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ORIGINAL PAPER

# From Tethys to Eastern Paratethys: Oligocene depositional environments, paleoecology and paleobiogeography of the Thrace Basin (NW Turkey)

**Yeşim İslamoğlu · Mathias Harzhauser · Martin Gross · Gonzalo Jiménez-Moreno · Stjepan Coric · Andreas Kroh · Fred Rögl · Jan van der Made**

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**Abstract** The Oligocene depositional history of the Thrace Basin documents a unique paleogeographic position at a junction between the Western Tethys and the Eastern Paratethys. As part of the Tethys, shallow marine carbonate platforms prevailed during the Eocene. Subsequently, a three-staged process of isolation started with the Oligocene. During the Early Rupelian, the Thrace Basin was still part of the Western Tethys, indicated by typical Western Tethyan marine assemblages. The isolation from the Tethys during the Early Oligocene is reflected by oolite formation and endemic Eastern Paratethyan faunas of the Solenovian stage. The third phase reflects an increasing continentalisation of the Thrace Basin with widespread coastal swamps during the Late Solenovian. The mollusc assemblages are predominated by mangrove dwelling taxa and the mangrove plant *Avicennia* is recorded in the pollen spectra. The final continentalisation is indicated by the replacement of the coastal swamps by pure freshwater swamps and fluvial plains during the Late Oligocene (mammal zone MP 26). This paleogeographic affiliation of the Thrace Basin with the Eastern Paratethys after ~32 Ma contrasts all currently used reconstructions which treat the basin as embayment of the Eastern Mediterranean basin.

**Keywords** Early Oligocene · Rupelian · Solenovian · Paleobiogeography · Paleoecology · Western Tethys · Eastern Paratethys

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Y. İslamoğlu (✉)
Geological Research Department,
General Directorate of Mineral Research and Exploration,
06520 Balgat, Ankara, Turkey
e-mail: yesimislamoglu@yahoo.com

M. Harzhauser · A. Kroh · F. Rögl
Natural History Museum Vienna,
Burgring 7, 1010 Vienna, Austria
e-mail: mathias.harzhauser@nhm-wien.ac.at

A. Kroh
e-mail: andreas.kroh@nhm-wien.ac.at

M. Gross
Landesmuseum Joanneum, Raubergasse 10,
8010 Graz, Austria
e-mail: martin.gross@museum-joanneum.at

G. Jiménez-Moreno
Departamento de Estratigrafía y Paleontología,
Facultad de Ciencias, Universidad de Granada,
Avda. Fuente Nueva S/N 18002, Granada, Spain
e-mail: gonzaloj@ugr.es

G. Jiménez-Moreno
Center for Environmental Science,
University of New Mexico, Albuquerque 86011, USA

S. Coric
Geologische Bundesanstalt, Neulinggasse 38,
1031 Vienna, Austria
e-mail: stjepan.coric@geologie.ac.at

J. van der Made
Consejo Superior de Investigaciones Científicas,
Museo Nacional de Ciencias Naturales, Madrid, Spain
e-mail: mcnjv538@mncn.csic.es

## Introduction

The Late Eocene orogeny of the Alpine thrust belt transformed the Early Oligocene Paratethys into a huge but largely isolated sea that covered an area from E-France and Switzerland in the West to inner Asia in the East (Rögl 1998). This initial isolating event was indicated already during the nannoplankton zones NP21/22 by the long-lasting anoxic bottom conditions (e.g. Schulz et al. 2005) and the deposition of black shales in large parts of the Paratethys (Rögl 1998). During the early NP23, a first endemic mollusc fauna evolved spreading from the Asian Eastern Paratethys towards the west (Popov et al. 1985, 1993). The associated Eastern Paratethyan regional stage Solenovian is name giving for this peculiar fauna (Solenovian fauna). During that time, diverse coral reefs and a tropical mollusc fauna flourished along the northern coast of the Western Tethys (Schuster 2002; Harzhauser 2004). A chain of mountains and microcontinents (e.g. Alps, Dinarids, Anatolia, Lesser Caucasus, Kopeth Dagh) formed a continental barrier which separated these very contrasting seas (Rögl 1998; Popov et al. 2002, 2004). The paleogeographic position of seaways connecting the Tethys and the Paratethys are controversially discussed and often still unclear due to subsequent tectonic processes which subducted or eroded the associated deposits.

One of the few promising but rarely considered gateway areas is the Thrace Basin. First comments on Paratethyan biota in the Thrace Basin have been reported by Kojumdgieva and Sapundgieva (1981) and paleogeographic relations with the Eastern Paratethys are discussed by Rögl (1998) and Özturk and Frakes (1995). In contrast, most paleogeographic maps (e.g. Popov et al. 2004) treat the area as Tethys embayment. Thus, a detailed analysis of the depositional environments of the Oligocene Thrace Basin and its relation to the Eastern Paratethys via marine gateways through the Stranjha Massif in the north and the Tethys in the south are missing. Therefore, the aim of this study is to clarify the stratigraphy of the Oligocene deposits and to interpret the successions and their paleontological content in terms of depositional environments, paleoecology and paleogeography.

## Geological setting

Having economic potential because of its lignites and manganese ores, the Thrace Basin has been target of numerous geological studies since the nineteenth century (e.g. Hochstetter 1872; English 1902; Arabu 1913; Taşman 1938; Pamir and Baykal 1947; Akartuna 1953; Kopp 1961; Kopp et al. 1969; Keskin 1974; Lebküchner 1974; Üşümezsoy and Öztunalı 1981; Turgut et al. 1991; Özturk and Frakes 1995; Görür and Okay 1996; Gültekin 1998; Çağlayan and Yurtsever 1998; Turgut and Eseller 2000; Zattin et al. 2005).

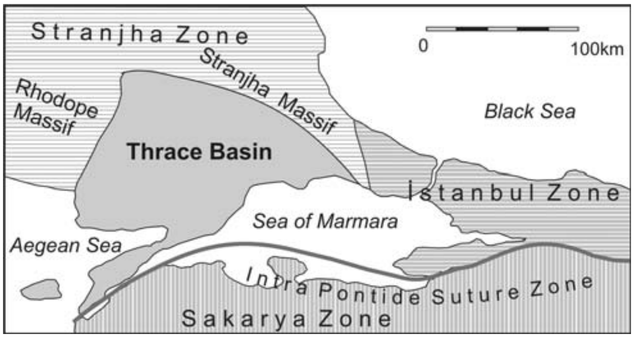


**Fig. 1** Tectonic setting of the Thrace Basin (modified from Görür and Okay 1996)

The Cenozoic Thrace Basin is a triangular shaped fore-arc basin (Fig. 1) with a c. 9,000-m-thick Eocene to Holocene basin-fill (Özturk and Frakes 1995; Görür and Okay 1996; Turgut and Eseller 2000). It is limited by the Stranjha Massif in the north, the Palaeozoic crystalline of the İstanbul Zone in the east, the Rhodope Massif in the west, and the Marmara melange and Sakarya zones in the south (Görür and Okay 1996; Çağlayan and Yurtsever 1998). It has formed during the Paleogene as consequence of the northward prograding subducting Intra-Pontide Complex (Görür and Okay 1996). Two main strike-slip fault systems influenced the basin evolution during the Oligocene and early Neogene (Görür and Okay 1996; Sakınç et al. 1999). The northern one, consisting of the Terzili and the Osmancik faults, extends from Greece to the Sea of Marmara. In the south, the Ganos Fault, being part of the North Anatolian Fault Zone, streches from the Aegean Sea into the Sea of Marmara. Its late Neogene evolution was mainly influenced by activity of the North Anatolian fault zone, reflected by wrench tectonics and graben structures (Özturk and Frakes 1995).

Sedimentation in the Thrace Basin commenced during the late Early Eocene, represented by coarse clastic deposits of the Karaağaç and Fıçıtepe formation in the west, the lower parts of the Gaziköy and Keşan formations in the south and the Hamitabat group in the east (Turgut and Eseller 2000). The Middle Eocene to lowermost Oligocene basin fill is represented by the Koyunbaba, Soğucak and Ceylan formations and the Yenimuhacir group (Kasar and Eren 1986; Sümengen et al. 1987; Çağlayan and Yurtsever 1998; Turgut and Eseller 2000). The up to 100 m-thick Koyunbaba Formation comprises conglomerates, pebbly sandstones and silty shales. It is overlain by the Sogucak Formation along the marginal parts of the basin and by the Hamitabat Formation in basinal settings (Turgut and Eseller 2000).

Typical deposits are reefal limestones which formed on carbonate platforms and marls in deeper settings. Dark shales, marls, siltstones and tuffaceous layers of the Ceylan Formation (200–2,000 m-thick) overlay the Soğucak Formation (Turgut and Eseller 2000). Upsection follows the Yenimuhacir Group which consists of the Mezardere, Pınarhisar, Osmancık and Danişmen formations. The Mezardere Formation, deposited in a prodeltaic environment, is composed of shales, marls and few tuffs of up to 2,500 m thickness. It can be followed in large surface outcrops in the north-east of Keşan, around İpsala and along the roads from Tekirdağ and Malkara to Greece (Mitzopoulos 1961; Lebküchner 1974; Kojumdgieva and Dikova 1980; Turgut and Eseller 2000) The c a. 50 m-thick Pınarhisar Formation overlies the Mezardere and the Sogucak formations discordantly and comprises mainly oolitic, sandy and bioclastic limestones with coquinas (Gökçen 1973; İslamoğlu and Taner 1995). The dating of this Lower Rupelian formation, referred to as “coquina bearing limestones” and “*Congeria*-bearing limestones” in the literature, was very vague and included Early to Late Miocene datings (e.g. English 1902; Aslaner 1966; Pamir and Sayar 1933; Akartuna 1953).

The Pınarhisar and Mezardere formations are overlain by the Oligocene aged Osmancık and Danişmen formations (Turgut and Eseller 2000). The Osmancık Formation consists of 500–1,000 m prodeltaic sandstones, shales, limestones and scattered tuffites (Çağlayan and Yurtsever 1998; Turgut and Eseller 2000). It contains a rich assemblage of molluscs, palynomorphs and plants and was dated in the literature as Chattian (e.g. Ediger et al. 1990; Elsik et al. 1990). The Danişmen Formation overlies the Osmancık formation concordantly (Turgut and Eseller 2000). It extends from the Gelibolu Peninsula into the Greek part of the basin and occurs even on the Imroz and Limnoz islands (English 1904; Kopp et al. 1969). The thickness of the formation ranges from 50 to 350 m. It comprises greenish grey shales, claystones, coals interbedded with fine grained sandstones and silts (Çağlayan and Yurtsever 1998). The Danişmen Formation is very fossiliferous and yields molluscs, fishes, mammals, palynomorphs, wood and leaf floras (Turgut and Eseller 2000). Nevertheless, the age estimations in the literature are extremely confused and span a range from the Rupelian to the Pontian (e.g. Middle to Upper Oligocene: Çağlayan and Yurtsever 1998; Middle Miocene: Rückert-Ülkümen 1960; Mio-Pliocene: Aslaner 1966; Upper Pontian: Akartuna 1953).

The post-Oligocene development is not within the scope of this paper and is only briefly summarised. After a major erosive episode, the Late Miocene and Pliocene are represented by terrestrial and shallow marine successions in the SW and SE (Sayar 1987; Sakınç et al. 1999; Turgut and Eseller 2000). Quaternary deposits are represented by terrestrial sediments in most parts of the basin and by fossiliferous marine terraces surrounding the coasts of the Marmara region. These terraces reflect strong sea level changes due to the glacial/interglacial rhythm and tectonic movements of the western continuation of the east-west trending North Anatolian Fault System (NAF) (Sakınç and Yaltırak 1997; Emre et al. 1998; İslamoğlu and Tchepalyga 1998; İslamoğlu et al. 2001; İslamoğlu 2008).

## Investigated sections: lithostratigraphy and fossil content

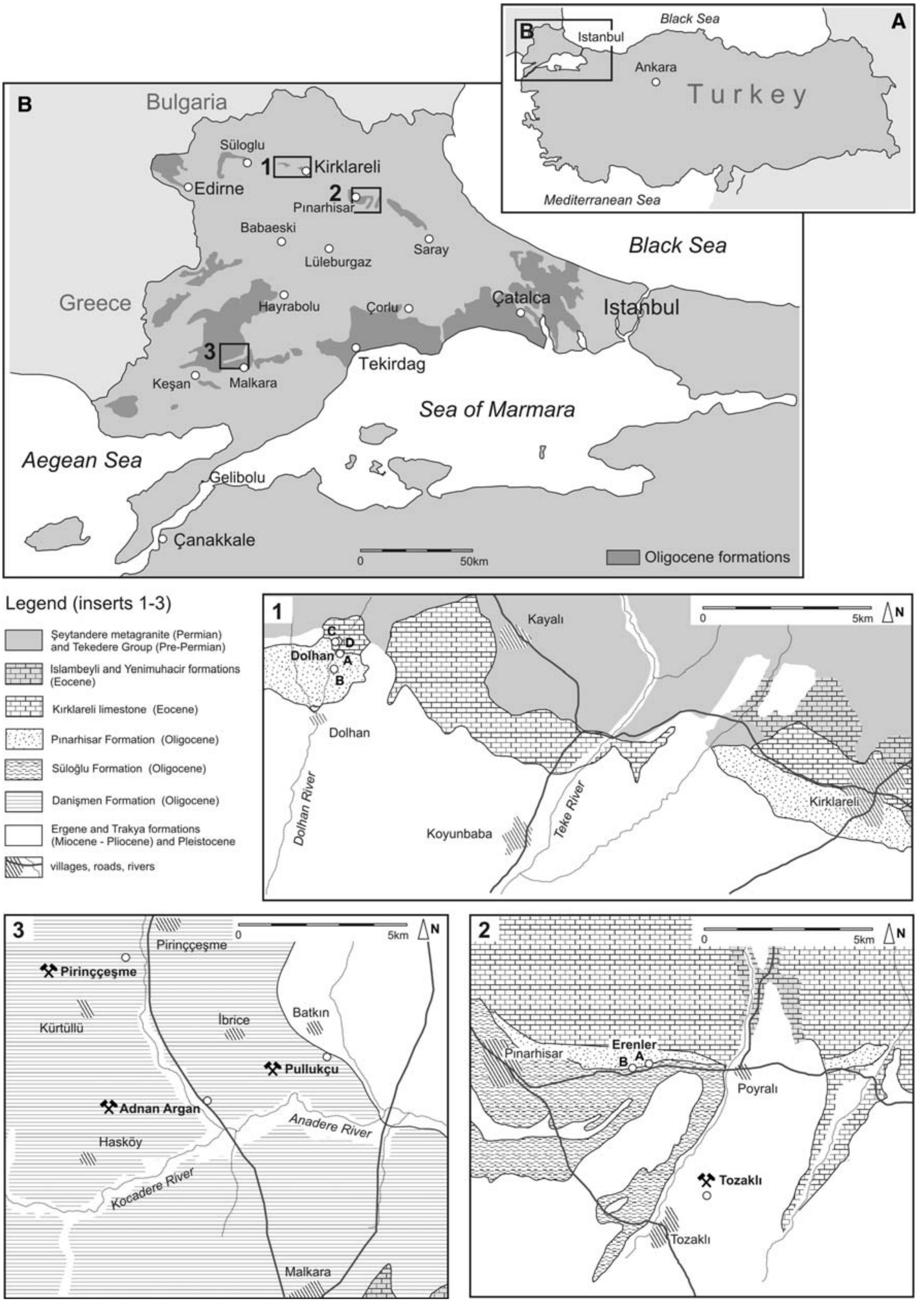
Three areas have been chosen to reconstruct the Thrace Basin evolution (Fig. 2): (1) Dolhan-Kırklareli in the NW, (2) Pınarhisar-Erenler in the NE and (3) Keşan-Malkara in the SW. These represent a stratigraphic succession covering the Koyunbaba Fm., the Sogucak Fm., the Pınarhisar Fm. and the Danismen Fm.

### Dolhan-Kırklareli area (Fig. 2/1)

In the NW of the Thrace Basin, Eocene and Oligocene successions are exposed close to the villages Dolhan and Kırklareli along the valley of the Dolhan river situated about 15 km west of Kırklareli. One section has been chosen as example for the Upper Eocene (Dolhan A; 41°46′46.2″N, 27°02′05.2″E). Three additional sections have been analysed within the Oligocene part of the Sogucak Formation: Dolhan-B (41°46′24.4″N, 27°02′0.1″E), Dolhan-C (41°46′51.5″N, 27°02′0.0″E) and Dolhan-D (41°46′51.5″N, 27°02′00.6″E).

#### *Dolhan A section (Koyunbaba Formation, Eocene) (Fig. 3)*

The about 10 m thick succession comprises a very indistinct and highly bioturbated interbedding of 20–40 cm thick sandy-marly limestones and 5–15 cm thick sandy marls with a rich echinoderm-mollusc-foraminifers assemblage. Encrusting foraminifera are common in the limestones. The marls yield characteristic shallow water assemblages with sessile species such as *Eorupertia incrassate* (Uhlig, 1886), and *Nummulites chavannesi* de la Harpe, 1883, *N. fabianii* (Prever in Fabiani, 1905), *Asterigerina bimammata* (Guembel, 1868), *A. rotula* (Kaufmann, 1867), together with common *Stomatorbina toddae* Haque, 1960. Spondylids, naticids, xenophorids, lucinids and rare *Campanile giganteum* (de Lamarck, 1804) and *Cepatia cepacaea* (de Lamarck, 1804) are typical constituents of the mollusc fauna. *Eupatagus rogeri* (Pinar, 1951) and extremely frequent coronas of the tiny *Echinocyamus* sp. occur among the echinoderms along



with astropectenid seastars of which only ossicles could be found. In-situ occurrence of tubes of the burrowing bivalve *Kuphus melitensis* Zammıt-Maempel, 1993 are typical.

The outcrop is a rather isolated erosional relic which currently does not expose a clear contact with the adjacent coral-limestones of the Kırklareli Formation. Following the

◀ **Fig. 2** Geographic and geological setting of the Thrace Basin and the investigated outcrop areas. *Insert* **a**: outline of Turkey indicating the position of the Thrace Basin: *insert* **b**: the Thrace Basin in the European part of Turkey with surface distribution of Oligocene deposits and inserts 1–3 which indicate the position of the investigated areas (regional geology modified from Çağlayan and Yurtsever (1998)

Dolhan river upstream, the marly limestones are repeatedly exposed in the river bed and bear abundant casts of *Campanile giganteum* (de Lamarck, 1804) and in-situ populations of large-sized lucinid bivalves. The contact to the sections described below is obscure. The abrupt facies change, however, suggests a fault zone which is currently not exposed.

### *Dolhan B, C and D sections (Sogucak Formation, Oligocene) (Fig. 3)*

Oligocene deposits of the Sogucak Formation are exposed in a series of outcrops along the Dolhan river. Dolhan-B is composed of a siliciclastic succession of 8 m thickness. The basal 2 m of silt are erosively overlain by a 1-m-thick bed of coarse, poorly sorted sand and gravel with a coquina of randomly oriented bivalve shells. Reworked pebbles of corals of up to 10 cm diameter and fragmented scutellid

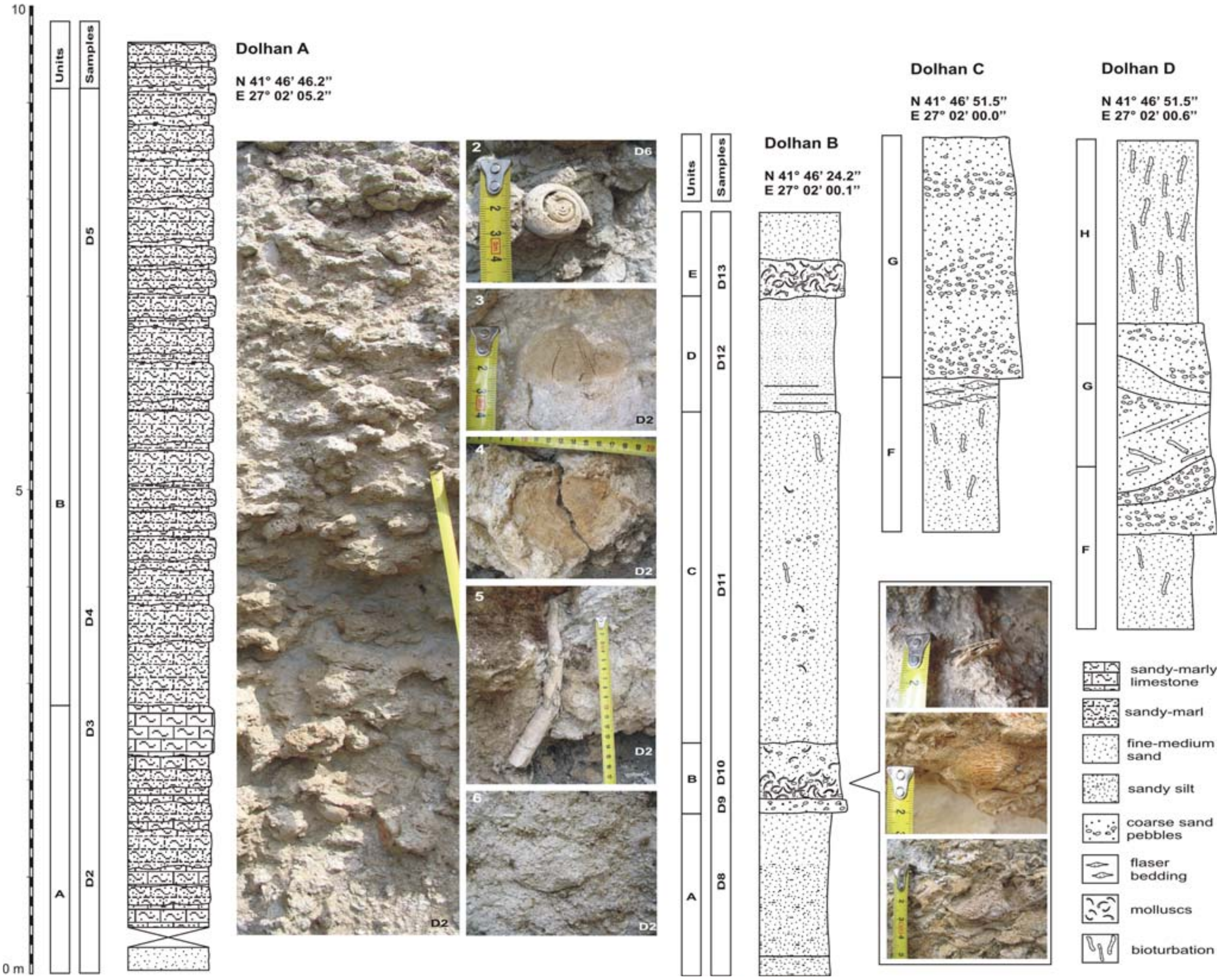


**Fig. 3** The Priabonian Dolhan A section and the Rupelian Dolhan A–C sections. Dolhan A displays a succession of bioturbated calcareous marls and limestones. The pictures elucidate the typical sedimentary structures and biota: *1* outcrop picture; *2 Cepatia cepacaea* (de Lamarck, 1804) and *3 Eupatagus rogeri* (Pinar, 1951) indicating an Eocene age; *4* a unnamed large-sized lucinid bivalve, which occurs in dense in-situ populations along the Dolhan River, *5* in situ occurrence of the bivalve *Kuphus melitensis* Zammıt-Maempel, 1993; *6* detail of the nummulite bearing limestone in the lower part of Dolhan A (length ~10 cm). Dolhan B, C and D represent a coastal siliciclastic depositional environment: the *inserts* show details of the coquina with a fragment of the echinoid *Parmulechinus* sp. (*upper picture*), *Macrocallista exintermedia* (Sacco, 1900) and a reworked coral block (*lower picture*)

echinoderms (*Parmulechinus* sp.), usually displaying imbrication, occur within the coquina. Most of the bivalves represent *Macrocallista exintermedia* (Sacco, 1900). Fragmented decapod remains are extremely abundant. Following this unit, about 3.5 m of badly sorted medium to coarse sand with stringers of pebbles characterised by heavy bioturbation is observed (*Ophiomorpha* and *Thalassinoides* type). In this sediments (sample D11) a small foraminiferal assemblage occurred with *Textularia* sp., *Pararotalia armata* (d'Orbigny, 1826), *P. inermis* (Terquem, 1882), *Amphistegina* sp., and small *Nummulites* (probably *N. fichteli* Michelotti, 1841). Upsection follow another 1 m of laminated sandy silt cut by again 30 cm thick coquina-bearing sandstone.

The end of the sedimentation is documented upstream by the Dolhan-C and Dolhan-D sections. Both expose about 3–5 m thick siliciclastic successions. The basal parts represent silty sandy marine deposits with flaser bedding and intense bioturbation by crustaceans. These deposits are topped by poorly sorted coarse sand and pebble with large-scale cross-bedding. Intercalations of bioturbated sand within this unit occur at the Dolhan-D section.

### Pınarhisar-Erenler area (Fig. 2/2)

#### *Erenler A and B sections (Pınarhisar Formation, Oligocene) (Fig. 4)*

The area in the NE of the Thrace Basin is represented by the outcrops at Erenler and Pınarhisar where carbonates of the Pınarhisar Formation occur. Close to the village Erenler, approximately 3.5 km east of Pınarhisar, the two sections, Erenler A (41°37′N40.4″, 27°33′54.8″E) and Erenler B (41°37′36″N, 27°33′29.4″E) have been investigated. Erenler A is topographically higher but stratigraphically lower than Erenler B and exposes an about 6-m-thick unit of well-sorted oolites and sandy oolites with mollusc coquinas. These are separated by mm-thin intercalations of plane-bedded marls. Towards the top, two layers of marls are intercalated.

The close-by Erenler-B section differs by its coarse clastic compounds admixed to the oolites. The section is 4 m high and allows a study of the lateral facies distribution along a length of more than 15 m. Its lower 2 m expose a plane-bedded succession of oolite beds with cm-thin marly intercalations. The oolite beds range between 10 and 50 cm thickness and display a thinning upward trend. This homogenous unit is discordantly overlain by oolite-sand dunes with internal cross-stratification and strongly variable amounts of quartz gravel and mollusc coquinas. Generally, the dune height seems to range between 1 and 1.5 m and the diameter (probably wave-length) exceeds 7 m. Both sections bear a small-sized and low diverse mollusc fauna with *Lenticorbula sokolovi slussarevi* (Merklin, 1974), *Cerastoderma chersonensis* (Nossovskii, 1962), *Mytilopsis* sp. and *Melanopsis impressa* Krauss, 1852. Further taxa are listed in Gökçen (1973) and İslamoğlu and Taner (1995), who mentioned the ostracods *Henryhowella asperrima echinata* (Reuss, 1851), *Xestoleberis obtusa* Lienenklaus, 1900, *Pokornyella limbata* (Bosquet, 1852), *Cytheretta tenuistriata* (Reuss, 1853), *Grinioneis triebeli* (Stchepinsky, 1960), the foraminifers

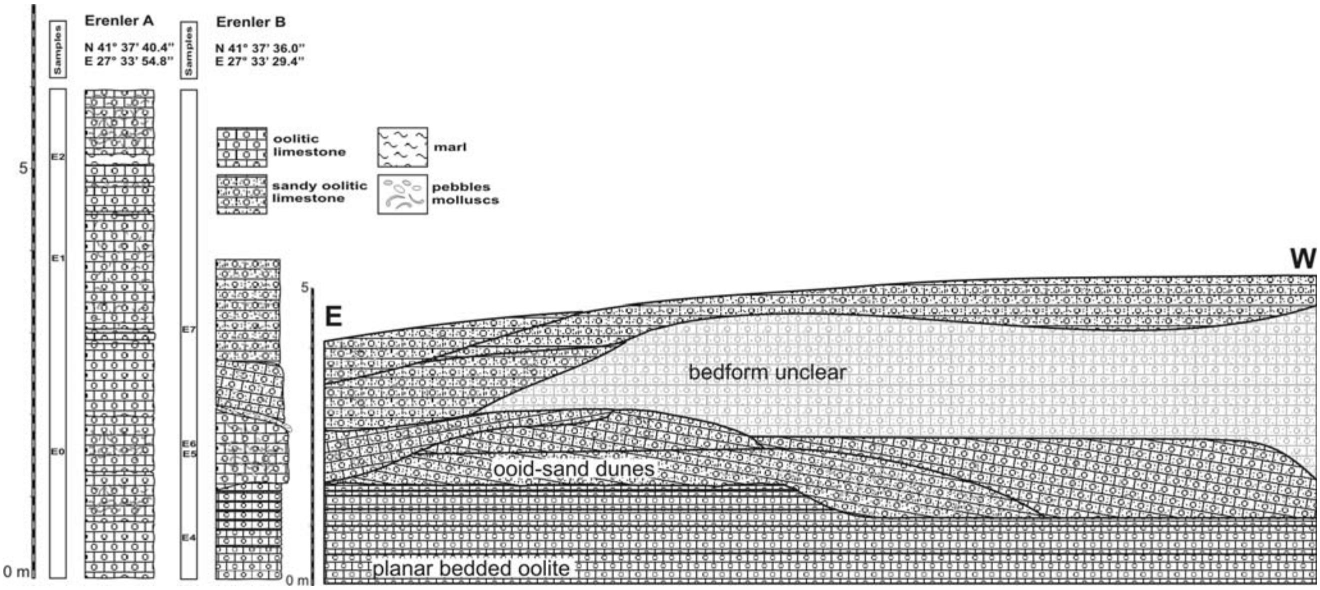


**Fig. 4** The oolites of Erenler A & B. The logs display the lithologic succession, whereas the of the outcrop-wall gives an impression of the dynamic development of the Erenler oolite shoal and its dune field

*Rotalia quantanamensis* Cushman & Bermudez, 1949, *Clavulinoides szaboi* (Hantken, 1875), *Bolivina reticulata* Parr, 1932, *Bolivinella rugosa* (Howe, 1930), *Nummulites vascus boucheri* de la Harpe, 1883, and the molluscs.

### *Tozaklı A, B and C sections (Danismen Formation, Oligocene) (Fig. 5)*

Aside from the limestones of the Pinarhisar Formation, the Oligocene basin fill in the NE of the Thrace Basin is mainly represented by siliciclastics of the Danismen Formation. It is well exposed in a large lignite mine about 6.5 km SE of Pınarhisar and 1 km NE of Tozaklı. There, an about 30 m thick lignite bearing succession was studied consisting of three logs (Tozaklı A: 41°35′30.2″N, 27°35′07.4″E; Tozaklı B: 41°35′26.3″N, 27°35′07.0″E; Tozaklı C: 41°35′25.1″N, 27°35′02.8″E).

Six major lignite intercalations of 40–200 cm thickness were recognized in the lower 20 metres (Tozaklı A, B). These lignites are united into three couples separated by about 4–5 m thick silt, sand and clay. In situ preservation of trunks and roots close to the lignites is common. Sedimentary structures such as lamination are indistinct in these areas as well. In contrast, the larger pelitic-psammitic units, separating the lignite couples, often display dm-thick bedding of silt-clay fining upward sets (unit E). Internally, these beds are characterised by convolute bedding and rarely show traces of ripples. Laterally, these units are fairly constant, differing only in thickness. Upsection, the uppermost 10 m (Tozaklı C) yield only two very thin lignites. The succession becomes coarser and two phases with fluvial channels occur. The associated channel-fills consist of large-scale cross-bedded medium to coarse sand cutting into silty fine sand. Aside from the ubiquitous plant fossils (roots, leaves) only few macrofossils have been detected. Shells of the gastropod *Tinnyea escheri* (Brongniart, 1823) are usually associated with the lignites.

An isolated mandible of an anthracothere occurred at Tozaklı A (unit D). The Eocene *Bakalovia* Nikolov & Heissig 1985 and Late Eocene and Early Oligocene *Elomeryx cripus* (Gervais, 1849) (=*E. woodi*, *E. porcinus*) were cited from Bulgaria and Thrace respectively (Lebküchner 1974; Ünay-Bayraktar 1989; Hellmund 1991). In the specimen from Tozaklı, the posterior crest of the hypoconid of the $M_3$ reaches the lingual side of the tooth, a crest connecting the hypo and entoconid is lacking, and the premolar row seems to be relatively short, which is unlike in *Bakalovia* (Hellmund 1991). The mandible from Tozaklı belongs to *Elomeryx*, but is larger than in *E. crispus*, while it coincides with *Elomeryx borbonicus* (Gervais, 1852) in morphology (no crest hypo-entoconid) and size. Hellmund (1991) included in this species *Elomeryx minor* (Depéret, 1906), however, it was argued that that form has shorter premolars and should be considered separate at least at the subspecies level (Van der Made 1999). The premolars of the specimen from Tozaklı are small, but their exact size cannot be measured because of damage.

Pollen analysis has been done on several samples from Tozaklı A section (Fig. 6). Pollen floras of Tozaklı are rich in thermophilous plants such as *Taxodium* type, *Myrica* or *Engelhardia*. There is an abundance of hygrophilous-riparian taxa (mainly *Taxodium* type, *Myrica*, *Carya* and *Alnus*) that are accompanied by aquatic herbs such as *Sparganium-Typha*, *Potamogeton*, etc., in the pollen spectra.

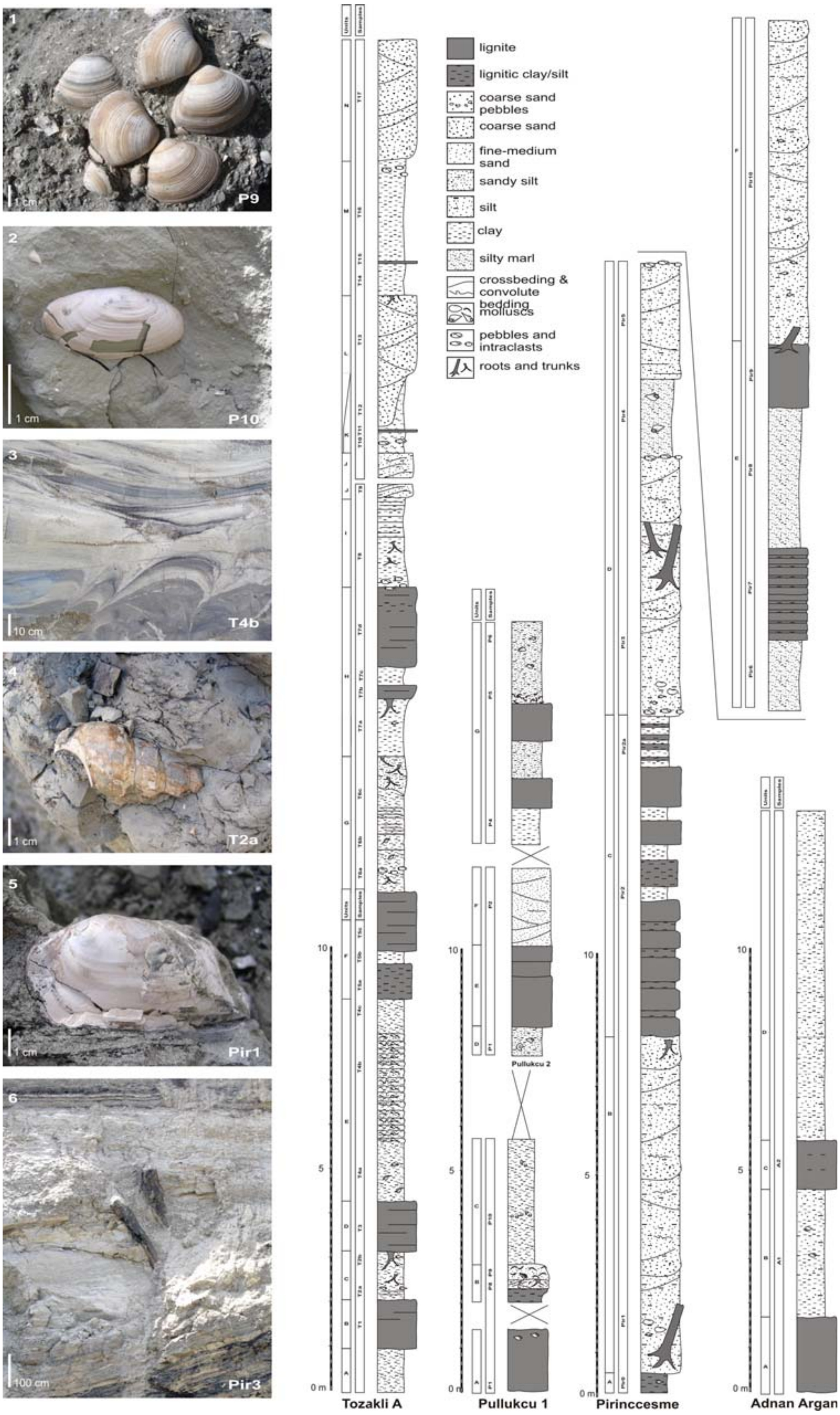
### Keşan-Malkara area (Fig. 2/3)

In the SW of the Thrace Basin lignite bearing units of the Danismen Formation predominate and are widely exposed in numerous lignite mines. Of these, three lignite mines have been examined: Pullukcu, Pirinccesme and Adnan Argan.

### *Pullukcu 1 and 2 sections (Danismen Formation, Oligocene) (Fig. 5)*

Two composite logs cover the succession of the Pullukcu lignite mine (Pullukcu 2, 40°57′19.0″N, 26°54′58.9″E and Pullukcu 1, 40°57′18.5″N, 26°54′38.3″E). The basal part of the succession (Pullukcu 2) is dominated by a 1.5-m-thick lignite bed. In its top, a nearly monospecific assemblage of *Melanopsis impressa* Krauss, 1852 was found. Within the lignites, only pseudomorphoses deriving from the tubes of the wood-dwelling bivalve *Teredina* sp. occur. The lignite bed is overlain by a 30–40 cm thick coquina in silty clay, traceable throughout the pit. It displays a multiphased, complex internal structure and consists of numerous shells of *Polymesoda subarata* (von Schlotheim, 1820) which occurs as disarticulated shells as well as articulated but gaping valves. Nesting is also frequent and weathering surfaces document a trend to convex side-up preservation. Along with the large-sized and relatively thick-shelled *Polymesoda subarata,* mainly thin-shelled dreissinids such as *Mytilopsis aralensis* (Merklin, 1974) and the gastropods *Tympanotonos margaritaceus* (Brocchi, 1814) and *Melanopsis impressa* Krauss, 1852 occur in masses. Small-sized shells of the planorbid-like *Anomalinorbina* dominate in numbers in quantitative samples. Serpulids, various undetermined fragments of fish-bones and small mammal remains were also detected in the samples. The ostracod fauna is dominated by *Hemicyprideis istanbulensis* Bassiouni, 1979 and accompanied by *Cytheromorpha zinndorfi* (Lienenklaus, 1905), *Elofsonia* sp. and candonids. Rare autochthonous nannoplankton is represented by *Sphenolithus capricornutus* (Bukry and Percival, 1971). The coquina-bearing clay and silt is overlain by a 3-m-thick unit

**Fig. 5** Logs of the lignite mines Tozaklı, Pirinccesme, Pullukcu and Adnan Argan. The pictures show typical biota and sedimentary structures of the sections: *1 Polymesoda*-coquina from Pullukcu with gaping but articulated valves of *Polymesoda subarata* (von Schlotheim 1820). *2 Gari* sp. from a lagoonal-marine interval at Pullukcu. *3* water-escape structures and convolute bedding at Tozaklı. *4 Tinnyea escheri* (Brongniart, 1823) from Tozaklı. *5* one of the articulated unionids floating in the sediment surrounding the trunks at Pirinccesme. *6* two in-situ trunks at Pirinccesme situated between two lignite beds (the *inserts* in the pictures indicate the position of each photo within the sample-column of the logs)



of greenish marly clay and silt with rare thin-shelled infaunal bivalves (*Angulus* sp., *Gari* sp.). Two samples from Pullukcu 1 and 2 were studied for pollen (Fig. 7). Pollen floras of Pullukcu are rich in thermophilous plants such as *Taxodium* type, *Myrica* or *Engelhardia*. The presence of *Avicennia*, a mangrove plant, in this section indicates the development of a mangrove on the coastal area, which is consistent with the occurrence of several indeterminate marine dinoflagellate cysts in the same sample. Pollen spectra are also rich in hygrophilous-riparian taxa (mainly *Taxodium* type, *Myrica*, *Carya* and *Alnus*) and in aquatic herbs such as *Sparganium-Typha*, Liliaceae, etc.

In Pullukcu 1 this level is topped by another about 2-m-thick lignite bed (unit E) associated by a characteristic *Polymesoda* coquina with rare *Melongena basilica* (Bellardi, 1872). A more than 2-m-thick unit of crossbedded silt and finesand with convolute bedding follows (unit F). The top unit (G) consists of a 5-m-thick succession of clayey silt with two lignite intercalations of 70–90 cm thickness. Brackish-marine molluscs such as *Melongena basilica* and *Tympanotonos margaritaceus* (Brocchi, 1814) occur throughout that unit.

### *Pirinccesme and Adnan Argan sections (Danismen Formation, Oligocene) (Fig. 5)*

The successions of the Pirinccesme (40°59′40.4″N, 26°50′15.7″E) and Adnan-Argan (40°57′10.5″N, 26°51′29.3″E) lignite mines are similar to the Tozaklı sections in the NE area.

At the about 50-m-thick Pirinccesme section the basal lignite is overlain by an 8-m-thick unit of silty sand with broad channel structures, low-angle cross-bedding and intense convolute bedding. In-situ trunks of more than 2 m height, accompanied by articulated unionids are common above the basal lignite. *Melanopsis impressa* Krauss, 1852 occurs in the middle part of that unit and *Tinnyea escheri* (Brongniart, 1823) is ubiquitous throughout. A 7-m-thick unit of an intense alternation of dm-thick lignites, lignitic clays and silty clays follows. The lignitic interval of unit C is overlain by a 10-m-thick unit of silty sand with channels and in-situ trunks, A second, about 8-m-thick clay-lignite unit, consisting of two 1.5–2-m-thick lignites with in-situ trunks and two intercalated clay intervals is topped by a final coarse siliciclastic unit (F) comprising silty sand to medium sand with channel structures and low-angle cross bedding. The entire section is rich in *Melanopsis* and *Tinnyea*

The shorter, 13-m-thick Adnan Argan section consists of dm-thick silt-clay alternations with two 1–2 m thick lignites in the base, separated by about 3 m silty clay. Macrofossils are rare aside from rather abundant *Melanopsis impressa* Krauss, 1852 shells. The topsurface of the lignites is covered with poorly preserved lymnaeids and planorbids. Moreover, rare shells of *Polymesoda subarata* (von Schlotheim, 1820) occur in the fine-sandy top unit of the succession.

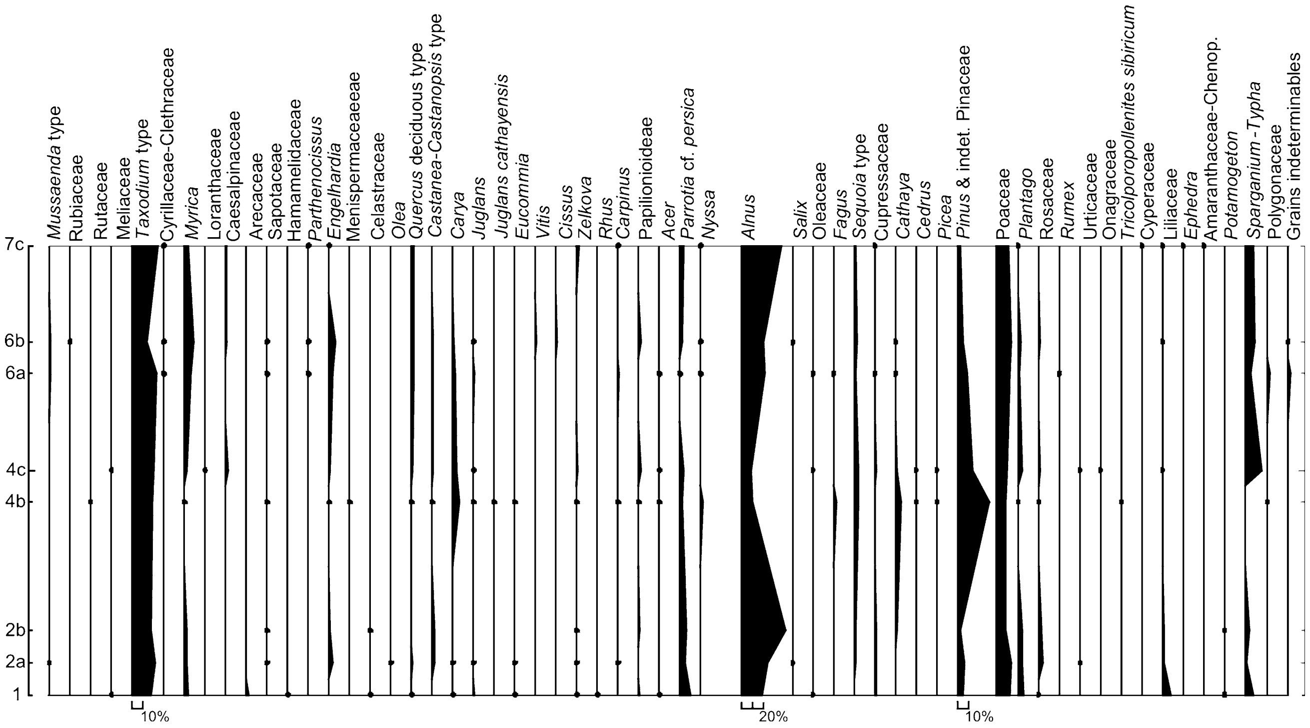


**Fig. 6** Detailed pollen diagrams of the Tozaklı A section. *Black dots* indicate percentages lower than 1%

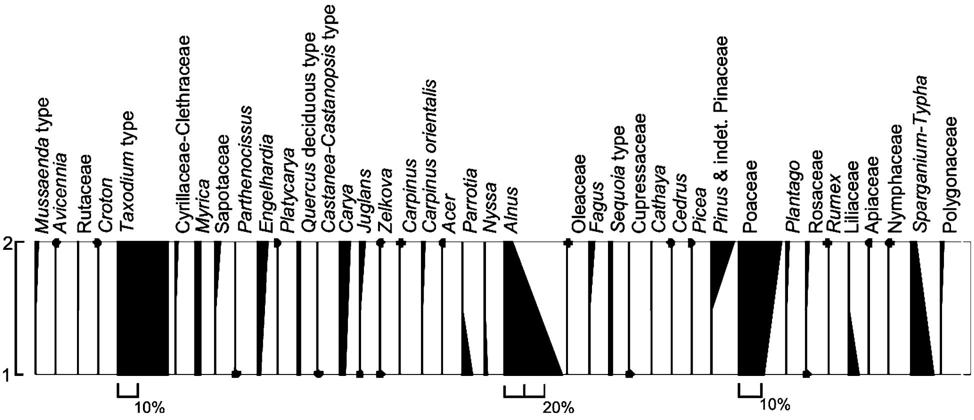


**Fig. 7** Detailed pollen diagram of the Pullukcu section. *Black dots* indicate percentages lower than 1%

## Biostratigraphy, depositional and ecological environment and paleobiogeographic affiliation

### Dolhan-Kırklareli area

The marls and limestones of Dolhan A represent the terminal Eocene depositional phase in the Thrace Basin. A Late Eocene age is deduced from the occurrence of the exclusively Eocene echinoid *Eupatagus rogeri* and the Late Eocene gastropods *Cepatia cepacaea* and *Campanile giganteum*. A Priabonian age is indicated by the foraminifera. Among the molluscs, the in situ occurrence of tubes of the burrowing bivalve *Kuphus melitensis* indicate a soft- to firm-ground habitat which suffered little disturbance by waves. Extant relatives of *Campanile giganteum* are restricted to extremely shallow, sandy nearshore environments (Houbrick 1981). The foraminiferal assemblage is characterised by sea-grass-dwelling and sessile species such as *Pararotalia armata* (d'Orbigny, 1826), *Stomatorbina toddae* Haque, 1960, *Queraltina epistominoides* Marie, 1950, *Asterigerina bimammata* (Guembel, 1868), *A. rotula*, (Kaufmann, 1867), *Eorupertia incrassata* (Uhlig, 1886), *Fabiania cassis* (Oppenheim, 1896), *Halkyardia minima* (Liebus, 1911), together with small nummulites. In the limestones encrusting forms as *Fabiania, Eorupertia, Solenomeris?* dominate. Based on the requirements of these taxa, the section is interpreted as calm and shallow back-reef lagoon with dense sea-grass meadows. The fauna represents a within-habitat-assemblage.

Based on the current outcrop situation it is unclear if the marls of Dolhan A represent the coeval, autochthonous back-reef environment of the Kırklareli reefs or if these units are separated by faults. The mollusc fauna, however, is clearly of Western Tethyan character and corresponds largely to that of the Upper Eocene Kırklareli reefal limestone in the area. The foraminiferal assemblages, mentioned above are typical for Late Eocene, as exemplified by *Nummulites chavannesi* de la Harpe, 1883 and *N. fabianii* (Prever in Fabiani, 1905). *Kuphus* is recorded from the Upper Eocene of northern Italy and Egypt (Oppenheim 1901) and *Campanile giganteum* is ubiquitous in Tethyan nearshore assemblages from the Arabian Peninsula in the east (own observation M.H.) to the London and Paris basins in the west (Cossmann and Pissarro 1911).

The contact of the siliciclastic successions of the Dolhan B, C and D sections with the Eocene marls is unclear, due to the poor outcrop situation. A strong shift in the depositional environment is obvious in respect to the absence of carbonates. *Macrocallista exintermedia* (Sacco, 1900), which is the main constituent of the coquinas, allows a correlation with Rupelian faunas of Northern Italy (cf. Sacco 1900) and Central Iran (own observation M.H.). A Rupelian or Early Chattian age is also proven by Sirel & Gündüz (1976) based on the occurrence of *Nummulites fichteli* Michelotti, 1861 and *Nummulites vascus* Joly & Leymerie, 1848 and by Saraç (2003) based on the rhinocerotid fauna. The succession of Dolhan B points to a deposition in the agitated shoreface zone where tempestites and coquinas could form. Only a small foraminiferal fauna is reported from this sequence, yielding small nummulites. Decapod crustaceans dwelled the poorly sorted sand in the very shallow sublittoral and scutellid echinoderms ploughed the sediment. The rare corals might have been transported from a patch reef in a habitat more suitable for coral growth than the represented agitated coast. Such reefoid facies of the Sogucak Formation is recorded in drillings in the north-western and easternmost part of the Thrace Basin (e.g. Sakınç 1994; Kolodziej and Marcopoulou-Diacantoni 2003). Coeval open marine conditions were established towards the east as documented by drillings (unpublished MTA reports). Upsection, as represented on Dolhan C and D, fluvial influx is increasing and fluvial channels cut into the marine shoreface sands. Intercalations of bioturbated sand within the fluvial deposits, at Dolhan D, document the transitional zone where the drainage from Stranjha Massif entered the sea.

Thus, the succession documents a gradual retreat of the shoreline in the NW Thrace Basin and the establishment of fluvial depositional environments during the Rupelian. Still, the mollusc fauna displays a Tethyan character, as indicated by *Macrocallista exintermedia* (Sacco, 1900), which is unknown from Oligocene Paratethyan deposits. Despite the change in depositional systems from Eocene coral reefs to Rupelian siliciclastics, the Thrace Basin was still part of the northern coast of the Tethys Ocean, in terms of paleogeography and paleobiogeography.

### Pınarhisar-Erenler area

The Oligocene deposits in the NE area consist of oolitic limestones which document still marine conditions and an active carbonate factory. The oolites of Erenler reflect a shallowing upward trend starting with a deeper sublittoral marine setting below wave base with marly deposition. High-energy events, such as storm events caused the transportation of ooids from the adjacent oolite shoals. Subsequently, due to a relative sea-level drop or due to the installation of high stand conditions, shallow sublittoral ooid-dunes prograded with erosive base. The high amount of well-rounded quartz pebbles coincides with an increasing input from the hinterland. Single floodings within the dune field are reflected by intercalations of marls. The mollusc assemblage with *Lenticorbula sokolovi slussarevi* (Merklin, 1974) and *Cerastoderma chersonensis* (Nossovskii, 1962) is characteristic for the Solenovian stage of the Eastern Paratethys. These species are endemics and did never occupy the Tethyan shores. Despite the marine character of the deposits, the fauna clearly documents isolation from the Tethys Ocean. Instead, the Thrace Basin became part of the Eastern Paratethys Sea and was simultaneously occupied by Eastern Paratethyan mollusc faunas. A correlation of these Solenovian faunas according to Popov et al. (2004) points to an Early Rupelian age of about 32–30 Ma corresponding to the nannoplankton zone NP 23.

After that marine Eastern Paratethyan phase, with agitated carbonate sedimentation, the depositional system changed fundamentally in the NE area of the Thrace Basin. Siliciclastic deposition and extensive lignite formation of the Danismen Formation replaced the oolite shoals. A coeval shift from carbonate to siliciclastic sedimentation is documented also from several other Paratethyan areas (Schmiedl et al. 2002). Shallow freshwater swamps with abundant *Taxodium* and *Myrica* accompanied by other riparian taxa (mainly *Alnus and Carya*) and aquatic herbs such as *Sparganium, Typha* and *Potamogeton* formed in the area of Tozaklı (Fig. 6). No marine influx is documented from that environment. Moreover, the succession at Tozaklı, documents a gradual replacement of the lentic lignite swamps by lotic environments reflected by fluvial channels and over bank deposits. The conspicuous lignite triplet, consisting of two lignite pairs each, as well as the regular silt-clay interbedding between the lignite pairs point to at least two rhythms which influenced the deposition.

The age assignment to the Late Oligocene is based on the occurrence of the anthracothere *Elomeryx borbonicus*, which is known from mammal units MP 26–27 and MN1 (Hellmund 1991). In the present context MP 26–27 seems likely, suggesting middle Chattian age corresponding to about 27–25 Ma, although a slightly younger age cannot be excluded

### Keşan-Malkara area

Marine Oligocene carbonates are missing in that area. Instead siliciclastic depositional systems with lignites prevail. Shallow marine environments alternating with brackish lagoons and mangrove swamps are indicated by the successions. Especially the Pullukcu mine documents the marine/freshwater interplay in coastal mangrove swamp. Mangrove trees are recorded by pollen of *Avicennia* and shallow freshwater swamps are indicated by the abundance of *Taxodium*, *Myrica* and other riparian plants (Fig. 7). In addition, the low diverse but extremely specimen-rich *Polymesoda-Tympanotonos* assemblages are significant for brackish mangrove swamps. Extant relatives of *Polymesoda subarata* (von Schlotheim, 1820) are typical brackish water dwellers which flourish under salinities from 0 to 10 psu (Morton 1983) and may survive short periods of marine influx as well. Modern *Polymesoda* needs water temperatures between 18 and 32°C and is most frequent on intertidal flats of estuaries, estuarine bays, oxbow lakes and especially in mangrove swamps (Morton 1983). The same environmental requirements are documented for extant *Tympanotonos* which is now restricted to the tropical part of the West-African coast (Bandel and Kowalke 1999). Similar *Polymesoda*-dominated taphocoenoses are widespread in the Oligocene and the Lower Miocene in the Central Paratethys (Baldi 1973) and in the Western Paratethys (Barthelt 1989; Reichenbacher et al. 2004) but occur also along the northern shore of the Western Tethys (Harzhauser and Kowalke 2001; Mandic et al. 2004). Dreissinid bivalves, balanids and serpulids were attached to shell hash and plant debris and roots, which are documented in numerous small lignite lenses. Floating wood was dwelled by the marine bivalve *Teredina*.

The brackish lagoons and swamps harboured abundant oligo-mesohaline ostracods such as *Cytheromorpha zinndorfi*, *Hemicyprideis istanbulensis*, *Elofsonia* sp., and *Fabaeformiscandona*? sp. Especially, *Cytheromorpha zinndorfi* occurs predominately in oligo- to polyhaline shallow marine settings (Müller 1985; Ducasse and Cahuzac 1996;

Witt 2000). *Hemicyprideis istanbulensis* is indicative for considerable salinity fluctuations within one life cycle (Keen 1971). *Fabaeformiscandona*? sp. belongs to the Candoninae which occur predominately in fresh but also in brackish (oligo- to mesohaline) waters. Phases of lignite formation seem to coincide with increasing freshwater influx as indicated by the mollusc fauna (*Melanopsis impressa* Krauss, 1852, *Lymnaea* sp., *Planorbarius* sp.). Lagoonal conditions of few metres water depth developed at Pullukcu during a short interval of elevated water tables. Infaunal filter feeding bivalves such as *Angulus* sp. and *Gari* sp. settled the muddy lagoons and marine dinocysts occur.

A further step towards continentalisation in the Keşan-Malkara area is documented by the Pirinccesme and Adnan Argan lignite mines. Only rare shells of *Polymesoda subarata* (von Schlotheim, 1820) are found in the upper parts of Pirinccesme whilst Adnan Argan lacks any marine or brackish water organisms. Moreover, an increasing amount of fluvial influence in the freshwater swamps is indicated by the abundant fluvial channels and the frequent occurrence of unionid bivalves and the gastropod *Tinnyea escheri*. Like its recent relative *Brotia*, the extinct *Tinnyea* was an exclusively fluvial freshwater dweller (Köhler and Glaubrecht 2006; Harzhauser et al. 2002a, b) which is unknown from calm lentic environments. The deposits of the Keşan-Malkara area are difficult to date. The co-occurrence of *Tympanotonos margaritaceus* (Brocchi, 1814), *Strebloceras* cf. *edwardsi* (Deshayes) and several species of *Anomalorbina* are indicative for a Rupelian age. The ostracod *Hemicyprideis istanbulensis* is also a characteristic species of the Early Oligocene. Similarly, the occurrence of *Sphenolithus capricornutus* in the brackish water deposits of Pullukcu points to the nannoplankton zones NP24/25, which roughly corresponds to an late Rupelian and Chattian age (Meulenkamp et al. 2000; Popov et al. 2004). This dating is in agreement with already existing data: Ünay-Bayraktar (1989) correlated a rodent assemblage from lignitic sandstones in the Keşan area with the MP23–27 biozones of the European mammal zonation. The associated tuffs, underlying these mammal-bearing sandstones were dated as 33.2 ± 4 Ma (Ünay-Bayraktar 1989). These data, considering the large error bar of 8 Ma, do not contradict a Late Rupelian age corresponding to the Late Solenovian of the Eastern Paratethys chronostratigraphy.

In terms of paleobiogeography, the assemblages are less indicative than those from Erenler and lack the strict Eastern Paratethys endemism. Similar assemblages are described from coeval deposits of lignite-bearing basins in Bulgaria and Georgia (Kojumdgieva and Sapundgieva 1981), Greece (Mitzopoulos 1961; Kopp et al. 1969), Romania (Moisescu 1972), Hungary (Baldi 1973) and Bavaria (Barthelt 1989; Reichenbacher et al. 2004) pointing to a predominately Paratethyan affiliation. Nevertheless, mangrove swamps in the Mesohellenic Basin display similar faunas in Rupelian times (Harzhauser 2004). Thus, this Rupelian respectively Late Solenovian brackish water mollusc fauna was quite uniform and widespread in the entire Paratethys and Tethys area.

## The paleobiogeography of the late Paleogene Thrace Basin: a synthesis

Based on the datings and lithostratigraphic position of the investigated sections a scheme of the paleobiogeographic development of the Thrace Basin can be postulated (Fig. 8). The marine phase with clear Tethyan affiliation lasted from the Eocene onwards into the Early Rupelian. The Early Oligocene flooding of the Thrace basin is reflected in the coastal sands of Dolhan. At that time, the Tethyan influence reached even further to the north-west as reflected by Tethyan mollusc faunas of the Mera Formation in the Transylvanian Basin (Moisescu 1972). This phase precedes the initial Paratethys event that is marked in the Alpine foreland basin and the Carpathian Flysch trough by the formation of long-lasting anoxic bottom conditions during the Early Rupelian (Schulz et al. 2005). The paleogeographic disconnection of the Paratethys is related to the third order sequence boundary RU2 of Hardenbol et al. (1998) at ~32 Ma. In the Dolhan-Kırklareli area of the Thrace Basin, this turnover might be indicated by the gradual retreat of the Tethys, by the take over of fluvial systems and a short phase of continentalisation.

A renewed marine transgression reached the Thrace Basin from the Eastern Paratethys during the mid-Rupelian corresponding to the Early Solenovian of the regional Eastern Paratethys chronostratigraphy. The transgression seems to correspond to the global third order sequence RU2/RU3 of Hardenbol et al. (1998). The biogeographic and paleogeographic connection is proven by the fully endemic Solenovian mollusc fauna at Erenler. The rapidly evolving and highly endemic Solenovian bivalve fauna was interpreted by Popov et al. (1985) and Nevesskaja et al. (1987) to indicate brackish water conditions. This scenario is now contradicted in the Thrace Basin by the occurrence of Solenovian oolite shoals, which require marine and carbonate oversaturated waters. No oolites have been recorded so far from the Oligocene of the Paratethys, but a peculiar Miocene phase of oolite formation occurred during the Sarmatian (Late Serravallian). Piller and Harzhauser (2005) and Latal et al. (2004) showed that the Sarmatian oolites formed in marine and partly hypersaline waters during a period of strong isolation of the Paratethys Sea. This now well-understood Sarmatian scenario might

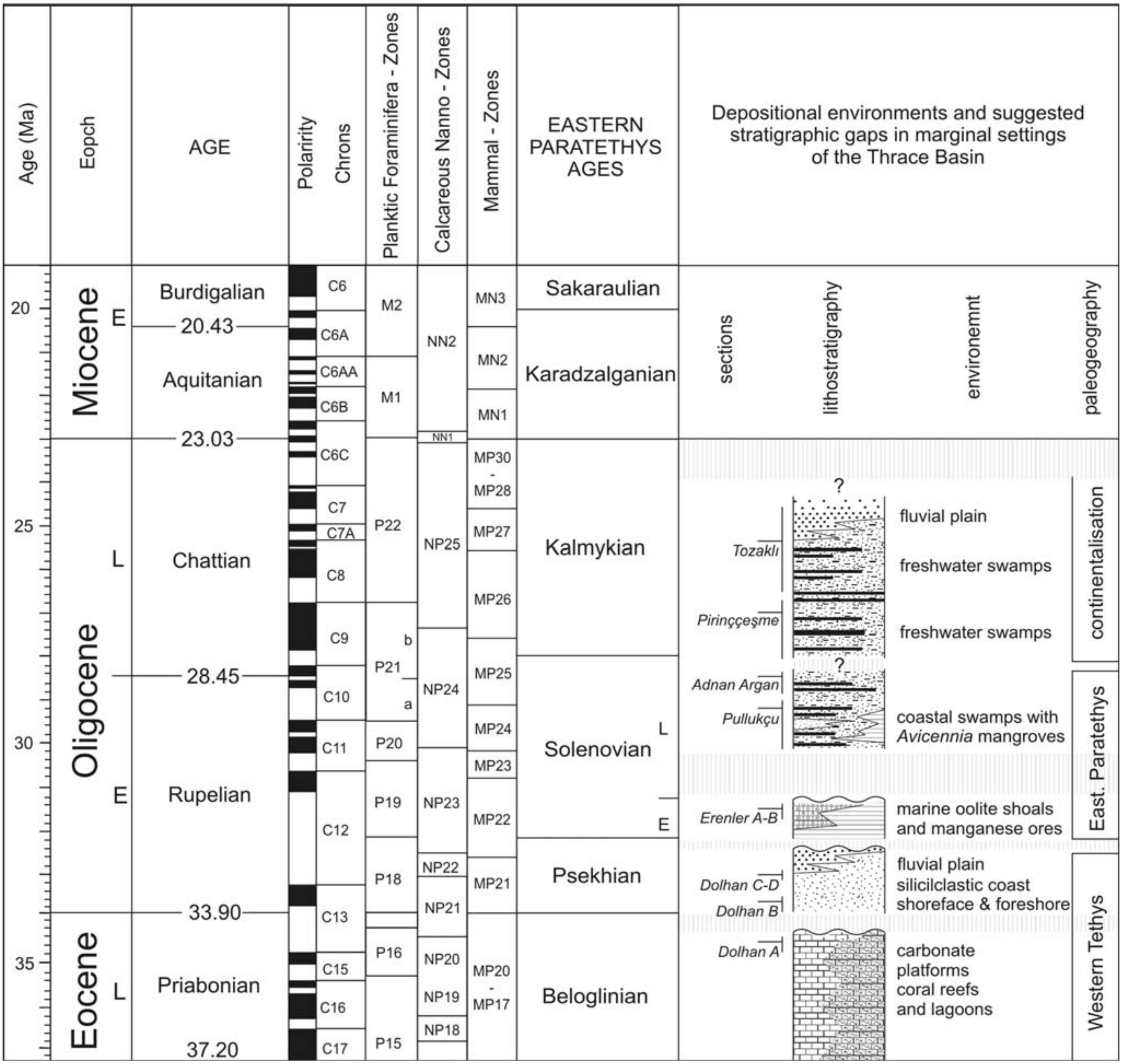


**Fig. 8** Chronostratigraphy and biozonations of the Late Eocene to Early Miocene according to Gradstein et al. (2004). The Eastern Paratethys ages are adopted from Popov et al. (2004) and Harzhauser et al. (2002b); mammal zones follow Steininger (1999) and Gradstein et al. (2004). The suggested stratigraphic position of the investigated sections, the supposed sedimentary gaps (at least in the marginal settings of the Thrace Basin), the predominant paleoenvironments and the paleogeographic affiliation are given in the right column (compare figs. 2–5 for lithologies)

thus act as model for the Solenovian oolites at least in this part of the Thrace Basin. The separation from the Western Tethys is most obvious considering the faunas of the rather close by northern coast of the Tethys. There, a belt of highly diverse tropical coral reefs reached from N-Italy, via Greece to Central Iran (Schuster 2002).

Widespread manganese ore mineralization occurred at the end of the oolite formation (Gültekin 1998), reflecting the retreat of the sea. Thus, already during the Late Solenovian (Late Rupelian) the highly agitated oolite shoals became replaced by an extended system of marine swamps as represented by the Pullukcu section. Lagoons and fringes of *Avicennia* mangroves developed in the Thrace Basin between ~30 and 28 Ma. The paleogeographic connection of these shallow marine systems is unclear; the ostracod fauna points to an Eastern Paratethyan affiliation whereas the mollusc fauna consists of widespread taxa, which occur in all marine swamps and mangrove systems of the circum-Tethyan and Paratethyan Oligocene. A strongly Eastern Paratethyan character is indicated by the dinocyst *Wetzeliella gochtii* (Batı et al. 1993), which is a zone-fossil of the Solenovian (Popov et al. 2004). The switch from carbonate factory towards coastal swamps and the increasing isolation during the Solenovian of the Thrace Basin might have been supported by the strongly oscillating and lowered global sea level during the Late Rupelian and Early Chattian (cf. Hardenbol et al. 1998).

During the Chattian, the continentalisation of the Thrace Basin was completed. Freshwater swamps replaced the marine coastal swamps at around ~27–26 Ma. The associated mollusc faunas consist exclusively of freshwater elements. The lignite mines, such as Tozaklı, display a strong rhythmicity expressed by the alternation of lignites and siliciclastics. This probably astronomic signal might help to achieve a more precise estimation of the represented time in future projects. The termination of the lignite-swamp phase is expressed by establishment of fluvial depositional environments in the upper parts of the lignite mines. No precise dating of this event is currently available, but any evidence for a continuation of sedimentation into the Miocene is missing.

This paleogeographic and paleobiogeographic affiliation of the Thrace Basin with the Eastern Paratethys after ~32 Ma contrasts most currently used paleogeographic reconstructions (e.g. Rögl 1998; Dercourt et al. 2000; Popov et al. 2004) which treat the Thrace Basin as embayment of the Eastern Mediterranean basin with poor and unclear connection to the Eastern Paratethys. Connections with the Central Paratethys, resulting in the usage of Central Paratethys regional stages in the Thrace basin, have been proposed as well (e.g. İslamoğlu and Taner 1995; Taner 1996; Sakınç et al. 1999). In contrast, Lüttig and Steffens (1976) discussed a marine connection between the Thrace Basin and the Rion-Kura area in the Lesser Caucasus depression via the Black Sea (Paratethys) during the Oligocene time.

Despite the clear paleobiogeographic affiliation, the paleogeography of the connecting gateway is unsolved. A possible connection between the Eastern Paratethys (western Black Sea Basin) and the Thrace Basin might have existed between the Balkanids in the north and the Stranjha Massif north-east.

## Conclusions

The depositional history of the Thrace Basin is an excellent archive to decipher the complex biogeographic and paleogeographic development at the Tethys-Eastern Paratethys interface. Herein, a new, threefold biostratigraphic and paleobiogeographic frame for the Oligocene Thrace Basin is proposed (Fig. 8):

1. In terms of paleobiogeography, the earliest Oligocene was a heritage of the tropical Eocene when Tethyan coral reefs structured the shallow areas of the basin (Kolodziej and Marcopoulou-Diacantoni 2003). Tethyan type molluscs, echinoderms and benthic foraminifers indicate a Western Tethyan influence. The orogeny of the Alpidic thrust belt accentuated by the glacio-eustatic regression started to structure the uniform northern Tethys area during the latest Eocene (Rögl 1998). Therefore, the emerged regions (Pontides, Lesser Caucasus, Elbruz, Kopeth Dagh regions) started to separate the Eastern Paratethys, from the Tethys Realm during the Late Eocene and the Oligocene (Rögl 1998; Meulenkamp et al. 2000; Popov et al. 2004). Although, still part of the northern coast of the Tethys, a change in depositional environments from reefal carbonates towards siliciclastic coastal systems occurred in the Thrace Basin during the Early Rupelian.
2. After a short continental phase, a renewed transgression from the north connected the basin with the young Eastern Paratethys. According to Meulenkamp et al. (2000) and Popov et al. (2004) the Solenovian was associated with overall moderately warm, humid climate conditions and an estuarine water circulation patterns. In the Thrace Basin, an active carbonate factory became established which has no counterpart along the coast of the Tethys. Marine conditions are reflected by the oolite shoals and contradict the brackish water scenario as usually proposed for the Solenovian eastern Paratethys (at least for the Thrace Basin). The manganese ore production is restricted to that Early Solenovian phase as well, whilst uranium rich and rare earth enriched deposits dominate the Late Solenovian (Stolyarov 1999; Stolyarov and Ivleva 1999; Öztürk and Frakes 1995). Such Early Solenovian sedimentary manganese ores are also known from the Varna area (NE Bulgaria), Nikopol (S Ukraine), Chiatura (West Georgia), Ciscaucasia, and the Volga-Don and Mangyshlak regions (Stolyarov and Ivleva 1999; Popov et al. 2002; 2004) pointing to a widespread Eastern Paratethyan phenomenon. Equivalents in the Central Paratethys occur in Hungary and Slovakia (Soták and Kováč 2002) but are unknown in the Tethys Realm.
3. During the Late Solenovian marine lagoons and mangrove swamps with Eastern Paratethyan affinity spread across the basin. This regressive phase was accompanied by tectonic activity and volcanism (Görür and Okay 1996; Sakınç et al. 1999; Çağlayan

and Yurtsever 1998; Turgut and Eseller 2000). During the subsequent Late Oligocene the coastal marine swamps successively graded into extended freshwater wetlands and finally into fluvial planes. Thus, the marine development in the Thrace Basin was mainly restricted to the Eocene and Early Oligocene. Most of the post-Eocene marine deposits of the Thrace Basin, variously referred to as Oligocene, Miocene and even Pliocene in the literature, have to be dated as Rupelian or Solenovian respectively. Moreover, the usage of Central Paratethyan regional stages such as Egerian, Badenian and Sarmatian in the Thrace Basin is inappropriate from the conceptual point of view.

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## References

Akartuna M (1953) Çatalca- Karacaköy jeolojisi. İstanbul Üniversitesi. Fen Fakultesi Monografileri 13:1–88

Arabu N (1913) Sur le Néogéne du nord de la mer de Marmara. C R Acad Sci Paris 157:347–349

Aslaner M (1966) Die Braunkohlen von Tozaklı-Poyralı und die Geologie der Umgebung von Pınarhisar. Bull Miner Res Explor Inst Turk 66:129–146

Baldi T (1973) Mollusc fauna of the Hungarian Upper Oligocene (Egerian). 1–511, Budapest (Akadémiai Kiadó)

Bandel K, Kowalke T (1999) Gastropod Fauna of the Cameroonian Coasts. Helgol Mar Res 53:129–140. doi:10.1007/s101520050016

Barthelt D (1989) Faziesanalyse und Untersuchungen der Sedimentationsmechanismen in der Unteren Brackwasser-Molasse Oberbayerns. Munchner Geowissenschaftliche Abh 17:1–118

Bassiouni MA (1979) Brackische und marine Ostrakoden (Cytherideinae, Hemicytherinae, Trachleberildinae) aus dem Oligozaen und Neogen der Türkei. Geol Jahrb 3:1–200

Batı Z, Erk S, Akça N (1993) Trakya havzası Tersiyer birimlerinin Palinomorf, foraminifer ve nannoplankton biyostratigrafisi. Turkish Petroleum Corporation, Report No: 1947 (unpublished)

Bellardi L (1872) I Molluschi dei Terreni Terziarii del Piemonte e della Liguria, Parte I. Mem Reale Accad Sci Torino 28:1–264

Bosquet J (1852) Description des Entomostracés fossiles des terrains Tertiaires de la France et de la Belgique. Memoires couronnes et Memoires des savants etrangers publies par l'Academie Royale des Sciences. des Lettres et des Beaux-arts de Belgique 24:1–142

Brocchi GV (1814) Conchiologia fossile subapennina con osservazioni geologiche sugli Apennini e sul suolo adiacente, Milano, pp 1–227

Brongniart A (1823) Mémoire sur les terrains de sédiment supérieur calcaréo-trappéen de Vicentin, et sur quelques terrains d'itlaie, de France, d'Allemagne, etc., qui peuvent se rapporter a la même époque. pp 1–86, Paris (Levrault)

Bukry D, Percival SF (1971) New Tertiary Calcareous Nannofossils. Tulane Stud Geol Paleontology 8:123–146

Çağlayan MA, Yurtsever A (1998) 1/ 100 000 ölçekli Türkiye Jeoloji Haritaları, Burgaz-A3, Edirne-B2 ve B3; Burgaz-A4 ve Kırklareli-B4; Kırklareli-B5 ve B6; Kırklareli-C6 paftaları, No: 20, 21, 22, 23, General Directorate of MTA, Geological Department, Ankara, pp 1–99

Cossmann AM, Pissarro G (1911) Iconographie complète des coquilles fossiles de l'Éocène des environs de Paris. Tome 2, pl. XXVI–XLV, Paris (Hermann)

Cushman JA, Bermudez PJ (1949) Some Cuban Species of Globorotalia. Contrib Cushman Lab Foraminifer Res 25:26–45

de la Harpe P (1883) Monographie der in Ägypten und der libyschen Wüste vorkommenden Nummuliten. Palaeontographica 30:155–218

de Lamarck J-BPA (1804) Suite des mèmoires sur les fossiles des environs de Paris. Ann Mus Hist Naturelle 5:179–357

Depéret C (1906) Les vertébrés de l'Oligocène Inférieur de Tarrega (Province de Lérida). Memorias Acad Cienc Artes Barc 5(21):401–451

Dercourt J, Gaetani M, Vrielynch B, Barrier E, Biju-Duval B, Brunet MF, Cadet JP, Crasquin S, Sandulescu M (2000) Atlas Peri-Tethys. Commission for the geologic maps of the world, Paris

Ducasse O, Cahuzac B (1996) Évolution de la faune d'ostracodes dans un cadre paléogéographique et interprétation des paléoenvironnements au Langhien en Aquitaine. Rev Micropaleontol 39:247–260. doi:10.1016/S0035-1598(96)90101-4

Ediger VŞ, Batı Z, Alişan C (1990) Paleopalynology and paleoecology of *Calamus*-like disulcate pollen grains. Rev Paleobotany Palynology 62:97–105. doi:10.1016/0034-6667(90)90019-F

Elsik WC, Ediger VŞ, Batı Z (1990) Fossil fungal spores: *Anatolinites* gen. nov. Palynology 14:91–104

Emre Ö, Erkal T, Tchepalyga A, Kazancı N, Keçer M, Ünay E (1998) Marmara bölgesinin Neojen–Kuvaterner'deki evrimi. Bull Miner Res Explor 120:233–258

English T (1902) Coal and Petroleum in European Turkey. Quaternary J Geol Soc Lond 58:150–162

English T (1904) Eocene and latter formations surrounding the Dardanelles. Quaternary J Geol Soc Lond 60:1–242

Gervais P (1849) Recherches sur les mammifères fossiles des genres *Palaeotherium* et *Lophiodon* et sur les autres animaux de la même classe que l'on a trouvé avec eux dans le midi de la France. Comptes Rendus de l'Académie des Sciences 29(381–384):568–579

Gervais P (1852) Zoologie et paléontologie française (animaux vertébrés). (A. Bertrand), Paris, 1–271

Gökçen N (1973) Pınarhisar formasyonunun yaşı ve ortamsal şartlarında görülen yanal değişimler (kuzey-uzeydoğu Trakya): Cumhuriyetin 50. Yılı Yerbilimleri Kongresi Tebliğleri, MTA Genel Müdürlüğü, Ankara, pp 128–143

Görür N, Okay AI (1996) A fore-arc origin for the Thrace basin, NW Turkey. Geol Rundsch 85:662–668. doi:10.1007/BF02440103

Gradstein FM, Ogg JG, Smith AG (2004) A geologic time scale 2004. (Cambridge University. Press), Cambridge, pp XIX + 1–589

Gültekin AH (1998) Geochemistry and origin of the Oligocene Binkılıç Manganese deposits; Thrace basin, Turkey. Turk J Earth Sci 7:11–24

Guembel CW (1868) Beiträge zur Foraminiferenfauna der nordalpinen älteren Eocängebilde oder der Kressenberge Nummulitenschichten. Abhandlungen der k. bayerischen Akademie der Wissenschaften, II. Classe 10:581–730

Hantken M (1875) A Cavulina szabói rétecek faunája. I. Rész. Foraminiferák. A Magyar Kir. Foldtani Intezet Erkonyve 4:1–82

Haque AFMM (1960) Some middle to late Eocene smaller foraminifera from the Sor Range, Quetta District, West Pakistan. Memoirs. Palaeontologica Pakistanica 2:1–79

Hardenbol J, Thierry J, Farley MB, Jacquin T, Graciansky P-C, Vail PR (1998) Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins. In: Graciansky C-P, Hardenbol J, Jacquin T, Vail PR (eds) Mesozoic and cenozoic sequence stratigraphy of European basins. SEPM, Special Publications 60:3–13

Harzhauser M (2004) Oligocene Gastropod Faunas of the Eastern Mediterranean (Mesohellenic Trough/Greece and Esfahan-Sirjan Basin/Central Iran). Courier Forschungsinstitut Senckenberg 248:93–181

Harzhauser M, Kowalke T (2001) Early Miocene brackish-water Mollusca from the Eastern Mediterranean and from the Central Paratethys—a faunistic and ecological comparison by selected faunas. J Czech Geol Soc 46:353–374

Harzhauser M, Kowalke T, Mandic O (2002a) Late Miocene (Pannonian) Gastropods of Lake Pannon with Special Emphasis on Early Ontogenetic Development. Annalen Naturhistorischen Museums Wien 103:75–141

Harzhauser M, Piller WE, Steininger FF (2002b) Circum-Mediterranean Oligo-Miocene biogeographic evolution—the gastropods' point of view. Palaeogeogr Palaeoclimatol Palaeoecol 183:103–133. doi:10.1016/S0031-0182(01)00464-3

Hellmund M (1991) Revision der europäischen Spezies der Gattung *Elomeryx* Marsh, 1894 (Anthracotheriidae, Artiodactyla, Mammalia)—odontologische Untersuchungen. Palaeontographica A 220:1–101

Hochstetter F (1872) Die geologischen Verhältnisse des östlichen Teiles der europäischen Türkei. Jahrb Geologische Reichsanstalt 20:23–46

Houbrick RS (1981) Anatomy, biology and systematics of *Campanile symbolicum* with reference to adaptive radiation of the Cerithiacea (Gastropoda: Prosobranchia). Malacologia 21:263–289

Howe HV (1930) Distinctive New Species of Foraminifera from the Oligocene of Mississippi. J Paleontol 4(4):327–331

İslamoğlu Y (2008) Middle Pleistocene bivalves of the Iznik lake basin (Eastern Marmara, NW Turkey) and a new paleobiogeographical approach. Int J Earth Sci (Geol Rundsch). doi:10.1007/s00531-008-0344-x

İslamoğlu Y, Kazancı N, Emre Ö, Alçiçek C (2001) Karangatian (= Early Upper Pleistocene) molluscan fauna from Yalova region and its paleoecologic features (NW Turkey). Fourth International Turkish Geology Symposium, 2001, Adana: 129

İslamoğlu Y, Taner G (1995) Pınarhisar (Trakya) ve çevresinin mollusk faunası ile Tersiyer stratigrafisi. Bull Miner Res Explor Inst 117:149–169

İslamoğlu Y, Tchepalyga AL (1998) Paleoenvironmental changes established by molluscan fauna of Marmara Sea during Neoeuxinian-Holocene. Geol Bull Turk 41:55–62

Joly N, Leymerie A (1848) Memoire sur les Nummulites considerees zoologiquement et geoiogiquement. Académie royale des Inscriptions et Belles-Lettres. Mem Toulouse 3:149–218

Kasar S, Eren AA (1986) Kırklareli—Saray—Kıyıköy bölgesinin jeolojisi. Turkish Petroleum Corporation, Report No: 2208 (unpublished)

Kaufmann FJ (1867) Geologische Beschreibung des Pilatus. Beiträge zur geologischen Karte der Schweiz 5:1–169

Keen MC (1971) A palaeoecological study of the ostracod *Hemicyprideis montosa* (Jones & Sherborn) from the Sannoisian of NW Europe. Bulletin du Centre de Recherches. Pau-Societe Nationale Petroles Aquitaine Supplement 5:523–543

Keskin C (1974) Kuzey Ergene havzasının stratigrafisi: Türkiye 2. Petrol Kongresi Tebliğleri, Ankara, pp 137–163

Köhler F, Glaubrecht M (2006) A systematic revision of the Southeast Asian freshwater gastropod *Brotia* (Cerithioidea: Pachychilidae). Malacologia 48:159–251

Kojumdgieva E, Dikova P (1980) Paleogene sediments of Borehole R-1, Svilengrad. Geologica Balcanica 10:107–110

Kojumdgieva E, Sapundgieva V (1981) Biostratigraphie de l'Oligocéne du bassin de la Haute d'aprés les mollusques. Geologica Balcanica 11:93–114

Kolodziej B, Marcopoulou-Diacantoni A (2003) Late Eocene-Oligocene corals from Evros (Thrace basin, NE Greece). Ber Instituts Geologie Palaontologie Graz 7:3–7

Kopp KO (1961) Geologie Thrakiens I: Beschreibung und Vergleich intramontaner Tertiärsenken beiderseits des Marmara-Meeres. Neues Jahrbuch Mineralogie, Paläontologie. Geologie 112:325–382

Kopp KO, Pavini N, Schindler C (1969) Geologie Thrakiens IV: Das Ergene-Becken. Beih Geologischen Jahrb 76:1–171

Krauss F (1852) Die Mollusken der Tertiär-Formation von Kirchberg an der Iller. Jahreshefte des Vereins für vaterländische Naturkunde in Württemberg 8:136–157

Latal C, Piller WE, Harzhauser M (2004) Paleoenvironmental Reconstruction by stable isotopes of Middle Miocene Gastropods of the Central Paratethys. Palaeogeogr Palaeoclimatol Palaeoecol 211:157–169

Lebküchner RF (1974) Orta Trakya Oligosen'inin jeolojisi hakkında. Bull Miner Res Explor Inst Turk 83:1–29

Liebus A (1911) Die Foraminiferenfauna der mitteleocänen Mergel von Norddalmatien. Sitzungsberichte der k.k. Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Classe 120:865–956

Lienenklaus E (1900) Die Tertiaer-Ostrakoden des mittleren Norddeutschlands. Z Dtsch Geol Ges 52:497–550

Lienenklaus E (1905) Die Ostrakoden des Mainzer Tertiaerbeckens. Bericht Senckenbergischen Naturforschenden Ges 1905:3–74

Lüttig G, Steffens P (1976) Explanatory notes for the paleogeographic atlas of Turkey from the Oligocene to the Pleistocene. Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, pp 1–64

van der Made J (1999) Superfamily Hippopotamoidea. In: Rössner GE, Heissig K (eds) The Miocene Land Mammals of Europe, München: 203–208 (Pfeil)

Mandic O, Harzhauser M, Roetzel R (2004) Taphonomy of spectacular shell accumulations from the type stratum of the Central Paratethys stage Eggenburgian (Early Miocene, NE Austria). Courier Forschungsinstitut Senckenberg 246:69–88

Marie P (1950) *Queraltina*, nouveau genre de foraminifere de l'Eocene pyreneen. Bull Soc Geol Fr 5(20):73–98

Merklin RL (1974) Handbook of Oligocene bivalvia of the south of the USSR. Trans Paleontolo Inst 145:1–189

Meulenkamp JE, Sissingh W, Londeix L, Chahuzac B, Calvo JP, Daams R, Studencka B, Kovac M, Nagymarosy A, Rusu A, Badescu D, Popov SV, Scherba IG, Roger J, Platel JP, Hirsch F, Sadek A, Abdel-Gawad GI, Yaich C, Ben Ismail-Lattrache K, Bouaziz S (2000) Late Rupelian (32 – 29 Ma). In: Dercourt J, Gaetani M, Vrielynck B, Barrier E, Biju-Duval B, Brunet MF, Cadet JP, Crasquin S, Sandulescu M (eds) Peri-Tethys Atlas, Paleogeographic maps with explanatory notes, pp171–178, Paris

Michelotti G (1841) Saggio storico dei rizopodi caratteristici dei terreni sopracretacei. Mem Societate Ital 22:253–302

Michelotti G (1861) Études sur le Miocène inférieur de l'Italie septentrionale. Mémoire publié par la Société Hollandaise des Sciences 15:1–183

Mitzopoulos MK (1961) Fund einer brackischen Molluskenfaunula oberoligozänen Alters in Westthrakien (Griechenland). Praktica Akademia Athen 36:324–332

Moisescu V (1972) Mollusques et echinids Stampiens et Egeriens de la region de Cluj-Huedin-Romanasi (Nord-Ouest de la Transylvanie. Inst Geologique Mem 16:1–152

Morton B (1983) Mangrove Bivalves. In: Russell-Hunter WD (ed) The Mollusca 6: 77–138, Accademic Press, Orlando

Müller D (1985) Biostratigraphische Untersuchungen in der subalpinen Unteren Süßwassermolasse zwischen Inn und Lech anhand von Ostrakoden. Palaeontographica A 187:1–57

Nevesskaja LA, Goncharova IA, Iljina LB, Paramonova NP, Popov SV, Voronina AA, Chepalyga AL, Babak EV (1987) History of the Paratethys. Ann Instituti Geologici Publici Hungarici 70:337–342

Nikolov J, Heissig K (1985) Fossile Säugetiere aus dem Obereozän und Unteroligozän Bulgariens und ihre Bedeutung für die Paläogeographie. Mitteilungen der Bayerischen Staatssammlung für Paläontologie und historische Geologie 25:61–79

Nossovskii MF (1962) Plastincatozabernie korbulevich sloev oligocena pricernomorskoj vpadini. Palaeontological J 1962:29–39

Oppenheim P (1896) Das Alttertiär der Colli Berici in Venetien, die Stellung der Schichten von Priabona und die oligocäne Transgression im alpinene europa. Z Dtsch Geol Ges 48:27–152

Oppenheim P (1901) Die Priabonaschichten und ihre Fauna im Zusammenhange mit gleichalterigen und analogen Ablagerungen. Palaeontographica 47:1–348

d' Orbigny A (1826) Tableau methodique de la classe des Cephalopodes. Annales de Sciences naturelles 7:96–314

d' Orbigny A 1850 Prodrome de paleontology stratigraphique universelle des animaux mollusques et rayonnes. 1: 1–392, 2: 1–427 (V. Masson) Paris

Öztürk H, Frakes LA (1995) Sedimentation and diagenesis of an Oligocene manganese deposit in a shallow subbasin of the Paratethys: Thrace basin, Turkey. Ore Geol Rev 10:117–132. doi:10.1016/0169-1368(95)00010-0

Pamir HN, Sayar AM (1933) Vértébrés Fossiles de Küçükçekmece. Bull Faculte Sci Universite Istanbul 8:1–119

Pamir HN, Baykal F (1947) Istranca Masifi'nin jeolojik yapısı. Turk Geol Soc Bull 1(1):7–26

Piller WE, Harzhauser M (2005) The Myth of the Brackish Sarmatian Sea. Terra Nova 17:450–455. doi:10.1111/j.1365-3121.2005.00632.x

Pinar N (1951) Sur les oursins de l'Éocène moyen de Çalalca-Karacaköy (Trakkya, Turquie). Bulletin de la Société Géologique de France (Série 6) 1:35–54

Popov SV, Iliana LB, Nikolayeva IA (1985) Molluscs and ostracodes of the Oligocene Solenovisky Horizon in Eastern Paratethys. Paleontological J 1:28–41

Popov SV, Akhmetev MA, Zaporozhets NI, Voronina AA, Stolyarov AS (1993) Evolution of Eastern Paratethys in the late Eocene-early Miocene. Stratigr Geol Correl 1:10–39

Popov SV, Akhmetiev MA, Bugrova EM, Lopatin AV, Amitrov OV, Andreyeva-Grigorovich AS, Zaporozhets NI, Zherikhin VV, Krasheninnikov VA, Nikolaeva IA, Sytcevskaya EK, Shcherba IG (2002) Biogeography of the Northern Peri-Tethys from the Late Eocene to the Early Miocene, Part 2. Early Oligocene. Paleontological J 36:185–259

Popov SV, Rögl F, Rozanov AY, Steininger FF, Scherba IG, Kovac M (2004) Lithological-Paleogeographic maps of the Paratethys (10 maps Late Eocene to Pliocene). Courier Forschungsinstitut Senckenberg 250:1–46

Reichenbacher B, Uhlig U, Kowalke T, Bassler B, Matzke-Karasz R, Schenk B (2004) Biota, palaeoenvironments and biostratigraphy of continental Oligocene deposits from the South German Molasse basin (Penzberg Syncline). Palaeontology 47(3):639–677. doi:10.1111/j.0031-0239.2004.00375.x

Reuss AE (1851) Ueber die fossilen Foraminiferen und Entomostraceen der Septarientone der Umgegend von Berlin. Z Dtsch Geol Ges 3:49–92

Reuss AE (1853) Ueber einige Foraminiferen, Bryozoen und Entomostrazeen des Mainzer Beckens. Neues Jahrbuch fuer Mineralogie, Geognosie. Geologie Petrefaktenkunde 1853:670–679

Rögl F (1998) Paleogeographic considerations for Mediterranean and Paratethys Seaways (Oligocene–Miocene). Annalen Naturhistorischen Museums Wien 99:279–310

Rückert-Ülkümen N (1960) Trakya ve Çanakkale mıntıkalarında bulunan Neojen balıklı formasyonları hakkında. İstanubl Üniversitesi. Fen Fakultesi Monografileri 16:1–80

Sacco F (1900) I Molluschi dei terreni terziarii del Piemonte e della Liguria. Parte XXVIII. Mem Reale Accad Sci Torino 1900:1–70

Sakınç M (1994) Karaburun (Istanbul) denizel Oligosen'in stratgirafisi ve paleontolojisi. Bull Miner Res Explor Inst 116:9–14

Sakınç M, Yaltırak C (1997) Güney Trakya sahillerinin denizel Pleyistosen çökelleri ve paleocoğrafyası. MTA Derg 119:43–62

Sakınç M, Yaltırak C, Oktay FY (1999) Palaeogeographic evolution of the Thrace Neogene Basin and the Tethys-Paratethys relations at northwestern Turkey (Thrace). Palaeogeogr Palaeoclimatol Palaeoecol 153:17–40. doi:10.1016/S0031-0182(99)00071-1

Saraç G (2003) Discovery of *Protaceratherium albigense* (Rhinocerotidae, Mammalia) in Oligocene coastal deposits of Turkish Thrace. Deinsea 10:509–517

Sayar C (1987) İstanbul ve çevresi Neojen çökelleri ve Paratetis içindeki konumu. Maden Fakultesi 40:250–266

Schulz H-M, Bechtel A, Sachsenhofer RF (2005) The birth of the Paratethys during the Early Oligocene: From Tethys to an ancient Black Sea analogue? Global Planet Change 49:163–176. doi:10.1016/j.gloplacha.2005.07.001

Schuster F (2002) Taxonomy of Oligocene to Early Miocene scleractinian corals from Iran, Egypt, Turkey, and Greece. Courier Forschungsinstitut Senckenberg 239:1–3

Schmiedl G, Scherbacher M, Bruch A, Hemleben C, Jelen B, Mosbrugger V, Nebelsick J, Rifelj H (2002) Paleoenovironmental evolution of the Paratethys in the eastern Alpine region during the late Paleogene. Int J Earth Sci 91:123–132. doi:10.1007/s005310000118

Schwager C (1883) Die Foraminiferen aus den Eocaenablagerungen der libyschen Wüste und Aegyptens. Beiträge zur Naturgeschichte der Vorzeit 30(3), Palaeontologischer Theil. Abtheilung 1:81–153

Sirel E, Gündüz H (1976) Kırklareli yöresi (Kuzey Trakya) denizel Oligosen'inin stratigrafisi ve *Nummulites* türleri. Türkiye Jeoloji kurumu Bülteni 19:155–158

Soták J, Kováč M (2002) In paleogeographic changes of the Western Carpathian Paleogene Basins in time of Paratethyan separation. Proceedings of XVII. Congress of Carpathian-Balkan Geological Association Bratislava. Geologica Carpathica 53:51–56

Stchepinsky A (1960) Étude des ostracodes du Sannoisien de l'Alsace. Bull Serv Carte Geol Alsace Lorraine 13:11–33

Steininger F (1999) Chronostratigraphy, Geochronology and Biochronology of the Miocene "European Land Mammal Mega-Zones" (ELMMZ) and the Miocene "Mammal-Zones (MN-Zones)". In: Rössner G, Heissig G (eds) The Miocene Land Mammals of Europe, pp 9–24, München (F. Pfeil)

Stolyarov AS (1999) Solenovian Rocks of the Lower Oligocene in the Ciscaucasia, Volga-Don, and Mangyshlak Regions (Central Part of the Eastern Paratethys): Communication 2. Facial-Paleogeographic Deposition Environments. Lithology Miner Resour 36:370–380

Stolyarov AS, Ivleva EI (1999) Solenovian Rocks of the Lower Oligocene in the Ciscaucasia, Volga-Don, and Mangyshlak Regions (Central Part of the Eastern Paratethys): Communication 1. Main Lithological and Structural Features. Lithology Miner Resour 34:259–276

Sümengen M, Terlemez İ, Şentürk K, Karaköse C, Erkan E, Ünay E, Gürbüz M, Atalay Z (1987) Gelibolu yarımadası ve güneybatı Trakya Tersiyer havzasının stratigrafisi, sedimantolojisi ve tektoniği. General Directorate of Mineral Research and Exploration, Report No: 8128 (unpublished)

Taner G (1996) Batı Trakya havzasının Egeriyen mollusk faunası. Bull Turk Assoc Petrol Geol 8:66–81

Taşman CE (1938) A geologic synopsis and status of oil exploration Sic 7 in Thrace. Miner Res Explor Inst 3:18–19

Terquem M (1882) Les foraminifers de l'Eocene des environs de Paris. Memoires de la Societe Geologique de France 3(2):1–193

Turgut S, Eseller G (2000) Sequence stratigraphy, tectonics and depositional history in eastern Thrace Basin, NW Turkey. Mar Pet Geol 17:61–100. doi:10.1016/S0264-8172(99)00015-X

Turgut S, Türkaslan M, Perinçek D (1991) Evolution of the Thrace sedimentary basin and its hydrocarbon prospectivity. In: Spencer AM (ed) Generation, accumulation, and production of Europe's hydrocarbons, Oxford University Press, pp 415–437

Uhlig V (1886) Über eine Mikrofauna aus dem Alttertiär de westgalizischen karpathen. Jahrbuch der k.k. geologischen Reichsanstalt 1882:71–72

Ünay-Bayraktar E (1989) Rodents from the middle Oligocene of Turkish Thrace. Ütrecht Micropaleontological Bulletins. Spec Publ 5:1–97

Üşümezsoy Ş, Öztunalı Ö (1981) Istranca ve Eybek masiflerinde kataklastik dokunun evrimi. İstanbul Üniversitesi Yerbilimleri 2:3–4

von Schlotheim EF (1820) Die Petrefactenkunde auf ihrem jetzigen Standpunkte durch die Beschreibung seiner Sammlung versteinerter und fossiler Überreste des Thier- und Pflanzenreichs der Vorwelt erläutert, 1–437, Gotha (Beckersche Buchhandlung)

Witt W (2000) Süßwasserostracoden der miozänen Vorlandmolasse Süddeutschlands. Mitteilungen der Bayerischen Staatssammlung für Paläontologie und historische Geologie 40:109–151

Zammit-Maempel G (1993) *Kuphus melitensis*, a new teredinid bivalve from the late Oligocene Lower Coralline Limestone of Malta. Contrib Tert Quarternary Geol 30(3–4):155–175

Zattin M, Okay AI, Cavazza W (2005) Fission-track evidence for late Oligocene and mid Miocene activity along the North Anatolian Fault in south-western Thrace. Terra Nova 17:95–101. doi: 10.1111/j.1365-3121.2004.00583.x