Cretaceous rudist-bearing platform carbonates from the Lycian Nappes (SW Turkey): Rudist associations and depositional setting

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ABSTRACT

Lycian Nappes (in SW Turkey) lie between the Menderes Massif and Bey Dağları carbonates and comprise thrust sheets (nappes piles) of Paleozoic-Cenozoic rocks, ophiolitic and tectonic mélanges and serpentinitized peridotites. This study focuses on identification of rudists and their palaeoenvironmental features observed within the Cretaceous low grade metamorphic successions (dominated by recrystallized limestones) from the Tavas and Bodrum nappes. The study is based on fifteen stratigraphic sections measured from Tavas, Fethiye, Koycegiz, Bodrum, Oren and Bozbüren areas. The Lower Cretaceous successions with rudists are very sparse in the Lycian Nappes and a unique locality including a Berriasian epidiceratid-requieniid assemblage is reported so far. A new requieniid-radiolitid assemblage was found within the pre-Turonian (?Albian-?Cenomanian) limestones. Four different Late Cretaceous rudist assemblages were firstly identified as well: 1) Caprinid-Ichthyosarcolitid assemblage (middle-late Cenomanian); 2) Distefanellid assemblage (late Turonian); 3) Hippuritid-Radiolitid assemblage (late Coniacian-Santonian-Campanian); 4) Radiolitid-Hippuritid assemblage (middle-late Maastrichtian). Microfacies data and field observations indicate that the rudists lived in the inner and outer shelves of the Cretaceous carbonate platform(s) in this critical part of the Neotethys Ocean. Rudists formed isolated patchy aggregations in very shallow palaeoenvironments and deposited as shell fragments particularly on the outer shelf environment, which is characterized by higher energy and platform slope characteristics.

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1. Introduction

The Late Cretaceous rudist faunas are a typical constituent of the Cenomanian-Maastrichtian formations and distributed widely in various tectono-stratigraphic units of Turkey (Fig. 1A) such as the Istanbul Zone, central Anatolia, central and eastern Pontides of the Sakarya Zone, Bornova Flysch Zone, metamorphic massifs (Menderes Massif, Tavşanlı and Afyon zones), Bey Dağları Autochthon and eastern Anatolia of the Anatolide-Tauride Block and southeastern Anatolia of the northernmost part of the Arabian Platform/Plate (see Steuber, 2002 for complete list; Özer, 2002, 2010a,b; Özer et al., 2008, 2009; Sari, 2006a,b; Sari and Özer, 2002, 2009; Sari et al., 2004; Steuber et al., 2009). The Early Cretaceous rudist faunas are only known from the Zonguldak-Amasra area in the western Pontides, the Karaburun Peninsula in the western Turkey and Bey Dağları in the western Taurides until now (Douvillé, 1896; Fenech-Masse, 2006; Mars et al., 2002, 2004, 2008, 2009). Although there is much information about the stratigraphic and geographic distribution of rudists in Turkey, we have almost no data on the rudists in the Lycian Nappes, which is one of the important tectono-stratigraphic units in the western Anatolia. The presence of the rudists and/or their fragments was reported from the platform-type carbonates of the Lycian Nappes (Akdeniz, 2011a,b; Bernoulli et al., 1974; Collins and Robertson, 1997, 1998, 1999, 2003; de Graciansky, 1968, 1972; de Graciansky et al., 1967; Gutnick et al., 1979; Kaaden and Metz, 1954; Konak, 2007; Konak et al., 1987;
However, none of the studies above focused on the rudists. Some rudists were described from the Cenomanian monotonous, platform-type marbles in a single locality (Serinhisar, Tavas, Denizli) by Özber (1998, 1999) and Özber et al. (2001) and from the Berriasian limestone megablock in the Bodrum area by Masse et al. (2015). The platform carbonates of the Serinhisar area were attributed to the cover rocks of the Menderes Massif in studies of the 1980’s and the 1990’s (Collins and Robertson, 1999; Çağlayan et al., 1980; Okay, 1989; Özber, 1990, 1991). Later, they were included into the Lycian Nappes (Akdeniz, 2011a,b; Konak, 2007; Şenel, 1997a,b,c).

This study deals with the presence of the Cenomanian-Maastrichtian and the Early Cretaceous rudist bivalves (radio-litid, hippocritid, canalicate rudists) from the Lycian Nappes. So, the aims of this study are to present the Cretaceous rudist associations from several localities such as Tavas-Denizli, Köyceğiz, Fethiye, Bodrum, Ören and Bozburun-Muğla areas through the Lycian Nappes (Fig. 1B) and emphasize the depositional
environments characteristics of rudist-bearing platform carbonates of the nappe piles.

2. Material and methods

The rudist material described and interpreted herein comes from the fifteen measured-stratigraphic sections (Figs. 1B, 2–4). The coordinates and explain better of these sections are given in Table 1.

As the rudists are mostly embedded within the pure, indurated limestones, it was impossible to collect matrix-free, loose specimens. We prepared transverse sections of rudists from the collected limestone samples to determine their internal features. The main problem in studying rudist-bearing limestones is recrystallization due to metamorphism during transportation of the nappe piles and internal tectonic movements. Fortunately, we have found stratigraphic intervals including ‘preserved’ rudist shells from several localities. We studied thin sections of the numerous limestone samples collected through the stratigraphic sections to describe the microfacies characteristics and microfossils as well. All the micropalaeontologic data will be presented in separate papers.


3. Geological setting

Lycian Belt is located between the Menderes Massif and the Bey Daglari Autochthon in the western Turkey (Fig. 1B). Various tectonic models have been proposed for the origin of the Lycian Belt. According to the most favored tectonical concepts, the nappes originated from the north of the Menderes Massif and thrust southward during the Late Cretaceous to Burdigalian/Langhian interval (de Graciansky, 1972; Dürr, 1975; Dürr et al., 1978; Gutmich et al., 1979; Ricou et al., 1979; Şengör and Yilmaz, 1981; Okay, 1989; Collins and Robertson, 1997, 1998, 1999, 2003; Güngör and Ergöndan, 2001; Oberhansli et al., 2001; Rimmel et al., 2006; Okay et al., 2012; Pourtau et al., 2016). But, some alternative studies considered a dual origin for the Lycian Nappes. Poisson (1985) proposed that the sedimentary thrust sheets originated from an intra-continental rift basin (the Kızıla-Corakgöl basin, which corresponds to the eastern prolongation of the Ionian Zone of Greece) between the Menderes and the Bey Dagları platforms, except the peridotite nappes drifting from the north of the Menderes Massif. Özay (1990, 1991) suggested that the thrust slices of the Lycian Nappes were derived from the İzmir-Ankara Zone to the north and the Alanya Basin to the south of the Menderes Massif. Essoy (1993a) accepted the dual origin concept of Poisson (1985). The tectonic klippe of the Lycian Nappes are very

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Fig. 2. Measured-stratigraphic sections and key to the stratigraphic sections (see Fig. 1B for locations of the sections). Numbers show meters.
sparse above the Menderes Massif and only found in the Söke-Selçuk area (the Dilek Peninsula) to the west (Güngör and Erdogan, 2001), around the Borlu area to the north (Rimmelé et al., 2006) and in the surroundings of Çal-Çivril area to the east (Sözbilir, 1997; Özler et al., 2001; Rimmelé et al., 2006).

In the early studies the Lycian Nappes were firstly subdivided into three main tectonic units such as: (i) the autochthonous series, (ii) the intermediate complex consisting of imbricated thrust sheets (the Karadağ, the Teke Dere, the Köyceğiz, the Hatticea Dağ and the İnlice series) and (iii) the peridotite nappe (de Graciansky et al., 1967; de Graciansky, 1968, 1972; Bernoulli et al., 1974). Later, the Lycian Nappes were separated into eight units (i.e. the Tavas, the Bozdağ, the Domuzdağ, the Yavuz, the Yeleme, the Gümüşlü, the Gülbahar, the ophiolitic nappe, the Kızılcadağmelange) by Poisson (1977), four major units (i.e. the Elmalı, the Köyceğiz, the Tavas, the Tefenni units) by Özkaya (1990), eight structural units (i.e. the Beydağları Autochthon, the Marmaris Ophiolitic Nappe, the Yeşilbarak, the Tavas, the Bodrum, the Dumanılağ, the Domuz Dağ,
the Gülbahar nappes) by Şenel (1997a,b,c) and three tectono-stratigraphic units (i.e., the Lycian thrust sheets consisting of Yavuz, Karadağ, Teke and Köyçezig units, the Lycian melange and the Lycian peridodite thrust sheet) by Collins and Robertson (1997, 1998, 1999). The rudists examined in this study come from the Köyçezig and the Ilnice Series of de Graciansky (1972), the Tavas and the Bozdag massifs of Poisson (1977), the Köyçezig and the Tavas units of Özkaya (1990), the Tavas and the Bodrum nappes of Şenel (1997a,b,c) and the Köyçezig thrust sheet of Collins and Robertson (1997, 1998). The tectono-stratigraphic nomenclature (the Tavas and the Bodrum nappes) followed here is that of Şenel (1997a,b,c).

When examining previous studies, we can suggest that the Tavas and the Bodrum nappes show almost the same lithologic succession consisting of alternation of limestones and cherty limestones. However, dolomitic limestones, cherty limestones and calciturbiditic limestones are more dominant in the Bodrum nappe, which tectonically overlies the Tavas nappe. The main difference between the Tavas and the Bodrum nappes is the presence of chert breccias named as ‘Sırna breccia’ in the uppermost part of the Upper Cretaceous succession of the Bodrum nappe, separating the platform-type carbonates from the turbidites. The Sırna breccia does not exist in the Tavas Nappes and the coeval stratigraphic interval is represented by an unconformity.

4. Stratigraphy and comparison

The rudists are found in the slightly metamorphic limestones of the Tavas, Fethiye, Köyçezig, Ören, Bodrum and Bozbunur areas. Location of the rudist-bearing measured-stratigraphic sections are given in Fig. 1B and the sections are presented in Figs. 2–4. The rudist contents of the measured-stratigraphic sections are presented in the following chapter.

4.1. Tavas area

Mesozoic monotonous platform-type limestones, showing low-grade metamorphism, have widespread outcrops between Tavas and Denizli (Fig. 1B). Previous studies suggest an imbricated internal structure for these carbonates (Collins and Robertson, 1999; Okay, 1989; Özkaya, 1990; Poisson, 1977, 1985). Microfosils are very poor or absent in these limestones due to the metamorphism. However, the rudist-bearing limestones can be found in the topmost part of the sequence, as explained below in Sarpdere (Serînhisar) section (Fig. 2A). They are the unique and important palaeontologic data for the recrystallized carbonate sequence in the area (Çağlayan et al., 1980; Özkaya, 1990; Özer, 1998; Özer et al., 2001; Özer and San, 2008). Three stratigraphic sections with rudists were measured in this area (Fig. 2A–C). Sarpdere section belongs to Tavas nappe, Külbaha and Balkica sections to Bodrum nappe (Akdeniz, 2011a,b; Şenel, 1997a,b,c). The details of the sections are given below;

4.1.1. Sarpdere section

Sarpdere is located to the north of Serînhisar town (formerly Kızlıhisar) in the Tavas area (Fig. 1B) and represents an excellent outcrop of rudist-bearing limestone that allowed us to understand the stratigraphy of the carbonate sequence. Our new observations show that the uppermost part of the Babadağ Formation consists of, in ascending order (Fig. 2A), (i) a 40–50-m-thick, intercalation of grey, massive dolomitic limestones and dark grey, un fossiliferous massive limestones, (ii) a 15–20-m-thick, dark grey, bituminous, thick-bedded limestones with canaliculate rudists indicating a middle-late Cenomanian age. Some radiolitids, requeniids and Chondrodonta sp. are also present (Fig. 5A–E). (iii) a 20–25-m-thick, grey, un fossiliferous massive limestones, (iv) a 15–20-m-thick, light grey, thick-bedded limestones characterized mainly by Distefanolana, but radiolitids and hippuritids are also present (Fig. 5F–N). The rudists indicate a late Turonian age, (v) a 15–20-m-thick, un fossiliferous thick-bedded limestones. This succession shows low grade metamorphism effects and so the microfossils are totally masked due to the recrystallization. The depositional texture can be only observed in upper Turonian limestones. Internal structure of the rudists can be distinguished despite the recrystallization.

Rudist-bearing limestones are unconformably overlain by megabreccias consisting mainly of serpentinites and limestone clasts and also limestone blocks with middle-upper Cenomanian and upper Turonian rudists in the reddish-metaclastic matrix of the Faralya Formation (Fig. 2A). These megabreccias rest on the various stratigraphic levels of the rudist-bearing platform-type limestones and contain intercalation of reddish, cherty and laminated micritic limestones, mudstones, conglomerates and sandstones to the top. The matrix of the Faralya Formation yields nanofossils suggesting an early Oligocene–early Miocene age (Özer et al., 2016).

Previous studies suggested Late Cretaceous or Cenomanian and Santonian ages for the rudist-bearing limestones in this section (Çağlayan et al., 1980; Okay, 1989; Özkaya, 1990; Özer, 1998; Özer et al., 2001, 2008; Akdeniz, 2011a). But, the new data obtained from the Late Cretaceous rudist fauna in the Sarpdere section indicate middle-late Cenomanian and late Turonian ages for the limestones. The Cenomanian-Turonian succession of the Sarpdere section shows clear similarity with the rudist-bearing limestones of the Bey Dağları Carbonate Platform (Özer, 1988; Sarı, 2006a; Sarı

Table 1

<table>
<thead>
<tr>
<th>No</th>
<th>Section</th>
<th>Location</th>
<th>UTM Coordinates (35S)</th>
<th>Fig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sarpdere</td>
<td>1 km north of Serînhisar town (formerly Kızlıhisar)-Tavas</td>
<td>0700201/4163554; 0700259/4163524</td>
<td>2A</td>
</tr>
<tr>
<td>2</td>
<td>Külbaha</td>
<td>10 km southwest of Serînhisar town, near Kızlıhisar village</td>
<td>0688930/4152406</td>
<td>2B</td>
</tr>
<tr>
<td>3</td>
<td>Balkica</td>
<td>25 km south of Tavas town, 1 km east of Balkica village</td>
<td>0687620/4130297; 0687744/4133476</td>
<td>2C</td>
</tr>
<tr>
<td>4</td>
<td>Hisarköy</td>
<td>64 km northeast of Fethiye, southeast of Urümük Dağ, around Hisarköy village</td>
<td>0691733/4110505; 0690475/4115850</td>
<td>2D</td>
</tr>
<tr>
<td>5</td>
<td>Çal Dağ</td>
<td>22 km northwest of Fethiye, 6 km northwest of Arpacık (formerly Nif) village</td>
<td>0688880/4082227; 0691755/4081569</td>
<td>2E</td>
</tr>
<tr>
<td>6</td>
<td>İnce</td>
<td>5 km east of Göçek town, north of İncevillage</td>
<td>0677407/4070017; 0677044/4069119</td>
<td>3A</td>
</tr>
<tr>
<td>7</td>
<td>Bayyarp Tepe</td>
<td>18 km northeast of Köyceğiz town, 7 km west of Ormanlar village</td>
<td>0666170/4010942; 0666156/4010578</td>
<td>3B</td>
</tr>
<tr>
<td>8</td>
<td>Akdikmen Tepe</td>
<td>15 km northeast of Köyceğiz town</td>
<td>0659540/4097855; 0659157/4098570</td>
<td>3C</td>
</tr>
<tr>
<td>9</td>
<td>Bozbunur Tepe</td>
<td>23 km southeast of Köyceğiz town</td>
<td>0646207/4070449; 0646052/4070553</td>
<td>3D</td>
</tr>
<tr>
<td>10</td>
<td>Konaack</td>
<td>3 km northwest of Bodrum town, northeast of Konaak village</td>
<td>0535816/4101635; 0536731/4102034</td>
<td>3A</td>
</tr>
<tr>
<td>11</td>
<td>Antenler</td>
<td>3 km northeast of Bodrum town</td>
<td>0535934/4102445; 0535930/4102230</td>
<td>3A</td>
</tr>
<tr>
<td>12</td>
<td>Bitez</td>
<td>3 km southwest of Bodrum town, near Bitez</td>
<td>0533821/4097382; 0533808/4097230</td>
<td>3D</td>
</tr>
<tr>
<td>13</td>
<td>Gökbül</td>
<td>Between YukarıMazköy and Gökbül villages, 2 km northwest of Gökbül village</td>
<td>0567365/4099593; 0567359/4098273</td>
<td>3C</td>
</tr>
<tr>
<td>14</td>
<td>Kıyıkşlak</td>
<td>5 km southwest of Kıyıkşlak village</td>
<td>0551076/4126024; 0549298/4125720</td>
<td>4D</td>
</tr>
<tr>
<td>15</td>
<td>Selimiye</td>
<td>10 km northeast of Bozbunur town, 6 km northeast of Selimiye village</td>
<td>0591952/4065148; 0598525/4065140</td>
<td>4E</td>
</tr>
</tbody>
</table>
Fig. 5. Rudists of the Sarpdere section (C–N are the outcrop photographs): A–E-middle-upper Cenomanian rudists (A and C from Ozer, 1988), A–B-Neocaprina gigantea Pleniar, the natural transverse sections of the right valve, sample nos S 92 01/M and 14-149R, the ventral canals (black arrow), the accessory cavities (white arrows) and the external carina (Vb) can be observed. Note the ghost appearances of the accessory cavities (white arrows) in B. C-Ichthyosarcolites poljakii Polsak, the transverse section of the right valve. Note the well-developed ridges and small round or oval canals (black arrows). D-Durania sp., the right valve transverse section with thick outer shell layer showing partially preserved polygonal prisms (black arrows). E-Caprinula aff. boissyi d’Orbigny, the oblique section of the right valve showing a row of large canals on inner side following one or three rows of small, round and may be sparse piriform pallial canals (black arrow). F–N-upper Turonian rudists, F-Distefanella montagnai Stikov, the transverse section of the right valve showing the concave radial bands characteristic of the species, G-Distefanella salmojraghii Parona, the transverse and radial sections of the right valves. Note the different shape of valve sections (round, oval or subtriangular), H-Distefanella salmojraghii Parona (Distefanella tavassiana Ozer), the transverse section of the right valve, note the concave radial bands, I-
and Ozer, 2009; Sari et al., 2009). The succession should be compared to sequences of southern Apennines-Italy (Cestari and Laviano, 2012) and of island of Cres-Croatia (Korbar et al., 2001) due to similarities of both lithologic aspects and faunal contents and also having recrystallization.

4.1.2. Kızıla section

Kızıla village is located to the southeast of Tavas town (Fig. 1B), where the first detailed Liassic-uppermost Cretaceous stratigraphic section was presented by Poisson (1977) and Poisson and Sarp (1985). Lower Liassic algal limestones (Ağlıca Formation), overl yliming Upper Liassic-Cenomanian reddish mudstones (Babadag Formation) and uppermost Cretaceous cherty limestones comprising limestone lenses with rudists (Yarankuyu Formation) were reported by Akdeniz (2011a) and Çakmakoğlu (1986). Kızıla section is measured in the ancient marble quarry located approximately 1 km north to the Kızıla village. The base of the approximately 15-m-thick section consists of a 3-m-thick pinkish claystone and lenticular limestone (Fig. 6A, B). A 0.15–0.40-m-thick clast band is parallel to the strike of the limestones. The cherty limestones are intercalated with rudist-bearing bioclastic limestones at the lower half of the section. Upward in the section, intercalations of the grey limestones and bioclastic limestones with rudists are seen. Cherty limestones appear at the top of the section again. The rudists are the main components of the bioclastic limestones and are observed as generally shell fragments. Many right valve sections of Radiolitidae show the prismatic cellular structure of the outer shell layer and a high content of carbon (Fig. 6A, B). The cherty limestones comprise well-preserved planktic foraminifers indicating an early Turonian age for the Yarankuyu Formation (Ozer et al., 2016). Similar pelagic successions are reported from the lowermost Cretaceous-Paleocene turbidites (Collin, 1962; de Graciansky et al., 1967; de Graciansky, 1972; Akdeniz, 2011a). The Çal Dağ section first presented by de Graciansky (1972, fig. 56) was a reference section for the Çal Dağ Limestone unit, which has been referenced in several studies (Akdeniz, 2011a; Bernoulli et al., 1974; Poisson, 1977; Şenel, 1997a,b,c). de Graciansky (1972) reported occurrences of some planktic and benthic foraminifers in the Çal Dağ Limestone and also rudist debris in the Albian-Cenomanian limestones from the Çal Dağ section. The Inlice Series (Inlice-Göcek, NW Fethiye) comprise from bottom to top, unfossiliferous cherty limestones, Maastrichtian limestones with benthic foraminifers and Eocene limestones and detritic rocks with Nummulites, which was recorded by de Graciansky (1972), Poisson (1977) and Şenel (1997a,b,c) as well. According to de Graciansky (1972) and Poisson (1977), Inlice Series belong to “intermediate complex” showing some stratigraphic differences from the other sections of the Lycian Nappes. The Çal Dağ and Hisarköy sections belong to the Bodrum nappe (Akdeniz, 2011a,b; Şenel, 1997a,b,c).

4.1.3. Balkça section

Balkça section was measured to the southernmost of Tavas town (Fig. 1B). This section consists of platform-type carbonates (Çal Dağ Limestone), which are overlain by turbidites (Karabörtlü Formation) (Fig. 3C). The peridodites overthrust the Karabörtlü Formation. The lower boundary of the carbonate succession is not seen in the section. The succession is characterized by a 40–45-m-thick, grey, bioclastic limestones as the base of the section. The rudists are the main components of these bioclastic limestones. Although they are mostly fragmental, some of them could be determined and may be suggested a Santonian age (Fig. 6C–F). Homalotypic corals, red algae, gastropods and some reworked benthic foraminifers are also present (Fig. 6H). These bioclastic limestones do not include any index microfossils. The bioclastic limestones continue with a 130-m-thick, unfossiliferous dark grey, massive limestones and cherty limestones, which are intercalated with chert breccias (Sirna breccia). The limestone clasts including the prismatic outer shell fragments of radiolitids are observed within the chert breccias (Fig. 6G). The cherty limestones yield some planktic foraminifers a middle Turonian-Santonian age (Ozer et al., 2016). According to the rudist fauna and planktic foraminifers a Santonian age may be suggested for the limestone succession. The pinkish calcareous shales and mudstones intercalated with greenish-grey sandstones and siltstones of the Karabörtlü Formation rest unconformably over the cherty limestones. Nannofossil data indicate an early Miocene age for the Karabörtlü Formation (Ozer et al., 2016).

Previous studies suggest a latest Cretaceous age for the limestone of the Balkça section based on very limited palaeontologic data such as some foraminifers (Poisson, 1977; Göktas, 1988; Akdeniz, 2011a,b). However, a Santonian age is suggested for the limestones in this study.

4.2. Fethiye area

Compiled stratigraphy of the Nif Mountain (Çal Dağ) and Hisarköy area to the north of the Fethiye town (Fig. 1B) comprises from old to young: the Lower Jurassic dolomitostones, the Middle Jurassic-Cenomanian limestones and calcarenites, and overlying uppermost Cretaceous-Paleocene turbidites (Collin, 1962; de Graciansky et al., 1967; de Graciansky, 1972; Akdeniz, 2011a). The Çal Dağ section first presented by de Graciansky (1972, fig. 56) was a reference section for the Çal Dağ Limestone unit, which has been referenced in several studies (Akdeniz, 2011a; Bernoulli et al., 1974; Poisson, 1977; Şenel, 1997a,b,c). de Graciansky (1972) reported occurrences of some planktic and benthic foraminifers in the Cretaceous limestones and also rudist debris in the Albian-Cenomanian limestones from the Çal Dağ section. The Inlice Series (Inlice-Göcek, NW Fethiye) comprise from bottom to top, unfossiliferous cherty limestones, Maastrichtian limestones with benthic foraminifers and Eocene limestones and detritic rocks with Nummulites, which was recorded by de Graciansky (1972), Poisson (1977) and Şenel (1997a,b,c) as well. According to de Graciansky (1972) and Poisson (1977), Inlice Series belong to “intermediate complex” showing some stratigraphic differences from the other sections of the Lycian Nappes. The Çal Dağ and Hisarköy sections belong to the Bodrum nappe (Akdeniz, 2011a,b; Şenel, 1997a,b,c).
Microfossils are not seen in the rudist-bearing limestones. A 50-m-thick upper part of the succession is characterized by thick-bedded, grey, cherty limestones. A 5-m-thick Sirna breccia consists of angular chert fragments and is observed at the uppermost part of the section. The planktic foraminifera suggesting a late Coniacian-Santonian age were described from the cherty limestones (Özer et al., 2016). So, the late Coniacian-Santonian age can be suggested for the Çal Dağ Ç2 1g Limestone. The Karabörün Formation consists of mudstones, sandstones, thin calcareous shale lens and limestone blocks. Nannofossil assemblages in fine-grained rocks indicate a late Maastrichtian-early Danian age (Özer et al., 2016).

Akdeniz (2011a) named limestones with rudist fragments as Ürmükdağ Limestone and reported that age of the formation is Berriasian-Cenomanian according to the stratigraphic relations. However, our data show that the lower part of the section comprises bioclastic limestones with some determinable rudists and the upper part includes cherty limestone with planktic foraminifera showing a late Coniacian-Santonian age.

4.2.2. Çal Dağ section

The Çal Dağ section comprises a 180-m-thick pelagic limestone succession (Fig. 2E). A 95-m-thick middle and upper parts of the
section are mainly made up cherty and bioclastic limestone alter-
nations. The Radiolaria, orbitolinids and bivalvia fragments are
abundant in the limestones. But, it was impossible to describe the
species due to bad preservation. Planktic foraminifera are very rare
throughout the succession, only a few samples from the middle of
the section yield planktonic foraminifera of late Albian age (Ozer
et al., 2016). The uppermost part of the section, around the peak
(2,184 m) of the Çal Dağ, is characterized by the presence of the
bioclastic limestones with rudist fragments intercalated with
cherty limestones. The rudist shells within the bioclastic limestone
interlayers (at the top of the section) are represented by canali-
culated rudists and radiolitids (Fig. 7A–D). The identified canali-
culated rudists suggest a Cenomanian (mostly middle-late) age.
Besides, indeterminable radiolitid fragments also occur. These
limestones do not yield foraminifera.

de Graciansky et al. (1967) reported a canaliculated rudist
Caprina choftafi Douvillé suggesting Cenomanian from the Nif
caille zone, without illustration and exact location. This species
is well-known from the upper Albian in Spain and Portugal (Steuber,
2002). The discrepancy between the stratigraphic distribution of
the species and the age of the Çal Dağ succession may arise from
wrong identification. According to de Graciansky (1972), the rudist
sections are seen in the upper Albian-upper Cenomanian lime-
stones from the top of the sequence. But, this study reveals that
they are only present in the Cenomanian bioclastic limestones to-
wards the uppermost part of the section.

4.2.3. Inlice section

This section consists mainly of approximately 190-m-thick
platform-type carbonates (Fig. 3A). The carbonates comprise three
different lithologic succession from bottom to top: (i) a 50-m-thick
basal part is made of cherty limestones. Planktic foraminifera in
this interval suggest latest Cenomanian-early Turonian and San-
tonian ages, (ii) a 45–50-m-thick middle part consists of thick
bedded, bioclastic limestones with abundant larger benthic fora-
aminifera and rudist, bivalve and coral fragments. Benthic forami-
fera show an early-middle ‘Maastrichtian’ age for this interval,
(iii) a 80–85-m-thick upper part is composed of calciturbiditic and
bioclastic limestones with larger benthic and planktic foraminifera
suggesting a middle-late Maastrichtian age. The rudist fragments
are the main components in the upper part of these limestones
and are mainly represented by radiolitid shells with prismatic
cells, some hIPPuritid and canaliculate shell sections are also
observed (Fig. 7E–F). Despite that all the rudists are observed as
shell fragments, some taxa suggesting a ‘middle-late’ Maastrich-
tian age can be identified. Middle Eocene pinkish-red micritic
limestones and grey, massive limestones with nummulitid and
planktic foraminifera rest unconformably over the rudist-bearing
bioclastic limestones.

The limestones with rudists and benthic foraminifera of the
Inlice section were reported as Maastrichtian calcarenites by de
Graciansky (1972), de Graciansky et al. (1967) and Poisson (1977).
This study shows that the bioclastic limestones with rudists and
benthic fossils and calciturbiditic limestones with planktic forami-
nera are intercalated at the upper part of the carbonate suc-
cession. Foraminiferal assemblages indicate an early-middle-late
Maastrichtian age. The presence of some rudist taxa suggesting
‘middle-late’ Maastrichtian age are very important for comparison
Inlice section with other localities in the Köyceğiz area.

4.3. Köyceğiz area

Mesozoic rocks show a wide distribution in the Köyceğiz area
and consist mainly of cherty limestones and are overlain by tur-
bidites (Akdéniz, 2011a,b; Bernoulli et al., 1974; de Graciansky,
1968, 1972; de Graciansky et al., 1967; Şenel, 1997a,b,c). Previous
studies have some information on the presence of rudist bivalves.
Only some rudist fragments were reported from the cherty lime-
stones, without any detailed information and description. How-
ever, our studies reveal that rudist exist and yield important
biostratigraphic data as explained below. Başyaşar Tepe and
Akdikmen Tepe sections belong to the Bodrum nappe. Bozbürun
Tepe section belongs to the Tavas nappe (Fig. 1B) (Akdéniz,
2011a,b; Şenel, 1997a,b,c).

4.3.1. Başyaşar Tepe section

Platform-type carbonates (Çal Dağ Limestone) consist mainly of
a 10-m-thick cherty limestones in this section (Fig. 3B). They are
intercalated with rudist-bearing limestones towards to top of the
section. The rudist sections are mostly recrystallized as a result of
low-grade metamorphism. Despite recrystallization some hIPPuritid
sections suggesting a Santonian-Campanian age could be
identified (Fig. 7G–N). The topmost part of the Çal Dağ limestone is
characterized by chert breccias (Sîrna breccia), which are alter-
nated with cherty limestones. The carbonate-dominated succes-
sion passes into sandstone and mudstone alternations with
bioclastic limestone lenses of Çamova Formation, which include
Maastrichtian-early Danian nannofossils (Ozer et al., 2016).

Akdéniz (2011b) and Şenel (1997a,b,c) described the rudist-
bearing limestones as Gökçeğiz Formation and suggested an
Early Cretaceous-Cenomanian age. However, the rudist fauna
described in this study suggests a Santonian-Campanian age for
these limestones.

4.3.2. Akdikmen Tepe section

The platform-type carbonates (Çal Dağ Limestone) of the
Akdikmen Tepe section are represented by thick-bedded lime-
stones and consist of from bottom to top (Fig. 3C), (i) alternation
of a 70–80-m-thick, allodapic nodular cherty limestones, (ii) a 10-m-
thonic dolomitic limestones and (iii) a 40–45-m-thick recrystalliz-
limestones. The latter includes approximately 10-m-thick rudist-
bearing limestones at the base, which comprises three levels of
patchy aggregations of rudist bivalves indicating a late Turonian
age (Fig. 8A–I). Calcareous mudstones with very rare planktic forami-
fera, some branching coral and gastropod sections between two
chort breccia (Sîrna breccia) levels (0,6–2-m-thick) were also found
towards the upper part of the massive recrystallized limestones
(Fig. 8J–K). The same limestones with coral and gastropod sections
are seen at the uppermost part of the carbonate succession to the
north of Köyceğiz, around Çalmak Tepe and Çamova. Platform-type
carbonates can be traced laterally to the west in that area. A 0,6-m-
thonic chert breccia level (Sîrna breccia) separates the massive car-
bonates (Çal Dağ Limestone) from the calcareous shales (Çamova
Formation). The latter consists of mudstones and siltstones
including bioclastic limestone lenses and blocks of various origin.
Nannofossils obtained from the fine-grained rock samples indicate
a late Maastrichtian and early Danian age for the Çamova Formation
(Ozer et al., 2016).

Akdikmen Tepe section was first reported by de Graciansky
(1972) and later accepted as a reference section for the Çal Dağ
Limestone, Sîrna breccia, Çamova and Karabörtlen formations in
many subsequent studies (Akdéniz, 2011b; Bernoulli et al., 1974;
Ersoy, 1989, 1993b; Konak, 2007; Poisson, 1977; Şenel, 1997a,b). However, Akdéniz (2011b) and Şenel (1997a,b,c) proposed the
name Gökçeğiz Formation for the rudist-bearing limestones.
The section is important for the Upper Cretaceous stratigraphy of
the Lycian Nappes. de Graciansky (1972) presented only 20-m-thick
uppermost part of the platform limestones (Çal Dağ Limestone) in
his section, probably due to harsh topography, de Graciansky (1972)
and other previous studies (Akdéniz, 2011b; Bernoulli et al., 1974;
Ersoy, 1989; Konak, 2007; Poisson, 1977; Şenel, 1997a,b) suggest that the ages of the Çal Dağ Limestone and overlying Sirna breccia are Berriasian-Cenomanian and Cenomanian respectively. Akdeniz (2011b) and Şenel (1997a,b,c) cautiously attributed Turonian age for the Çal Dağ Limestone. Our data come from an approximately 135 m thick upper part of the Çal Dağ Limestone. The late Turonian rudists and two levels of the Sirna breccia in the succession are first described in this study for the Köyceğiz area.
4.3.3. Bozburun Tepe section

The base of the platform-type carbonates (Babadag Formation) comprises 40–50-m-thick cherty limestones, which are intercalated with brecciated limestones with some rudist, benthic foraminifer and coral sections (Fig. 3D). These limestones yield planktic foraminifer taxa suggesting a late Campanian-Maastrichtian age (Ozer et al., 2016). The top of the section is characterized by a 30–40-m thick, calciturbiditic massive limestones including abundant rudist sections and intercalated thin bedded pelagic limestones. Rudist fauna suggests a ‘middle’-late Maastrichtian age (Fig. 9A–J). The planktic foraminifer assemblages within the pelagic limestones confirm the late Maastrichtian age (Ozer et al., 2016).

The limestones cropping out in the BozburunTepe and surrounding area were named as the Babadag Formation by Şenel (1997a). The age of the formation was accepted as Toarcian-Maastrichtian based on the previous studies around Fethiye, Çameli and Elmalı (Şenel, 1991; Şenel et al., 1994). The same author indicated that the uppermost part of the limestone sequence contains abundant rudist fragments. Recently, the origin of the cherts in the calciturbiditic limestones of the Bozburun Tepe was studied by Gül (2015). Our study suggests a ‘middle’-late Maastrichtian age, based on the rudist fauna, for the first time for the succession.

4.4. Bodrum area

The carbonate succession of the Bodrum area is characterized from bottom to top, by thick Jurassic-Cretaceous cherty limestones (Çal Dağ Limestone), chert breccias (Sirna breccia) and turbidites (Karaköprü Formation) (Bernoulli et al., 1974; Çakmakoglu, 1985; Ersoy, 1989, 1993b; de Graciansky, 1972; de Graciansky et al., 1967; Konak, 2007; Poisson, 1977; Şenel, 1997a,b,c), but, there is no information on the presence of rudists in these studies. Although palaeo-oceanographic origin of the “Bitez block” is unclear, the first report of Eastern Mediterranean Tethys by Masse et al. (2015).

The karst breccia is a thin-skinned, bedded, cherty limestone/marble with calcite forming rosetta structures and chert breccias (Sirna breccia). The Karabördüen Formation overlies these carbonate succession (Çakmakoglu, 1985; Rimmel et al., 2004; Konak and Çakmakoglu, 2007; Ozer et al., 2016). Although these rocks show a wide distribution in the eastern area, around Aşağı-Yukarı Mazköy, Gökbël and between Çamlıköy and Kıyıkışlack, no palaeoontological data (both rudist and microfossil) have been presented by previous studies so far. Nine stratigraphic sections were measured in this area. Two of them will be presented below as the only two includes information on rudists. The Gökbël section belongs to the Bodrum nappe and the Kıyıkışlack section belongs to the Tavş nappe (Fig. 1B).

4.5. Oren area

The low grade metamorphic rocks outcropping around the Oren area were named as Oren Unit by Konak et al. (1987) and included to the Bodrum nappe by Konak and Çakmakoglu (2007). The platform-type carbonates (Ula Marbles) consist of thick-bedded dolomitic limestones/marbles, thin to medium bedded cherty limestones/marbles with calcite forming rosetta structures and chert breccias (Sirna breccia). The Karabördüen Formation overlies these carbonate succession (Çakmakoglu, 1985; Rimmel et al., 2004; Konak and Çakmakoglu, 2007; Ozer et al., 2016). Although these rocks show a wide distribution in the eastern area, around Aşağı-Yukarı Mazköy, Gökbël and between Çamlıköy and Kıyıkışlack, no palaeo-ontological data (both rudist and microfossil) have been presented by previous studies so far. Nine stratigraphic sections were measured in this area. Two of them will be presented below as only the two includes information on rudists. The Gökbël section belongs to the Bodrum nappe and the Kıyıkışlack section belongs to the Tavş nappe (Fig. 1B).

4.5.1. Gökbël section

Cherty limestones of the Ula Marbles are thicker than 100 m and are folded in this locality. Bioclastic limestones consisting mainly of rudist fragments are observed in the uppermost part of the sequence (Fig. 4C). Description of rudists is impossible due to the intense fragmentation. However, some transverse sections of radiolitids and many right valve fragments showing cellular structure of the radiolitids and dark-grey calcitic outer shell layer of huppuritids can be recognized in the bioclastic limestone horizons (Fig. 10C). The top of the section is characterized by a 10–15-m-thick alternation of cherty limestones and brecciated limestones (Sirna breccia). The Karabördüen Formation comprising sandstones, siltstones and mudstones with limestone blocks and olistostromal levels rests over the Ula Marbles. Some late Maastrichtian nanofossils were described from the Karabördüen Formation (Ozer et al., 2016).
Fig. 8. A–I. Rudists of the Akdikmen Tepe section, middle-upper Turonian, the transverse sections of the right valve. A–B. Distefanella salmojraghi Parona, A-outcrop photograph of the Distefanella-bearing recrystallised limestones, B-sample no 15-57. C–D. Durania sp. (D. aff. arnaudi (Choffat)), many small right valve transverse sections, sample nos 15-58 B and 15-59 A, E. Durania arnaudi (Choffat), the transverse section of the right valve showing fine ribbing on the intended radial bands, the L is absent. It is a large form than previous
Stratigraphic characteristics of the uppermost part of the carbonate succession of the Ula Marbles show clear similarity with those of Konaci-Andenler sections in the Bodrum area (Figs. 1B, 4A). Although, it was not possible to obtain detailed faunal composition of the rudists in these sections, documenting of distribution of the bioclastic limestones with rudist fragments could be important if they are a meaningful level at the uppermost part of the carbonate successions between the Bodrum and Ören areas.

4.5.2. Kıyıkışlacık section

The Ula Marbles, consisting mainly of grey, thick-bedded dolomitic and cherty marbles, have widespread distribution to the northwest of Ören village, around Akbük, Bozbük, Gürçamlar and Kıyıkışlacık villages and tectonically overlie the metamorphic rocks of the Menderes Massif (Brinkmann, 1967; Dürr, 1975; Arslan et al., 2013; Ozer et al., 2016). The Kıyıkışlacık stratigraphic section consists, from bottom to top, of thick-bedded dolomitic marbles,

Fig. 9. A–J-rudists of the Bozburun Tepe section, ‘middle’-upper Maastrichtian, outcrop photographs. A–B-Hippurites cornucopie De France, the transverse sections of the right valve, the first pillar is open at the base, but the second one is slightly pinched, note the radial riblings in the outer shell layer, C-Biradiolites sp., the transverse section of the right valve, D–E-Lappeiroiusia sp., the transverse sections of the right valves, note the pseudopillars (arrows) and the preserved cellular structure of the outer shell layer, F-Durania sp., the transverse section of the right valve, the Pb and Pb are well-observed, but Ab seems to be obscured in the left side, G-Praperadiolites sp., the transverse section of the right valve, note the partially preserved cellular structure of the outer shell layer, H-a fragment of a radiolitid with well-developed ribs reminiscent those of Biradiolites sp. (Biradiolites aff. chaperi Toucas) and small right valve transverse section of Durania sp. (arrow), I-Bournonia aff. fascicularis (Pirona), the transverse section of the right valve, J-Bournonia/Biradiolites sp., the transverse section of the right valve showing two radial ribs, the posterior one is more developed than the other, Scale bars are equal to 10 mm.
Fig. 10. Rudists of the Bodrum and Bozburun peninsulas and Ören area: outcrop photographs. A–B: Bodrum Peninsula, uppermost Cretaceous, Antenler locality. A: the general view of the bioclastic limestones with rudist fragments and sections (white arrows). Black arrow shows enlarged rudist section in the next figure. B: radiolitid indet (?Biradiolites sp.). C: the bioclastic limestones characterized mainly by small and large (arrows) rudist fragments, uppermost Cretaceous, Ören area, Gökbel locality. D–G: Bodrum Peninsula, Bitez locality, Berriasian. D: the facies characteristics of the Bitez limestone block showing the gastropod sections (white arrow), branching coral colony (in the middle of the photo) and rudist sections, E–F: a longitudinal bivalve section of Heterodiceras luci (Defrance) and the left valve section of Hypelasma salevensis (Joukowsky and Favre), respectively. G: coral, H: limestone showing requieniid rudist sections (white arrows) and radiolitid sections (a–c) with very little ligamental ridge (L), pre Turonian (?Albian–?Cenomanian). Bozburun Peninsula, Selimiye locality. I–K: some badly preserved rudist sections due to metamorphism in the marbles, Ören area, Kıyıkşalik section, uppermost part of the Upper Cretaceous, I: hippuritid right valve transverse sections showing the pillars (arrows). J–K: radiolitid indet (?Durania sp.). Scale bar indicates 10 mm.
approximately 300-m-thick, usually folded, thin to medium bedded cherty marbles and 50-m-thick, massive marbles without cherts (Fig. 4D). This levels include some ‘ghost’ rudist sections (Fig. 10I—K). These rudist sections show similarities with those of described from the marbles of southern and northern sectors of the Menderes Massif by Ozer (1993, 1998) and Ozer et al. (2001). Alternations of sandstones, mudstones and siltstones with rare recrystallized limestone blocks of the Karabörtlen Formation overlie the carbonate succession along a questionable contact.

Previous studies suggest that the Lycian Nappes consist mainly of dolomitic marbles and cherty marbles without fossils between Çamlıköy and Kyıkışlacık (Brinkmann, 1967; Dürr, 1975; Arslan et al., 2013). The rudist sections from the Kyıkışlacık section are the first palaeontologic data from this area.

4.6. Bozburun area

A few geological studies in the Bozburun Peninsula record the presence of the Upper Triassic-Cretaceous platform-type carbonates and Upper Cretaceous-Palaeocene blocky flysch (i.e. Ersoy, 1993b; Şenel and Bilgin, 1997). The age of these units was based on limited palaeontologic data. Five stratigraphical sections were measured from the Bozburun Peninsula. One of them is presented below as the platform-type carbonates include rudist bivalves.

4.6.1. Selimiye section

This section is located to the northeast of the Bozburun town (Fig. 1B), where platform-type carbonates are widely exposed. Rudist, gastropod and coral sections are observed within the uppermost part of the grey, 10-m-thick massive platform-type carbonates (Fig. 4E). Rudist sections observed belong to Requienia and Radiolitidae (Fig. 10H). Some orbitolinids and indeterminable benthic foraminifera are observed in these limestones. Pinkish pelagic infillings (i.e. neptunian dykes) within the upper part of the rudist-bearing limestones yield a planktic foraminifera assemblages of early Turonian age (Ozer et al., 2016). A 9-m-thick pinkish-reddish cherty limestones with planktic foraminifera, suggesting a Santonian age, rest over the rudist-bearing limestones. Silstones and mudstones overlie the pinkish-reddish cherty limestones and yield some early Danian nannofossils (Ozer et al., 2016).

A few studies carried out in the platform-type carbonates of the Bozburun area did not yield any information on the rudists (Ersoy, 1993b; Şenel and Bilgin, 1997). The current study presents information on the rudist for the first time within the uppermost part of the carbonate succession, which has widespread geographic distribution in the Bozburun Peninsula. The facies characteristics of the rudist-bearing limestones may be comparable with the Albion (Lower Cretaceous) limestones with *Eoradiolites* in the Mediterranean Tethys (Masse et al., 1998, 2010). Further detailed palaeontological data are required for precise determination of the Lower Cretaceous stages and correlations. The pinkish infillings of the neptunian dykes of early Turonian age indicate that the rudist-bearing platform limestones in the Bozburun area are older than the Turonian (?Cenomanian or older). Lower Cretaceous calcarenites and calcirudites with *Orbitolina* were reported by Orombelli et al. (1967) from the Datça Peninsula. So, the limestones with orbitolinid foraminifera of the Selimiye section may be compared with that of Orombelli et al. (1967). The Cretaceous sequences in the Lycian Nappes are mainly characterized by cherty limestones. As the rudist-bearing limestones of the Selimiye section do not contain cherts, they could be compared with the Berriasian Bitez block of the Bodrum area.

5. Rudist associations

The previous studies suggest that the Cretaceous sequences consist mainly of the platform-type cherty limestones without siliciclastic input in the Lycian Nappes. Limited studies suggest only rudist fragments from the Upper Cretaceous carbonate successes (Akdıniz, 2011a, b; de Graciansky et al., 1967; Şenel, 1997a,b,c)

However, this study reveals the presence of the rudist associations in the recrystallized limestones and/or bioclastic limestones of the Tavas and the Bodrum nappes as explained below:

5.1. Lower Cretaceous

The Lower Cretaceous successions with rudists are very sparse in the Lycian Nappes. Rudists were recently described by Masse et al. (2015) from the Bitez limestone block in the Bodrum area. A Berriasian age was obtained based on the benthic foraminifera, calcareous green algae, problematica, rudists and *Chondrodonta* sp. in Bitez section (Fig. 4B). The epiderciatid-requieniid assemblage of the Bitez limestone block has a low density and consists of *Heterodiceras luci* (Defrance), *Heterodiceras* sp.1, *Heterodiceras* sp. and *Hypelasma salvensis* (Joukowsky and Favre). This rudist assemblage, associated with corals and non rudist bivalves (Fig. 10D—G), shows similarity with the Berriasian successions of France (Masse et al., 2015). The rudist-bearing Bitez limestone block shows different characteristics concerning both lithology and age when compared with the Lower Cretaceous of the Lycian Nappes. There has been no information on the Berriasian neritic fauna (rudists, corals, benthic foraminifera etc.) from the Lower Cretaceous limestones (without chert) in the Lycian Nappes so far. So, the origin of the Bitez limestone block is enigmatic at the moment.

Rudist-bearing platform-type limestones with requeniids and radiolitids are found in the Bozburun area (Fig. 4E: Selimiye section). The radiolitid-requieniid association is represented by low density (Fig. 10K). The age of this association is clearly older than Turonian (?Cenomanian or older). Although the facies characteristics of these limestones show similarity with the Albian (Lower Cretaceous) limestones of the Mediterranean Tethys, new precise palaeontological data are required for the area for finer evaluations.

Although, the origin of the Bitez block is unclear at the moment and the palaeontological data from the Selimiye section are not enough to compare this succession with the rest of the Lycian Nappes, these preliminary data could be later useful for uncover the Lower Cretaceous stratigraphy of the Lycian Nappes when combined with the forthcoming data.

5.2. Upper Cretaceous

The Upper Cretaceous sequences with rudist have wider distribution in the Lycian Nappes than the Lower Cretaceous. Four main rudist assemblages were distinguished within the Upper Cretaceous sequences of the Lycian Nappes:

a) the middle-late Cenomanian caprinid-ichthyosarcoiditid assemblage is observed in the Tavas and Fethiye areas, which belong to the Tavas and Bodrum nappes, respectively.

b) the late Turonian distefanelloid assemblage is determined from the Tavas area in the Tavas nappe and the Köyceğiz area in the Bodrum nappe.

c) the late Coniacian-Santonian-Campanian hippocurid-radiolitid assemblage is widely represented in the Bodrum nappe.

d) the ‘middle’-late Maastrichtian radiolitid-hippuriditid assemblage is observed in the Köyceğiz and Fethiye areas in the Tavas nappe.
5.2.1. Caprinid-ichthyosarcolithid assemblage

This assemblage is observed in the Sarpdere and Çal Dağ sections. The assemblage is characterized by abundant canaliculated rudists (caprinids and ichthyosarcolithids) in the Sarpdere section. The rudist sections appear mostly as ghost due to the slight metamorphism. Despite the metamorphism, the rudist sections could be described thanks to the protected canal structures. The assemblage comprises Neocaprina gigantea Plenicer, Caprina schiosensis Boehm, Schiosia cf. schiosensis Boehm, Sphaero-ucaprina cf. woodwardi Gemmellaro, Ichthyosarcolithus bicarinatus (Gemmellaro), I. triangularis Desmarest, I. monocarinatus Sliskovic (synonymous with Ichthyosarcolithus rotundus Polsak, see Cestari et al., 1998), I. poljaki Polsak, Eoradiolites sp., Durania sp., and requeniids (Atrypicida sp.) and is presented so far by Özer (1998) and Özer et al. (2001). Chondrodonta sp. is associated to this fauna. The right valve transverse sections of N. gigantea is remarkably similar to that of the species determined by Plenicer & Jurkovsek (2000, pl. 4, fig. 2) (Fig. 5A, B). I. poljaki presents the well-developed ridges and small round or oval canals in the transverse section of the right valve (Fig. 5C). The additional sections are obtained from the new field observations: Caprinula aff. boissyi d’Orbigny and Durania sp (Fig. 5D, E). The oblique section of the first species presents a single row of large canals on the inner side following one or three small, round and piriform pallial canals may be compared with those of C. boissyi described by Douville (1888, pl. 22). This species is first found in Turkey. The second one have a thick outer shell layer with partially preserved polygonal prisms.

The Çal Dağ section shows a poor rudist fauna than Sarpdere section, but some canaliculated rudists like Caprina cf. schiosensis Boehm, Caprina sp., Ichtysarcolithes cf. poljaki Polsak and Ichthyosar- colithes cf. monocarinatus Sliskovic and radiolitid can be identified (Fig. 7A–D).

This assemblage is well known from the middle-upper Cenomanian of the northern (especially central and eastern) and also from the southern sides of the Mediterranean Tethys (Steuber, 2002). In Turkey, the similar assemblage is well documented from the middle-upper Cenomanian of the Bey Dağları Carbonate Platform by Özer (1988), Sari (2006b) and Sari and Özer (2009).

5.2.2. Distefanellid assemblage

This assemblage is observed in the Sarpdere and Akdikmen Tepe sections. It is mainly characterized by the abundance of Distefanella salmognajghi Parona in the Sarpdere section. The right valve transverse sections of this species show close similarities with D. bassani Parona. Özer (1998) and Özer et al. (2001) identified these type of sections as D. bassani and Özer (1999) also described a new species Distefanella tavassianae showing concave radial bands (Fig. 5H) as well. However, Cestari (2008) showed that all the sections described as D. bassani Parona and the new species indicated above are synonymous with Distefanella salmognajghi Parona, which is accepted in this study. D. montagnai Sliskovic is rare (Fig. 5H).

Moreover, some hippuritids and radiolitids are newly found in the Sarpdere section: Hippurites cf. socialis Douville, Vaccinites cf. praegiganteus (Toucas), V. cf. rousseli Douville, Durania cf. gaensis Dacqué, Durania sp. (Durania aff. laevis Douville) and Sauvagesia/ Durania sp. (Fig. 5F–N).

The shape of the siphonal pillars of Hippurites cf. socialis Douville may be compared with the specimens of Douville (1893), Toucas (1903) and Sari and Özer (2009). The ligamental ridge and the siphonal pillars of Vaccinites cf. praegiganteus (Toucas) present typical characters of the species of Chikhi-Aouimeur (2010), Sari and Özer (2009), Sari et al. (2004), Simonpietri (1999), Steuber (1999) and Toucas (1904). The shape of the ligamental ridge of Vaccinites cf. rousseli Douville shows similarities with that of determined by Chikhi-Aouimeur (2010), Douville (1894, 1897), Özer and Ahmad (2015) and Simonpietri (1999). It can also be compara- ble with Hippuritella libanus Douville, however the latter seems to be synonymous with V. rousseli (see Chikhi-Aouimeur, 2010; Özer and Fayez, 2015). The wide and depressed ventral radial band of Durania cf. gaensis Dacqué shows typical character of the species of Abdelgawad et al. (2011), Douville (1910) and Polsak (1967). The shape of the transverse section of the right valve and the radial bands of Durania sp. (Durania aff. laevis Douville) show some similarities with specimen of Douville (1910).

Many sections of Distefanella salmognajghi Parona and small forms of Bournonia africana Douville, Durania arnauddi (Choffat) and Durania sp. are observed in the Akdikmen Tepe section. The developed radial bands of Bournonia africana Douville can be compared with those of Bournonia excavata d’Orbigny, however the anterior radial band of the latter species is always more developed than the other (Cestari and Sirna, 1989: Cestari, 2008; Pons and Vicens, 2008; Santiago, 2014). The radial bands of Bournonia africana Douville show variability in same association (Fig. 8F–G). This variability and also the oval or round shape of the inner shell margin may be compared with specimens from Gafsa region (Tunisia) and Dionyssos (Greece) described by Chikhi-Aouimeur et al. (2004), Simonpietri (1999), and Steuber (1999), respectively.

This association indicates a late Turonian age, well-known and shows a wide distribution within the upper Turonian formations of the Mediterranean Tethys (Steuber, 2002).

5.2.3. Hippuritid-radiolitid assemblage

This assemblage has wider distributions than the others through the Lycian Nappes. Despite wider distribution, it can be described from the right valve sections within the bioclastic limestones of the Balkica, Hisarköy, Başyar Tepe and Koynušjakı sections. Some hippuritid and radiolitid species were described as Hippurites cf. nabresinensis Futterer, Hippuritella aff. lapeirousei (Goldfuss), Vaccinites sp., Hippurites sp. and Bournonia sp. (Bournonia aff. wionzeki Pejovic), Bournonia sp. (Bournonia aff. hvarense Pejovic), Biradiolites sp. (Biradiolites aff. fissicostatus d’Orbigny), ?Biradiolites sp., Sauva-gesia sp. and Durania sp (Figs. 6C – K, 7G – N, 10K). The taxa show a wide stratigraphic distribution within the upper Coniacian-Santonian-Campanian successions in the Mediterranean Tethys (Steuber, 2002). Hippurites nabresinensis is reported from the upper Coniacian-middle Santonian, uppermost Santonian-lower Campa-nian and middle Campanian, and Hippuritella lapeirousei from the upper Campanian-lowermost Maastrichtian rudist biozones in the
central-eastern Mediterranean provinces by Steuber and Schlüter (2012). Radiolitids are described from the Coniacian-Santonian, Santonian-Maastrichtian and Campanian-Maastrichtian of the northern side of the Mediterranean Tethys (Steuber, 2002). Therefore, a late Coniacian-Santonian-Campanian age could be attributed to this assemblage.

5.2.4. Radiolitid-Hippuritid assemblage

This assemblage shows very limited distribution in the Lycian Nappe, it is only observed from the Bozburun and Inlice sections. The Bozburun section comprises well preserved and rich rudist fauna than the Inlice section. This assemblage is characterized by the abundance of radiolitids such as *Bournonia aff. adriatica* Peviović, *Bournonia aff. fascicularis* (Pirona), *Bourbonia sp.*, *Biradiolites sp.* (Biradiolites aff. chaperi Toucas, pro Rajka spinosa Milovanovic and Grubic according to Pons and Vicens, 1986), *Lapeirousia sp.*, *Durania sp.*, *Praeradiolites sp.* and *Sauvagesia sp.* Hippuritids are represented by only a single species: *Hippurites cornucopiae* Defrance, which is abundantly observed through the Bozburun stratigraphic section (Figs. 7E–F, 9). *Hippurites cornucopiae* is well-known from the ‘middle’-upper Maastrichtian deposits in the northern and southern sides of the Mediterranean Tethys (Steuber, 2002). *Hippurites cornucopiae* Interval Zone is determined in the central-eastern Mediterranean provinces and Arabian Plate chronostratigraphically indicating a ‘middle’-late Maastrichtian age (Steuber and Schlüter, 2012). *Bournonia adriatica* is well-known from the ‘middle’-late Maastrichtian of the central Mediterranean Tethys (Steuber, 2002). *Biradiolites chaperi* shows a wide distribution in the upper Campanian–Maastrichtian and also ‘middle’-upper Maastrichtian formations of the Mediterranean Tethys (Steuber, 2002). This association suggests a ‘middle’-late Maastrichtian age.

6. Depositional setting and correlation

Obtained lithologic, biotic and microfacies data emphasize distinct depositional settings, where the rudists were flourished, fragmented or reworked through the Cretaceous time in the Lycian platform(s) (Figs. 11–13).

The rudists of the Lower Cretaceous Successions are still less known than those of the Upper Cretaceous as explained above. We found Berriasian rudists (essentially epiderceridats and requienidiid) together with corals, benthic foraminifera, calcareous algae and calcionellids only in the Bitez massive limestone block of the Bodrum Peninsula (Fig. 10D–G), indicating a shallow water settings in the distal, marginal parts of the carbonate platform (Steuber, 2002, Özer et al., 2014, 2016). These limestones have been recently determined as “Strambek type limestones” by Masse et al. (2015). In the Bozburun Peninsula, Selimiye stratigraphic section show some requeniid and radiolitid sections and associated corals, gastropods and benthic foraminifera (orbitolinitids) within the limestones suggest a very shallow marine conditions. Corals are generally thrived in outer platform conditions (Fenceri-Masse, 2006; Moro et al., 2016; Scott, 1988, 1995). Depositional texture of the limestones is packstone/grainstone with abundant bivalvia debris and orbitolinitid foraminifera. Intense fragmentation and micritization are observed (Fig. 11A).

The Upper Cretaceous rudist-bearing limestones present much more data than the Lower Cretaceous concerning depositional characteristics.

The middle-late Cenomanian canaliculate rudist-bearing limestones of the Sarpdere section should have been deposited mostly in a restricted, low-energy, inner platform conditions due to the features of the limestones (dark grey, bituminous) and also low diversity of rudist fauna. There are no other macrofossils accompanying rudists. Autochthonous rudist aggregations and small isolated rudist patches are observed. Besides, accumulations of broken debris of rudists, indicative of an agitated environment caused by constant or ephemeral wave action, are also present. The rudist-bearing limestones are recrystallized and depositional textures are always masked by recrystallization, and so, it is impossible to determine their microfacies characteristics and depositional texture. We have to rely on macroscopic features of rudists to infer depositional environment. High-energy platform margin environment has been proposed for many canaliculate rudist-bearing Cenomanian carbonate platform successions in the northern side (especially center and eastern regions) (Carbone et al., 1971; Philip and Mermigis, 1989; Sartorio et al., 1992; Carbone, 1993; Cestari and Sartorio, 1995; Laviano et al., 1998b; Stefano and Ruberti, 2000; Stüssel and Bernoulli, 2000; Korbar et al., 2001; San and Özer, 2009; Cestari and Laviano, 2012), in the southern side (Chikhi-Aouimeur et al., 2006; Schulze et al., 2003, 2004) of the Mediterranean Province and in the Gulf of Mexico (Scott, 1990). Cenomanian (mostly upper) low-energy inner shelf environment with canaliculate and radiolitid rudists has been also reported from Apennines of Italy (Cestari and Laviano, 2012), from Provence-France (Philip and Auiraud-Crumiere, 1991), from Prebetic Domain (Martin-Chivelet et al., 1990), from south Pyrenees of Spain (Caus et al., 1993), from Egypt (Bauer et al., 2002, 2003; Bachmann et al., 2003), from Oman (Philip et al., 1995) and from Jordan (Schulze et al., 2003; Özer and Ahmad, 2015).

The middle-upper Cenomanian limestones of the Cal Dagr section show different facies characteristics from the Sarpdere section. The canaliculate rudist and radiolitid fragments are embedded within the wackestone/packstone beds with abundant radiolarians and calcispheres, which are intercalated with the cherty limestones (Fig. 11B). This data suggests that the rudist debris were transported from the high energy platform edge environment to the adjacent pelagic environment along the platform slope.

The lower Turonian cherty pelagic limestones of the Kızılca section are intercalated with abundant rudist debris-bearing bioclastic limestones, which show grainstone/rudstone depositional texture. Presence of abundant rudist fragments indicates reworking and intense fragmentation (Fig. 11C), which is explained by transportation of rudists from probably a Cenomanian shallow-marine carbonate platform. These data indicate mainly slope depositional settings.

Light grey, massive recrystallized limestones characterized by abundant distefanellids suggest presence of a shallow platform environment for the late Turonian. Small rudist patches and limited fragmentation of rudist shells are present in the limestones of the Sarpdere section. In thin sections, sparry (equant) calcite cement and fine-grained carbonate sediments entirely or partially filled the voids of cellular outer shell layer of radiolitid fragments within the

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Fig. 12. Microfacies photographs of the rudist-bearing limestones. Note intense fragmentation of rudists, micritization around the fragments, bioerosional features and sparry (equant) calcite cement and fine-grained carbonate sediments entirely or partially filled the cellular outer shell layers of radiolitids. A–packstone with rudist debris, Başyasar Tepe section, sample no. 14-109, B–C–packstone/rudstone with abundant rudist debris and benthic foraminifera (b), Inlice section, sample nos. 14-266 and 15-99 respectively, D–E–rudstone/packstone/grainstone with abundant rudist debris and benthic foraminifera, Bozburun section, sample no. 15-13, F–grainstone with rudist debris and benthic foraminifera, Bozburun section, sample no. 15-02, G–floatstone/packstone with rudist and bivalve debris, Konaç section, sample no. 14-29, H–packstone with rudist debris, Gökbel section, sample no. 14-27. Scale bars are equal to 1 mm. See figures 2–4 for the stratigraphic positions of the thin sections.
The bioclastic limestones are also observed in the Balkan, Hisarköy and Başyazıcı Tepe stratigraphic sections. They are grey, light grey, thick bedded with small rudist patches and/or accumulations of radiolitids and hippuritids, which are associated with hermatypic corals and gastropods. Depositional texture is mainly represented by packstone/grainstone with chert breccias concretions and coral fragments at the upper part of the succession. These levels are represented by rudist debris showing intense fragmentation, micritization and biogenic features. The basal part of the bioclastic limestones in the Balkan, Hisarköy and Başyazıcı Tepe stratigraphic sections. They are grey, light grey, thick bedded with small rudist patches and/or accumulations of radiolitids and hippuritids, which are associated with hermatypic corals and gastropods. Depositional texture is mainly represented by packstone/grainstone with chert breccias concretions and coral fragments at the upper part of the succession. These levels are represented by rudist debris showing intense fragmentation, micritization and biogenic features. The basal part of the bioclastic limestones consists of packstone/rudist depositional textures with abundant benthic foraminifera, red algae and sponge are also observed. The oriented rudist fragments commonly have micritic envelopes (Figs. 11G, H, 12A). These features suggest an outer platform setting for the rudist-bearing limestones. Increasing of the amount of transported rudist debris (i.e. floatstone and grainstone textures) especially in the uppermost part of sequence indicates development of the high energy marginal slope conditions in the depositional environment. The grading upward of these bioclastic limestones to the pelagic, cherty thin bedded, laminated limestones with chert breccias confirms the slope environment. Existence of rudist debris and neritic limestone clasts within the cherty limestones indicates an intense transportation from outer platform through the slope. The facies characteristics of the succession suggest a moderate to high energy shallow-marine environment for the initial stages and a deeper-water setting for the later stages of the Coniacian-Campanian interval. Several studies have reported similar Coniacian-Santonian-Campanian rudist-bearing limestones reflecting an outer platform settings with marginal slope influenced by the pelagic conditions (Carbone, 1993; Carranante et al., 1998; Laviano et al., 1998b; Moro and Cósović, 2000; Stössel and Bernoulli, 2000; Moro et al., 2002, 2016; Simone et al., 2003; Steuber et al., 2005; Sari, 2006b; Sari and Özer, 2009; Cestari and Laviano, 2012).

The Maastrichtian rudist-bearing limestones present two types of facies: (i) bioclastic limestones and (ii) calciturbiditic (alloadic) limestones. The first facies is observed in the Inlice section, which is mainly characterized by bioclastic limestones overlying the uppermost Conomanian-Santonian pelagic cherty limestones. The basal part of the bioclastic limestones consists of packstone/rudist depositional textures with abundant benthic foraminifera and rudist debris showing intense fragmentation, micritization and biogenic features (Fig. 12B). Coral and red algae debris accompany the rudists and benthic foraminifera. Planktic foraminifera are generally rare throughout the section, but abundantly present at some levels. Several limestone breccia levels are observed within the succession and rudist debris are abundantly presented in the upper part of the succession. These levels are represented by rudist/grainstone/packstone depositional textures with abundant rudist debris showing intense fragmentation, micritization, bioerosional features. Sparry (equant) calcite cement and fine-grained carbonate sediments entirely or partially filled the cellular outer shell layer of radiolitid fragments (Fig. 12C). These data reflect margin of an outer platform environment. Here, the bioclastic limestones were deposited under high to moderate energy conditions.
conditions. Sometimes, pelagic incursions occurred probably in that gently slope settings, where transported rudist debris abundantly deposited. The second facies is detected in the Bozburun section, which is characterized by cherty limestones, calciturbiditic (allophoric) limestones with rich plankitic foraminifera, and some benthic foraminifera. Rudists are observed in the limestones without cherts and they are commonly fragmented due to mechanical compaction, but determinable rudist sections were found towards the upper part of the section. These rudist fragments could have been derived from small patches of rudist aggregations from adjacent environments. The rudstone/packstone/grainstone depositional environments have been derived from small patches of rudist aggregations from adjacent environments. The rudstone/packstone/grainstone depositional environments have been derived from small patches of rudist aggregations from adjacent environments.


The facies and depositional features of the rudist-bearing limestones of the Lycian Nappes show that the rudists lived and formed associations in the inner and outer shells of the carbonate platforms.

7. Conclusions

The Cretaceous rudist associations and the depositional settings are first described from the low grade metamorphic successions (dominated by recrystallized limestones) of Lycian Nappes. The rudist data was obtained from fifteen measured-stratigraphic sections in Tavas, Fethiye, Köyceğiz, Ören, Bodrum and Bozburun areas.

The Lower Cretaceous with rudists is very sparse in the Lycian Nappes and a epiderciat-requienidi assemblage (Berriasian) is only reported from the Bitez limestone block in the Bodrum Peninsula (Masse et al., 2015). It has a low density and consists of Heterodiceras luci (Defrance). Heterodiceras sp.1, Heterodiceras? sp. and Hylpeslasma saleensis (Joukowsky and Favre). A requienidi-radiolitid assemblage showing a low density is first found in the platform-type limestones of the Bozburun Peninsula. The age of this association is clearly older than Turonian (?Albian-?Cenomanian), due to the presence of the lower Turonian pelagic infillings within the upper part of the rudist-bearing limestones. But, further detailed palaeontological data are required for precise determination of the Lower Cretaceous stages.

The Upper Cretaceous sequences have widespread distribution in the Lycian Nappes than the Lower Cretaceous. Four main rudist assemblages are distinguished within the Upper Cretaceous sequences of the Lycian Nappes:

1) Caprinid-Ichthyoscarcolitid assemblage (middle-late Cenomanian; Sarpdere, Serinhisar-Tavas and Çağ Dag-Fethiye) comprises Neocaprina gigantea Plenïcar, Caprina schioenisis Boehm, Schioenisis cf. schioenisis Boehm, Sphaerarcaprina cf. woodwardi Gemmellaro, Ichthyoscarcolites bicornatus (Gemmellaro), I. triangularis Desmarest, I. monocarinatus Sljškovicî, I. poljaki Polsak, Caprina aff. boisiyi d’Orbigny, Eoradolitides sp., Durania sp. and requienidi (Apricardina sp.).

2) Distefaneliid assemblage (late Turonian; Sarpdere, Serinhisar-Tavas and Akdemken Tepe-Köyceğiz) is represented by Distefanella salmojraghii Parona, D. montagnai Sljškovicî, Hippurites cf. socialis Douville, Vaccinites cf. praeagiganteus (Touchas), V. cf. rouselli Douville, Durania arnauadi (Choffat), Durania cf. gaensis Daqué, Durania sp. (Durania aff. laevis Douville), Bournonia africana Douville and Sauvagesia/Durania sp.

3) Hippuritid-Radiolitid assemblage (late Coniacian-Santonian-Campanian; Balkta-Tavas, Hisarköy-Fethiye, Başyayar Tepe-Köyceğiz, Gökbel and Kıyıkışlak-Oren-Ula, Konacik and Antenler-Bodrum) consists of Hippurites cf. nabresinesis Puterter, Hippuritella aff. lapereiounie (Goldfuss), Vaccinites sp., Hippurites sp., Bournonia aff. hvarensis Pejovic, Bournonia aff. wionztki Pejovic, Biradolitides sp. (Biradolitides aff. fisicostatus d’Orbigny), Biradolitides sp., Sauvagesia sp. and Durania sp.

4) Radiolitid-Hippuritid assemblage (middle-late Maastrichtian; Inlice-Fethiye and Bozburun Tepe-Köyceğiz) comprises Bournonia aff. adriaetica Pejovic, Bournonia cf. fassicularis (Pirona), Bournonia sp., Biradolitides sp. (Biradolitides aff. chaperi Touchas), Lapeirousia sp., Durania sp., Sauvagesia sp. and Hippurites corinopias Defrance.

This study reveals for the first time that the rudists, which were regarded as shell fragments in previous studies comprise assemblages indicating different ages in the Lycian Nappes. The biostratigraphic data obtained from rudists provide valuable contribution to better understand the Upper Cretaceous stratigraphy of the Lycian nappes. The rudists and the microfacies characteristics of the limestones provide information on the depositional environments of the Cretaceous successions. The data obtained reveal that the limestones were deposited in the inner and outer shelves of the Cretaceous carbonate platform(s). Rudists formed small isolated patches and aggregations in these environments and commonly deposited as shell fragments particularly on the outer shelf in response to increasing energy and platform slope characteristics.

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