Cretaceous Research 101 (2019) 30–42

Contents lists available at ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

Primitive *Helicorbitoides* (Foraminifera) and associated larger benthic foraminifera from the Campanian Tonya Formation, Trabzon, eastern Pontides, NE Turkey

Ercan Özcan [a, *], J.T. van Gorsel [b], Bilal Sarı [c], Ali Osman Yücel [a], Sadıkcan Erbay [a], Aral I. Okay [a, d]

[a] *Department of Geological Engineering, Faculty of Mines, İstanbul Technical University (İTU), Maslak, 34469, İstanbul, Turkey*
[b] *6516 Minola St., Houston, Tx 77007, USA*
[c] *Department of Geological Engineering, Faculty of Engineering, Dokuz Eylül University, 35160, Buca, İzmir, Turkey*
[d] *İstanbul Technical University, Eurasia Institute of Earth Sciences, Maslak 34469, İstanbul, Turkey*

ARTICLE INFO

Article history:
Received 9 January 2019
Received in revised form
27 March 2019
Accepted in revised form 10 April 2019
Available online 29 April 2019

Keywords:
Helicorbitoides voigti
Systematics
Biometry
Campanian
Northeastern Turkey

ABSTRACT

The genus *Helicorbitoides* MacGillavry represents an evolutionary stage in the transition of rotaloidean with primary spiral chambers to the forms displaying an orbitoidal-type growth pattern in the Campanian. Unlike the widespread distribution of its possible ancestor *Pseudosiderolites* (Douvillé) and its descendant *Lepidorbitoides* Silvestri, *Helicorbitoides* was reported from only a few localities in Europe and Turkey (Western Tethys). The genus has been previously subdivided into two evolutionary stages, *H. voigti* van Gorsel and *H. longispiralis* (Papp and Küpper) based on quantitative and qualitative test parameters. We here introduce a primitive developmental stage of *Helicorbitoides* by studying a new population from a calciturbidite bed of the Campanian Tonya Formation in NW Turkey. This provides the first biometric data of the genus from this part of the Tethys. The *Helicorbitoides* specimens, with thick robust lenticular tests, possess a low trochospiral to planispiral primary spiral of chambers that reach up to the periphery of the test, and 'orbitoidal-type' chamberlets (secondary chamberlets) between the whorls and on the wall of the last whorl. The secondary chamberlets, however, never form complete cycles. In axial sections, the lateral chambers are dense and occupy both the axial and the lateral sides of the whorls. The number of primary spiral chambers with a single stolon varies between 8 and 12 (with an average of 9.63). According to previously proposed species limits, our population is assigned to an advanced developmental stage of *H. voigti*, and represents a transitional developmental stage between two successive species (*H. voigti-longispiralis*). The associated orbitoidids belong to *Orbitoides medius*, with an embryo size (Li + li) ranging from 370 to 800 μm (with an average of 525.4 μm). The number of epi-embryonic chambers (E) varies between 4 and 6 (with an average of 4.5). *Pseudosiderolites vidali* is the only siderolitid genus in the studied sample. The age of the turbidite bed is considered as early late Campanian (referable to the *Radotruncana calcarata* Zone) or slightly older ('*Inoceramus*' *tenuilineatus* Zone) based on the previous records of planktonic foraminifera and inoceramids from the same section and the occurrence of *Pseudosiderolites vidali*.

1. Introduction

Helicorbitoides MacGillavry is a Late Cretaceous genus of larger benthic foraminifera (LBF) characterized by a thick lenticular test consisting of an equatorial layer with planispiral to low trochospiral chambers, between the whorls of which smaller arc-shaped 'orbitoidal-type' chamberlets are formed (van Gorsel, 1973, 1975). In the third dimension of the test, lateral chamberlets are formed at both sides of the equatorial layer, and the test becomes discoidal-lenticular in shape, as in the Late Cretaceous orbitoidal genera *Orbitoides* d'Orbigny and *Lepidorbitoides* Silvestri. *Helicorbitoides* represents the earliest group of LBF displaying the morphological characters of both rotaloidean and orbitoidal foraminifera in the Campanian deposits of the Western Tethys (Papp

---

* Corresponding author.
E-mail addresses: ercanozcan034@yahoo.com, ozcanerc@itu.edu.tr (E. Özcan).

https://doi.org/10.1016/j.cretres.2019.04.006

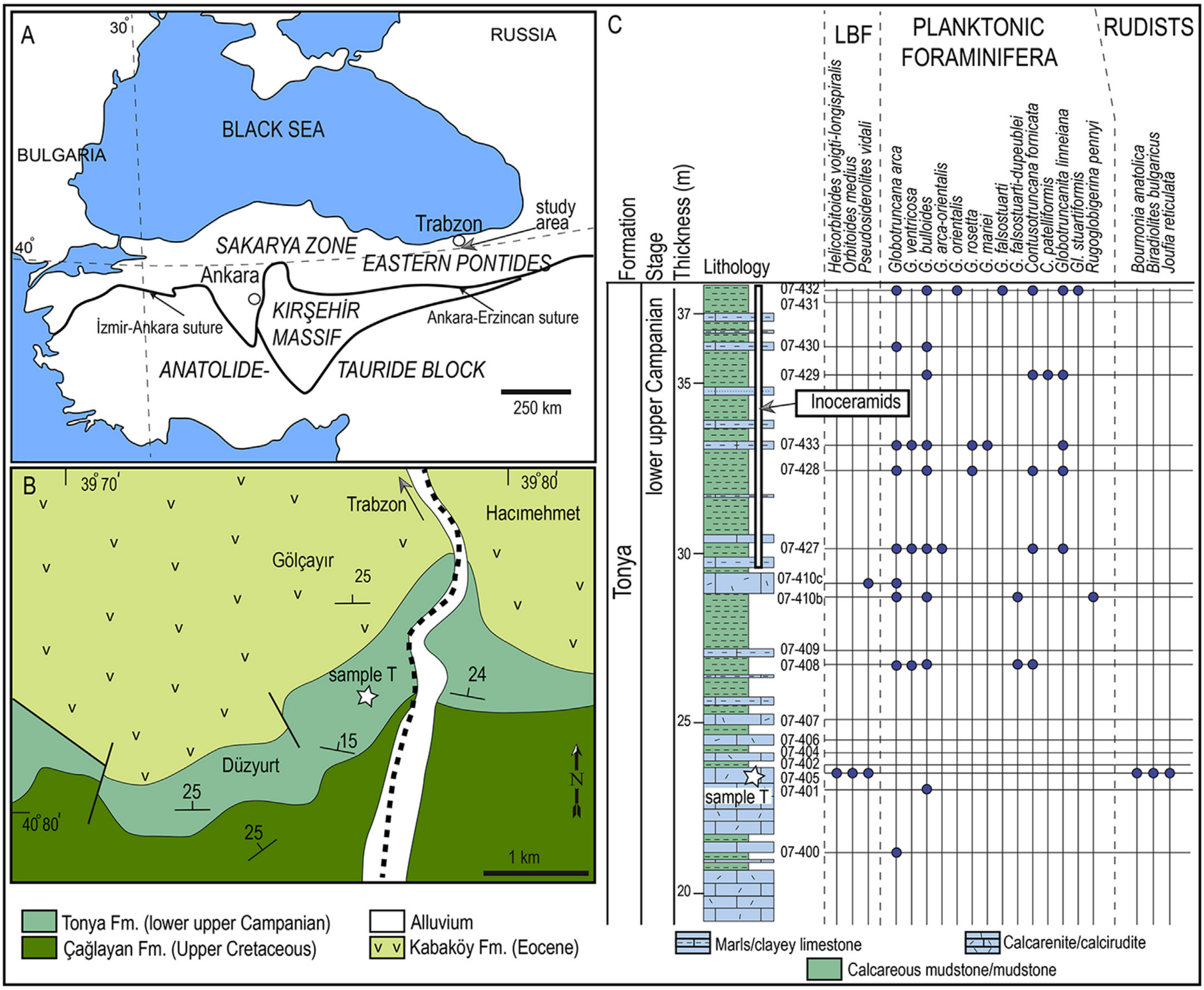

Fig. 1. A- Location of the study area in NE Turkey. B- Geological map of Gölçayır-Hacımehmet area and location of the studied turbidite bed (sample T). C- Lithostratigraphic column of the Tonya formation and distribution of planktonic foraminifera and rudists with respect to the studied level based on the work of Sarı et al. (2014). LBF studied here have been integrated. The geological map is after Sarı et al. (2014).

and Küpper, 1953; Papp, 1954; MacGillavry, 1963; van Gorsel, 1973, 1978; Wannier, 1983). The genus is commonly associated with *Pseudosiderolites* Smout, a rotaloidean with thick marginal crest (flange) and radial canals, and *Orbitoides* displaying typical orbitoidal growth, a pattern of chamber arrangements first appearing in the Santonian (e.g., in '*Monolepidorbis*' Astre; also see the discussion in Albrich et al., 2014 for the validity of this genus).

The chamber arrangement in *Helicorbitoides*, however, differs notably from those in many orbitoidal groups in the Late Cretaceous and Cenozoic in having both spiral chambers and 'orbitoidal-type' secondary chamberlets in the equatorial plane of the test. The primary spiral chambers, notably larger than the secondary chamberlets, continue almost up to the periphery of the test. The first chamber with two stolons is formed due to the introduction of a second (retrovert) stolon at the distal side of one of the spiral chambers. The previous data from two separate localities in Europe demonstrated that the first chamber with two stolons is formed at different stages of phylogenetic development, in accordance with the principle of nepionic acceleration (Tan Sin Hok, 1936; Drooger, 1993) or nepionic reduction (MacGillavry, 1963). The secondary chamberlets are confined between the whorls of the primary spiral chambers and also on the last whorl of the primary spire, but never form complete cycles. Thus, orbitoidal growth is never achieved. Although its successor *Lepidorbitoides* has been widely reported from the Tethyan and American bioprovinces (assuming that the American *Orbitocyclina* is the same as *Lepidorbitoides*, which is still debatable) (Caus et al., 1988; van Gorsel, 1972, 1978; Özcan et al., 1999a, b; Aguilar et al., 2002; Goldbeck and Langer, 2009; Malarkodi et al., 2017), *Helicorbitoides* is only known in Austria, Sweden, Switzerland and Turkey. This may be due to the restricted geographic range of the genus (Goldbeck and Langer, 2009), insufficient studies or its limited stratigraphic range.

The aim of this paper is to introduce a primitive developmental stage of *Helicorbitoides* from the Campanian Tonya Formation cropping out in Eastern Pontide Mountains near Trabzon in NE Turkey (Figs. 1A-B, 2) and give a detailed biometric account of the identified species. *Helicorbitoides* is associated with *Orbitoides* and *Pseudosiderolites* in a calciturbidite bed (sample T), which was previously assigned to lower upper Campanian by the planktonic foraminifera and inoceramids above this bed (Sarı et al., 2014) (Figure 1C). Thus, we also attempt a correlation among evolutionary stages of three evolutionary lineages that are biostratigraphically important: *Helicorbitoides*, *Orbitoides*, *Pseudosiderolites*. This manuscript provides the first biometric data of the genus from this part of the Neotethys.

2. Geological setting and stratigraphy

The Eastern Pontides are a mountain chain ca. 500 km long and 100 km wide along the southeastern coast of the Black Sea. They are the remainder of a paleo-island arc, which was formed above the northward-subducting (Neo-) Tethyan Ocean during the Late Cretaceous (Okay and Şahintürk, 1997). Tectonically, they form the eastern part of the Sakarya Zone of the Pontides bounded to the south by the Ankara-Erzincan Neo-Tethyan suture and to the north by Black Sea Basin (Fig. 1A) (Okay, 1989). The Sakarya Zone, which includes the Eastern Pontides, is characterized by the presence of Paleo-Tethyan Permo-Triassic accretion-subduction complexes and by an Early Jurassic transgression. The northern part of the Eastern Pontides is dominated by Upper Cretaceous and middle Eocene volcanic and volcaniclastic rocks. On the other hand, Lower Cretaceous rocks are widely exposed in the southern Eastern Pontides (Özsayar et al., 1981; Okay and Şahintürk, 1997).

The Upper Cretaceous succession to the south of Trabzon is subdivided into the Çatak, Kızılkaya, Çağlayan and Tonya formations (Konak et al., 2009). The Çatak Formation is composed of andesites and tuffs, intercalated with argillaceous limestones, sandy limestones, tuffites and red pelagic limestone. The unit contains boulders of Upper Jurassic–Lower Cretaceous shallow marine limestone. The Kızılkaya formation is composed of rhyodacite-dacite and their pyroclasts with subordinate argillaceous and sandy limestone. The Çağlayan Formation is composed mainly of deep-water limestone, marl, sandstone, alternating with spilitic basalts and andesites. The Tonya Formation consists of pelagic marls and calciclastic turbidites containing allochthonous fragments of shelf-derived bivalves, echinoderms, benthic foraminifera, red algae and bryozoans (Korkmaz, 1993; Sarı et al., 2014). Based on the study of planktonic foraminifera, the age of the unit was given as Campanian-Danian by Korkmaz (1993) and Campanian by Sarı et al. (2014) (Fig. 1C). The Tonya Formation is unconformably overlain by the Eocene (Lutetian) Kabaköy Formation, consisting of andesite, basalt and pyroclastic rocks.

Fig. 2. Field aspects of the Tonya Formation and location of the turbidite bed (with star).

3. Historical background, morphostructure and species concept in *Helicorbitoides* MacGillavry

Helicorbitoides MacGillavry is a Late Cretaceous LBF with a thick lenticular test superficially similar to typical orbitoidal foraminifera (e.g. *Orbitoides* d'Orbigny and *Lepidorbitoides* Silvestri) due to the presence of orbitoidal-type chamberlets in the equatorial plane and lateral chamberlets on both sides of the test (Fig. 3). The test surface is characterized by heavy granulation, and septa of the primary spiral chambers are only seen externally when the test surface is abraded. In spite of some similarities to the Late Cretaceous orbitoidal foraminifera such as the contemporaneous *Orbitoides*, the internal structure and chamber arrangement in *Helicorbitoides* differ significantly from them by having a large primary spiral in the equatorial plane of the test and radial canals in a thick marginal crest (peripheral flange). The primary spiral, consisting of as many as 50–60 large chambers, continues almost up to the periphery of the test and the orbitoidal chamberlets are confined to the enlarged area between the whorls of the spire (Fig. 3B-C). Thus, the test consists of both a long primary spiral with large chambers and small arc-shaped chamberlets (secondary chambers of van Gorsel, 1975) formed between the whorls of spiral chambers in equatorial part of the test. The wall is strongly thickened in the marginal crest and consists of radial canals, similar to those in *Pseudosiderolites* (Fig. 3B-C).

The chamber arrangement in *Helicorbitoides* was first illustrated by Papp and Küpper (1953) from the Campanian of Silberegg, Austria (Fig. 3B). They noticed some radial wall structures in the marginal crest, which they considered to be similar to those in the American genus *Pseudorbitoides,* and assigned these specimens to *P. longispiralis* n. sp. MacGillavry (1963), on the other hand, erected a new genus, *Helicorbitoides* for these specimens, because of the long primary spire, which is not present in the Late Cretaceous genus *Lepidorbitoides* Silvestri, 1907, and also concluded that the radial structures in the new genus are different from those in *Pseudorbitoides*. A new species of *Helicorbitoides, H. voigti*, was later erected by van Gorsel (1973) from Bastad, south Sweden, for small, asymmetric, lenticular specimens having more primitive characters than *H. longispiralis* (Fig. 4A). According to Gorsel, *H. voigti* has more spiral chambers with a single stolon than *H. longispiralis* and the orbitoidal chamberlets appear in a later ontogenetic developmental stage, compared to *H. longispiralis*. In addition, lateral chamberlets in *H. voigti* are weakly developed and occur only in the central part of the test (see figure 3.5–6 in van Gorsel, 1973). He noted that in *H. voigti,* the number of spiral chambers with single-stolon (parameter Y) varies between 6 and 22, with an average of 12.9. In addition to its type-locality in Sweden, this species is possibly

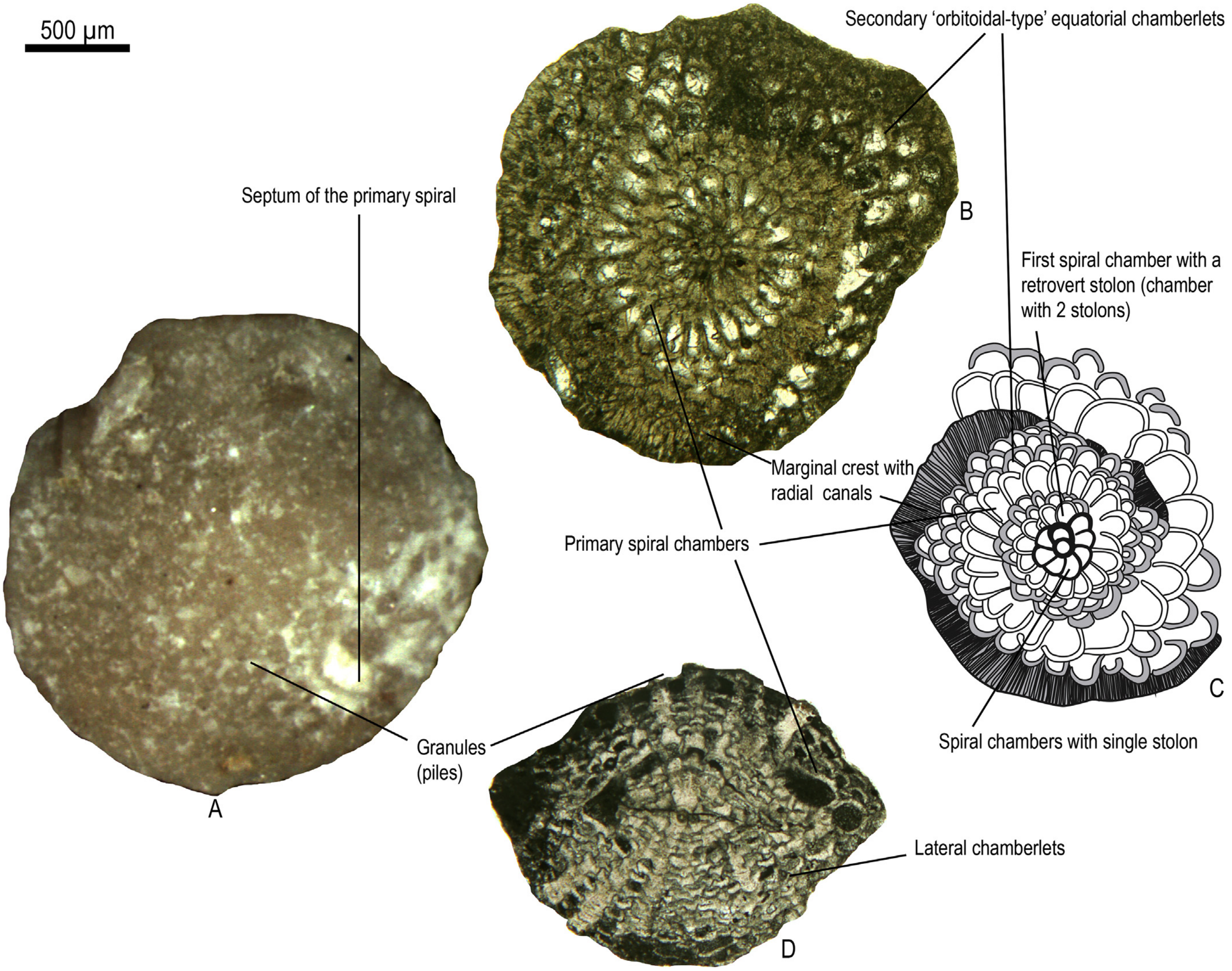

Fig. 3. External view (A), equatorial (B–C) and axial sections of *Helicorbitoides* from sample T showing the test features such as primary spiral and secondary chamberlets in the equatorial plane, thick wall with radial canals at the flange, lateral chamberlets and pillars. The spiral chambers with a single stolon are shown by dark wall. The secondary 'orbitoidal-type' equatorial chamberlets have gray walls. A: EO/T41, B: EO/T70, C: EO/T1, D: EO/T19.

also present in Turkey (Sirel, 1995; Matsumaru, 2016). Van Gorsel (1973) introduced another assemblage of *H. longispiralis* from Stafversvad in southern Sweden (Fig. 4C-D) and carried out biometric studies on this species as well as topotypes from Silberegg (Fig. 4B). The author counted 3 to 8 (with an average of 5.4) uni-apertural chambers (primary spiral chambers with a single stolon, parameter Y) in Silberegg, and 3 to 6 (with an average of 4.5) in Stafversvad. Van Gorsel (1975) tentatively established a morphometric species limit of $3.5 \leq Y_{\text{mean}} \leq 7.5$ for *H. longispiralis* and $Y_{\text{mean}} > 7.5$ for *H. voigti* (Fig. 5). *Helicorbitoides* MacGillavry, 1963 was accepted as a valid genus name by subsequent authors (e.g., van Gorsel, 1975, 1978; Sirel, 1995; Sarı et al., 2014), and considered as the probable ancestor of *Lepidorbitoides*, a Campanian-Maastrichtian genus widespread in the Tethys (Drooger, 1993; Goldbeck and Langer, 2009). Further eastward from the above localities, *Helicorbitoides* was recorded from two Campanian sections in Turkey (Sirel, 1995; Sarı et al., 2014). Sirel (1995) erected a new species *H. boluensis* to accommodate some intermediate forms between *H. voigti* and *H. longispiralis* from hard rock sections. The oblique sections clearly show the *Helicorbitoides* inner structure but fail to show complete development of the primary spiral and secondary chamberlets and thus, it is not possible to determine the number of spiral chambers with single stolon (parameter Y). A biometric scheme of the evolutionary parameters was not given. The *Helicorbitoides* specimens from the same level with the present study were assigned to *H. boluensis* by Sarı et al. (2014) based on vertical sections without information on the chamber arrangement in the equatorial layer. The species was reported in association with *Pseudosiderolites vidali* (Douvillé), *Orbitoides medius* (d'Archiac), *Orbitoides tissoti* Schlumberger and *Sirtina orbitoidiformis* Brönnimann.

Helicorbitoides has only been recorded from deposits associated with *Pseudosiderolites*, a key Campanian rotalid foraminifer, *Orbitoides* and *Sirtina* (Papp and Küpper, 1953; Papp, 1954; MacGillavry, 1963; Hottinger, 1967; van Gorsel, 1973, 1975; Sirel, 1995; Sarı et al., 2014). Some authors agree that *Helicorbitoides* represents a transitional stage between *Pseudosiderolites vidali* (Douvillé) and *Lepidorbitoides* Silvestri (Papp and Küpper, 1953; van Gorsel, 1975, 1978; Drooger, 1993). Drooger (1993) however rejects the genus name *Helicorbitoides* and considers it as a primitive member of

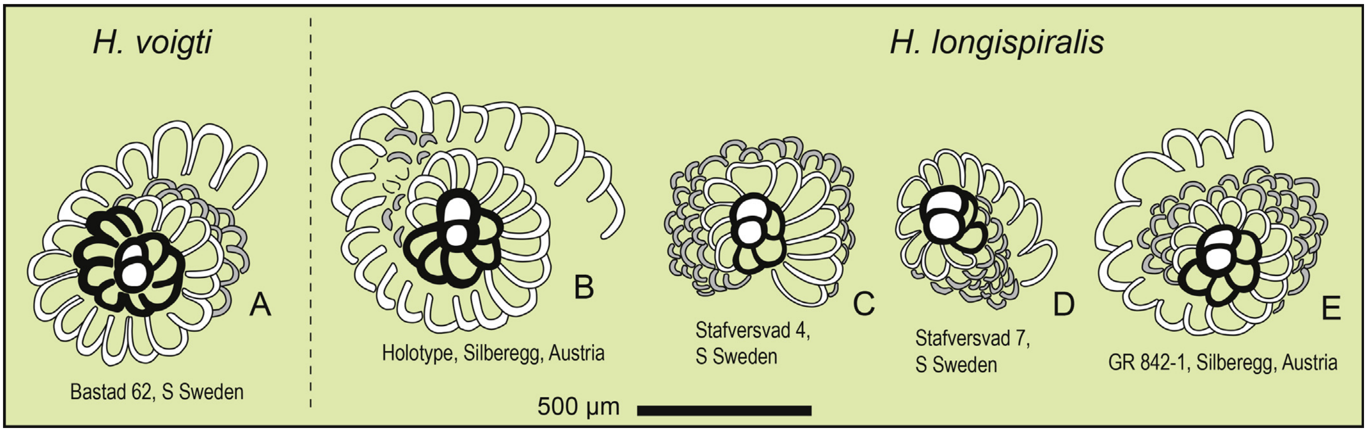

Fig. 4. Chamber arrangement in the equatorial plane of *Helicorbitoides voigti* (A) and *H. longispiralis* (B–E) from Europe. The spiral chambers with a single basal stolon are shown by dark chamber wall. The secondary chamberlets are marked with gray chamber wall. The holotype of *H. longispiralis* (B) is drawn after the original illustration by Papp and Küpper (1953). The others are from van Gorsel (1973, 1975, 1978). The scale is approximate.

Lepidorbitoides lineage. The geographic distribution of the *Helicorbitoides* appears to be confined to a limited area ranging from south Sweden to central Europe and Turkey, implying a restricted distribution in the Western Tethyan domain (Goldbeck and Langer, 2009). The stratigraphic range of the genus in the Campanian was not yet well constrained due to the scarcity of the records and lack of independent dating with pelagic organisms or isotopes.

4. Materials and methods

A hard limestone sample (40°56′28.44″N; 39°43′39.76″E) from a turbidite bed of the Tonya Formation was collected near Hacımehmet area, to the 6.9 km south of Trabzon (Fig. 1A-C). The location is described in the field guidebook in Konak et al. (2009) and in Sarı et al. (2014). The stratigraphic position of the sample in the Tonya Formation and its relation to the fossil record by Sarı et al. (2014) is shown in Figures 1C and 2. The material consists of 155 loose specimens of *Helicorbitoides*, *Orbitoides* and *Pseudosiderolites*, extracted from this bed, and investigated through equatorial and axial sections of the test. The equatorial sections, essential for taxonomy, require the grinding of the lateral parts of the free test on both sides of the equatorial layer by a fine grinding paper to obtain a section exposing the embryo and equatorial chambers. The measurements and counts used in the morphometry of *Helicorbitoides* include inner cross-diameters of the proloculus (p), second chamber (d), and their ratios (d/p), number of

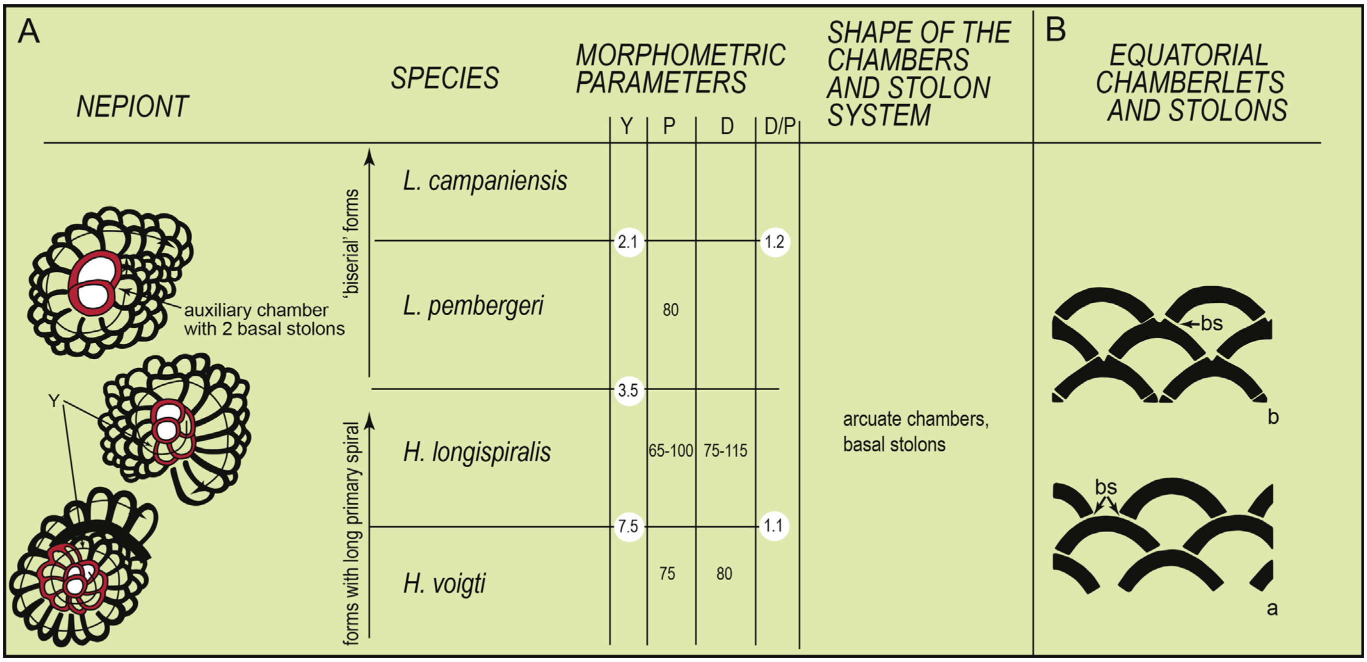

Fig. 5. A- Chamber arrangement and nepionic acceleration recorded in the *Helicorbitoides-Lepidorbitoides* lineage (only the primitive members *L. pembergeri* and *L. campaniensis* are shown) in the Campanian. The morphometric species concept follows van Hinte (1976) and van Gorsel (1975, 1978). The chambers with a single stolon (Y) are shown by red color. Arrows denote the spirals. B- Shape of the equatorial chamberlets and stolons as observed in equatorial sections: a and b-arcuate chamberlets (from van Gorsel, 1975). P: proloculus, D: second chamber. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

chambers in the primary spiral (C), and number of the spiral chambers with single stolon (Y) obtained from the equatorial sections of megalospheric specimens (Fig. 3C). The parameters for *Orbitoides* include size of the embryo (Li + li) and total number of epi-embryonic chamberlets (E: sum of primary and accessory epi-embryonic chamberlets). The proloculus diameter and diameter of the test were measured in *Pseudosiderolites*. The biometrical data are summarized in Table 1. All specimens are deposited in the paleontological collections of the Geology Department of İstanbul Technical University under the code EO/.

5. Systematic paleontology

Phylum Foraminifera d'Orbigny, 1826
Class Globothalamea Pawlowsky, Holzmann and Tyska, 2013
Order Rotaliina Délage and Hérouard, 1896
Family Lepidorbitoididae Vaughan, 1933

Genus *Helicorbitoides* MacGillavry, 1963

Helicorbitoides voigti ex. interc. *voigti* van Gorsel (1973) –*H. longispiralis* Papp and Küpper (1953).
Figures 3A–D, 6A–E, 7A–I, 8

1973 *Helicorbitoides voigti* n. sp; van Gorsel, p. 276–280, pl. 1, figs. 2–4, pl. 2, figs. 1–3, pl. 3, figs. 2–6.
2014 *Helicorbitoides boluensis*; Sarı et al., Text fig. 9C.

Description. The test is small, strongly inflated, lenticular and densely granulated (Figs. 3A, 6A-E). Test diameter varies between 1.75 and 2.6 mm, with an average of 2.22 mm (based on 26 specimens). Test thickness varies between 1.02 and 1.68 mm, with an average of 1.44 mm (based on 10 specimens). The average test diameter/thickness ratio is 1.54. The piles (granules) are ca. 100–125 μm in diameter in the central part of the test, and are uniformly distributed over the test surface. The initial chamber arrangement is very low trochospiral (Figs. 6A-E), which results in the formation of a slightly asymmetric test in the early stage. The thickness of the marginal crest consisting of radial canals is variable, being ca. 200 μm maximum. The uniform growth of lateral

Table 1
Morphometric data of *Helicorbitoides voigti-longispiralis*, *Orbitoides medius* and *Pseudosiderolites vidali* from sample T. N denotes the number of measured specimens. p and d: inner-cross diameter of proloculus and second chamber in *Helicorbitoides* and *Pseudosiderolites*, Y: number of spiral chambers with singe stolon in *Helicorbitoides*, Li + li and E: embryon size and number of epi-embryonic chamberlets of *Orbitoides*, D and T: diameter and thickness of the test.

N	p (μm)		d (μm)		Y		Li + li (μm)		E		D (mm)	T (mm)	Species
	range	mean	range	mean	range	mean	range	mean	range	mean	range	range	
26	45–85	62.65 ± 2.4	50–100	70.0	8–12	9.63					1.75–2.6	1.02–1.68	*H. voigtilongispiralis*
18							370–800	525.4	4–9	7.9	2.1–3.2	1.1–1.5	*O. medius*
21	60–115.0	83.7 ± 4.3	75–130	103.2							1.5–3.27	0.8–1.4	*P. vidali*

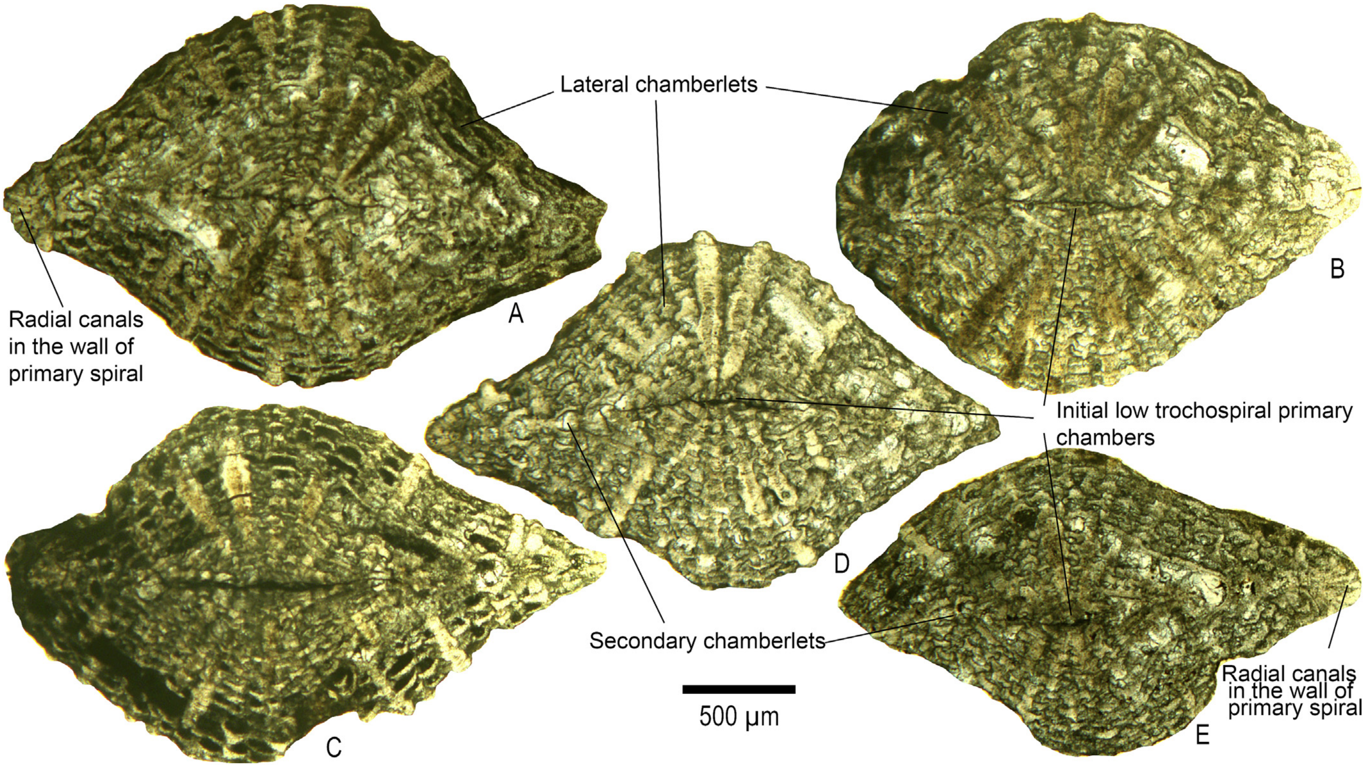

Fig. 6. Axial sections of *Helicorbitoides* ex. interc. *voigti-longispiralis* from sample T. note the early low trochospiral chambers and thick wall in the flange of the test. A: EO/T34, B: EO/T30, C: EO/T32, D: EO/T31, E: EO/T28.

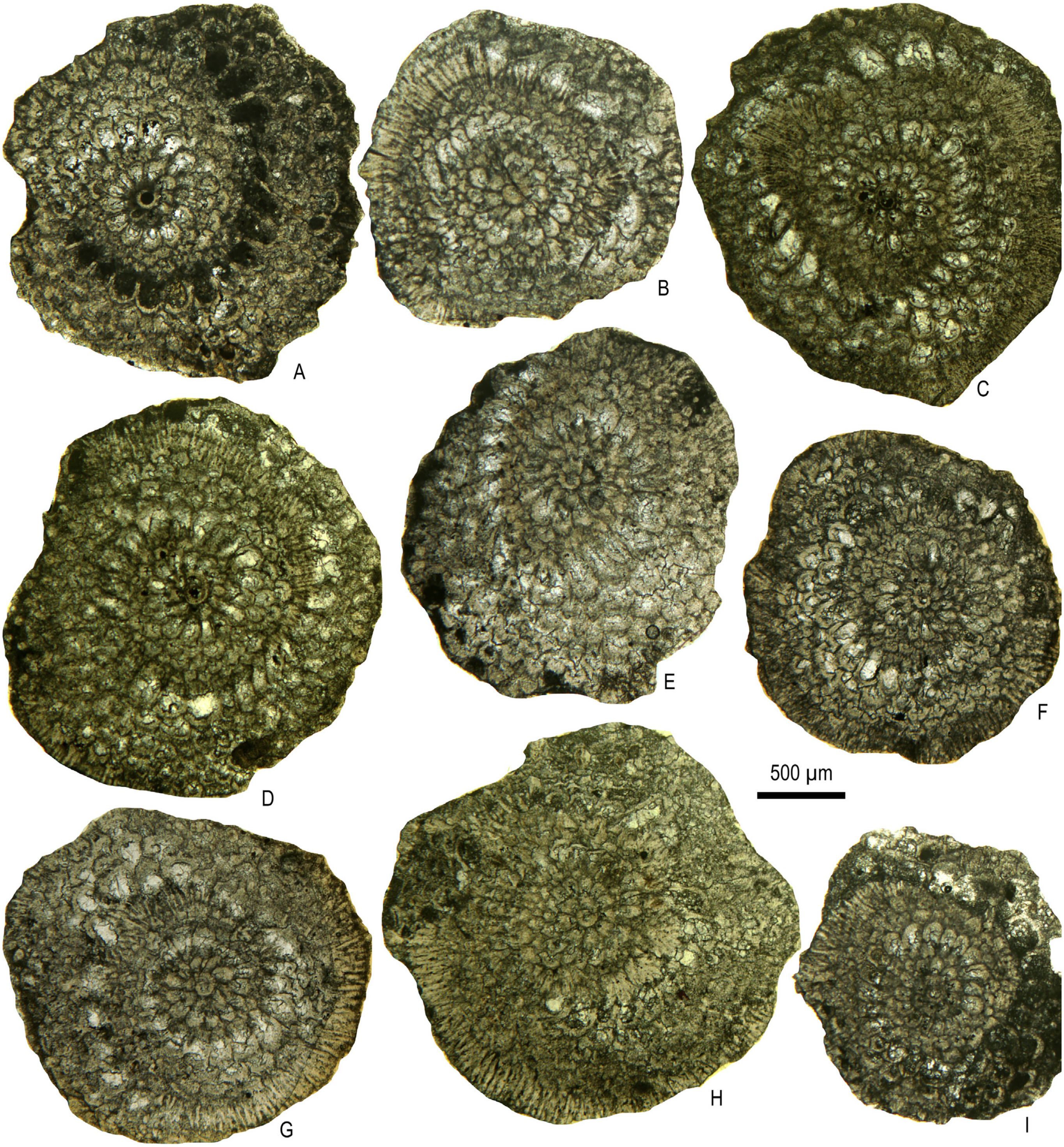

Fig. 7. Equatorial sections of *Helicorbitoides* ex. interc. *voigti-longispiralis* from sample T. A: EO/T2, B: EO/T17, C: EO/T76, D: EO/T41, E: EO/T15, F: EO/T5, G: EO/T11, H: EO/T69, I: EO/T1.

chamberlets on both sides of the test, however, achieves an overall test symmetry in the adult stage.

The diameter of the spherical protoconch varies between 45 and 85 μm, with an average of 62.65 μm (Fig. 9). The diameter of the second chamber, slightly larger than the proloculus, varies between 50 and 100 μm, with an average of 70 μm. These two chambers are followed by 2.3–3.3 whorls of large spiral chambers that reach up to the periphery of the test (Fig. 7). The number of the spirally arranged chambers varies between 46 and 52. The arcuate secondary chamberlets are formed between the whorls of the primary spiral originating from the 9th to the 13th spiral chamber with the introduction of a distal stolon (retrovert stolon). These chambers are arranged in a similar pattern as in orbitoidal growth, but never form complete cycles. The number of spiral chambers with a single

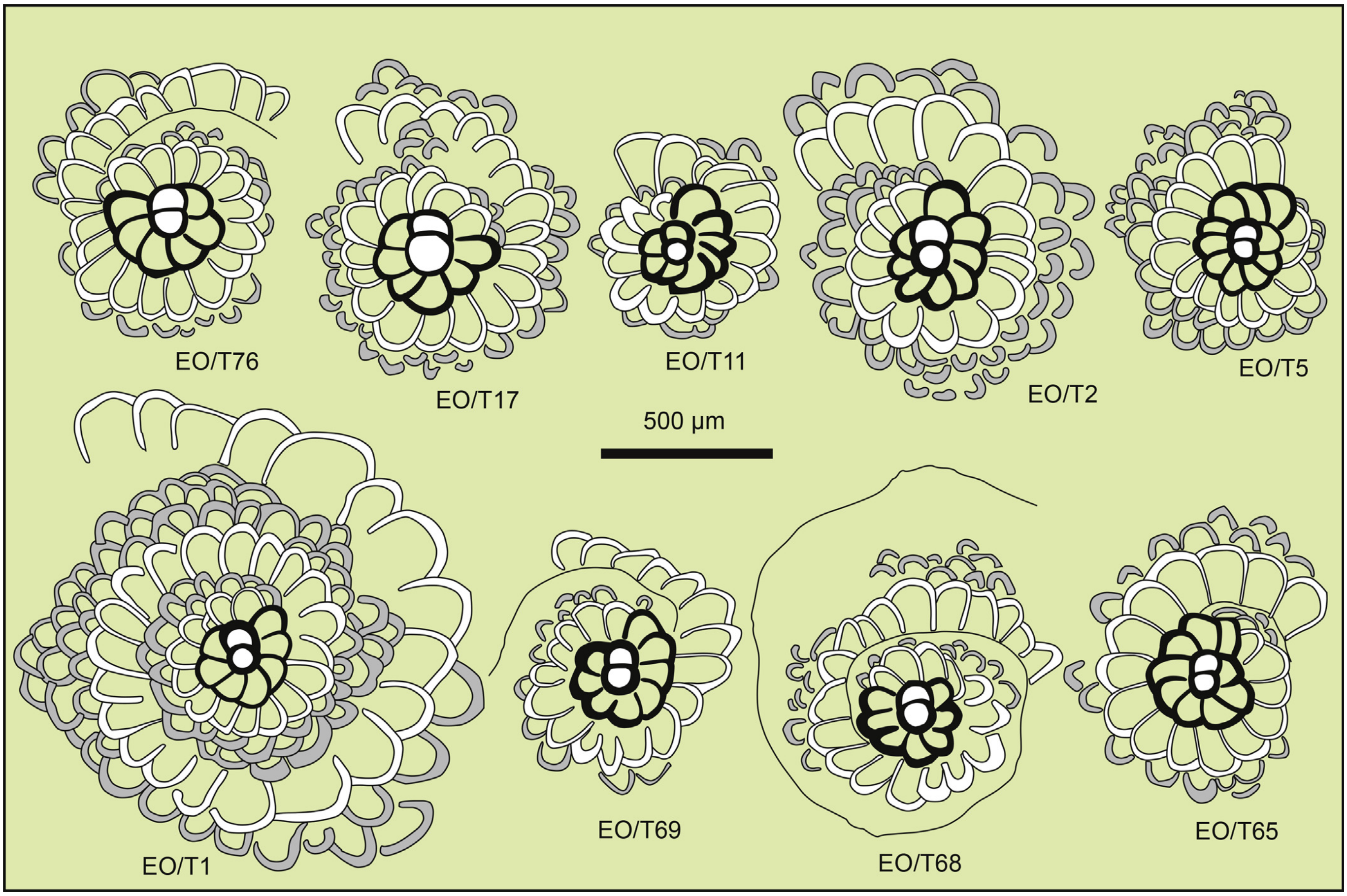

Fig. 8. The chamber arrangement in the equatorial layer of *Helicorbitoides* ex. interc. *voigti-longispiralis* from sample T. The chambers with a single stolon (Y) are shown by dark and secondary chamberlets with gray colours. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

stolon (parameter Y) varies between 8 and 12 with an average of 9.63 (Fig. 9).

In axial section, the height of the protoconch and deuteroconch is about 60 and 65 µm based on a single specimen. The large spiral chambers and small secondary chamberlets are located along the central part of the test. The thickness of the primary spiral chambers varies between 100 and 150 µm near the periphery of the test. The lateral chamberlets are well developed, occupying the central and lateral sides of the test. The pillars are 110–120 µm in thickness. No microspheric forms were found.

Remarks. The morphometric species concept applied to *Helicorbitoides* by van Gorsel (1973, 1975) depends on three populations; one at its type locality in Austria, and two other localities in south Sweden. Van Gorsel has tentatively established the species boundary at $3.5 \leq Y_{mean} \leq 7.5$ for *H. longispiralis* and $Y_{mean} > 7.5$ for *H. voigti.* The axial sections of *H. voigti* illustrated by van Gorsel (1973) show that the lateral chamberlets are weakly developed. In our specimens, the lateral chamberlets are more densely developed and also the average number of the chambers with a single stolon is much less than the specimens in south Sweden. Based on the above morphometric limits, our specimens from sample T represent an advanced stage of *H. voigti,* and may be considered to correspond to a transitional developmental stage between two successive species of the genus. *Helicorbitoides boluensis* Sirel (1995) possesses the same morphological features of *H. voigti-longispiralis* lineage. Its developmental stage cannot be reliably judged from the illustrations of the oblique sections and in the absence of biometric data. The axial sections of this species show well-developed lateral chamberlets. Sirel (1995) argued that the test size of *H. boluensis* is smaller than in *H. voigti* and *H. longispiralis* and used this as one of the criteria to establish the new species. We believe that test size depends on various parameters and should not be applied directly for the discrimination of a new species.

Family Orbitoididae Schwager, 1876

Genus *Orbitoides* d'Orbigny, 1848

Orbitoides medius (d'Archiac, 1837).
Figures 10A–P

1837 *Orbitolites media* n. sp.; d'Archiac, p. 178.

Description. The shape of the test is variable, commonly lenticular with a circular outline (Fig. 10A). It is either symmetric with respect to the equatorial plane or asymmetric, being saddle-shaped in some specimens (Fig. 10N-P). The diameter of the test ranges from 2.1 to 3.2 mm and the thickness from 1.1 to 1.5 mm. The surface is covered by coarse granules, which are fused into ridges at the axial part of the test (Fig. 10A, P). The embryon consists of protoconch, deuteroconch and two tritoconchs, such that depending on the level of sectioning on the equatorial plane, it produces usually three or four-chambered configurations in the equatorial sections (Fig. 10B-M). The embryon is commonly semi-spherical in outline, but rarely irregular, possibly due to the deformation during the hatching in asexual reproduction (Fig. 10G). The size of the

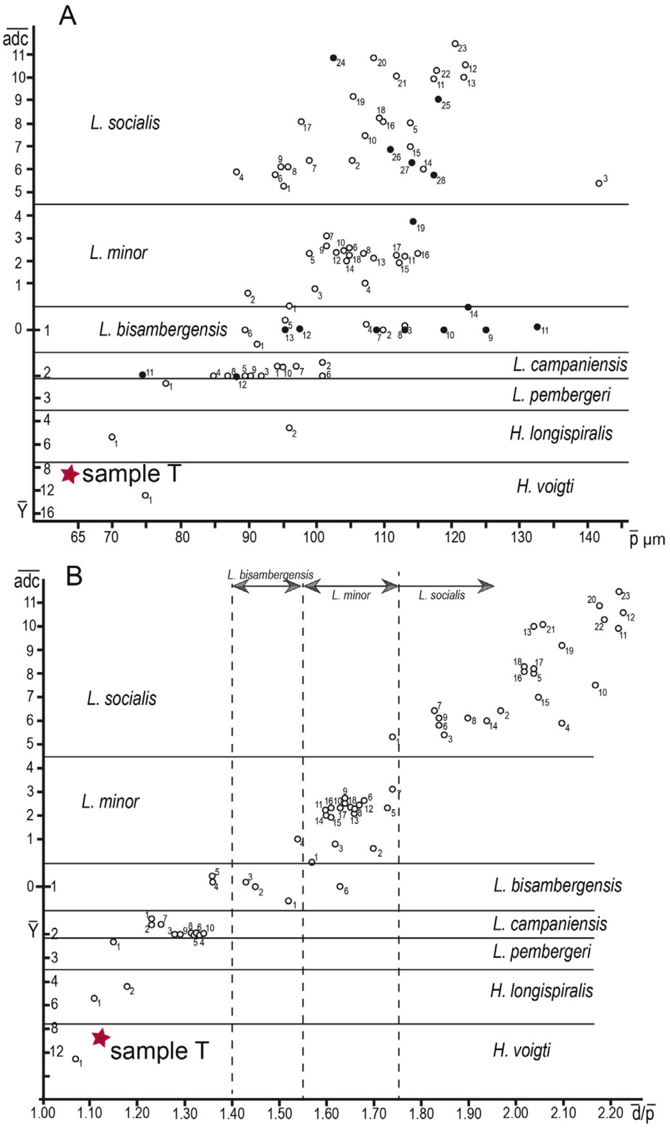

Fig. 9. Relation between the number of primary spiral chamber with a single stolon (Y) and inner-cross diameter of proloculus (p) (A), and Y vs. ratio of second chamber (d)-proloculus (p) in the studied sample (B) and their comparison with *Helicorbitoides-Lepidorbitoides* populations from Europe. The numbers along the empty circles refer to the code numbers of the samples from Netherlands, France, and Spain studied by van Gorsel (1975). Locations of the samples from Europe are tabulated in van Gorsel (1975). The black circles in A refer to the samples from Turkey (Özcan and Özkan-Altıner, 1999a, b). adc: auxiliary chamberlets in *Lepidorbitoides*.

embryon (Li + li) varies between 370 and 800 μm, with an average of 525.4 μm. The embryon is followed by primary and accessory epi-embryonic chamberlets (E) and orbitoidal cycles of arc shaped equatorial chamberlets. The number of epi-embryonic chamberlets varies between 4 and 6 with an average of 4.5.

Remarks. *Orbitoides medius* is widely known from the Campanian type section in SW France and other Campanian and Maastrichtian localities in the Tethys (van Hinte, 1966; van Gorsel, 1978; Baumfalk, 1986; Caus et al., 1996; Özcan and Özkan-Altıner, 1999a; Goldbeck and Langer, 2009). Although *O. medius* was originally established on material from the Campanian of SW France, its stratigraphic range appears inconsistent in the literature because of different taxonomic concepts, based on either typological or morphometric methods (see Baumfalk, 1986 for a discussion). Authors who adopted the morphometric species concept (e.g. van Gorsel, 1978; Caus et al., 1996) consider that the species is of late Campanian age. The validity of the widely used species name (*O. media*) is also controversial and presently it follows the common use of this species name rather than nomenclatural rules (see van Gorsel, 1978; Baumfalk, 1986). We are aware that the species name *O. faujasi* (Defrance, 1823) has the priority over the *O. medius* (although both species were neither illustrated in the original works nor adequately described) but retain the latter name because of the common use of *O. medius,* often misspelled as *O. media* in the literature. The morphometric species concept is applied here for the species assignment and *Orbitoides* specimens in our sample is assigned to *O. medius* following the species limits $500 < \mathrm{Li} + \mathrm{li}_{\mathrm{mean}} < 600$ and $4 < \mathrm{E}_{\mathrm{mean}} < 5.5$, proposed by van Gorsel (1978).

Superfamily Rotaloidea Ehrenberg, 1839
Family Siderolitidae Finlay, 1939

Genus *Pseudosiderolites* Smout, 1955

Pseudosiderolites vidali (Douvillé, 1906)
Figures 11A–H

1906 *Siderolites vidali* n. sp.: Douvillé, p. 598–599, pl. 18, fig. 9.

Description. The test is large, inflated, lenticular and densely granulated (Fig. 11A). Test diameter varies between 1.5 and 3.27 mm, with an average of 2.33 mm (based on 21 specimens). The pillars are ca. 80–125 μm in diameter in the central part of the test, and 40–50 μm near the test periphery. The chamber arrangement is planispiral (Fig. 11E). The bilamellar wall is thick with radial canals in the marginal crest.

The diameter of the spherical protoconch varies between 60 and 115 μm, with an average of 83.7 μm. The diameter of the second chamber, larger than the proloculus, varies between 75 and 130 μm, with an average of 103.2 μm. These two chambers are followed by 2.3–3.0 whorls of large spiral chambers

Remarks. According to Robles-Salcedo (2014), *P. vidali* has a restricted stratigraphic range from ca. 77 to 75.7 Ma (Fig. 12). Its stratigraphic range corresponds to the *R. calcarata* and a part of *Contusotruncana plummerae* zones.

6. The age of the studied sample

Van Gorsel (1975, 1978) proposed an ‘early’ late Campanian age for *H. voigti* and *H. longispiralis,* considering the co-occurrence of *H. voigti* and *Belemnitella mucronata mucronata* (Schlotheim) and *Belemnitella mucronata senior* Novak at the type locality of *H. voigti. Belemnitella mucronata mucronata* is accepted to have a restricted stratigraphic range in the lower part of the upper Campanian (Christensen et al., 1975). According to the planktonic foraminifera by Sarı et al. (2014), studied in the same section with the present work, the age of the turbidite bed consisting of *H. voigti-longispiralis* is considered as ‘early’ late Campanian or slightly older. The inoceramids collected by these authors from the levels above the sample T (Fig. 1C) are represented by several species, among which ‘*Inoceramus*’ *tenuilineatus* Hall and Meek and *Cataceramus haldemensis* (Giers) are the most characteristic taxa. ‘*Inoceramus*’ *tenuilineatus* Zone is correlated with the whole range of the *Radotruncana calcarata* and a part of the underlying *Contusotruncana plummerae*

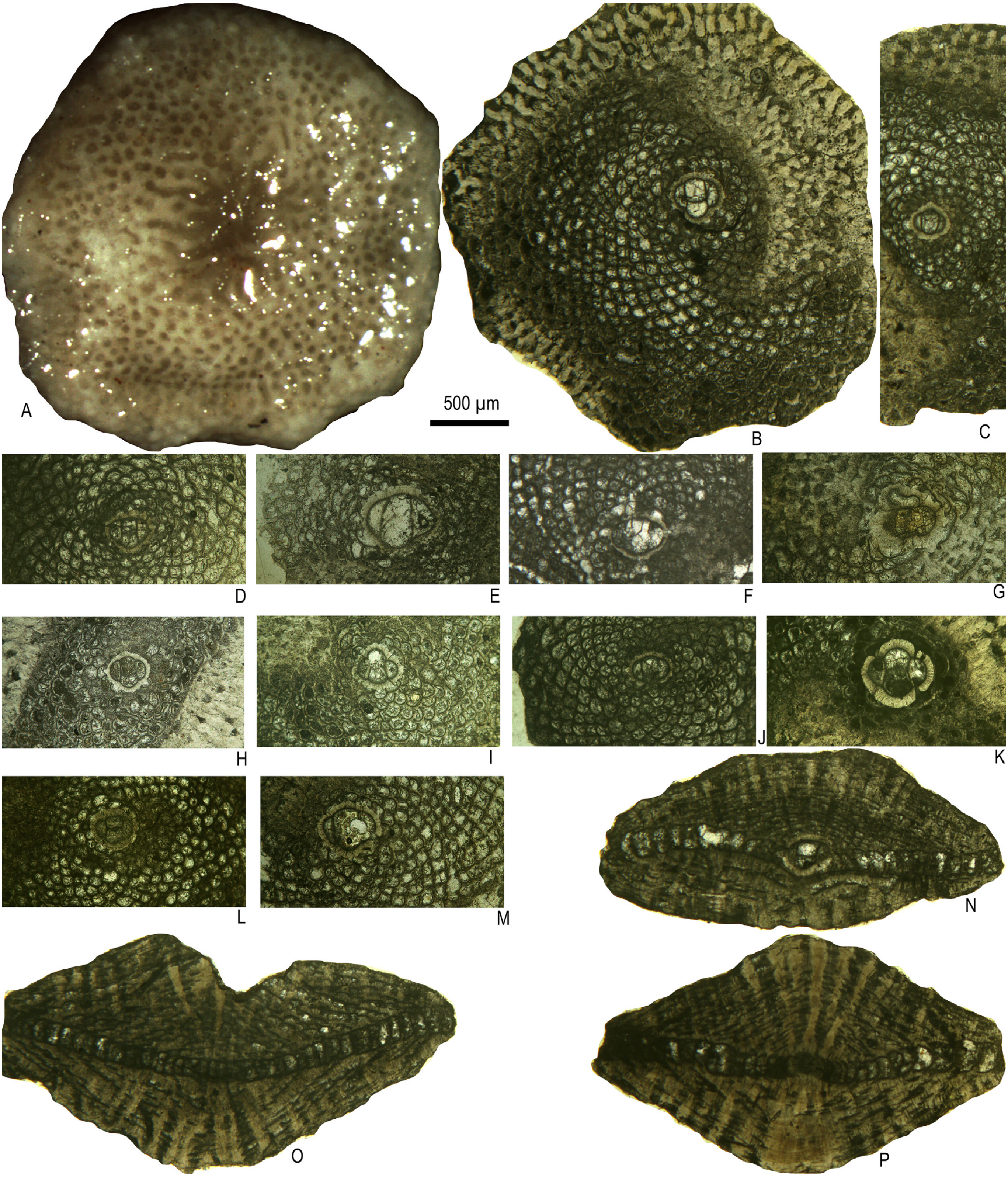

Fig. 10. External view (A), equatorial (B–M) and axial to near-axial sections (N–P) of *Orbitoides medius* d'Orbigny from sample T. A–B: EO/T40, C: EO/T74, D: EO/T73, E: EO/T6, F: EO/T8, G: EO/T13, H: EO/T16, I: EO/T10, J: EO/T51, K: EO/T62, L: EO/T63, M: EO/T37, N: EO/T35, O: EO/T27, P: EO/T33.

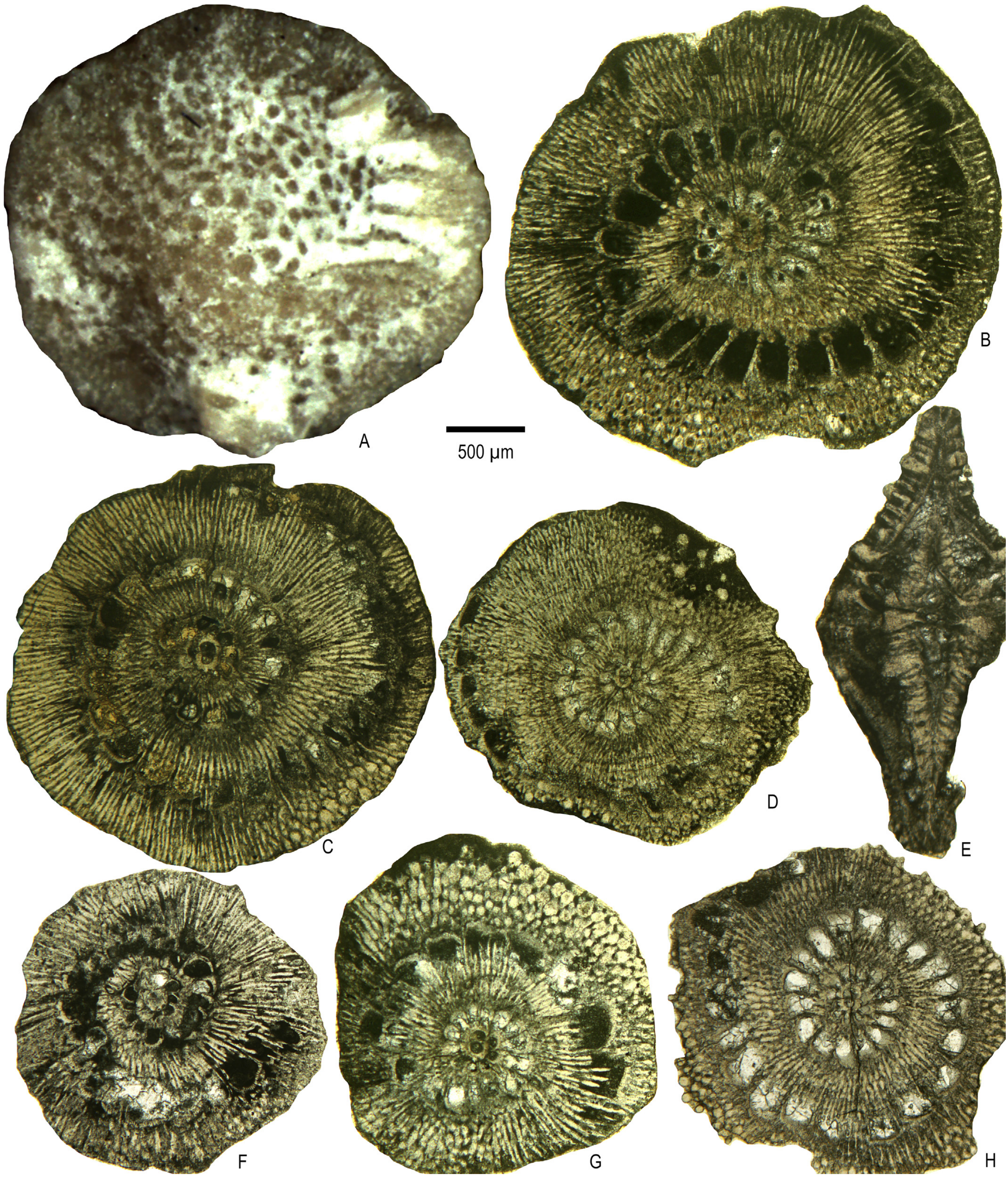

Fig. 11. External view (A), equatorial (B-D, F-H) and near-axial (E) sections of *Pseudosiderolites vidali* (Douvillé) from sample T. A: EO/T44, B: EO/T24, C: EO/T4, D: EO/T67, E: EO/T7, F: EO/T12, G: EO/T18, H: EO/T3.

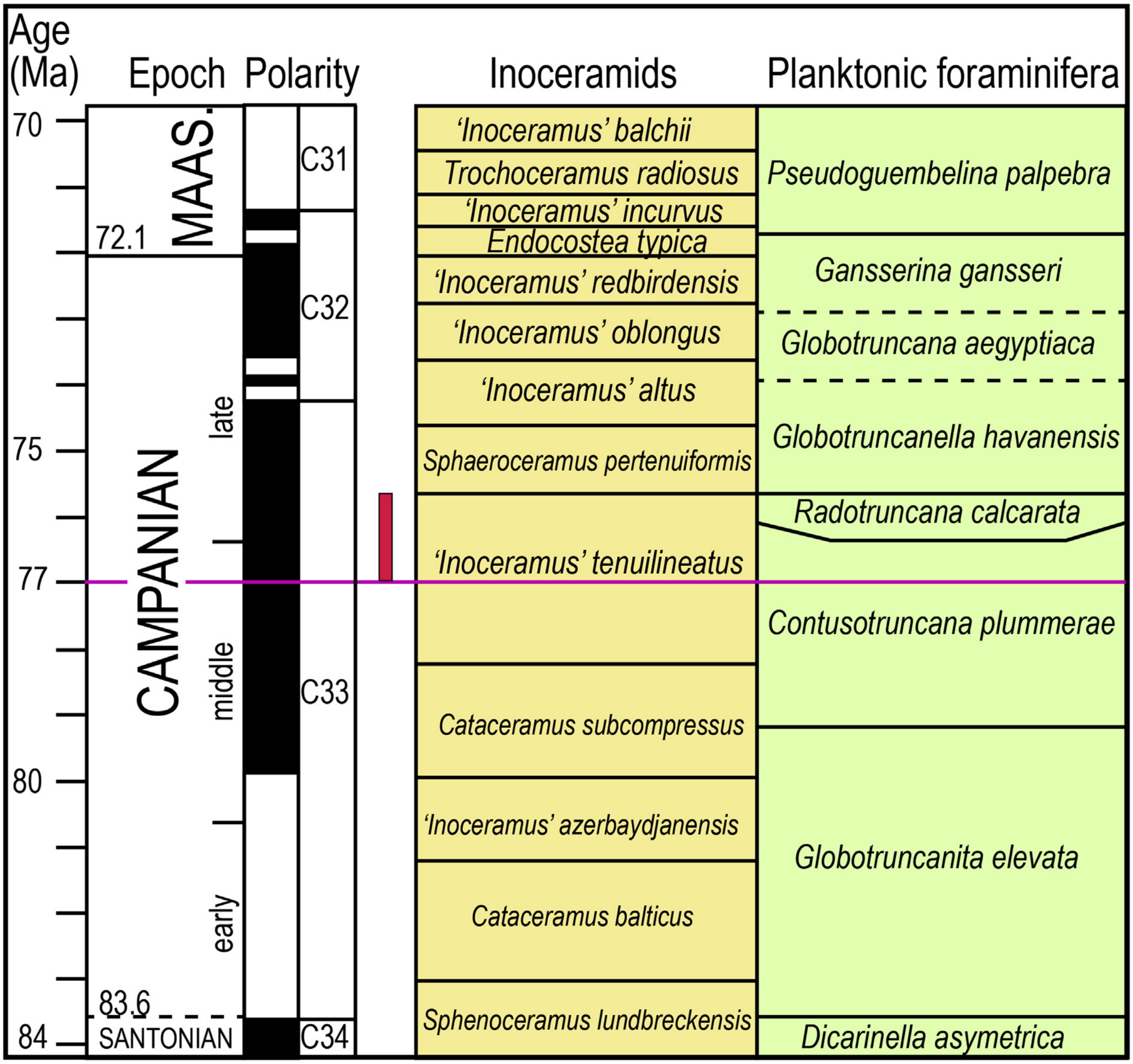

Fig. 12. Campanian planktonic foraminifera and inoceramid zones in the Tethys and age interpretation (from Gradstein, 2012). Possible age of the studied sample is within the range of red vertical line. The red horizontal line is the first appearance datum plane for *Pseudosiderolites vidali* (ca. 77 Ma) after Robles-Salcedo (2014). This species disappears at the *R. calcarata-G. havanensis* zonal boundary. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

planktonic foraminiferal zones (Fig. 12) (Gradstein, 2012). The proposed age is also consistent with the stratigraphic range of *Pseudosiderolites vidali*, given by Robles-Salcedo (2014). According to this author, *P. vidali* first appears at ca. 77 Ma, which falls within the *Contusotruncana plummerae* Zone (Gradstein, 2012) and disappears at *R. calcarata-G. havanensis* zonal boundary.

7. Conclusions

The platform-derived, allochthonous LBF occur in some calciturbidite levels of the deep-marine Tonya formation, from which we have managed to collect isolated specimens from one level. This sample consists of *Helicorbitoides, Orbitoides* and *Pseudosiderolites*, associated with resedimented rudists, bryozoans, and red algae. *Helicorbitoides* corresponds to an advanced developmental stage of *H. voigti* and may be assigned to the transitional developmental stage between *H. voigti* and *H. longispiralis* after the morphometric data. *Orbitoides* is assigned to *O. medius* and *Pseudosiderolites* to *P. vidali*, which is consistent with the previous records of these taxa in Europe. The subdivision of *Helicorbitoides* lineage into successive species depends presently on very scarce morphometric data. It may be possible to discriminate and subdivide this lineage to more than two chrono-species by gathering more data in the Tethys. We reject *H. boluensis* created by Sirel (1995) from the Campanian of central Turkey because of several reasons. This species was erected from oblique sections from hard rock, and consequently important test features, which are seen only from the equatorial layer of the test, are lacking. These features are hardly seen in oblique sections. Thus, a correlation of the morphometric features of this species with *H. voigti* and *H. longispiralis* is not possible. In addition the size of the test, used as a criterion to justify the establishment of this species, is unreliable in the light of the fact that test size depends on various parameters. The calciturbidite bed is assigned to the uppermost Campanian (or slightly older) based of the distribution of planktonic foraminifera and inoceramids stratigraphically above the studied level and presence of *P. vidali* in the studied sample.

Acknowledgements

The material was collected during the field excursion to northeastern Turkey in 2009 in the frame of 2nd International symposium on the geology of the Black Sea region held in Ankara on 5–9 October 2009. The authors thank Mr. Neşat Konak and Mr. Yavuz Hakyemez (MTA, Ankara) for their contribution to organize the field trip. We thank Johannes Pignatti (Rome) and Esmeralda Caus (Barcelona) for review.

References

Aguilar, M., Bernaus, J.M., Caus, E., Hottinger, L., 2002. *Lepidorbitoides minima* Douvillé from Mexico, a foraminiferal index fossil for the Campanian. Journal of Foraminiferal Research 32, 126–134.

Albrich, S., Frija, G., Parente, M., Caus, E., 2014. The evolution of the earliest representatives of the genus *Orbitoides*: implications for Upper Cretaceous biostratigraphy. Cretaceous Research 51, 22–34.

Archiac, A.d'., 1837. Mémoire sur la formation Crétacée du sud-Ouest de la France. Mémoires de la Société géologique de France 7, 157–192.

Baumfalk, Y.A., 1986. The evolution of *Orbitoides media* (Foraminiferida) in the Late Campanian. Journal of Foraminiferal Research 16, 293–312.

Caus, E., Bernaus, J.M., Gomez-Garrido, A., 1996. Biostratigraphic utility of species of the genus *Orbitoides*. Journal of Foraminiferal Research 26, 124–136.

Caus, E., Gomez-Garrido, A., Rodes, D., 1988. Reevaluation of *Lepidorbitoides* evolution as a function of the age relations between species as established with nannoplankton biostratigraphy. Revue de Paléobiologie 2, 421–428.

Christensen, W.K., Ernst, G., Schmid, F., Schulz, M.-G., Wood, C.J., 1975. *Belemnitella mucronata mucronata* (Schlotheim, 1813) from the upper Campanian: Neotype, biometry, comparisons and biostratigraphy. Geologisches Jahrbuch A28, 27–57.

Drooger, C.W., 1993. Radial Foraminifera; morphometrics and evolution. Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen. Afdeling Natuurkunde 41, 1–242.

Goldbeck, E.J., Langer, M.R., 2009. Biogeographic provinces and patterns of diversity in selected Upper Cretaceous (Santonian-Maastrichtian) larger foraminifera. Geologic Problem Solving with Microfossils: A volume in Honor of Garry D. Jones. SEPM Special Publication No. 93, 187–232.

Gradstein, F.M., Ogg, J.G., Schmitz, M., Ogg, G., 2012. The Geologic Time Scale 2012. Elsevier, The Netherlands.

Hottinger, L., 1967. Zur Grossforaminferenfauna des Niesenflyschs am Niesengipfel. Bulletin der Vereinigung Schweiz. Petroleum-Geologen und Ingenieure 33 (84), 70–71.

Konak, N., Okay, A.I., Hakyemez, Y., 2009. Tectonics and stratigraphy of the eastern Pontides. In: 2nd International Symposium on the Geology of the Black Sea Region. Field trip guide book, pp. 1–120.

Korkmaz, S., 1993. Stratigraphy of the Tonya-Düzköy (SW Trabzon) area, NE Turkey. Geological Bulletin of Turkey 36, 151–158 in Turkish).

Mac Gillavry, H.J., 1963. Phylomorphogenesis and evolutionary trends of Cretaceous orbitoidal foraminifera. In: von Koeningswald, G.H.R., et al. (Eds.), Evolutionary trends in foraminifera. Elsevier, pp. 139–179.

Malarkodi, N., Özcan, E., Venkataraman, D., Somappa, S.C., Gowda, S.P., Nagaraja, K.T., Yücel, A.O., 2017. *Lepidorbitoides* (Foraminifera) from the lower Maastrichtian Kallankuruchchi Formation, Cauvery Basin, India: morphometry and paleobiogeography. Cretaceous Research 77, 143–157.

Matsumaru, K., 2016. Larger foraminiferal biostratigraphy of the upper Cretaceous (Campanian) to Paleogene (Lutetian) sedimentary rocks in the Haymana and Black Sea regions, Turkey. Micropaleontology 62 (1), 1–68.

Okay, A.I., 1989. Tectonic units and sutures in the Pontides, northern Turkey. In: Şengör, A.M.C. (Ed.), Tectonic evolution of the Tethyan region: NATO ASI Series C259. Kluwer, Dordrecht, pp. 109–116.

Okay, A.I., Şahintürk, Ö., 1997. Geology of the Eastern Pontides. In: Robinson, A.G. (Ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Region. American Association of Petroleum Geologists (AAPG) Memoir No. 68, pp. 291–311.

Özcan, E., Özkan-Altıner, S., 1999a. The genera *Lepidorbitoides* and *Orbitoides*: evolution and stratigraphic significance in some Anatolian basins. Geological Journal 34, 275–286.

Özcan, E., Özkan-Altıner, S., 1999b. The genus *Lepidorbitoides*: evolution and stratigraphic significance in some Anatolian basins (Turkey). Revue de Micropaléontologie 42, 111–131.

Özsayar, T., Pelin, S., Gedikoğlu, A., 1981. Cretaceous in the Eastern Pontides. Earth Sciences Bulletin of Karadeniz Technical University, Geology 1/2, 65–114 in Turkish).

Papp, A., 1954. Über die Entwicklung von Pseudorbitoides und Lepidorbitoides in Europa, Vol 3. Verhandlungen der Geologischen Bundesanstalt, Wien, pp. 162–170.

Papp, A., Küpper, K., 1953. Die Foraminiferenfauna von Guttaring und Klein St. Paul (Kärnten). III. Foraminiferen aus dem Campan von Silberegg. Sitzungsberichte Osterr. Akad. Wiss., Wien, Math.- Naturw, Klasse I 162, 345–357.

Robles-Salcedo, R., 2014. La familia Siderolitidae (Macroforaminíferos del Cretácico superior): Arquitecture de la concha, bioestratigrafía, distribución paleoambiental y paleobiogeografía. PhD Thesis. Universitat Autonoma de Barcelona, p. 183.

Sarı, B., Kandemir, R., Özer, S., Walaszczyk, I., Görmüş, M., Demircan, H., Yılmaz, C., 2014. Upper Campanian calciclastic turbidite sequence from the Hacımehmet area (eastern Pontides, NE Turkey); integrated biostratigraphy and microfacies analysis. Acta Geologica Polonica 64, 393–418.

Schlumberger, C., 1901. Premiere note sur les Orbitoïdes. Bulletin de la Société géologique de France 4, 459–467.

Sirel, E., 1995. Occurrence of the genus *Helicorbitoides* MacGillavry (Foraminiferida) in Turkey. Revue de Paléobiologie 14, 85–94.

Tan, Sin Hok, 1936. Zur Kenntnis der Miogypsiniden. De Ingenieur in Nederlandsch-Indie 3 (3), 45–61.

Van Gorsel, J.T., 1972. *Orbitocyclina minima* (H. Douvillé) at its type-locality, with remarks about its origin, evolution and systematic place. Proceedings Koninklijke Nederlandse Akademie Van Wetenschappen Ser. B 75 (4), 339–347.

Van Gorsel, J.T., 1973. *Helicorbitoides* from southern Sweden and the origin of the *Helicorbitoides-Lepidorbitoides* lineage. Proceedings Koninklijke Nederlandse Akademie van Wetenschappen Ser. B 76 (4), 273–286.

Van Gorsel, J.T., 1975. Evolutionary trends and stratigraphic significance of the late Cretaceous *Helicorbitoides-Lepidorbitoides* lineage. Utrecht Micropaleontological Bulletins 12, 1–99.

Van Gorsel, J.T., 1978. Late Cretaceous orbitoidal foraminifera. In: Hedley, R.G., Adams, C.G. (Eds.), Foraminifera. Academic Press, London, pp. 1–120.

Van Hinte, J.E., 1966. *Orbitoides* from the Campanian type section. Proceedings Koninklijke Nederlandse Akademie Van Wetenschappen Ser. B 69, 79–109.

Van Hinte, J.E., 1976. A Cretaceous time scale. American Association Petroleum Geologists Bulletin 60, 498–516.

Wannier, M., 1983. Evolution, biostratigraphie et systématique des Siderolitinae (Foraminifères). Revista Española de Micropaleontología 15, 5–37.