Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), Vol. 19, 2010, pp. 473–496. Copyright ©TÜBİTAK
doi:10.3906/yer-0907-19 First published online 14 November 2009

Oligocene History of the Çardak-Dazkırı Sub-basin (Denizli, SW Turkey): Integrated Molluscan and Planktonic Foraminiferal Biostratigraphy

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Received 17 July 2009; revised typescript receipt 04 November 2009; accepted 11 December 2009

Abstract: The detailed analysis of molluscan and planktonic foraminiferal fauna in the Oligocene Çardak-Dazkırı sub-basin, in northeastern Denizli province (western Turkey) allowed accurate dating of the deposits, together with interpretation of their depositional environments. Gastropod, bivalve, scaphopod and planktonic foraminiferal assemblages identified in ten sections reveal a succession which was deposited between the Late Rupelian and Early Chattian. Planktonic foraminifera, documented for the first time in the basin, indicate the P19 Zone (*Turborotalia ampliapertura* Zone) of the Late Rupelian at the base of the succession whereas Molluscan fauna, determined for the first time in this study, assign the whole succession, to the Late Rupelian–Early Chattian. In addition to the precise dating, the palaeoenvironmental reconstruction of the studied Oligocene succession has been enabled by the use of integrated palaeontological data. Six sections from the southwest (Baklan) area, two from the southeast (Dazkırı) area and two from the north (Tokça) area indicate the varying depositional environments at different stages of basin evolution. The southwest area mainly represents a regime changing from deep to shallow marine facies during the Late Rupelian. The southeast area comprises shallow marine and brackish lagoonal facies deposited from the Late Rupelian to Early Chattian. Finally, exclusively brackish-shallow marine deposits cropping out in the northern area were deposited in the Early Chattian.

Key Words: Late Rupelian, Early Chattian, Çardak-Dazkırı subbasin, Lycian molasse basin, mollusca, planktonic foraminifera, biostratigraphy, palaeoenvironments

Çardak-Dazkırı Alt Havzasının Oligosen Tarihçesi (Denizli, GB Türkiye): Birleştirilmiş Mollusk ve Planktonik Foraminifer Biyostratigrafisi

Özet: Denizli'nin (Batı Türkiye) kuzeydoğu bölgesinde yeralan Oligosen yaşlı Çardak-Dazkırı alt havzasındaki mollusk ve planktonik foraminifer faunasının detaylı olarak incelenmesi, çökellerin ortamsal yorumları ile birlikte detaylı olarak yaşlandırılmalarına olanak sağlamıştır. On ölçülü stratigrafi kesitinde tanımlanan gastropod, bivalv, scaphopod ve planktonik foraminifer toplulukları, istifin Geç Rupeliyen–Erken Şattiyen zaman aralığında çökelmiş olduğunu ortaya koymaktadır. Havzada ilk kez tanımlanan planktonik foraminiferler, istifin taban bölümünde Geç Rupeliyen'in P19 Zonu'nun (*Turborotalia ampliapertura* Zonu) varlığına işaret ederken, yine bu çalışmayla ilk kez saptanan mollusk faunası istifin tümünü Geç Rupeliyen–Erken Şattiyen olarak yaşlandırmaktadır. Birleştirilmiş palaeontolojik veriler yardımıyla, incelenen Oligosen istifi detaylı olarak yaşlandırılırken palaeoortamsal olarak da yorumlanmıştır. Havzanın güneybatı bölgesindeki (Baklan) altı kesit ile güneydoğu (Dazkırı) ve kuzey (Tokça) bölgelerindeki ikişer kesit, havza evriminin farklı dönemlerinde değişen çökelme ortamlarının varlığını ortaya koymaktadır. Buna göre; güneybatı bölge, geç Rupeliyen sırasında genel olarak derinden sığ koşullara doğru değişen ortam koşullarını temsil etmektedir. Güneydoğu bölge Geç Rupeliyen–Erken Şattiyen yaşlı sığ denizel ve brakiş ortam çökellerini içermektedir. Son olarak, kuzey bölgede brakiş-sığ denizel ortam koşullarını temsil eden istifin çökelimi erken Şattiyen'de gerçekleşmiştir.

Anahtar Sözcükler: Geç Rupeliyen, Erken Şattiyen, Çardak-Dazkırı alt havzası, Likya molas havzası, mollusk, planktonik foraminifer, biyostratigrafi, palaeoortamlar

Introduction

Oligo–Miocene deposits, widely exposed in southwest Turkey, extend to the tectonic contacts between the Menderes Massif and Lycian nappes (Figure 1). Termed 'Lycian molasse', they include in NE–SW-directed depressions the Denizli, Kale-Tavas and Çardak-Dazkırı sub-basins (Sözbilir 2005). These sub-basins are highly significant, being located in an area that experienced one of the most complex trains of tectonic events in the Aegean/Eastern Mediterranean region (Dewey & Şengör 1979; Şengör & Yılmaz 1981). From the Oligocene to the present, the continuing effects of African and Eurasian closure caused various changes and regional differentations in basinal developments in the convergent boundary zone (Meulenkamp *et al.* 2000; Meulenkamp & Sissingh 2003). Although numerous geological studies have attempted to resolve many geological problems in the area, interpretations of the origin, timing and evolution of molassic sediments related to the regional geodynamic mechanism remain controversial. These debates are beyond our main scope, although because of their importance in regional Oligo–Miocene basinal development, some related arguments are summarized here. Generally, it is thought that the tectonic regimes in southwestern Turkey developed in three different regional phases; palaeotectonic, transition and neotectonic periods respectively (Şengör & Yılmaz 1981; Koçyiğit 1984). Of these, the first (palaeotectonic) phase is characterized by a compressional tectonic regime, indicated mainly by emplacement of ophiolitic nappes; the transition period is characterized by both compressional and tensional regimes, whereas the neotectonic period is marked by N–S continental crust extension. It was suggested that the Oligo–Miocene deposits in the Denizli region developed during the regional transition period (Koçyiğit 1984). But, different views and approaches were presented by subsequent authors. Some claimed that the compressional regime terminated at the end of the Oligocene and the N–S extensional regime in the Early Miocene, which was related to orogenic collapse, immediately followed the tightening trend (Seyitoğlu & Scott 1991; Seyitoğlu *et al.* 1992). Some authors proposed an earlier extensional collapse phase: the latest Oligocene–Early Miocene (Işık *et al.* 2004) or Early Oligocene (Rupelian) (Sözbilir 2005). But, subsequent researchers rejected the 'earlier extension' idea and instead proposed crustal shortening during the Oligocene–Early Miocene and crustal extension in the Late Miocene (Westaway *et al.* 2005; Westaway 2006). Therefore, the palaeontological data obtained from the molasse basins are crucial to the interpretion of the history of basinal development.

This study deals with the Oligocene sequence of the Çardak-Dazkırı sub-basin, which has the most debatable datings of the Lycian molasse. It is located along the northern flank of the Acıgöl Graben and in the footwall of the Baklan Fault, between Baklan, Bozkurt, Çardak, Dazkırı and Tokça (Göktaş *et al.*1989; Şenel 1997) (Figure 1). The basinal deposits rest on the Mesozoic Lycian nappes and supra-allochthonous Palaeocene–Eocene sediments (Göktaş *et al.*1989; Şenel 1997; Sözbilir 2005). Its infill consists primarily of siliciclastic and partly of carbonate rocks deposited in various facies from terrestrial to brackish and shallow marine environments.

The first regional geological and stratigraphical studies in the Çardak-Dazkırı sub-basin are those of Nebert (1956), Dizer (1962) and Bering (1967). The Oligocene sediments were interpreted firstly as flysch (Nebert 1956) and later as molasse (Bering 1967). Dizer (1962) first reported the presence of the Oligocene benthic foraminifera in the region. These postorogenic molasse deposits, termed the Acıgöl group by Göktaş *et al.* (1989), included the Armutalanı, Çardak, Hayrettin, Tokça and Bozdağ formations. They referred the Armutalanı formation to the Oligocene, the Çardak formation to the Stampian, the Hayrettin and Tokça formations to the Oligocene/Chattian and the Bozdağ formation to the Late Oligocene (?)–Early Miocene respectively. The Hayrettin and Tokça formations were assigned to the Early Oligocene (palynological data of Benda 1971) or Oligocene–Aquitanian age (Bering 1967).

Although different kinds of macro- and microfossils within these deposits have been described by many researchers (Göktaş *et al.* 1989; Akkiraz & Akgün 2005; İslamoğlu *et al.* 2005, 2006; Gedik 2008; Özcan *et al.* 2009), molluscan and

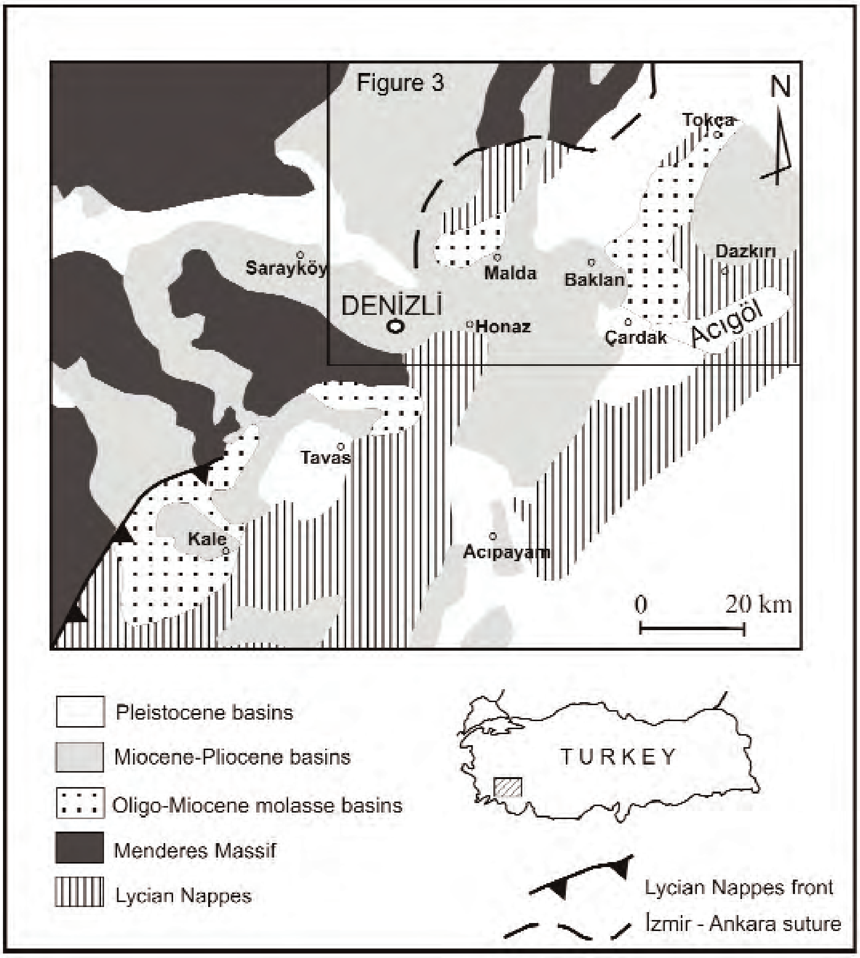

Figure 1. Oligo–Miocene molasse basins and surrounding tectonic units in the Denizli region (modified from Şengör & Yılmaz 1981; Şengör *et al.* 1985; Konak *et al.* 1986: unpublished MTA report; Seyitoğlu & Scott 1991; Akgün & Sözbilir 2001).

planktonic foraminiferal assemblages have not hitherto been studied in detail. Thus, this study aims to establish the detailed biostratigraphic framework and palaeoenvironmental history of the Çardak-Dazkırı sub-basin by using planktonic foraminifera and molluscs (gastropods, bivalves and scaphopods) obtained from the Çardak, Hayrettin and Tokça formations.

Investigated Sections: Lithology and Fossil Contents

The Oligocene sections presented in this paper comprise the Armutalanı, Çardak, Hayrettin and Tokça formations (Figures 2 & 3). In lithology, fossil content and geographical position, the sections are grouped into three areas; soutwest (Baklan), southeast (Dazkırı) and north (Tokça). The sample numbers are shown as 'abbreviations' in both the text and Figures 4 & 5. Fossil distribution is shown in Tables 1 & 2, and some species of planktonic foraminiferal and molluscan fauna are also illustrated in Figures 6–8.

Southwest Area (Baklan)

In this area, the basement rocks are transgressively covered by the units (Armutalanı and Çardak

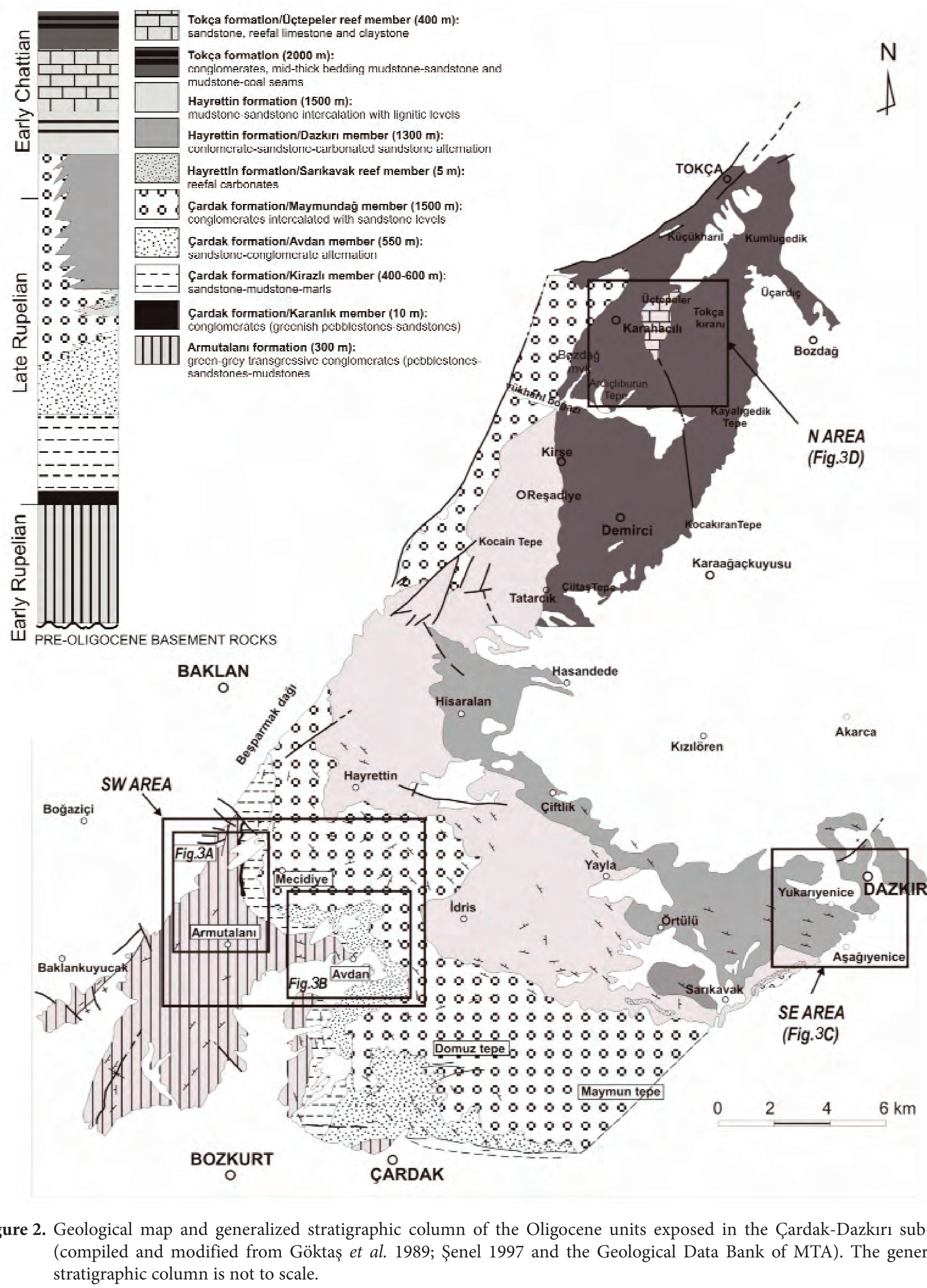

Figure 2. Geological map and generalized stratigraphic column of the Oligocene units exposed in the Çardak-Dazkırı sub-basin (compiled and modified from Göktaş *et al.* 1989; Şenel 1997 and the Geological Data Bank of MTA). The generalized stratigraphic column is not to scale.

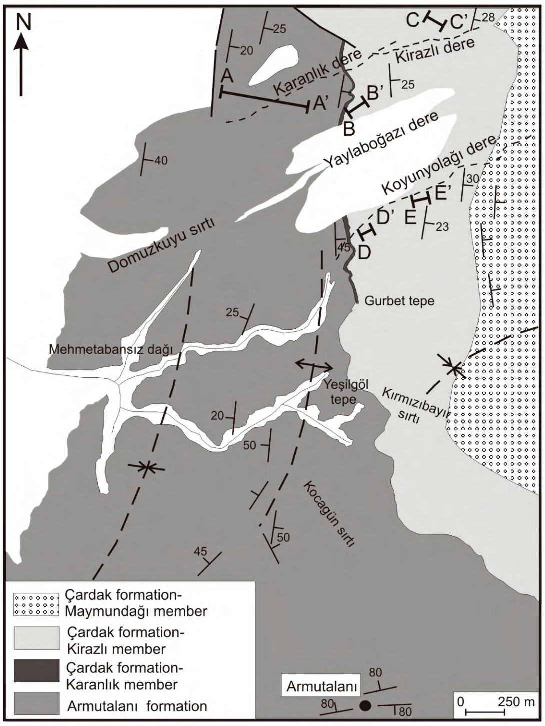

Fig. 3A [SW (Baklan) Area]

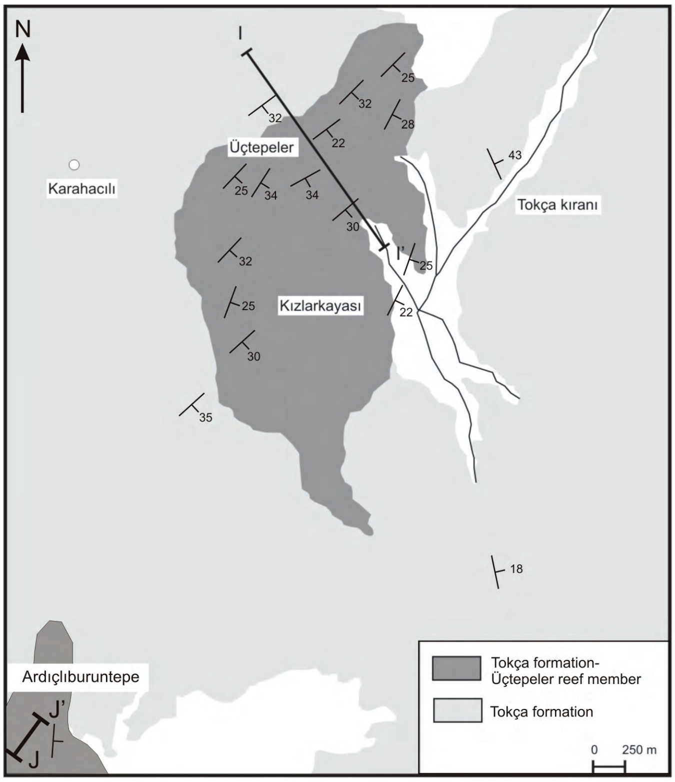

Fig.3D [N (Tokça) Area]

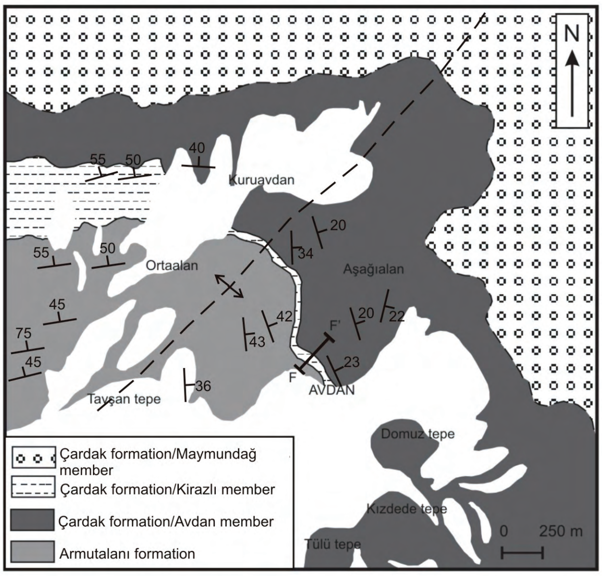

Fig.3B [SW (Baklan) Area]

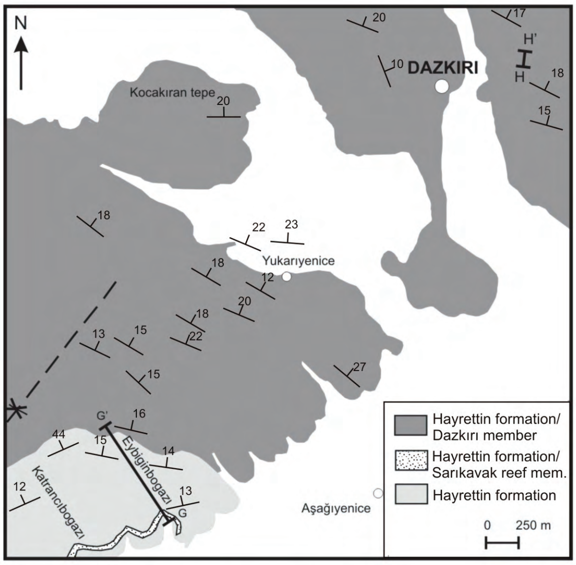

Fig. 3C [SE(Dazkırı) Area]

Figure 3. The localities and sites of the measured stratigraphic sections in the Çardak-Dazkırı subbasin. **(A)** AA'– Karanlıkdere-1, BB'– Karanlıkdere-2, CC'– Kirazlıdere, DD'– Koyunyolağıdere-1, EE'– Koyunyolağıdere-2; **(B)** FF'– Avdan; **(C)** GG'– Eybiginboğazı, HH'– Dazkırı; **(D)** II'– Üçtepeler, JJ'– Ardıçlıburun (the geological maps are taken from the archives of MTA).

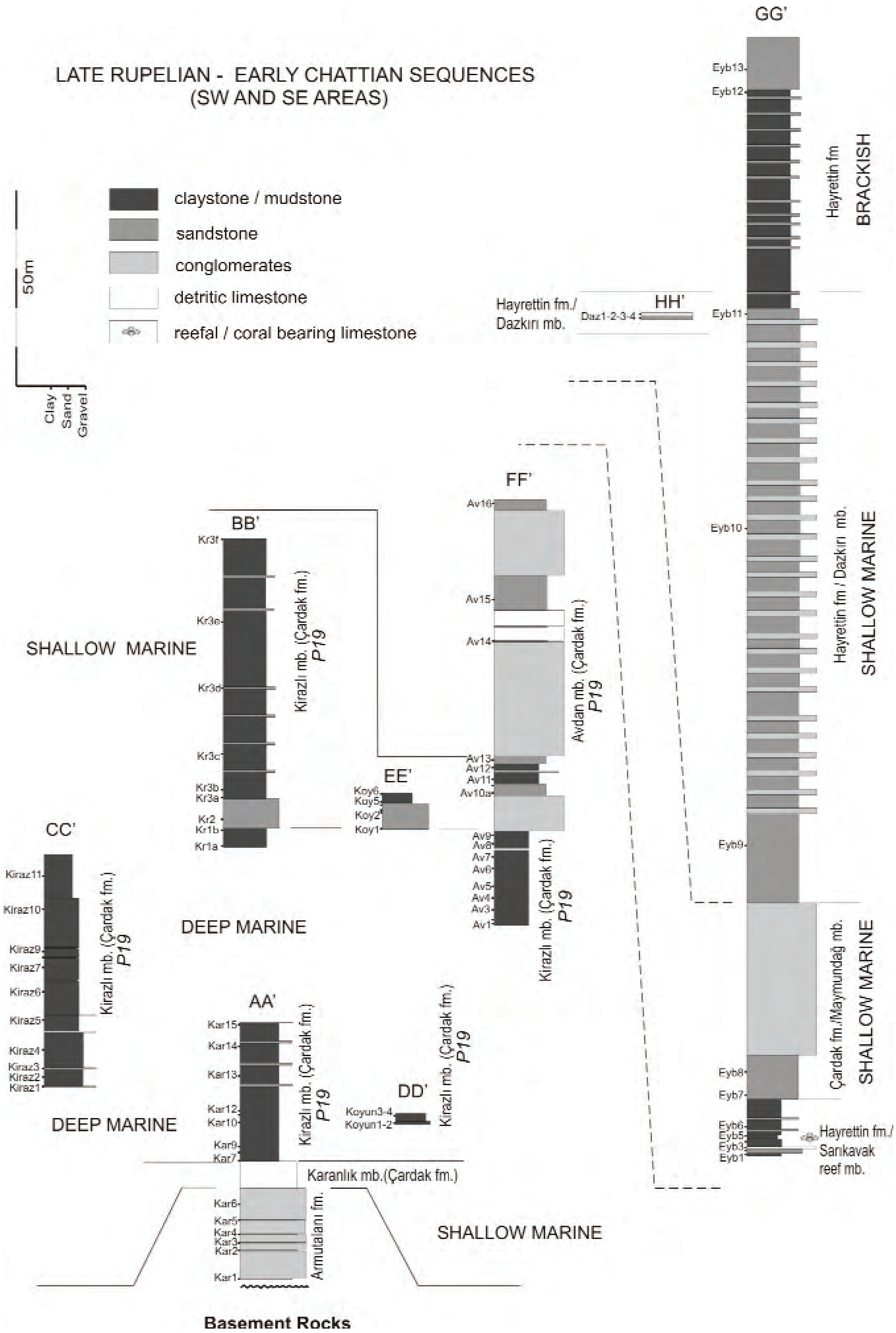

Figure 4. Litho- and biostratigraphical correlation of the sections (southwest and southeast areas) and facies in the Late Rupelian–Early Chattian. SW (Baklan) area: AA'– Karanlıkdere-1, BB'– Karanlıkdere-2, CC'– Kirazlıdere, DD'– Koyunyolağıdere-1, EE'– Koyunyolağıdere-2, FF'– Avdan. SE (Dazkırı) area: GG'– Eybiginboğazı, HH'– Dazkırı.

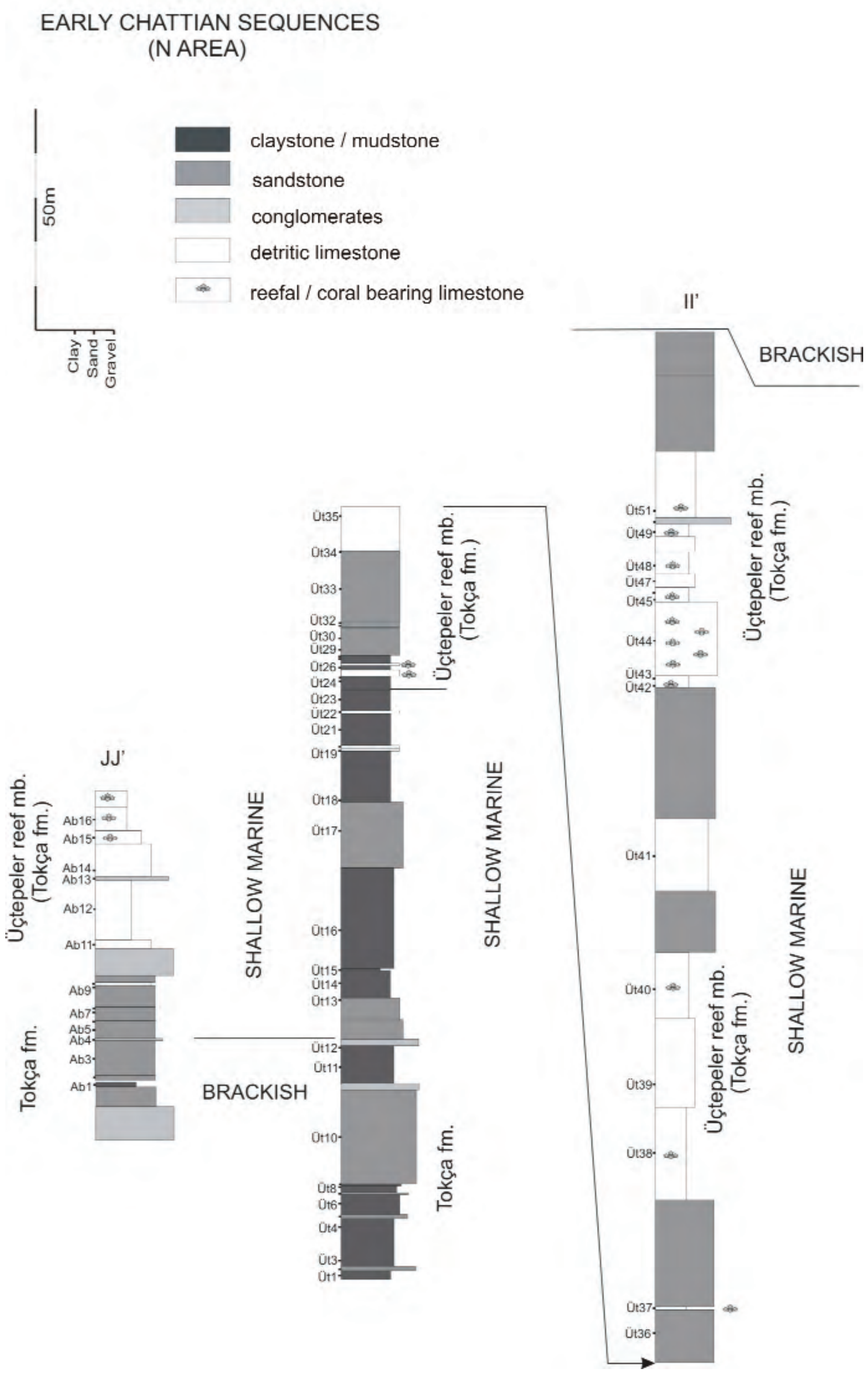

Figure 5. Litho- and biostratigraphical correlation of the sections (north area) and facies in the Early Chattian. N (Tokça) area: II'– Üçtepeler, JJ'– Ardıçlıburun.

Table 1. Distribution of planktonic foraminifera determined in the studied sections [Symbols: Kr– Karanlıkdere-2 section (1), Kar– Karanlıkdere-1 section (2), Kiraz– Kirazlıdere section (3), Koyun– Koyunyolağıdere-1 section (4), Koy– Koyunyolağıdere-2 section (5), Av– Avdan section (6), Eyb– Eybiginboğazı section (7), Daz– Dazkırı section (8), Üt– Üçtepeler section (9), Ab– Ardıçlıburun section (10)].

SAMPLES	Kar					Koyun				Kiraz										Kr				Koy		Avdan		
	8	9	10	13	14	1	2	3	4	2	3	4	5	6	7	8	9	10	11	3a	3b	3c	3f	1	3	1	9	11
PLANKTONIC FORAMINIFERA																												
Turborotalia ampliapertura	+	+	+		+				+		+	+		+	+	+	+					+	+			+	+	+
Turborotalia pseudoamliapertura	+		+		+		+								+								+					
Turborotalia increbescens			+																									
Dentoglobigerina galavisi		+	+	+																								
Dentoglobigerina globularis				+																								
Subbotina yeguaensis	+		+					+															+					
Subbotina angiporoides	+		+	+	+									+														
Subbotina officinalis	+		+		+						+					+												
Subbotina gortanii	+				+																+		+	+		+	+	
Globoquadrina venezuelana	+	+	+	+	+		+		+			+		+	+				+			+	+				+	+
Globoquadrina tripartita	+			+	+				+		+			+		+						+						
Globoquadrina selii					+		+																					
Globoquadrina prasaepis			+	+			+		+			+		+		+			+									
Globoquadrina rohri					+				+				+	+												+		
Globorotaloides suteri	+			+	+		+		+						+								+			+	+	
Catapsydrax dissimilis									+														+					
Catapsydrax unicavus	+													+														
Catapsydrax martini					+		+																					
Paragloborotalia nana															+								+					
Globigerina ouachitaensis ouachitaensis	+	+		+			+		+					+								+						
Subbotina sp.	+	+		+		+	+	+	+	+	+			+	+	+	+	+		+	+	+	+		+	+	+	+

formations) comprising the older part of the Oligocene succession (Figure 2). Unconformable surfaces between the Oligocene units and the Lycian Nappes and Upper Eocene (Priabonian) sediments have been previously described (Göktaş *et al.* 1989; Şenel 1997), but in this study, however, the contact between the Oligocene and the Upper Eocene rocks was not observed.

The lower unit of the transgressive sequence, the Armutalanı formation, consists of transgressive conglomerates, mudstones and sandstones. The upper unit, the Çardak formation, includes different units including conglomerates (Karanlık member), sandstones-mudstones-marls (Kirazlı member), sandstone-conglomerate alternation (Avdan member) and conglomerates intercalated with sandstones (Maymundağ member). In general, the depositional environments of the Armutalanı and Çardak formations are interpreted as fan delta facies (Göktaş *et al.* 1989).

In the southwest area, six sections [Karanlıkdere-1 (N29°34´57.25″, E37°1´54.08″), Karanlıkdere-2 (N29°34´24.97″, E37°1´44.96″), Kirazlıdere (N29°35´17.57″, E37°2´28.71″), Koyunyolağıdere-1 (N29°35´2.77″, E37°1´22.33″), Koyunyolağıdere-2 (N29°35´11.83″, E37°1´30.7″) and Avdan (N29°39´21.41″, E37°53´43.13″)] were measured (Figures 3A & 3B).

Karanlıkdere-1 Section (Armutalanı Formation, Karanlık and Kirazlı Members of the Çardak Formation) (Figures 3A & 4): The section is composed of a siliciclastic succession 65 m thick. Its lower part 23.5 m thick belongs to the Armutalanı formation. This unit comprises alternations of 1.5–8-m-thick, massive, dark green, poorly sorted and rounded conglomerates composed of mainly ophiolitic, and partly limestone pebbles, and 5–20-cm-thick beds of grey-green sandstones with dispersed small pebbles (samples Kar1-Kar6). The Armutalanı formation is overlain by the Karanlık member of the Çardak formation. The Karanlık

Table 2. Distribution of gastropods, bivalves, scaphopods and corals identified in the studied sections (see symbols in Table 1).

SAMPLES	Koy	Eyb				Üt							Ab			
	2	2	3	5	12	2	3	10	12	13	30	32	4	5	11	15
GASTROPODA																
Ampullinopsis crassatina		+									+					+
Globularia gibberosa											+					+
Tympanotonos margaritaceus					+											
Tympanotonos trochlearispina					+											
Haustator conofasciata																
Haustator cf. *asperula*	+															
Turritella (*Peyrotia*) *strangulata*		+														
Cerithium meneghini	+															
Athleta (*Neoathleta*) *affinis*	+											+				
Lyria harpula											+					
Amalda tournoueri	+															
Turris coronata	+															
Conus carcarensis	+															
BIVALVIA																
Pycnodonte gigantica callifera				+												
Crassostrea fimbriata										+						
Hyotissa hyotis				+												
Pecten arcuatus										+				+	+	
Amussiopecten labadyei														+	+	
Costellamussiopecten deletus														+		
SCAPHOPODA																
Dentalium kickxii	+															
CORALS																
Stylophora thirsiformis													+	+		
Stylophora microstyla													+	+		
Stylophora conferta						+	+						+	+		
Astrocoenia septemdigitata								+					+	+		
Montastraea inaequalis										+			+	+		
Antillia calcarensis													+	+		
Tarbellastraea organalis													+	+		
Mycetophyllia mirabilis								+					+	+		
Heliastraea sp.			+													
Tarbellastraea sp.			+													
Porites sp.				+		+	+	+		+			+	+		
Mussismilia sp.													+	+		
Astrocoenia sp.								+					+	+		
Favites sp.										+			+	+		
Lithophyllia sp.						+	+									
Meandrina sp.								+	+							
Montastraea sp.								+								

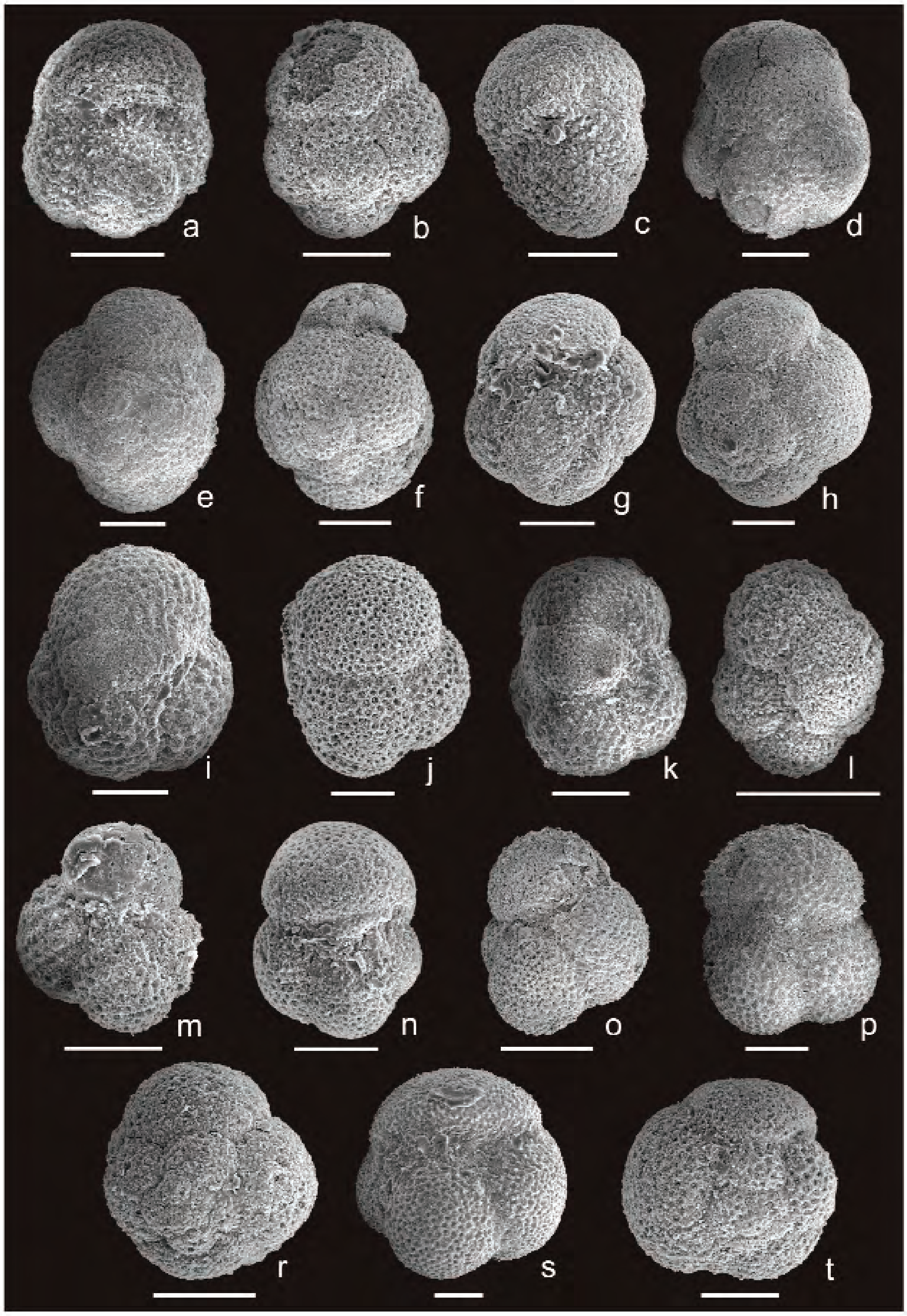

Figure 6. Planktonic foraminiferal assemblage of P19 Zone. **(a–c)** *Turborotalia ampliapertura* (Bolli), **(a)** umbilical view, **(b)** spiral view, **(c)** side view, Sample Kar8; **(d)** *Turborotalia increbescens* (Bandy), umbilical view, Sample Kar10; **(e, f)** *Subbotina gortanii* (Borsetti), **(e)** spiral view, **(f)** side view, Sample Kr3b; **(g, h)** *Turborotalia pseudoampliapertura* (Blow and Banner), **(g)** umbilical view, **(h)** spiral view, Sample Kar8; **(i)** *Catapsydrax dissimilis* (Cushman and Bermudez), umbilical view, Sample Kr3f; **(j)** *Subbotina* sp., spiral view, Sample Koyun4; **(k)** *Catapsydrax unicavus* Bolli, Loeblich and Tapan, umbilical view, Sample Kar8; **(l)** *Globorotaloides suteri* Bolli, umbilical view, Sample Kiraz7; **(m)** *Subbotina officinalis* (Subbotina), umbilical view, Sample Kar8; **(n)** *Subbotina yeguaensis* (Weinzierl and Applin), umbilical view, Sample Kar10; **(o)** *Globigerina ouachitaensis ouachitaensis* Howe & Wallace, umbilical view, Sample Kiraz6; **(p)** *Dentoglobigerina galavisi* Bermudez, umbilical view, Sample Kar13; **(r)** *Subbotina angiporoides* (Hornibrook), umbilical view, Sample Kar14; **(s)** *Globoquadrina prasaepis* (Blow), umbilical view, Sample Kar10; **(t)** *Globoquadrina venezuelana* (Hedberg), umbilical view, Sample Kar8, Scale bars: 100 µm.

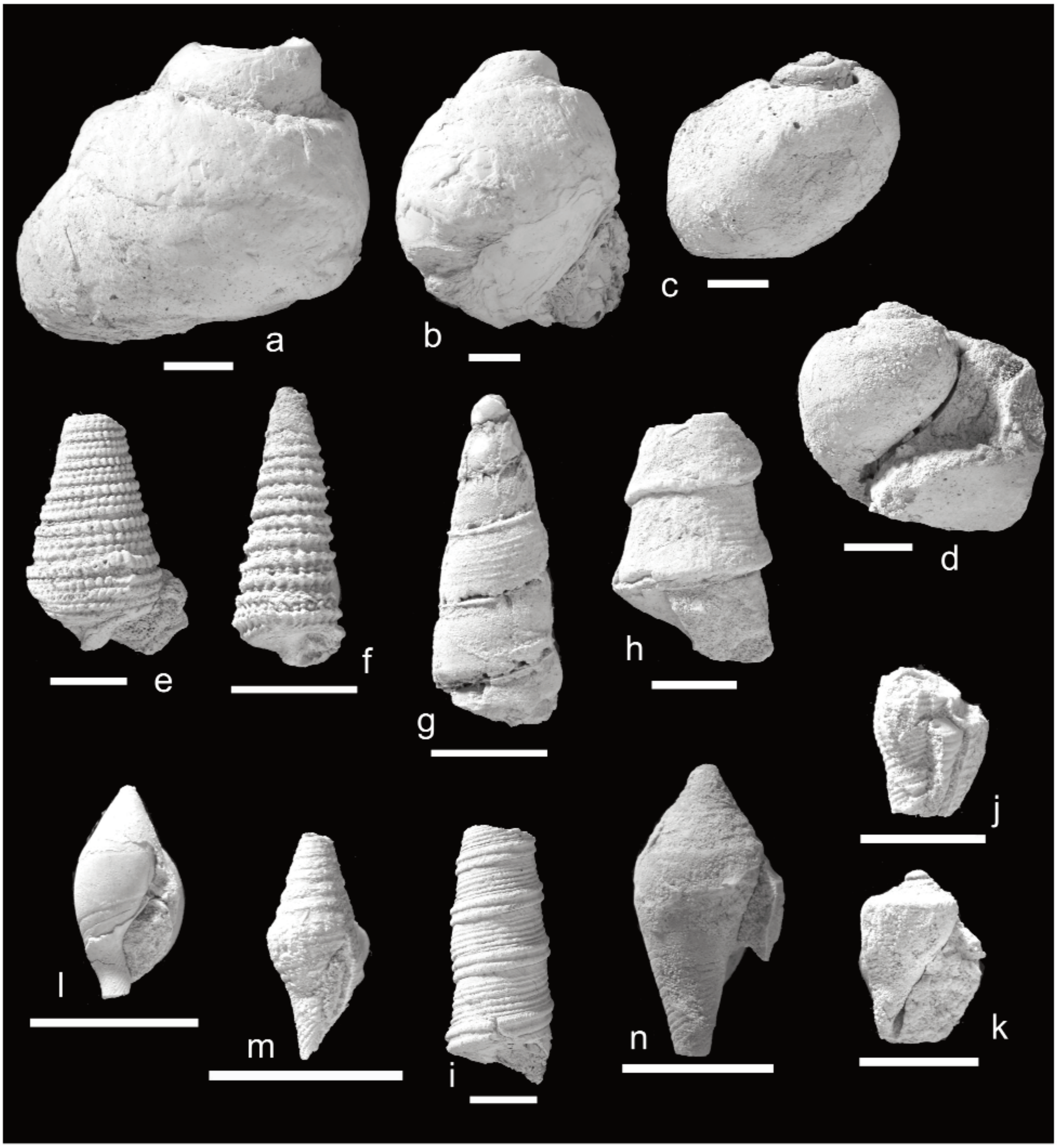

Figure 7. Late Rupelian–Early Chattian gastropod assemblage. **(a, b)** *Ampullinopsis crassatina* (Lamarck), **(a)** back view, Sample Eyb2; **(b)** apertural view, Sample Üt30; **(c-d)** *Globularia gibberosa* (Grateloup), Sample Üt30, **(c)** back view, **(d)** apertural view; **(e)** *Tympanotonos margaritaceus* (Brocchi), apertural view, Sample Eyb12; **(f)** *Tympanotonos trochlearispina* (Sacco), apertural view, Sample Eyb12; **(g)** *Haustator* cf. *asperula* (Brongniart), apertural view, Sample Koy2; **(h)** *Turritella (Peyrotia) strangulata* Grateloup, apertural view, Sample Eyb2; **(i)** *Haustator conofasciata* (Sacco), apertural view, Sample Eyb2; **(j, k)** *Athleta (Neoathleta) affinis* (Brocchi), apertural view, Sample Koy2; **(l)** *Amalda tournoueri* (Cossmann), apertural view, Sample Koy2; **(m)** *Turris coronata* (Münster in Goldfuss), apertural view, Sample Koy2; **(n)** *Conus carcarensis* Sacco, apertural view, Sample Koy2. Scale bars: 1 cm.

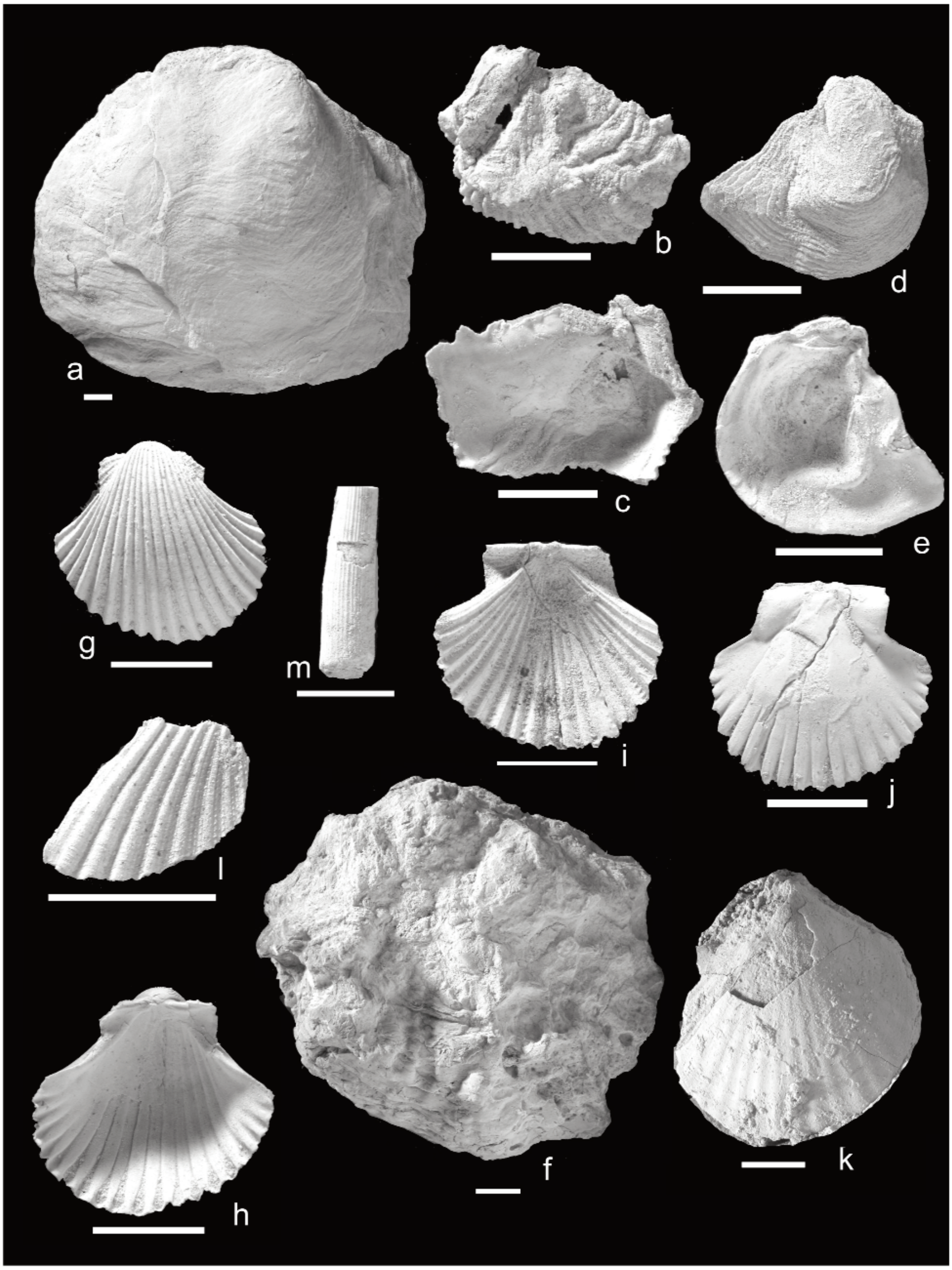

Figure 8. Late Rupelian–early Chattian bivalve and scaphopod assemblage. **(a)** *Pycnodonte gigantica callifera* (Lamarck), left valve, outer view, Sample Eyb5; **(b–e)** *Crassostrea fimbriata* (Grateloup in Roulin and Delbos), Sample Üt13, **(b)** left valve, outer view, **(c)** left valve, inner view, **(d)** right valve, outer view, **(e)** right valve, inner view; **(f)** *Hyotissa hyotis* (Linnaeus), left valve, outer view, Sample Eyb5, **(g, j)** *Pecten arcuatus* (Brocchi), Sample Üt13, **(g)** right valve, outer view, **(h)** right valve, inner view **(i)** left valve, outer view, **(j)** left valve inner view; **(k)** *Amussiopecten labadyei* (d'Archiac and Haime), left valve, outer view, Sample Ab5; **(l)** *Costellamussiopecten deletus* (Michelotti), left valve, outer view, Sample Ab5; **(m)** *Dentalium kickxii* (Nyst), Sample Koy2, side view. Scale bars: 1 cm.

member, 7 m thick, consists of highly consolidated yellowish-grey, carbonate cemented, coarse sandy conglomerates. The upper part of the section, which consists of 21.5-m-thick marls intercalated with mudstones representing deeper facies, belongs to the Kirazlı member of the Çardak formation. Increasing water depth is supported by a decrease of coarse siliciclastic content and by abundant calcareous planktons (planktonic foraminifera and nannofossils). Upwards, the marls grade into a 13.5-m-thick marl-calcareous sandstone alternation. The planktonic foraminifera identified in the Karanlıkdere-1 section are shown in Table 1.

Karanlıkdere-2 Section (Kirazlı Member of Çardak Formation) (Figures 3A & 4): The 63-m-thick section, corresponding to the middle-upper part of the Kirazlı member, mainly comprises mudstones intercalated with sandstones. The section starts with 5 m of mudstones (Kr1a and Kr1b) and continues with 7.5 m of grey, thick bedded, hard sandstones with rare pebbles, 2.5 m of mudstones, and a 50-m-thick grey mudstone-sandstone alternation. Samples from the lower part (Kr3b, Kr3c and Kr3d) include gastropod shell fragments. In the uppermost level (Kr3f), the species number of planktonic foraminifera is much more than in the other samples from the section (Table 1).

Kirazlıdere, Koyunyolağıdere-1, Koyunyolağıdere-2 Sections (Kirazlı Member of the Çardak Formation) (Figures 3A & 4): The Kirazlıdere section is 59.5 m thick. 50 cm of basal green sandstones (Kiraz1) are overlain by 4.5 m of green claystones (Kiraz2) containing some mollusc and foraminifer shell fragments. The overlying 40-cm-thick sandstone comprises planktonic foraminifera and nodosarid-rotalid benthic foraminifera (Kiraz3). Finally 28-m-thick green claystones (Kiraz4-Kiraz9) and overlying 21.5 m of marls (Kiraz10, Kiraz11) include planktonic foraminifera (Table 1).

Koyunyolağıdere-1 and Koyunyolağıdere-2 are short sections (3 m and 12.5 m thick, respectively). Koyunyolağıdere-1 consists entirely of greenish grey marls. In the section, the species number of planktonic foraminifera is considerably increased (Koyun2 and Koyun4) (Table 1). Some benthic foraminifer fragments were observed together with planktonic foraminifera. The Koyunyolağıdere-2 section consists of sandy mudstones. Its calcareous plankton content is relatively poorer than the Koyunyolağıdere-1 section (Table 1). In the lower part of the section, shallow marine molluscs (gastropods: *Cerithium meneghini* Michelotti, *Haustator* cf. *asperula* (Brongniart), *Athleta (Neoathleta) affinis* (Brocchi), *Amalda tournoueri* (Cossmann), *Turris coronata* (Münster in Goldfus), *Conus carcarensis* Sacco; scaphopods: *Dentalium kickxii* (Nyst) were identified (Table 2). Benthic foraminifera (*Nummulites fichteli* Michelotti, *Nummulites vascus* Joly and Leymerie, *Operculina complanata* (Defrance) are also associated with the molluscs (Koy2, Koy4) (İslamoğlu *et al.* 2005). In the uppermost levels, the sandy mudstones change into carbonate cemented sandstones (Koy5, Koy6).

Avdan Section (Kirazlı and Avdan Members of the Çardak Formation) (Figures 3B & 4): The 111-m-thick sequence comprises grey sandy mudstones in its lower part (Kirazlı member, 24.5 m in thickness) and a sandstone-conglomerate alternation in its upper part (Avdan member). The lower and uppermost levels of the Kirazlı member in the section (Av1 and Av9) include a planktonic foraminiferal assemblage (Table 1). Overlying 9 m of conglomerates and 3 m of silty sandstones are followed by 1.8 m of thick mudstones (Av11) containing a similar assemblage. 30 cm of an overlying thick yellow, pebbly sandstone bed and 3.2 m of mudstones include only nannofossils (İslamoğlu *et al.* 2005). The rest of the section is dominated by coarse detritals consisting of a thick conglomerate-sandstone alternation. No fossils were obtained in these coarse detrital sediments.

Southeast Area (Dazkırı)

In the southeast area, the Maymundağ member of the Çardak formation, the Sarıkavak reef and Dazkırı members of the Hayrettin formation have been logged. These units represent approximately the middle part of the Oligocene succession of the Çardak-Dazkırı sub-basin. The Maymundağ member, consisting mainly of conglomerates, grades laterally and vertically into the Hayrettin formation. The reef carbonates (Sarıkavak reef member) within the lower part of the Hayrettin formation can be followed as a guide horizon in the southeast area (Figure 3). The Dazkırı member, comprising a conglomerate-sandstone and carbonate-cemented sandstone alternation, represents the main part of the Hayrettin formation, whereas mudstones including some gypsum and lignite levels are observed both in its lower and upper levels. In this area, two sections [Eybiginboğazı (N29°50´16.33″, E37°53´28.61″) and Dazkırı (N29°16´37.72″, E37°29´47.76″) sections] have been measured (Figure 3C).

Eybiginboğazı Section (Maymundağ, Sarıkavak Reef and Dazkırı Members) (Figures 3C & 4): The Eybiginboğazı section is 287 m thick. Its lower 26 m represent the Sarıkavak reef member. This unit starts with 70 cm of greenish grey mudstones (Eyb1). The overlying 1.3-m-thick yellow pebbly sandstones contain gastropods *Haustator conofasciata* (Sacco), *Ampullinopsis crassatina* (Lamarck), *Turritella (Peyrotia) strangulata* Grateloup] (Eyb2). 50 cm of overlying thick carbonate-cemented conglomerates include poorly sorted coral pebbles (*Heliastraea* sp., *Tarbellastraea* sp.) (Eyb3). Above, 2 m of fine bedded mudstones (Eyb4) are overlain by 60 cm of very hard, thick bedded, greenish grey clayey limestones (Eyb5) containing shallow marine thick-shelled ostreids *Pycnodonte gigantica callifera* (Lamarck) and *Hyotissa hyotis* (Linneaus) and corals (*Porites* sp.). The upper part contains the shallow marine-sublittoral gastropod assemblage *Haustator conofasciata* (Sacco), *Ampullinopsis crassatina* (Lamarck), *Turritella (Peyrotia) strangulata* Grateloup and corallian reef limestones. Near the top, a coarsening trend is marked by 9.6 m of a greenish-grey calcareous sandstone-mudstone alternation (Eyb6), 3.3 m of grey sandstone (Eyb7), and 8 m of beige thin-medium bedded sandstones (Eyb8). This part of the section is followed by 39 m of poorly sorted and rounded polygenetic conglomerates corresponding to the Maymundağ member of Çardak formation.

The next 141-m-thick part of the section belongs to the Dazkırı member. Its lower 19.5 m of medium-bedded yellow sandstones are overlain by a thick (122 m) conglomerate-sandstone alternation (Eyb9-Eyb11). In the uppermost level, carbonated sandstones (Eyb11) contain *Nummulites fichteli* Michelotti and *Operculina complanata* (Defrance) (İslamoğlu *et al.* 2005). The overlying 54 m of thin-medium bedded sandstones and mudstones includes brackish-water gastropods *Tympanotonos margaritaceaus* (Brocchi) and *Tympanotonos trochlearispina* (Sacco) in their upper levels (Eyb-12), indicating a regressive trend in the region. These deposits are capped by 16.5 m of fossil-free yellow thin-bedded sandstones (Eyb13).

Dazkırı Section (Dazkırı Member of Hayrettin Formation) (Figures 3C & 4): The section belonging to the Dazkırı member of the Hayrettin formation is very short (1.5 m). It starts with 60 cm of thin bedded sandstone (Daz1) overlain by 45 cm of sandstone (Daz2, Daz3). The uppermost level, 50 cm of hard, carbonated sandstone (Daz4), contains benthic foraminifera (*Eulepidina* sp., *Nummulites* sp., *Operculina* sp., *Amphistegina* sp., *Neorotalia* sp., *Asterigerina* sp.) and a bryozoan assemblage (İslamoğlu *et al.* 2005).

North Area (Tokça)

The sequence in this area contains both transgressive and regressive units (Tokça formation, Üçtepeler reef member) which are the younger part of the Oligocene succession in the basin. It consists of fine detritals, reef carbonates and lignite-bearing mudstones. Two sections have been analysed: Üçtepeler (N29°45´21.52″, E38°7´6.56″) and Ardıçlıburun (N29°43´44.41″ E38°4´51.78″) (Figures 3D).

Üçtepeler Section (Tokça Formation, Üçtepeler Reef Member) (Figures 3D & 5): The 424-m-thick sequence includes conglomerate-sandstone-mudstone alternations in its lower and middle parts, overlain by reef limestones and sandstones, some calcareous sandstone-sandstone in the upper part.

The lower part of the section starts with 2 m of yellow-beige silty mudstone (Üt1), overlain in turn by 1.2 m of yellow, medium sorted and rounded polygenic sandy conglomerates and 15.7 m of yellow sandstone (Üt3). Above, 1.5 m of thick yellow sandy siltstones (Üt7) are overlain in turn by 60 cm of yellow sandstones, 1.5 m of grey, medium sorted, lenticular conglomerates with angular small pebbles, 8.5 m of yellowish brown sandy mudstone with dispersed small pebbles (Üt10), 15 cm of greenish grey claystone with trace fossils (Üt11), 1.5 m of yellowish beige conglomerates and 9 m of yellow sandstones (Üt12) containing rare pebbles.

In the middle part of the section, marine flooding is indicated by the presence of shallow marine molluscan fossils. This part comprises 6.3 m of yellow mudstones containing the pectinid *Pecten arcuatus* (Brocchi) and ostreid *Crassostrea fimbriata* (Grateloup in Roulin & Delbos) (Üt13), a 23-m-thick unit of pebbly, sandy and clayey siltstones and 15 m of yellow-beige coarse sands and pebbles with large-scale cross-bedding. Above, the section continues with 11.5 m of reddish-yellowish mudstones (Üt17-Üt18), 20 cm of dark grey sandstones (Üt19) and 30 cm of yellow sandstones. Within this part of the section, some molds of gastropods and bivalves were observed in a fossiliferous layer (Üt20). This unit is followed by 7 m of beige mudstones and 30 cm of beige sandstone containing benthic foraminifera *Nephrolepidina* sp., *Eulepidina* sp. (Üt21-22) (İslamoğlu *et al.* 2005). Overlying this are 12 m of yellowish beige mudstones and calcareous sandstones (Üt23-Üt28), 6 m of pale yellow sandy mudstones (Üt29), and 50 cm of pebbly sandstones yielding shallow marine gastropods *Ampullinopsis crassatina* (Lamarck), *Globularia gibberosa* (Grateloup) and *Lyria harpula* (Lamarck) (Üt30). Above this level, 50 cm of pebbly calcareous sandstones intercalated with clay beds including bivalve shell fragments and bryozoans are exposed. Above, 17 cm of yellow hard sandstones contain miliolids and the shallow marine gastropod *Athleta (Neoathleta) affinis* (Brocchi) (Üt32-Üt34). The overlying unit is 12 m of thick yellow calcareous sandstones (Üt36) containing the larger benthic foraminifera *Eulepidina dilatata* (Michelotti) (İslamoğlu *et al.* 2005).

In the upper part of the section, carbonates, represented by an alternation of reef limestone and calcareous sandstone, become dominant. At the base are 60 cm of white limestones, overlain in turn by corallian reef limestones (Üt37), 24 m of sandstones, 20.5 m of white massive limestones containing benthic foraminifera and corallinacea algae (Üt38), 20 m of clayey limestones (Üt39), 15 m of corallian reef limestones (Üt40) and 14 m of beige sands. These are followed by 12.5 m of pale yellow-beige calcareous sandstones containing benthic foraminifera and some molluscan shell fragments (Üt41). These are overlain in turn by 31.5 m of yellow sandstones, 2.5 m of limestones containing benthic foraminifera, molluscs and corals (Üt42-Üt43), 16.5 m of pebbly sandstones with clayey corallian limestone pebbles (Üt44), and 19 m of reef limestones alternating with calcareous sandstones (Üt45-Üt49). The section continues with 1.5 m of muddy and sandy conglomerates with coral pebbles (Üt50) and 15 m of yellow calcareous sandstones (Üt51), and 50 cm of reddish brown sandstones. The Üçtepeler sequence is capped by 16.5 m of yellow sandstones and 10 m of grey clayey sandstones.

Ardıçlıburun Section (Tokça Formation, Üçtepeler Reef Member) (Figures 3D & *5)*: The Ardıçlıburun section, 66 m thick, consists of 7.5 m of conglomerates containing limestone pebbles, 4.5 m of yellow sandstones and 1 m of coal-bearing clays (Ab1), 1 m of hard beige sandstones (Ab2a, Ab2b) and 8.5 m of beige coarse pebbly sandstones (Ab3, Ab4) in its lower part.

The upper part of the section begins with 3.6 m of yellow sandstones with pectinids, *Pecten arcuatus* (Brocchi), *Costellaamussiopecten deletus* (Michelotti), *Amussiopecten labadyei* (d'Archiac & Haime) (Ab5) and continues with 3 m of hard sandstones, (Ab6-Ab8), 7 m of yellow-beige sandstones (Ab9) intercalated with grey calcareous sandstones (Ab10), 6.4 m of medium rounded and poorly sorted polygenetic conglomerates intercalated with coarse sandstones. The overlying unit consists of 2 m of beige calcareous sandstones with pectinid bivalves *Pecten arcuatus* (Brocchi), *Amussiopecten labadyei* (d'Archiac & Haime) and some small benthic foraminifera (Ab11). Above, the section continues with 13.5 m of beige clayey limestones (Ab12), 80 cm of grey calcareous and pebbly coarse sandstones (Ab13) and 7.5 m of yellow calcareous sandstones with benthic foraminifera (*Operculina* sp, *Nephrolepidina* sp. (Ab14) (İslamoğlu *et al.* 2005). The overlying 3 m of yellowish beige sandy and clayey limestones include shallow marine gastropods *Ampullinopsis crassatina* (Lamarck), *Globularia gibberosa* (Grateloup) (Ab15). The section is capped by 9 m of light grey massive corallian reef limestones.

Biostratigraphy

In this study, a total of ten sections have been logged. The fossil and lithological data provided a solid base for determination of palaeoenvironmental changes. The samples indicating fossiliferous levels and the distribution of molluscs and planktonic foraminifera are presented in Tables 1 & 2. Some molluscs are in the repositories of the Natural History Museum of Vienna (NHMW-Austria) and the Natural History Museum of MTA.

In the studied region, the P19 planktonic foraminifer biozone is recorded in moderately deep and shallow-marine environments (Figure 4). Its definition is based on Berggren *et al.*'s (1995) zonal scheme. Molluscan biozonation is summarized from Sacco (1895, 1904), Mandic (2000), Harzhauser (2004), Harzhauser & Mandic (2001); Harzhauser *et al.* (2002). The zonal calibration with the standard geologic time scale follows Haq *et al.* (1987, 1988), Berggren *et al.* (1995), Rögl (1996, 1998), Hardenbol *et al.* (1998) and Gradstein *et al.* (2004) (Figure 9).

The P19 Zone (*Turborotalia ampliapertura* Zone) [(*Globigerina ampliapertura* Zone (P20) of Blow (1969)] is defined by the interval between the last occurrence (LO) of *Pseudohastigerina* spp. and the last occurrence (LO) of the zonal marker, *Turborotalia ampliapertura* (Bolli). Its lower and upper boundaries could not be determined in this study. However, the absence of *Pseudohastigerina* spp. and the presence of *Turborotalia ampliapertura* (Bolli) clearly indicate that the studied sections in the southwest area correspond to the P19 Zone. The planktonic foraminiferal fauna is generally represented by a sparse, moderately diversified and poorly preserved assemblage. It is dominated by globoquadrinids; *Globoquadrina venezuelana* (Hedberg), *Globoquadrina prasaepis* (Blow), *Globoquadrina rohri* (Bolli), *Globoquadrina tripartita* (Koch), *Globoquadrina prasaepis* (Blow), *Globoquadrina sellii* Borsetti, and some subbotinids; *Subbotina angiporoides* (Hornibrook), *Subbotina officinalis* (Subbotina), *Subbotina gortanii* (Borsetti), *Subbotina yeguaensis* (Weinzierl & Applin) and *Globorotaloides suteri* Bolli. The zonal marker, *Turborotalia ampliapertura* (Bolli), and *Turborotalia pseudoampliapertura* (Blow & Banner) are consistently present in the most of the samples, whereas *Turborotalia increbescens* (Bandy), *Catapsydrax dissimilis* (Cushman & Bermudez), *Catapsydrax unicavus* Bolli, Loeblich & Tappan, *Catapsydrax martini* (Blow & Banner), *Dentoglobigerina globularis* Bermudez, *Paragloborotalia nana* (Bolli) are recorded in only single specimens in a few samples (Figure 6).

Molluscs in the studied area are also important components for the assemblage biozonation, since some of their stratigraphic ranges do not cross the Oligocene/Miocene boundary [*Ampullinopsis crassatina* (Lamarck), *Pycnodonte gigantica callifera* (Lamarck), *Lyria harpula* (Lamarck)] and the Eocene/Oligocene boundary [*Crassostrea fimbriata* (Grateloup in Roulin & Delbos), *Globularia gibberosa* (Grateloup), *Tympanotonos margaritaceus* (Brocchi), *Turritella (Peyrotia) strangulata* Grateloup, *Turris coronata* (Münster in Goldfuss) and *Dentalium kickxii* Nyst] (Wolf 1897; Karagiuleva 1964; Harzhauser & Mandic 2001; Harzhauser 2004; İslamoğlu 2008) (Figures 7 & 8). Moreover, the ranges of the pectinid bivalves [*Pecten arcuatus* (Brocchi), *Costellaamussiopecten deletus* (Michelotti), *Amussiopecten labadyei* (d'Archiac & Haime)] indicate late Rupelian–early Chattian time (Karagiuleva 1964; Mandic 2000) (Figure 8). The potamidid gastropod, *Tympanotonos trochlearispina* (Sacco) is known in the Rupelian (Popov *et al.* 2002) 'Tongriano beds' in northern Italy (Sacco 1895), late Rupelian–early Chattian units in Kale-Tavas and the Denizli sub-basins (İslamoğlu 2008) and in the Mediterranean-Iranian province (Harzhauser *et al.* 2002). The shallow marine gastropods *Athleta* (*Neoathleta*) *affinis* (Brocchi), *Amalda tournoueri* (Cossmann), *Cerithium meneghini* Michelotti, *Conus carcarensis* Sacco are reported only from Oligocene rocks in the Western Tethys realm (Sacco 1895, 1904; Cossmann 1919; Harzhauser *et al.* 2002; Harzhauser 2004) (Figure 7).

Southwest Area (Baklan): Late Rupelian (Çardak Formation)

Oligocene sedimentation starts with the transgressive unfossiliferous Armutalanı formation in the Çardak-Dazkırı sub-basin. The earliest fossil data of the Oligocene sequence are obtained from the

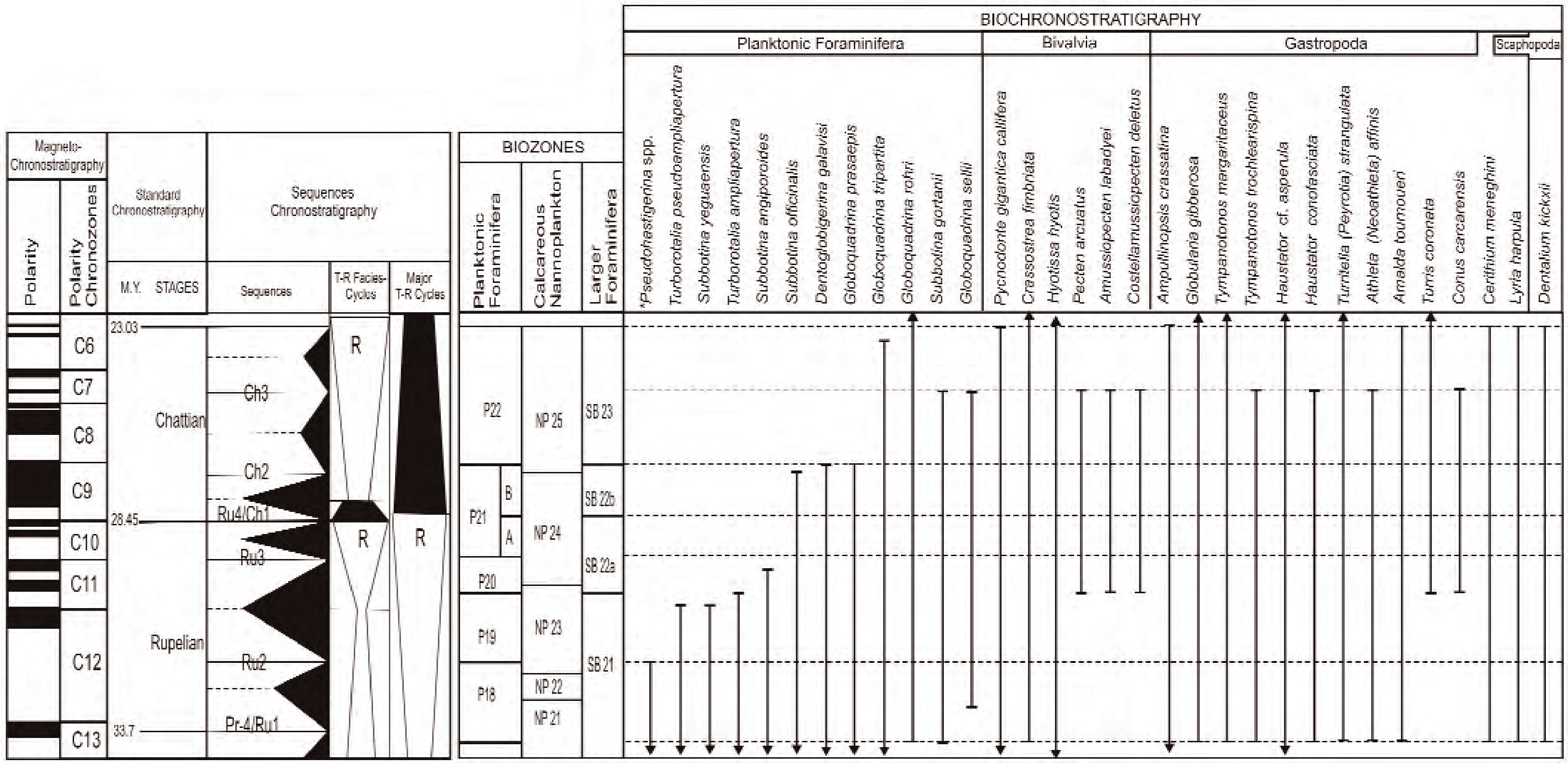

Figure 9. Chart showing stratigraphic ranges of molluscan and planktonic foraminiferal species identified in the Çardak-Dazkırı sub-basin and their correlation of Oligocene chronostratigraphy and biostratigraphy (compiled from Blow 1969; Martini 1971; Berggren & Miller 1988; Cahuzac & Poignant 1997; Berggren *et al.* 1995; Coccioni *et al.* 2008; Haq *et al.* 1987, 1988; Hardenbol *et al.* 1998; Gradstein *et al.* 2004) (**Note:** asterisk indicates the zonal marker defining the lower boundary of planktonic foraminifera (P19) Zone which are not recorded in this study).

Kirazlı member of the Çardak formation (Figures 4 & 9). The P19 biozone of the late Rupelian is seen in the Karanlıkdere-1, Karanlıkdere-2, Kirazlıdere, Koyunyolağıdere-1 and Avdan sections. In contrast, the Oligocene shallow marine gastropods *Cerithium meneghini* Michelotti, *Haustator* cf. *asperula* (Brongniart), *Athleta (Neoathleta) affinis* (Brocchi), *Amalda tournoueri* (Cossmann), *Turris coronata* (Münster in Goldfuss), *Conus carcarensis* Sacco and scaphopod *Dentalium kickxii* Nyst are only found in the Koyunyolağıdere-2 section, which does not contain any planktonic foraminifera (Table 2).

Southeast Area (Dazkırı): Late Rupelian–Early Chattian (Hayrettin Formation)

The late Rupelian–early Chattian gastropod *Tympanotonos trochlearispina* (Sacco) (Sacco 1895; İslamoğlu 2008) is found in the uppermost brackish-lagoonal levels of the sequence. The same species together with a similar assemblage is known in the contemporaneous molassic deposits of a nearby area, the Denizli and Kale-Tavas sub-basins (İslamoğlu 2008).

North Area (Tokça): Early Chattian (Tokça Formation)

In the lower part of the sequence, the late Rupelian–early Chattian marine ostreid *Crassostrea fimbriata* (Grateloup in Roulin & Delbos) and the pectinids [*Pecten arcuatus* (Brocchi), *Costellamussiopecten deletus* (Michelotti), *Amussiopecten labadyei* (d'Archiac & Haime)] are found. In the upper part, Tethyan-type gastropods [*Ampullinopsis crassatina* (Lamarck), *Globularia gibberosa* (Grateloup), *Athleta (Neoathleta) affinis* (Brocchi), *Lyria harpula* (Lamarck)] which are also common in the late Rupelian–early Chattian units of Greece and Iran (Harzhauser *et al.* 2002; Wielandt-Schuster *et al.* 2004; Harzhauser 2004) are observed.

Throughout the sequences, the scleractinian coral assemblage (*Stylophora conferta* Reuss, *Stylophora thirsiformis* (Michelotti), *Stylophora microstyla* (Meneghini), *Stylophora conferta* Reuss, *Astrocoenia septemdigitata* Catullo, *Montastraea inaequalis* (Gümbel), *Mycetophyllia mirabilis* Gerth, *Antillia carcarensis* (Michelotti), *Tarbellastraea organalis* (Calmus), *Cricocyathus* cf. *annulatus* (Reuss), *Agathiphyllia gregaria* (Catullo), *Antiguastraea* cf. *lucasiana* (Catullo) is found in the reef limestones alternating with the detrital carbonates (Göktaş *et al.* 1989; İslamoğlu *et al.* 2005). According to Schuster (2002a, b) this assemblage corresponds to the Chattian interval.

Stratigraphic Correlation and Palaeoenvironments

In Oligo–Miocene molassic basins, observation of vertical and lateral relationships between lithostratigraphical units is generally very difficult (Wielandt-Schuster *et al.* 2004; Sözbilir 2005). Moreover, fossil assemblages in their coarse detrital deposits, mostly up to thousands of metres thick, are neither abundant nor well preserved (Berger 1992). It is well-known that the sedimentation in the Çardak-Dazkırı sub-basin and surrounding area is influenced by post-orogenic tectonic processes (Becker-Platen 1970; Koçyiğit 1984; Göktaş *et al* 1989; Sözbilir 2005). Therefore, providing detailed biostratigraphic data is very important not only to establish the stratigraphic framework but also in revealing the palaeoenvironmental history of these deposits.

The basal part of the Oligocene deposits in the basin is exposed only in the southwest area, whereas their middle and upper parts crop out in both the southeast and north areas. These deposits preserve successive transgressive-regressive units. The deepening and shallowing trends of these units and the correlation of the sections based on fossil contents and lithology can be followed in Figures 4 & 5.

In the southwest area, transgressive sedimentation starts with the Amutalanı formation. While the prograding marine deposits are represented by the Karanlık and Kirazlı members (Çardak formation), regressive deposition is indicated by the coarse detritals of the Avdan and Maymundağ members (Çardak formation). Deep marine marls and mudstones (Kirazlı member) including planktonic foraminifera (170 m) grade up into shallower marine sandstones and conglomerates (Avdan member) in the late Rupelian (Figure 4). In the uppermost part of the Kirazlı member the gastropods *Cerithium meneghini* Michelotti, *Haustator* cf. *asperula* (Brongniart), *Athleta (Neoathleta) affinis* (Brocchi), *Amalda tournoueri* (Cossmann), *Turris coronata* (Münster in Goldfus), *Conus carcarensis* Sacco and scaphopod *Dentalium kickxii* (Nyst) indicate a shelf environment. The uppermost unit of the Çardak formation, the Maymundağ member, is widely exposed in this area, and consists of a thick unfossiliferous conglomeratic succession (Figure 2).

In the southeast area, the 248-m-thick sequence (Hayrettin formation) consists of mudstones and reef limestones (Sarıkavak reef member), a conglomerate-sandstone alternation (Dazkırı member) and mudstones. Limited outcrop of the Maymundağ member (Çardak formation) is exposed in the lower part of the sequence in the southeast area. This data supports the lateral and vertical relationships between the Maymundağ member and the Hayrettin formation, reported in previous studies (Göktaş *et al.* 1989; Şenel 1997). Fossils (molluscs, corals and benthic foraminifera) from the Hayrettin formation indicate a changing environment from sublittoral, reef (Sarıkavak reef member) and shallow marine facies (Dazkırı member) to brackish facies during late Rupelian–early Chattian time (Figure 4). Molluscs and corals are found in the transgressive-regressive sequences of the southeast area, but calcareous planktons are not. A gastropod assemblage, *Haustator conofasciata* (Sacco), *Ampullinopsis crassatina* (Lamarck), *Turritella (Peyrotia) strangulata* Grateloup from the lowermost part of the sequence records a shallow marine environment. The coastline location could be determined by the presence of the stenohaline ostreid bivalves, *Pycnodonte gigantica callifera* (Lamarck) and *Hyotissa hyotis* (Linneaus). Only the upper part (İslamoğlu *et al.* 2005, 2006) of the thick rhythmic sediments (Dazkırı member) contain rare benthic foraminifera indicating shallow marine conditions. The uppermost fine detritals in the southeast area, intercalated with many thin bedded lignitic levels, include euryhaline gastropods *Tympanotonos margaritaceus* (Brocchi) and *Tympanotonos trochlearispina* (Sacco) representing a brackish environment. All molluscan assemblages of this basin are well correlated with those of the Upper Rupelian–Lower Chattian deposits from the Kale-Tavas and Denizli sub-basins of the Lycian molasse in southwest Anatolia (İslamoğlu 2008).

The Lower Chattian sequences (424 m) consist of fine detritals, corallian reef carbonates (Üçtepeler reef member), carbonate-cemented sandstones and lignite-bearing mudstones, widespread in the N (Tokça) area (Figure 5). Molluscs, benthic foraminifera and corals are frequently found, although calcareous planktons are not present in these transgressive-regressive sequences. Stenohaline pectinid bivalves *Pecten arcuatus* (Brocchi), *Costellaamussiopecten deletus* (Michelotti), *Amussiopecten labadyei* (d'Archiac & Haime), ostreid bivalve *Crassosrea fimbriata* (Grateloup in Roulin & Delbos) and gastropods *Ampullinopsis crassatina* (Lamarck), *Globularia gibberosa* (Grateloup), *Athleta (Neoathleta) affinis* (Brocchi), *Lyria harpula* (Lamarck) indicate shallow marine conditions. Mollusc-bearing detritals alternate with corallian reef limestones in early Chattian time (Figure 5).

Later, the sea retreated from the Çardak-Tokça sub-basin completely. The shallow marine sediments are overlain by the thick coal measures ('Tokça lignites'). Thus, an environmental change from shallow marine to brackish is proposed for the early Chattian. This regressive trend, previously mentioned by Göktaş *et al.* (1989), can be observed in the studied sections (Figure 5).

In the study region, late Rupelian–early Chattian deepening and shallowing trends may result from global sea-level oscillations (Haq *et al.* 1987, 1988; Hardenbol *et al.* 1998) (Figure 9), in addition to the post-orogenic tectonic movements. During the Rupelian, the regressive sedimentation in the basin resulted from falling sea level can be linked to global cooling effects (Zachos *et al*. 2001; Miller *et al*. 2005). This climatic deterioration is determined by the faunal changes from the warm Eocene to the relatively cooler climates of the Rupelian (Lüttig & Steffens 1976; Rögl & Steininger 1984; Rögl 1996, 1998; Meulenkamp *et al.* 2000; Pickering 2000; Popov *et al*. 2004). Our fossil indicators may support these global events. The molluscan and corallian assemblages obtained from the southwest and southeast areas are quite different from those in the north area. However, the planktonic foraminiferal fauna, only found in the Upper Rupelian deposits (southwest area), comprise a moderately diverse but scarce assemblage. They include warm water [(*Turborotalia ampliapertura* (Bolli) and *Turborotalia pseudoampliapertura* (Blow & Banner)], warm-temperate water [*Subbotina galavisi* (Bermudez), *Globoquadrina sellii* Borsetti, *Globoquadrina tripartita* (Koch)], temperate water [*Globoquadrina venezuelana* (Hedberg)], cool-temperate water [(*Paragloborotalia opima nana* (Bolli)] and cool water [*Subbotina angiporoides* (Hornibrook), *Subbotina officinalis* (Subbotina), *Globorotaloides suteri* Bolli, *Catapsydrax* spp.] representatives (Spezzaferri & Premoli Silva 1991; Spezzaferri 1995, 1996; Menichini 1999; Li *et al.* 2003]. Unfortunately, the scarcity of specimens does not allow a palaeoclimatic interpretation to be undertaken based on quantitative faunal analysis. In addition to planktonic foraminifera, other fossil groups (benthic foraminifers, molluscs and corals) are also rare in the Upper Rupelian sections in the southwest area. Thus, this data can be interpreted as the result of a global cooling trend (Meulenkamp *et al.* 2000; Popov *et al.* 2002, 2004, Miller *et al.* 2005) that might affected the environmental conditions, causing impoverishment of the biota in the basin. After the cooling phases and sea-level falls in the late Rupelian, the shorter warming phases occurred again causing sea-level to rise once more (Haq *et al.* 1987, 1988; Hardenbol *et al.* 1998; Zachos *et al.* 2001; Miller *et al.* 2005) (Figure 9).

In contrast to the Rupelian, the faunal assemblages of the early Chattian indicate a return to warmer, tropical to subtropical conditions, accompanied by eustatic sea-level changes (Haq *et al.* 1987, 1988; Hardenbol *et al.* 1998; Pekar *et al.* 2006). Although deeper marine sedimentation with calcareous planktons did not occur in the north area, the increasing specimen numbers of benthic species (molluscs, corals and benthic foraminifera), indicate that warmer and relatively calm environmental conditions prevailed in the early Chattian**.** The dominant thick carbonate sedimentation in this area also supports this idea.

Conclusion and Discussion

In this study, the Oligocene stratigraphic framework of the Çardak-Dazkırı sub-basin has been established using planktonic foraminifera and molluscan biostratigraphy. The basinal infill of the basin, up to approximately 6000 m thick, consists of marine and brackish sediments. Ten sections yielding invertebrate fossils have been logged in the southwest (Baklan), southeast (Dazkırı) and north (Tokça) areas of the basin. The P19 planktonic foraminiferal biozone of the late Rupelian, together with late Rupelian–early Chattian molluscs are determined in the sections for the first time. The sequences in the southwest and southeast areas represent deepening and shallowing marine and brackish facies in the late Rupelian–early Chattian, whereas only lower Chattian deposits indicating brackish-shallow marine facies are exposed in the north area.

No fossils could be found at the base of the Oligocene deposits, within the Armutalanı formation and the overlying Karanlık member. However, an early Rupelian age can be deduced from their stratigraphical position between the Pribonian Başçeşme formation and the Upper Rupelian Kirazlı member of the Çardak formation. The first precise dating, late Rupelian, was obtained from the Kirazlı and Avdan members by using planktonic foraminifera. The late Rupelian–early Chattian age of the following sequence (Hayrettin formation, and its Sarıkavak reef and Dazkırı members) is determined using the molluscan fauna. However, the age of the Dazkırı member is assigned to the SBZ22 Zone (late Rupelian–early Chattian) by İslamoğlu *et al.* (2005, 2006) and to the SBZ22b Subzone (early Chattian) by Özcan *et al.* (2009) based on the larger benthic foraminifera.

In this study, the Maymundağ member, the uppermost unit of the Çardak formation, is observed between the Sarıkavak and Dazkırı members of the Hayrettin formation in the southeast area. Its age can thus be assigned to the late Rupelian–early Chattian interval based on the age of Hayrettin formation. Moreover, its stratigraphical position allows confirmation of the previous view about the vertical and lateral relationships between the Çardak and Hayrettin formations (Göktaş *et al.* 1989).

The age of the Tokça formation is the most uncertain age in the basin. Its coal-bearing sediments were dated as 'Early Oligocene' (Akkiraz & Akgün 2005), whereas the brackish-marine units of the formation were assigned to the 'Chattian' (Göktaş *et al.*, 1989). Recent studies have suggested that the SBZ 23 Zone corresponds to a late early Chattian–late Chattian age (İslamoğlu *et al.* 2005, 2006), based on a few suspicious miogypsinoid forms. However, Göktaş *et al.* (1989) reported the presence of lepidocyclinids together with rare nummulitids without any data on miogypsinoids, indicating a late Rupelian–early Chattian age (SBZ 22 Zone of Cahuzac & Poignant 1997). The present work indicates that the Tokça formation is early Chattian in age, based on the pectinid, ostreid and coral assemblages.

Faunal and lithological similarities allow correlation with nearby sub-basins surrounding the Çardak-Dazkırı sub-basin. The Oligocene deposits (the Mortuma and Sağdere formations) of the Kale-Tavas and Denizli subbasins are dated as late Rupelian–early Chattian based on the presence of similar shallow marine-brackish molluscs (İslamoğlu 2008). A similar planktonic foraminifera assemblage (*Globigerina ampliapertura* Zone) to those of the present study was found in another nearby area (Korkuteli, Antalya, Western Taurides) by Bizon *et al.* (1974).

However, widespread Oligo–Miocene marine conditions including rich micro- and macrofauna are known from several basins in the eastern Mediterranean-Iranian province, notably: Mesohellenic molasse basin (Greece), Qom and Esfahan-Sirjan basins (Iran) (Mandic 2000; Harzhauser *et al.* 2002; Wielandt-Schuster *et al.* 2004; Harzhauser 2004; Reuter *et al.* 2007) and E–SE regions of Turkey (Sirel 2003); from more distant basins in the Western Mediterranean-European province: Aquitaine basin (France), Swiss molasse basin and Piedmont basin (Italy) (Sacco 1895, 1904; Berger 1992; Lozouet 1998; Mandic 2000; Mancin & Pirini 2001; Harzhauser *et al.* 2002; Mancin *et al.* 2003), and even in some Paratethyan basins (Gürs 1995; Harzhauser & Mandic 2001). Our data on the marine deposits and invertebrate discoveries are relatively limited in the Çardak-Dazkırı sub-basin, compared to that of the other regions and basins. These data clearly indicate that the severe and changeable environmental conditions, controlled by regional tectonism (Koçyiğit 1984; Sözbilir 2005), restricted not only the presence of the organisms but also their preservation as fossil assemblages compared to those of stable marine conditions free of tectonism.

Consequently, we consider that our late Rupelian and early Chattian data obtained from this tectono-sedimentary sub-basin will provide useful information for subsequent studies in this region.

Acknowledgements

This study is part of the results of project number 2002-16 B45 supported by the MTA (General Directorate of Mineral Research and Exploration, Turkey). The molluscs were studied in the NHMW (Natural History Museum Vienna, Austria) with support from the EU Synthesys foundation (AT-TAF-356). The authors wish to thank Hulusi Sarıkaya (MTA) and Neşat Konak (MTA) for their kind help during the field work. Special thanks are extended to Mathias Harzhauser (Natural History Museum of Vienna, NHMW, Austria), and Şevket Şen (CNRS-National Natural History Museum, Paris, France), who provided opportunities to visit the rich molluscan collections of these museums. The authors also would like to thank Oleg Mandic (NHMW, Austria), Şevket Şen and Ercan Özcan (İTÜ, İstanbul Technical University, Faculty of Mines, İstanbul) for their helpful comments and critical reading of an early version of the manuscript. The photographs of the molluscs were taken in the Natural History Museum, Vienna, Austria; those of planktonic foraminifers in Department of Metallurgical and Materials Engineering in the Middle East Technical University, Turkey.

References

Akgün, F. & Sözbilir, H. 2001. A palynostratigraphic approach to the SW Anatolian molasse basin: Kale-Tavas molasse and Denizli molasse. *Geodinamica Acta* **14**, 71–93.

Akkiraz, S. & Akgün, S. 2005. Palynology and age of the Early Oligocene units in Çardak–Tokça Basin, Southwest Anatolia: paleoecological implications. *Geobios* **38**, 283–299.

BECKER-PLATEN, J.D. 1970. Lithostratigraphische unterschungen in Kanozoikum südwest – Anatoliens (Kanozoikum und Braunkohlen der Türkei, 2). Beihefte zum *Geologischen Jahrbuch* **97**, 1–244.

BENDA L. 1971. Grundzüge einer pollenanalytischen Gliederung des türkischen Jungtertiärs (Känozoikum und Braunkohle der Türkei. 4). Beihhefte zum *Geologischen Jahrbuch* **113**, 1–46.

BERGER, J.P. 1992. Correlative chart of the Europen Oligocene and Miocene: application to Swiss Molasse Basin. *Eclogae Geologicae Helvetiae* **85**, 573–609.

BERGGREN, W.A. & MILLER, K.G. 1988. Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology. *Micropaleontology* **34**, 362–380.

BERGGREN, W.A., KENT, D.V., SWISHER, C.C. III & AUBRY, M.-P. 1995. A revised Cenozoic geochronology and chronostratigraphy. *In*: BERGGREN, W.A., KENT, D.V., AUBRY, M.P. & HARDENBOL, J. (eds), *Geochronology, Time Scales and Global Stratigraphic Correlation***.** Society of Economic Paleontologists and Mineralogists (SEPM), Special Publication **54**, 129–212.

BERING, D. 1967. *Acıgöl Havzasının Linyit Etüdü [Lignite Study of Acıgöl Basin]*. MTA report no. **6095** [in Turkish, unpublished].

BIZON, G., BIJU-DUVAL, B., LETOUZEY, J., MONOD, O., POISSON, A., ÖZER, B. & ÖZTÜMER, E. 1974. Nouvelles précisions stratigraphiques concernant les bassins Tertiaires du sud de la Turquie (Antalya, Mut, Adana). *Revue de l'institut Français du Pétrole* **29**, 305–324.

BLOW, W.H. 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. *In*: BRÖNNIMANN, P. & RENZ, H.H. (eds), *Proceedins of the First International Conference on Planktonic Microfossils*. Geneva, 199–421.

CAHUZAC, B. & POIGNANT, A. 1997. Essai de biozonation de l'Oligo–Miocène dans les bassins européens à l'aide des grands foraminifères néritiques.*Bulletin de la Société Géologique de France* **168**, 155–169.

COCCIONI, R., MONTANARI, A., BELLANCA, A., NERI, R., BICE, D.M., BRINKHUIS, H., CHURCH, N., MACALADY, A., MCDANIEL, A., DEINO, A., LIRER, F., SPROVIERI, M., MAIORANO, P., MONECHI, S., NINI, C., NOCCHI, M., PROSS, J., ROCHETTE, P., SAGNOTTI, L., TATEO, F., TOUCHARD, Y., VAN SIMAEYS, S. & WILLIAMS, G. 2008. Integrated stratigraphy of the Oligocene pelagic sequence in the Umbria-Marche basin (northeastern Apennines, Italy): a potential Global Stratotype section and Point (GSSP) for the Rupelian/Chattian boundary. *Geological Society of America Bulletin* **120**, 487–511.

COSSMANN, M. 1919. Monographie illustrée des Mollusques Oligocéniques des environs de Rennes. *Journal Conchyliologie* **64**, 133–199.

DEWEY, J.F. & ŞENGÖR, A.M.C. 1979. Aegean and surrounding regions: complex multiple and continuum tectonics in a convergent zone. *Geological Society of America Bulletin* **90**, 84–92.

DİZER, A. 1962. Denizli bölgesinin Eosen ve Oligosen foraminiferleri [Eocene and Oligocene foraminefers of Denizli region]. *İstanbul Üniversitesi Fen Fakültesi Mecmuası* **B27**, 39–45 [in Turkish with English abstract].

GEDİK, F. 2008. Foraminiferal description and biostratigraphy of the Oligocene shallow marine sediments in Denizli region, SW Turkey. *Revue de Paléobiologie* **27**, 25–41.

GÖKTAŞ., F., ÇAKMAKOĞLU, A., TARI, E., SÜTÇÜ, Y.F. & SARIKAYA, H. 1989. *Çivril- Çardak Arasının Jeolojisi [Geology of Çivril-Çardak Area]*. MTA report no. **8701** [in Turkish, unpublished].

GRADSTEIN, F.M., OGG, J.G. & SMITH, A.G (eds) 2004. *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge.

GÜRS, K. 1995. *Revision der marinen Molluskenfauna des unteren Meeressandes (Oligozan, Rupelium) des Mainzer Beckens*. PhD Thesis, Johannes Gutenberg University, Mainz-Germany.

HAQ, B.U., HARDENBOL, J. & VAIL, P.R. 1987. Chronology of fluctuating of sea levels since the Triassic (250 million years to Present). *Science* **235**, 1156–1167.

HAQ, B.U., HARDENBOL, J. & VAIL, P.R. 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. *In*: WILGUS, K., HASTINGS, B.S., KENDALL, C.G, POSAMENTIER, H.W., ROSS, C.A. & VAN WAGONER, J.C. (eds), *Sea-level Change: An Integrated Approach*. Society of Economic Paleontologists and Mineralogists (SEPM), Special Publications **42**, 71–108.

HARDENBOL, J., THIERRY, J., FARLEY, M.B., JACQUIN, T., GRACIANSKY, P.C. & VAIL, P.R. 1998. Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. *In*: GRACIANSKY, P.C., HARDENBOL, J., JACQUIN, T. & VAIL, P.R. (eds), *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins*. Society of Economic Paleontologists and Mineralogists (SEPM), Special Publications **60**, 763–81.

HARZHAUSER, M. 2004. Oligocene gastropod faunas of the Eastern Mediterranean (Mesohellenic Through/ Greece and Esfahan-Sirjan Basin/Central Iran). *Courier Forschungsinstitut Senckenberg* **248**, 93–181.

HARZHAUSER, M. & MANDIC, O. 2001. Late Oligocene gastropods and bivalves from the Lower and Upper Austrian Molasse Basin. *In*: PILLER, W.E. & RASSER, M.W. (eds), *Paleogene of the Eastern Alps*. Österreichische Akademie der Wissenschaften Schriftenreihe der Erdwissenschaftlichen Kommissionen, Band 14, Verlag der Österreichischen Akademie der Wissenschaften, Vienna, 671–795.

HARZHAUSER, M., PILLER, W.E. & STEININGER, F.F. 2002. Circum-Mediterranean Oligo–Miocene biogeographic evolution – the gastropods' point of view. *Palaeogeography, Palaeoclimatology, Palaeoecology* **183**, 103–133.

IŞIK, V., TEKELİ, O. & SEYİTOĞLU, G. 2004. The $^{40}Ar/^{39}Ar$ age of extensional ductile deformation and granitoid intrusion in the northern Menderes core complex: implications for the initiation of extensional tectonics in western Turkey. *Journal of Asian Earth Sciences* **23**, 555–566.

İSLAMOĞLU, Y. 2008. Molluscan biostratigraphy and paleoenvironmental reconstruction of Oligocene deposits in the Denizli and Kale-Tavas subbasins (SW Turkey). *Geodiversitas* **30**, 261–85.

İSLAMOĞLU, Y., ATAY, G., GEDİK, F., AYDIN, A., HAKYEMEZ, A., BABAYİĞİT, S. & SARIKAYA, H. 2005. *Batı Toroslardaki Denizel Oligosen–Miyosen Biyostratigrafisi (Denizli) [Marine Oligocene-Miocene Biostratigraphy of Western Taurides (Denizli, SW Turkey)]*. MTA report no. **10763** [in Turkish, unpublished].

İSLAMOĞLU, Y., GEDİK, F., AYDIN, A., ATAY, G., HAKYEMEZ, A. & BABAYİĞIT, S. 2006. Denizli bölgesindeki lagüner ve denizel çökellerin Oligosen biyostratigrafisi (GB Türkiye) [Oligocene biostratigraphy of lagoonal and marine deposits in Denizli region]. *Geological Congress of Turkey, Ankara, Abstracts,* 245–249.

KARAGIULEVA, J.D. 1964. Les fossiles de Bulgarie. Paléogène Mollusca. *Académie des Sciences de Bulgarie* **6a**,1–270.

KOÇYİĞİT, A. 1984. Intra-plate tectonic development in southwestern Turkey and adjacent areas. *Bulletin of the Geological Society of Turkey* **27**, 1–16 [in Turkish with English abstract].

LI, Q., MCGOWRAN, B. & JAMES, N.P. 2003. Eocene–Oligocene foraminiferal biostratigraphy of sites 1126, 1130, 1132, and 1134, ODP Leg 182, Great Australian Bight. *In*: HINE, A.C., FEARY, D.A. & MALONE, M.J. (eds), *Proceedings of the Ocean Drilling Program, Scientific Results,* **182** 1–28.

LOZOUET, P. 1998. Nouvelles espèces de Gastéropodes (Mollusca: Gastropoda) de l'Oligocène et du Miocène inférieur de L'Aquitaine (sud-ouest de la France). *Cossmanniana* **5**, 61–102.

LÜTTIG, G. & STEFFENS, P. 1976. *Explanatory Notes for the Paleogeographic Atlas of Turkey from the Oligocene to the Pleistocene*. Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, 1–64.

MANCIN, N. & PIRINI, C. 2001. Middle Eocene to Early Miocene foraminiferal biostratigraphy in the Epiligurian succession (Northern Apennines, Italy). *Rivista Italiana di Paleontologia e Stratigrafia* **107**, 371–393.

MANCIN, N., PIRINI, C., BICCHI, E., FERRERO, E. & VALLERI, G. 2003. Middle Eocene to Middle Miocene planktonic foraminiferal biostratigraphy for internal basins (Monferrato and northern Appennines, Italy). *Micropaleontology* **49**, 341–358.

MANDIC, O. 2000. *Oligocene to Early Miocene Pectininid Bivalves of Western Tethys (N. Greece, S. Turkey, Central Iran and NE. Egypt), Taxonomy and Paleobiogeography*. PhD Thesis, University of Vienna, Vienna-Austria [unpublished].

MARTINI, E. 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In*: FARINACCI, A. (ed), *Proceedings II Planktonic Conference*, Roma, 739–785.

MENICHINI, M. 1999. Planktonic foraminiferal biostratigraphy and palaeoclimatic modeling of the pelagic Oligocene-vasal Miocene from the Piobbico area (Marche Basin, Central Italy). *Rivista Italiana di Paleontologia e Stratigrafia* **105**, 417–438.

MEULENKAMP, J.E. & SISSINGH, W. 2003. Tertiary palaeogeography and tectonostratigraphic evolution of the Northern and Southern Peri-Tethys platforms and the intermediate domains of the African-Eurasian convergent plate boundary zone. *Palaeogeography, Palaeoclimatology, Palaeoecology* **196**, 209–228.

MEULENKAMP, J.E., SISSINGH, W., LONDEIX, L., CAHUZAC, B., CALVO, J.P., DAAMS, R., STUDENCKA, B., KOVAC, M., NAGYMAROSY, A., RUSU, A., BADESCU, D., POPOV, S.V., SCHERBA, I.G., ROGER, J., PLATEL, J.P., HIRSCH, F., SADEK, A., ABDEL-GAWAD, G.I., YAICH, C., BEN ISMAIL-LATTRACHE, K., BOUAZIZ, S. 2000. Late Rupelian (32–29 Ma). *In*: DERCOURT, J., GAETANI, M., VRIELYNCK, B., BARRIER, E., BIJU-DUVAL, B., BRUNET, M.F., CADET, J.P., CRASQUIN, S. & SANDULESCU, M. (eds), *Peri-Tethys Atlas, Paleogeographic Maps with an Explanatory Notes* Paris, 171–178.

MILLER, K.G., KOMINZ, M.A., BROWNING, J.V., WRIGHT, J.D., MOUNTAIN, G.S., KATZ, M.E., SUGARMAN, P.J., CRAMER, B.S., CHRISTIE-BLICK, N. & PEKAR, S.F. 2005. The Phanerozoic record of global sea-level change. *Science* **310**, 1293–1298.

NEBERT, K. 1956. *Denizli-Acıgöl Mevkiinin Jeolojisi* [*Geology of Denizli-Acıgöl Locality*]. MTA report no. **2509** [in Turkish, unpublished].

ÖZCAN, E., LESS, G., BÁLDI-BEKE, M., KOLLÁNYI, K. & ACAR, F. 2009. Oligo–Miocene foraminiferal record (Miogypsinidae, Lepidocyclinidae and Nummulitidae) from the Western Taurides (SW Turkey): biometry and implications for the regional geology. *Journal of Asian Earth Sciences* **34,** 740–760.

PEKAR, S.F., DECONTO, R.M. & HARWOOD, D.M. 2006. Resolving a late Oligocene conundrum: deep-sea warming and Antarctic glaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology* **231**, 29–40.

PICKERING, K.T. 2000. The Cenozoic world. *In:* CULVER, S.J. & RAWSON, P.F. (eds), *Biotic Response to Global Change. The Last 145 Million Years*. Cambridge University Press, Cambridge, 20–34.

POPOV, S.V., AKHMETIEV, E.M., BUGROVA, E.M., LOPATIN, A.V., AMITROV, O.V., ANDREYEVA-GRIGOROVICH, A.S., ZAPOROZHETS, N.I., ZHERIKHIN, V.V., KRASHENINNIKOV, V.A., NIKOLAEVA, I.A., SYTCEVSKAYA, E.K. & SHCHERBA, I.G. 2002. Early Oligocene. *In*: NEVESSKAYA, L.A. (ed), *Biogeography of the Neorthern Peri-Tethys from the Late Eocene to the Early Miocene*, *Part 2. Paleontological Journal* **36**, 185–259.

POPOV, S.V., RÖGL, F., ROZANOV, A.Y., STEININGER, F.F., SCHERBA, I.G. & KOVAC, M. 2004. Lithological-paleogeographic maps of the Paratethys (10 maps Late Eocene to Pliocene). *Courier Forschungsinstitut Senckenberg* **250**, 1–46.

REUTER, M., PILLER, W.E., HARZHAUSER, M., MANDIC, O., BERNING, B., RÖGL, F., KROH, A., AUBRY, M.-P., WIELANDT-SCHUSTER, U. & HAMEDANI, A. 2007. The Oligo–Miocene Qom Formation (Iran): evidence for an early Burdigalian restriction of the Tethyan seaway and closure of its Iranian gateways. *International Journal of Earth Sciences* **98**, 627–650.

Rögl, F. 1996. Stratigraphic correlation of the Paratethys Oligocene and Miocene. *Mitteilungen der Gesellschaft der Geologie und Bergbaustudenten in Österreich* **41**, 65–73.

Rögl, F. 1998. Paleogeographic considerations for Mediterranean and Paratethys seaways Oligocene–Miocene). *Annalen des Naturhistorischen Museums in Wien* **99A**, 279– 310.

Rögl, F. & Steininger, F.F. 1984. Neogene Paratehys, Mediterranean and Indo-pacific seaways. *In*: Brenchley, P. (ed), *Fossils and Climate*. Chichester, John Wiley and Sons, 171–200.

Sacco, F. 1895. Molluschi dei terreni terziari del Piedmonte e della Liguria. *Memorie Royal Accademie Science Torino* **17**, 1–83.

Sacco, F. 1904. Molluschi dei terreni terziari del Piedmonte e della Liguria. *Memorie Royal Accademie Science Torino* **30**, 1–203.

Schuster, F. 2002a. Taxonomy of Oligocene to Early Miocene scleractinian corals from Iran, Egypt, Turkey and Greece. *Courier Forschungs Institut Senckenberg* **239**, 1–3.

Schuster, F. 2002b. Scleractinian corals from the Oligocene of the Qom formation (Esfahan – Sirjan fore-arc basin, Iran). *Courier Forschungs Institut Senckenberg* **239**, 5–55.

Şenel, M. 1997. *Denizli-J9 Quadrangle, 1:100.000 Scale Geological Map and Explonatary Text*. Mineral Research and Exploration Institute of Turkey (MTA) Publications [in Turkish with English abstract].

Şengör, A.M.C. & Yilmaz, Y. 1981. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics* **75**, 181–241.

Şengör A.M.C., Görür, N. & Şaroğlu, F. 1985. Strike-slip formation, basin formation and sedimentation; strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. *In*: Biddle, K.T. & Christie-Blick, N. (eds), *Strike-slip Faulting and Basin Formation*. Society of Economic Paleontologists and Mineralogists, Special Publications **37**, 227–64.

Seyİtoğlu, G. & Scott, B. 1991. Late Cenozoic crustal extension and basin formation in west Turkey. *Geological Magazine* **128**, 155–166.

Seyİtoğlu, G., Scott, B.C. & Rundle, C.C. 1992. Timing of Cenozoic extensional tectonics in west Turkey. *Journal of Geological Society of London* **149**, 533–538.

Sİrel, E. 2003. Foraminiferal description and biostratigraphy of the Bartonian, Priabonian and Oligocene shallow-water sediments of the southern and eastern Turkey. *Revue de Paléobiologie* **22**, 269–339.

Sözbİlİr, H. 2005. Oligo–Miocene extension in the Lycian orogen: evidence from the Lycian molasse basin, SW Turkey. *Geodinamica Acta* **18**, 255–282.

Spezzaferri, S. 1995. Planktonic foraminiferal paleoclimatic implication across the Oligocene-Miocene transition in the oceanic record (Atlantic, Indian and South Pasific). *Palaeogeography, Palaeoclimatology, Palaeoecology* **114**, 43–74.

Spezzaferri, S. 1996. Paleoclimatic interpretation of the Late Oligocene–Early Miocene planktonic foraminiferal record from Lemme-Carrosio section (northern Italy). *Giornale di Geologia* **58**, 119–139.

Spezzaferri, S. & Premoli Silva, I. 1991. Oligocene planktonic foraminiferal biostratigraphy and paleoclimatic interpretation from the Hole 538A, DSDP Leg 77, Gulf of Mexico. *Palaeogeography, Palaeoclimatology, Palaeoecology* **83**, 217–263.

Westaway, R. 2006. Cenozoic cooling histories in the Menderes Massif, western Turkey may be caused by erosion and flat-subduction, not low-angle normal faulting. *Tectonophysics* **412**, 1–25.

Westaway, R., Guillou, H., Yurtmen, S., Demİr, T., Scaillet, S. & Rowbotham, G. 2005. Constraints on the timing and regional conditions at the start of the present phase of crustal extension in western Turkey, from observations in and around the Denizli region, *Geodinamica Acta* **18**, 209–238.

Wielandt-Schuster U., Schuster F., Harzhauser M., Mandic O., Kroh A., Rögl F., Reisinger, J., Liebetrau, V., Steininger, F.F. & Piller W.E. 2004. Stratigraphy and palaeoecology of Oligocene and Early Miocene sedimentary sequences of the Mesohellenic basin (NW Greece). *Courier Forschunginstitut Senckenberg* **248**, 1–55.

Wolf, W. 1897. Die Fauna der südbayerischen Oligocaenmolasse. *Palaeontographica* **43**, 223–311.

Zachos, J.M., Pagani, M., Sloan, L., Thomas, E. & Billups, K. 2001. Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science* **292**, 686–693.