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Cretaceous Pelagic Red Beds and Black Shales (Aptian-Santonian), NW Turkey: Global Oceanic Anoxic and Oxic Events

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Abstract: The study areas located near the towns of Göynük, Mudurnu and Nallıhan in the central northwestern part of Turkey lie on the 'Sakarya Continent', which is one of the tectonic entities of the Cretaceous geology of Turkey. Measured stratigraphic sections comprise the Aptian pelagic carbonates and the overlying Albian–Coniacian turbiditic sequences, which are all capped by a Late Santonian red pelagic succession. Lower and Upper Aptian, Upper Albian and Cenomanian/Turonian marine black shales recognized in the sections are followed by Lower and Upper Aptian, Upper Albian and Turonian marine red beds. The black shales are generally silty, laminated, and include pyritized radiolarian and planktonic foraminifera. The red beds are composed of red-pink limestones, which are of packstone facies with abundant planktonic foraminifera, bivalve, echinoidea, iron infillings and coatings. They also include red silty marls with quartz, iron and glauconite minerals as well as bivalve fragments. Sedimentologic, sequence stratigraphic and cyclostratigraphic properties of black shales and red beds recorded along the measured stratigraphic sections have been determined and Fischer plot analysis has been applied for their correlation and coherency. Their sequence stratigraphic positions and cyclic nature indicate that black shales were generally deposited in the early transgressive system tracts. However, red beds represent the late transgressive/high-stand systems tracts. In some areas, the Upper Santonian red beds are observed in association with a drowning event and overlie a Type-3 sequence boundary. Their stratigraphic position and sedimentology are used to better understand the oceanic events and tectonic movements recorded in this basin. These black shales and red beds are recognized within coeval biostratigraphic intervals as in their global counterparts.

Key Words: Cretaceous, red beds, black shales, global anoxic and oxic events, sedimentology, cyclostratigraphy, sequence stratigraphy, NW Turkey

Kretase Pelajik Kırmızı Tabakaları ve Siyah Şeylleri (Apsiyen–Santoniyen), Kuzey Batı Türkiye: Küresel Anoksik ve Oksik Olaylar

Özet: Türkiye'nin orta kuzeybatısında yeralan ve Göynük, Mudurnu ve Nallıhan yakınlarını kapsayan çalışma alanları Türkiye'nin Kretase jeolojisinin önemli tektonik dilimlerden biri olan Sakarya Kıtası üzerinde bulunmaktadır. Ölçülü stratigrafik kesitler Apsiyen pelajik karbonatlarını ve üzerine gelen Üst Santoniyen–Kampaniyen kırmızı tabakaları ile örtülmüş Albiyen–Koniyasiyen türbiditik istiflerini içermektedir. İstiflerde tanımlanmış olan Alt ve Üst Apsiyen, Üst Albiyen ve Senomaniyen/Turoniyen denizel siyah şeyllerinin Alt ve Üst Apsiyen, Üst Albiyen ve Turoniyen denizel kırmızı tabakaları ile takip edildiği gözlenmiştir. Siyah şeyller genellikle siltli, laminalı ve piritleşmiş radyolarya ve planktonik foraminifer içermektedir. Kırmızı tabakalar ise bol planktonik foraminifera, bivalve, ekinid, demir doguları ve kaplamaları içeren istif taşı fasiyesindeki kırmızı-pembe renkli kireçtaşları ile bivalve kırıntıları, glakoni, demir ve kuvars içeren siltli kırmızı marnlardan oluşmaktadır. Bu çalışmada ölçülü kesitler boyunca incelenmiş olan siyah şeyllerin ve kırmızı tabakaların sedimentolojik, sekans stratigrafik ve devirsel stratigrafik özellikleri tespit edilmiş ve Fischer eğrileri çıkarılarak kontrolleri ve karşılatırmaları yapılmıştır. Sekans stratigrafik pozisyonları ve devirsel stratigrafik yapıları siyah şeyllerin genellikle erken transgresif sistemlerde çökeldiği fakat kırmızı tabakaların ise geç transgresif/yüksek duruş sistemleri temsil ettiğini göstermektedir. Yer yer, Üst Santoniyen kırmızı tabakalarının boğulma olayları ile ilişkili oldukları ve Tip-3 sekans sınırlarını üzerledikleri görülmüştür. Sedimantolojisi ve stratigrafik konumları havza içerisindeki kayıtlanmış okyanusal olayların ve tektonik hareketlerin daha iyi anlaşılmasında kullanılmıştır. Tespit edilmiş olan siyah şeyller ve kırmızı tabakalar küresel eşlenikleri ile benzer biyostratigrafik aralıklarda gözlenmiştir.

Anahtar Sözcükler: Kretase, kırmızı tabakalar, siyah şeller, küresel anoksik ve oksik olaylar, sedimantoloji, devirsel stratigrafi, sekans stratigrafisi, KB Türkiye

Introduction

The Cretaceous period has long been analyzed worldwide for oceanic, climatic and tectonic events. Several studies, especially those concerning organic carbon-rich black shale occurrences within pelagic successions in the Cretaceous are related to 'Cretaceous oceanic anoxic events' (Schlanger & Jenkyns 1976; Jenkyns 1980; Reyment & Bengtson 1985; Rawson *et al.* 1996; Erba 2004; Erbacher *et al.* 2007 and many others). A number of discussions have been published on the origin and causes of the global oceanic anoxic events in the Valanginian, Aptian, Albian, Cenomanian/Turonian and Late Santonian–Campanian stages from many parts of the world (Schlanger & Cita 1982; Herbert & Fischer 1986; Jenkyns & Clayton 1986; Bralower *et al.* 1994; Barrera & Johnson 1999; Herrle *et al.* 2003; Skelton *et al.* 2003; Erba 2004; Coccioni *et al.* 2006). Carbon and oxygen stable isotopes together with other geochemical analyses carried out on these anoxic sediments have been of special interest (Weissert & Bréhéret 1991; Weissert & Lini 1991; Menegatti *et al.* 1998; Jenkyns & Wilson 1999; Stoll & Schrag 2000; Wissler *et al.* 2001; Price 2003; Yılmaz *et al.* 2004a). Cyclostratigraphic and sequence stratigraphic analyses of these black facies have also been applied to explain their mode of occurrences (Herbert & Fischer 1986; Einsele *et al.* 1991; Claps & Masetti 1994; Claps *et al.* 1995; House & Gale 1995; Yılmaz *et al.* 2000, 2004a, b; Einsele 2001; Yılmaz 2002).

Pelagic red bed occurrences in the Cretaceous within the concept of global oceanographic events have been less studied compared to black shales. In the Early Cretaceous (Barremian, Aptian, Albian) and Late Cretaceous (Cenomanian–Turonian, Santonian–Campanian, Maaestrichtian) epochs, pelagic red beds are documented all around the world from the north Atlantic to China (Malata *et al.* 2002; Tüysüz 2002, 2003; Jansa 2003; Hu *et al.* 2005a, b; Wang *et al.* 2005; Yılmaz & Altıner 2005a, b, c, 2006). Their consistent occurrences during certain time intervals have been interpreted as evidence of global oceanographic events (Hu *et al.* 2005a, b). Furthermore, geochemical analyses carried out on the red beds have also been used as an important tool to understand their genesis (Hu *et al.* 2005a, b; Wang *et al.* 2005). However, sequence stratigraphic and cyclostratigraphic approaches to analyse their mode of occurrences and genesis have not been used extensively in their study.

In Turkey, Upper Cretaceous red beds were recorded in the Pontides by Görür *et al.* (1993), Eren & Kadir (1999), Eren & Taslı (2002) and Tüysüz (1999, 2002, 2003) within Upper Cretaceous turbidite sequences. Eren & Kadir (1999) studied the major oxide elements and emphasized the diagenetic colouring of the red beds in the eastern Pontides.

The black shale interval recorded in the Lower Aptian deposits in the Nallıhan area of northwestern Turkey has been studied by Yılmaz *et al.* (2004a) and interpreted as OAE1a. The black shale interval at the Cenomanian/Turonian boundary in the Antalya area of southwestern Turkey was studied by Yurtsever *et al.* (2003), and interpreted as equivalent to the 'Bonarelli' level (OAE 2).

The present study mainly focuses on the sedimentology and stratigraphy of the Lower and Upper Cretaceous pelagic red beds and black shales recorded within an intra-basinal trough on the Sakarya Continent (Figure 1). Their petrographic, sequence stratigraphic and cyclostratigraphic analyses are discussed and a correlation is established based on their chronostratigraphic positions within the basin. Comparison of the results with coeval global Cretaceous oceanographic events is presented as evidence of global anoxic and oxic events also recorded on the Sakarya Continent.

Geologic Setting

The study areas are located on the former Sakarya Continent, which is surrounded by the Intra-Pontide suture zone to the north, and the İzmir-Ankara-Erzincan suture zone to the south. Both are related with the closure of the northern branch of the Neotethyan Ocean (Figure 1). The areas studied on this former continent include, from west to east, Göynük, Mudurnu and Nallıhan, which are parts of a rift basin along the Sakarya Continental margin called the Mudurnu Trough (Koçyiğit *et al.* 1991) as shown in Figure 2.

The Palaeozoic metamorphic basement, and the overlying Mesozoic and Cenozoic sedimentary succession can be observed as three main rock units on the 'Sakarya Continent'. Palaeozoic basement metamorphic rocks were overthrust by Triassic metamorphics and their non-metamorphic equivalents during the Karakaya Orogeny. All these amalgamated rock assemblages are in turn

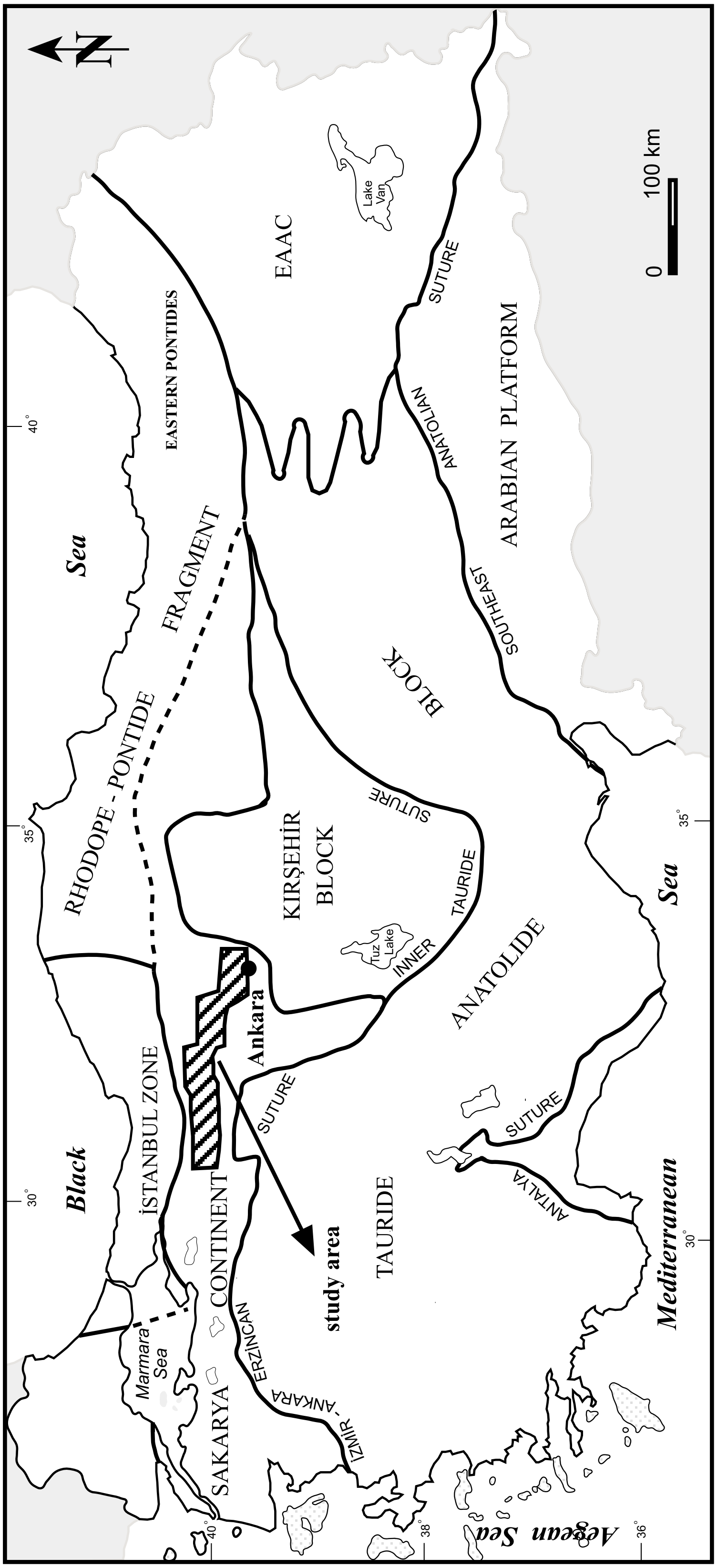

Figure 1. Geographic locations of the study areas on the tectonic suture map of Turkey (modified from Yılmaz *et al.* 1997).

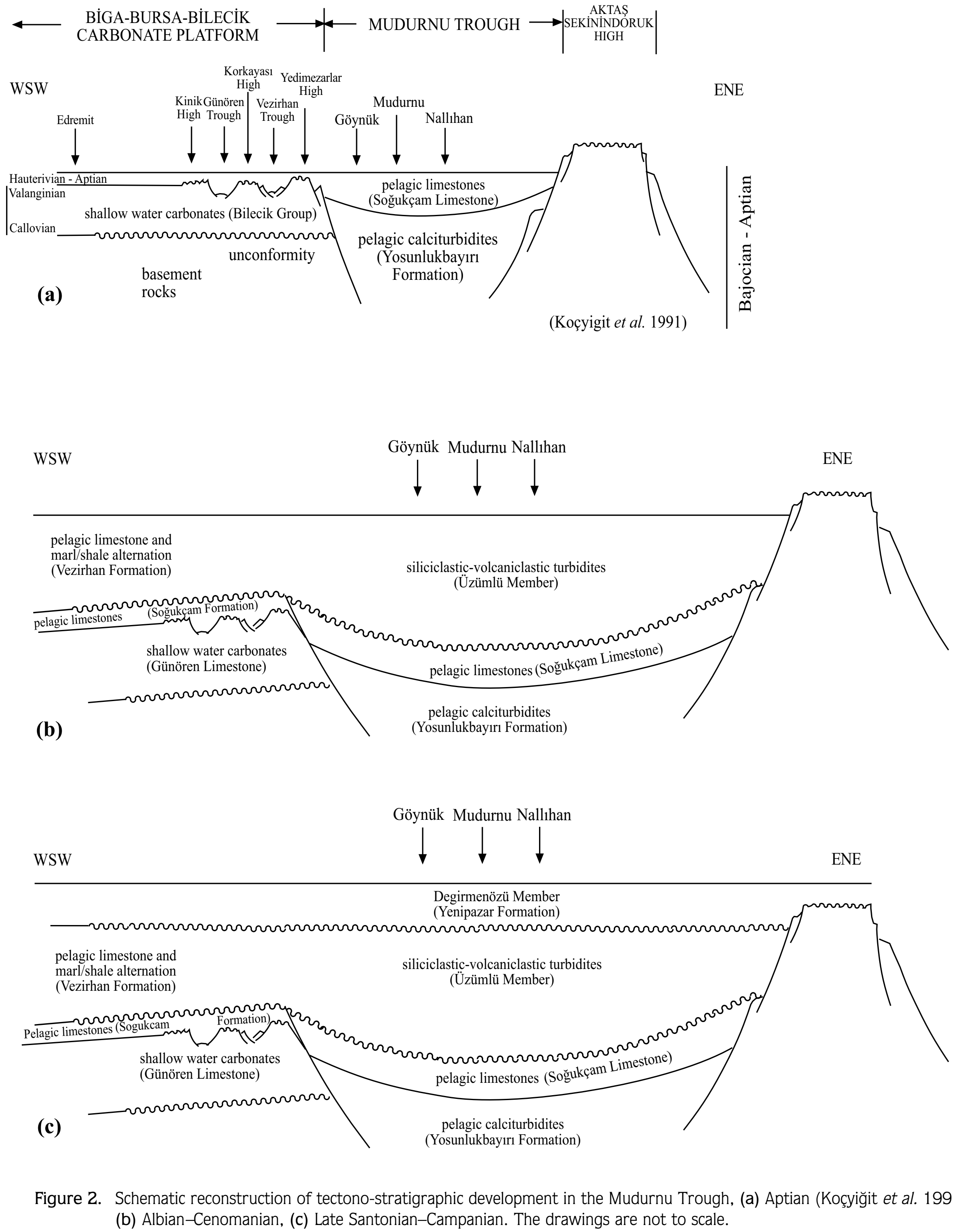

Figure 2. Schematic reconstruction of tectono-stratigraphic development in the Mudurnu Trough, (a) Aptian (Koçyiğit *et al.* 1991), (b) Albian–Cenomanian, (c) Late Santonian–Campanian. The drawings are not to scale.

unconformably overlain by transgressive Liassic (Lower Jurassic) successions, including 'Ammonitico Rosso' facies (Altıner *et al.* 1991). The overlying Upper Jurassic to Cretaceous succession starts with alternating shelf carbonates, pelagics, volcanics, cherts, and volcaniclastics, and continues with Upper Cretaceous slope and basinal deposits. In the Göynük, Mudurnu and Nallıhan areas, the Barremian–Aptian slope/basin pelagic carbonates represented by the Soğukçam Limestone form the lower part of the studied successions. These pelagic deposits have been interpreted to represent transgressive cover that developed over the Mudurnu Trough (Önal *et al.* 1988; Altıner 1991; Altıner *et al.* 1991) and are associated with a drowning event (Figure 2). The Soğukçam Limestone is characterized by pelagic carbonates without any visible volcanic or chert intercalations, and can be distinguished from other formations by its distinctive limestone-shale/marl couplets. Unconformably overlying the Soğukçam Limestone is the Üzümlü Member of the lower part of the Yenipazar Formation, which is characterized by an Albian–Cenomanian turbiditic succession. This unit is a part of the turbiditic basin that developed widely on the 'Sakarya Continent' (Figure 2). The upper units in the studied successions consist of red-pink Santonian–Campanian pelagic limestones and marls (Değirmenözü Member of Yenipazar Formation) (Timur & Aksay 2002), which form a prominent marker interval in the basin (Figure 2). They show an unconformable contact with the underlying turbiditic sequence, whereas the upper part grades into the superjacent succession of Campanian–Maastrichtian age (Yenipazar Formation), which consists of turbidites.

Twelve stratigraphic sections have been measured and correlated in between and within the basin.

The Red Beds

Biostratigraphy

The biostratigraphic framework of the pelagic red beds is conformable to the biozones of planktonic foraminifera given in De Graciansky *et al.* (1998). The Early Cretaceous series includes three levels of red beds in the studied sections: two are recognized in the Lower and Upper Aptian within the upper part of the *G. blowi* (Bolli) – and the lower part of the *L. cabri* (Sigal) and *G. algerianus* (Cushman and Ten Dam) - *P. cheniourensis* (Sigal) zones, respectively; the last zone is recognized in the Late Albian within the chronozone of *B. breggiensis* (Gandolfi) (Figure 3).

Deposits assigned to the Late Cretaceous show two levels of red beds. One is within the *D. asymmetrica* (Sigal) zone assigned to the Late Santonian age, and the other is in the *W. archaeocretacea* (Pessagno) zone corresponding to the Latest Cenomanian to Early Turonian age (Figure 3).

Lithostratigraphy

The Lower Cretaceous pelagic red beds constitute prominent levels at the top of the Soğukçam Limestone and within the lower part of the Üzümlü Member of the Yenipazar Fomation (Figure 3). The Lower and Upper Aptian red beds occur just at the boundary between the Soğukçam Limestone and the Üzümlü Member and are overlain by turbiditic successions. They are underlain by an alternating sequence of white-cream coloured pelagic limestone and marl/shale. The Upper Albian red beds occur within the marly interval of turbidites which are composed of alternation of thin- to medium-bedded, parallel laminated or partly bioturbated, arkosic, litharenitic or wacke sandstones with normal graded bedding, shales/mudstones and thin-bedded polygenic conglomerates with fining-upward structures displaying part of a Bouma sequence.

They are overlain by grey coloured marl/shales and turbiditic sandstones, whereas they are underlain by interbeds of purple-brown turbiditic sandstone and dark grey-black coloured marl/shale (Figure 3).

The Upper Cretaceous pelagic red beds (Değirmenözü Member) unconformably overlie Lower Cretaceous turbiditic successions, and intergrade with overlying turbiditic successions (Yenipazar Formation).

Sedimentology

The red beds recorded in the Early and Late Aptian (both in *G. blowi - L. cabri* zone and *G. algerianus - P. cheniourensis* zones) consist of red to pink (ranging from moderate pink [5R 7/4], light red [5R 6/6], moderate red [5R 4/6] to very dark red [5R 2/6], of The Rock-Colour Chart [Geological Society of America 1995]) limestones and marls in the Mudurnu and Göynük areas (Soğukçam, Değirmenözü, Samsaçavuş, Mudurnu and Sünnetgölü

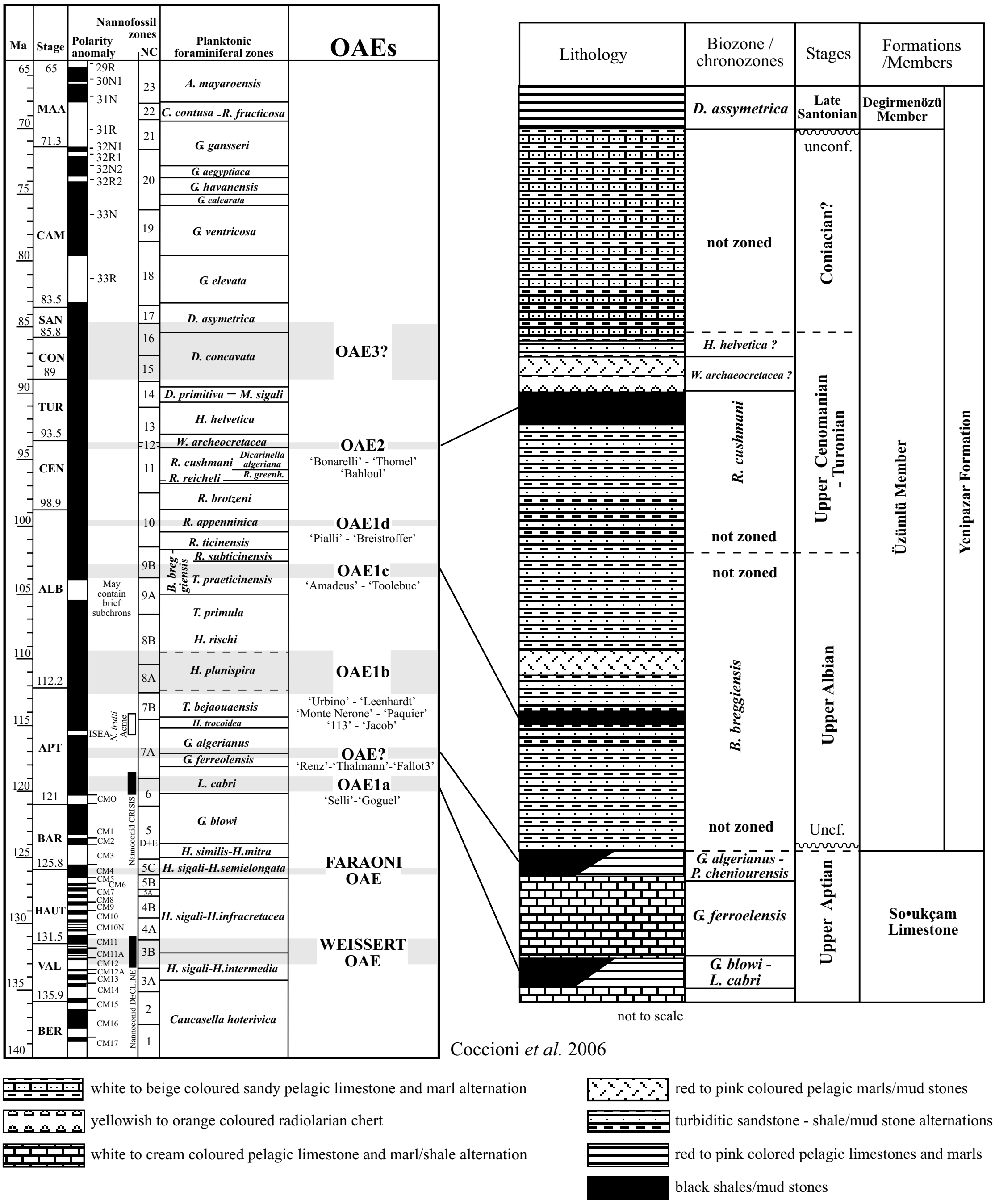

Figure 3. Biostratigraphic framework of the studied intervals in the Mudurnu and Göynük areas, and the position of black shales and red beds.

sections) presently separated from each other by a distance of 60 km (Figures 4–9). Compared to the underlying limestones, these facies show a sudden increase in the abundance of planktonic foraminifera, bivalves and echinoidea. The red limestones (light-moderate red; 5R 5/6) are of packstone facies (Figure 10a) and the red marls (moderate-very dark red; 5R 3/6) and limestones include reddish iron crystals, a few green minerals (glauconite) in the micritic/clayey matrix together with reddish iron infillings within the chambers

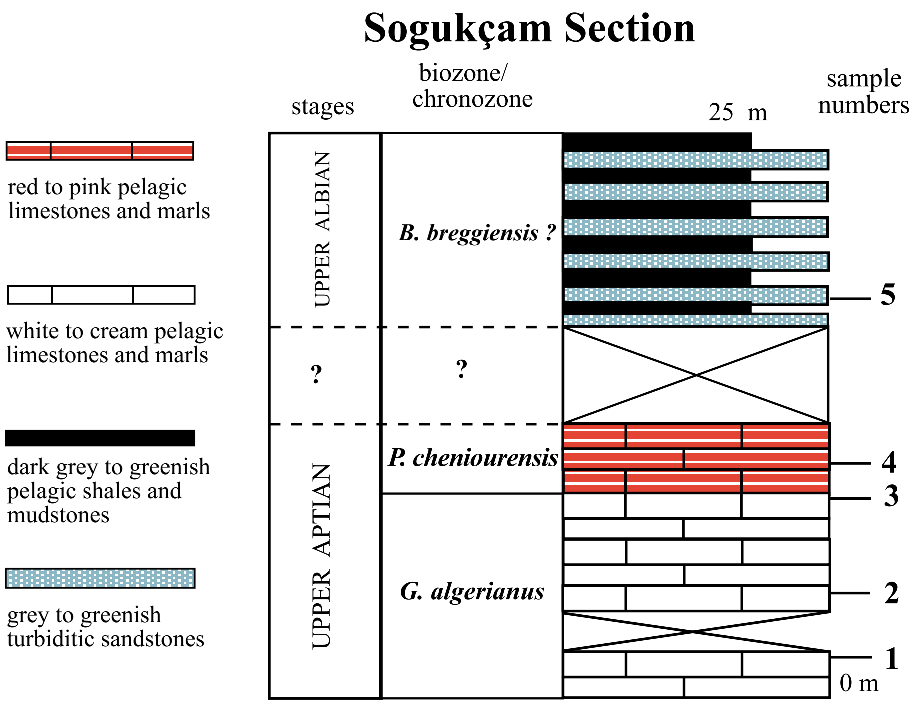

Figure 4. The Soğukçam measured stratigraphic section.

of planktonic foraminifera. Silicilastic silt/sand components are rarely observed in the limestones, and there is no apparent bioturbation in the red limestones and marls. Marl facies exhibit fine laminae composed of an alternation of quartz silt and iron rich mud.

In the Mudurnu section (Figures 8 & 11a, b), red to pink limestones are cut across by 'Neptunian dyke'-like structures at the contact with superjacent Upper Albian turbidite successions. These structures are filled with purple to brown (between greyish red purple [5RP 4/2] and pale purple [5P 4/2]) calcareous sand that includes angular quartz and feldspar grains, glauconite, iron minerals, abundant planktonic foraminifera and belemnites. Cracks penetrate into the underlying limestones to about 1 meter (Figures 8–10). Sandy limestones with abundant bivalve shells occur just above the contact zone (Figures 8, 10b & 11a, b). The sandy limestones contain intraclasts of underlying pelagic limestones, quartz and feldspar grains, glauconite, iron minerals and Upper Albian planktonic foraminifera. This boundary is interpreted as an unconformity (disconformity) between two different formations and best observed in the Mudurnu section.

In the Upper Albian, red marls/shales (moderate-very dark red; 5R 3/6) that occur in the Mudurnu area (Figure 8) are composed of quartz silt/sand, phosphorite clasts, reddish iron minerals, planktonic foraminifera, and calcareous micritic matrix (Figure 10d) and display fine parallel laminae. Reddish iron crystals are disseminated in the micritic/clayey matrix, and the chambers of foraminifera are also filled with very fine reddish iron oxides.

Planktonic foraminifera are relatively more abundant in these red marls than in the underlying sandy beds as well as in the overlying grey marls and mudstones (Figure 11c).

The Turonian in the Göynük-Sünnet section (Figure 12) shows red coloured marls/shales (moderate red; 5R 4/6) overlying the yellow to reddish (between dark yellowish orange; 10YR 6/6) and greyish orange (10YR 7/4) cherty interval. The red marls/shales are succeeded by the alternation of white-cream coloured bioturbated limestones with calcareous sandstones which is in turn is followed upwards by Upper Cretaceous Red Beds of Late Santonian age (Figure 13d).

The Upper Cretaceous (Upper Santonian) red beds (moderate-very dark red; 5R 3/6) occur in all sections studied, and crop out extensively in the study areas. They are mainly composed of alternating red-pinkish limestones and marls, and occasional thin volcanic tuff

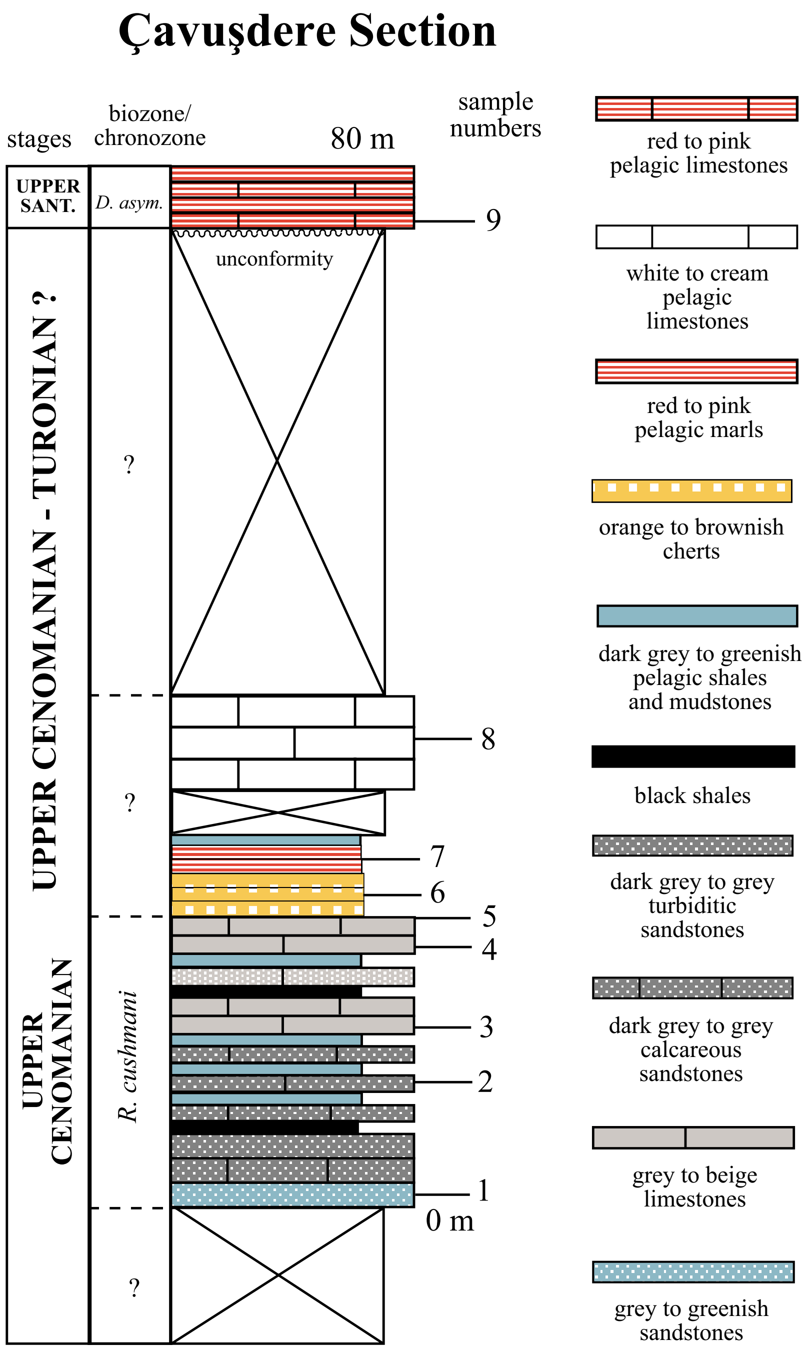

Figure 5. The Çavuşdere measured stratigraphic section.

layers intercalated with the reddish limestones. A *Globotruncana* packstone facies is the characteristic feature of the red beds (Figure 10f). In the Mudurnu area, these red levels unconformably overlie siliciclastic turbidite successions (Figure 11d). In the İsmailler (Figure 14) and the Mudurnu sections (Figure 8), red chert (very dark red; 5R 2/6) nodules are present at some levels within the limestones. In addition to structures like 'Neptunian dykes' filled with sandy materials, some iron oxide nodules or impregnations and some bioturbations filled with dark red or purple muddy materials also occur at the contacts with the red beds. The presence of transported/reworked '*Inoceramus*' shells in the limestones of the Mudurnu area indicates

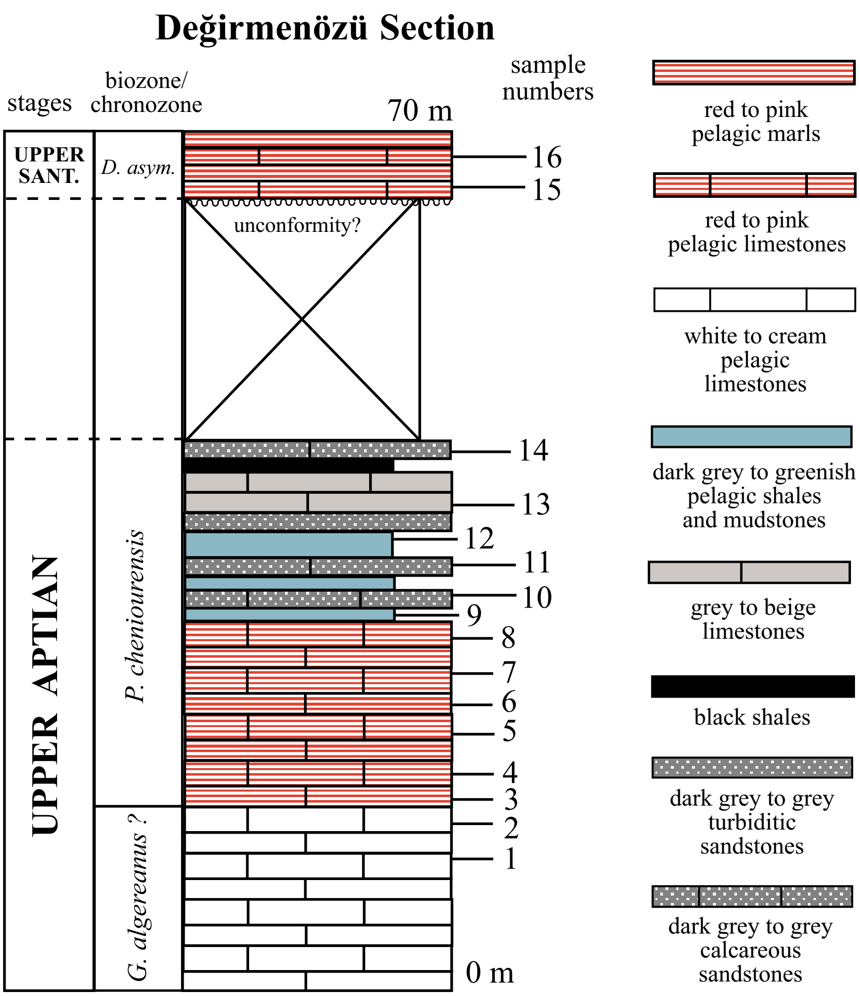

Figure 6. The Değirmenözü measured stratigraphic section.

that calcareous materials from shallower environments were occasionally transported into the pelagic environment. Iron oxide is present as crystals disseminated within the micritic matrix and as a fine-grained infilling material within the chambers of planktonic foraminifera.

Sequence Stratigraphy and Cyclostratigraphy

High resolution cyclostratigraphic and sequence stratigraphic analyses have been carried out in the Mudurnu and İsmailler sections. The other sections were analyzed at lower resolution, but in conjunction with the results of these two sections and within their same biostratigraphic framework and their coeval global counterparts (Figure 3).

In the sequence stratigraphic concept, the red beds display two different positions in the basin. One is related to a Type-3 sequence boundary and the other is related to late transgressive system tracts. The Upper Aptian red-pinkish limestones/marls are interpreted as related to high-stand/still-stand system tracts below a Type-3 sequence boundary (Schlager 1999). At this boundary, red Upper Aptian pelagic limestones are overlain by Upper Albian–Cenomanian siliciclastic turbidites in the Mudurnu area. The unconformity surface between turbidites and red beds is easily marked by the presence of the infillings of the overlying siliciclastic materials down into the underlying limestones through ‘Neptunian dyke’ like structures (Figure 11a, b). Belemnites are abundant throughout the turbiditic succession and even within the infilling of sandy materials. Just above this boundary, the

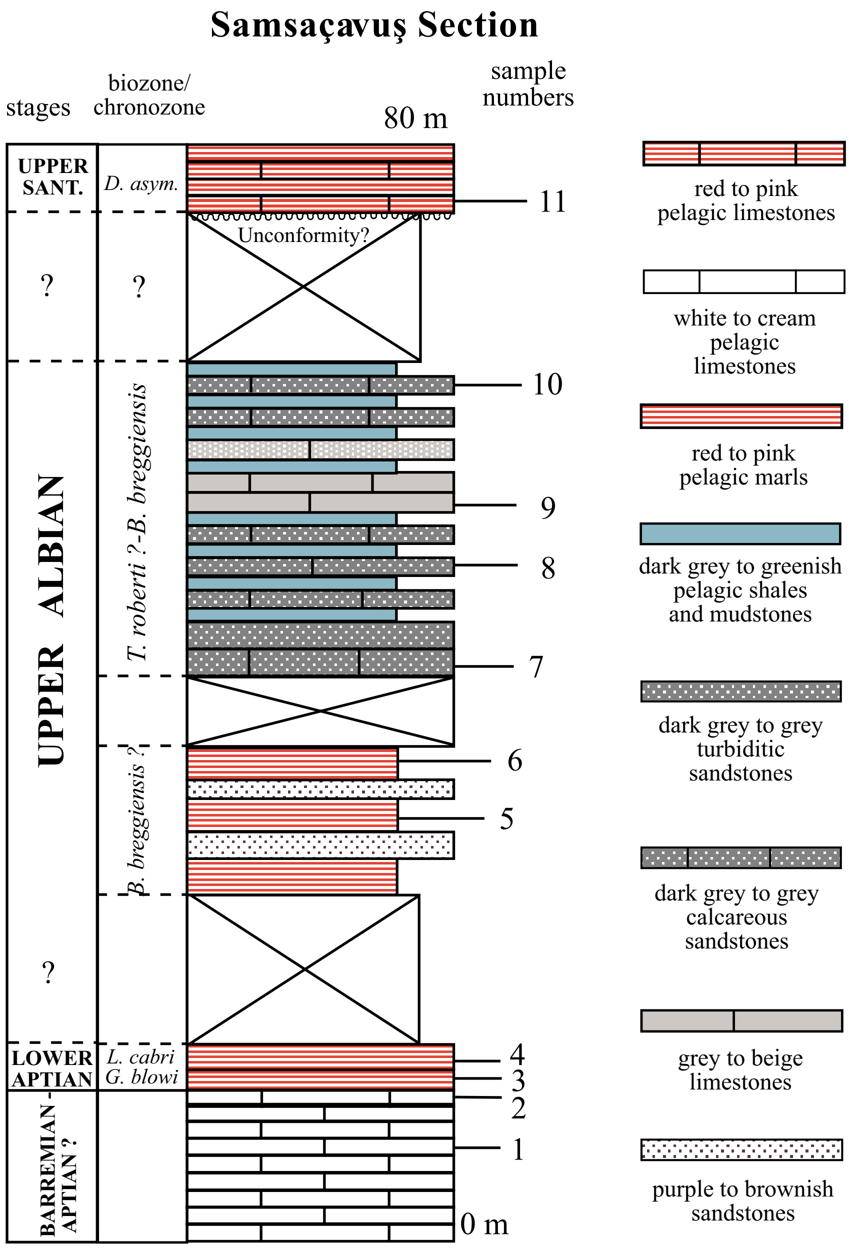

Figure 7. The Samsaçavuş measured stratigraphic section.

presence of shell accumulations with some iron and glauconite minerals is interpreted as sediment starvation conditions and sudden increase in accommodation space. Therefore, the Type-3 sequence boundary took place on these red beds, which were deposited during high-stand/still-stand conditions and in comparison with underlying succession are characterized by abrupt increase in abundance of planktonic foraminifera, bivalve and echinoid fragments (Figure 10b), and the presence of iron oxide minerals. The pelagic red beds were probably deposited in upper slope pelagic conditions, but relatively shallow. Because there are no deep pelagic environment indicators, such as deep marine ichnofacies, deep marine benthic formaninifera or other organisms. Moreover, the presence of iron minerals that can be terrestrial/volcanic in origin and a hiatus at the boundary indicate that these red beds are subjected to exposure conditions or very shallow water conditions which can be enhanced by extensional tectonics creating also ‘Neptunian dykes’. There is also no indication of CCD fluctuation to generate

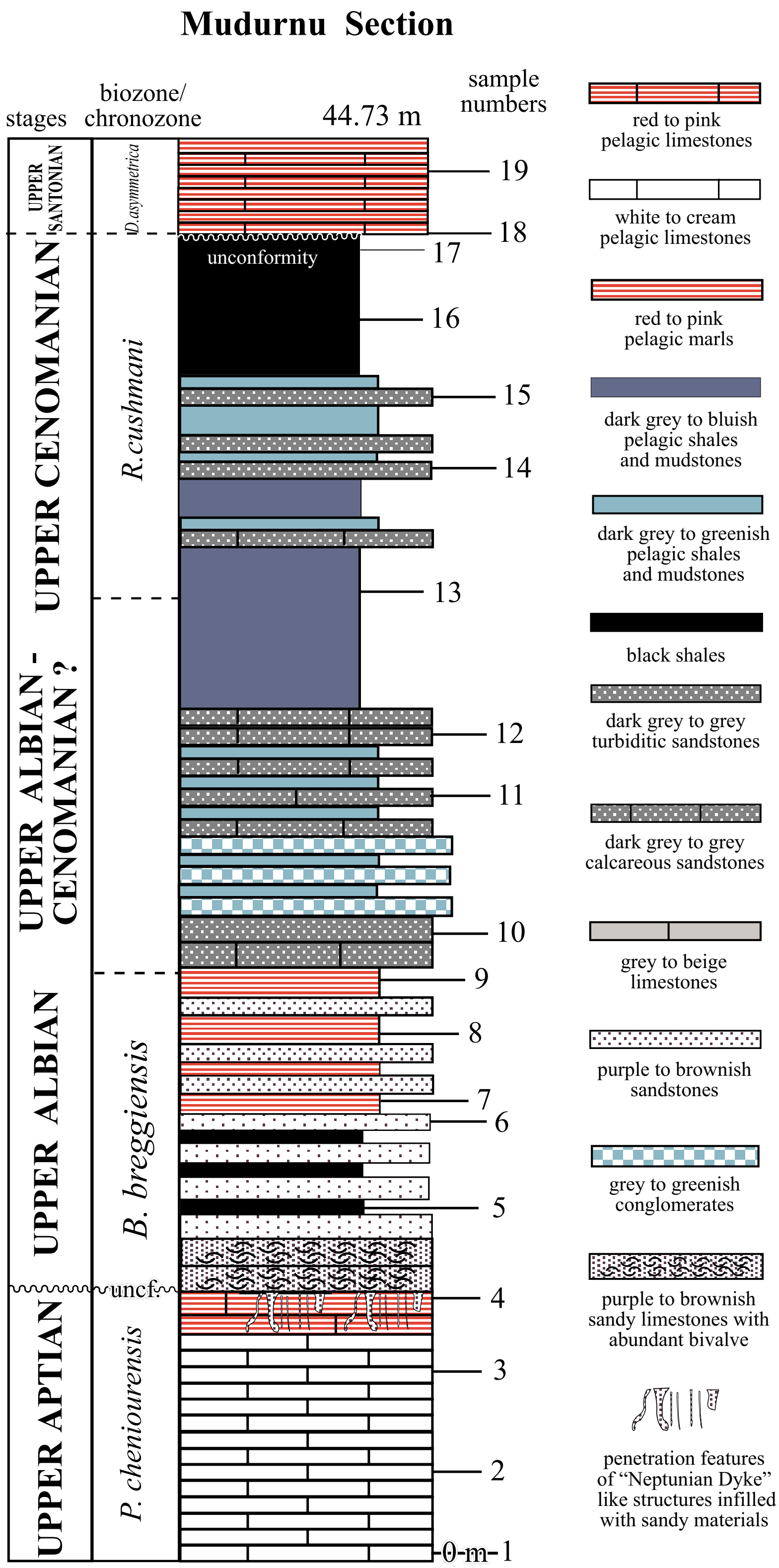

Figure 8. The Mudurnu measured stratigraphic section.

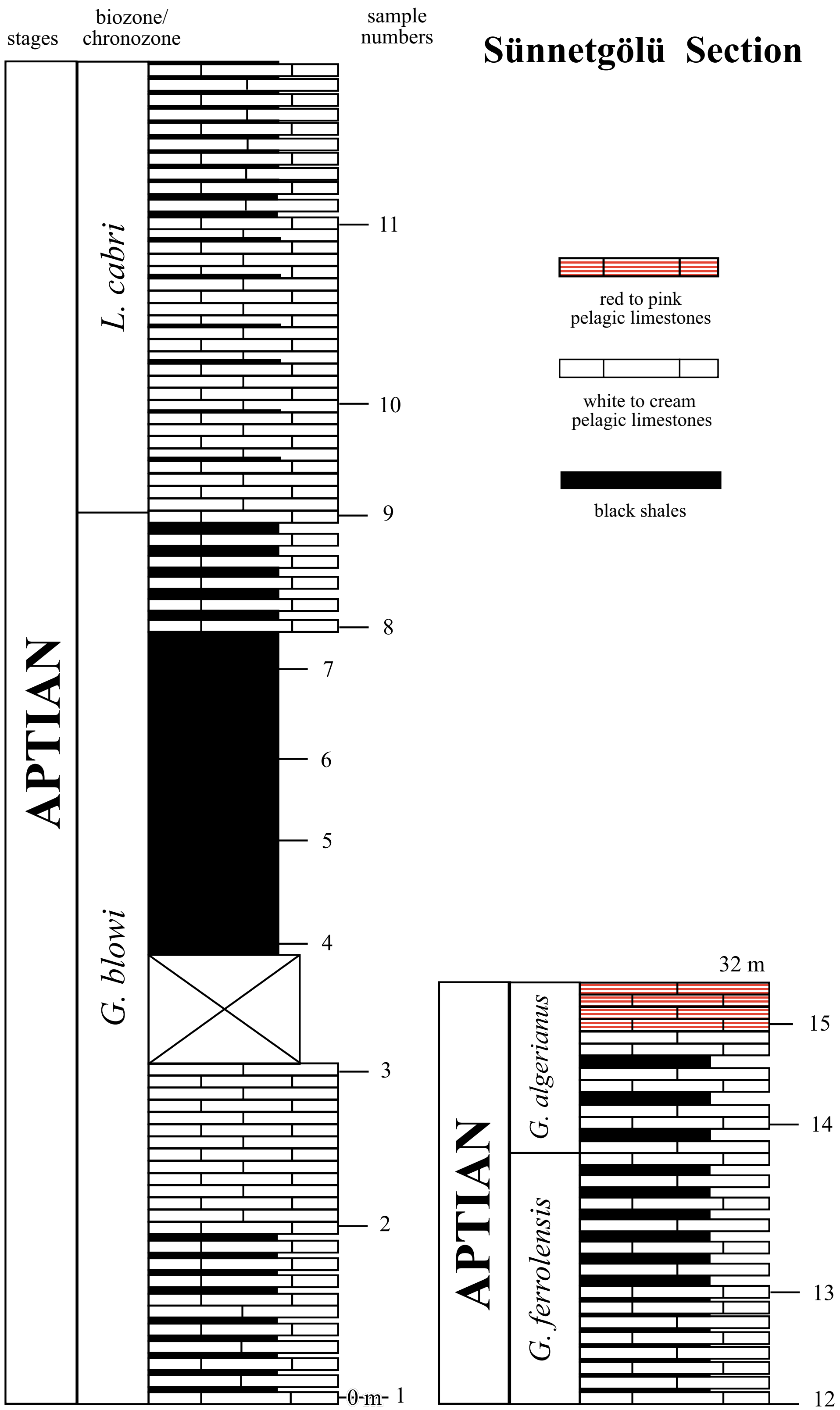

Figure 9. The Sünnetgölü measured stratigraphic section.

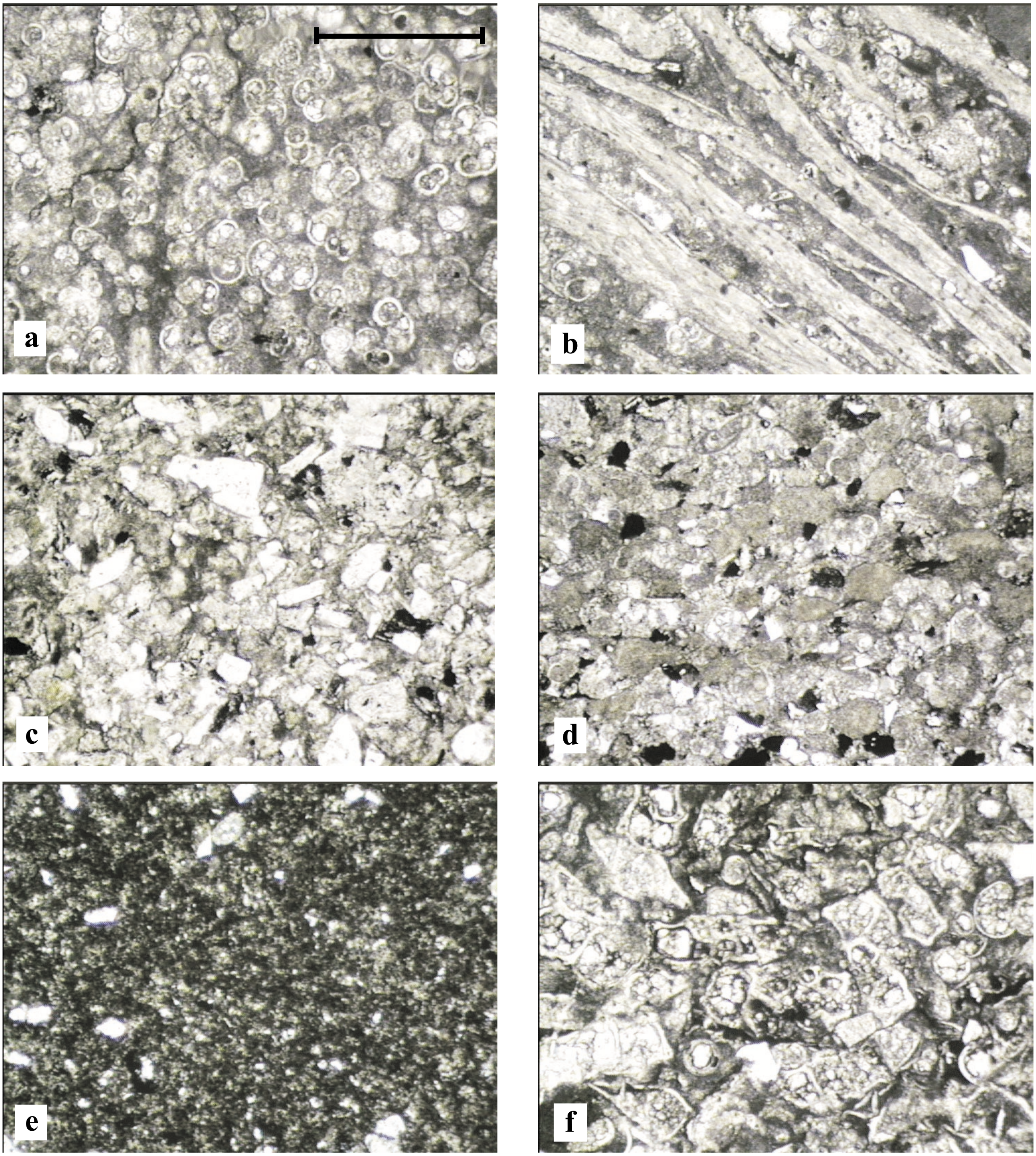

Figure 10. Photomicrographs of microfacies. White scale bar is 0.5 mm and applies for all. (a) Packstone with planktonic foraminifera of pink-red Aptian limestone in the Mudurnu section (Sample no. 20, Figure 15); (b) calcareous siltstone/sandstone with abundant bivalve shells of Late Albian age resting on the unconformity surface in the Mudurnu section (Sample no. 21, Figure 15); (c) arkosic-litharenite of the Mudurnu section (Sample no. 42, Figure 15); (d) purple-brownish silty marn with iron and phosphatic minerals in the Mudurnu section (Sample no. 75a, Figure 15); (e) silty black shale of Aptian age in the Sünnetgölü section (Sample no. 5, Figure 9); (f) red packstone with planktonic foraminifera of Late Cretaceous age in the İsmailler section (Sample noç 12, Figure 14).

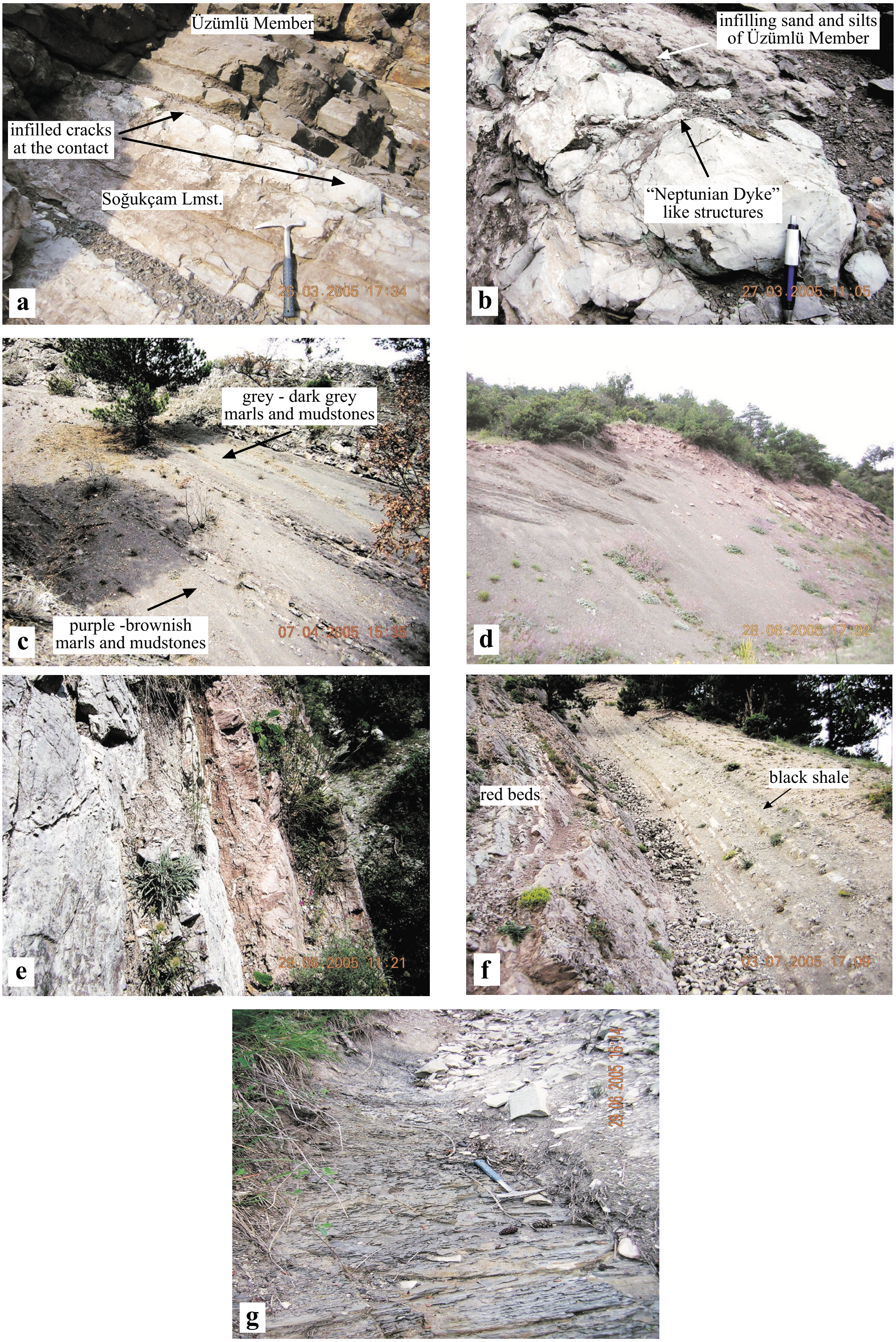
Üzümlü Member
infilled cracks
at the contact
Soğukçam Lmst.
a
infilling sand and silts
of Üzümlü Member
"Neptunian Dyke"
like structures
b
grey - dark grey
marls and mudstones
purple -brownish
marls and mudstones
c
d
e
red beds
black shale
f
g

Figure 11. Field photographs of red beds and black shales: (a) The contact between the Soğukçam Limestone (white unit) and Uzumlu Member (dark unit) in the Mudurnu secion (samples between 15–25, Figure 15); (b) close-up view of the penetration of sand/siltstones along 'Neptunian dyke'-like structures in a; (c) grey to dark grey marl/mudstones overlying purple-brownish marls/mudstones of Late Albian age in the Mudurnu section (samples between 75a–85, Figure 15); (d) red pelagic limestones of Santonian–Campanian age overlying black/dark shales/mudstones of Cenomanian age in the upper part of the Mudurnu section (samples between 16–19, Figure 8); (e) red-pink pelagic limestones and marls of *L. cabri-G. blowi* zone over the white limestones of Aptian age in the Samsacavus section (samples between 2–3, Figure 7); (f) Upper Aptian red to pink limestones/marls overlain by Upper Aptian turbiditic succession including black shale interval in the Degirmenözü section (samples between 7–14, Figure 6); (g) Aptian black shales in the Sünnetgölü section (samples between 4–7, Figure 9).

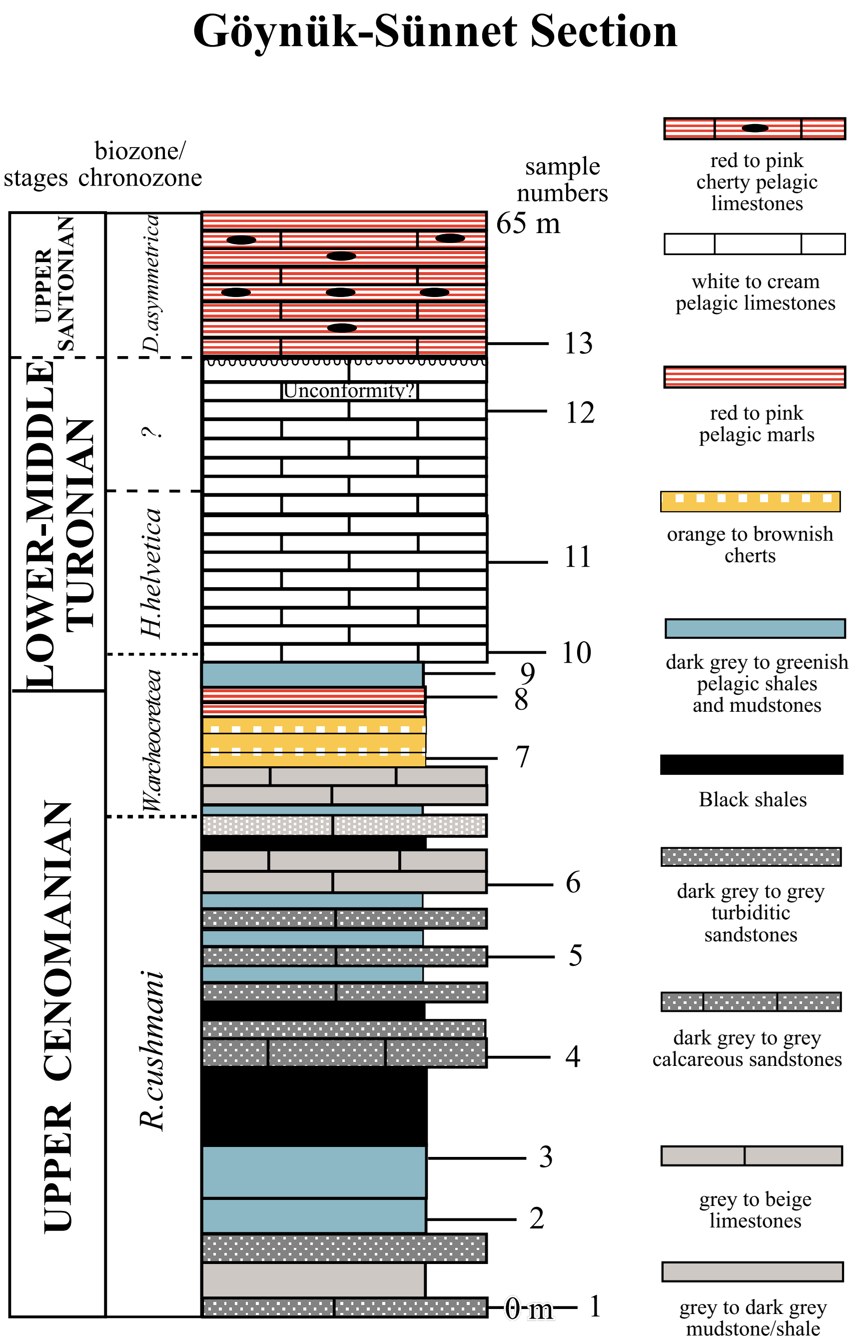

Figure 12. The Göynük-Sünnet measured stratigraphic section.

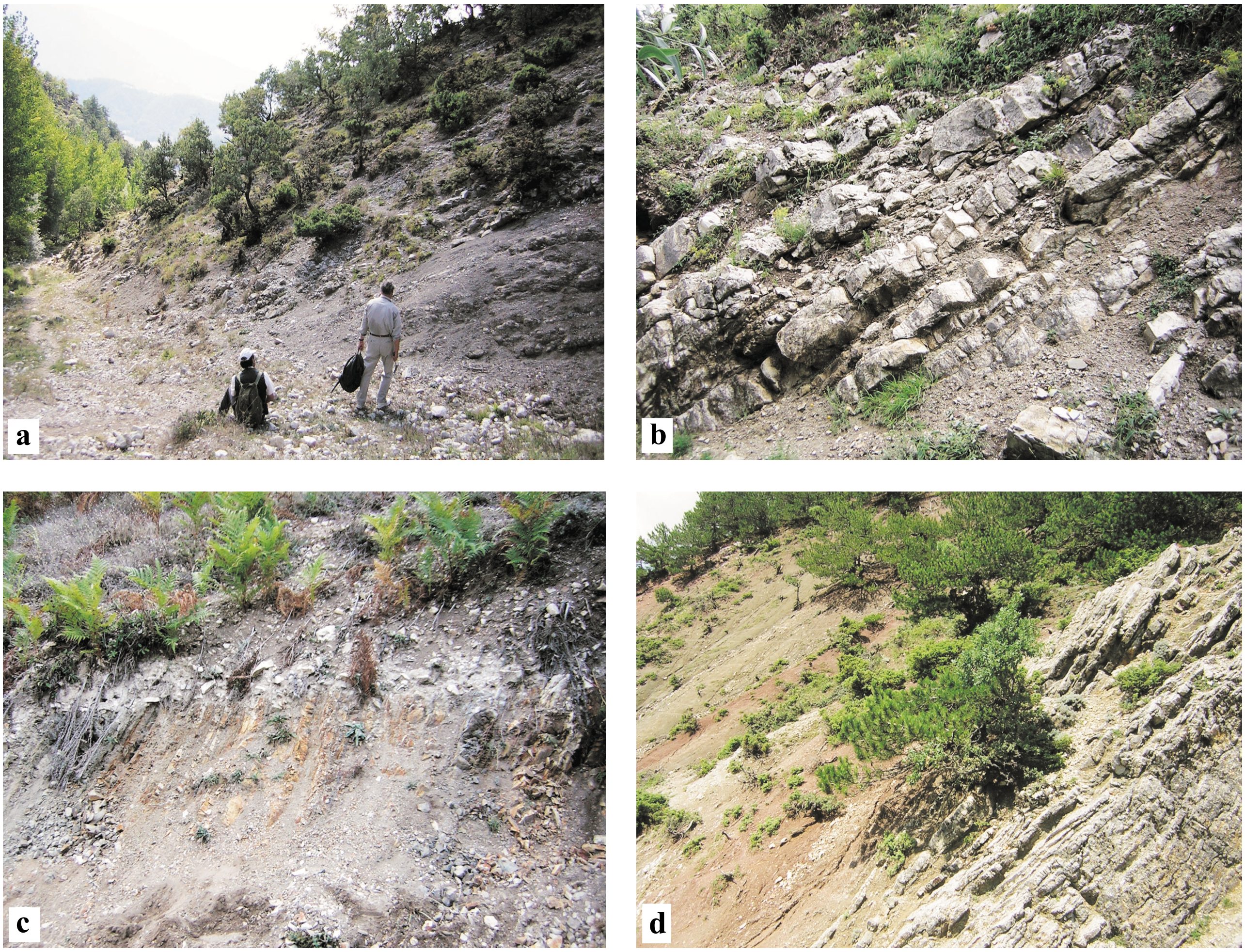

Figure 13. Field views of outcrops of İsmailler section: (a) shale-dominated bottom part of the section; (b) carbonate-dominated mid-part of the section; (c) chert interval in the upper part; (d) Upper Santonian red beds covering the top part of the section.

this type of reddish carbonate successions overlain by calcareous sand that includes angular quartz and feldspar grains, glauconite, iron minerals, abundant planktonic foraminifera and belemnites.

The Değirmenözü section in the Göynük area (Figure 6), also includes upper Aptian red-pinkish limestones/marls (moderate-very dark red; 5R 3/6), but they are overlain by siliciclastic turbidites, including an Upper Aptian black shale interval. The boundary is sharp and does not contain any exposure or hardground structures, and neither hiatus. Although the content of the Upper Aptian red beds in the Mudurnu and Göynük areas are the same, their respective contact with the overlying successions is different. In both cases, the red beds are overlain by facies indicative of a drowning event that might have resulted from the sudden increase in relative sea level, and interpreted as related to a Type-3 boundary (Schlager 1999).

In the Early Aptian, of the *G.blowi-L.cabri* zone, red marls/limestones (moderate red; 5R 4/6) are recorded only in the Samsaçavuş section, in the Göynük area (Figure 7 & 11e), and they rest on Barremian–Aptian white/cream coloured thin-bedded limestones alternating with marls/shales. The contact between these units is sharp and does not show any exposure/hardground structures. These red beds are overlain by a silciclastic turbidite succession of Late Albian age. However, the boundary between red beds and turbidites could not be observed because of the soil and vegetation cover. The presence of red beds in the *G.blowi-L. cabri* zone, which corresponds to the 'Selli' interval elsewhere (Yılmaz *et al.* 2004a) has been interpreted to be related to a local tectonic event associated with differential tectonic uplift within the basin. This tectonism may have enhanced the formation of black shales within depressions, while allowing deposition of red beds on uplifted horst-like blocks by percolating and upwelling waters, which might be rich in Fe and nutrients at that time and/or may be associated with volcanic or hydrothermal sources in the area.

The Upper Albian red marls/shales are interpreted as related to late transgressive system tract. In the Mudurnu and Göynük areas, these red beds are recorded within the marly interval of the siliciclastic turbidites, which contain abundant phosphorite clasts and reddish iron minerals. However, the adjacent marly intervals of the turbidite sequence do not contain any phosphorite clasts and iron minerals. These marly intervals rest on sandy intervals and their positions are probably related to a late transgressive system tract. Perhaps, they are related to sudden increase in nutrient and Fe content in the water and associated with upwelling conditions during that time.

In the Late Cretaceous (Late Santonian), a 10–50-m-thick interval of alternating red limestones and marls/shales unconformably overlies the siliclastic turbidite succession of Late Albian–Cenomanian age (Figures 5–8, 12 & 14). These red beds are interpreted to be related to a drowning event that probably took place during sudden subsidence succeeding a major uplift phase in the basin. This drowning event could also be related to the sudden submergence of emerging ridges around the basin, as proposed in the case of the Outer Carpathian Cretaceous Basins between Albian–Cenomanian (Bak 2006). With this assumption, these red beds can thus be interpreted to be related to a tectonically-affected Type-3 sequence boundary in the sequence stratigraphic concept.

The intercalating pattern of the red beds indicates that they are actually acyclic or arhythmic (Einsele *et al.* 1991; Einsele 2001). They display random occurrence in the İsmailler section around the Cenomanian–Turonian boundary. However, some rhythmic alternations within the red beds occur in the Late Albian interval in the Mudurnu section (Figures 15 & 16). From detailed sampling in the Mudurnu and İsmailler sections, the high-resolution cyclostratigraphic study further indicates that generally rhythmicity occurs mainly as alternation of sandstones and marls/black shales, or limestones and marls/black shales, throughout the sections. Intervals of the sections that show some degree of cyclicity such as the Albian red marls/mudstones include rhythmic alternation with purple-brownish sandstones, as shown in the middle part of the Mudurnu section (Figures 8 & 15). Also over the Late Santonian, the transition between red beds and the overlying turbiditic successions appears as alternating grey-greenish mudstone/sandstone and red-pink marls/mudstones. Therefore, the presence of rhythmic alternation between red beds and turbidites indicates that this transition may coincide with an increase in sea level in the sequence stratigraphic scheme.

Cyclicity observed in the İsmailler section occurs as alternation of white to light grey bioturbated limestones/marls and black shales/dark grey silty mudstones in most of the section (Figure 16). They are overlain by orange to brownish radiolarian cherts and grey marls, which are succeeded by red coloured marls/limestones that do not present any cyclicity. Since the İsmailler section is dominated by alternation of bioturbated limestones/marls and black shales/dark grey silty mudstones, changes in thickness increments of limestones or shales are used to set up correlative conformities of sequence boundaries and system tracts (Figure 16). In the sequence stratigraphic framework, carbonate-dominated intervals are taken as representing the high-stand, and shale dominated intervals as transgressive system tracts in general. The red beds may have taken place in late transgressive system tracts. The positions assigned to the sequence boundaries and system tracts have been independently correlated within the same biozones of the global sequence stratigraphy chart of De Graciansky *et al.* (1998), and it is found that the number of sequences and the position of the red beds conform to the same numbers and transgressive intervals in the global chart, respectively (Figures 3 & 17).

The recurrent variations of facies in the sections have also been analyzed for sequence stratigraphic purpose. The parameters used include: appearance and clustering of conglomerates at particular position within the sections (Figure 15); change in thickness of cycles along the sections; change in position of carbonate or shale dominated intervals. They are used to set up sequence boundaries/correlative conformities, and system tracts in this type of pelagic settings. Independently from facies

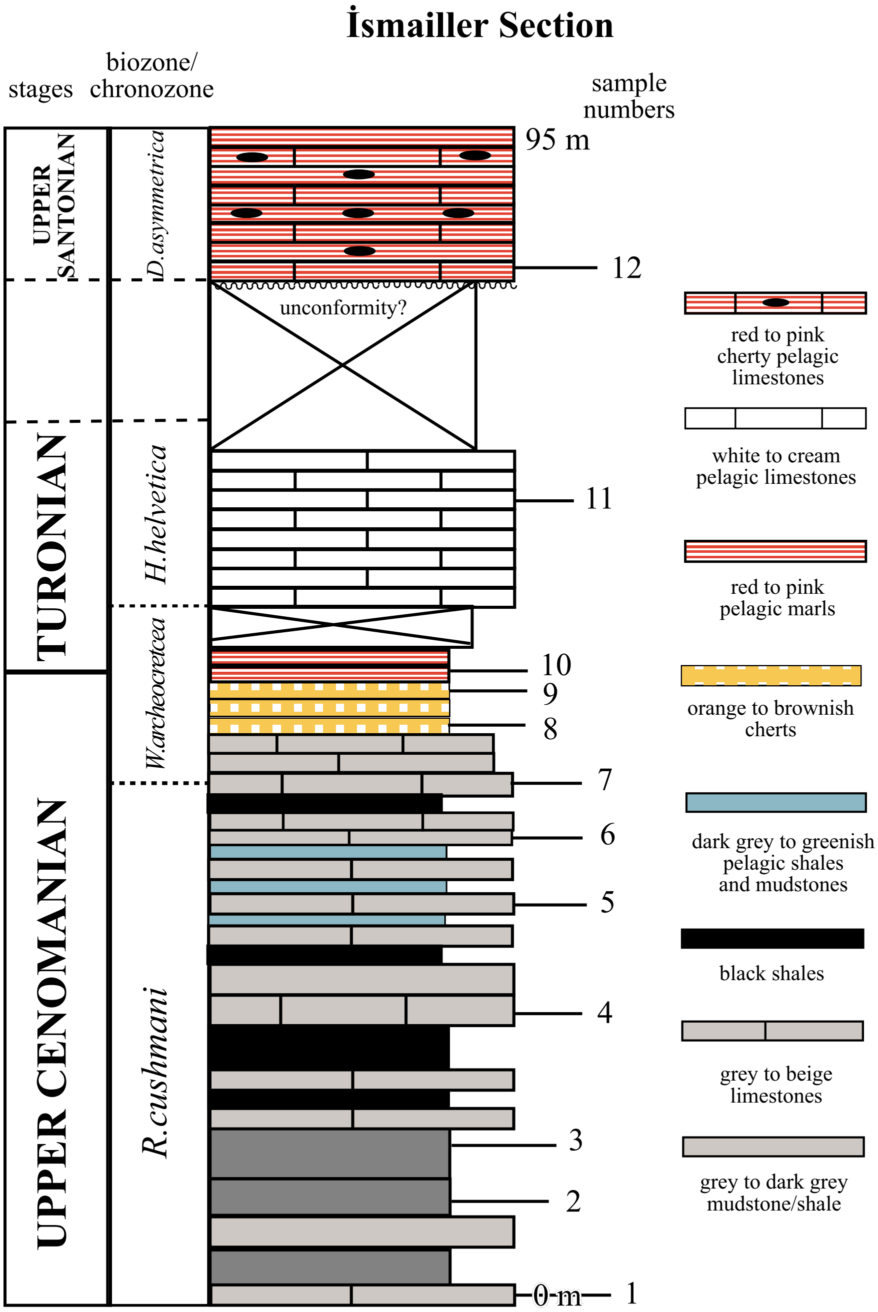

Figure 14. The İsmailler measured stratigraphic section.

analysis, Fischer plot curves (Sadler *et al.* 1993) have been prepared for the Mudurnu and İsmailler sections by using patterns of change in cycle thicknesses along each section (Figure 18–20). They are analyzed for change in accommodation space in relation to sea level fluctuations. Sequence boundaries obtained by facies analysis correspond to the end of the falling limbs of the curves indicating decreased accommodation space, whereas black shales and red marls correspond to rising limbs thus implying increased accommodation space. Red limestones associated with a type-3 sequence boundary are observed towards the falling limbs due to high-stand conditions,

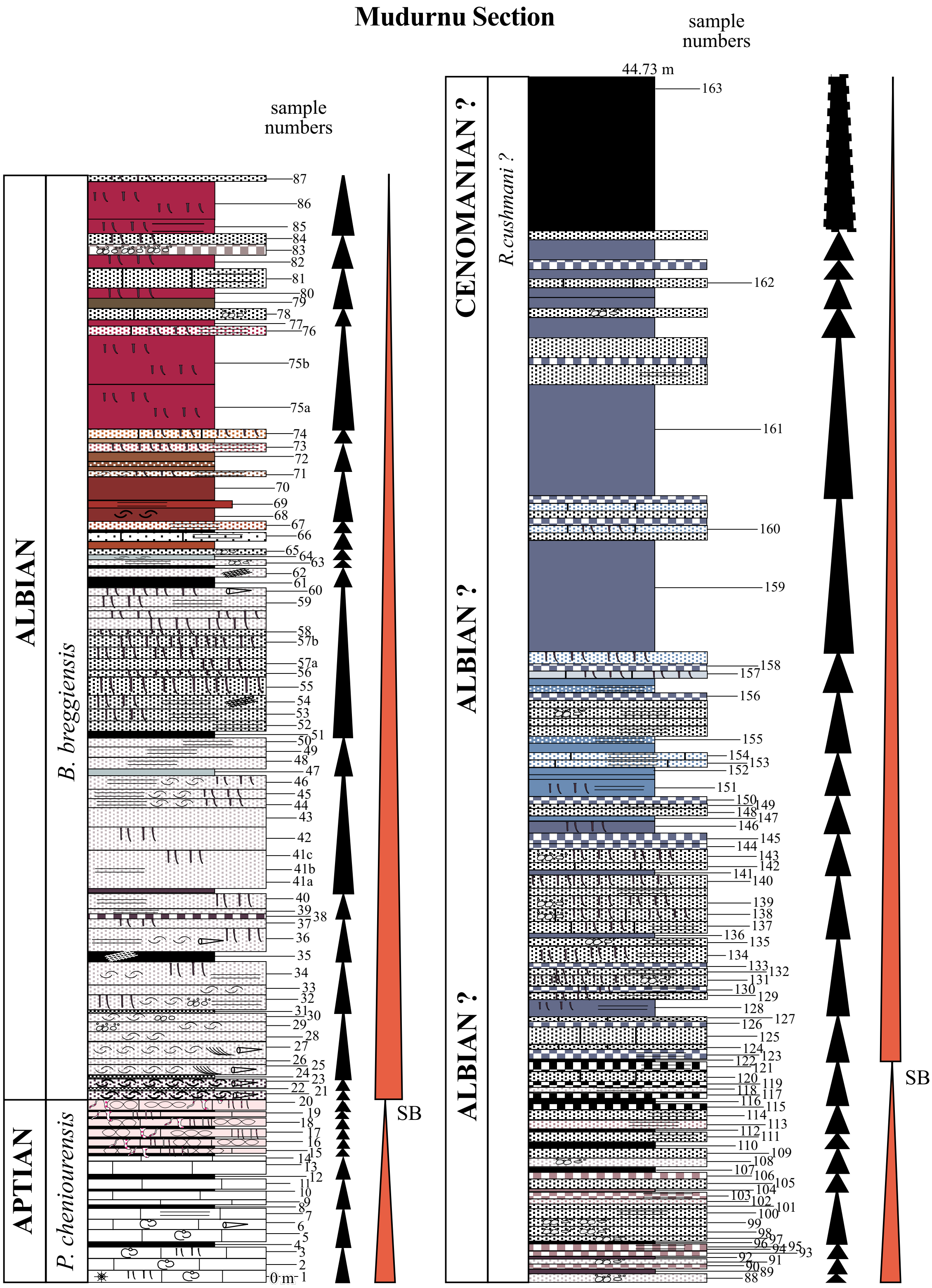

Figure 15. High resolution lithostratigraphy of the Mudurnu measured section. Short black arrows represent cycles and long red arrows represent sequences. For facies descriptions see Appendix.

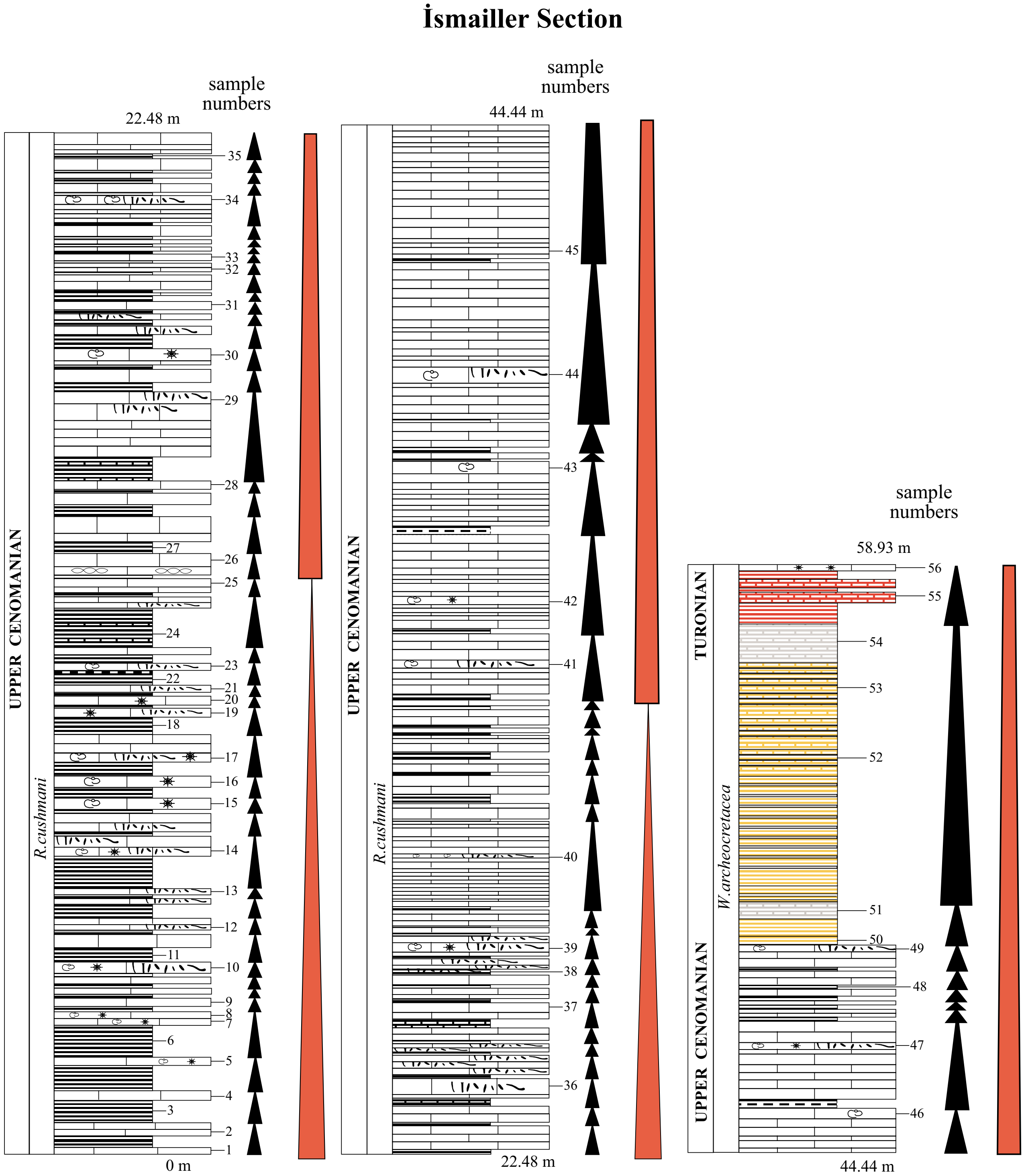

Figure 16. High resolution lithostratigraphy of the İsmailler measured section. Short black arrows represent cycles and long arrows represent sequences. For facies descriptions see Appendix.

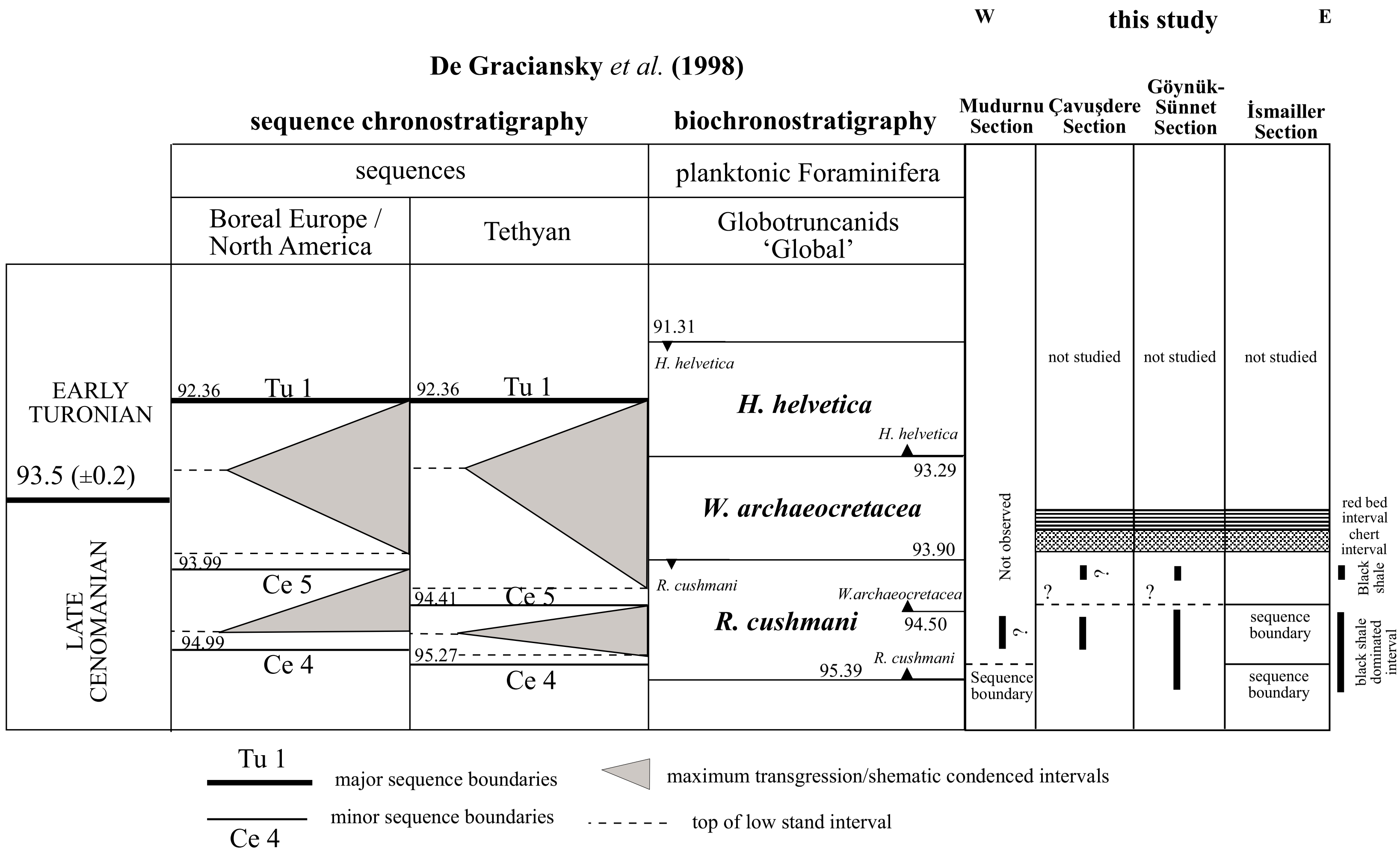

Figure 17. Correlation of sequence boundaries, and occurrences of black shales and red beds in the İsmailler section, with sequence boundaries and system tracts with global charts (De Graciansky *et al.* 1998). The age assigned in the brackets is from Gradstein *et al.* (2004).

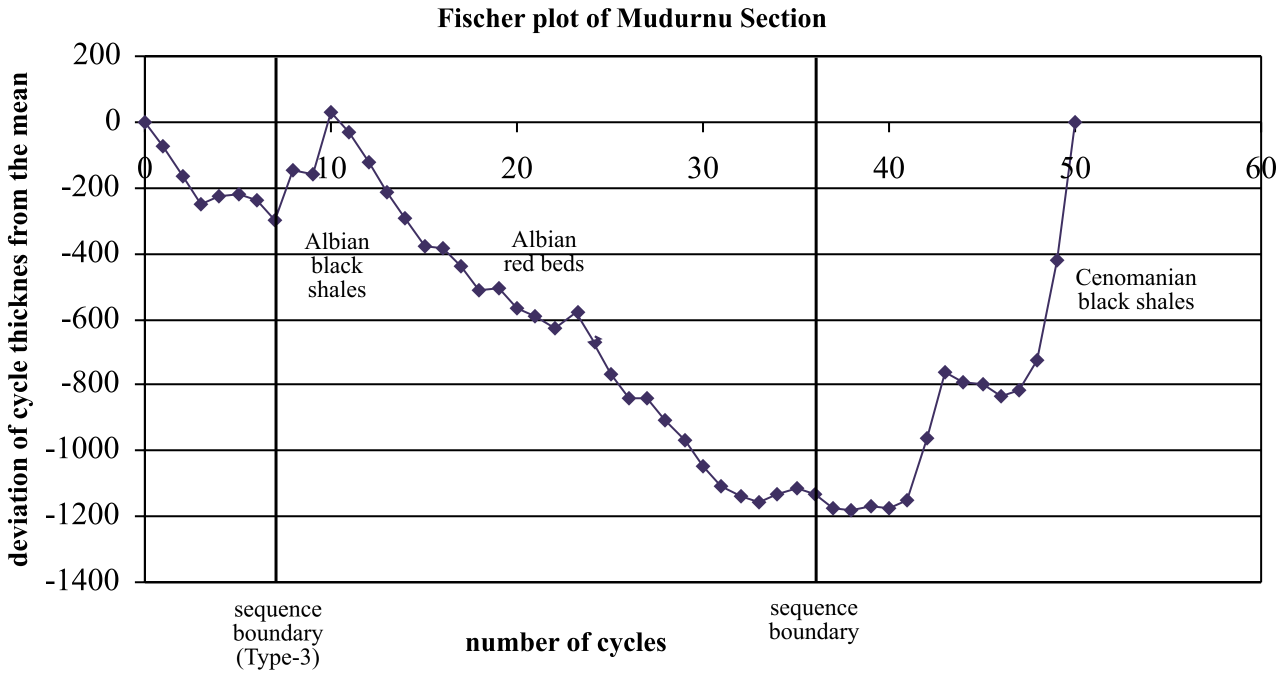

Figure 18. Fischer plot curve of the Mudurnu detailed measured section.

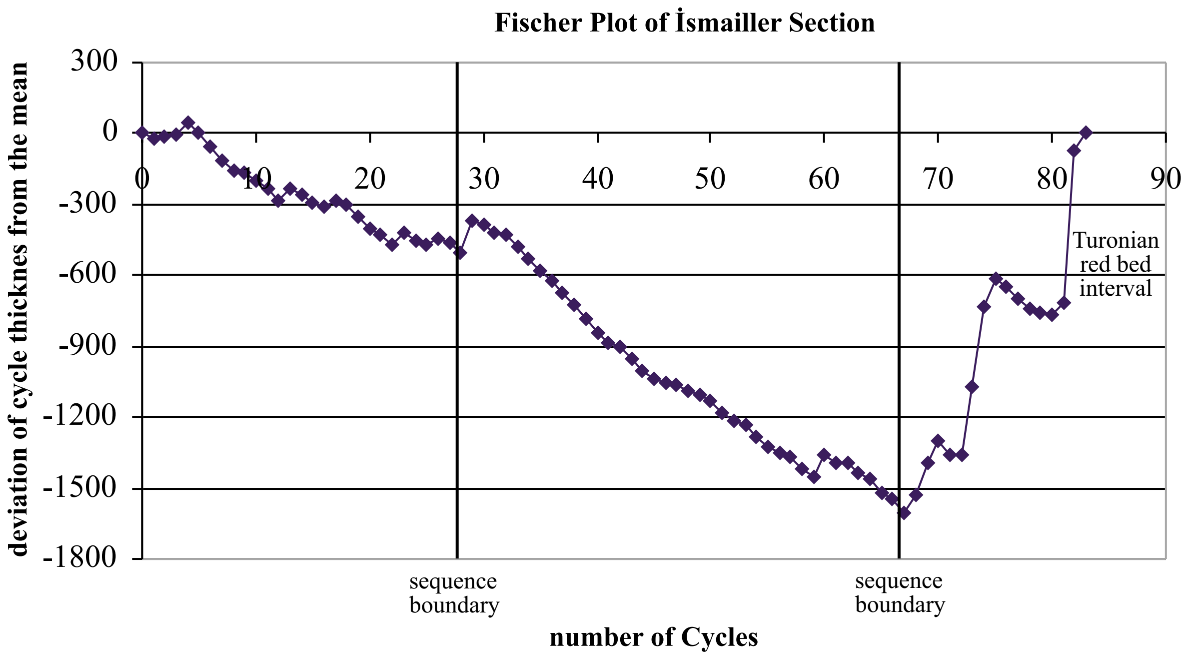

Figure 19. Fischer plot curve of the İsmailler detailed measured section.

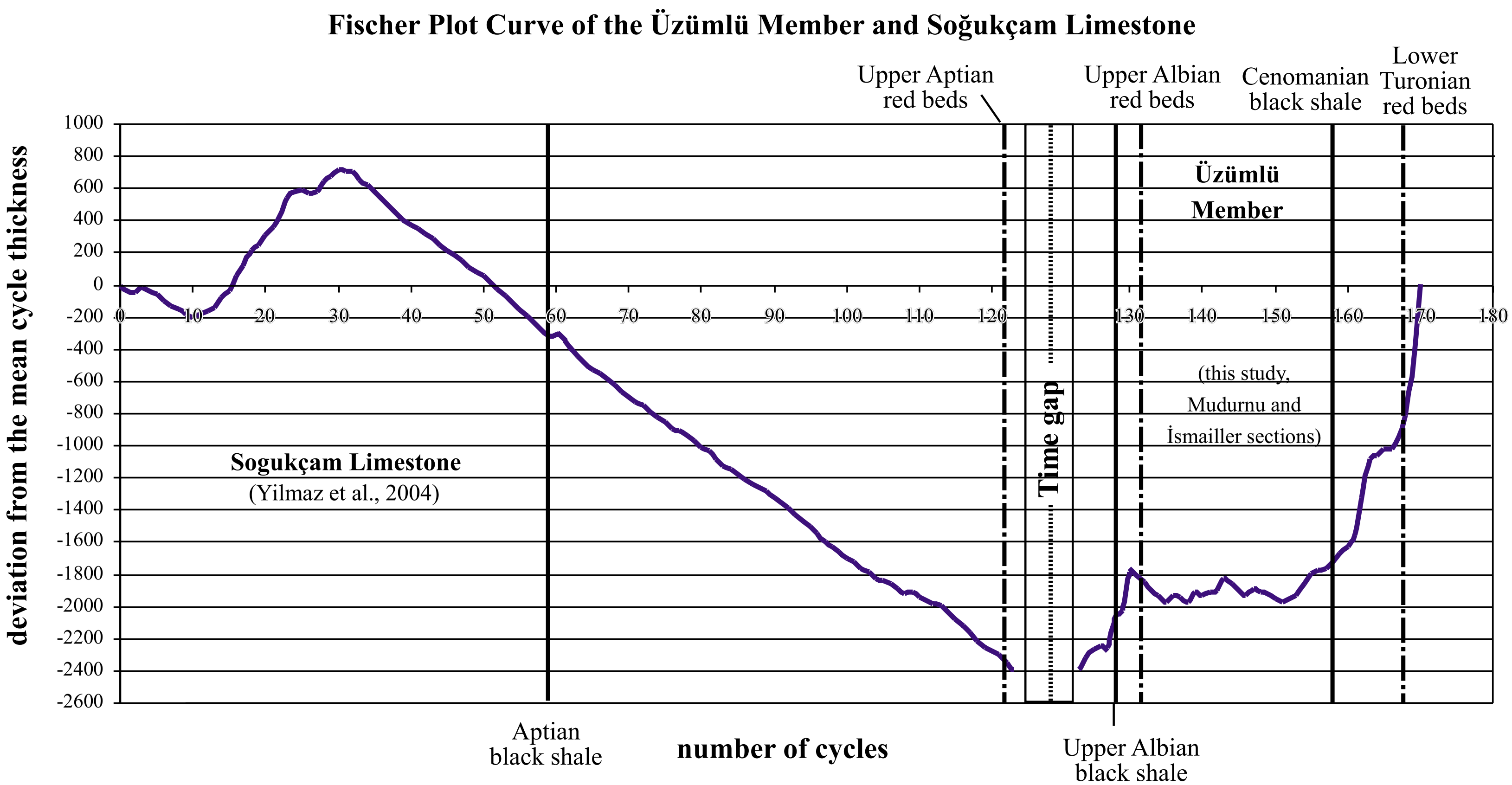

Figure 20. Fischer plot curve of the Üzümlü Member (Mudurnu and İsmailler sections) and Soğukçam Limestone (data from Nallıhan section of Yılmaz *et al.* 2004a). Dotted line represents the boundary between two formations.

which implies a high-stand system tracts/falling stage system tracts just before the sudden drowning.

The low-stand system tracts are not clearly defined in the measured sections due to lack of exposure of geometrical relationship of the beds in the study areas, and dominance of pelagic successions of the drowned margin. However, in the Mudurnu section (Figures 15), a fining-upward trend occurs within the sandstones superjacent to the sequence boundary associated with conglomerates (Figure 15, samples between 125 and 160). This may be interpreted as the short record of low stand condition related to a drop (cf. Catuneanu 2006), and abruptly followed by transgressive system tracts. In the İsmailler section (Figure 16), it is not possible to differentiate low-stand deposits, therefore one may infer that the site was located in a more distal position within the basin, or that tectonic subsidence was enough to destroy the signals of low stand system tracts and amplify the signal of transgressive system tracts.

The Black Shales/Mudstones

Biostratigraphy

The biostratigraphic framework of the black shales/mudstones is constructed by using planktonic foraminifera zonation (De Graciansky *et al.* 1998). The Early Cretaceous comprises four distinct levels of black shales/mudstones in the studied sections. Two are recognized in the Early and Late Aptian within the upper part of the *G. blowi* – and lower part of the *L. cabri* and *G. algerianus-P. cheniourensis* zones, respectively. The other two are recognized in the Late Albian within the *B. breggiensis* chronozone, and the Late Cenomanian within the zone of *R. cushmani* (Morrow) zone (Figure 3).

Lithostratigraphy

Black shales/mudstones occur in the Lower Cretaceous within the Soğukçam Limestone and within the lower and upper part of the Üzümlü Member of the Yenipazar Fomation (Figure 3). The Lower Aptian black shales (ranging from dark grey [N3] to black [N1]) are recognized in the Göynük (Sünnetgölü sections) (Figure 9) and Mudurnu (Mudurnu-2 section) (Figure 8) areas. Yılmaz *et al.* (2004a) previously recognized the Lower Aptian black shale in the Nallıhan and Mudurnu areas, within the same biozone as in the Soğukçam Limestone. In this study, a second section has been measured in the Mudurnu area that includes the Lower Aptian black shale interval (Sünnetgölü section) (Figure 9). Alternating beds of white/cream pelagic limestones and black/grey marls/shales occur above and below the black shale interval of the Soğukçam Limestone. An Upper Aptian black shale/mudstone (ranging from dark grey [N3] to black [N1]) interval is also recognized just above the Upper Aptian red-bed succession within the Üzümlü Member in the Göynük area (Değirmenözü section) (Figure 6).

The Upper Albian black shale/mudstone (ranging from dark grey [N3] to black [N1]) interval is recognized in the Mudurnu (Figure 8) and Göynük areas within the Üzümlü Member of the Yenipazar Fomation. The black shale interval is intercalated in a unit composed of purple, medium- to thick-bedded, parallel-laminated sandstones that include belemnite and siliciclastic with feldspars and lithic fragments (Figure 10c). The lower boundary between sandstones and shales is sharp and sandstones in this interval do not display intense bioturbation as compared to sandstones at higher stratigraphic intervals.

The black shale (ranging from dark grey [N3] to black [N1]) interval of the Late Cenomanian and around the Cenomanian/Turonian boundary is recognized within the upper part of the Üzümlü Member of the Yenipazar Formation and well exposed in the Mudurnu (Figure 8) and Göynük (Figure 12) sections. These black shales overlie the turbiditic successions composed of alternating grey (between dark grey [N3] and medium dark grey [N4]) sandstone and marl/shale, and are overlain by a succession of interbedded white-cream (between white [N9], very light grey [N8] and yellowish grey [5Y 8/1]) pelagic limestone rich in Radiolaria and planktonic foraminifera, and grey marl/shale of the same member.

Sedimentology

The Lower Aptian black shales/mudstones are about 10 m thick and have been recorded in two of the studied sections: the Mudurnu (Mudurnu area) and Sünnetgölü (Figures 9 & 11g) sections in this study. Yılmaz *et al.* (2004a) recorded the 'Selli' level, OAE 1a in the Mudurnu and the Nallıhan areas, where the event occurs in the same black shale in a coeval biozone. Hence, they can be correlated over a distance of about 100 km from Nallıhan to Göynük. Moreover, there is no considerable change in the facies of the black shales between these areas.

Black shales occuring within the lower part of the succession show no clear evidence of bioturbation, and some are well laminated (Figure 11g). However, some bioturbation appears in the black shales in the upper part of the successions. Silty and/or sandy black shale facies are recorded throughout the interval (Figure 10e). As carbonate content increases upward in the succession, the colour changes from black to grey, between dark grey (N3) and medium dark grey (N4); and pale grey, between medium dark grey (N4) and medium bluish grey (5B 5/1). The lower and upper black shales include pyritized radiolarian, and some planktonic foraminifera show iron coatings around the chambers (Figure 10). Yılmaz *et al.* (2004a) detected a positive C^{13} isotope excursion within the same black shale interval in the Nallıhan area. The sedimentological properties of the black shales in the Nallıhan area are similar to the black shales of the Sünnetgölü and Mudurnu sections, however, in the Nallıhan area, an iron enrichment level and an arkosic sandstone bed occur just after the dark black shale part of the interval. Ammonites are present just before the positive C^{13} excursion level in the same black shale interval. Shales and marls varying in colour between dark grey (N3) and medium dark grey (N4); and pale grey, between medium dark grey (N4) and medium bluish grey (5B 5/1), overlie or alternate with the dark black shale forming couplets within the black shale interval in the Nallıhan section.

All black shale intervals, intergrade with the overlying limestone-dominated intervals and the transition is marked by the appearance of interbedded limestone and black shales, which decrease in thickness within predominantly carbonate interval.

The Upper Aptian black/dark grey shale interval is recognized within the turbiditic sandstones and marls of the Üzümlü Member in the Göynük area (Değirmenözü section; Figure 6). The basal contact of the turbiditic sandstones with the underlying Upper Aptian red beds is sharp, although there is no evidence of hardground or unconformity in between. The microfacies of the Upper Aptian black shale are similar to the ones in the Lower Aptian, and are characterized by the presence of pyritized radiolaria, organic matter and some silt/sand sized quartz.

The Upper Albian black shales represent an interval between purple and medium- to thick-bedded sandstones, which are bioturbated and include belemnites. The triple appearance of black shales within the sandstones in this interval presents an important marker level within the *R. breggiensis* chronozone. The dark grey/black shales also include some quartz silt/sand, and some plant fragments. The presence of pyritized radiolaria, disseminated pyrite minerals in the matrix (Figure 10), and abrupt decrease in planktonic foraminifera concurrent with an increase in organic matter in the black shale beds are corroborative evidence of anoxic conditions during deposition.

A black shale zone of about 20 m thick occurs in the Late Cenomanian of the Mudurnu area (Figure 8). It is composed of alternating dark grey-black silty shale/mudstone and grey marl. Around the Cenomanian/Turonian boundary in the Göynük area (İsmailler and Göynük-Sünnet sections; Figures 12–14), the black shale interval is overlain predominantly by white-cream bioturbated pelagic limestone with planktonic foraminifera (Figure 13a, b). Dark grey-black shales and marls intercalate with these limestones forming couplets at the base of the interval and decrease toward the upper part where limestones dominate in the section. This succession is overlain by a yellow-reddish cherty interval. Red marls/shales overlie this cherty interval (Figure 13).

Sequence Stratigraphy and Cyclostratigraphy

Sequence stratigraphy and cyclostratigraphy have been applied with different resolutions in the different sections, and they are based on petrographic and statistical methods as explained in previous sections.

The cyclicity in the Mudurnu and İsmailler sections (Figure 15 & 16) is expressed as alternation of sandstones and marls/black shales or limestones and marls/black shales throughout.

In the sequence stratigraphic framework, black shales/mudstones are interpreted to have been deposited in the early transgressive systems tracts (Schlanger & Cita 1982; Einsele *et al.* 1991; Tyson & Pearson 1991; Emery & Myers 1996; Miall 1997; Barrera & Johnson 1999; Einsele 2001; Coe 2003; Skelton *et al.* 2003; Catuneanu 2006) and are all observed before the red beds. The Lower Aptian black shales are recognized within the transgressive systems tracts of the Nallıhan and Mudurnu sections. Their positions within the biostratigraphic framework corresponding to the upper

G. blowi/ lower *L. cabri* zone also concur with the biochronozones in the global sea-level charts (De Graciansky *et al.* 1998) and they fit into the main transgressive phase before the Lower Aptian sea level fall. Yılmaz *et al.* (2004a) presented the stable isotope (C and O) curves of the Aptian black shale interval in the Nallıhan section, and discussed as well the sequence stratigraphic and cyclostratigraphic implications of the Nallıhan and Mudurnu sections. They indicated that the position of the black shale interval corresponds with the transgressive systems tracts supported by the evidence from the isotope curve, sequence stratigraphy and cyclostratigraphy.

The black shale/mudstone intervals in the Upper Aptian occur within the turbiditic succession just above the Upper Aptian red limestones (Değirmenözü section; Figures 6 & 11f). Poor exposure of the rest of the succession in the section does not allow us to define their sequence stratigraphic or cyclostratigraphic positions. However, because of their relationship with the underlying red limestone which is suddenly replaced by thin beds of sandstones and black shales, these facies can be interpreted to represent a sudden increase in accommodation in relation to early transgressive system tracts. This Upper Aptian black shale/mudstone interval has been recorded within the *G. algerianus* (Cushman and Ten Dam) - *P. cheniourensis* (Sigal) zones in the Değirmenözü section. However, Coccioni *et al.* (2006) reported that the Upper Aptian Oceanic Anoxic Event was recorded around the boundary between *G. ferreolensis* (Moullade) and *G. algerianus* (Cushman and Ten Dam) zones as: the Thalmann level in the Calera Limestone of the Franciscan Complex of Northern California; as the Niveau Fallot 3 level of the Vacontian Basin and Mazagon Plateau (DSDP site 545); and as the Renz level in upper black shale levels of the Fucoidi Formation in Italy. The slight shift between the zones can be attributed to local diachronism in the event or as a biostratigraphic calibration problem. The position of the black shale in the global sequence stratigraphic chart can be seen in the transgressive system tracts.

The Albian black shales constitute a zone in the Mudurnu and Göynük sections characterized by an alternation of black shales and purple sandstones (Figures 8 & 15; Mudurnu section). They are overlain by red marls that precede the sequence boundary represented by conglomerates. Thus, as stated earlier this zone can be interpreted to fit early transgressive systems tracts.

The black shales/mudstones in the Late Cenomanian or around the Cenomanian/Turonian boundary (Figures 12, 14 & 16; İsmailler section) are observed as a zone that includes alternation of thinner bioturbated limestones/marls with thicker black shales/mudstones. This zone is overlain by a limestone-dominated interval with thinner black shale/mudstone intercalations. Changes in thickness of cycles along the sections, as well as changes in the position of carbonate or shale-dominated intervals are used to set up sequence boundaries/correlative conformities and system tracts in this type of pelagic setting. Within the sequence stratigraphic framework, this relationship with bioturbated limestones and cyclic alternations further indicate that the black shale/mudstone interval took place within the early transgressive system tracts.

When the determined positions of sequence boundaries and system tracts are correlated with the global sequence stratigraphy chart of De Graciansky *et al.* (1998), they fall within the same biozones, and the number of sequences and the position of black shale intervals conform to the same numbers of transgressive intervals in the global chart (Figures 3 & 17). Two sequence boundaries have been determined in the *B. breggiensis* zone in the Mudurnu section. The positions of these sequence boundaries and positions of red bed interval and black shale/mudstone intervals in this section can be correlated with the ones in the global chart (Figures 3 & 21). However, due to poor exposures above and below the red bed and black shale intervals of the Soğukçam and the Samsaçavuş sections, these sequence boundaries are not determined in these sections. In the Early Aptian, the correlative conformities of sequence boundaries and the levels of black shale/mudstone of the Sünnetgölü, Mudurnu and Nallıhan sections lie in the same biozones of the global chart (Figures 3, 21 & 22).

As explained earlier in the sequence stratigraphic concept, Fischer plot curves (Sadler *et al.* 1993) were prepared for the Mudurnu and İsmailler sections by using cycle thickness change patterns along the section (Figures 18–20). The sequence boundaries based on change in position of carbonate and shale dominated intervals, and increase or decrease in thickness of carbonates and shales, correspond to the end of the falling limbs of the curves. Such correlation is indicative of decreased accommodation space, whereas black shales are generally observed in the rising limbs.

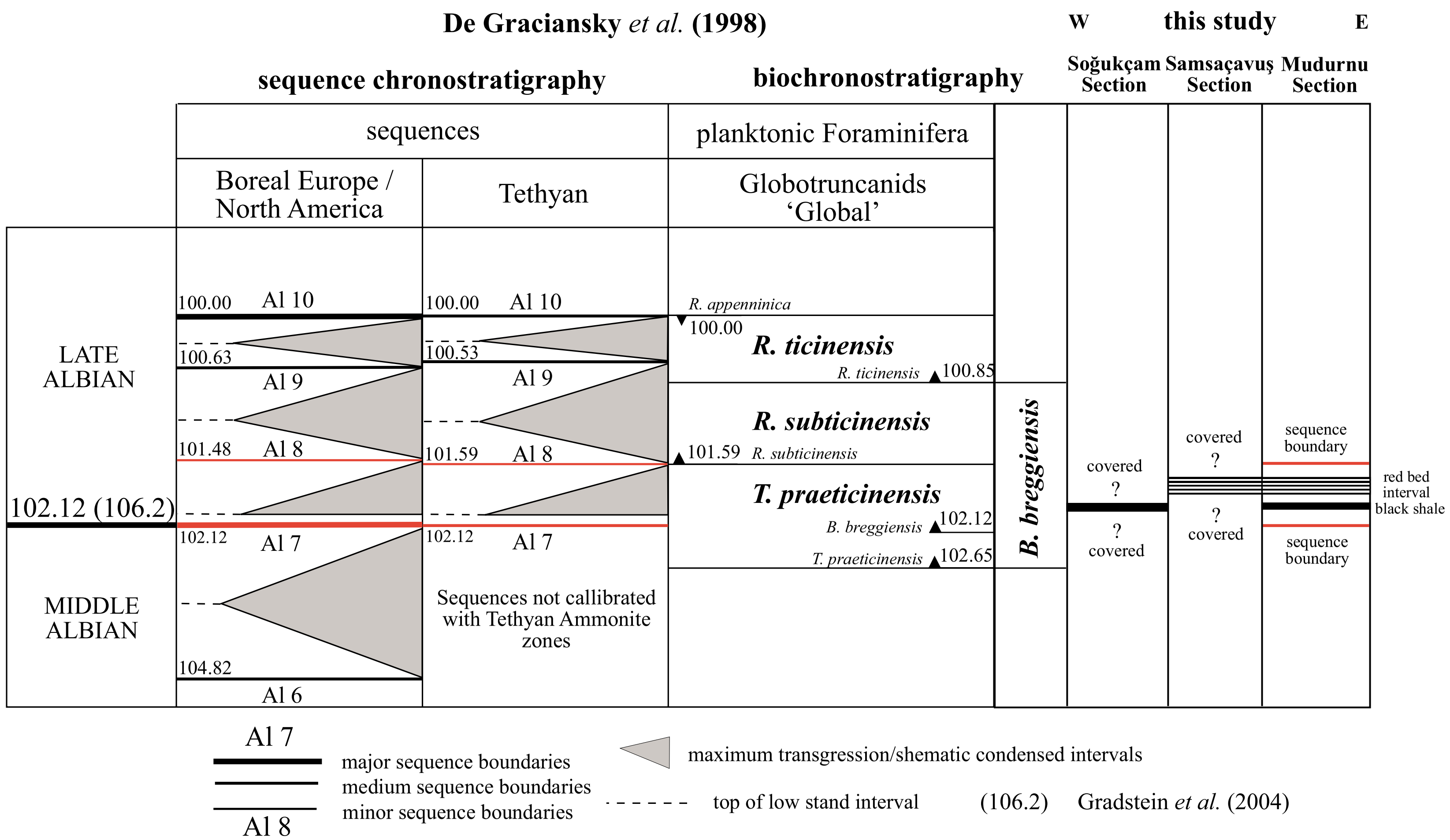

Figure 21. Correlation of sequence boundaries, and occurrences of black shales and red beds in the Mudurnu, Samsaçavuş and Soğukçam sections, with sequence boundaries and system tracts with global charts (De Graciansky *et al.* 1998). The age assigned in the brackets is from Gradstein *et al.* (2004).

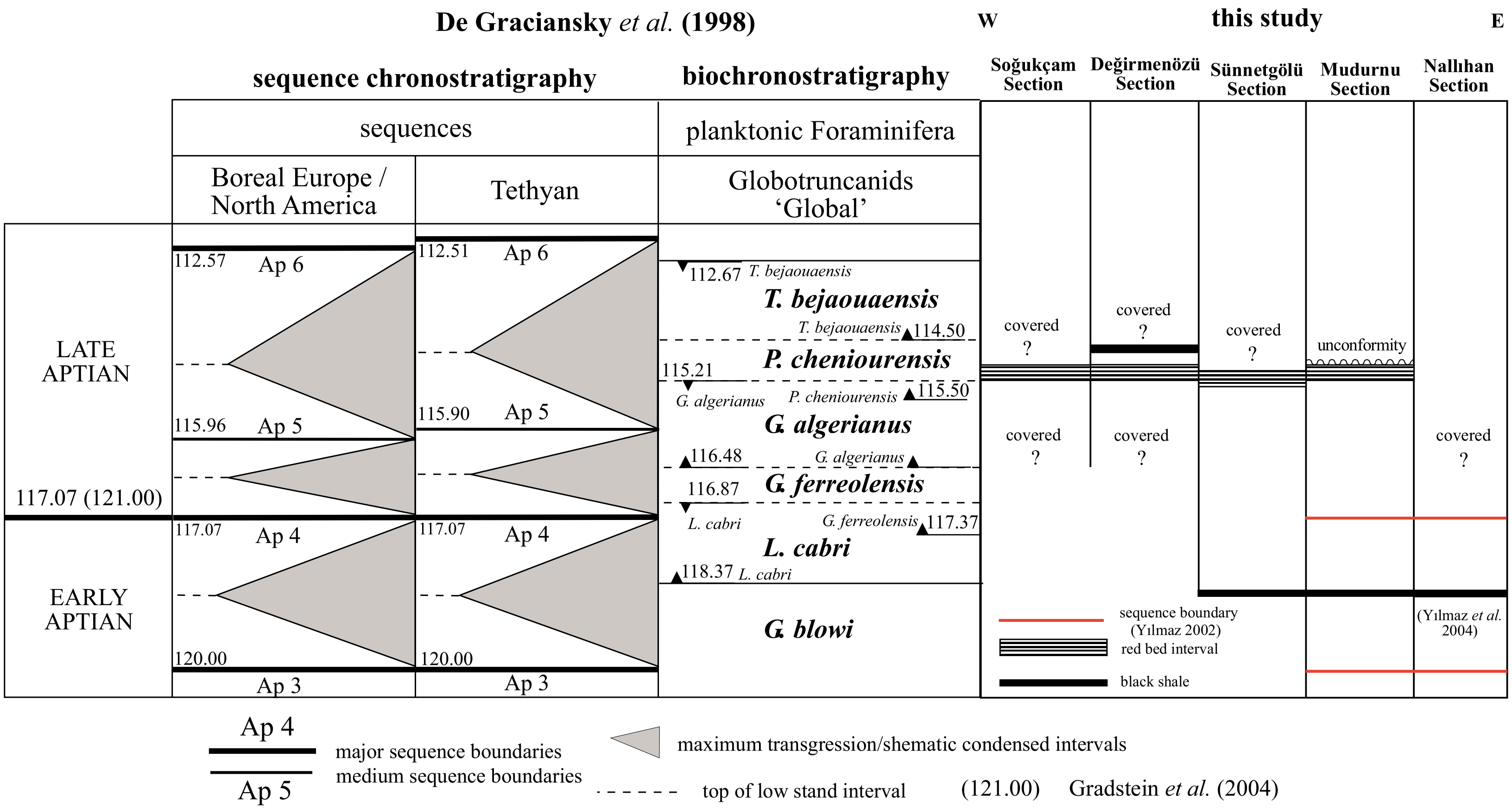

Figure 22. Correlation of sequence boundaries, and occurrences of black shales and red beds in the Soğukçam, Değirmenözü, Sünnetgölü, Mudurnu, and Nallıhan sections, with sequence boundaries and system tracts with global charts (De Graciansky *et al.* 1998). The age assigned in the brackets is from Gradstein *et al.* (2004).

As stated before, low-stand system tracts are not clearly defined in the measured sections. This discrepancy may be related to lack of exposure of geometrical relationship of the beds in the study areas, as well as predominance of pelagic successions of the drowned margin.

Evidence for Global Anoxic and Oxic Events

The presence of black shales within pelagic/hemipelagic successions within nearly the same biostratigraphic zones, indicates that anoxic or dysoxic conditions developed on the Sakarya Continent.

The Aptian 'Selli' OAE 1a event is recorded within the pelagic carbonates of the Nallıhan, Mudurnu and Göynük areas, or from east to west of the Sakarya Continent over with a distance of nearly 100 km. The 'Selli' event is represented by silty, parallel laminated, and locally by finely bioturbated, black shales with sparse fauna, pyritized radiolaria and foraminifera. The presence of a black shale interval within the pelagic limestone successions indicates a time interval with sudden change in sedimentation and depositional pattern at the site of the Sakarya Continental block characterized by a drop in carbonate production and increasing preservation of organic matter. Yılmaz *et al.* (2004a) showed that the C stable isotope curve of the black shale interval in the Nallıhan section corresponds with the global C curve within the same biostratigraphic interval that includes global anoxic events such as those found in Italy (Umbria-Marche Basin; Erba 2004), in the Mediterranean Tethys, the North Atlantic, the Central Pacific, and some areas in Europe (Reyment & Bengtson1985).

Succeeding the black shales, carbonate sedimentation prevailed in the Upper Aptian, and the presence of red-pink coloured pelagic limestones/marls with abundant planktonic foraminifera, iron minerals, gastropoda, echinoidea and bivalves may indicate an increase in nutrient and oxygenation in the water column. This may be due to the change in circulation in relation to tectonic movements, or sea level change, or both, that took place in this part of the continent. The switch from Lower Aptian 'Selli' anoxic conditions to Upper Aptian oxidized pelagic successions may also be associated with large-scale global oceanographic changes. A similar red marl/limestone interval is recorded in Italy (Hu *et al.* 2005b).

In the Upper Albian series, silty black shales appear within the purple sandstones in the Mudurnu section. The presence of fine parallel laminae, very rare fauna, pyritized radiolaria, foraminifera, some plant fragments, and the absence of bioturbation are indicative of anoxic/dysoxic condition (OAE 1c) in this part of the basin. This shale interval is placed within the *B. breggiensis* chronozone. An Upper Albian black shale interval is also reported in many parts of the world such as Italy in Europe (Reyment & Bengtson 1985; Erba 2004).

The red-purple silty marls/mudstones overlying the Upper Albian black shales are also in the same biozone in the Mudurnu section, they include phosphatic clasts, iron and some glauconite minerals. They display fine parallel laminae and are partially bioturbated. Identical marls/mudstones are recorded west of the Mudurnu area at a distance of 25 km away from the previous section. This marl/mudstone interval is interpreted as the record of another oxidizing condition that took place following this anoxic event in the basin. As implied before, a sudden change in the circulation pattern, sea level and nutrient availability in the basin may have resulted in such a facies relationship. An Upper Albian red marl/mudstone interval is also recorded in Italy (Hu *et al.* 2005b).

In the Late Cenomanian and around the Cenomanian/Turonian boundary distinct black shales occur within the *R. cushmani* zone. The presence of silty, finely laminated, black shales with sparse fauna and pyrite minerals punctuates the anoxic conditions during this time interval in this part of the continent. This event is coeval with the black shale interval (OAE 2) that has been reported from several locations worldwide (Coccioni & Galeotti 2003; Coccioni *et al.* 2006), and especially in Italy, in the Umbra-Marche basin that is the type section for the Bonarelli level (Erba 2004).

The black shale interval is succeeded in the Early Turonian by white pelagic carbonate, which is in turn overlain by red-purple marls/mudstones. The presence of abundant planktonic foraminifera and iron minerals within these marls/mudstones indicates that sedimentation took place under oxidizing conditions. Sudden change in facies, increase in the abundance of planktonic foraminifera and iron minerals are interpreted as related to the sudden change in circulation pattern, sea level or nutrient availability in the basin. The same type of red marl/mudstone interval is also recorded in Italy (Rawson *et al.* 1996).

The presence of unaltered silt or fine sand-sized feldspar and quartz minerals in the Aptian, Albian and Cenomanian black shales of the areas studied may provide further evidence of a relationship between anoxic event and global volcanic eruptions (Erba 2004; Wignall 2005), as well as the effects of erosion and transportation in relation to regional tectonic movements.

Conclusions and Interpretations

This study presents the analytical results based on sedimentology and stratigraphy of pelagic successions of the Mudurnu Trough that includes black shales and red beds ranging from Early Aptian to Late Santonian. Field and laboratory analyses of facies indicate that black shales and red beds reveal respective anoxic and oxic conditions. Their occurrences in the Mudurnu Trough of the Sakarya Continent (Figure 3) are synchronously recorded with their global counterparts. The black shales recorded in the Early Aptian are the equivalent of OAE 1a 'Selli' level. The one in the Late Aptian is recorded only at one locality in this study, and is interpreted as the Upper Aptian Oceanic Anoxic Event reported by Coccioni *et al.* (2006) as the Thalmann level in the Calera Limestone of the Franciscan Complex of Northern California; as the Niveau Fallot 3 level of the Vocontian Basin and Mazagon Plateau (DSDP site 545); or as the Renz level in upper black shale levels of the Fucoidi Formation in Italy. The black shales recorded in the Late Albian are interpreted to correspond to OAE 1c. The black shale levels recorded at the Cenomanian/Turonian boundary are the equivalent of OAE2 'Bonarelli' level. All black shale intervals are interpreted as the record of early transgressive system tracts within the sequence stratigraphic framework (Figures 17–22). The red beds recorded in the Late Albian that succeeded the black shales are interpreted as the record of oxic conditions switched on after the anoxic conditions. However, Lower Aptian red beds are coeval with the Lower Aptian black shale at one location in Turkey. These red beds are interpreted to be related to local tectonic movements in the basin that created horst and graben-like structures controlling the deposition of reddish beds on elevated structures within the basin, whereas black shales accumulated in the subsided and restricted areas in between. The position of the Upper Albian red beds within the sequence stratigraphic framework is interpreted as the record of late transgressive systems tracts. However, in the Late Aptian and Late Santonian, the red beds are associated with Type-3 sequence boundary. The Upper Santonian red beds transgressively overlie the boundary, however the ones in the Upper Aptian are below the boundary and represent late high-stand or still-stand conditions followed by sudden drowning. The Upper Aptian black shales were deposited in the nearby trough areas surrounding the red beds. The effect of tectonism is reflected in the deposition of these different facies within short distances in the basin. A Fischer plot curve (Sadler *et al.* 1993) obtained from the cyclostratigraphic analysis of the upper part of the Soğukçam Limestone and overlying Üzümlü Member displays third-order relative sea level changes. In this curve, it is possible to see relative fall of sea level followed by sudden rise just over the Aptian red beds of the Soğukçam Limestone at the bottom of the Üzümlü Member. This independent method also reveals red beds associated with the rise of sea level, and the drowning at the bottom of the Üzümlü Member that follows the sudden rise (Figure 20). Background tectonic effects can also be inferred as long relative fall with gentle slope in the upper part of the Soğukçam Limestone. The positions of the Aptian, Albian and Cenomanian red beds and black shales within the Fischer plots can also be determined, although the curve includes tectonic effects. Development of Type-3 sequence boundary at the bottom of the Üzümlü Member recorded as drowning event can be clearly seen in the Fischer plot curve as associated with sudden development of a pelagic marine turbiditic basin over the pelagic carbonate succession (Soğukçam Limestone) in the Mudurnu region (Figure 20). The iron content and red colouring of the red beds are probably related to volcanic or terrestrial source and could have been modified by burial diagenesis. Hydrothermal source for colouring could also be possible, but other hydrothermal minerals, structures and alteration zones are not recorded in association with the red beds.

Moreover, consistent positioning of red beds at certain levels is more compatible with sediment dynamics and sea level changes and not related to hydrothermal events. Further corroborative evidence is given by the fact that the red bed levels observed occur in the same biochronozones as red beds in other parts of the world.

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APPENDIX

Symbols used in the detailed measured sections