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ORIGINAL PAPER

Carbonate sedimentation in an extensional active margin: Cretaceous history of the Haymana region, Pontides

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Abstract The Haymana region in Central Anatolia is located in the southern part of the Pontides close to the İzmir–Ankara suture. During the Cretaceous, the region formed part of the south-facing active margin of the Eurasia. The area preserves a nearly complete record of the Cretaceous system. Shallow marine carbonates of earliest Cretaceous age are overlain by a 700-m-thick Cretaceous sequence, dominated by deep marine limestones. Three unconformity-bounded pelagic carbonate sequences of Berriasian, Albian–Cenomanian and Turonian–Santonian ages are recognized: Each depositional sequence is preceded by a period of tilting and submarine erosion during the Berriasian, early Albian and late Cenomanian, which corresponds to phases of local extension in the active continental margin. Carbonate breccias mark the base of the sequences and each carbonate sequence steps down on older units. The deep marine carbonate deposition ended in the late Santonian followed by tilting, erosion and folding during the Campanian. Deposition of thick siliciclastic turbidites started in the late Campanian and continued into the Tertiary. Unlike most forearc basins, the Haymana region was a site of deep marine carbonate deposition until the Campanian. This was because the Pontide arc was extensional and the volcanic detritus was trapped in the intra-arc basins and did not reach the forearc or the trench. The extensional nature of the arc is also shown by the opening of the Black Sea as a backarc basin in the Turonian–Santonian. The carbonate sedimentation in an active margin is characterized by synsedimentary vertical displacements, which results in submarine erosion, carbonate breccias and in the lateral discontinuity of the sequences, and differs from blanket like carbonate deposition in the passive margins.

Keywords Cretaceous · Stratigraphy · Foraminifera · Forearc · Carbonates · Pontides · Haymana

Introduction

Cretaceous was a time for major tectonic events in the Pontides including subduction, accretion, emplacement of ophiolitic mélange, development of magmatic arc and opening of the Black Sea as a backarc basin (e.g., Şengör and Yilmaz 1981; Okay and Nikishin 2015). The Tethyan ocean south of the Pontides became narrower throughout the Cretaceous and the inception of continental collision with the Anatolide–Tauride Block started at the end of the Maastrichtian (e.g., Meijers et al. 2010). Here, we provide precise and detailed geological and biostratigraphic data from a newly recognized Cretaceous section in the Haymana region in Central Anatolia and investigate the imprints of the tectonic events in the sedimentary sequence. The new data are used along with other precise regional stratigraphic information to constrain the Cretaceous evolution of the southern margin of the Pontides.

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During the Turonian to Campanian interval, the Haymana region was in a forearc position between the magmatic arc in the north and the trench in the south. Most modern and ancient forearc sequences are dominated by siliciclastic turbidites derived from the magmatic arc (e.g., Dickinson 1995; Noda 2016). In contrast, the Turonian–Santonian sequence of the Haymana region consists mainly of deep marine carbonates and constitutes a rare case of carbonate deposition in a forearc setting.

Cretaceous stratigraphic and tectonic framework of the Pontides

The Pontides and the Anatolide–Tauride Block constitute the two major terranes of Turkey separated by the İzmir–Ankara suture. At the beginning of the Cretaceous, the Pontides were covered by a shallow marine carbonate platform, which in the Eastern Pontides passed south to a continental margin with pelagic carbonate and calciturbidite deposition. The Upper Jurassic–Lower Cretaceous carbonates constitute the most distinctive, laterally traceable marker horizon in the Pontides. The next sequence, which is observed throughout the inner Pontides, is the Campanian–Maastrichtian siliciclastic rocks, represented mainly by turbidites. The units between these two pan-Pontic series are poorly developed and show major lateral variations in facies (Fig. 2).

In the Central Pontides, the Upper Jurassic–Lower Cretaceous limestones are unconformably overlain by the mid-Cretaceous (Barremian–Aptian) siliciclastic turbidites, over 2000 m in thickness (Fig. 2, Tüysüz 1999; Hippolyte et al. 2010). The distal parts of this mid-Cretaceous turbidite fan were entrained in the trench and underwent low-grade metamorphism, which is dated as Albian (112–103 Ma, Okay et al. 2013). During the Albian, there was also accretion of a major oceanic subduction complex to the southern part of the Central Pontides; this Central Pontide Supercomplex includes eclogites and blueschist with Albian (112–100 Ma) metamorphic ages (Fig. 1, Okay et al. 2013). Although there is evidence for subduction during the Albian, the only sign of magmatism in the Pontides is a thin local sequence of Albian volcanogenic sandstones. In contrast to the Central Pontides, mid-Cretaceous (Barremian to Cenomanian) deposits are generally not recognized in the Eastern Pontides, and in the Western Pontides, Albian to Cenomanian sequences are rarely present, thin and laterally discontinuous (Fig. 2). During the Cenomanian–Turonian, oceanic accretionary complexes were emplaced north over the Pontide margin; these are now represented by ophiolitic mélange (Okay and Şahintürk 1997).

The mid-Cretaceous turbidite deposition, subduction–accretion and metamorphism were followed by widespread pelagic carbonate deposition during the Coniacian–Santonian. Red pelagic limestones of Coniacian–Santonian age crop out over wide regions in the Pontides and lie unconformably over the older units, locally stepping down to the Variscan basement (Tüysüz 1999). The Cretaceous arc volcanism in the Pontides started in the Turonian but became intense during the Santonian and middle Campanian (e.g., Kaygusuz et al. 2014; Aydin 2014; Özdamar 2016). The preserved volcanic products are all submarine and are represented predominantly by volcaniclastic rocks, which are intercalated with deep marine limestones (e.g., Eyuboglu 2015). During this time, the Pontides became separated from Eurasia with the opening of the Black Sea as a backarc basin (e.g., Okay and Nikishin 2015). Another major Late Cretaceous magmatic arc was the Kirşehir Massif (e.g., Lefebvre et al. 2013). However, its location with respect to the Pontides and the Anatolide–Tauride Block is not well constrained, and it is generally regarded as a separate plate. In the Pontides, the volcanism waned toward the end of Campanian, and the Maastrichtian is represented mainly by carbonates in the north and by thick siliciclastic turbidites in the south (e.g., Sari et al. 2014). The Pontides were uplifted at the end of the Paleocene due to collision with the Anatolide–Tauride Block.

Cretaceous system in the Haymana area

The Haymana region west of Ankara is located on the southern margin of Pontides 45 km northeast of the İzmir–Ankara suture (Fig. 1). The geology of the region is dominated by a late Campanian–Middle Eocene siliciclastic sequence, over 5 km in thickness, which constitutes the Haymana basin. The Haymana basin is interpreted as a forearc basin located above the northward-dipping Tethyan oceanic lithosphere (Görür et al. 1984, 1998; Koçyiğit 1991; Nairn et al. 2013). Pre-Campanian sequences are generally found in the core of anticlines, the largest being close to the town of Haymana (Yüksel 1970; Ünalan et al. 1976). We mapped the core of the Haymana anticline in detail, and studied paleontologically over 100 thin sections to establish the Cretaceous biostratigraphy and to understand its geological development.

The main structure in the Haymana region is an east–west trending tight anticline (Fig. 3), which formed after the Middle Eocene, when the Haymana basin was deformed and uplifted. Published geological maps and publications show Upper Jurassic–Lower Cretaceous shallow marine limestones in the core of the Haymana anticline (Ünalan et al. 1976; Turhan 2002; Rojay 2013; Nairn et al. 2013), which are unconformably overlain by the Campanian–Maastrichtian turbidites. Yüksel (1970) in his unpublished Ph.D. thesis describes pelagic Upper Cretaceous limestones below the turbidites. Our geological mapping and paleontological studies showed the presence of three

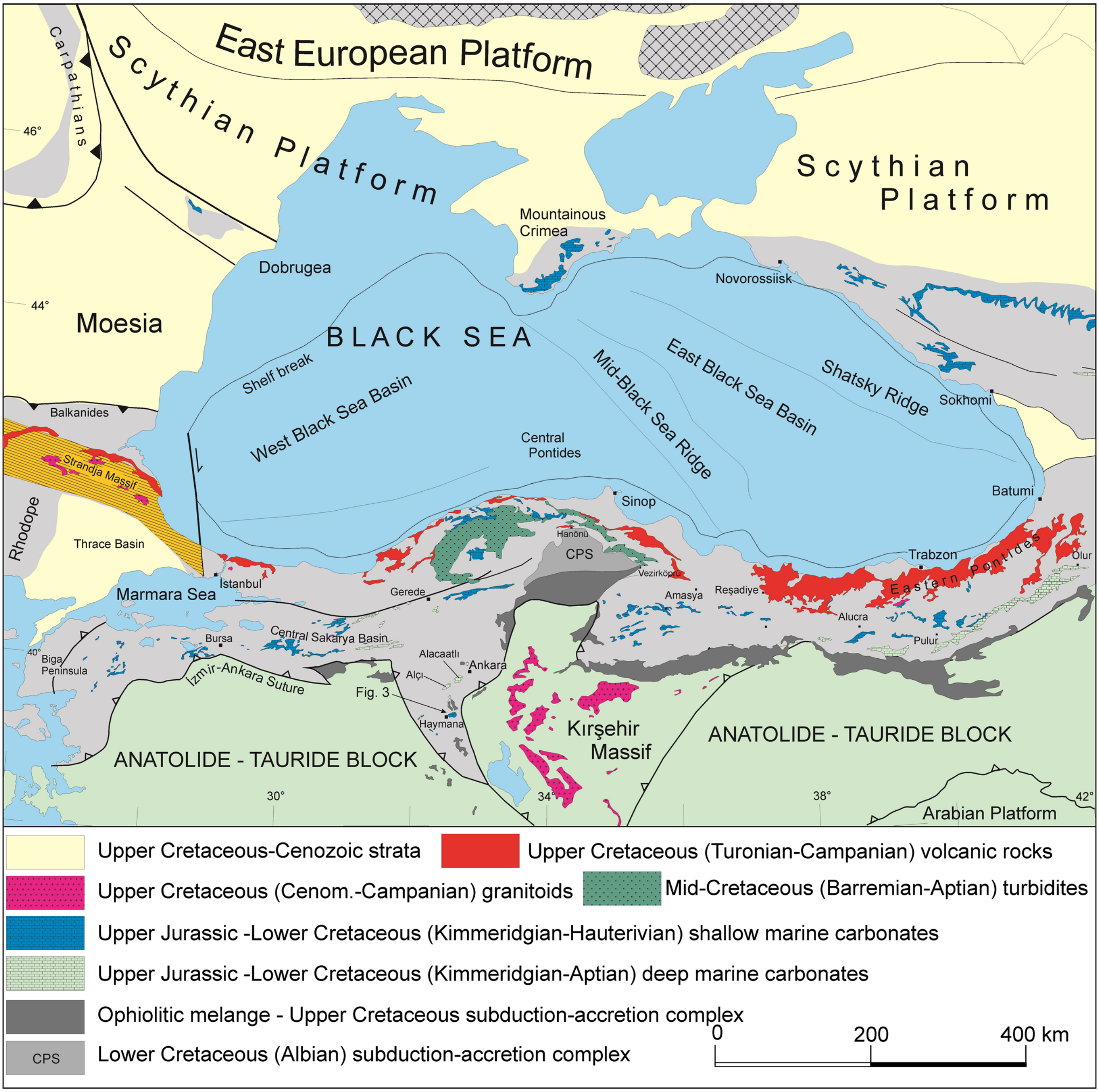


Fig. 1 Tectonic map of the circum-Black Sea region showing the distribution of some Upper Jurassic and Cretaceous sequences. *CPS* Central Pontide Supercomplex

unconformity-bounded Cretaceous deep marine carbonate sequences between the Upper Jurassic–Lower Cretaceous shallow marine carbonates and the Upper Cretaceous turbidites (Figs. 3, 4). The carbonate sequences range in age from Berriasian to Santonian and provide critical data on the geological evolution of the southern margin of the Pontides. Comparable Cretaceous sequences are only known from the Central Sakarya Basin more than 150 km northwest of Haymana (Fig. 1).

Upper Jurassic–Lower Cretaceous shallow marine carbonates: the Bilecik limestone

Massive, light gray shallow marine limestones constitute the core of the Haymana anticline (Fig. 3). The limestones contain lamellibranch, gastropod, coral fragments, algae and benthic foraminifera. The fauna in the limestone samples include *Protopeneroplis ultragranulata*, *Coskinoconus alpinus, Coskinoconus delphinensis*, *Mohlerina basiliensis*, *Charentia*

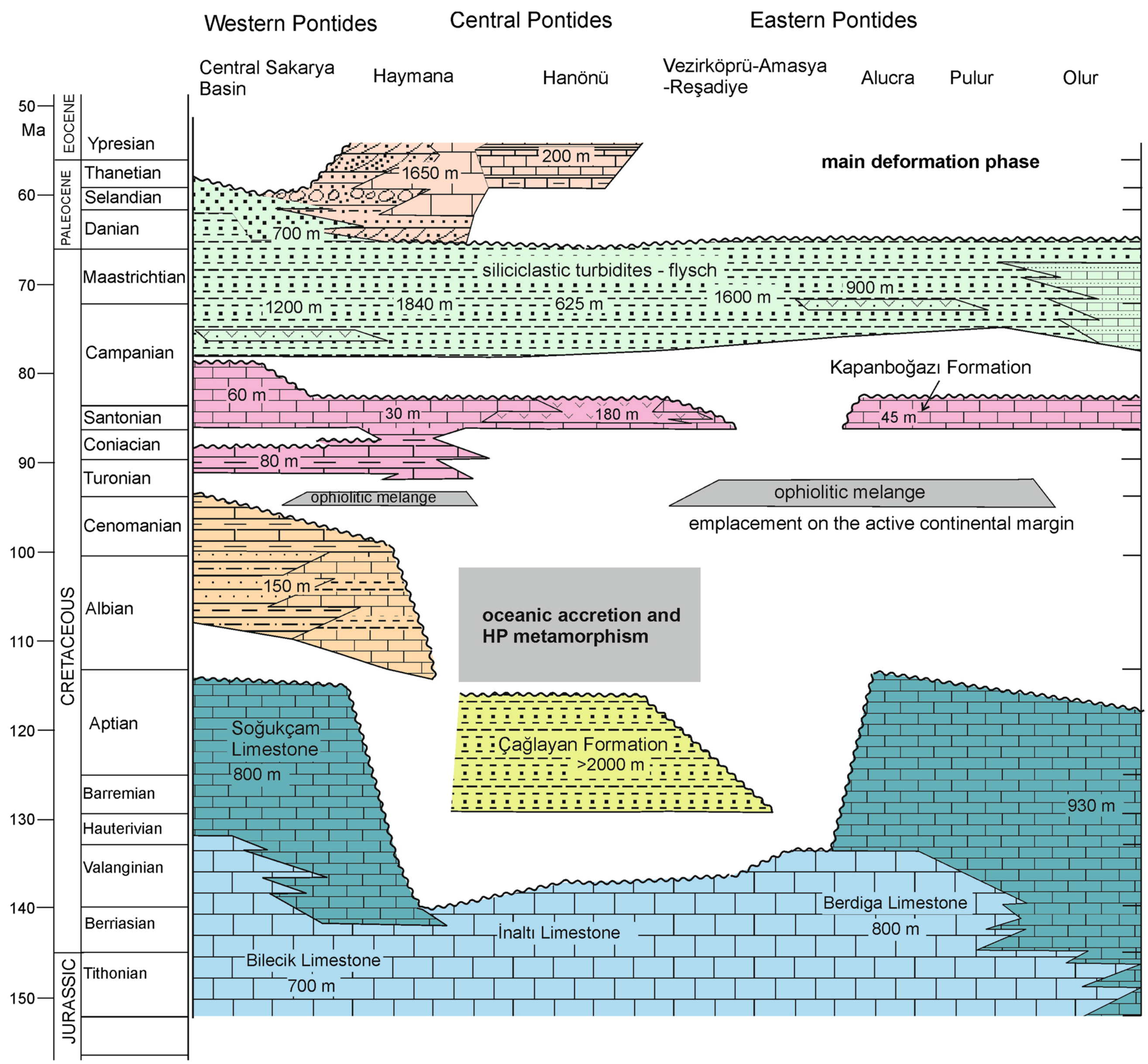


Fig. 2 Generalized west to east stratigraphic section of the Pontides. The section is along the southern part of the Pontides and omits the Late Cretaceous arc volcanism

sp. and *Crescentialla morronensis* indicate an uppermost Jurassic to lowermost Cretaceous (Tithonian–Berriasian) age range (Fig. 5, Table 1, *Protopeneroplis ultragranulata* Zone of Altiner 1991; Altiner and Özkan 1991). Carbonates of similar facies and ages are widespread throughout the Pontides and are known as the Bilecik Limestone in the Western Pontides (Altiner et al. 1991), as the Inalti Formation in the Central Pontides and as the Berdiga Limestone in the Eastern Pontides (Koch et al. 2008). We have to note here that the Bilecik Limestone has been used in the group rank in this study. Altiner et al. (1991) had previously divided the Bilecik Limestone into two distinct formations as the Taşcibayiri Formation (Callovian–Kimmeridgian) and the Günören Limestone (Kimmeridgian–Hauterivian) in the Western Pontides by raising the previously named Bilecik Limestone into the group rank. The Bilecik Limestone samples collected from the studied outcrops correspond to the Günören Limestone of Altiner et al. (1991).

Berriasian pelagic limestones and debris flows: the Soğukçam limestone

In the Haymana region, the Bilecik Limestone is overlain by Lower Cretaceous (Berriasian) pelagic limestones and

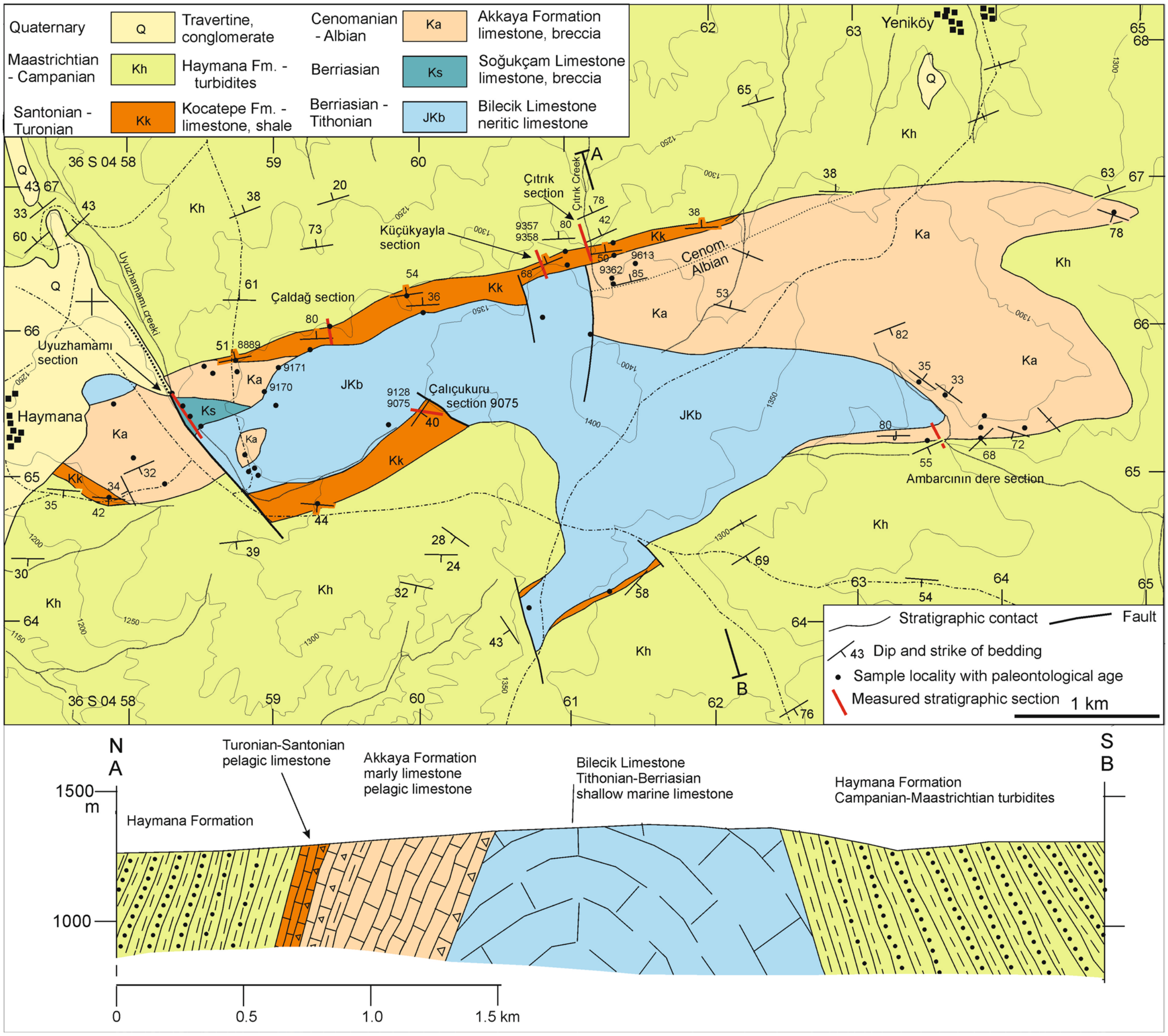


Fig. 3 Geological map and cross-section of the Haymana region. For location, see Fig. 1. The UTM coordinates are on European 1979 datum

breccias, which are preserved only in a small area east of the town of Haymana (Fig. 3). The Berriasian sequence, exposed along the Uyuzhamami creek, starts with a 10-m-thick breccia horizon, which lies directly on the massive shallow marine carbonates of the Bilecik Limestone (Figs. 6, 7). The breccia consists of angular to subrounded clasts of the Bilecik Limestone, 20–40 cm across, surrounded by a white micritic carbonate matrix. Several samples from the clasts gave a Berriasian shallow marine fauna of *Protopeneroplis ultragranulata*, *Quinqueloculina robusta*, *Everticyclammina*? sp., *Coskinoconus delphinensis*, *Coskinoconus cherchiae*, *Coskinoconus alpinus*, *Nautiloculina* sp., *Pseudocyclammina lituus*, *Mohlerina basiliensis*, *Earlandia*? *brevis* and *Crescentiella morronensis* (Fig. 5, Table 1). A similar Berriasian age is also obtained from the pelagic matrix of the breccia, which has *Calpionella alpina* and *Remaniella cadischiana*. The angular to subrounded nature of the clasts, the pelagic carbonate matrix of the breccias and the Berriasian age obtained both from the breccias and from the underlying shallow marine carbonates indicate that the breccias represent debris flows associated with the collapse of the shallow carbonate platform; the paleontological data indicate that the collapse occurred in the Berriasian.

The Berriasian breccias are overlain by a 100-m-thick sequence of thinly bedded, white radiolarian cherty micritic limestones, which contain late Berriasian foraminifera *Calpionellopsis simplex* and *Tintinopsella longa* (Fig. 8).

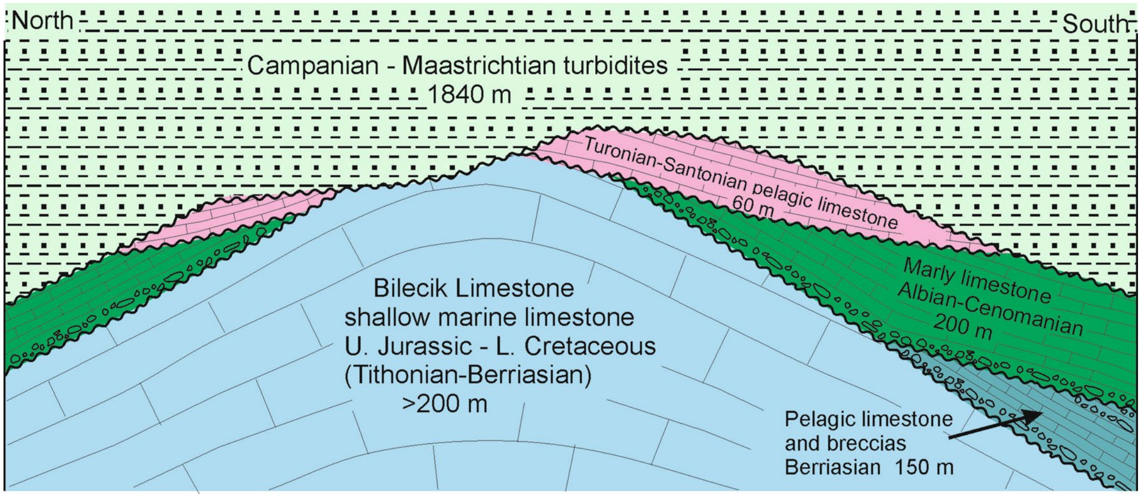


Fig. 4 Schematic north–south cross-section across the Haymana anticline showing the relation between Cretaceous lithostratigraphic units

The radiolarian limestones are in turn overlain by Albian breccias with clasts of Bilecik Limestone, which constitute the base of the overlying Akkaya Formation (Figs. 6, 7).

Lower Cretaceous pelagic limestones, called as the Soğukçam Limestone, are known from the Central Sakarya Basin in northwest Turkey, where they lie over the massive shallow marine carbonates of the Bilecik Limestone (Altinli 1976; Altiner et al. 1991). In the Central Sakarya Basin, the basal age of the Soğukçam Limestone is time-transgressive and ranges from late Tithonian in the east to Hauterivian in the west and its upper age is late Aptian (Altiner 1991; Altiner and Özkan 1991). The Berriasian sequence in the Haymana region can be correlated with the Soğukçam Limestone except for the presence of breccias.

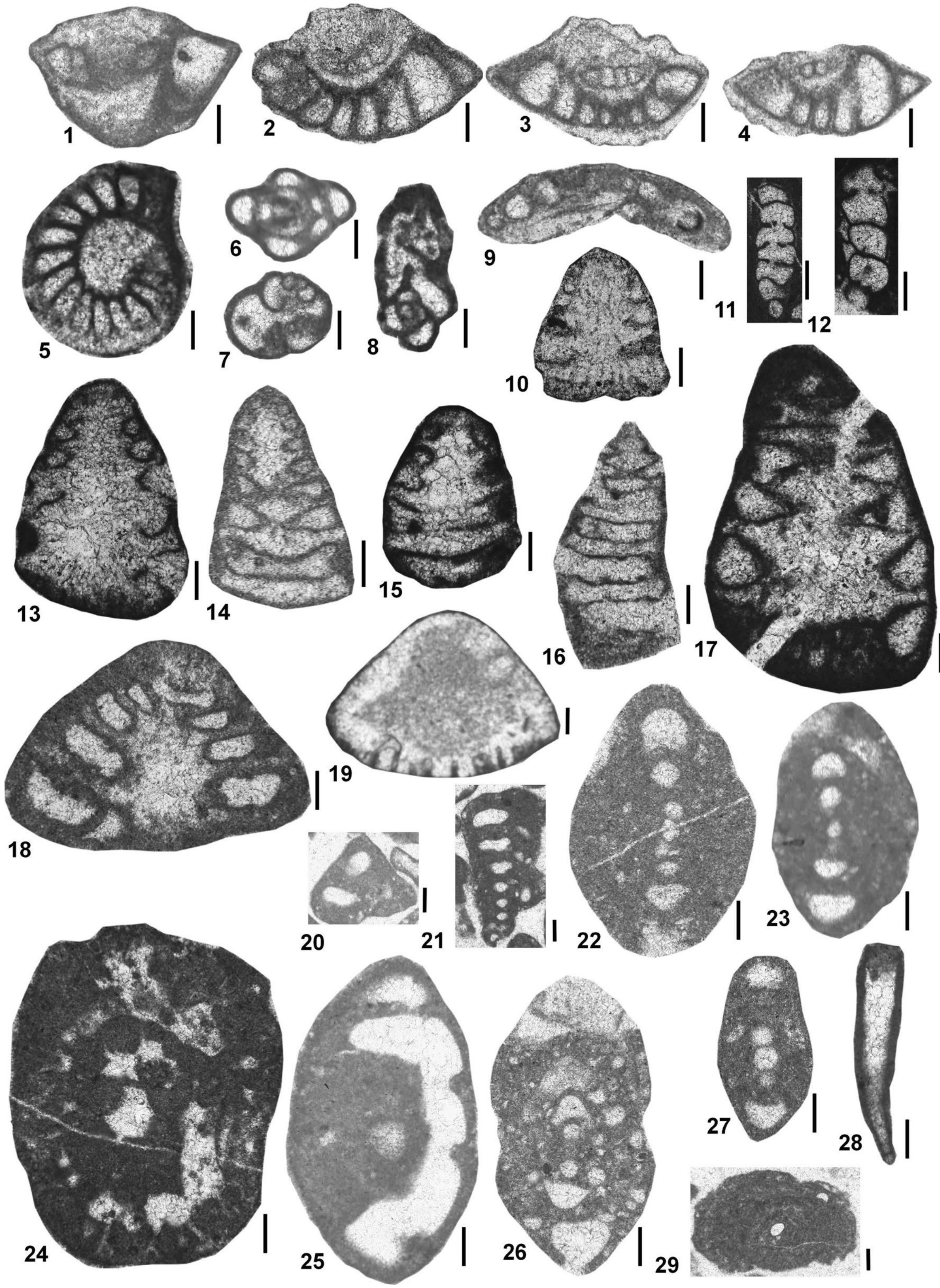
Albian–Cenomanian limestones and debris flows: the Akkaya formation

In the Haymana region, the Bilecik Limestone and the Soğukçam Limestone are unconformably overlain by a carbonate-rich sequence, 500 m thick, consisting mainly of glauconite-bearing marly limestone and radiolaria-bearing pelagic limestone with lesser amounts of breccia, calciturbidite and sandstone. The sequence is Albian to Cenomanian age and is called here as the Akkaya Formation. This interval was previously not known from the Haymana or from the Ankara region. The type section of the Akkaya Formation is along the Uyuzhamami Creek east of Haymana (Fig. 3).

Along the Uyuzhamami creek, east of the town of Haymana, the Akkaya Formation starts over the Berriasian radiolarian limestones with limestone breccias with clasts of Bilecik Limestone. The breccias layers contain *Ticinella roberti*, *Ticinella praeticinensis*, *Muricohedbergella rischi* and *Muricohedbergella delrioensis* in the matrix and indicate an Albian age. The breccias are followed by medium-bedded glauconite-bearing marly micrites, which contain middle Albian foraminifera *Ticinella roberti* and *Ticinella* spp. When traced eastward, the base of the Akkaya Formation steps down to the Bilecik Limestone, and the glauconite-bearing marly micrites with middle Albian foraminifera *Ticinella roberti*, *Ticinella* spp. and *Muricohedbergella* spp. (samples 9170, 9171) lie directly on the shallow marine carbonates of the Bilecik Limestone (Fig. 3). The rapid lateral truncation of the Soğukçam Limestone indicates tilting and erosion before the Albian.

The base of the Akkaya Formation is also observed in a quarry along the Ambarcinin creek, where a stratigraphic section was measured (Fig. 9). Along this section, massif carbonates of the Bilecik Limestone are overlain by a 30-m-thick breccia horizon representing submarine debris

Fig. 5 Foraminifera from the Bilecik Limestone and from the clasts ▶ of Bilecik Limestone in the overlying units from the Haymana area. *1–5 Protopeneroplis ultragranulata* Gorbatchik, *6* '*Quinqueloculina*' *robusta* Neagu, *7 Dobrogelina ovidi* Neagu, *8 Everticyclammina*? sp. *9 Mohlerina basiliensis* (Mohler), *10 Neotrocholina* sp., *11*, *12 Troglotella incrustans* Wernli and Fookes, *13–15 Coskinoconus delphinensis* (Arnaud-Vanneau, Boisseau and Darsac), *16 Coskinoconus cherchiae* (Arnaud-Vanneau, Boisseau and Darsac), *17 Coskinoconus campanellus* (Arnaud-Vanneau, Boisseau and Darsac), *18 Coskinoconus* sp., *19 Coskinoconus alpinus* Leupold, *20*, *21* Verneulinid foraminifera, *22*, *23 Nautiloculina* sp., *24 Pseudocyclammina lituus* (Yokoyama), *25*, *26 Melathrokerion* ? sp., *27 Nautiloculina* or *Charentia* sp., *28 Earlandia* ? *brevis* Arnaud-Vanneau, *29 Crescentiella morronensis* (Crescenti). Sample 9594—1, 7, 12 and 17; sample 9164—2; sample 9595C—3, 4, 13, 20 and 21; sample 9595B—5, 6, 8, 15, 19, 23, 25, 28 and 29; sample 9600—10; sample 9071A—11; sample 9071B—14, 22 and 27; sample 9595G—16; sample 9595D—18 and 26; sample 9595A—24. The *scale* is 200 µ. The sample numbers are shown on the geological map in Fig. 3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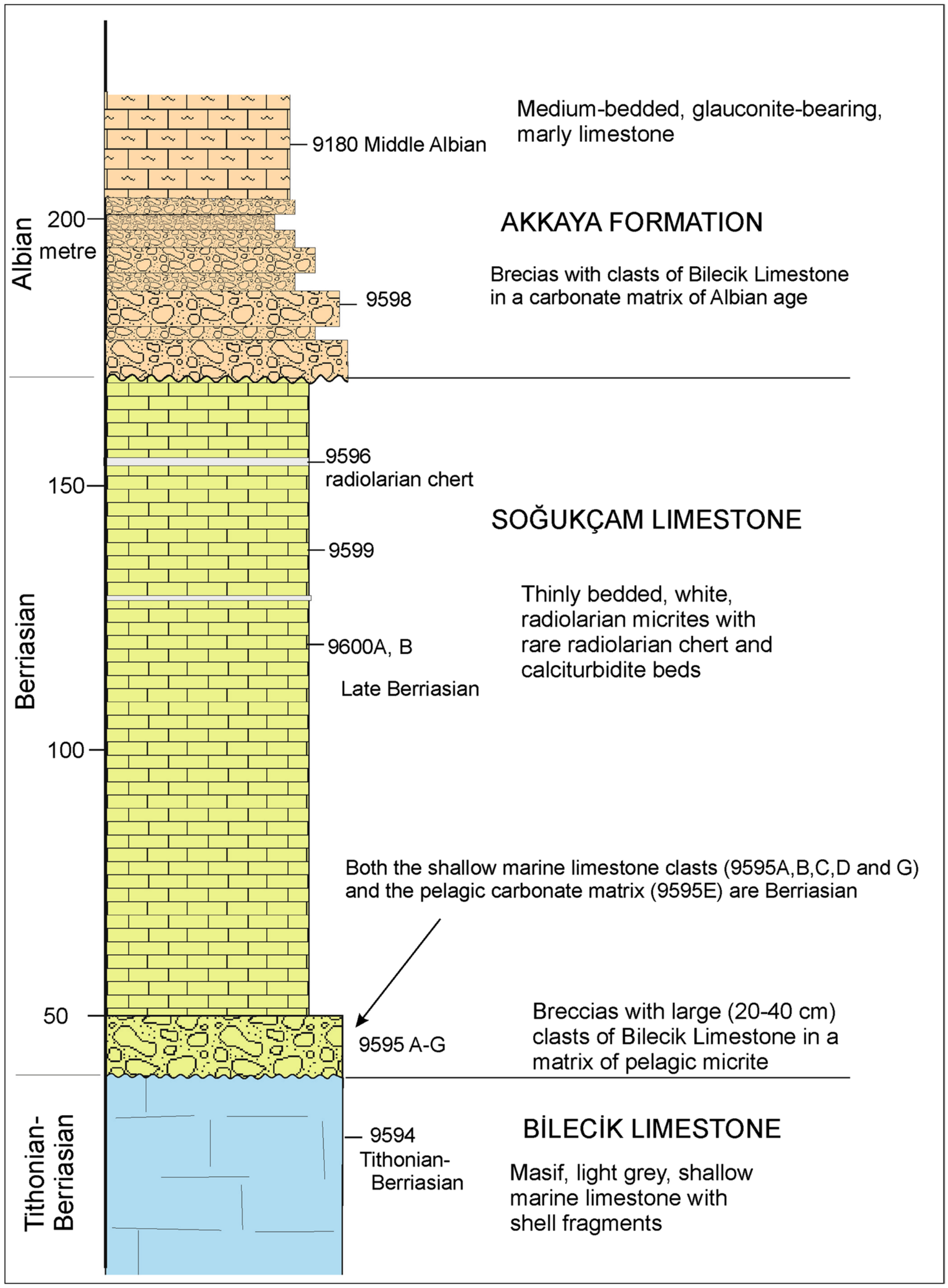


Fig. 6 Stratigraphic section of the Soğukçam Limestone at the Uyuzhamami creek east of the town of Haymana. For location, see Fig. 3. The UTM coordinates are on European 1979 datum

flows, which are equivalent to those in the Uyuzhamami section. The breccia beds, each a few meters thick, consist mainly of angular clasts of Soğukçam Limestone, up to 40 cm across, in a marly carbonate matrix (Fig. 9). The breccias change from clast-supported at the base to matrix-supported at the top, and the individual breccia beds are separated by thin, pink, greenish, laminated siltstones. In the upper parts of the section, the matrix of the breccia beds is made up of glauconite-bearing sandy limestone and contains an association of Albian foraminifera including *Loeblichella hessi*, *Muricohedbergella rischi* and *Ticinella* sp. (Fig. 8). The breccias are overlain by thinly bedded radiolarian limestones with intercalation of thin (2–5 cm) calciturbidites beds. The bulk of the Akkaya Formation is of Albian age based on foraminifera fauna from several spot samples: *Ticinella roberti*, *Ticinella* spp., Muricoh*edbergella planispira* and *Muricohedbergella* spp.

The upper parts of the Akkaya Formation crops out along the Çitrik creek (Fig. 3). Here, pelagic limestones are intercalated with thin- to medium-bedded fine-grained

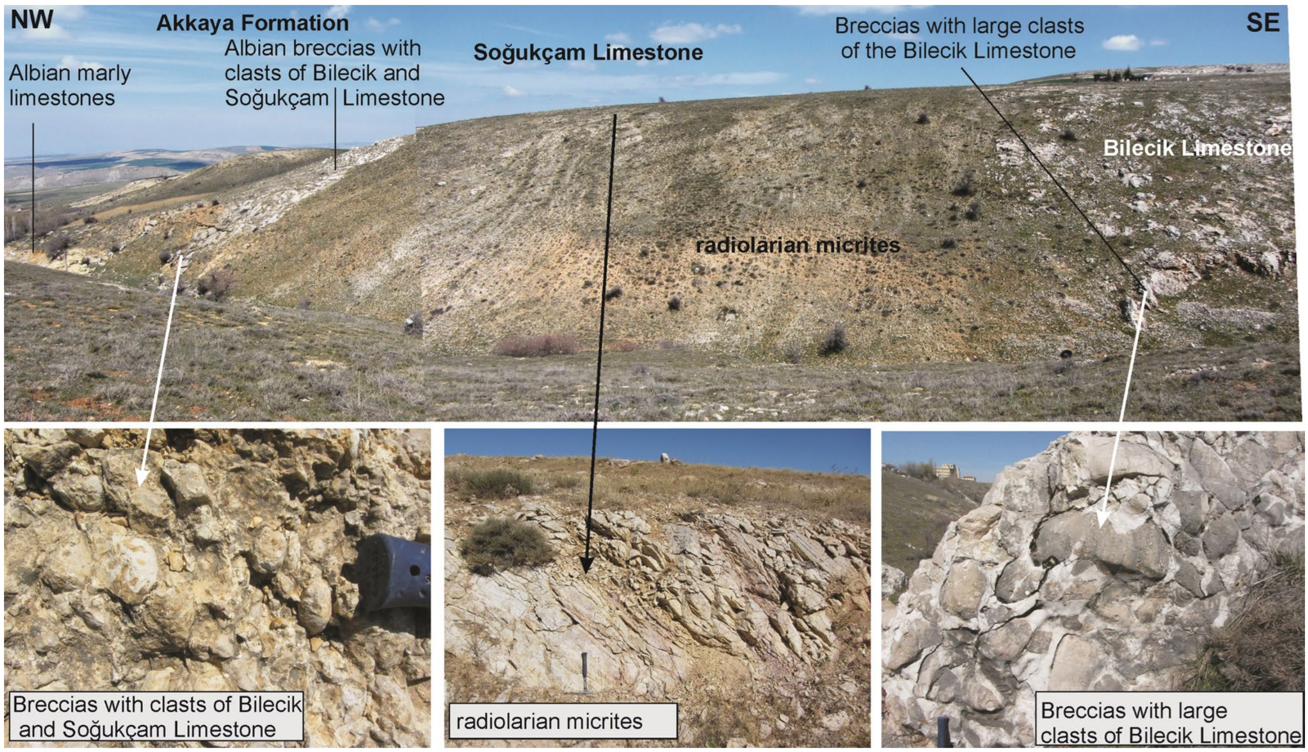


Fig. 7 Field photographs of the Soğukçam Limestone at the Uyuzhamami creek east of the town of Haymana. For location see Fig. 3

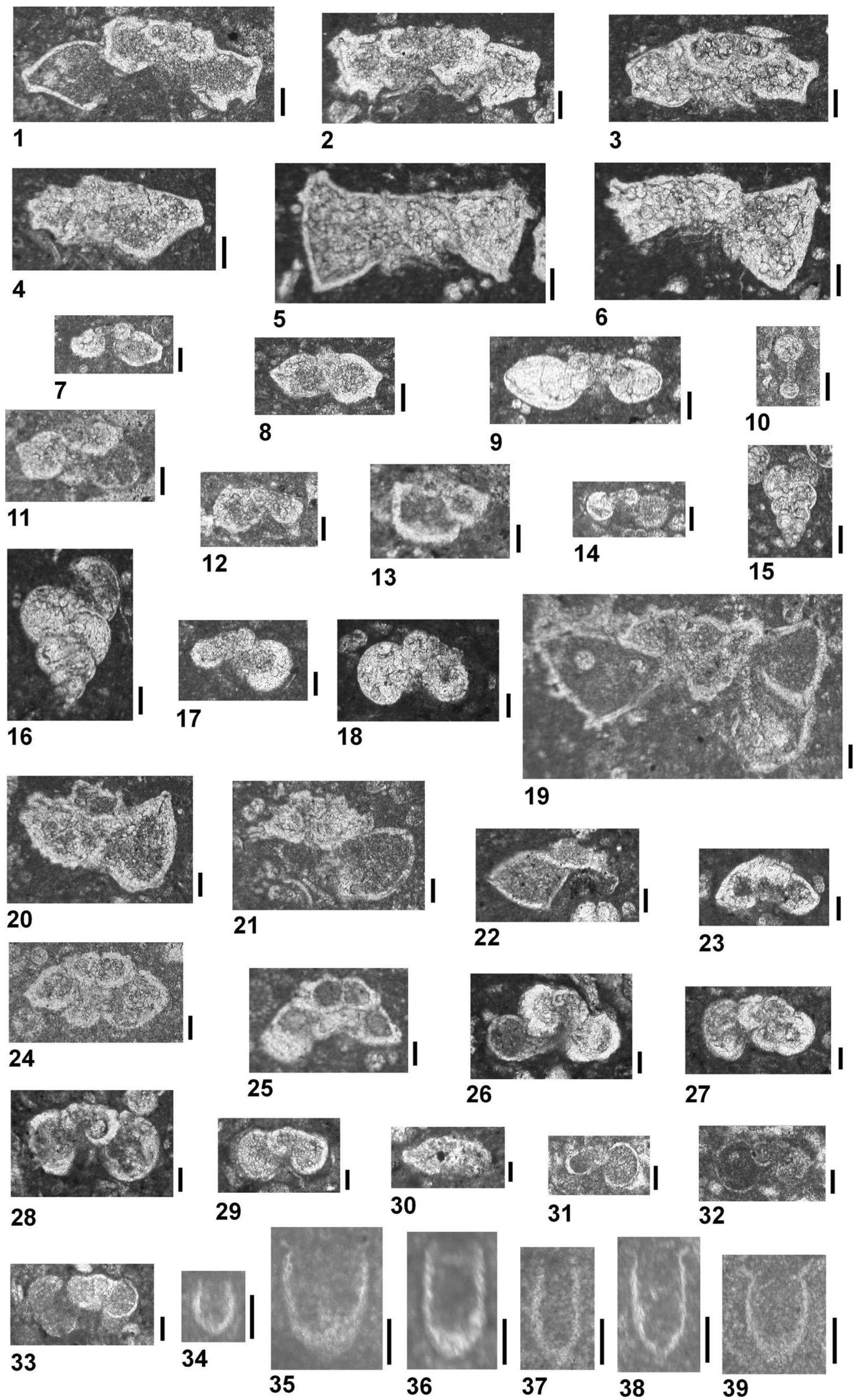
sandstones with carbonate and quartz grains. Samples from the pelagic limestones from this region (9362, 9613) contain a Cenomanian foraminifera fauna of *Whiteinella* sp., *Praeglobotruncana stephani*, *Praeglobotruncana gibba*, *Praeglobotruncana delrioensis*, *Rotalipora* cf. *cushmani* and *Rotalipora* spp. The Akkaya Formation is overlain by the Turonian–Santonian pelagic limestones or by the Campanian–Maastrichtian turbidites (Figs. 3, 4).

Turonian–Santonian pelagic limestones: the Kocatepe formation

Both the Akkaya Formation and the Bilecik Limestone are unconformably overlain by a pelagic Upper Cretaceous sequence of limestone and shale, 100 m in thickness, called the Kocatepe Formation (Yüksel 1970). The contact with the Bilecik Limestone is exposed at the Küçükyayla ridge about 8 km northeast of Haymana, where a section was measured (Fig. 10). The Küçükyayla section starts in the massive shallow marine carbonates of the Bilecik Limestone, which are overlain by a 5-m-thick breccia with clasts of Bilecik Limestone, 2–10 cm across, in a carbonate matrix. The limestone breccia is in turn overlain by a 54-m-thick sequence of thinly to medium-bedded pelagic limestone. The lower part of the pelagic section is made up of beige radiolarian micrites, which are overlain by red pelagic micrites with thin red shale intervals. The amount of shale increases up-section. The red limestones are overlain by thinly to medium-bedded sandstone and shale of the overlying Haymana Formation.

The lower 40 m of the Küçükyayla section, consisting of beige pelagic limestones, is of lower middle Turonian age as indicated by the foraminifera fauna including *Helvetoglobotruncana helvetica*, *Marginotruncana pseudolinneana*, *Marginotruncana marginata*, *Dicarinella* sp., *Heterohelix globulosa*, *Heterohelix moremani*, *Macroglobigerinelloides bollii* and *Whiteinella* sp. (samples 9356A, 9357). The red pelagic limestone samples (9358A, B) in the upper part of the carbonate sequence yielded foraminifera characteristic for Santonian: *Dicarinella asymetrica, Dicarinella* cf. *concavata, Muricohedbergella flandrini*, *Marginotruncana pseudolinneiana*, *Marginotruncana coronata*?, *Marginotruncana* sp., *Globotruncana bulloides, Heterohelix globulosa* and *Heterohelix moremani*.

The Küçükyayla section indicates an early Turonian transgression following the tilting and erosion of the Akkaya Formation and part of the Bilecik Limestone. Turonian pelagic limestones are also recorded above the Bilecik Limestone on the southern flank of the Haymana anticline in the Çaliçukuru section (Fig. 3). Here, massive Bilecik Limestone is overlain through a limestone breccia interval by medium-bedded, yellowish beige, light gray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◀ **Fig. 8** Foraminifera and calpionellid from the Soğukçam Limestone (Berriasian), Akkaya Formation (Albian–Cenomanian) and from the Turonian–Santonian pelagic limestones. *1 Marginotruncana renzi* (Gandolfi), *2*, *3 Marginotruncana pseudolinneiana* Pessagno, *4 Marginotruncana coronata* (Bolli), *5 Dicarinella asymetrica* (Sigal), *6 Dicarinella concavata* (Brotzen), *7 Dicarinella algeriana* (Caron), *8 Dicarinella* cf. *primitiva* (Dalbiez), *9 Muricohedbergella flandrini* (Porthault), *10 Macroglobigerinelloides ultramicrus* (Subbotina), *11 Marginotruncana marginata* (Reuss), *12*, *13 Helvetoglobotruncana helvetica* (Bolli), *14 Muricohedbergella planispira* (Tappan), *15 Heterohelix reussi* (Cushman), *16 Heterohelix globulosa* (Ehrenberg), *17 Whiteinella baltica* Douglas and Rankin, *18 Whiteinella* sp., *19–21 Rotalipora deecki* (Franke), *22 Rotalipora* cf. *cushmani* (Morrow), *23*, *24 Praeglobotruncana stephani* (Gandolfi), *25 Praeglobotruncana gibba* Klaus, *26–28 Ticinella roberti* (Gandolfi), *29 Ticinella praeticinensis* Sigal, *30 Pseudothalmanninella subticinensis* (Gandolfi)?, *32 Muricohedbergella rischi* (Moullade), *33 Loeblichella hessi* (Pessagno), *34 Calpionella alpina* Lorenz, *35 Remaniella cadischiana* (Colom), *36 Calpionellopsis simplex* (Colom), *37 Calpionellopsis oblonga* (Cadisch), *38 Tintinopsella longa* (Colom), *39 Tintinopsella carpathica* (Murgeanu and Filipescu). Sample 9612—1, 2 and 8 and 17; sample 9358B—3, 9 and 16; sample 9173E—4; sample 9358—5 and 15; sample 9173C—6; sample 9362—7 and 14; sample 9357—10 and 12; sample 9356A—11 and 13; sample 9613A—18; sample 9363—19–21 and 24–25; sample 9613C—22 and 23; sample 9604A—26–29 and 33; sample 9605—30; sample 9598—31 and 32; sample 9595E—34 and 35; sample 9600A—36; sample 9071B—37 and 39; sample 9600B—38. The *scale* is 50 µ. The sample numbers are shown on the geological map in Fig. 3

pelagic limestones, about 60-m thick. A sample from the base of the pelagic sequence (9075A) contains a planktonic foraminifera fauna not older than Albian: *Heterohelix moremani, Muricohedbergella planispira* and *Globigerinelloides* sp. A sample farther up (9075B) contains Turonian–Lower Santonian fauna of *Dicarinella* sp. *Marginotruncana pseudolinneiana*, *Marginotruncana renzi*, *Heterohelix* sp. and *Muricohedbergella planispira*. A sample from the top of the sequence has uppermost Turonian–Coniacian foraminifera of *Dicarinella primitiva, Marginotruncana pseudolinneiana, Marginotruncana coronata*, *Globigerinelloides* sp., *Heterohelix* sp. and *Muricohedbergella flandrini*.

The Coniacian stage, which was not sampled in the Küçükyayla section, is recognized in the Çaldağ section, about 1 km farther west (Fig. 3). The Çaldağ section consists of pelagic limestones, which rest on the Bilecik Limestone although the contact does not crop out. Most samples from the 32-m-thick measured section (9173A to H) contain a Coniacian (topmost Turonian–lowermost Santonian) fauna of *Dicarinella concavata, Dicarinella canaliculata, Marginotruncana pseudolinneiana, Marginotruncana coronata, Marginotruncana marginata*, *Heterohelix moremani, Macroglobigerinelloides bollii, Muricohedbergella planispira* and *Muricohedbergella flandrini*. Only the topmost sample (9173I) has a late Santonian fauna of *Dicarinella concavata*, *Dicarinella asymetrica*, *Marginotruncana pseudolinneiana, Globotruncana bulloides*, *Heterohelix globulosa* and *Muricohedbergella planispira*. The zone fossil of the late Santonian, *Dicarinella asymetrica*, was also found along with *Dicarinella concavata*, *Marginotruncana pseudolinneiana, Marginotruncana coronata, Globotruncana bulloides, Heterohelix globulosa, Heterohelix* sp. and *Muricohedbergella* sp. in the pink to white, thinly bedded marly pelagic limestones, which crop out on the Ankara–Haymana road 20 m below the Upper Campanian–Maastrichtian turbidites (samples 8889A, B, C).

Paleontological data from several sections indicate a condensed carbonate deposition from early Turonian to late Santonian for a period of about 10 million years. This period was characterized by intense submarine volcanism in the outer Pontides. The only evidence for this volcanism in the Haymana region is rare altered volcanic ash clasts in the limestone beds, which make up less than 2 % of the rock.

Campanian–Maastrichtian turbidites: the Haymana formation

The Kocatepe Formation is overlain by clastic rocks of Campanian–Maastrichtian age, called the Haymana Formation (Yüksel 1970; Ünalan et al. 1976). The contact is best exposed along the Çitrik creek, where Huseynov (2007) measured a 250-m-thick section. In the Çitrik section, the Haymana Formation starts with mudstones and shales with thin sandstone and siltstone beds, representing distal turbidites and basin deposits; these lie on the red pelagic limestones of the Kocatepe Formation (Fig. 11). A late Santonian foraminifera fauna is described from the limestones 2 m below the contact (Huseynov 2007). Upsection the sequence becomes more proximal with increase in the grain size and in the thickness of the sandstone beds. Foraminifera from the mudstones and shales give a broad Campanian age.

Previous studies regarded the contact between the Santonian limestone of the Kocatepe Formation and the overlying Campanian–Maastrichtian turbidites as conformable (e.g., Özcan and Özkan-Altiner 1997; Özkan-Altiner and Özcan 1999; Huseynov 2007). Although there is no angular unconformity between these two formations, geological mapping during this study has shown that the base of the Haymana Formation steps down from the Kocatepe Formation to the Akkaya Formation and the Bilecik Limestone (Fig. 3). Furthermore, several of the faults, which displace the pre-Campanian strata, do not extend into the Haymana Formation, indicating tilting and erosion during the early Campanian before the deposition of the clastic rocks. These faults have been largely inferred from the truncation of bedding in the Akkaya and Kocatepe Formations (Fig. 3); the faults are subvertical and most likely of strike-slip character. Evidence for subaerial exposure and shortening

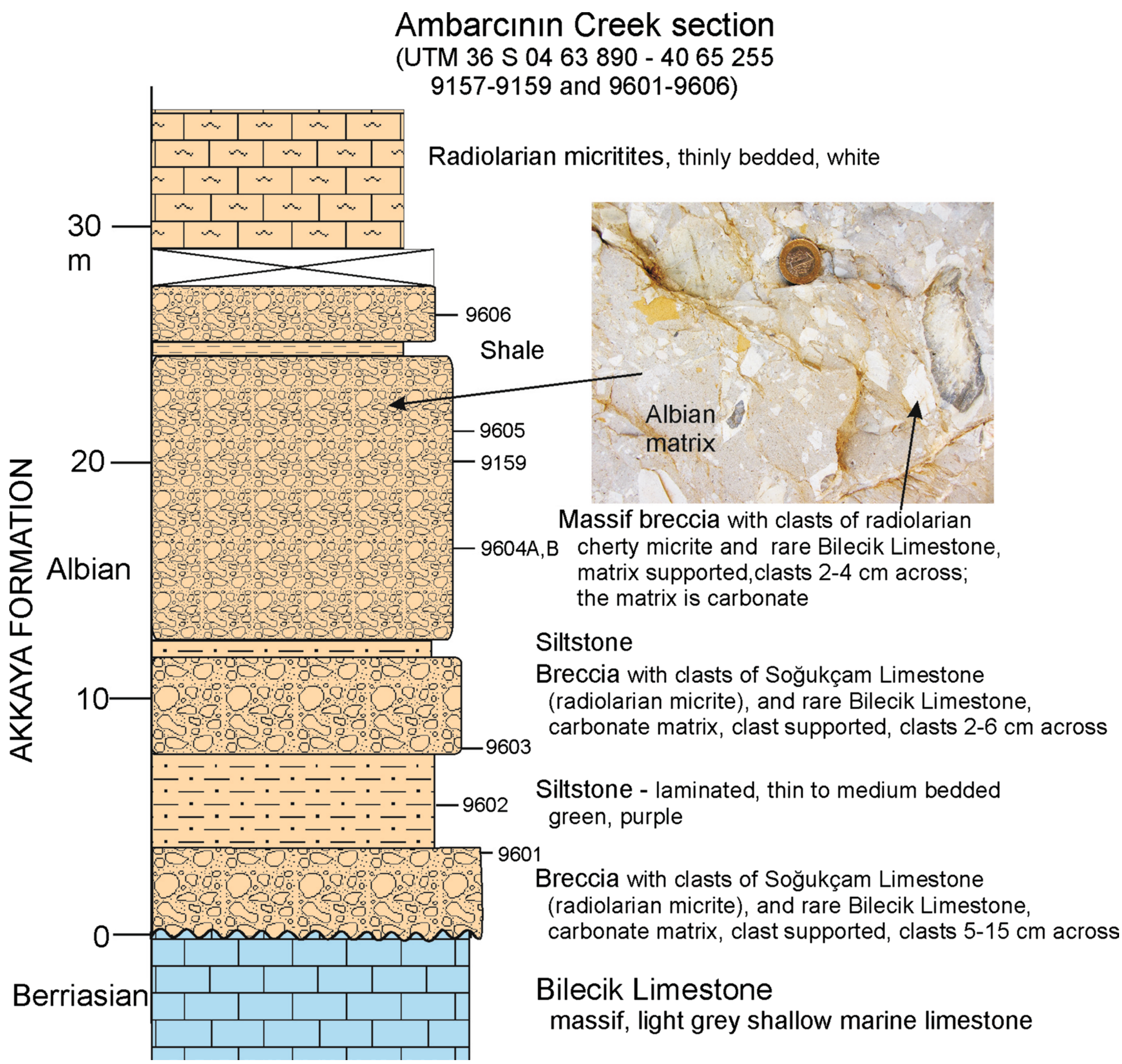

Fig. 9 Measured stratigraphic section at the base of the Akkaya Formation at the Ambarcinin creek. For the location of the section, see Fig. 3. The UTM coordinates are on European 1979 datum

during the Campanian are found in the Alçi area, 38 km north of Haymana (Fig. 1), where Maastrichtian continental red beds and shallow marine limestones lie with an angular unconformity over the folded Upper Cretaceous (Cenomanian–Turonian) strata (Koçyiğit 1991; Rojay and Süzen 1997; our own observations).

The Haymana Formation is 1800 m thick and consists of interbedded sandstone and siltstone with conglomerate lenses. It shows sedimentary structures typical of turbidites including graded bedding, sole structures, convolute and parallel lamination (e.g., Yüksel 1970; Ünalan et al. 1976; Nairn et al. 2013). It is dated as Late Campanian to Maastrichtian based on planktonic foraminifera and on transported benthic foraminifera (Toker 1979; Özcan and Özkan-Altiner 1997) and passes up into Paleocene and Eocene clastic rocks.

Cretaceous series in the Ankara region and in the Central Sakarya Basin

Here, we compare the Cretaceous sequence in the Haymana region with the sporadic and isolated Cretaceous outcrops in the Ankara region and with the more continuous sections in the Central Sakarya Basin in northwest Turkey (Fig. 12). In the Alacaatli area southwest of Ankara, the Tithonian to Valanginian interval is represented by white, thinly bedded, cherty radiolaria-bearing limestones with calciturbidite beds and carbonate breccia horizons (Batman et al. 1978; Bragin and Tekin 1999). In the Alçi area north of Haymana, Rojay and Süzen (1997) describe deep marine marly limestones of Cenomanian–Turonian age with carbonate olistoliths (Fig. 12).

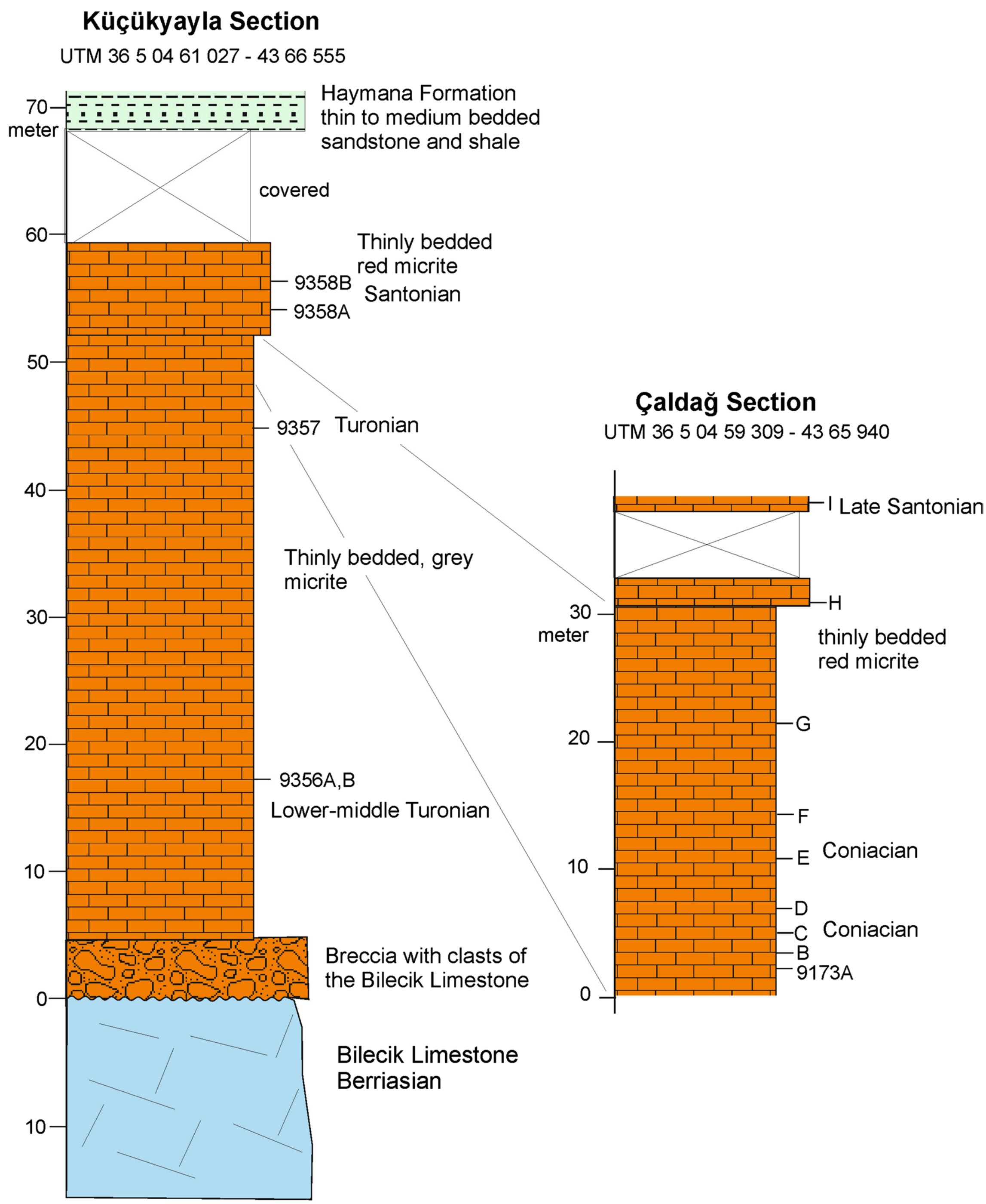

Fig. 10 Measured stratigraphic sections in the Turonian–Santonian pelagic limestones of the Kocatepe Formation on the northern flank of the Haymana anticline. For location of the sections, see Fig. 3. The UTM coordinates are on European 1979 datum

The Jurassic–Cretaceous stratigraphy is more complete and better studied in the Central Sakarya Basin in northwest Turkey (Fig. 1). Here, the collapse of the carbonate platform starts in the east during the Tithonian and progresses westward (Fig. 12, Altiner et al. 1991). In the late Valanginian, all of the Bilecik carbonate platforms have subsided and the deposition of thinly to medium-bedded porcelaneous limestones of the Soğukçam Formation continues from the Valanginian to the late Aptian (Altiner et al. 1991). The top of the Soğukçam Limestone in the Central Sakarya Basin is marked by a disconformity of early Albian age, which corresponds to the tilting and erosion observed in the Haymana region. The Albian sequence in the Central Sakarya Basin is represented by volcanogenic sandstone

Fig. 11 Photograph of the Çitrik creeks section showing transition from Turonian–Santonian pelagic limestones into shale and sandstone of the Campanian Haymana Formation

and shale, 20–50 m in thickness, which passes up into a Cenomanian–Turonian sequence of pelagic limestone, shale and minor sandstone (Yilmaz 2008; Yilmaz et al. 2010). A disconformity marks the base of Santonian, which consists of pink limestone with shale intervals, which pass without a break into the Campanian (Fig. 12). The Santonian–Campanian limestone–shale sequence is about 70 m thick and is sharply overlain by a very thick sequence (>1 km) of siliciclastic turbidites with pyroclastic and volcanic horizons, equivalent of the Haymana Formation.

Discussion

The Haymana region preserves a record of Cretaceous system extending from Berriasian to Maastrichtian. The interval from Berriasian to late Santonian is represented by deep marine carbonates and breccias and the Campanian–Maastrichtian interval by thick siliciclastic turbidites. Although there are gaps in the Cretaceous sequence, there is no evidence for pre-Campanian Cretaceous contractional deformation in the Haymana region.

The lowermost Cretaceous (Berriasian) shallow marine carbonates are ubiquitous in the Pontides (Fig. 1). Their presence in the Haymana region indicates that during the earliest Cretaceous, the region formed part of the Pontides and had a continental crust of normal thickness. The earliest tectonic event recorded in the Haymana region is the collapse of the carbonate platform in the Berriasian, which is tightly constrained from the age of the shallow marine carbonates and that of the pelagic matrix of the breccias. Latest Jurassic and earliest Cretaceous subsidence is widespread in the Pontides (e.g., Altiner et al. 1991). The transgressive and fining-upward character of the Early Cretaceous sequence suggest that the subsidence is related to regional extension. The extension resulted in isolated carbonate highs separated by basinal areas, which received carbonate breccias from the high-standing platforms (Fig. 13b). The Upper Jurassic–Lower Cretaceous sequences at around Ankara consist of pelagic micrites, calciturbidites and carbonate breccias and may represent one such basinal area, which surrounded coeval carbonate platforms such as that existed in the Haymana region during the Tithonian–Berriasian (Fig. 12, Bragin and Tekin 1999; Kuznetsova et al. 2003).

Data from the Central Sakarya Basin indicate that the carbonate platform was completely drowned by the late Valanginian and pelagic carbonate deposition continued from the Valanginian into the late Aptian (Fig. 13c, Altiner et al. 1991). A similar depositional pattern can be envisaged for the Haymana region. Although most of the sedimentary record is erased during the early Albian erosion, this inference is supported by the remnant outcrop pattern of the Soğukçam Limestone in the Haymana area (Fig. 3) and by the presence of Soğukçam Limestone clasts in the basal parts of the overlying Akkaya Formation (Fig. 9).

Early Albian erosion removed most of the Soğukçam Limestone in the Haymana region, and the Albian sequence rests generally on the Bilecik Limestone (Fig. 3). An early Albian hiatus is also recognized in the Central Sakarya Basin, where middle Albian sandstones lie over the late Aptian deep marine limestones (Yilmaz 2008). The early Albian uplift is probably related to coeval subduction–accretion, contractional deformation and metamorphism in the Central Pontides, where there are eclogites and blueschists dated 112–103 Ma (Okay et al. 2013). However, in the Haymana region and in the Central Sakarya Basin, there is no evidence for contractional deformation during

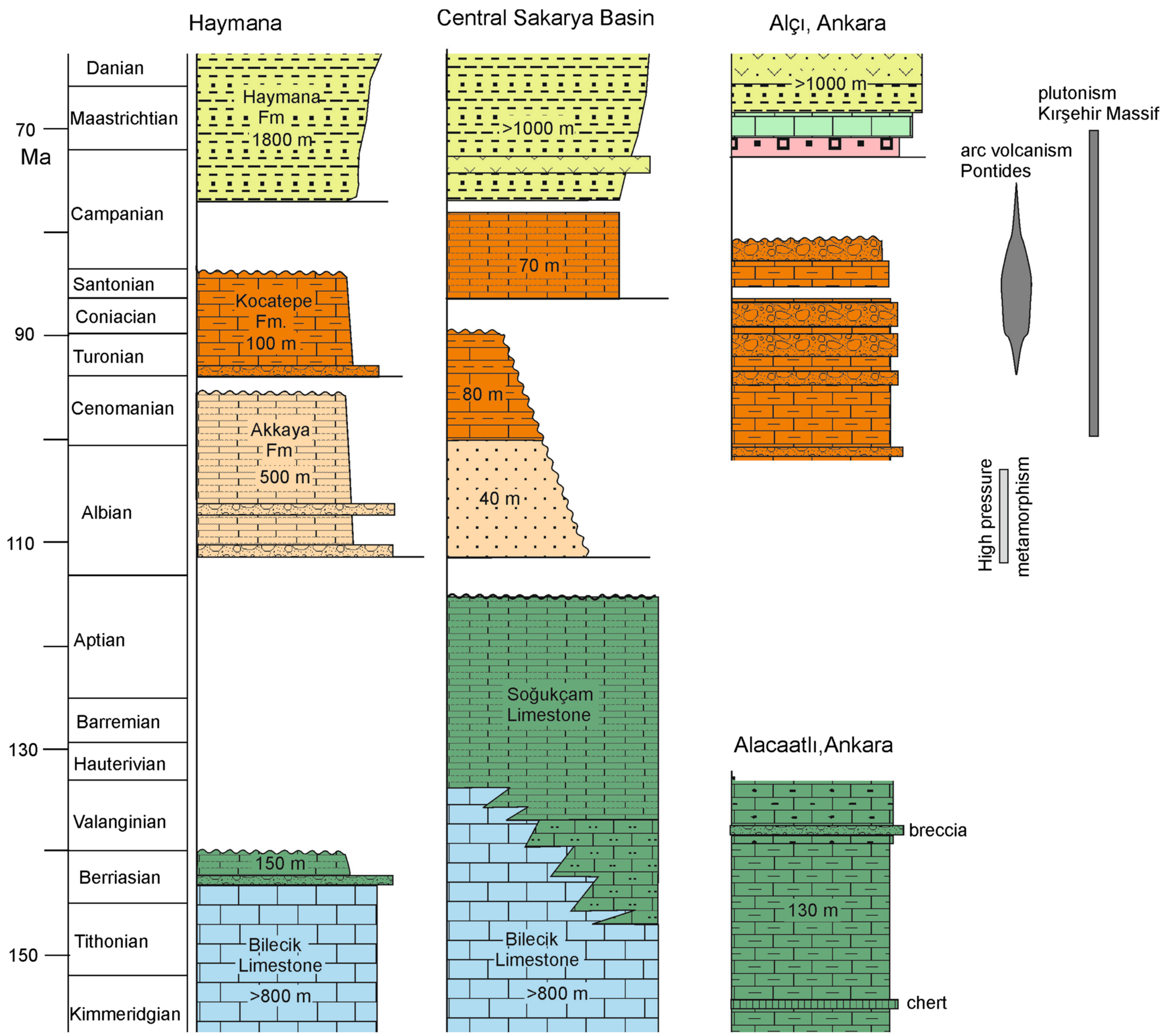

Fig. 12 Cretaceous stratigraphic sections from Haymana, Central Sakarya Basin and the Ankara region. The data are from Altiner et al. (1991), Rojay and Süzen (1997), Bragin and Tekin (1999), Yilmaz (2008), Yilmaz et al. (2010) and this study

the early Albian, which suggests either segmentation of the Pontide margin or that the contractional deformation was confined to the trench.

Although there is Albian subduction, an Albian magmatic arc is not known in the Pontides. The arc volcanism starts in the Turonian and is particularly widespread in the Santonian, which is represented by an over 2-km-thick volcanic and volcaniclastic succession in the northern margin of the Pontides (Okay and Şahintürk 1997). During the Turonian–Santonian, the Haymana region was in a forearc position but unlike most modern or ancient forearcs (e.g., Dickinson 1995) received almost no detritus from the arc and was the site of carbonate deposition (Fig. 13e). In the Pontides, there was no topographic barrier between the arc and the forearc, as envisaged for example in the Calabrian subduction zone (Cavazza and Barone 2010). Instead the Pontide arc was extensional and the volcanic detritus from the arc was trapped in the intra-arc basins, and very little volcanic detritus reached the forearc basin or the trench. The Upper Cretaceous arc sequence in the Pontides consists mainly of epiclastic and volcaniclastic strata interbedded with deep marine limestones (e.g., Okay and Şahintürk 1997; Eyuboglu 2015); subareal volcanic rocks are not known. The subduction–accretion complex, which developed south of the Pontides, is made up of oceanic upper crustal rocks with very little continent-derived detritus.

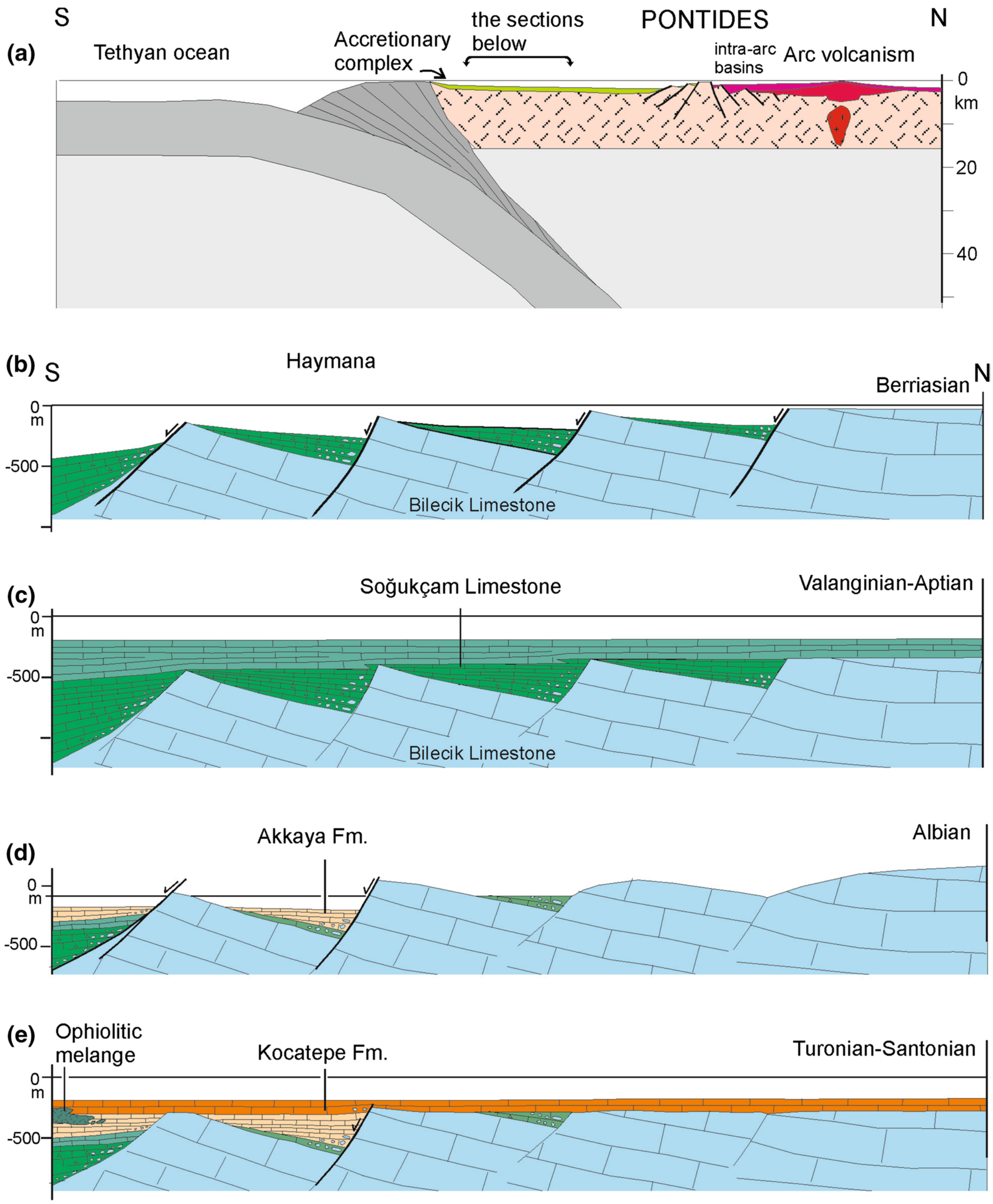

Fig. 13 Schematic sections illustrating the Cretaceous development of the inner Pontides in the Haymana and Ankara regions. **a** The general tectonic setting of the Haymana region in a forearc position, **b–e** schematic sedimentation and tectonism in the forearc region during the Cretaceous

Triassic and Jurassic radiolarian cherts are described from the accretionary complexes in the Ankara region (Bragin and Tekin 1996), which indicate an old and hence thick and dense subducting oceanic slab; this would have induced slab retreat and hence extension in the overriding plate. The extensional nature of the subduction zone is also shown by the Santonian opening of the Western Black Sea Basin as an oceanic backarc basin.

A drastic change in sedimentation in the Haymana region occurred during the late Campanian, when there was a switch from carbonate to siliciclastic turbidite deposition. The upper Campanian–Maastrichtian turbidites in the Haymana region and in the Central Sakarya Basin are generally regarded as forearc deposits (e.g., Görür et al. 1984, 1998; Koçyiğit 1991). However, these basins started to form when the arc volcanism was waning (Fig. 12). Understanding the origin of these clastic basins requires further information on the nature and location of their source areas.

Conclusions

The Haymana region in Central Anatolia preserves a record of the Cretaceous system represented largely by deep marine carbonates and carbonate breccias. A carbonate platform of latest Jurassic–earliest Cretaceous age collapsed in the Berriasian, followed by the deposition of carbonate breccias and of deep marine limestones. The Berriasian to upper Santonian sequence is characterized by long periods of pelagic carbonate deposition separated by relatively short-lived tectonic events involving uplift, tilting and submarine erosion possibly caused by block faulting (Fig. 13). Three such events are recognized in the Berriasian, early Albian and late Cenomanian. These events are probably related to the local dynamics of the subduction zone and are not laterally traceable.

Although the Haymana region was in a forearc position during the Turonian–Santonian, it received no detritus from the magmatic arc and was a region of deep marine carbonate deposition. This was because the Late Cretaceous arc was extensional, and the volcanic detritus accumulated in the intra-arc basins and did not reach the forearc. Carbonate deposition in an active margin such as the Cretaceous of the Haymana region is characterized by episodes of tilting and submarine erosion and thus differs from blanket like deposition in passive margins.

There is no evidence for pre-Campanian Cretaceous contractional deformation in the Haymana region. The region was a site of deep marine carbonate deposition during most of the Cretaceous suggesting extension rather than contraction was the dominant mode in the region.

A major change in sedimentation occurred during the Campanian, when condensed carbonate deposition was replaced by the deposition of a thick sequence of siliciclastic turbidites. Although the upper Campanian to Maastrichtian turbidites are generally considered as forearc deposits, their deposition coincides with the waning of arc magmatism in the Pontides.

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