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ORIGINAL PAPER

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Presence and tectonic significance of Cretaceous rudist species in the so-called Permo-Carboniferous Göktepe Formation, central Menderes metamorphic massif, western Turkey

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Abstract A schist sequence of the central Menderes Massif, in which lenses of fossiliferous marbles are found, is observed in the southern flank of the Aydın Mountain, north of Köşk (Aydın), around Eğrikavak village. These rocks have been considered as Permo-Carboniferous in age and are included in the Göktepe Formation of earlier studies. However, some rudist species are described from thickly bedded gray marbles that have a concordant contact with the overlying schist sequence. Although the rudists have been metamorphosed, it is observed that some contain fossils are well enough preserved to determine the following rudist fauna: *Hippurites lapeirousei* (GOLDFUSS), *Hippurites nabresinensis* FUTTERER, *Hippurites* cf. *colliciatus* WOODWARD. This rudist fauna dates the schist sequence as Santonian–Campanian. The schist sequence is overlain by a thick tectonostratigraphic pile of orthogneiss which has been interpreted as the Pan-African metamorphic core of the Menderes Massif. A widespread cataclastic and mylonitic zone is present between the underlying rudist-bearing marbles and the structurally overlying orthogneiss sequence. The existing kinematic studies in the footwall and hangingwall of this tectonic contact reveal two different phases of deformations, a contractional phase followed by an extensional phase. During the contractional event, which occurred at 36 Ma, the orthogneiss sequence was thrust faulted northwards over the schist sequence. This thrust fault was later reactivated as a low-angle normal fault beneath a supradetachment sedimentary basin of Early-Middle Miocene age. The fossil discoveries of this study and the existing kinematic studies reveal that a new structural model for the central Menderes Massif in which the tectonometamorphic units form a major southward closing recumbent fold needs to be reviewed.

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Introduction

The Menderes Massif is an extensional metamorphic core complex (Bozkurt and Park 1994; Hetzel et al. 1995) in the western Anatolian extensional province (Şengör 1987). Two different stages of crustal extensional events, namely an extensional collapse followed by a rift stage, characterize the province (Seyitoğlu et al. 1992; Sözbilir and Emre 1996; Koçyiğit et al. 1999; Bozkurt 2000; Lips et al. 2001). The Massif itself is bordered by the İzmir-Ankara Zone in the north (Şengör and Yılmaz 1981), and by the Lycian nappes in the south (de Graciansky 1972).

A sequence of high-grade metamorphic core rocks overlain by a low-grade metamorphic cover has long been accepted as the stratigraphy of the Menderes Massif (Schuiling 1962; Dürr 1975; Çağlayan et al. 1980; Şengör et al. 1984; Dora et al. 1990). However, recent studies have provided evidence that the core sequence is not the lowest structural unit of the Menderes Massif, but is emplaced above a younger cover sequence (Candan et al. 1992; Hetzel et al. 1995, 1998; Emre and Sözbilir 1997; Gessner 2000; Lips et al. 2001). This phenomena is particularly well observed in the central Menderes Massif (Fig. 1).

Okay (2001) has claimed that the central Menderes is an inverted metamorphic sequence, and proposed a new and provocative structural model that is characterized by a large-scale recumbent anticline having a core of Precambrian–Cambrian orthogneiss. According to Okay, the overturned limb of the fold consists of an inverted sequence of fusulinid-bearing Göktepe Formation and the conformably overlying schist sequence in the Aydın Mountain. He claimed that recrystallized dark limestones of the Göktepe Formation carry brachiopods, algae and fusulinid-type foraminifera attesting to a Permo-Carboniferous age, without giving any names and figures of the mentioned fossils. However, we have discovered for

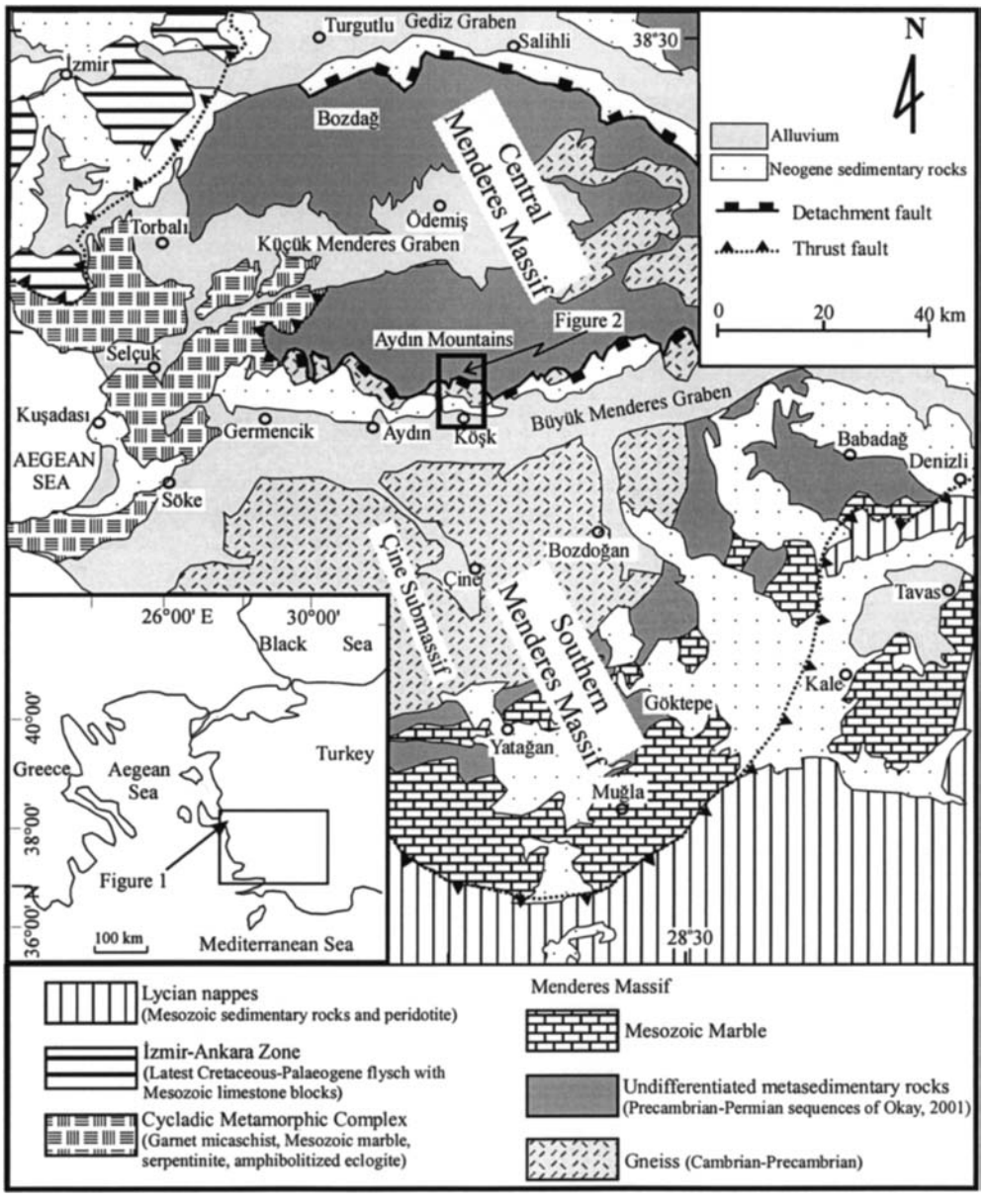

Fig. 1 Simplified geological map of the central and southern Menderes Massif (compiled from Çağlayan et al. 1980; Dora et al. 1990, 1995; Gessner 2000; Özer et al. 2001; Okay 2001). *Inset* shows location of Fig. 1. The geology of the framed area is indicated in Fig. 2

the first time some recognizable rudist species in the so-called Göktepe Formation, which forms the southern flank of the Aydın Mountain in an area south of Eğrikavak village (Fig. 2).

The aim of this study is to present new palaeontological evidence supporting the Late Cretaceous age of the so-called Göktepe Formation, and to show its importance in the tectonic evolution of the Menderes Massif.

Stratigraphy and palaeontology

The structural studies of the rocks exposed around Eğrikavak village, an area north of Köşk (Aydın), reveal two distinct tectonostratigraphic units that are separated by a low-angle normal fault (Fig. 2). The structurally lower sequence has recently been named the Göktepe Formation by Okay (2001). It is characterized by a thick-bedded marbles at the bottom followed by a succession of schist intercalated with marbles towards the top. The thick-bedded marbles, up to 200 m thick, are exposed along the Koçak stream southeast of Eğrikavak village.

New occurrences of rudists have been found in the marbles (Fig. 3). The rudist fauna consist mainly of hippuritids such as *Hippurites lapeirousei* (GOLDFUSS), *Hippurites nabresinensis* FUTTERER, *Hippurites* cf. *colliciatus* WOODWARD. Some indeterminable radiolitid sections (*Durania* sp., *Sauvagesia* sp.) are also observed. These hippuritid species are well known and have been identified in Santonian-Campanian marbles of the southern sector of the Menderes Massif, around the Akbük-Milas and Yatağan-Kavaklıdere areas (Özer 1993, 1998; Özer et al. 2001).

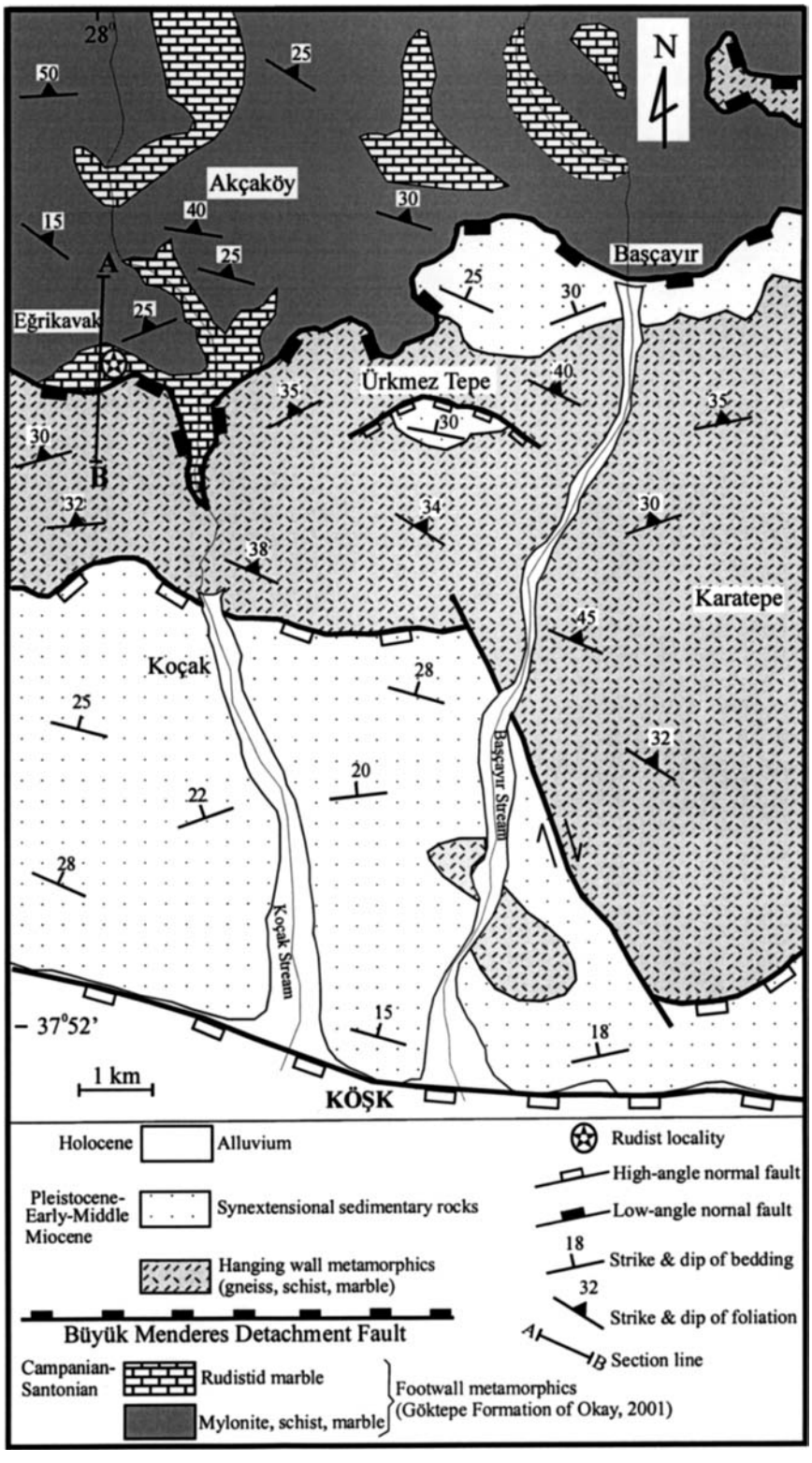

Fig. 2 Detailed geological map of the Eğrikavak area, north of Köşk (Aydın) (modified from Emre and Sözbilir 1997 and own field observations). *A–B* refers to cross section in Fig. 4

Hippurites nabresinensis has been reported from the Santonian–Campanian megablock limestones of the İzmir-Ankara zone (Özer 1989) and is found also from the Santonian–Campanian limestones of Slovenia, Croatia, Austria, Italy and Romania (Milovanovic 1934; Plenicar 1960, 1975; Lupu 1976; Polsak 1979; Accordi et al. 1982). This species has also been identified in Maastrichtian limestones of Bosnia (Sladic-Trifunovic 1972) and Bulgaria (Pamouktchiev 1981).

Hippurites lapeirousei is widespread in the Campanian–Maastrichtian of the Mediterranean province (Sanchez 1981). *Hippurites colliciatus* is found from the Santonian

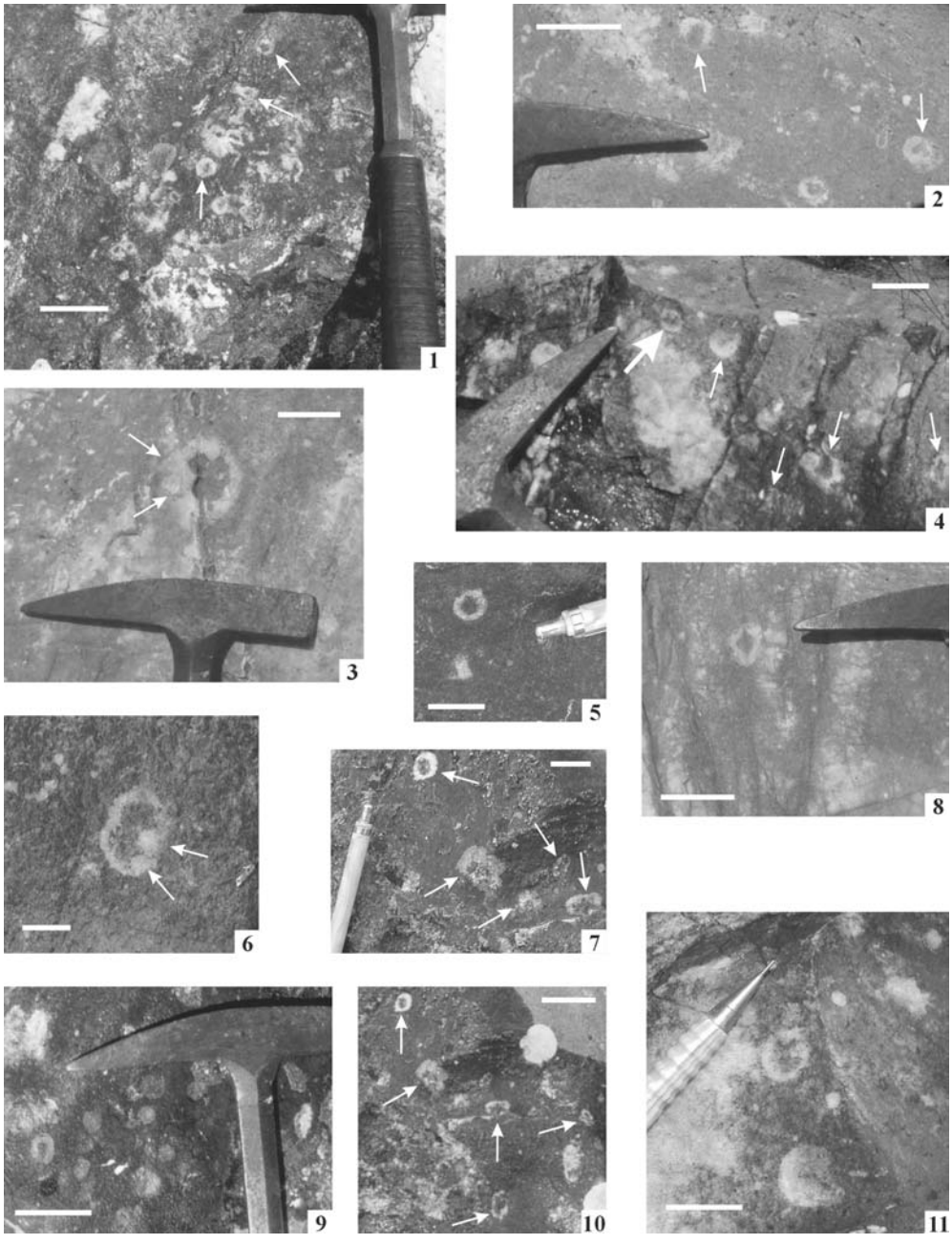

Fig. 3 Field photographs illustrating several rudist sections from the marbles, south of Eğrikavak village. **1** Marbles consist of many hippuritid sections. Some sections (*arrows*) show the characteristic siphonal pillar features of *Hippurites lapeirousei* (GOLDFUSS). *Scale bar* 5 cm. **2** Marbles with hippuritid sections (*arrows*). *Scale bar* 4 cm. **3** *Hippurites* cf. *colliciatus* WOODWARD. Transverse section of the lower valve. Note the preservation of ridge costae (*arrows*). *Scale bar* 5 cm. **4** Marbles including hippuritid sections (*thin arrows*) and transerve section of the lower valve of *Hippurites nabresinensis* FUTTERER (*thick arrow*). *Scale bar* 1 cm. **5** *Hippurites lapeirousei* (GOLDFUSS). Transverse section of the lower valve. *Scale bar* 1 cm. **6** Hippuritid section showing partly preserved siphonal pillars (*arrows*). *Scale bar* 1 cm. **7** Hipputitid sections belonging probably to *Hippurites lapeirousei* (GOLDFUSS) (*arrows*). *Scale bar* 1 cm. **8** *Hippurites lapeirousei* (GOLDFUSS). Transverse section of the lower valve. Note slightly developed siphonal pillars. *Scale bar* 4 cm. **9** Marbles with many hippuritid section, *Scale bar* 4 cm. **10** Marbles showing the transverse section of the lower valve of *Hippurites lapeirousei* (GOLDFUSS) (*arrows*). *Scale bar* 3 cm. **11** *Hippurites nabresinensis* FUTTERER. Transverse section of the lower valve. The siphonal pillars are clearly observed. *Scale bar* 2 cm

of Austria, Italy (Apennines), Yugoslavia (Dinarids), Romania, Greece and Iran (Sanchez 1981), the Campanian–Maastrichtian of the Apennines (Cestari and Sirna 1989), Carpathians (Andrusov 1976) and in Tunisia (Negra and Philip 1986), and from the Middle Campanian of Bulgaria (Swinburne et al. 1992), and Maastrichian of southern Italy (Borgomano and Philip 1989). This species is also present in Upper Senonien limestones of Turkey (Karacabey 1968; Özer 1994; Steuber et al. 1998; Fenerci 1999). The reported rudist species indicates a Santonian-Campanian age for the marbles of the Eğrikavak area.

The rudist-bearing marbles are tectonically overlain by a thick gneiss sequence (Figs. 2, 4) that consists dominantly of bluish augen gneiss in which an older granitic texture can be recognized. In the sequence, rare biotite schists and metagabro lenses were also observed (Candan et al. 1992; Oberhansli et al. 1997, 1998). East of Eğrikavak village, near Başçayır, a sedimentary sequence of Early-Middle Miocene age (Emre and Sözbilir 1997; Akgün and Akyol 1999) is exposed above both the rudist-bearing sequence and the gneiss sequence (Emre and Sözbilir 1997). The sedimentary sequence rests unconformably on the gneiss sequence, but is in fault contact with the underlying rudist-bearing sequence (Fig. 2).

The contact between these two tectonostratigraphic sequences is the previously documented south-dipping Büyük Menderes detachment fault (also termed the Başçayır detachment by Emre and Sözbilir 1997, and

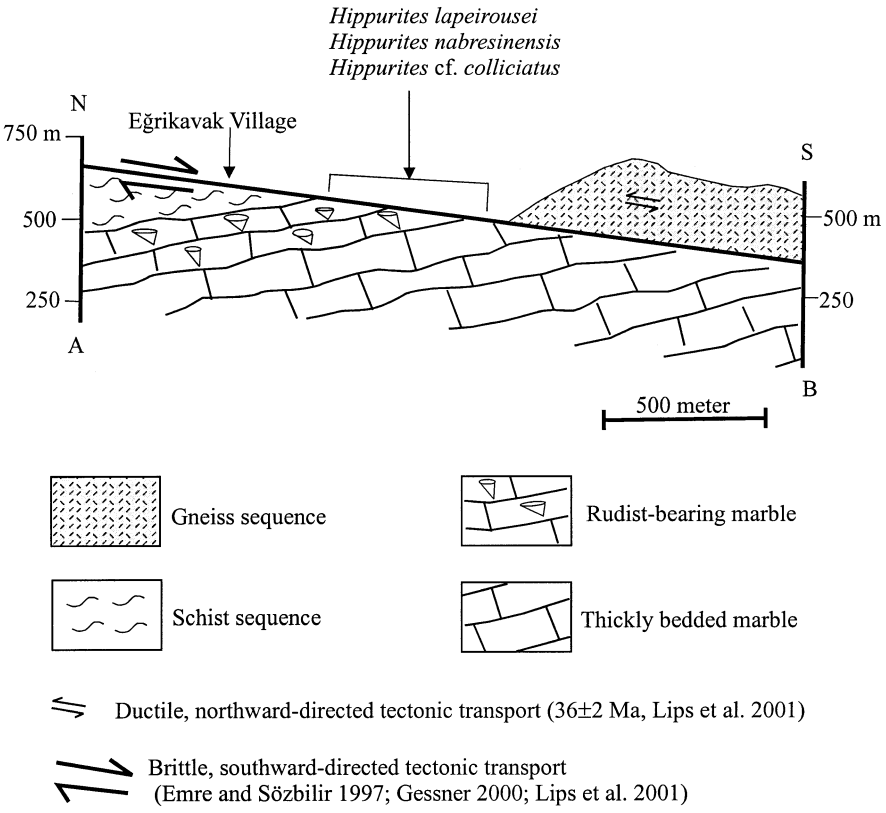

Fig. 4 Geological cross section showing the contact relationships between the rudist-bearing footwall rocks and the structurally overlying gneiss sequence (see Fig. 2 for location of the section). Note the reactivated nature of the Büyük Menderes detachment fault. The footwall rocks were mapped as the Permo-Carboniferous Göktepe Formation in Figs. 2 and 4 of Okay (2001)

the Güney detachment by Ring et al. 1999) that defines the northern margin of the Miocene supradetachment basin (Lips et al. 2001). The Büyük Menderes detachment fault is characterized by semiductile to brittle fault behavior (Lips et al. 2001). The ductile fabrics indicate a northward tectonic transport of the hangingwall gneiss sequence (Fig. 4) above the rudist-bearing sequence and pre-date subsequent top-to-south detachment faulting (Lips et al. 2001).

Discussion and conclusion

The stratigraphy of the Menderes Massif was based principally on the metamorphic sequences of the Çine submassif where a Pan-African core sequence is overlain by a Palaeozoic-Mesozoic metasedimentary cover sequence. The core sequence is characterized by polyphase deformational events (Dora et al. 1995) and consists of metagranite, paragneiss, schist and migmatite. The oldest dated geological event in the core rock assemblage was the intrusion of the granites at ~550 Ma (Loos and Reischmann 1999; Hetzel and Reischmann 1996; Hetzel et al. 1998). These granites were subsequently transformed to augen gneisses within the Çine submassif.

The overlying metasedimentary cover sequence consists, from bottom to top, of garnet micaschist, mica schist and quartzite with intercalations of Permo-Carboniferous black marble, a thick succession of Mesozoic emery- and rudist-bearing marble, and Palaeocene flysch-like sediments (Dürr 1975; Çağlayan et al. 1980; Şengör et al. 1984; Okay 1985, 1989; Konak et al. 1987; Dora et al. 1995; Özer 1998, 1999; Özer et al. 2001).

This study reveals the presence of rudist species of a Santonian-Campanian age in the cover series of the central Menderes Massif (Fig. 5), north of Köşk (Aydın); these rocks were originally mapped and correlated with the Permo-Carboniferous Göktepe Formation by Okay (2001). Equivalent units consisting of a schist sequence with marble intercalations and rudist-bearing marbles are also well exposed in the southern sector of the Menderes Massif around Yatağan-Kavaklıdere (Özer 1998; Özer et al. 2001).

The type Göktepe Formation was described from the Göktepe region, north of Muğla, where it consists of bituminous and fossiliferous dark marble intercalated in schist and quartzite (Önay 1949; Schuiling 1962; Çağlayan et al. 1980). In this type area, Carboniferous and Permian fossils were found and described from the marbles. Equivalent units were also defined in the Babadağ region, southwest of Denizli (Okay 1985) where an alternation of micaschist, quartzite and black marble define the Karıncalıdağ Formation (Okay 1985, 1989). The black marbles contain gastropods, crinoids and foraminifera, indicating a Permo-Carboniferous age. This unit is conformably overlain by Mesozoic dolomitic marble of the Yılanlı Formation.

The contact relationship between the Pan-African core and the overlying Paleozoic-Mesozoic cover sequence in the southern Menderes Massif has not yet been resolved.

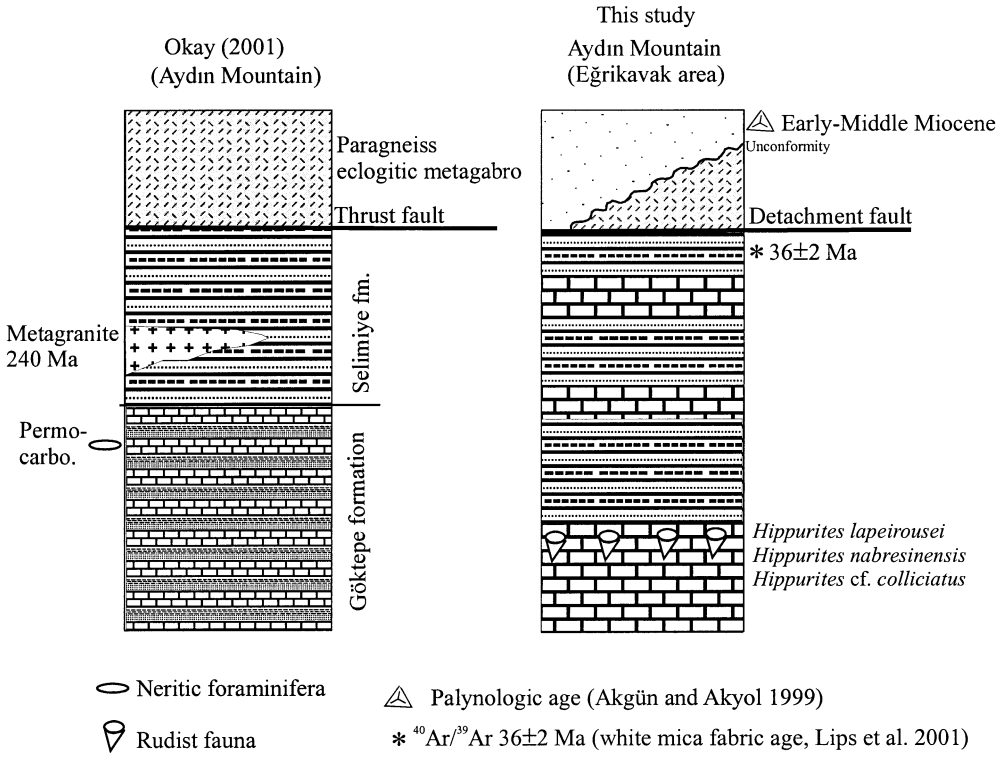

Fig. 5 Stratigraphic columnar section of the study area and its correlation with that of Okay (2001)

According to Dürr (1975), Çağlayan et al. (1980), Şengör et al. (1984), Konak et al. (1987) and Dora et al. (1990, 1995), the basal part of the cover sequence in the southern Menderes Massif is characterized by a metaconglomerate that contains clasts derived from the core series. However, Bozkurt and Park (1994) claimed that the so-called core metagranite is, in fact, a synextensional granite intruded into the overlying cover schist along a top-to-south extensional shear zone during the Late Oligocene. Recently, Ring et al. (1999) argued for the same contact as a thrust fault.

The contact between the core and the cover sequence has also been observed on the central Menderes Massif, but with a reverse stratigraphic order, where the older core units were emplaced on the younger cover sequence (Fig. 5; Candan et al. 1992; Emre and Sözbilir 1997; Hetzel et al. 1998; Lips et al. 2001; Okay 2001). Tectonic klippen of the gneissic basement have been reported on top of the cover sequence in the central submassif, south of Salihli (Hetzel et al. 1995; Emre and Sözbilir 1997) and north of Aydın (Candan et al. 1992; Emre and Sözbilir 1997). Although the contact south of Salihli has been described and accepted as a detachment fault (Hetzel et al. 1995; Emre and Sözbilir 1997; Hetzel et al. 1998; Lips et al. 2001; Sözbilir 2001), the contact north of Köşk has been interpreted both as a thrust fault (Candan et al. 1992; Dora et al. 1995; Okay 2001) and a low-angle normal fault (a reactivated thrust fault, Emre and Sözbilir 1997; Lips et al. 2001; Gessner et al. 2000).

Northward tectonic transport by thrust faulting throughout the core sequence has been documented by Hetzel et al. (1998), Ring et al. (1999) and Lips et al. (2001). The timing of this tectonic event was interpreted to be Pan-African (Ring et al. 1999) or Alpine (Hetzel et al. 1998; Lips et al. 2001) in age. The presence of rudists in the underlying marble indicates that the emplacement of the gneiss sequence over the rudist-bearing cover sequence must have occurred after the Late Cretaceous, probably at ~35–40 Ma, a time of imbrication of the Menderes sequence by northward directed thrusting (Lips et al. 2001). During the extensional collapse of the Lycian orogen (Collins and Robertson 1997, 1998, 1999) in the latest Oligocene to Early Miocene (Seyitoğlu et al. 1992), some of these thrust faults were reactivated as low-angle normal faults (or detachment faults) beneath major supradetachment basins. Lacustrine supradetachment basin fill deposits rest unconformably on the hangingwall gneiss sequence, but are in fault contact with the underlying rudist-bearing footwall sequence. This suggest that the gneiss klippen together with the overlying synextensional sedimentary sequence have been transported as extensional allochthons (Emre and Sözbilir 1997) towards the south along the Büyük Menderes detachment fault.

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