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Multiple *Orbitoides* d'Orbigny lineages in the Maastrichtian? Data from the Central Sakarya Basin (Turkey) and Arabian Platform successions (Southeastern Turkey and Oman)

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Abstract

The standard reconstruction of species of *Orbitoides* d'Orbigny into a single lineage during the late Santonian to the end of the Maastrichtian is based upon morphometric data from Western Europe. An irreversible increase in the size of the embryonic apparatus, and the formation of a greater number of epi-embryonic chamberlets (EPC) with time, is regarded as the main evolutionary trends used in species discrimination. However, data from Maastrichtian *Orbitoides* assemblages from Central Turkey and the Arabian Platform margin (Southeastern Turkey and Oman) are not consistent with this record. The Maastrichtian Besni Formation of the Arabian Platform margin in Southeastern Turkey yields invariably biconvex specimens, with small, tri- to quadrilocular embryons and a small number of EPC, comparable to late Campanian *Orbitoides medius* (d'Archiac). The upper Maastrichtian Taraklı Formation from the Sakarya Basin of Central Turkey contains two distinct, yet closely associated forms of *Orbitoides,* easily differentiated by both external and internal features. Flat to biconcave specimens possess a small, tri- to quadrilocular embryonic apparatus of *Orbitoides medius*-type and a small number of EPC, whereas biconvex specimens possess a large, predominantly bilocular embryonic apparatus, and were assigned to *Orbitoides* ex. interc. *gruenbachensis* Papp–*apiculatus* Schlumberger based on morphometry. The flat to biconcave specimens belong to a long overlooked species *Orbitoides pamiri* Meriç, originally described from the late Maastrichtian of the Tauride Mountains in SW Turkey. This species is herein interpreted to be an offshoot from the main *Orbitoides* lineage during the Maastrichtian, as are forms that we term *Orbitoides* '*medius*', since they recall this species, yet are younger than normal occurrence with the accepted morphometrically defined lineage. The consistent correlation between the external and internal test features in *O. pamiri* implies that the shape of the test is not an ecophenotypic variation, but appears to be biologically controlled. We, therefore, postulate that more than one lineage of *Orbitoides* exists during the Maastrichtian, with a lineage that includes *O.* '*medius*' and *O. pamiri* displaying retrograde evolutionary features.

Keywords: *Orbitoides*, Maastrichtian, Morphometry, Central Sakarya Basin, Arabian Platform margin, Turkey

Introduction

Orbitoides d'Orbigny is an orbitoidal larger foraminifer that thrived in the tropical and sub-tropical shallow marine carbonate platforms and ramps from Central America to Asia during the late Santonian to the end of the Maastrichtian (Goldbeck & Langer, 2009; Loeblich & Tappan, 1987; van Gorsel, 1978). The genus evolved from

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a simple test, consisting of solely an equatorial layer with a small embryonic apparatus and a few epi-embryonic chamberlets (EPC), to large tests with thick lateral layers on both sides of the equatorial layer, large embryons and many epi-embryonic chamberlets. A single evolutionary succession of species (from oldest to youngest: *Orbitoides hottingeri* van Hinte, *Orbitoides douvillei* (Silvestri), *Orbitoides tissoti* Schlumberger, *Orbitoides medius* (d'Archiac), *Orbitoides megaloformis* Papp and Küpper, *Orbitoides gruenbachensis* Papp, *Orbitoides apiculatus* Schlumberger, and *Orbitoides gensacicus* (Leymerie)) has been constructed, ranging from the late Santonian or early Campanian to the end of the Maastrichtian (Caus et al. 1996; Eggink & Baumfalk, 1983; van Gorsel, 1978; van Hinte, 1966a, 1968, 1976). Recently, Albrich et al. (2014) interpreted *Orbitoides sanctaepelagiae* (Astre) as a valid species and considered it as a transitional form between *O. hottingeri* and *O. douvillei*.

The Maastrichtian part of the *Orbitoides* lineage was constructed mainly from data gathered from the Maastrichtian type section in the Netherlands and some sections in SW France and Spain. It, therefore, more properly represents the evolution of the genus in Western Europe. The exact stratigraphic distribution of the species within this lineage is not yet precisely calibrated against the standard geologic time scale. In spite of these uncertainties, three species, *O. gruenbachensis, O. apiculatus* and *O. gensacicus,* have commonly been reported from Maastrichtian sediments. These species correspond to an advanced developmental stage of the presumed lineage and are characterised by a relatively large embryonic apparatus (the size of which is expressed by Li + li) and many epi-embryonic chamberlets (expressed by E, the total number of primary and accessory epi-embryonic chamberlets (EPC)).

It is noteworthy that specimens with rather small embryons and a small number of epi-embryonic chamberlets (morphometrically in the range of the Campanian species *O. medius*) have been reported associated with the 'advanced' members of the genus within Maastrichtian strata (Baumfalk, 1986; Baumfalk & Willemsen, 1986; Eggink & Baumfalk, 1983; Görmüş & Meriç, 2000; Özcan & Özkan-Altıner, 1997). Most of these studies do not consider typologically different specimens as separate species, but rather assume a single species is present, following the morphometric species concept where all specimens from one population receive the same species name. According to the morphometric approach, morphologic characters of the majority of the specimens in a population are also considered to be more important for species determination than the characters of the individual specimens (Drooger, 1993; van Gorsel, 1978; van Hinte, 1966b). This means that variations in test features such as shape, features of lateral layers, chamberlets and piles are explained by variations in environmental conditions, and are not considered to possess taxonomic value in species discrimination (see van Gorsel, 1978 for discussion).

Having recognised two morphologically distinct groups of tests of *Orbitoides* during outcrop-based studies of the upper Maastrichtian Taraklı Formation in Nallıhan region (Central Turkey), we carried out a detailed study to record embryonic-nepionic developmental stages, paying special attention to external test features. In addition to the well-known species *O.* ex. interc. *gruenbachensis–apiculatus*, we show that these late Maastrichtian populations include predominantly flat- to biconcave specimens, possessing small, tri- to quadrilocular embryonic apparatus of *Orbitoides medius*-type and a small number of EPC, previously recorded from southern Turkey as *O. pamiri*, but not known from Europe. We also present unpublished data of EÖ from the Maastrichtian Besni Formation from the Arabian Plate margin, previously assigned to *Orbitoides 'medius'* in the frame of his PhD studies (Özcan, 1994). For further context, *Orbitoides* from the upper Maastrichtian Beyobası Formation of the Haymana Basin (Central Turkey) and upper Campanian–Maastrichtian Qahlah and Simsima Formations of Oman are also discussed briefly, with the overall aim of testing the hypothesis that more than one evolutionary lineage of *Orbitoides* occurs within the Maastrichtian.

Geological setting, stratigraphy and larger foraminiferal assemblages

Central Sakarya Basin (Central Turkey)

The Jurassic–Cretaceous Central Sakarya Basin is located in the Sakarya Zone of the Pontides (Okay & Tüysüz, 1999). The sedimentary sequence begins with Lower Jurassic conglomerates, sandstone and shales, which unconformably overlie a Variscan and Cimmeride basement (Ocakoğlu et al. 2019; Saner, 1980). The Lower Jurassic siliciclastic rocks are overlain by Upper Jurassic to Lower Cretaceous limestones, no younger than Aptian (Altıner et al. 1991). The Albian to Santonian sequence is represented by sandstone, shale, pelagic limestone and marl. Siliciclastic turbidite deposition begins in the Campanian and extends into the Maastrichtian (Ocakoğlu et al. 2019). These turbidites, the Yenipazar Formation (Saner, 1980), have a thickness of more than 1000 m and form a regressive sequence. Turbidites pass up into massive marls, the Seben Formation (Saner, 1980), which grades into 'neritic' sandstones of the Taraklı Formation (the focus of our study), recording the final stage of extensive Cretaceous marine sedimentation in the Central Sakarya Basin (Saner, 1980) (Fig. 1a and b). The palaeogeographic position of the basin is shown in Fig. 2.

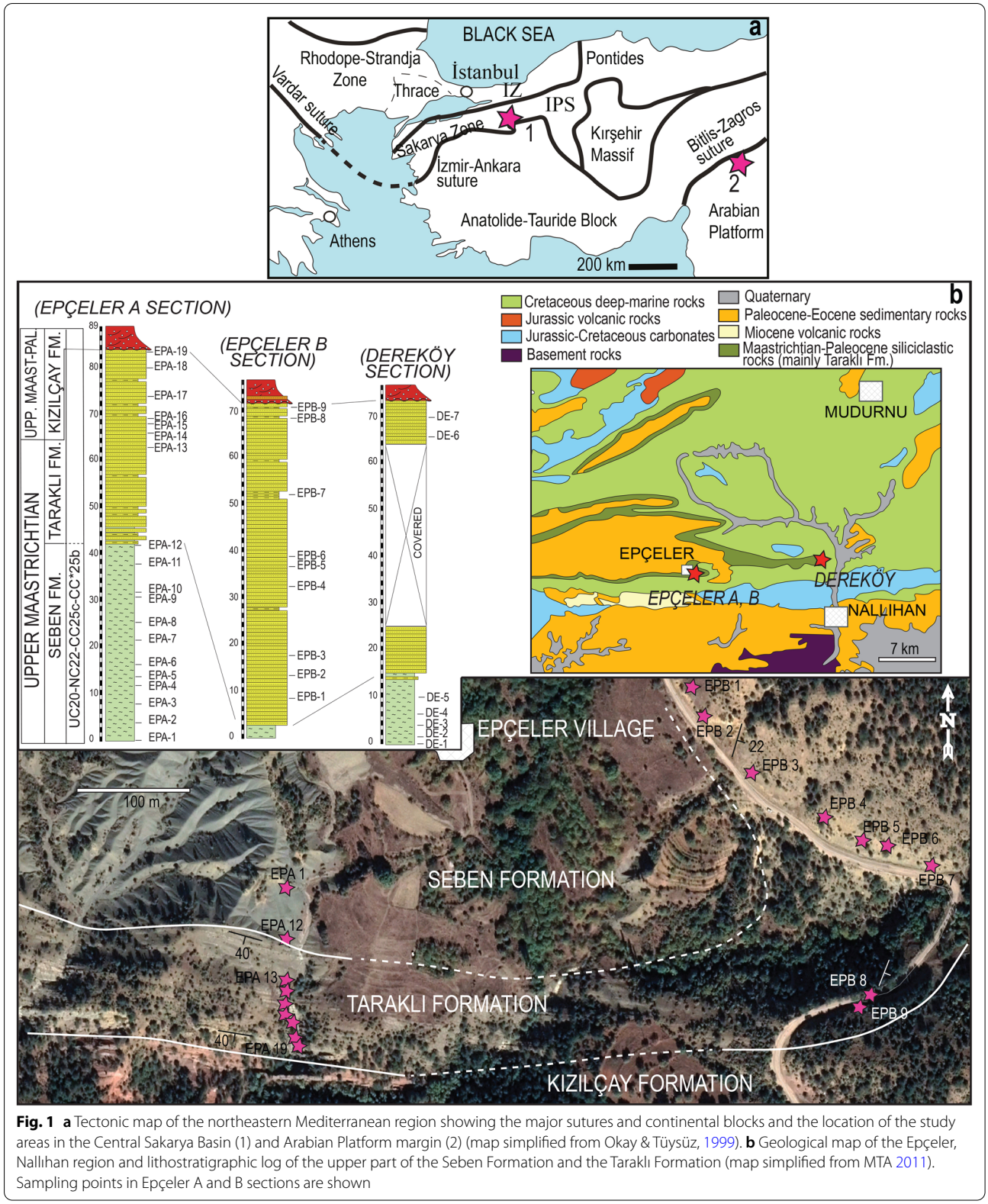

Fig. 1 **a** Tectonic map of the northeastern Mediterranean region showing the major sutures and continental blocks and the location of the study areas in the Central Sakarya Basin (1) and Arabian Platform margin (2) (map simplified from Okay & Tüysüz, 1999). **b** Geological map of the Epçeler, Nallıhan region and lithostratigraphic log of the upper part of the Seben Formation and the Taraklı Formation (map simplified from MTA 2011). Sampling points in Epçeler A and B sections are shown

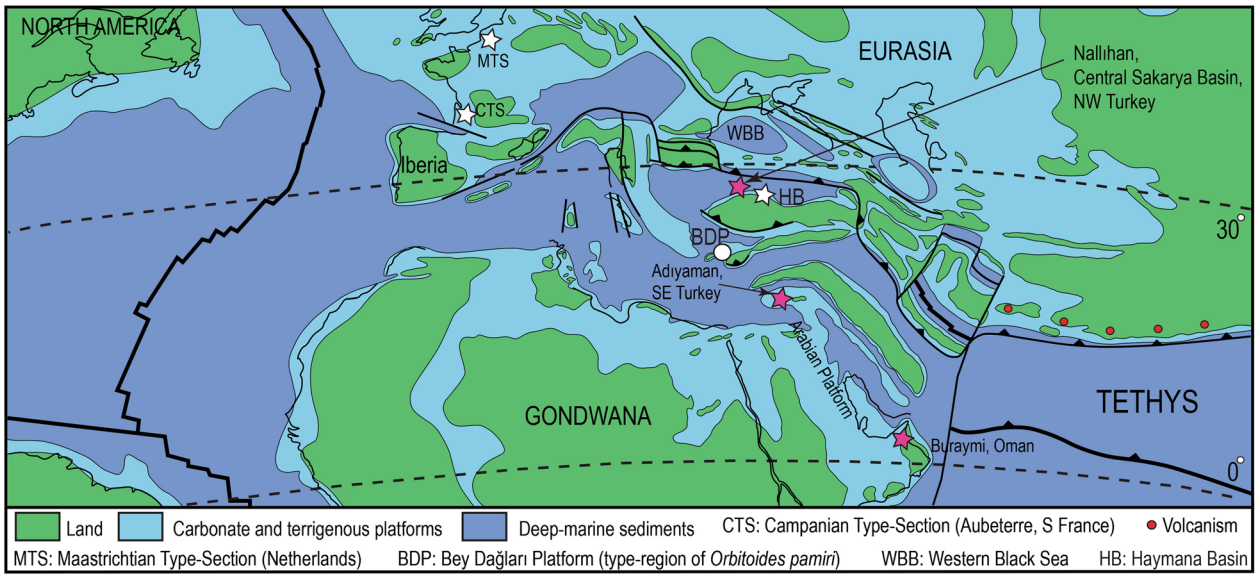

Fig. 2 Maastrichtian palaeogeography and locations of the studied sections in Turkey and Oman (shown by red) (map simplified from Barrier et al. 2018). The locations of the Campanian and Maastrichtian type sections in SW France and the Netherlands and the Haymana Basin in Central Turkey are shown

The Taraklı Formation is composed of a sandstone–siltstone succession, 100–300 m-thick, with larger foraminifera and bivalves present in some intervals. It is unconformably overlain by either continental clastic rocks of the Kızılçay Group or shallow marine carbonates of the Selvipınar Formation (Fig. 1b). The age of the Taraklı Formation was reported as Maastrichtian in the southern part of the Central Sakarya Basin (Saner, 1980), and Maastrichtian–Paleocene in the northern part (Ocakoğlu et al. 2019; Saner, 1980). Our data (including new nannofossil analyses) from the Epçeler Sections (Epçeler A and B) to the northwest of Nallıhan, and from Dereköy to the north of Nallıhan, indicate a late Maastrichtian age for the Taraklı Formation. The fauna present in the Epçeler and Dereköy sections is not diverse, and is predominantly composed of *Orbitoides,* very rare *Lepidorbitoides, Siderolites,* a few broken tests of *Omphalocyclus* and bivalve debris (Fig. 3).

Kahta, Adıyaman region (Southeastern Turkey)

The northern margin of the Arabian Platform in Southeastern Turkey is characterised by allochthonous and pre-and/ or post-emplacement autochthonous or parautochthonous units (Perinçek, 1980; Rigo de Righi & Cortesini, 1964; Yılmaz, 1993) (Fig. 4). The Kahta region of the Adıyaman province is one of the areas at the northern border of Arabian fold belt in which Late Cretaceous nappe emplacement and post-emplacement Late Cretaceous sedimentation are fully recorded (Meriç, 1965; Meriç et al. 1987; Özcan, 1993, 1994) (Fig. 4). The post-emplacement Terbüzek (also known as 'Antak') Formation is a thick-bedded to massive, friable and polygenetic coarse conglomerate unit with local sandstone intercalations (samples TF2 and 5). The formation is a continental to shallow marine clastic unit, which forms part of a new transgressive cycle following the Campanian– (?) early Maastrichtian nappe emplacement (Özcan, 1993, 1994). The fauna from the Terbüzek Formation consists of *O. megaloformis* Papp and Küpper, 1953, *Lepidorbitoides bisambergensis* (Jaeger, 1914), *Omphalocyclus anatoliensis* Özcan, 2007, *Planorbulinella* sp., *Goupillaudina* sp., and *Marssonella* sp., associated with rudists (Özcan, 1994, 1995, 2007; Özer, 1986). The Besni Formation is a clastic-carbonate unit, interpreted as a biohermal carbonate or beach deposit, conformably overlying the Terbüzek Formation (Meriç et al. 1987) (Fig. 4). The rapid proliferation and abundance of many larger benthic foraminiferal taxa such as *Orbitoides, Siderolites, Omphalocyclus, Loftusia, Clypeorbis, Lepidorbitoides, Sirtina, Goupillaudina*, together with the presence of rudists is a very characteristic feature of this formation (Özcan, 1993, 1994). Özcan (1994, 2007) assigned *Orbitoides* assemblages to *O. 'medius'* associated with *Siderolites calcitrapoides* Lamarck, 1801, *Omphalocyclus anatoliensis* Özcan, 2007, *Sirtina* cf. *orbitoidiformis* Brönnimann and Wirtz, 1962, and *Clypeorbis* aff. *mamillatus* (Schlumberger, 1902). An early Maastrichtian age for the Besni Formation was proposed by Özcan (1994). The overlying

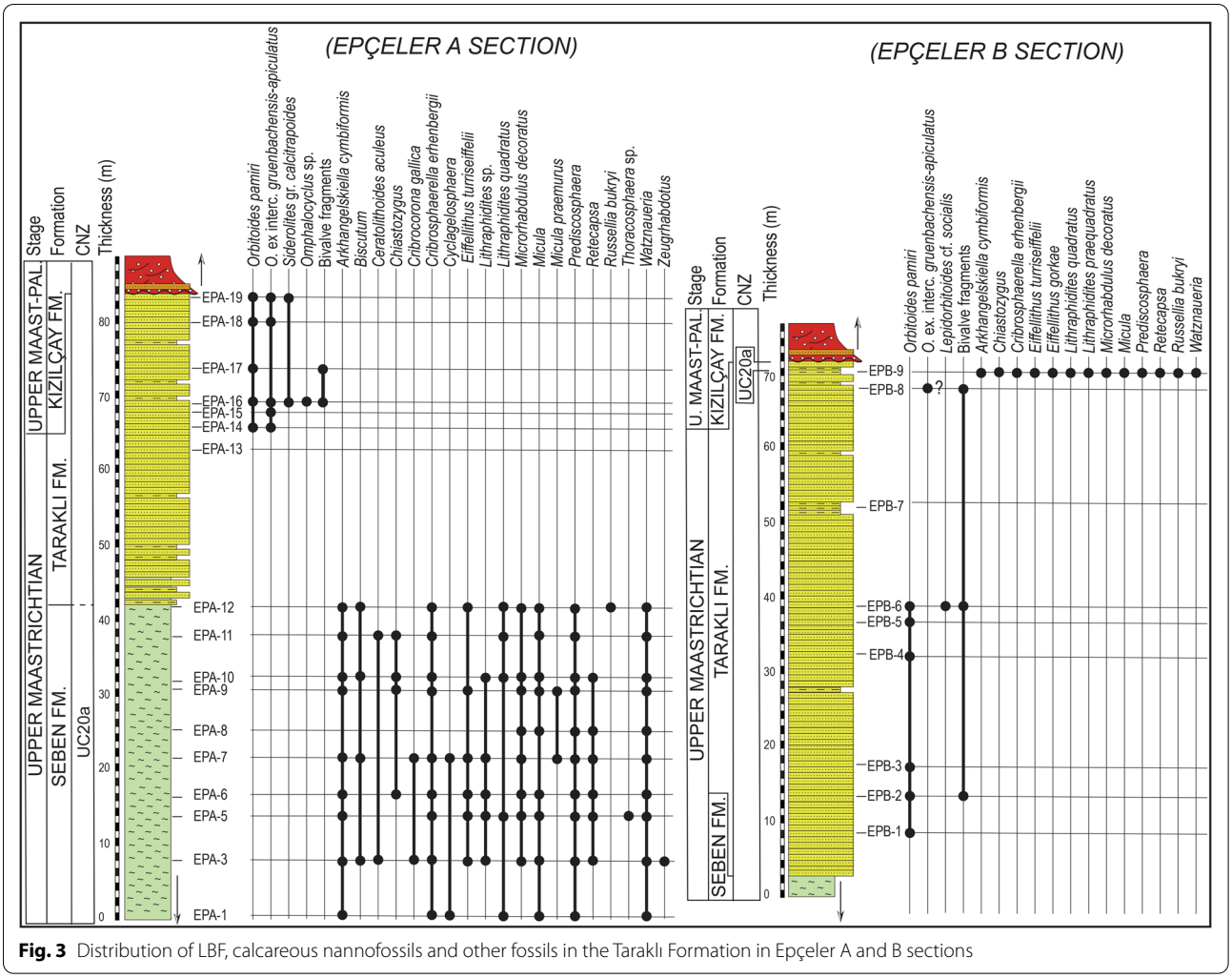

Fig. 3 Distribution of LBF, calcareous nannofossils and other fossils in the Taraklı Formation in Epçeler A and B sections

Germav Formation is predominantly composed of fine siliciclastic rocks with planktonic foraminifera. Two turbiditic beds (sample GA64 yielded an assemblage of *O. 'megaloformis'* and *L.* gr. *minor-socialis* associated with *Siderolites calcitrapoides*, *Siderolites denticulatus* Douvillé, 1906, *Omphalocyclus.* cf. *macroporus* (Lamarck, 1816), *Pseudomphalocyclus blumenthali* Meriç, 1980, *S.* cf. *orbitoidiformis*, and *Loftusia* spp. (Özcan, 1993, 1994). The age of the Germav Formation has been reported as early-middle/late Maastrichtian. Tertiary deposits unconformably overlie the Upper Cretaceous units and are represented by the continental red beds of the Gercüş Formation and carbonates of the Midyat Group.

Haymana Basin, Central Turkey

The Haymana Basin is a thick clastic depocentre of Late Cretaceous to Eocene age in central Anatolia (Özcan et al. 2020). The Beyobası Formation, the uppermost stratigraphic unit of the Cretaceous sequence, is a shallow marine-mixed carbonate-siliciclastic deposit consisting of siltstone-sandstone and bioclastic limestone beds. The Beyobası Formation contains *O. apiculatus*, *O. 'medius'*, *L. socialis*, *O. macroporus*, *Siderolites* sp., *Loftusia* sp., *Sirtina* sp., *Hellenocyclina* sp. and *Cideina* sp., accompanied by *Cyclolites* sp., bivalves and gastropods indicating a late Maastrichtian age (Özcan & Özkan-Altıner, 1997).

Buraymi region, North Oman

The Qahlah and Simsima Formations are the first autochthonous sediments deposited on the obducted ophiolite complex in Oman. They are characterised by an abundance of benthic foraminifera and rudists, along with corals, calcareous algae, gastropods and echinoids (Abdelghany, 2003; Béchennec et al. 1993; Kayğılı et al. 2021; Nolan et al. 1990; Roger et al. 1993; Schlüter et al. 2008; Skelton et al. 1990). A road-cut section to the northeast of Buraymi in North Oman shows an expanded section of the marine part of the Qahlah Formation