: *L.* cf. *minor* has often been reported from the Maastrichtian (Van Gorsel, 1978; Meriç, 1980; Özgen et al., 1993; Özcan and Özkan Altıner, 1999a, 1999b; Abdelghany, 2006). In this study, *L.* cf. *minor* determined in the Silsilekaya Tepe Section is dated as middle-late Maastrichtian.

Genus: *Pseudosiderolites* Smout, 1955

Type species: *Siderolites vidali* Douvillé, 1907, p. 599.

***Pseudosiderolites vidali* (Douville, 1906)**

Figures 11C, 14A–14C

1955 *Pseudosiderolites* Smout, p. 206.

Samples no: Forty-four specimens from samples Ü1, Ü3-16, Ü18, and Ü19.

Description: The test, in addition to being large, has an inflated, lenticular outline and is also densely granular (Figure 11C). The test diameter ranges from 1.35 mm to 4.10 mm, with an average of 2.53 mm. The megalospheric specimens' test thickness ranges from 0.67 mm to 1.70 mm, with sample averages of 1.12 mm. The arrangement of the chamber is planispiral. Radial canals in the marginal crest cause the bilamellar wall to become thicker. The spherical protoconch's mean diameter ranges from 66 µm to 101 µm (one measured section, sample from 17 levels, 44 specimens). The second chamber's mean diameter is larger than the proloculus and ranges between 81 µm and 132 µm. Following these two chambers are 2–3 whorls of large spiral chambers (Figures 14A–14C).

Remarks: *Pseudosiderolites* Smout is a larger benthic foraminifer genus. According to Zakrevskaya (2009), it is prevalent in the Campanian-early Maastrichtian outcrops of the central regions of the Tethys, as well as the northern and southern Mediterranean and southeastern Asia.

Age: *P. vidali* (Douvillé) was recorded from late Campanian (Özcan, 1993; Özcan and Özkan Altıner, 1999a, 1999b; Özcan et al., 2019; Erdem et al., 2021). It was also recorded from late Campanian-early Maastrichtian (Aksoy et al., 1999; Zakrevskaya, 2009). In this study, *P. vidali* reported from the late Campanian in the Ürünveren Section is associated with *O. medius*, *O. megaloformis*, *L. campaniensis*.

Superfamily: Rotalioidea Ehrenberg, 1839

Family: Calcarinidae Schwager, 1876

Genus: *Siderolites* Lamarck, 1801

Type species: *Siderolites calcitrapoides* Lamarck, 1801, p. 376.

***Siderolites* gr. *calcitrapoides* Lamarck, 1801**

Figures 14D, 14E

1801 *Siderolites calcitrapoides* Lamarck, p. 181, figs. 9-16.

Samples no: Four specimens from samples S10, Z1, and Z2.

Description: Because no loose specimens were available, no direct observation of the nature of the test surface was possible. There are 1/2 spines (Figures 14D, 14E). The test diameter ranges from 1137 µm to 3304 µm, with an average of 2143 µm. A dense network of piles covers the test surface. The smaller proloculus has an inner cross diameter of 49 µm to 85 µm with sample averages of 70 µm, followed by a slightly larger second chamber. The second chamber is large, with an inner cross-diameter varying from 52 µm to 100 µm and sample averages of 84 µm.

Remarks: The *Siderolites* genus is characterized by the externally canaliferous spines or denticulate periphery, and internally by the presence of short radial marginal canals. These diagnostic features determined in the geological record in the uppermost Campanian continue to be present until the upper Maastrichtian (Robles Salcedo et al., 2018).

Age: *S. calcitrapoides* has been reported from late Campanian (Erdem et al., 2021) and mostly Maastrichtian (Özcan, 1993; Özgen et al., 1993; İnceöz, 1996; Matsumaru, 1997; Caus et al., 2016; Özcan et al., 2022). In this study, *S.* gr. *calcitrapoides* determined in the middle-late Maastrichtian in the Silsilekaya Tepe and Ziyaret Taşı Tepe sections is associated with *O. gruenbachensis*, *P. blumenthali, O. macroporus*, *S.* cf. *orbitoidiformis, H. beotica*, *L.* cf. *minor*.

6. Discussion and conclusions

Several stratigraphically important LBF such as *Orbitoides*, *Pseudomphalocyclus, Omphalocyclus, Sirtina, Hellenocyclina, Lepidorbitoides*, *Pseudosiderolites*, and *Siderolites* were determined in the Harami Formation. This genus were recorded from Central America to Asia in the tropical and subtropical shallow marine carbonate platforms and ramps (Van Gorsel, 1978; Loeblich and Tappan, 1987; Goldbeck and Langer, 2009).

The general evolutionary trend of *Orbitoides* specimens, from Campanian to the end of Maastrichtian, is characterized by increasing embryo size and having a greater number of epi-embryonic chamberlets (Figure 15). However, *Orbitoides* specimens having only small embryons and several epi-embryonic chambers, such as *O. medius* and *O. megaloformis,* have been frequently reported as being associated with phylogenetically advanced specimens, such as *O. gruenbachensis*, *O. apiculatus*, and *O. gensacicus,* during the Maastrichtian period (Baumfalk, 1986; Özcan and Özkan Altıner, 1997, 1999b; Özer et al., 2009; Özcan et al., 2021, 2022). Small embryons containing a few epi-embryonic chamberlets, such as *O. medius* and *O. megaloformis*, were determined in the late Campanian-Maastrichtian, while advanced species, such as *O. gruenbachensis* in the middle-late Maastrichtian.

Lepidorbitoides are grouped into seven successive species based on morphometric criteria and some characteristic features such as the spiral chambers arrangement, shape of the equatorial chambers, and stolons' type (Papp, 1954, 1955; Van Gorsel, 1975; Özcan, 1995; Özcan and Özkan Altıner, 1999a, 1999b, 2001). The nepionic configuration is defined by the sample means of the number of adauxiliary chamberlets, the deutroconch and protoconch sample means, and their ratios (Malarkodi et al., 2017). Because of its morphological evolution over time, as recorded in the embryon and the test equatorial layer, and its extensity, *Lepidorbitoides* is a valuable stratigraphic marker (Papp, 1954, 1955; MacGillavry, 1955; Van Gorsel, 1975, 1978; Özcan, 1995; Özcan and Özkan Altıner, 1999a, 1999b, 2001). Based on the biometry of the populations, the different developmental stages in *L. pembergeri*, *L. campaniensis*, *L. bisambergensis*, *L. minor*, *L. socialis* have been described and illustrated (Van Gorsel, 1978; Özcan and Özkan Altıner, 1999a, 1999b). The general evolutionary trend of *Lepidorbitoides* specimens, from Campanian to the end of Maastrichtian is characterized by increasing embryo size and occur of a greater number of adauxiliary chambers and biserial and quadriserial nepionic arrangement (Figure 15). The biserial peri-embryonic arrangement, with auxiliary chamber is diagnostic feature for *L. campaniensis*. A quadriserial nepionic arrangement, with secondary auxiliary chamberlets, without adauxiliary chambers is a distinctive feature for *L. bisambergensis* and the quadriserial arrangement and a small number of adauxiliary chambers for *L.* cf. *minor* (Figure 15).

Based on the rudist and larger benthic foraminifera content of the outcrops in northeast Elazığ, the late Maastrichtian age was assigned to Harami Formation (İnceöz, 1996). On the other hand, based on the foraminifera content of the outcrops in the northeast, southwest, and west of Elazığ, the middle-late Maastrichtian age was assigned to the Harami Formation by Kaya and İnceöz (2001). In the southwest of Elazığ, the late Campanian-early Maastrichtian age was given to the unit based on larger benthic foraminifera and planktonic foraminifera assemblage (Aksoy et al., 1999).

Based on the larger benthic foraminifera such as *O. medius*, *O. megaloformis*, *O. gruenbachensis*, *P. blumenthali*, *O. macroporus*, *S.* cf. *orbitoidiformis, H. beotica, L. campaniensis*, *L. bisambergensis, L.* cf. *minor*, *P. vidali,* and *S.* gr. *calcitrapoides,* the late Campanian-Maastrichtian age was assigned to Harami Formation in this study.

Findings from this study are partly compatible with those from previous studies carried out by Aksoy et al. (1999), İnceöz (1996), and Kaya and İnceöz (2001).

In Turkey, sequences of the Campanian-Maastrichtian are typically characterized by medium-to coarse-grained clastics at the bottom and grade upward into shallow marine limestone, reefal limestone, and deep marine fine-grained clastics (Özer et al., 2009). In the Elazığ region, the Harami Formation has generally restricted outcrops and begins with reddish conglomerate and sandstone at the base and passes into sandy limestone, limestone, and massive limestone upwards (İnceöz, 1996; Aksoy et al., 1999). According to previous studies, Harami Formation overlies the Elazığ Magmatics with an unconformity (İnceöz, 1996). The conglomerate and sandstone at the bottom of the Harami Formation was interpreted as fan delta deposits (İnceöz, 1996; Aksoy et al., 1999). The vertical and horizontal relationships between the lenticular limestone and the pyroclastic rocks point that the Harami Formation was deposited on the shallow parts of the Neotethys Ocean during the last stage of the arc that formed the Elazığ Magmatics and that there is no unconformity between the Elazığ Magmatics and the Harami Formation (Aksoy et al., 1999).

The conformable boundary relationship between these two units is also consistent with the geotectonic evolution of the region. Otherwise, a basin, on which the Harami Formation was deposited, is expected to be formed after the closure of the southern branch of the Neotethys Ocean. There is no field data supporting this approach. For that reason, the Harami Formation has a key role in understanding the geotectonic evolution of the southern branch of Neotethys.

The new age findings and field observations indicate that the Harami Formation was deposited conformably on the Elazığ Magmatics in a shallow ramp environment during the last closure stage of the southern branch of the Neotethys Ocean.

Acknowledgements

The author is grateful to Prof. Dr. Ercan AKSOY (Fırat University) for his support in the fieldwork. The author

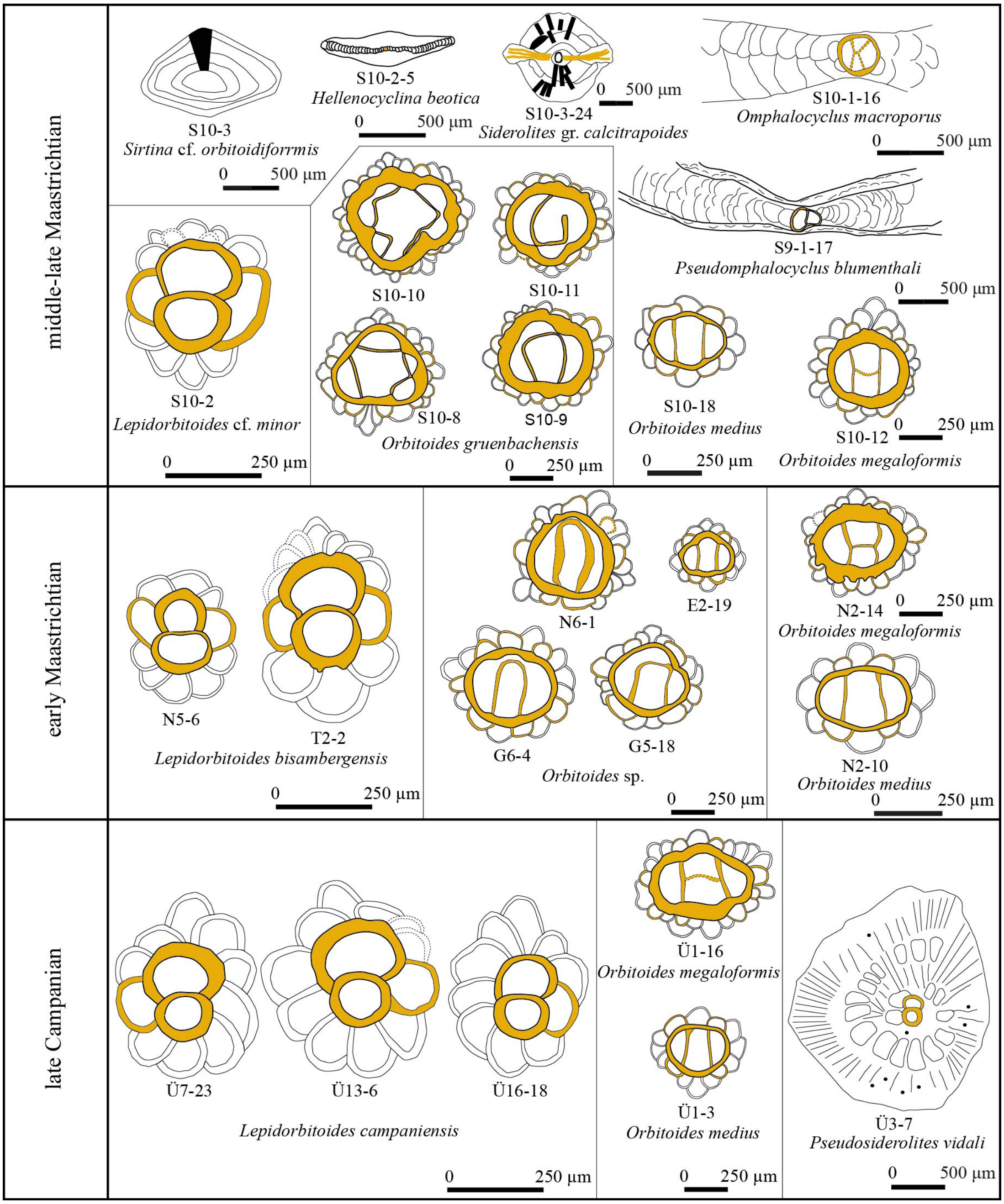

Figure 15. The evolutionary scheme of the late Campanian-Maastrichtian larger benthic foraminifera of the Harami Formation.

is grateful to Prof. Dr. Mehmet ÖZKUL (Pamukkale University) for his support in the petrographic investigation of the thin sections. I would like to thank Prof. Dr. Hükmü ORHAN (Konya Technical University) for proofreading earlier versions of the manuscript. The author would like to thank Prof. Dr. Muhittin GÖRMÜŞ (Ankara University) and two anonymous referees for their critical and constructive reviews of the manuscript. Since it encourages the study of the Harami Formation, this paper is dedicated to Prof. Dr. Ercan ÖZCAN (İstanbul Technical University), who passed away on 15 December 2022.

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