Molluscan biostratigraphy and paleoenvironmental reconstruction of Oligocene deposits in the Denizli and Kale-Tavas subbasins (SW Turkey)

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ABSTRACT
This paper deals with Oligocene molluscan biostratigraphy of the Denizli and Kale-Tavas subbasins. A total of seven stratigraphic sections have been logged and lagoonal and brackish-shallow marine molluscs (11 gastropod and seven bivalve species) have been sampled. The molluscan fauna indicates the Rupelian age by the presence of characteristic species: for gastropods *Haustator conofasciata* (Sacco, 1895), *Ampullinopsis crassatina* (Lamarck, 1804), *Tympanotonos trochlearispina* (Sacco, 1895) and *Tympanotonos conjunctoturris* (Sacco, 1895) and for bivalves *Pycnodonte gigantica callifera* (Lamarck, 1819) and *Gari* cf. *protracta* (Mayer-Eymar, 1893). These sections also contain typical Oligocene benthic foraminifer and coral fossils which are characteristic for the whole Tethys Province. The corals (*Glyphastraea laxelamellata* (Michelotti, 1838), *Siderastrea* (*Siderofungia*) *morloti* (Reuss, 1868), *Antiguastraea alveolaris* (Catullo, 1856), *Astrocoenia bodellei* (Calmus, 1973)) represent the Rupelian-Chattian age and the occurrence of the benthic foraminifer *Nephrolepidina partita* Douvillé, 1911, indicates SB22 biozone (late Rupelian-early Chattian). Therefore, both two groups support our age attribution. Litho- and biostratigraphic correlation of the sections points out that Oligocene lagoonal-marine deposits of the Denizli and Kale-Tavas subbasins (Sağdere and Mortuma Formations respectively) are assigned to late Rupelian-early Chattian. Paleobiogeographically, the distribution of the molluscan species suggests that the studied region belongs to the Mediterranean-Iranian Province.

KEY WORDS
Oligocene,
Mollusca,
biostratigraphy,
paleoecology,
paleoenvironments,
paleobiogeography,
SW Turkey,
Mediterranean-Iranian
Province.

RÉSUMÉ

Biostratigraphie des mollusques et paléoenvironnements des formations oligocènes dans les sous-bassins de Denizli et de Kale-Tavas (SW Turquie).

Cet article traite de la biostratigraphie à partir des mollusques des formations oligocènes des sous-bassins de Denizli et Kale-Tavas (SW Turquie). Sept coupes stratigraphiques ont été échantillonnées et 11 espèces de gastéropodes et sept de bivalves, représentatives des mers peu profondes à lagunaires saumâtres, ont été récoltées. La faune de mollusques indique le Rupélien par la présence d'espèces caractéristiques : pour les gastéropodes *Haustator conofasciata* (Sacco, 1895), *Ampullinopsis crassatina* (Lamarck, 1804), *Tympanotonos trochlearispina* (Sacco, 1895) et *Tympanotonos conjunctoturris* (Sacco, 1895), et pour les bivalves *Pycnodonte gigantica callifera* (Lamarck, 1819) et *Gari* cf. *protracta* (Mayer-Eymar, 1893). Ces coupes stratigraphiques contiennent également des foraminifères benthiques et des coraux typiques de l'Oligocene, leur présence étant caractéristique de la province téthysienne. Les coraux (*Glyphastraea laxelamellata* (Michelotti, 1838), *Siderastrea* (*Siderofungia*) *morloti* (Reuss, 1868), *Antiguastraea alveolaris* (Catullo, 1856) et *Astrocoenia bodellei* (Calmus, 1973)) indiquent un âge rupélien-chattien. La présence du foraminifère benthique *Nephrolepidina partita* Douvillé, 1911 indique la biozone SB22 (Rupélien supérieur-Chattien inférieur). En résumé, les âges induits par les trois groupes sont cohérents pour affirmer que les formations étudiées sont d'âge oligocène. La corrélation litho- et biostratigraphique des coupes échantillonnées montre que les dépôts marins-lagunaires des sous-bassins de Denizli et Kale-Tavas (respectivement les formations de Sağdere et Mortuma) sont d'âge Rupelien supérieur-Chattien inférieur. Du point de vue de la paléobiogéographie, la distribution spatiale des espèces de mollusques reconnues suggère que la région étudiée appartient à la sous-province de Méditerranée-iranienne.

MOTS CLÉS
Oligocène,
mollusques,
biostratigraphie,
paléoécologie,
paléoenvironnements,
paléobiogéographie,
SW Turquie,
sous-province de
Méditerranée-iranienne.

INTRODUCTION

In southwestern Anatolia, Oligo-Miocene deposits are mapped in the Denizli, Kale-Tavas and Çardak-Dazkırı molasse subbasins which are altogether included in the Lycian molasse (Sözbilir 2005). They are located around Denizli city along the tectonic contact between the Menderes massive and the Lycian nappes (Fig. 1).

The Oligocene units of these basins consist essentially of clastic rocks deposited in terrestrial and marine environments and are rich in invertebrate fossils. However, their Oligocene age is still controversial. In previous studies, based on the lithological resemblances and some fossil finds, these units have been dated with a range from Eocene to Miocene (Altınlı 1954, 1955; Nebert 1956, 1961; Dizer 1962; Erentöz & Öztemür 1964; Bering 1967; Becker-Platen 1970; Benda 1971; Erişen 1971; Becker-Platen *et al.* 1977; Konak *et al.* 1986; Hakyemez 1989; Akgün & Sözbilir 2001). The mollusc fauna is scarce and poorly studied. Nebert (1956, 1961) reported middle Eocene gastropods from the Acıdere region (Denizli molasse) and distinguished a separate flysch unit there. Becke-Platen (1970) studied Cenozoic deposits of SW Anatolia and assigned an Oligocene-Burdigalian age to the Acıgöl molasse. Konak *et al.* (1986) named this unit "Bayıralan Formation" and suggested a late Oligocene-early Miocene age based on bivalves and gastropods. Erentöz & Öztemür (1964) described marine molluscs from the Çukurköy region in the Kale-Tavas subbasin and stated that these molasse

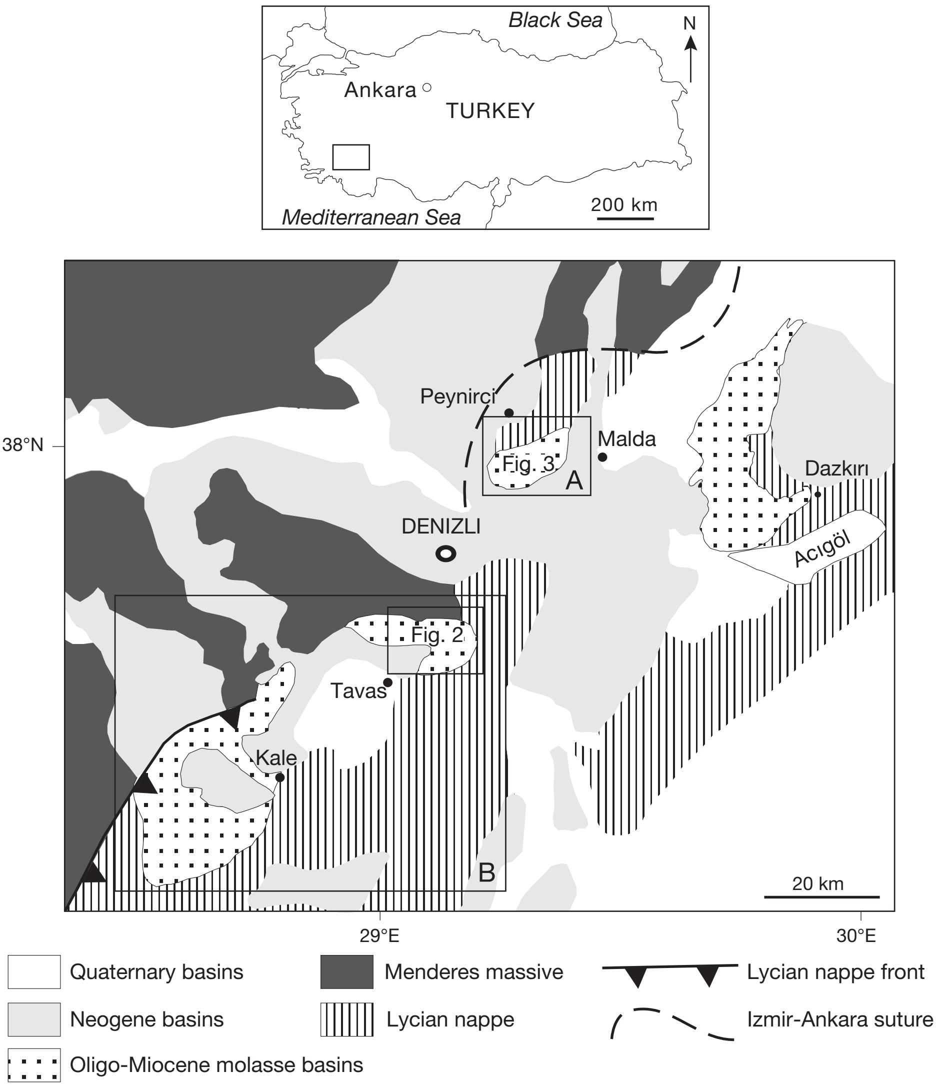

FIG. 1. — Molasse subbasins and main geological units in Denizli region (Turkey): **A**, Denizli; **B**, Kale-Tavas (simplified from Şengör & Yılmaz 1981; Şengör *et al.* 1985; Konak *et al.* 1986; Seyitoğlu & Scott 1996; Akgün & Sözbilir 2001; Sözbilir 2005).

deposits are Oligocene in age. Hakyemez (1989) called these sediments "Mortuma Formation" and dated them to the late Oligocene based on gastropods and pollen. A more recent biostratigraphic approach tried to explain the Oligo-Miocene history of the Denizli and Kale-Tavas molasse basins by using palynological data (Akgün & Sözbilir 2001). According to these authors, the Denizli molasse subbasin includes Chattian-Aquitanian brackish-marine units (Çaykavuştu and Sağdere Formations) whereas the Karadere and Mortuma Formations of the Kale-Tavas molasse subbasin consist only of Chattian deposits. All these previous biochronologic age assignments and environmental interpretations need to be completed by additional studies and more detailed information on the fossil content of related stratigraphic units.

The main objective of the present work is to explain the depositional history of the marine-brackish Oligocene units in the Denizli and Kale-Tavas molasse subbasins (SW Anatolia) based on the correlation of the measured sections and their fossil contents. Besides molluscs, benthic foraminifers, corals and ostracods are also taken into account for stratigraphic correlations. All figured molluscan specimens are deposited in the Natural History Museum of Vienna (NHMW). The rest of the collection is in the repository of the Geological Research Department of the General Directorate of Mineral Research and Exploration (MTA, Ankara).

GEOLOGICAL SETTING

Pre-Oligocene rocks

The main basement structures surrounding the studied area are the Paleozoic-Mesozoic rocks of the Menderes massif and the Triassic-Upper Cretaceous Lycian nappes. The Oligocene molasse basins are settled on these rocks and also contain Neogene and Quaternary deposits (Şengör & Yılmaz 1981; Şengör *et al.* 1985; Konak *et al.* 1986; Seyitoğlu & Scott 1996; Akgün & Sözbilir 2001; Sözbilir 2005) (Fig. 1). Sözbilir (2005) included the Oligo-Miocene basins of the Denizli area in the Lycian molasse which is a NE-SW-oriented sedimentary complex. According to this view, the Lycian molasse basins of SW Turkey have developed on an imbricated basement, comprising the allochthonous Mesozoic rocks of the Lycian nappes and Paleocene-Eocene supra-allochthonous sediments.

Oligocene rocks

The Oligocene deposits in the Denizli region occur along the tectonic contacts between the Menderes massive and the Lycian nappes (Fig. 1). The molasse sediments of SW Anatolia have been intensively studied because of their importance for regional tectonics. However, interpretations on their origin and timing remain controversial. It is suggested that molasse deposits of soutwestern Anatolia developed during post-orogenic tectonic activities such as compression, streching and uplifting (Koçyiğit 1984). Seyitoğlu & Scott (1996) proposed that Late Cenozoic N-S extensional tectonics in western Turkey began in the latest Oligocene-early Miocene (*c.* 23.5-20 Ma) and have been related to the spreading and thinning of an over-thickened crust (i.e. orogenic collapse) created by an earlier Palaeogene (*c.* 65-23.5 Ma) compressional regime.

According to another idea, the formation of Oligo-Miocene molasse basins (Lycian molasse) is related to the emplacement of different tectonic units from Late Cretaceous to late Eocene (Sözbilir 2005). Following imbrication, the extensional collapse of the Lycian orogen resulted in extensive emergent areas surrounded by interconnected depressions of the Kale-Tavas, Çardak-Dazkırı and Denizli molasse subbasins (Sözbilir 2005). Most recent studies proposed a crustal shortening during Oligocene and an extensional phase during late Miocene (Westaway *et al.* 2005; Westaway 2006).

Kale-Tavas subbasin

The Kale-Tavas subbasin is located between Kale and Tavas towns, SW Denizli city (Fig. 1). The Oligocene-early Miocene terrestrial and marine sediments are named Akçay group (Hakyemez 1989; Akgün & Sözbilir 2001). The Akçay group is divided in five formations: Karadere, Mortuma, Yenidere, Kale and Künar Formations (Hakyemez 1989). Among the Oligocene units, the Karadere Formation is terrestrial while the Mortuma Formation is composed of terrestrial, lagoonal, deltaic and shallow marine deposits (Hakyemez 1989; Akgün & Sözbilir 2001). The Mortuma Formation is overlain unconformably by the Yenidere Formation which has been dated as Aquitanian based on molluscs, ostracods, benthic foraminifers, corals and palynomorph assemblages (Hakyemez 1989; Akgün & Sözbilir 2001; İslamoğlu *et al.* 2005, 2007). The Kale Formation rests conformably on the Yenidere Formation and includes marine benthic fauna of Burdigalian age (Hakyemez 1989; İslamoğlu *et al.* 2005, 2007).

In the present work, only the Mortuma Formation is considered. One stratigraphic section (Sancaktepe) has been measured in Çukurköy region, NE of the Kale-Tavas Basin (Fig. 2). The Sancaktepe section is located near the Ortaoluk stream, 4 km SW of Çukurköy town and 2 km NE of Sancaktepe, approximately 10 km SE of Denizli city. It is located in the 1/25 000 scaled topographic map "Denizli M22-d21/2" (Hakyemez 1989). Its coordinates are x: 92750, y: 71250.

Denizli subbasin

The Denizli subbasin is located between Malda and Peynirci, NE Denizli city (Fig. 1). The molasse sediments rest unconformably on the basement units. The deltaic-shallow marine deposits including coal lenses and patch reefs overlie terrestrial conglomerates (debris flows, fluvial and alluvial facies) (Nebert 1956, 1961; Becker-Platen 1970; Becker-Platen *et al.* 1977; Konak *et al.* 1986; Göktaş 1990; Çakmakoğlu 1990; Akgün & Sözbilir 2001; Sözbilir 2005). The coarse terrestrial sediments belong to the Çaykavuştu Formation, while the marine deposits belong to the Sağdere Formation (Akgün & Sözbilir 2001).

Six sections have been measured in the lagoonal, brackish and shallow marine facies of the Sağdere Formation (Fig. 3). The sections Acıdere-1, Acıdere-2 and Acıdere-3 have been measured along the valley of Acıdere stream, approximately 1 km NW of Acıdere village. The coordinates are x: 03420, y: 95843; x: 03329, y: 95656; x: 03327, y: 95461 respectively (1/25 000 scaled "Denizli M22-b1" map). The Sağdere section has been measured along Sağdere stream, 3 km NW of Acıdere village ("Denizli M22-b1" map, x: 02950, y: 97500). The Bayıralan section has been measured along the road between Baklançakırlar and Bayıralan villages ("Denizli M22-b1" map, x: 04950, y: 02250). The Kuşbuymuş section is at about 4 km NW of Acıdere village ("Denizli M22-b1" map, x: 98550, y: 01800).

LITHOLOGY AND FOSSIL CONTENTS OF THE MEASURED STRATIGRAPHICAL SECTIONS

On the whole, seven stratigraphical sections have been logged and sampled for molluscs, benthic foraminifers, corals and ostracods (Figs 2-4; Table 1).

The Sancaktepe section (43 m) begins with a 50 cm thick thin-medium bedded, yellowish hard mudstone (Sancak-1) in which thin sandstone, siltstone and claystone horizons are intercalated. Upward, the following succession is measured

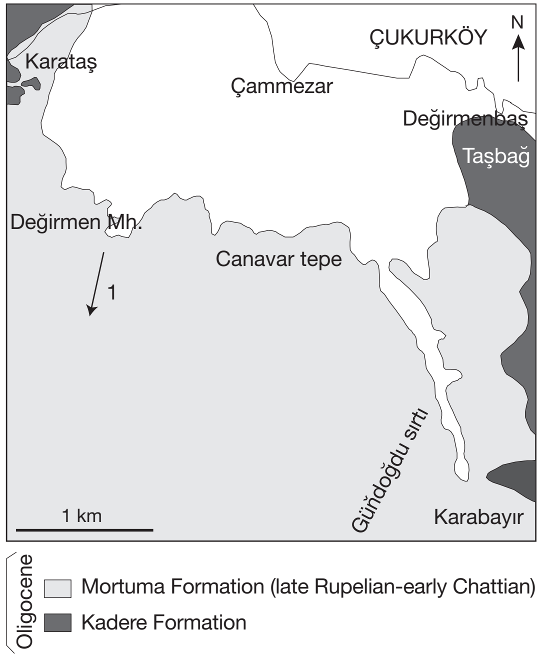

Fig. 2. — Locality of the measured statigraphical section in the Kale-Tavas subbasin (Turkey) (adapted from Hakyemez 1989). Mortuma Formation: **1**, Sancaktepe section. Abbreviations: **Mh.**, Mahallesi.

as: 60 cm coal bearing claystones with ostracods (Sancak-2), 6 m cross-bedded yellow sandstones with clay bands and leaf fossils (Sancak-3), 21 m siltstones intercalated with sandstones with plant remnants (Sancak-4) and gastropods (*Agapilia picta* (Férussac, 1825), *Melanopsis impressa* Krauss, 1852, *Tympanotonos conjunctoturris* (Sacco, 1895), *T. margaritaceus* (Brocchi, 1814), *T. trochlearispina* (Sacco, 1895)) (Sancak 5a). The upper part of the section (15 m) is formed of siltstone-sandstone alternations included in levels rich in turritellids (*Haustator conofasciata* (Sacco, 1895), *H. imbricataria* (Lamarck, 1819)) (Sancak-5b).

The 19 m thick Acıdere-1 section begins with a 80 cm thick grey sandstone bearing mollusc shell fragments (sample Acı-1). A 3 m thick greenish-grey and thin bedded claystone overlies the sandstones (Acı-2). The following 2.2 m thick greenish-grey silty claystone includes gastropods such as *Ampullinopsis crassatina* (Lamarck, 1804), *Haustator conofasciata* and *H. imbricataria*, littoral-epineritic ostracods (*Cytheridea* (*Cytheridea*) sp.) and benthic foraminifers

(*Ammonia* sp.) (Acı-3 and Acı-4). Above it, a 2.6 m thick brown sandstone is thin-medium bedded and includes claystone intercalations (Acı-5). It is followed by a 2.8 m thick grey siltstone (Acı-6) and a 1.3 m thick dark-grey claystone including some plant debris (Acı-7). Acıdere-1 section ends with a 6.8 m thick light greenish-grey claystone bearing gastropods and ostracods (Acı-8a and Acı-8b). The sample Acı-8b yielded ostracods (*Cytheridea* (*Cytheridea*) sp., *Buntonia* sp. and *Krithe* sp.) and only one gastropod (Cypraeoid indet.).

The Acıdere-2 section is 12.7 m thick. It begins with 3.5 m thick green-grey claystones (samples Ad-1, Ad-2 and Ad-3) and continues with a 1.5 m thick coal bearing claystone with undetermined plant remnants. Above this level, coral and bivalve fragments are found in 20 cm thick marl. Upward, 1.1 m thick dark-grey siltstones include the marine bivalves *Mytilus* (*Crenomytilus*) *aquitanicus* (Mayer-Eymar, 1858), *Panopea menardi* (Deshayes, 1828) and *Gari* cf. *protracta* (Mayer-Eymar, 1893) and small benthic foraminifers (*Ammonia* sp.) (Ad-6). Finally, 4.5 m thick greenish-grey thin bedded sandstones are covered with a 40 cm thick grey coloured carbonaceous claystone with leaf fossils, 1.8 m thick grey claystones and 20 cm thick carbonatic claystones, respectively.

The Acıdere-3 section is 5.7 m thick. It begins with a 1.2 m thick dark-grey, hard, carbonaceous claystone, intercalated with sandstone lenses. The faunal elements of this level are mainly gastropods (Acıdere-1) such as *Agapilia picta*, *Melanopsis impressa*, *Tympanotonos margaritaceus*, *Tympanotonos trochlearispina* and *Granulolabium plicatum* (Bruguière, 1792). The section ends with the 4.5 m thick, thin bedded, yellow sandstones which also contain the gastropod *T. margaritaceus* (Acıdere-2).

The Sağdere section (43 m) begins with a 5 m thick, dark grey, thin-medium bedded siltstone (Sağ-1). In this level some plant remains can be observed. Above it, there is a 50 cm thick hard, medium bedded sandstone (Sağ-2). Upward, 6 m thick, greenish-grey sandy and silty claystones are intercalated with coal lenses and include benthic foraminifers (*Ammonia* sp.) and ostracods (*Cytheridea* (*Cytheridea*) sp.) (Sağ-3). The following grey sandstones (50 cm) contain the gastropod *Haustator conofasciata* (Sağ-4a). The sandstones are followed by a 12 m thick greenish-grey claystone (Sağ-4). A 5.5 m thick dark-grey coloured sandstone rests on the claystones and bears an accumulation of the bivalve *Pitar villanovae* (Deshayes, 1825) (Sağ-5). Overlying this, a 5.4 m thick, grey coloured, hard siltstone-sandstone level contains some badly preserved and scattered bivalve fragments (Sağ-6). Upward, the section continues with a 1 m thick siltstone, a dark-grey and laminated claystone (80 cm), a hard sandstone (1 m), a grey coloured mudstone (5 m) intercalated with yellowish-brown sulphuric levels, and a light-grey hard limestone (30 cm).

The Kuşbuymuş section (21.6 m) has at the base a 3 m thick yellow sandstone, composed of ferrigenous sediments locally. It is followed by 1 m thick, bedded, dark-grey carbonated sandstones (Kuş-1, Kuş-2) which include molluscs and corals. The fossils are *Haustator conofasciata* for gastropods, *Hyotissa hyotis* (Linnaeus, 1758), *Spondylus bifrons* Münster *in* Goldfus, 1840 and *Panopea menardi* for bivalves and *Glyphastraea laxelamellata* (Michelotti, 1838), *Mycetophyllia* sp., *Agathiphyllia* sp., *Siderastrea* (*Siderofungia*) *morloti* (Reuss, 1868), *Meandrina* sp., *Lithophyllia* sp., *Antillia* sp., *Antiguastraea alveolaris* (Catullo, 1856), *Stylophora* sp., *Glyphastraea* sp. for corals. Above this horizon, 2 m thick yellow sandstones contain at the base large ostreid shell accumulations including *Pycnodonte gigantica callifera* (Lamarck, 1819) and *Hyotissa hyotis* (Kuş-3). The uppermost level of this sandstone yielded ostracods (*Cytheridea* sp.). The section continues with a 1.5 m thick dark-grey siltstone and a 6 m thick grey sandstone in which some reddish ferrigenous bands are intercalated. The sandstones are followed by yellowish-grey carbonatic sandstones (60 cm) (Kuş-3a), yellowish sandstones (50 cm) and yellowish-grey, hard sandstones (1 m) which contain larger benthic foraminifers (*Nephrolepidina partita* Douvillé, 1911) and corals. Above, a 3 m thick yellowish-grey sandstone includes abundant large shelled ostreids *Hyotissa hyotis*. The section ends with a 3 m thick pebbly sandstone.

The Bayıralan section (23.2 m) begins with a level of greenish-grey claystones (10 m) intercalated with 5-30 cm thick lenticular sandstones (By-1a). This level is covered by a 1.7 m thick, thin bedded, greenish-grey claystone which contains plant remnants and dark coal-bearing levels (By-1). Upwards,

FIG. 3. — Localities of the measured stratigraphical sections in the Denizli subbasin (Turkey) (modified from Konak *et al*. 1986; Göktaş 1990; Çakmakoğlu 1990; Akgün & Sözbilir 2001). Sağdere Formation sections: **1**, Sancaktepe; **2**, Acıdere-1; **3**, Acıdere-2; **4**, Acıdere-3; **5**, Sağdere; **6**, Kuşbuymuş; **7**, Bayıralan. Abbreviations: **Mh.**, Mahallesi.; **Mvk.**, Mevkii; **T.**, Tepe.

a 30 cm thick hard siltstone (By-2), a 4.5 m thick yellow sandstone (By-3) and 2 m thick yellowish-grey clayey sandstones (By-4) were measured. The sandstones include small pebbles at the base and upwards irregular coal bands. The faunal elements of this facies are mainly gastropods as *Melanopsis impressa*, *Terebralia bidentata* (Defrance *in* Grateloup, 1840), *Tympanotonos conjunctoturris*, *Granulolabium plicatum*, *Tympanotonos margaritaceus* and *Tympanotonos trochlearispina*. Sample By-4b was taken at the uppermost level of the sandstone and yielded gastropods (*Ampullinopsis crassatina* and *Globularia gibberosa* (Grateloup, 1847)). The section ends with a 4.7 m thick yellow sandstone with siltstone lenses.

FACIES AND PALEOENVIRONMENTS

Based on the paleoceocological features of their fossil content and lithology, three types of facies are described. These units represent successive sequences of affiliated facies in the studied region (Fig. 4).

Brackish lagoonal sediments (Unit-1)

Lithology

Twenty-eight meters of alternating grey, greenish-grey sandstones, siltstones, claystones, carbonaceous claystones are exposed which underlie the very shallow marine clastics of Unit-2. Dark grey coal-bearing and organic-rich levels, sometimes including undetermined plant remnants, are intercalated in the claystones and siltstones.

Fossil content and paleoecology

The Unit-1 contains gastropods: *Terebralia bidentata*, *Tympanotonos conjunctoturris*, *Tympanotonos* (*Tympanotonos*) *margaritaceus*, *Melanopsis impressa*, *Granulolabium plicatum* and *Agapilia picta* are found together in coal-bearing clays and in sandy-muddy sediments. *Agapilia-Melanopsis-Tympanotonos* communities are regarded as fluviatile influenced, low salinity assemblages of brackish water lagoons and/or mangrove swamps (Baldi 1973). *Tympanotonos* (*Tympanotonos*) *margaritaceus* and *Granulolabium plicatum* are interpreted as facies indices for lagoonal to littoral environments indicating oligo/mesohaline salinities (Baldi 1973, Barthelt 1989). *Tympanotonos* (*Tympanotonos*) *margaritaceus* and *Granulolabium plicatum* are abundant and common in sublittoral coastal mudflats (Harzhauser 2004). *Tympanotonos* (*Tympanotonos*) *margaritaceus*, *Granulolabium plicatum* and *Agapilia picta* are also reported to have lived in lagoonal and brackish conditions in fluvial-estuarine facies (Harzhauser & Mandic 2001). *Tympanotonos-Granulolabium* communities are well known from Oligocene deposits in France, Hungary, Austria, Greece and central Iran; their present relatives are inhabitants of coastal areas, but prefer estuaries, swamps and lagoons (Baldi 1973; Gitton *et al.* 1986; Harzhauser & Mandic 2001; Lozouet *et al.* 2001; Harzhauser 2004).

On the other hand, based on the palynological and sedimentological datas, the coal bearing sediments in the studied region are interpreted to have formed in the flood plains and lagoonal part of the deposits (Akgün & Sözbilir 2001). In respect to above mentioned paleo-community analyses, these associations in the sections from the Denizli and Kale-Tavas basins indicate a brackish lagoonal environment probably influenced by marine ingressions.

Brackish-shallow marine sediments (Unit-2)

Lithology

The Unit-2 is composed of up to 30 m thick, predominantly fine clastics. Greenish-grey siltstones and claystones are followed by grey, yellow, yellowish-brown sandstones. Sandstones are intercalated with siltsones, claystones, organic-rich dark grey claystones and marly levels including plant debris, some bivalves, ostracods and small benthic foraminifers (*Ammonia* sp.). Rarely, the sandstones include pebbles at the base.

Fossil content and paleoecology

The Unit-2 includes euryhaline brackish-shallow marine gastropods (*Ampullinopsis crassatina*, *Globularia gibberosa*, *Haustator conofasciata*, *Haustator imbricataria*) and bivalves (*Pitar villanovae*, *Mytilus* (*Crenomytilus*) *aquitanicus*, *Panopea menardi*, *Gari* cf. *protracta*). In comparison to the previous brackish lagoonal facies, potamidids disappear, whilst turritellids and venerids appear and become predominant. Especially, *Haustator conofasciata* is the most abundant species. This type of fauna reflects an increase in salinity and a gradual shift from littoral to sublittoral environments. For example, *Ampullinopsis crassatina* is a euryhaline species, occuring in brackish lagoonal environments in the Hungarian and Bavarian Oligocene as well as in shallow sublittoral assemblages of the central Paratethys and eastern Atlantic/western Mediterranean (Baldi 1973; Gitton *et al.* 1986; Barthelt 1989; Harzhauser 2004). In the eastern Mediterranean (Mesohellenic Basin, Greece), the large sized *Ampullinopsis crassatina* and *Globularia gibberosa* also lived infaunally in the soft corallinacean-lepidocyclinid sands indicating fully marine condition (Harzhauser 2004).

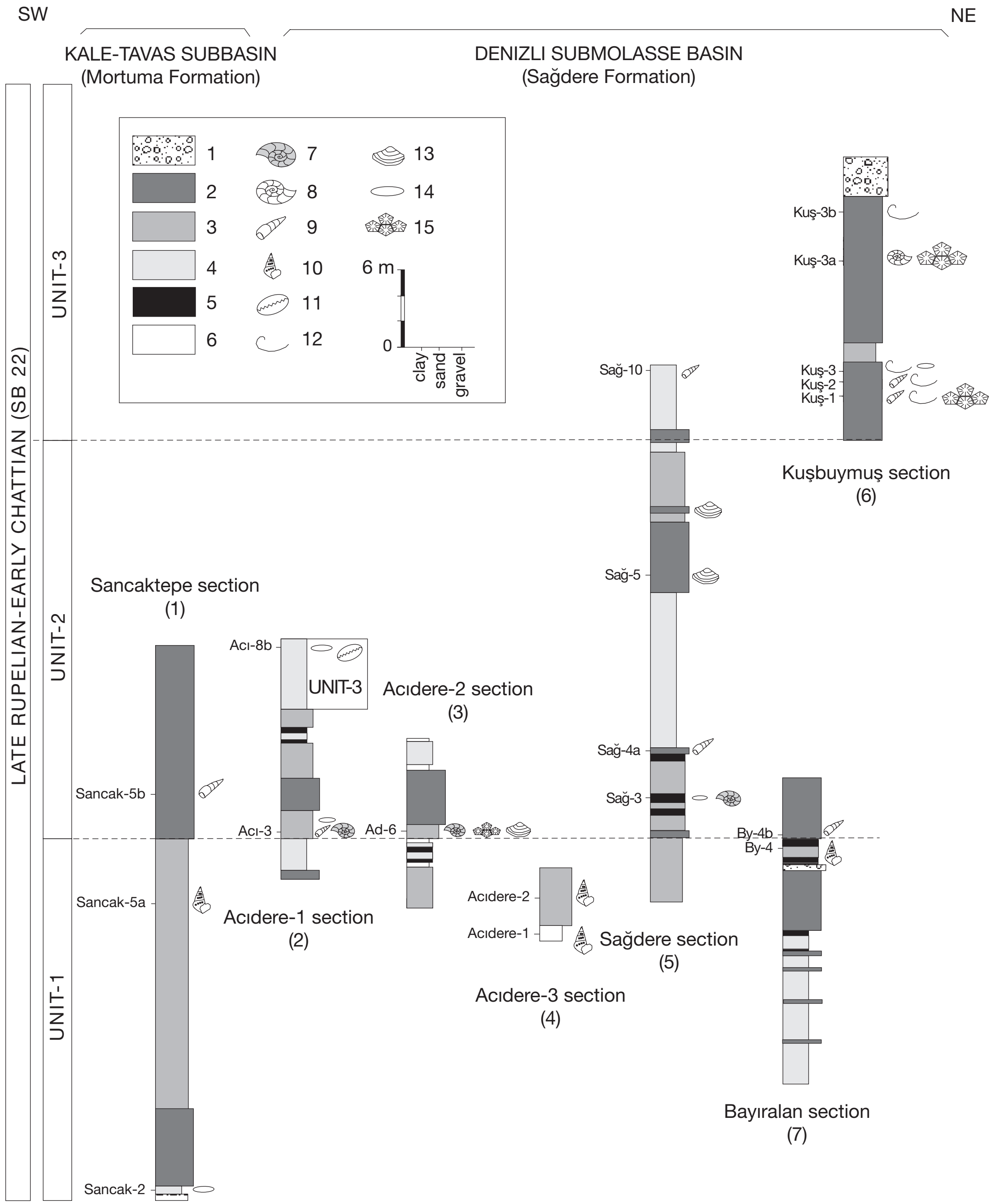

FIG. 4. — Correlation of the measured stratigraphic sections from Denizli (Sağdere Formation) and Kale-Tavas subbasins (Mortuma Formation) (Turkey): **1**, pebblestone-sandy pebblestone; **2**, sandstone; **3**, mudstone; **4**, claystone; **5**, coal beds, organic-rich levels, plant remains; **6**, marl-detritic limestone; **7**, euryhaline benthic foraminifer (*Ammonia* sp.); **8**, stenohaline benthic foraminifer (*Nephrolepidina partita* Douvillé, 1911); **9**, euryhaline shallow marine gastropods; **10**, brackish lagoonal gastropods; **11**, stenohaline shallow marine gastropods (cypraeoid); **12**, stenohaline shallow marine bivalves; **13**, euryhaline shallow marine bivalves; **14**, ostracods; **15**, corals.

On the other hand, in platform and marginal seas of the Tethys, situated in the regions of present-day eastern Europe and western Asia, coastal zones and lagoons were inhabited by euryhaline infaunal suspension feeders of bivalve taxa such as venerids and mytilids (Nevesskaja 2003). Among them, the late Oligocene species of *Pitar* are part of shallow sublittoral communities (Baldi 1973). *Mytilus* (*Crenomytilus*) *aquitanicus* and *Gari* cf. *protracta* are documented in the late Oligocene lagoonal and shallow sublittoral communities of Austrian molasses basin (Harzhauser & Mandic 2001).

The mollusc fauna is associated with littoral-epineritic ostracods (*Cytheridea* (*Cytheridea*) sp.) and euryhaline-marine benthic foraminifers (*Ammonia* spp.). Therefore, in the view of analyses of faunal assemblages, the facies represent a brackish-shallow marine environment.

Fully shallow marine sediments (Unit-3)

Lithology

The Unit-3 is composed of 22 m thick yellow-grey sandstones, carbonated sandstones, pebbly sandstones. Sandstones composed of ferrigenous sediments locally at the base. This is followed by carbonatic sandstones including ostreids, large sized bivalves, corals and benthic foraminifers. Sandstones are intercalated with siltstone beds. The sequence reflects a shallowing upward trend by the presence of pebbly sandstones and sandy pebblestones at the uppermost level.

Fossil content and paleoecology

In this facies, the stenohaline shallow marine bivalves such as *Spondylus bifrons*, *Pycnodonte gigantica callifera* and *Hyotissa hyotis*, *Panopea menardi*, *Haustator conofasciata* and cypraeoid gastropods are observed. Generally, marginal seas of Oligocene including the marginal (estuaries lagoons and bays) and coastal zones of the Atlantic ocean (NW Europe), Tethys and Paratethys were inhabited by settlements of many kind of epifaunal ostreids, often building banks (Nevesskaja 2003). Among them, *Pycnodonte gigantica callifera* and *Hyotissa hyotis* are stenohaline ostreids living in the sublittoral environments under the fully marine conditions (Harzhauser & Mandic 2001; Nevesskaja 2003). These ostreids are accompanied by cemented *Spondylus bifrons* in the sublittoral environments (Harzhauser & Mandic 2001; Nevesskaja 2003). *Panopea menardi* is a deeply burrowing taxa. On the other hand, the corals *Glyphastraea laxelamellata*, *Mycetophyllia* sp., *Agathiphyllia* sp., *Siderastrea* (*Siderofungia*) *morloti*, *Meandrina* sp., *Lithophyllia* sp., *Antillia* sp., *Antiguastraea alveolaris*, *Stylophora* sp., *Glyphastraea* sp. and rare ostracods (*Cytheridea* sp.) accompanied the molluscan-bearing levels. It is known that coral-reef buildups at depths of about 50 m were inhabited by cemented oysters and *Spondylus* (Nevesskaja 2003). Larger benthic foraminifers (*Nephrolepidina partita*) are found just above the mollusc and coral-bearing beddings. They represents also fully marine conditions.

BIOSTRATIGRAPHY

In this study, the biostratigraphic data obtained from molluscs, corals and benthic foraminifers are interpreted together. Eleven gastropod and seven bivalve species are identified from the seven measured stratigraphic sections. The stratigraphic ranges of the molluscs are shown in Figure 5 and are correlated to the Mediterranean stages, biozones and standard time scale (Rögl *et al.* 1993; Rögl 1996, 1998; Cahuzac & Poignant 1997, 1998; Steininger 1999; Harzhauser *et al.* 2002; Gradstein *et al.* 2004).

All molluscan assemblages in the seven measured sections indicate a Rupelian age. In addition to these, the presence of corals (*Glyphastraea laxelamellata*, *Siderastrea* (*Siderofungia*) *morloti*, *Antiguastraea alveolaris*, *Astrocoenia bodellei* (Calmus, 1973)) supports the Rupelian-Chattian age assignment (Cahuzac & Chaix 1994). However, the finding of *Nephrolepidina partita* characterizes the SB22 benthic foraminifer biozone ranging from the late Rupelian-early Chattian (Cahuzac & Poignant 1997, 1998). Evaluating litho- and biostratigraphic correlation, the age of the studied units (Sağdere and Mortuma Formations) are dated late Rupelian-early Chattian (Figs 4; 5).

The distribution of the fossils and sample numbers are given in Table 1 and Figure 4.

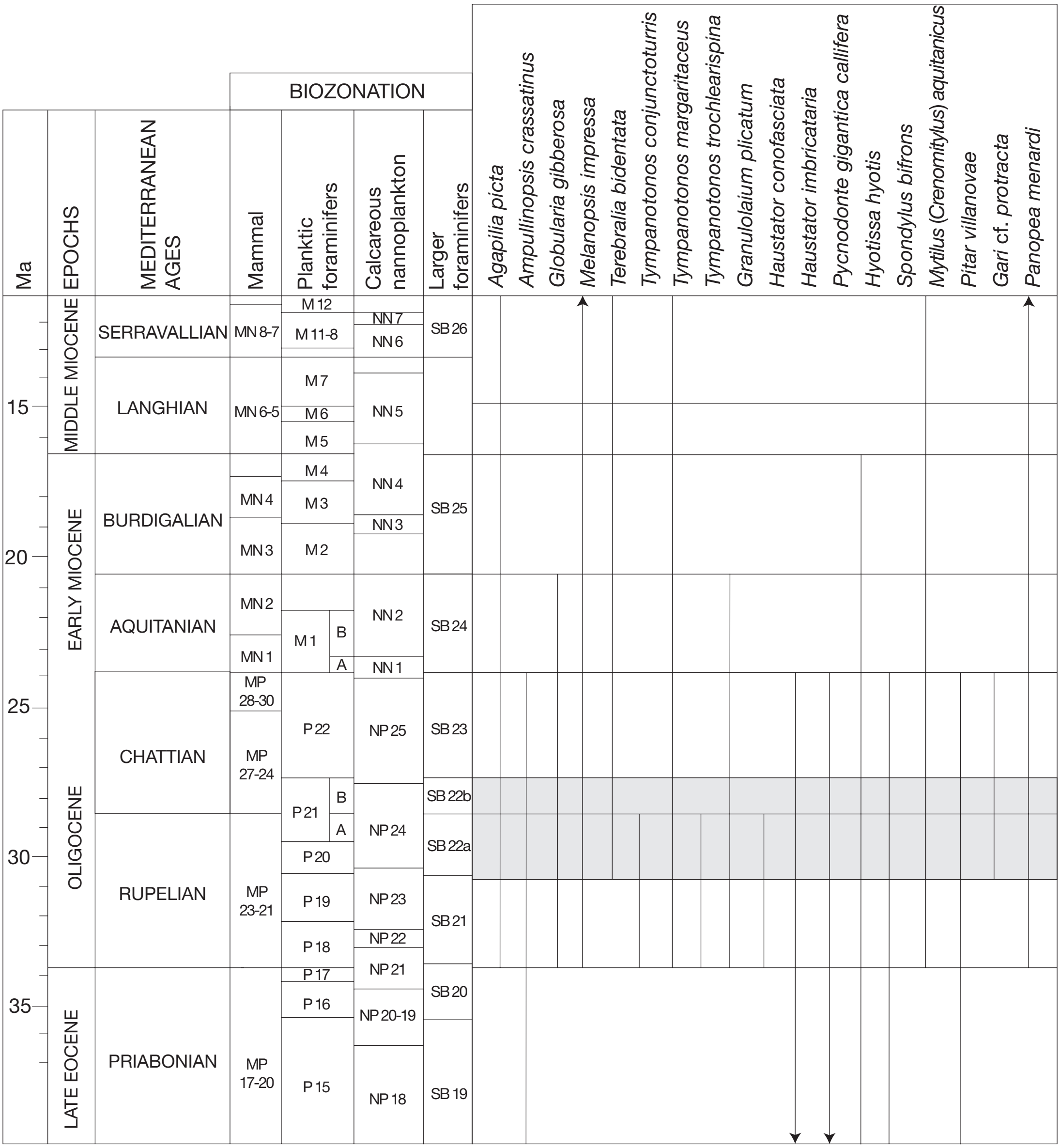

FIG. 5. — Stratigraphic range of the molluscs found in the Denizli and Kale-Tavas subbasins (Turkey) corresponding to geochronologic time table and biozones (Perch & Nielsen 1985 [nannoplanktones]; Rögl 1996, 1998; Rögl *et al.* 1993; Cahuzac & Poignant 1997, 1998 [benthic foraminifers]; Steininger 1999 [mammals]; Gradstein *et al.* 2005; mollusc data from Sacco 1895; Mandic 2000; Harzhauser *et al.* 2002; Harzhauser & Mandic 2001; Harzhauser 2004).

MOLLUSCAN BIOSTRATIGRAPHY

A total of 18 mollusc species was recovered from the Denizli and Kale-Tavas samples. The time ranges and paleo(bio)geographic and stratigraphic distributions of all species recorded in these sections are given in Figure 5 and Tables 1-3. In addition, the species are illustrated in Figures 6 and 7:

Agapilia picta (Fig. 6A-C), *Ampullinopsis crassatina* (Fig. 6D-F), *Globularia gibberosa* (Fig. 6G, H), *Melanopsis impressa* (Fig. 6I, J), *Terebralia bidentata* (Fig. 6K), *Tympanotonos conjunctoturris* (Fig. 6L), *Tympanotonos trochlearispina* (Fig. 6M), *Tympanotonos margaritaceus* (Fig. 6N, O), *Granulolabium plicatum* (Fig. 6P), *Haustator conofasciata* (Fig. 6Q, R) and *Haustator imbricataria* (Fig. 6S) for gastropods, *Pycnodonte gigantica callifera* (Fig. 7A, B), *Hyotissa hyotis* (Fig. 7C, D), *Spondylus bifrons* (Fig. 7E), *Mytilus* (*Crenomytilus*) *aquitanicus* (Fig. 7F), *Pitar villanovae* (Fig. 7G), *Gari* cf. *protracta* (Fig. 7H) and *Panopea menardi* (Fig. 7I) for bivalves.

According to the published data on Tertiary molluscs, nine of them (*Ampullinopsis crassatina*, *Tympanotonos conjunctoturris*, *T. trochlearispina*, *Haustator conofasciata*, *H. imbricataria*, *Pycnodonte gigantica callifera*, *Spondylus bifrons*, *Pitar villanovae*, *Gari* cf. *protracta* have a great biostratigraphic significance: their time ranges nowhere pass the Oligocene/Miocene boundary. In addition to this, two of them (*T. conjunctoturris*, *T. trochlearispina*) are known only from the Rupelian series of North Italy in the Tethys Province. Moreover, two gastropod species (*T. conjunctoturris*, *T. trochlearispina*) are known only from the Rupelian series of North Italy in the Tethys Province.

Gastropoda

Ampullinopsis crassatina (Fig. 6D-F) is a common Oligocene species. It has been reported from northern Italy (Sacco 1891); Paris Basin (Gitton *et al.* 1986); it is abundant in the Mainz Basin (Koenen 1868) and in the Paratethys realm (Mészáros 1957; Karagiuleva 1964; Moisescu 1972; Baldi 1973). It is mentioned in the late Rupelian-early Chattian from the Mesohellenic Basin in Greece and from the Esfahan-Sirjan Basin in Iran (Harzhauser 2004), and even from Pakistan (Vredenburg 1928).

Tympanotonos conjunctoturris (Fig. 6L) and *T. trochlearispina* (Fig. 6M) have been found in the "Tongriano beds" in northern Italy (Sacco 1895) which are of Rupelian age (Popov *et al*. 2002).

Haustator conofasciata (Fig. 6Q, R) appears in the Rupelian of the Piedmonte Basin of northern Italy (Sacco 1895) and in the Oligocene of Greece (Brunn 1956) and Pakistan (Vredenburg 1928). It also occurs in the late Rupelian-early Chattian of the Mesohellenic Basin in Greece and in the Esfahan-Sirjan Basin in Iran (Harzhauser 2004).

Haustator imbricataria (Fig. 6S) is generally found in the Eocene-Oligocene deposits accross Europe. It is known from the early Eocene-Early Oligocene of the Transilvania Basin in Romania (Mészáros 1957). The species was reported from the Eocene of France, Belgium, Italy, Hungary, Bulgaria, Caucasia as well as Egypt (Mészáros 1957; Karagiuleva 1964).

Bivalvia

Pycnodonte gigantica callifera (Fig. 7A, B) is found in the Rupelian of the Paris Basin (Harzhauser & Mandic 2001) and the Rupelian-Chattian of the North Sea Basin (Görges 1952) and Mainz Basin (Gürs 1995). It is also reported from the Kiscellian to early Egerian of the Paratethys realm (Baldi 1973).

Spondylus bifrons (Fig. 7E) occurs from late Eocene to Oligocene (Boussac 1911; Karagiuleva 1964).

Pitar villanovae (Fig. 7G) has been found in the late Eocene-Oligocene in Italy, France, Hungary, Romania and Caucasia (Mészáros 1957).

Gari cf. *protracta* (Fig. 7H) is reported from the late Rupelian-Chattian of Liguria (Sacco 1901) and from the late Kiscellian-early Egerian of the central and western Paratethys (Wolf 1897; Senes 1958; Baldi 1973; Harzhauser & Mandic 2001).

CORRELATION, PALEOENVIRONMENTS AND SEDIMENTARY HISTORY

The faunal and stratigraphical data from the Sağdere and Mortuma Formations allow the correlation between the Denizli and Kale-Tavas molasse subbasins (Figs 4; 5) (Table 1). The late Rupelian-early Chattian deposits of the Denizli and Kale-Tavas subbasins (Sağdere and Mortuma Formations) are extremely poor in molluscs, benthic foraminifers, and coral assemblages. However, they show important faunal and facial changes from the brackish-shallow marine to the fully marine conditions. The correlation of the outcrop areas is based on the analyses of lithology, paleoecology and biostratigraphy of the measured stratigraphical sections presented above.

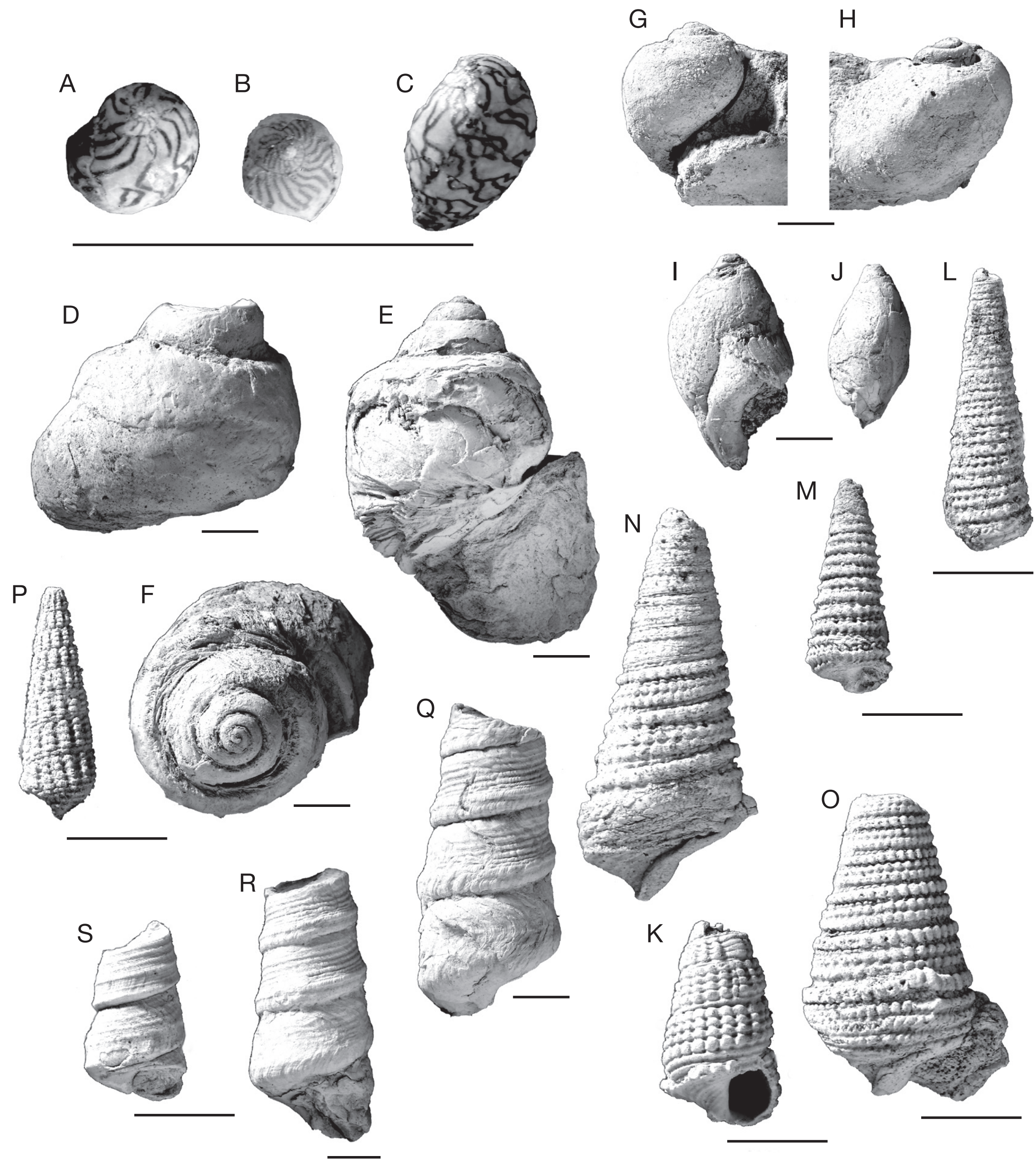

FIG. 6. — Gastropods (deposited in the repository of the Natural History Museum, Vienna): **A**-**C**, *Agapilia picta* (Férussac, 1825); **D**-**F**, *Ampullinopsis crassatina* (Lamarck, 1804); **G**, **H**, *Globularia gibberosa* (Grateloup, 1847); **I**, **J**, *Melanopsis impressa* Krauss, 1852; **K**, *Terebralia bidentata* (Defrance *in* Grateloup, 1840); **L**, *Tympanotonos conjunctoturris* (Sacco, 1895); **M**, *Tympanotonos trochlearispina* (Sacco, 1895); **N**, **O**, *Tympanotonos margaritaceus* (Brocchi, 1814); **P**, *Granulolabium plicatum* (Bruguiére, 1792); **Q**, **R**, *Haustator conofasciata* (Sacco, 1895); **S**, *Haustator imbricataria* (Lamarck, 1819). Scale bars: 1 cm.

The lateral facies relationship is traced in seven measured sections (Fig. 4). The base of the initial late Rupelian-early Chattian marinal influence is clearly defined by the presence of brackish water shallow marine assemblages (Fig. 4). The lower parts of the Sancaktepe (Sancak 1-5a), Acıdere-1

(Acı 1-2), Acıdere-2 (Ad 1-5), Acıdere-3 (Acıdere 1-2), Sağdere (Sağ 1) and Bayıralan (By 1a-4) sections include mudstones and claystones intercalating thin coal bands with sulphur, and they mainly contain brackish lagoonal gastropods. Upwards, the sequences show a gradual transition to sandstones, siltstones and carbonates including shallow marine molluscs, corals and rare benthic foraminifers. The upper part of the Sancaktepe (Sancak 5b), Acıdere-1 (Acı 3-8), Acıdere-2 (Ad 6-9), Sağdere (Sağ 2-10), and Bayıralan (By 4b) sections include euryhaline molluscs, benthic foraminifers and ostracods representing the brackish-shallow marine environments. These units are also known as deltaic facies in the region (Akgün & Sözbilir 2001). The sequence continues with the fine clastics intercalating carbonate-rich sediments which is observed in the whole Kuşbuymus section (Kuş 1-3) and the uppermost part of the Acıdere-1 (Acı 8b) sections. The presence of shallow marine molluscs, corals and benthic foraminifers indicate fully shallow marine conditions. These units are interpreted as shallow marine and reefal facies (Akgün & Sözbilir 2001). Upper Rupelian-early Chattian sedimentation ends with the coarse sediments observed in the uppermost levels of the Kuşbuymuş section.

PALEOBIOGEOGRAPHY

The paleobiogeographic distribution of the molluscan species in the studied region has been examined in view of new paleobiogeographic concepts. In recent studies, based on the distribution patterns of gastropods in Iran (Qom Basin, Esfahan-Sirjan Basin, Zagros mountains), in Turkey (Mut and Sivas Basins), in Greece (Mesohellenic Basin) and in northeastern Egypt, a new paleobiogeographic terminology arised for the Oligocene and Miocene in the circum-Mediterranean area (Harzhauser *et al.* 2002). For the Oligocene, it is proposed that the "western Tethys Region" includes two subunits, the "Mediterranean-Iranian Province" and the "western Indian-eastern African Province" (Harzhauser *et al.* 2002). The Mediterranean-Iranian Province covered the area of the modern Mediterranean Sea and probably included the European Atlantic coast up to the Bay of Biscay to the West and reached central Iran to the Southeast. The western Indian-eastern African Province became established in the area of Pakistan, India, East Africa (Somalia and Kenya) and Oman (Harzhauser *et al.* 2002). In addition, the "Danubian Province" has been proposed as a new paleobiographic unit characterised by the total fauna of the western, central and eastern Paratethys (Harzhauser *et al.* 2002).

For a paleobiogeographic interpretation, the faunas of the studied region were compared with that of the near shore molluscs from the eastern Atlantic/western Mediterranean (Italy and France), Iran, Greece, western, central and eastern Paratethys and India (Table 3). Strong similarities have been mainly observed with the faunal assemblages from Italy, France, Greece and Iran. *Haustator conofasciata*, *Ampullinopsis crassatina*, *Agapilia picta*, *Granulolabium plicatum*, *Globularia gibberosa*, *Melanopsis impressa* and *Pycnodonte gigantica callifera* are the most common species which are reported as widespreaded in the Mediterranean-Iranian Province (Harzhauser *et al.* 2002; Harzhauser 2004). On the other hand, *Ampullinopsis crassatina* is also known in the Early Oligocene series of eastern Atlantic/western Tethian region (Gitton *et al.* 1986). With this study, *Tympanotonos conjunctoturris* and *T. trochlearispina*, which were only known from Italy, are reported from the eastern side of the province for the first time.

Endemic species which are peculiar to the Danubian and western Indian-eastern African Provinces are not observed in the studied area. However, some Tethyan originated euryhaline species, which were able to adapt both the Paratethyan and Tethyan marine-brackish environments in Oligocene, such as *Ampullinopsis crassatina*, *Agapilia picta*, *Melanopsis impressa*, *Tympanotonos margaritaceus* and *Granulolabium plicatum* have also been found in the studied region.Therefore, based on the paleobiogeographic distribution and strong affinities of the molluscan assemblages, the studied region is included in the Mediterranean-Iranian Province (Table 3).

DISCUSSION AND CONCLUSION

Denizli and Kale-Tavas subbasins have transgressive sequences (Sağdere and Mortuma Formations)

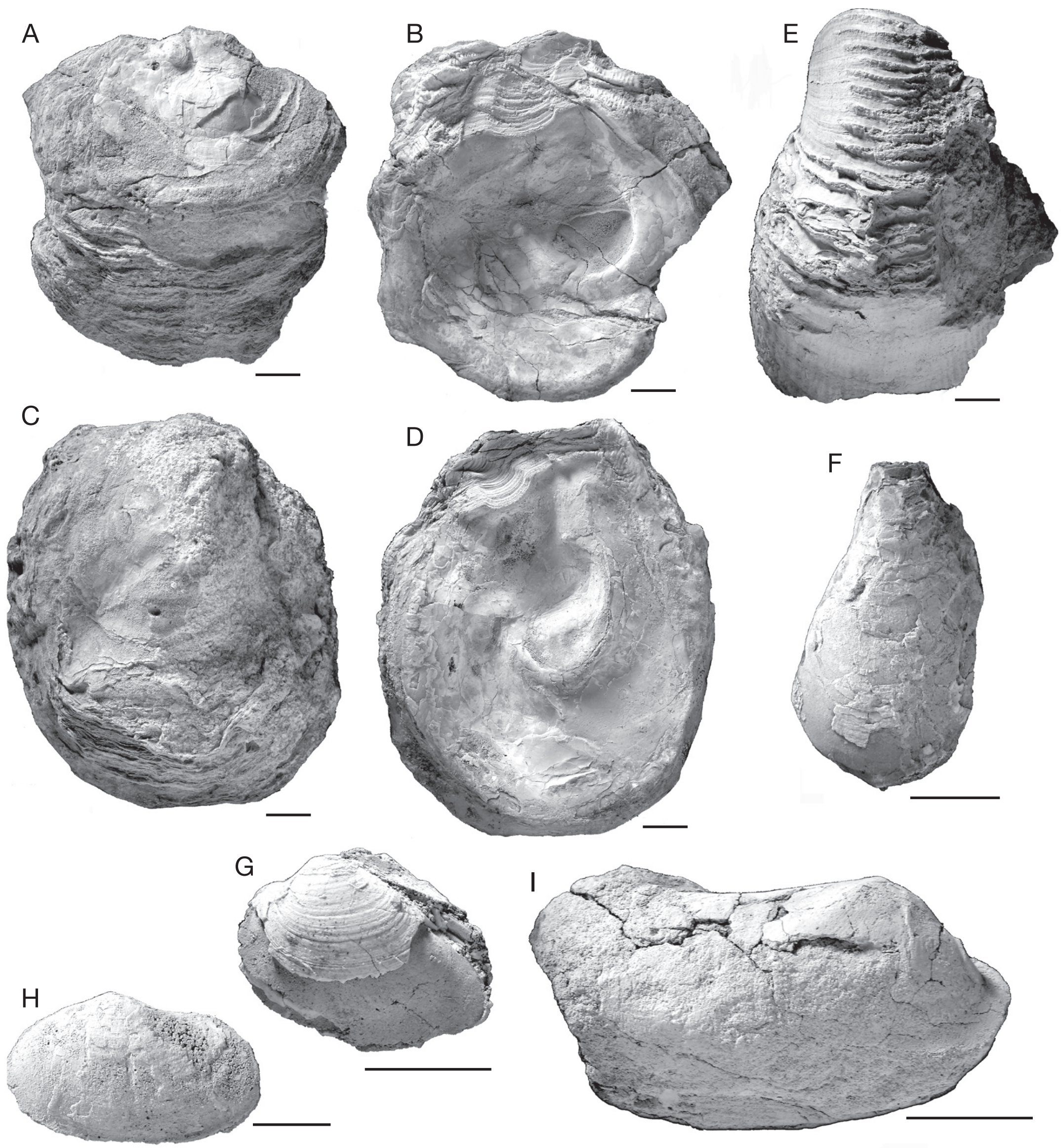

Fig. 7. — Bivalves (deposited in the repository of the Natural History Museum, Vienna): **A**, **B**, *Pycnodonte gigantica callifera* (Lamarck, 1819); **C**, **D**, *Hyotissa hyotis* (Linnaeus, 1758); **E**, *Spondylus bifrons* Münster *in* Goldfuss, 1840; **F**, *Mytilus* (*Crenomytilus*) *aquitanicus* (Mayer-Eymar, 1858); **G**, *Pitar villanovae* (Deshayes, 1825); **H**, *Gari* cf. *protracta* (Mayer-Eymar, 1893); **I**, *Panopea menardi* Dehayes, 1828. Scale bars: 1 cm.

overlying the terrestrial deposits (Karadere and Çaykavuştu Formations). The previous age determinations of the Sağdere Formation (Denizli subbasin) and the Mortuma Formation (Kale-Tavas subbasin) are debated. In previous studies (see above), various ages between middle Eocene and early Miocene have been proposed. For the Mortuma Formation (Kale-Tavas molasse subbasin) Erentöz and Öztemur (1964) suggested an Oligocene age, while Hakyemez (1989) and Akgün & Sözbilir (2001) dated it to the Chattian only. On the other hand, the Sağdere Formation (Denizli molasse subbasin) was dated as Chattian-Aquitanian based on the palinostratigraphical data and biostratigraphical interpretations.

But the transgressive deposits of both formations include the mollusc asssemblages which are typical for the Rupelian (Fig. 5). The same units include Rupelian-Chattian corals and one late Rupelian-early Chattian benthic foraminiferal species (*Nephrolepidina partita*) which is characteristic for the SB 22 zone. Therefore, the new results allow to date the Sağdere and Mortuma Formations as late Rupelian-early Chattian. Due to the lack of any marine Chattian and early Miocene fossil taxa, the claim of Chattian-Aquitanian age for the Sağdere Formation (Akgün & Sözbilir 2001) should be abandoned.

On the other hand, the strong faunal and lithologic similarities of the facies allow to correlate to the late Rupelian-early Chattian sequences in the region. Facial changes from brackish lagoonal to brackish-shallow marine and fully shallow marine conditions are well observed in the measured sections of outcrop area. This turnover in the environmental conditions from the brackish lagoonal to brackish-shallow and fully marine conditions for both Mortuma and Sağdere Formations is approved by the faunal assemblages, and support the previous interpretations (Hakyemez 1989; Akgün & Sözbilir 2001).

In addition to this, the late Rupelian-early Chattian mollusc fauna of the region displays strong similarities and could be correlated to the assemblages from the Mediterranean-Iranian Province.

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APPENDIX

TABLE 1. — Distribution of gastropods, bivalves, corals, benthic foraminifers and ostracods in the sampled sections from the Denizli and Kale-Tavas subbasins (Turkey). Abbreviations: **Acı**, Acıdere-1 section; **Acıdere**, Acıdere-3 section; **Ad**, Acıdere-2 section; **By**, Bayıralan section; **Kuş**, Kuşbuymuş section; **Sağ**, Sağdere section; **Sancak**, Sancaktepe section.

Samples	**Sancak**			**Acı**		**Ad**	**Acıdere**		**Sağ**				**Kuş**					**By**	
	2	5	6	3	8b	6	1	2	3	4a	5	10	1	2	3	3a	3b	4	4b
Gastropoda																			
Agapilia picta		x					x												
Ampullinopsis crassatina				x															x
Globularia gibberosa																			x
Melanopsis impressa		x					x											x	
Terebralia bidentata																		x	
Tympanotonos conjunctoturris		x																x	
Tympanotonos margaritaceus		x					x	x										x	
Tympanotonos trochlearispina		x					x											x	
Granulolabium plicatum							x											x	
Turritella (*Haustator*) *conofasciata*			x	x						x		x	x						
Turritella (*Haustator*) *imbricataria*			x	x															
Pycnodonte gigantica callifera														x	x				
Hyotissa hyotis													x	x	x				
Spondylus bifrons													x						
Mytilus (*Crenomytilus*) *aquitanicus*						x													
Pitar villanovae			x								x								
Gari cf. *protracta*						x													
Panopea menardi						x						x							
Corals																			
Glyphastraea laxelamellata													x			x			
Antiguastraea alveolaris													x			x			
Siderofungia morloti													x						
Mycetophyllia sp.													x			x			
Agathiphyillia sp.													x						
Meandrina sp.													x						
Lithophyllia sp.													x			x			
Antillia sp.													x						
Stylophora sp.													x						
Glyphastraea sp.													x						
Benthic foraminifers																			
Nephrolepidina partita																x			
Ammonia sp.				x		x													
Ostracoda																			
Cytheridea (*Cytheridea*) sp.				x	x				x						x				
Buntonia sp.					x														
Krithe sp.					x														
Candona sp.	x																		

TABLE 2. — Paleogeographic and stratigraphic distributions of some molluscan species from the Denizli and Kale-Tavas subbasins (Turkey) in the Tethys and Paratethys areas, and related references.

Fossils	Paleogeographic and stratigraphic distributions		References
	eastern Atlantic/Tethys	central/eastern Paratethys	
Agapilia picta	Burdigalian (Piedmonte Basin, Italy)		Sacco (1896)
	Aquitanian-Burdigalian (France)		Cossmann & Peyrot (1917), Lozouet *et al.* (2001)
	late Rupelian-early Chattian (Iran)		Harzhauser (2004)
	late Burdigalian (Mut Basin, S Turkey)		Mandic *et al.* (2004)
		Oligocene-middle Miocene	Hörnes (1856), Wolf (1897), Schaffer (1912), Papp (1952), Steininger *et al.* (1971), Baldi (1973), Harzhauser & Kowalke (2001)
	late Rupelian-early Chattian (Iran, Greece)		Harzhauser (2004)
	late Burdigalian (Antalya Basin-Turkey)		İslamoğlu (2002), İslamoğlu & Taner (2004)
Ampullinopsis crassatina	Oligocene (northern Italy, eastern lessinian Alps)		Sacco (1891), Coletti *et al.* (1973)
	Rupelian (Paris Basin, France)		Gitton *et al.* (1986)
	Oligocene (Atlantic, Mainz Basin)		Koenen (1868)
	Oligocene (Pakistan)		Vredenburg (1928)
	late Rupelian-early Chattian (Greece)		Harzhauser (2004), Wielandt-Schuster *et al.* (2004)
	late Rupelian-early Chattian (Iran)		Harzhauser (2004)
		Oligocene	Mészáros (1957), Senes (1958), Hölzl (1962), Karagiuleva (1964), Baldi (1973)
	Oligocene (southern France)		Cossmann (1921)
	Oligocene (Ermenia)		Abich (1882)
Globularia gibberosa	Oligocene (Pakistan)		Vredenburg (1928)
	Oligocene (Italy)		Fuchs (1870)
	Oligocene (France)		Grateloup (1847)
		Oligocene	Karagiuleva (1964), Baldi (1973)
	Burdigalian (Piedmonte Basin, Italy)		Sacco (1891)
	late Rupelian-early Chattian (Greece)		Harzhauser (2004), Wielandt-Schuster *et al.* (2004)
Melanopsis impressa		Oligocene-late Miocene	Wolf (1897), Strausz (1966), Baldi (1973), Harzhauser & Kowalke (2001), Harzhauser & Mandic (2001)
	late Rupelian-early Chattian (Greece)		Harzhauser (2004)
	late Pliocene (Mediterranean Sea)		Rust (1997)

Fossils	Paleogeographic and stratigraphic distributions		References
	eastern Atlantic/Tethys	central/eastern Paratethys	
Terebralia bidentata	late Oligocene-early Miocene (France)		Lozouet (1986), Lozouet *et al.* (2001)
	late Rupelian-early Chattian (Greece)		Harzhauser (2004)
		early-middle Miocene	Baldi & Steininger (1975)
	late Burdigalian (Mut Basin, S Turkey)		Erünal-Erentöz (1958), Mandic *et al.* (2004)
	middle-late Miocene (Adana Basin, S Turkey)		Erünal-Erentöz (1958)
	late Burdigalian (Antalya Basin, SW Turkey)		İslamoğlu (2002), İslamoğlu & Taner (2004)
Tympanotonos conjunctoturris	Rupelian (Italy)		Sacco (1895)
Tympanotonos trochlearispina	Rupelian (Italy)		Sacco (1895)
Tympanotonos margaritaceus	Rupelian (Italy)		Sacco (1895)
	Aquitanian (SW France)		Lozouet *et al.* (2001)
		Oligocene-middle Miocene	Wolf (1897), Baldi (1973), Harzhauser (2004)
Granulolabium plicatum		Oligocene-early Miocene (central Paratethys)	Hörnes (1856), Wolf (1897), Harzhauser & Kowalke (2001), Harzhauser & Mandic (2001), Schaffer (1912), Moisescu (1972)
	early Miocene (France)		Lozouet (1986), Lozouet *et al.* (2001)
	late Rupelian-early Chattian (Iran, Greece)		Harzhauser (2004), Wielandt-Schuster *et al.* (2004)
Haustator conofasciata	Oligocene (northern Italy, Pakistan)		Sacco (1895), Vredenburg (1928)
	late Rupelian-early Chattian (Greece)		Harzhauser (2004)
Haustator imbricataria		early Eocene-Oligocene (Romania, Hungary, Caucasia)	Mészáros (1957), Karagiuleva (1964)
	Eocene (France, Belgium, Italy)		Boussac (1911)
Pycnodonte gigantica callifera	middle-late Eocene, Rupelian (France)		Boussac (1911), Harzhauser & Mandic (2001)
	Oligocene (Italy)		Coletti *et al.* (1973)
		Middle-late Eocene (Bulgaria, Romania, Hungary)	Karagiuleva (1964)
	Rupelian-Chattian (Mainz Basin)		Gürs (1995)
		Oligocene (central Paratethys)	Wolf (1897), Hölzl (1962), Baldi (1973), Harzhauser & Mandic (2001)
	Oligocene (North Sea Basin)		Görges (1952)
	Rupelian (Paris Basin, France)		Cossmann (1921)
Spondylus bifrons	Oligocene (N Italy)		Sacco (1898)
	Late Eocene (France)		Boussac (1911)
		middle-late Eocene (Bulgaria, Ukrania)	Karagiuleva (1964)

Fossils	Paleogeographic and stratigraphic distributions		References
	eastern Atlantic/Tethys	**central/eastern Paratethys**	
Hyotissa hyotis	Rupelian (N Italy)		Sacco (1904)
	Rupelian (Paris Basin, France)		Gitton *et al.* (1986)
	late Eocene-Oligocene (France)		Deshayes (1824), Boussac (1911), Cossmann (1922)
		Oligocene (Germany), late Eocene-Oligocene (Bulgaria)	Wolf (1897), Karagiuleva (1964)
	late Burdigalian (Mut Basin, S Turkey)		Mandic *et al.* (2004)
	Burdigalian (Kale-Tavas Basin, SW Turkey)		İslamoğlu *et al.* (2007)
Mytilus (*Crenomytilus*) *aquitanicus*	late Oligocene-middle Miocene (NW France)		Cossmann & Peyrot (1914)
	late Burdigalian (Mut Basin, S Turkey)		Mandic *et al.* (2004)
		late Oligocene-early Miocene (central Paratethys)	Hörnes (1870), Wolf (1897), Steininger *et al.* (1971), Moisescu (1972), Studencka *et al.* (1998), Harzhauser & Mandic (2001)
Pitar villanovae	late Eocene (France)		Boussac (1911)
		late Eocene-middle Oligocene (Hungary, Romania, Caucasia)	Mészáros (1957)
Gari cf. *protracta*	late Rupelian-Chattian (Liguria/Italy)		Sacco (1891), Venzo (1937)
		late Kiscellian-early Egerian (central Paratethys)	Wolff (1897), Senes (1958), Baldi (1973), Harzhauser & Mandic (2001)
Panopea menardi	Rupelian-Chattian (North Sea)		Nyst (1836), Görges (1952)
	Miocene (North Sea)		Glibert (1945)
	Rupelian (Paris & Mainz Basins)		Gürs (1995)
	Late Chattian (Italy)		Venzo (1937)
	Aquitanian-Tortonian (N Italy)		Sacco (1901)
	Burdigalian-Serravallian (Lusitanian Atlantic region)		Dollfus & Dautzenberg (1902), Cossmann & Peyrot (1909)
	late Burdigalian (Kasaba Basin, SW Turkey)		İslamoğlu (2004), İslamoğlu & Taner (2002)
		late Oligocene-middle Miocene (eastern Paratethys)	Popov *et al.* (1993), Nevesskaja *et al.* (1993)
		Oligocene, early-midlle Miocene (Badenian) (central Paratethys)	Hörnes (1870), Wolf (1897), Studencka *et al.* (1998)

TABLE 3. — Paleo(bio)geographic distribution of the molluscan species from the Denizli and Kale-Tavas subbasins during the late Rupelian-early Chattian in the Mediterranean-Iranian, Indian-eastern African and Danubian Provinces: **A**, SW France (Aquitaine and Paris Basins): Deshayes 1824; Sacco 1904; Cossmann 1919, 1921; Gitton *et al*. 1986; Gürs 1995; **B**, N Italy (Piedmonte Basin): Sacco 1890-1904, Mészáros 1957; **C**, Greece (Mesohellenic Basin): Harzhauser *et al.* 2002; Harzhauser 2004; Wielandt-Schuster *et al.* 2004; **D**, Iran (Esfahan-Sirjan Basin): Harzhauser *et al.* 2002; **E**, Pakistan and NW India: Vredenburg 1928; **F**, Germany (Mainz Basin, South Bavaria): Wolf 1897; Gürs 1995; **G**, Austria (lower & upper Austria molasse Basin): Harzhauser & Mandic 2001; **H**, Romania (Transilvania Basin): Mészáros (1957); **I**, Bulgaria, former Soviet Union and Georgia: Karagiuleva 1964; Kojumdgieva & Sapundgieva 1981; Popov & Titova 1982; Popov *et al.* 1985; Popov 1993.

	Mediterranean/Iranian Province				**W Indian/ E African Province**	**Danubian Province**			
	E Atlantic/ W Mediterranean		**eastern Mediterranean**			**western Para-tethys**	**central Para-tethys**	**eastern Paratethys**	
	A	B	C	D	E	F	G	H	I
Gastropoda									
Agapilia picta	x	x	x	x		x	x		
Ampullinopsi crassatina	x	x	x	x	x	x		x	
Globularia gibberosa	x	x	x	x	x				
Melanopsis impressa		x	x			x	x		x
Terebralia bidentata	x	x	x		x				
Tympanotonos conjunctoturris		x							
Tympanotonos margaritaceus	x	x	x			x	x		x
Tympanotonos trochlearispina		x							
Granulolabium plicatum	x	x	x	x	x	x	x		x
Haustator conofasciata	x	x	x		x				
Haustator imbricataria								x	
Bivalvia									
Pycnodonte gigantica callifera		x				x	x		x
Spondylus bifrons	x	x							x
Hyotissa hyotis	x	x				x			
Mytilus (Creno-mytilus) aquitanicus	x					x	x		
Pitar villanovae	x	x							x
Gari cf. *protracta*		x				x	x	x	
Panopea menardi	x					x			