Carbonates and Evaporites (2019) 34:1737–1755
https://doi.org/10.1007/s13146-019-00523-1

ORIGINAL ARTICLE

The bio-lithoclastic carbonate facies analysis: Şahinkaya Member Maastrichtian (Late Cretaceous) skeletal carbonate deposit, Sakarya Zone, NE Turkey

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Accepted: 30 July 2019 / Published online: 9 August 2019

Abstract
The eastern Sakarya Zone is consensually known as a back-arc setting during the Late Cretaceous period. The region has records, which are in accordance with the environments unstable and carbonate sedimentation formed into different stages of subduction-related conditions. The Tonya Formation that outcropped in the area represents the uppermost part of the Mesozoic sequence in the eastern Sakarya Zone. The Tonya Formation is mainly composed of calciclastic turbidites, including thin grey–red pelagic limestone. The Tonya Formation was subdivided into the Şahinkaya Member basing on its sedimentological properties and fauna contents. The Şahinkaya Member is interpreted as a thick carbonate succession of the Maastrichtian in the study area. To decipher the facies and depositional environment of the Şahinkaya Member, two measured sections were studied in the Çayırbağı-Çalköy area in terms of microfacies analyses. Here, six microfacies types were distinguished based on their depositional texture, petrographic characteristics, and fauna content. Bio-lithoclastic rudstones, grainstones, and packstones are common texture in the carbonates. For the first time, the conglomerate levels have been defined within the member and correspond to an unconformity surface or hiatus together with angular differences in the layers, which have developed due to regional tectonic events such as erosion/uplift and magmatic intrusions. The facies characteristics of the carbonates and the fossil fauna findings included in the Şahinkaya Member of the Tonya Formation point to the development of a slope/toe of slope environment. All the sedimentological properties, combined with the regional data, suggest that the member was deposited at the shore of the back-arc Black Sea basin during the northward subduction of Neotethyan Oceanic Lithosphere and affected by the outcrop of the subduction-related magmatic products.

Keywords Maastrichtian · Foraminifera · K–Pg transition · Şahinkaya Member · NE Sakarya Zone

Introduction

The Eastern Black Sea Basin is located at the eastern part of the Sakarya Zone (Okay and Tüysüz 1999) and was tectonically affected by the convergence margin of the northern branch of Neotethys' realm during the Cenomanian–Paleocene periods. Along the east–west line of the Sakarya Zone, approximately 700-m maximum thickness Campanian–Maastrichtian–Paleocene-aged deposits were accumulated in various from the Samsun to Artvin area within the Neotethys branch systems shaped by convergent plate movements (Özsayar et al. 1981; Korkmaz 1993; Okay and Şahintürk 1997; Okay and Tüysüz 1999; Kurt et al. 2005; Özer et al. 2009; Kırmacı and Akdağ 2005; Sofracıoğlu and Kandemir 2013; Sari et al. 2014; Nikishin et al. 2015b; Türk-Öz and Özyurt 2018; Köroğlu 2018). The magmatic arc of the zone and several back-arc basins (Balkans, Black Sea, Caucasus, etc.) developed in response to the northward subduction events of Neotethyan oceanic lithosphere during the Late Cretaceous–early Paleogene (Şengör and Yılmaz 1981; Görür 1988, 1997 Okay et al. 1994, 2001, 2013; Bektaş et al. 1995; Okay and Şahintürk 1997; Yılmaz et al. 2000; Adamia et al. 2011; Nikishin et al. 2015a, b). According to the regional studies tectonic and sedimentary rock deposits were emplaced into the northern edge of the İzmir–Ankara–Erzincan suture

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(İAES) during the latest Cretaceous period. All basin evolutions suggested that within a plate tectonic regime, the Black Sea opened as a rifted "back-arc" basin north of the south-facing convergent İAES plate boundary during the latest Cretaceous period (Okay et al. 1994, 2013; Görür 1997; Okay and Şahintürk 1997; Munteanu et al. 2011; Adamia et al. 2011; Nikishin et al. 2015a, b).

In this study, particularly Cretaceous–Paleogene (K–Pg) boundary was determined in the Şahinkaya Member of the Tonya Formation (Korkmaz 1993; İnan et al. 1999). The Şahinkaya Member is made up of grey-yellowish and white-coloured, thin–medium–thick-bedded nodular limestones at the bottom. The member ended with medium–thick-bedded white-coloured limestones and it is represented by bio-lithoclastic grainstone and rudstone bearing abundant benthic foraminifera, red algae, rudist, echinoid, bryozoan, different mollusc shell fragments, coral, rock fragments, and rare planktonic foraminifera. The K–Pg boundary was explained as transitional in the previous studies (Korkmaz 1993; İnan et al. 1999; Hippolyte et al. 2015). Sedimentological observations on the locations, such as the presence of conglomerates with well-rounded dacite–rhyodacite pebbles at various pebble dimensions of 3 m thickness, angular-visual and presence of red-colored iron-bearing sediments observed within member, indicate that the late Maastrichtian-aged Şahinkaya Member is not conformable, as is mentioned in the previous studies. The Şahinkaya Member was known as reefal limestones (Ayaz et al. 1996). The unit contains benthic organisms in a wide variety of fragile and poorly sorted structures, and the fact that these organisms are derived from skeletal grains of the reefal environment indicates that the limestone was deposited in a fore-reefal environment (Bulguroğlu 1991; Korkmaz 1993; Ayaz et al. 1996). Sofracıoğlu and Kandemir (2013) suggest that Tonya Formation deposits consist of Şahinkaya Member derived from a shallow-water carbonate depositional environment formed in a back-arc environment in the Eastern Pontides during late Campanian.

The detailed microfacies and depositional properties of the Şahinkaya Member have rarely been conducted, and no definite depositional model has been proposed so far. The main aim of this paper is to describe and interpret the different microfacies using both field and petrographic observations and depositional controls of the Maastrichtian Şahinkaya Member.

Geological background

Turkey is one of the major components of the Alpine–Himalayan orogenic belt and geologically composed of four major tectonic blocks separated by three main high-pressure belts (Okay and Tüysüz 1999). The study area is located at the eastern part of the Sakarya Zone (Fig. 1a). The Sakarya Zone can be basically divided into two parts. The main differences between the southern and northern parts are dominantly magmatic rocks in the northern and dominantly sedimentary rocks in the southern, defined by different lithological, stratigraphical, and tectonically properties (Özsayar et al. 1981; Okay and Şahintürk 1997).

In the Çayırbağı and Çalköy areas (SW Trabzon), the stratigraphy is described as follows (Fig. 1b): basement rocks of the region are Early–Middle Jurassic rocks of the Şenköy Formation. The Şenköy Formation is dominated by Early Jurassic clastic sediments, pillow lavas, and basaltic pyroclastic rocks, and is accompanied by Ammonitico Rosso-type limestones at the base of the sequence (Kandemir 2004; Kandemir and Yılmaz 2009). The Şenköy Formation is conformably covered by platform carbonates of the Berdiga Formation (Pelin 1977). Berdiga Formation is composed of mainly sandy limestone, dolomitic limestone, dolomites and chert nodules, largely characterized by platform type carbonates. The Late Cretaceous is dominated by volcanic-sedimentary sequences, approximately 2 km thick, and comprises five formations, namely the Çatak, Kızılkaya, Çağlayan, Tirebolu (Güven 1993) and Tonya Formation (Korkmaz 1993). The Çatak Formation consists of andesite, basalt and tuffs intercalated with clayey limestones, sandy limestones, tuffite and red pelagic limestones. The Kızılkaya Formation is composed of rhyodacitic–dacitic lavas and pyroclastic rocks with clayey and sandy limestone intercalations. The Çağlayan Formation is composed mainly of marls, sandstones and sandy limestones, locally alternating with spilitic basalts, andesites and associated pyroclastics (Kırmacı and Akdağ 2005). The Tirebolu Formation is composed of rhyolite–rhyodacite–dacitic lava and pyroclastic rocks, as well as sandstone, claystone and siltstone, as lenses between these acidic rocks and grey- and red-colored pelagic limestones in the form of regular stacks where volcanism density is reduced. The Tonya Formation forms the uppermost level of the Late Cretaceous sequence. The Tonya Formation is mainly composed of thin- to medium-bedded, white limestone, sandy limestone and marl rocks alternatively. The formation mostly found in the Tonya area was named as the Tonya Formation described by Korkmaz (1993). Also, the Tonya Formation in the west of the Çayırbağı area, the unit called the Şahinkaya Member is made up of massive calcareous sediments (Fig. 2). The Tonya Formation is stratigraphical transposed to the Şahinkaya Member in the horizontal direction. The lower boundary of the Tonya Formation is conformity with the Tirebolu Formation.

The thickness of the Tonya Formation is measured to be about 317 m (Korkmaz 1993). The age of the Tonya Formation based on planktonic foraminifera biostratigraphy at the Karşılar section (218 m thick) was dated as the late Campanian to Danian (Özkar and Kırcı 1997). According to

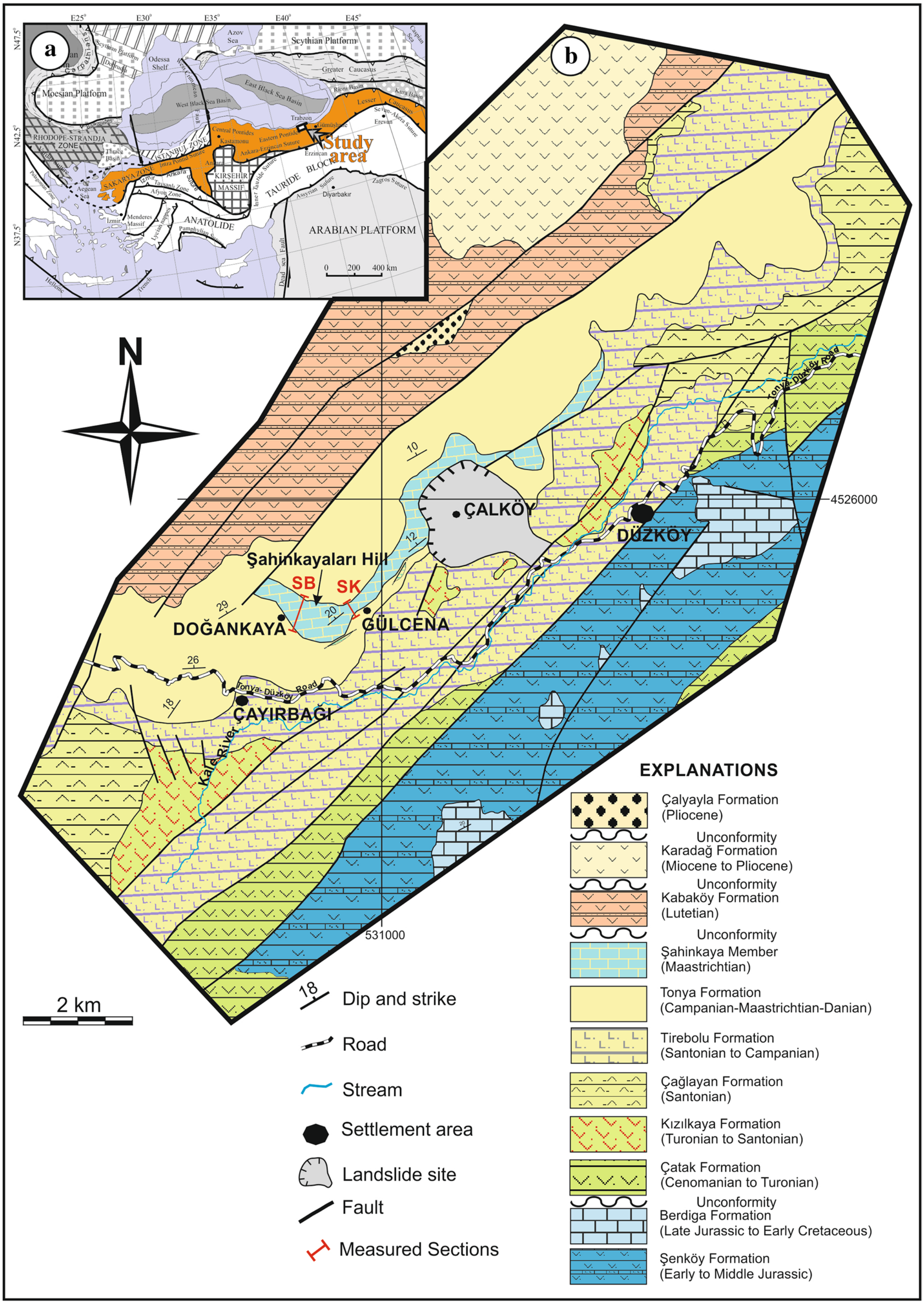

Fig. 1 **a** Regional tectonic setting of Turkey with main blocks (modified from Okay and Tüysüz 1999). **b** Geological map of Çayırbağı and Çalköy areas and surroundings

Fig. 2 The field views of Şahinkaya Member on the Şahinkayaları Hill (Doğankaya District)

Sofracıoğlu and Kandemir (2013), the Tonya Formation in the Hacımehmet and Gürbulak areas of the Trabzon coastal region is classified into two stratigraphical units depending on the deciduous rock types, facies architecture, sediment textures, and depositional environment as follows: (1) Calciclastic rocks were deposited in a submarine fan system (CFSs), based on the grain size, channels, suprafan lobes, and slump structures of the sediments. (2) Calcarenites/calcirudites and hemipelagic rocks comprise an alternation of marls and mudstones and were deposited in the calciclastic submarine fan system (CFSs). Tonya Formation rock units were observed to be fed by material derived from a shallow-water or reefal carbonate depositional environment in the eastern Sakarya Zone during the Campanian–Maastrichtian boundary. The late Campanian–Maastrichtian age, with rudist fauna was claimed by Özer et al. (2009). According to both macro- and microfossil fauna, the age of the Tonya Formation in the Hacımehmet area (Trabzon), the late Campanian age, was suggested from the benthic and planktonic foraminiferal biostratigraphy, and the "*Inoceramus tenuilineatus*" zone, corresponding to the (early–middle–late) Campanian age, was suggested to be from Inoceramidae fauna, respectively (Sari et al. 2014). In the current studies on Tonya Formation age, nannoplankton (Hippolyte et al. 2015) and planktonic foraminiferal (Türk-Öz and Özyurt 2018) biostratigraphies were indicated by Campanian age.

The yellowish white–grey, massive and thick-bedded limestones in the Tonya Formation are defined as the Şahinkaya Member (the name derives from Şahinkayaları Hill), and the unit is typically exposed to the Çayırbağı and Çalköy areas. In the Çayırbağı area, Kayaüstü plateau way (SB) and Kayaüstü plateau (SK), two measured sections, 83.5 m and 103.5 m thickness, respectively, are inferred from this study. The sections are composed of massive or thick-layered limestone, varying from yellow to grey and occasionally including clay, sandy limestone and dolomite (Fig. 2). Six-level conglomerates (30 cm–3 m thickness) containing dacite–rhyodacite pebbly grains were deposited into the limestones in the Kayaüstü plateau way (SB) and Kayaüstü plateau (SK), respectively. The age of the Şahinkaya Member at the Çalköy area was suggested as the Maastrichtian–Thanetian, based on the larger benthic foraminiferal biostratigraphy (İnan et al. 1999). In addition, the rudist fauna in the Şahinkaya Member indicates that the shallow sea in the Maastrichtian (Özer et al. 2008, 2009). According to Hippolyte et al. (2015), the Şahinkaya Member consisted of Campanian–Maastrichtian–Thanetian-aged limestones.

The Tonya Formation is unconformably overlain by the Kabaköy Formation (Güven 1993). The Kabaköy Formation consists of andesite, basalt and their pyroclastics, with lesser amounts of sandstone, sandy limestone and tuffite limestone patches, including *Nummulites* spp. that are located at the bottom of the formation. The Miocene–Pliocene Çalyayla Formation is composed of diorite pebbly, matrix-supported conglomerate identified by Kurt et al. (2005) in the Çalköy. The Pliocene Karadağ Formation comprises olivine–augite basalt and various pyroclastic rocks (Aydin et al. 2009).

Materials and methods

Systematic sampling was provided two sections, with 106 samples collected from the SB (Kayaüstü plateau way) and SK (Kayaüstü plateau) section lines. All thin sections were analyzed under the microscope in the view of biostratigraphy and facies. Uncovered and unpolished thin sections were studied by optical microscopy with magnification from 15× to 200×. Selected section lines are not a repeat of the previous studies. The section lines were taken from three pieces to reveal the lithological changes between floor and top. Resulting microscopic photography and samples of the thin sections were deposited in Recep Tayyip Erdogan University, Rize, Turkey. The identification of fossils and other fragments was distinguished by Loeblich and Tappan (1988), Ellis and Messina (1940–2016), Özcan and Özkan-Altiner

(1997), Özkan-Altiner and Özcan (1999), Meriç and Görmüş (1999, 2000), Yıldız and Gürel (2005), BouDagher-Fadel (2013, 2018), Özer et al. (2008, 2009), Sofracıoğlu and Kandemir (2013), Sari et al. (2014, 2016) and Hippolyte et al. (2015). The classification of carbonate rocks followed the nomenclature of Wilson (1975), Dunham (1962) and Embry and Klovan (1971). Facies definition is based on microfacies features including depositional texture, grain composition, grain size and fossil content (Flügel 2010).

Results

Sedimentology and biostratigraphy of the Şahinkaya Member

The two measured stratigraphical sections, Kayaüstü plateau way (SB section) and Kayaüstü plateau (SK section) of the Çayırbağı area (SW Trabzon), are investigated in this study (Fig. 1).

The neritic carbonate rocks are first separated into members of the "Şahinkayaları Hill" area named Şahinkaya Formation (Bulguroğlu 1991). The Maastrichtian–Danian Tonya Formation with sedimentary rocks (marl, white limestone, neritic limestone, and calciturbidites) are classified by Korkmaz (1993). Then, the Tonya Formation is separated by member rank level; the Şahinkaya Member instead of the Şahinkaya Formation is named by Korkmaz (1993). Generalized stratigraphic and sedimentological properties of the member are depicted in Fig. 3. The Şahinkaya Member is underlined by the Tonya Formation in all the sections in the study area. It is generally formed calcareous sequences. The member starts with thin–medium-bedded nodular limestones including abundant brachiopoda and echinoids and alternation of marls. The member is composed of the mid-thick-bedded limestones including abundant biogene particles after this level. This level formed as the main body of the member. The conglomerate levels are observed after 25 m in SB section and 60 m in SK section. The bed thickness is thinning upward in all the sequences (Fig. 3). Sedimentology description of grainstone–rudstone is as follows: *Orbitoides* spp., red algae, overlain by a well-bedded succession of fore-reef and reefal limestones found in the regional literature. This unit was used to evaluate the deposit structure of neritic platform edge or slope/toe of slope facies architecture.

The Tonya Formation is the uppermost unit of the Mesozoic succession in the eastern Sakarya Zone. Foraminifera assemblages display a Maastrichtian–Danian (Korkmaz 1993) or Maastrichtian–Thanetian (İnan et al. 1999) age for the Tonya Formation. The age of the Şahinkaya Member is attributed to the Maastrichtian, based on the LBZ (Assemblage 2, 3, 4) and planktonic foraminifera *Gansserina gansseri* zone as the combined results of the analysis for all data from larger and planktonic foraminiferal fauna (Matsumaru 2016).This study investigated the larger benthic foraminiferal assemblages of the Çayırbağı-Çalköy areas, based on the accurate correlation of the detailed biostratigraphic sequences of larger foraminifera with planktonic foraminiferal zones. The larger foraminiferal assemblage zone (assemblage zones 2, 3 and 4) was recognized for the first time in the Çayırbağı–Çalköy areas (Matsumaru 2016). This is correlated with the planktonic foraminifera *G. gansseri* zone (Robaszynski 1998; Premoli-Silva and Verga 2004). The Şahinkaya Member is not older than Campanian. The age of the member can be given as Maastrichtian based on the defined Larger Benthic Foraminifera (LBF) species. In addition, Consorti and Koorosh (2019) have suggested that Tarbur Formation (Iran) is represented by *Cibicidoides succedens* for distinctive lamellar Foraminifera from the Maastrichtian from Sardinia (Dieni 2010) towards Middle East (Ezampanah et al. 2018).

Facies analysis

The description of carbonate facies is largely based on the observations of thin section from the rock samples of the Şahinkaya Member. Two measured stratigraphical sections (SB and SK) for six microfacies are defined based on the sedimentary structures: fabric, the lithological variations and the fossil assemblages (Fig. 4). The examination of the thin-section microphotograph under the microscope shows internal sedimentary structures and fossil-abundant ratio. The textures of 106 thin sections which belong to microphotograph were defined as following the classification scheme of Dunham (1962) and Embry and Klovan (1971). The specific nature of the grains (changes of ratio, bioclasts, lithoclasts, foraminifera and its fragments, rudist fragments, echinoderm fragments, red algal fragments, quartz grains) and that of the cement (micrite and sparry calcite) was used as variables in the thin sections. The microfacies term has been originally defined as the petrographic and paleontological data studied in thin sections (Flügel 2010). Furthermore, the identification of depositional setting conditions and facies zones (FZ) was separated based on Wilson (1975).

Analysis of the vertical facies distribution reveals the sedimentary evolution of the study area from the Campanian–Maastrichtian to Paleogene through sedimentary evolutionary stages, showing how facies patterns and structural setting evolved through time. Rudstone–grainstone textures increase upward bedding, along with assemblages rich in benthic foraminifera, rare planktonic foraminifera, red algae and various fragments. In the late Campanian, the floor facies are replaced by basin environment. The upper part of the Maastrichtian depositional sequence crops out both Çayırbağı and Çalköy areas consisting of neritic-bedded bio-lithoclastic limestone (Fig. 4).

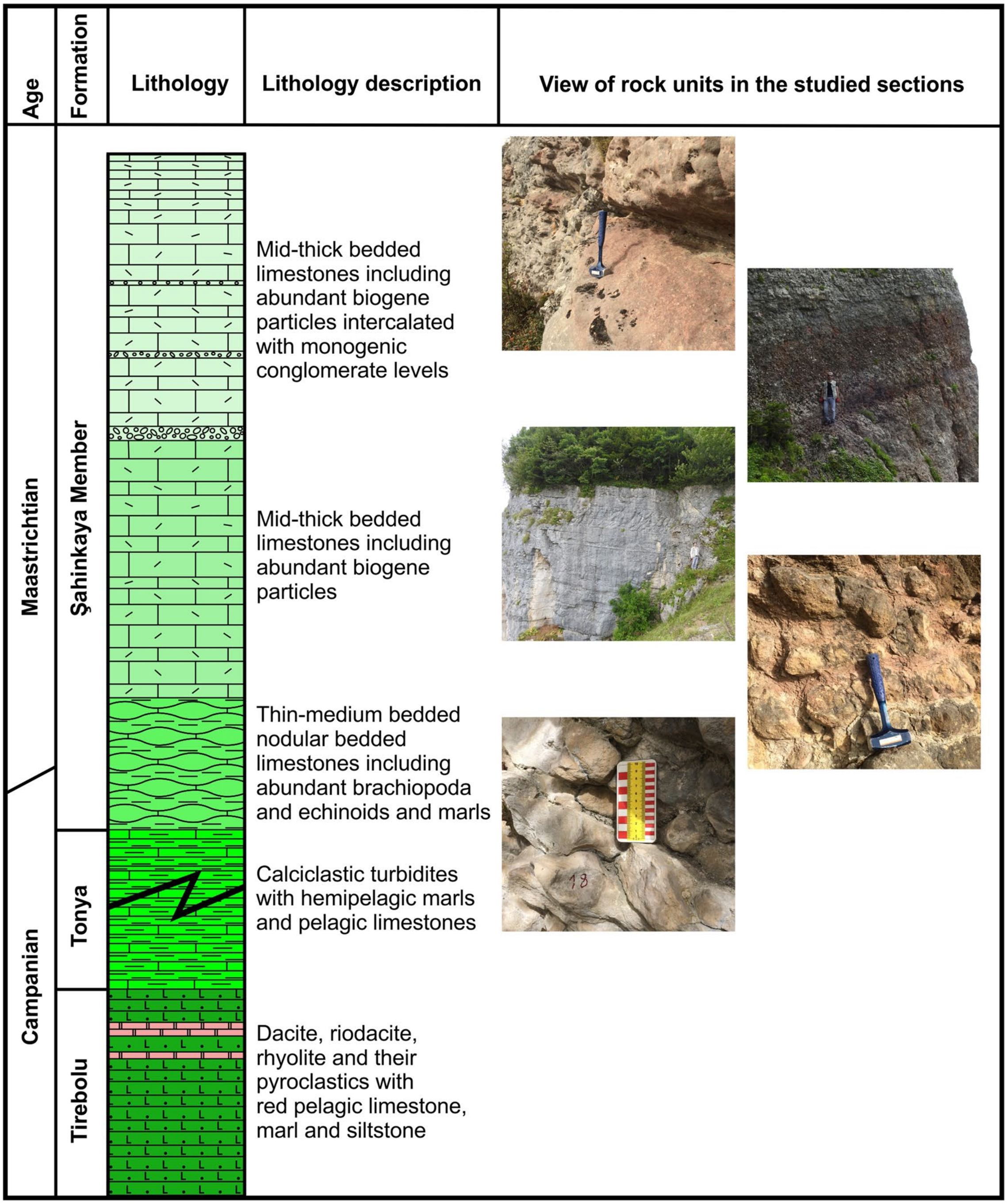

Fig. 3 Generalized stratigraphic column of the uppermost section of the Mesozoic sequence in the northern parts of the Eastern Pontides

Maastrichtian-aged slope/toe of slope deposits are found only in the Çayırbağı and Çalköy which are composed of densely packed shelf-margin derivation skeletal of rounded grainstone–rudstone rich in Orbitoidal type foraminifera, rudist fragments, red algal fragments, and non-bioclastic sediments.

Six microfacies types (MFT) were identified by rock samples as a result of examinations of facies analysis in the Şahinkaya Member. Microfacies types and their sedimentary properties are given in Table 1.

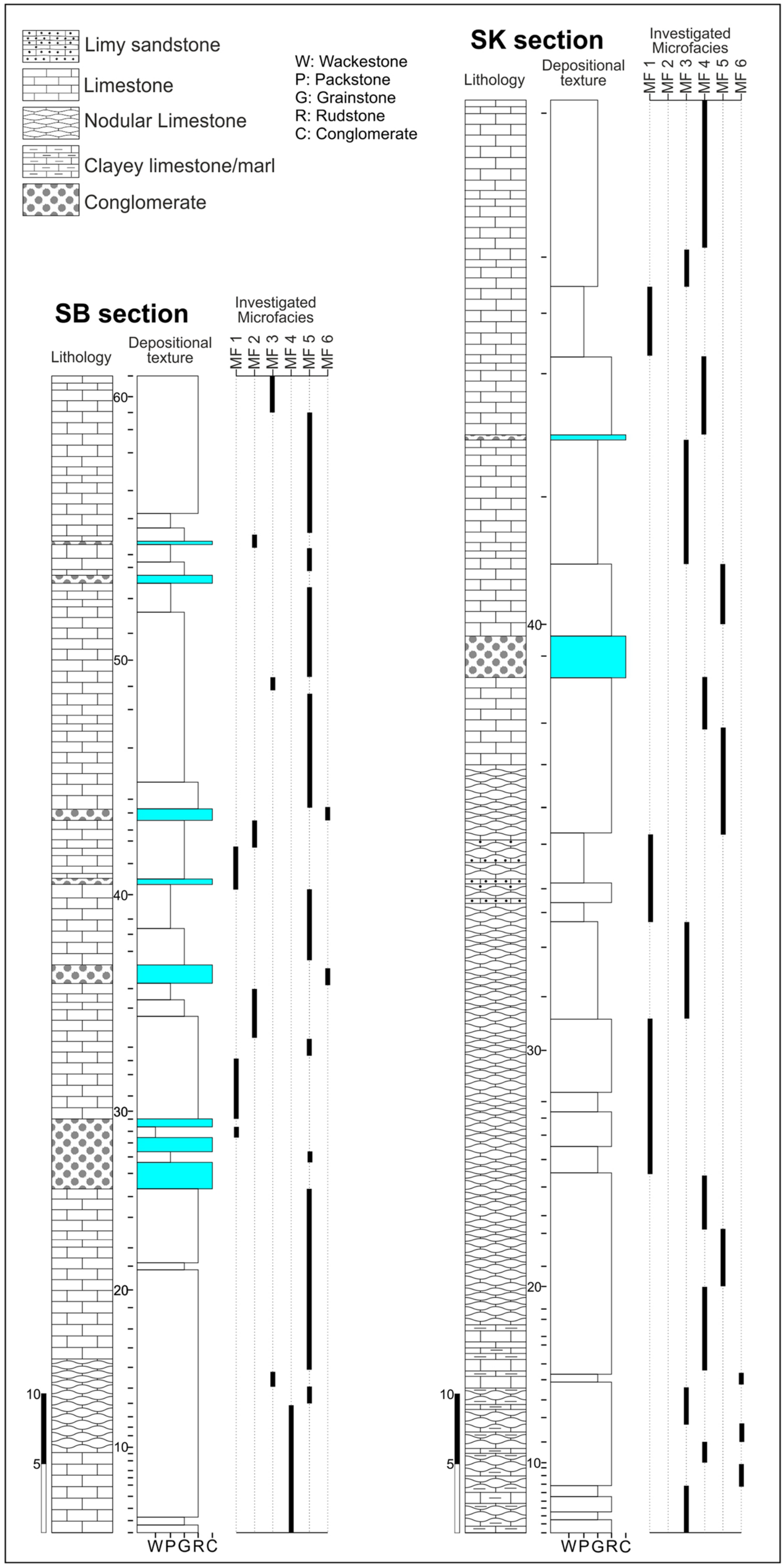

Fig. 4 Details of Şahinkaya Member in the SB and SK sections

Table 1 Microfacies types and sedimentation environments of Şahinkaya Member

No	MFT	Field description	Main components	Depositional setting
1	Wackestone–packstone with planktonic foraminifera	Red-colored sandy limestone	Planktonic foraminifera, quartz fragments, benthic foraminifera, red algal fragments, rock fragments	Toe of slope-deep shelf
2	Grainstone–packstone with bioclastic–lithoclastic grain	Grey-white-colored limestone	Bio-lithoclasts and rock fragments	Toe of slope
3	Grainstone with larger benthic foraminifera and calcareous red algae	Yellowish-colored bioclastic limestone	Larger and smaller benthic foraminifera, red algal fragments, bryozoans, rudist fragments, echinoderm fragments, glauconite	Slope/toe of slope
4	Grainstone–rudstone with calcareous red algae	Yellow-grey colored bioclastic limestone	Red algal fragments, larger and smaller benthic foraminifera, rudist fragments, bryozoans, echinoderm fragments, rock fragments	Slope/toe of slope
5	Grainstone–rudstone with larger benthic foraminifera	Yellowish-colored bioclastic limestone	Larger benthic foraminifera, red algal fragments	Slope/toe of slope
6	Rudstone with quartz and rock fragments	Conglomeratic limestone with red-colored matrix	Quartz, biotite, dacite–rhyodacite fragments, benthic foraminifera, red algal and rock fragments	Slope/toe of slope

MFT-1: wackestone–packstone with planktonic foraminifera

This facies is characterized by a guide level for the sequence in the red-colored thin–medium-bedded limestone in the middle part of the measured stratigraphical sections. This level has a calciturbidite texture composed of pelagic forms, microcrystalline calcite clasts, red algal fragments, volcanic rock fragments. Since both planktonic and benthic forms coexist in thin sections, it has been observed that the species with two different living environments are a combination. This facies may also be composed of differently derived grains, fine-grain breccias, generally grain worn, roundness, environmentally derived bioclasts, transported shallow water materials, and previously cemented lithoclasts. Graded textures are widely observed in thin sections. As the cement component is predominantly microcrystalline calcite and component dimensions are smaller than 2 mm, it is called planktonic foraminiferal wackestone–packstone (Fig. 5a, b). This facies also includes quartz, chert and extraclast particles. This rock type contains fine-grained debris created by turbidites. Within this facies, the number of larger benthic foraminifera, red algae and other bioclast has been reduced. However, the rock fragments and quartz in the studied sections increased significantly. It can be said that the facies (FZ, 2–3) depositional environment is dependent on sudden changes in sea level or tectonical activity. The combination of micritic matrix and abundance of typical open marine skeletal fauna suggests a low–medium energy, open marine environment (Flügel 2010).

MFT-2: grainstone–packstone with bioclastic–lithoclastic grain

This facies consists of grey-white-colored, thin–medium-bedded limestones and is observed predominantly in the upper portion of the measured sections. The foraminifera and red algae are accompanied by the fragments of micrite and sparry calcite lithoclasts. MFT-2 is classified as grainstone–packstone with a wide variety of bioclasts (Fig. 5c, d). The type of facies is described in the description of SMF-3 and SMF-4; fine-grained breccias, debris, round and locally derived bioclasts, transported shallow water materials, and pre-cemented lithoclasts. In this facies (FZ, 2), it is expected that the size and type relationships of the components in the pre-slope environment are intertwined. It is revealed that the accumulations observed in thin sections move from the environment. The existence of lithoclasts and the presence of planktonic foraminifera parts side by side indicate that the environment is unstable.

MFT-3: grainstone with larger benthic foraminifera and calcareous red algae

This facies is represented by grey-yellowish-colored bioclastic grainstone at the range of lower and upper parts of the section and characterized by abundant microfossils and their fragments in a sparry calcite cement binding (Fig. 5e, f). The bioclastic grains are composed of both larger benthic foraminifera including *Orbitoides* spp., *Lepidorbitoides* sp. and *Siderolites calcitrapoides*; other bioclast calcareous red algae (indet.) are abundant in this facies. Neritic marine environment also including mollusc fragments (brachiopods),

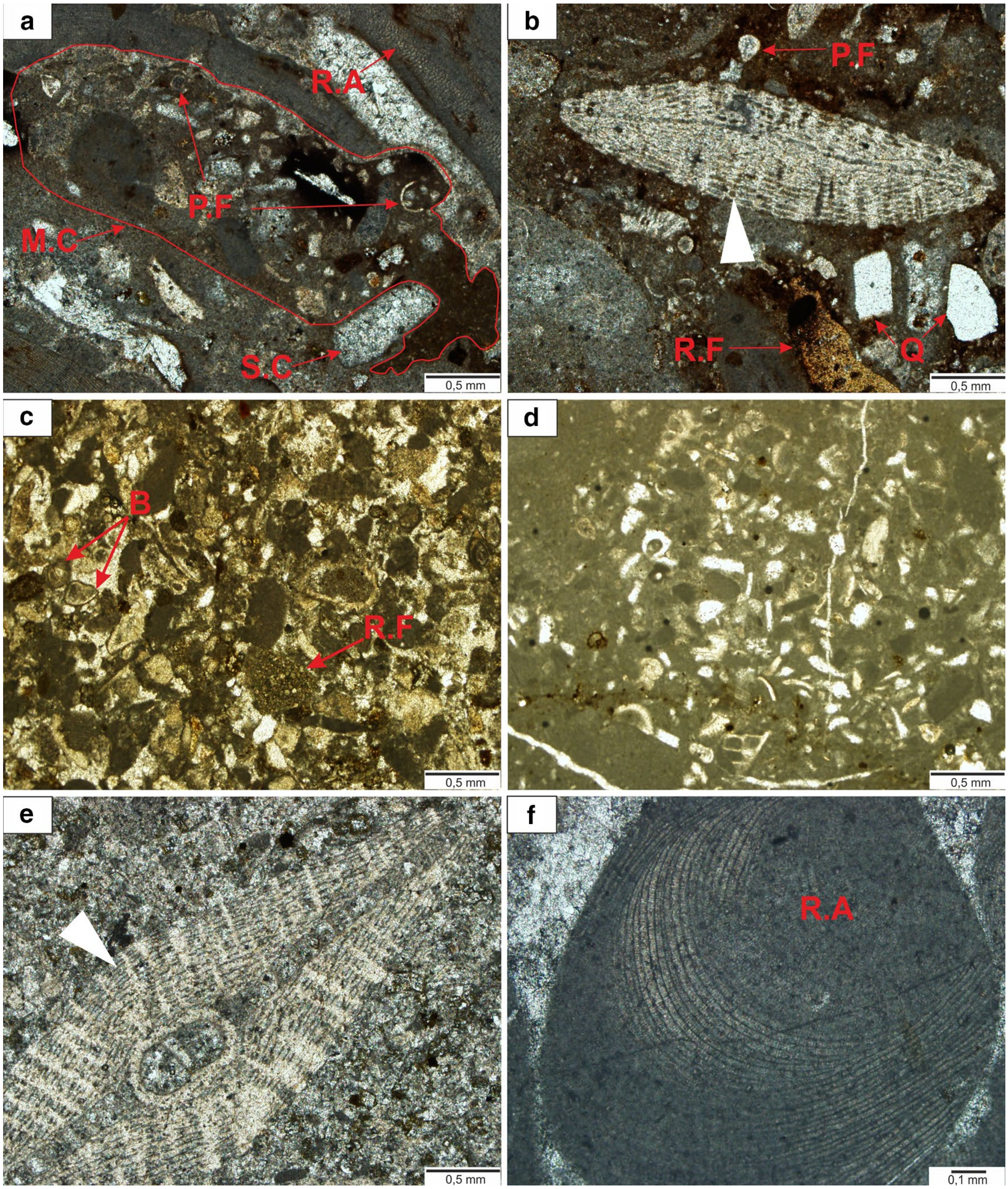

Fig. 5 Microscopic photographs of wackestone–packstone with planktonic foraminifera facies (MFT-1) (**a** *R.A* red algal fragment, *P.F* planktonic foraminifer, *S.C* sparry calcite, *M.C* microcrystalline calcite, **b** white arrow: *Lepidorbitoides* sp., *P.F* planktonic foraminifera, *R.F* rock fragment, *Q* quartz). Microscopic photographs of grainstone–packstone with bioclastic–lithoclastic facies (MFT-2) (**c** *B* bioclast, *R.F* rock fragments, **d** bioclasts in a matrix of micrite–sparry calcite). Microscopic photographs of grainstone with large benthic foraminifera and calcareous red algal facies (MFT-3) (**e** white arrow: *Orbitoides apiculata*, **f** *R.A* red algal fragment)

echinoderm fragments and its spines, bryozoans, glauconite, and lithoclasts are also present. The sections lower parts including rare planktonic foraminifera (suborder Globigerinina) are present. The size of the components is coarse and the percentage of the sparry calcite cement shows variability within the microfacies texture. The amount of sparry calcite in the sample's variety is also seen in low portion. MFT-3 corresponds to a slope/toe of slope environment, which is a platform interior reef and restricted to open marine conditions. Larger rotaliinid benthic foraminifera are rocks forming in restricted and open marine environments in the platform interiors and inner ramps (Flügel 2010). Furthermore, calcareous red algae occur only in the photic zone and in the platform margins and inner ramp to mid-ramp settings (Flügel 2010). According to Wray (1978), the depositional environments of fossil algal species red algae are restricted to reef bank flank. This microfacies type is equivalent to the standard microfacies (SMF-5) type description for the same characteristics presented. It is also similar to facies zone (FZ, 3–4) and slope/toe of slope environment as definition by Wilson (1975).

MFT-4: grainstone–rudstone with calcareous red algae

This facies has been identified in thin–medium–thick-bedded limestones with yellow–grey color transitions in terrain. Apart from the cement bioclast that forms limestones, sparry calcite is formed completely. The red algae that existed until the end of the measured section in the studied sections show gradual changes in their dimensions. It has been observed that individual dimensions have been differentiated with environmental changes and disintegrated by the dynamic effects of the environment. Since the growth of red algae is not clear, it has not been possible to identify. It is mostly similar to SMF-5 in that it is composed entirely of fossils and organisms derived from reef fossils. Bioclasts are characterized by SMF-5 in the presence of a chaotic regime. The grains may generally consist of worn, round, locally derived bioclasts, transported shallow water materials, and pre-cemented lithoclasts. The presence of SMF-4 represents the medium in which the grains are derived from polymictic or monogenic composition. Dimensional variability corresponds to the facies of the slope/toe of slope depositional environment (FZ, 3–4) to the deepest parts of the shallow marine areas of these algae, towards deep parts and less to the sun's rays (Wray 1978). The variations in the size of the red algae are about 2 mm and the cement sparry calcite is called facies grainstone–rudstone (Fig. 6a, b).

MFT-5: grainstone–rudstone with larger benthic foraminifera

This type of facies, which is found in the lower parts of the yellowish-colored medium–thick-bedded limestones, is intermittently observed from the standpoint. This facies type is seen in a composition formed by larger benthic foraminifera (*Orbitoides* spp.), its fragments and a few red algal fragments. Although the cement among the bioclast grains is a slightly sandy mixture, sparry calcite is formed almost completely. It is mostly similar to SMF-5, with all of its fossils being composed of fossils and high percentage of reef-derived organisms. It is characterized by the presence of a chaotic regime of bioclasts and the presence of SMF-5. The grains may generally consist of worn, round, locally derived bioclasts, transported shallow water materials, and pre-cemented lithoclasts. The presence of SMF-4 also characterizes the presence of polymictic origin or a single composition of grain. The depositional environment of this facies zone (FZ, 3–4) was defined as the slope/toe of slope, because it was living at a shallow water depth of among 40–80 m according to Hottinger (1997) of *S. calcitrapoides*, which is a benthic foraminifera species and indicative of shallow depth environments (Fig. 6c, d).

MFT-6: rudstone with quartz and rock fragments

This facies is generally distinguished as medium–thick reddish-colored limestones in the middle parts of the measured stratigraphical sections. Benthic foraminifera and red algae are also observed together, including large quartz and volcanic rock fragments (Fig. 6e, f). Bioclastic, grain size and matrix composition indicate that the formation of this facies (FZ, 3–4) was deposited on slope/toe of the slope environment. In general, in accordance with the criteria of SMF-5 and the formation of all fossils and high-order reef-derived organisms and fossil fragments, bioclasts are characterized by a chaotic regime or unstable depositional environment. The reef-bank facies slope (FZ, 4) is observed on the reef-front, and reef slopes are adjacent to the reef or in the reef-back environments. In addition, limestones have gained a red color due to the alteration of dacite–rhyodacite rock fragments. The observations of bioclasts as fracture or less fracture suggest a possible migration process. Inclusions of large-scale terrigenous can be explained by a tectonic uplift process, erosion in terrestrial environments, and sedimentation on the basin edge slopes.

Conglomerate levels

The investigated materials from the conglomerate level of the Şahinkaya Member provide us important evidence on the sedimentary basin environment evaluation of the eastern Sakarya Zone. The conglomerate level of the Şahinkaya Member is mainly composed of extraformational lithoclasts of dacite–rhyodacite pebbles and matrix derivation of terrigenous dacite–rhyodacite pebbles (Fig. 7). The conglomerate level is identified as oligomictic type and matrix support as dacite–rhyodacite pebbly conglomerates. The conglomerates that include dacite–rhyodacite pebbles, which are derived from the Kızılkaya and Tirebolu formations in the Late Cretaceous back-arc basin sediments in the eastern Sakarya Zone, indicate larger tectonic movements in the back-arc basin during the Maastrichtian (Late Cretaceous). The conglomerates also include planktonic and benthic foraminifers with other marine fossil groups in the matrix. Köroğlu (2018) suggests that these conglomerates were deposited in the Late Cretaceous back-arc basin during the Maastrichtian

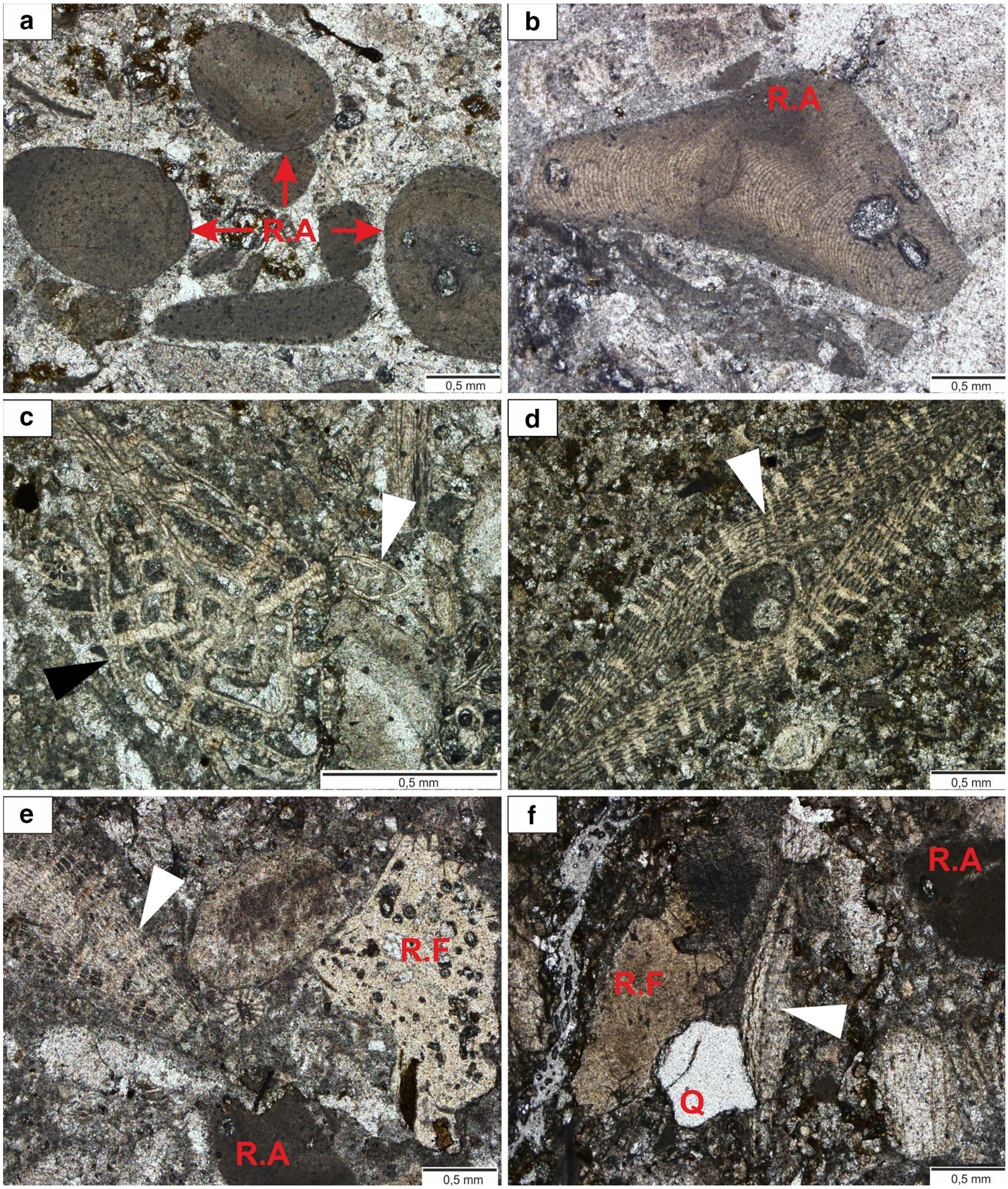

Fig. 6 Microscopic photographs of grainstone–rudstone with calcareous red algal facies (MFT-4) (**a**, **b** *R.A* red algal fragments). Microscopic photographs of the grainstone–rudstone with larger benthic foraminifera facies (MFT-5) (**c** black arrow: *Siderolites calcitrapoides,* white arrow: *Cibicidoides succedens* and **d** white arrow: *Orbitoides apiculata*). Microscopic photographs of rudstone with quartz, rock fragment facies (MFT-6) (**e** *R.A* red algal fragment, white arrow: *Orbitoides* sp., *R.F* rock fragment. **f** *R.A* red algal fragment, white arrow: *Lepidorbitoides* sp., *R.F* rock fragment, *Q* quartz)

period. Regional tectono-sedimentary evolution of the Late Cretaceous period in the region reveals a northward subduction event in the old magmatic arc. This phenomenon affected by active arc magmatism of the oceanic plate is inferred to be the trigger of tectonic movements such as erosion/uplift and magmatic intrusions (in general, the granitic stocks) in the Kızılkaya or Tirebolu formations derived from pebbles that ends up with conglomerate level in the Şahinkaya Member. All components from the investigated conglomerate level can be interpreted as a key unit of especially erosion/uplift period and environment in the

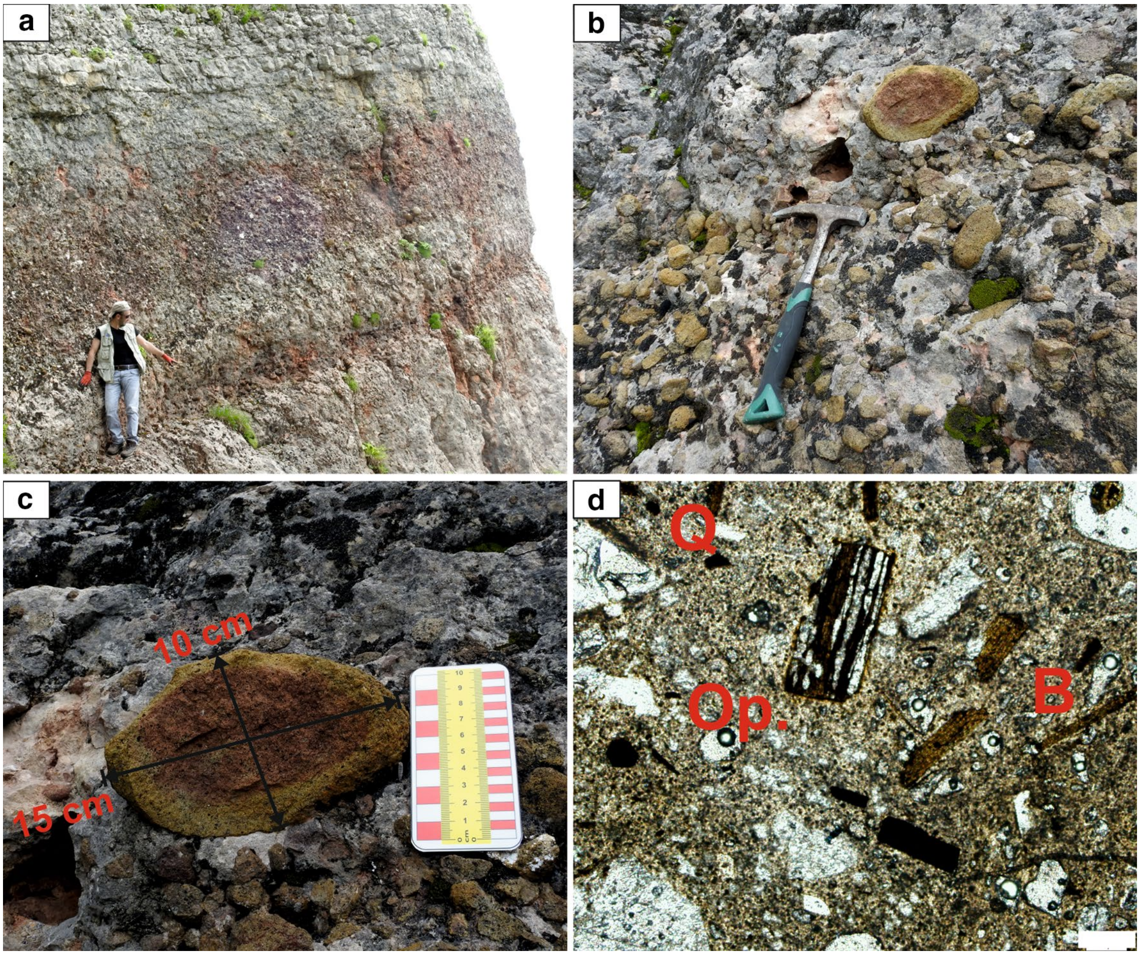

Fig. 7 Detailed view of the conglomerate level of SB section. **a** The color difference (human body, scale bar = 180 cm) due to the alteration of the gravels at the conglomerate level. **b** The appearance of matrix-supported gravels (rock hammer, scale bar = 30 cm). **c** Grain sizes of gravel (scale bar = 10 cm). **d** Thin-section photograph of the gravel sample (*Q* quartz, *B* biotite, *Op* opaque mineral, cross-polarized light, scale bar = 200 µm)

tectono-sedimentary history of the Maastrichtian (Late Cretaceous) in the Sakarya Zone.

This conglomerate level represents the only regional tectonic impact evidence for deposits largely eroded elsewhere in the area with larger benthic foraminiferal assemblage, which is highly informative of both biostratigraphic and paleoenvironmental points of view. This triple aspect of larger benthic foraminifera, rare planktonic foraminifera, and pelagic sediment is the key to investigation at the base of the present study. The conglomerate level of description of the stratigraphic age and texture of the microfacies is represented in the mineralogical composition in detail microphotographs (Fig. 7).

Discussion

Depositional setting

The eastern Sakarya Zone can be basically divided into northern and southern parts, defined by different lithological, stratigraphical and tectonic properties (Özsayar et al. 1981; Okay and Şahintürk 1997). Until the Late Cretaceous, the lithostratigraphical development in the northern part of the eastern Sakarya Zone was very similar to that of the southern part. The sedimentation in the northern part of the zone is characterized by a volcano-sedimentary sequence more than 2 km thick (Sofracıoğlu and Kandemir 2013). The latest Cretaceous sedimentary rocks in the northern part of the zone featured by platform, slope and basin facies including both pelagic facies and neritic facies in the Late Cretaceous–early Paleogene-aged limestones have been accepted by several authors (Gedikoğlu et al. 1979; Özsayar et al. 1981; Korkmaz 1993; İnan et al. 1999; Sofracıoğlu and Kandemir 2013; Sari et al. 2014; Hippolyte et al. 2015; Türk-Öz and Özyurt 2018).

The uppermost deposits of Mesozoic sequence are well exposed in the Tonya (Trabzon) region and named as the Tonya Formation by Korkmaz (1993). Campanian–Maastrichtian–Paleocene Tonya Formation is composed of thin- to medium-bedded, pelagic limestone, white limestone, sandy limestone and marl rock alternation (Korkmaz 1993; Özkar and Kırcı 1997). Neritic limestones in the Tonya Formation are named as the Şahinkaya Member in Çayırbağı area. The transition from the Late Cretaceous to early Paleogene which is an evolution of the sedimentary pattern to neritic reefal limestone by İnan et al. (1999) is accepted as benthic foraminiferal fauna context conformable to K–Pg transition. We believe that the sediment pattern in the Tonya and Çayırbağı areas depends on several different factors. These can be ordered as interaction between local tectonic differences, paleogeographic environment, eustatic sea-level changes and range of shallow water to slope and toe of slope deposits.

The Çayırbağı area is generally characterized by reefal limestone deposits during the Cretaceous–Paleogene transition. However, the Paleocene-aged fossil was not found in the area inside our paleontological data. This fossil fauna is derived from reworked sediment accumulation, mechanism of calciturbidite and uplifted areas of the Cretaceous carbonate platform and from mobilization of loose skeletal material deposited on the reef environment. In the studies carried out to date, there are no forms of autochthonous coral and rudist within a shallow reefal area. Therefore, it is likely that the existence of such a source area in the region is covered by the Eocene volcanism or eroded with orogeny. As a result of the Şahinkaya Member facies definition is slope/toe of slope depositional environment. The most important finding supporting our views on the depositional setting environment is the habitat of benthic foraminifera (Fig. 8). The biostratigraphic value of larger foraminifera has been recognized since the middle of the nineteenth century, whereas their usage as a tool for interpreting depth and depositional environment has been fully developed in the last decades (Hottinger 1997; Di Carlo et al. 2010). They almost represent an ecosystem of their own (comparatively independent from the remaining ecosystem); with a few exceptions, they do not appear to play a role in the food chain of invertebrates and fish and may represent the end member of a food chain, feeding on bacteria, diatoms or pellets produced by planktonic organisms (Hottinger 1997). In particular, a detailed environmental analysis of marine life, sedimentation and paleoclimate can be reached using *Orbitoides* spp. from species of the benthic foraminifera. The genus *Orbitoides* spp. displays some of the widest latitudinal and longitudinal extents among the larger Late Cretaceous foraminifera species (Goldbeck and Langer 2009). The especially wide distribution over the circumtropical warm water belt of the Cretaceous ocean (Tethys Ocean) is comparable to the distribution of modern amphisteginids (Langer and Hottinger 2000).

The age of the Şahinkaya Member is given as late Maastrichtian based on benthic foraminifera species. The Late Cretaceous corresponds to the time span at which a volcanic arc was initiated on the northern shelf of the Black Sea due to the northward subduction of Neotethyan Oceanic Lithosphere (Boztuğ et al. 2006, 2007; Kaygusuz et al. 2008; Aydin 2014; Karsli et al. 2010, 2012; Dokuz et al. 2019) (Fig. 9a). Şahinkaya Member must be deposited in slope and toe of slope of this northern shelf of the Black Sea. The bio-lithoclastic components in the investigated limestones suggest a close contemporaneous shallow marine carbonate depositional environment as their source during their deposition (Fig. 9b).

In the eastern part of the Sakarya Zone, the sedimentary rocks that contain rudists and rudist fragments are observed in the north and south zones. These rocks reach a thickness of 195 m around Bayburt-Maden in the south (Özer et al. 2008) (Fig. 9a). The fossilized rudists in situ and different communities including rudists are found in every level of the sediments in this place. Bedded rudist biostromes are also determined in this area (Özer et al. 2008). These limestones that contain rudists are covered by Paleocene volcanites (Bektaş et al. 1995). The rudist-bearing limestones are referred as Maastrichtian by Özer and Fenerci (1993) and Fenerci (1994) in the Maden-Bayburt area. In addition, Özer et al. (2008) suggests the same age depending on the rudist faunas. Özer et al. (2008) stated that these sediments consist of reefal facies but are not deposited on a platform edge as a barrier reef. There are not any sedimentary rocks including rudist in situ in the north part of the eastern Sakarya Zone. Nevertheless, rudist fragments are a significant bioclastic component of deposits and investigated in calciturbidites of Tonya Formation including Şahinkaya Member (Özer et al. 2008, 2009; Sofracıoğlu and Kandemir 2013). Rudists are also inhabitants of shallow water environments and all these rudist fragments in Tonya Formation are redeposited, which demonstrates that the shallow water carbonate deposition environments suitable for rudists life could be possible in the late Campanian–Maastrichtian time span in the northern zone. The fact that rudist-bearing deposits cannot be observed suggests that the eastern Sakarya Zone was eroded due to the rise after Mesozoic in the northern zone.

Tectono-sedimentary evolution of Tethys in the eastern Sakarya Zone

The eastern Sakarya Zone has been considered controversial by different research groups both tectonically and

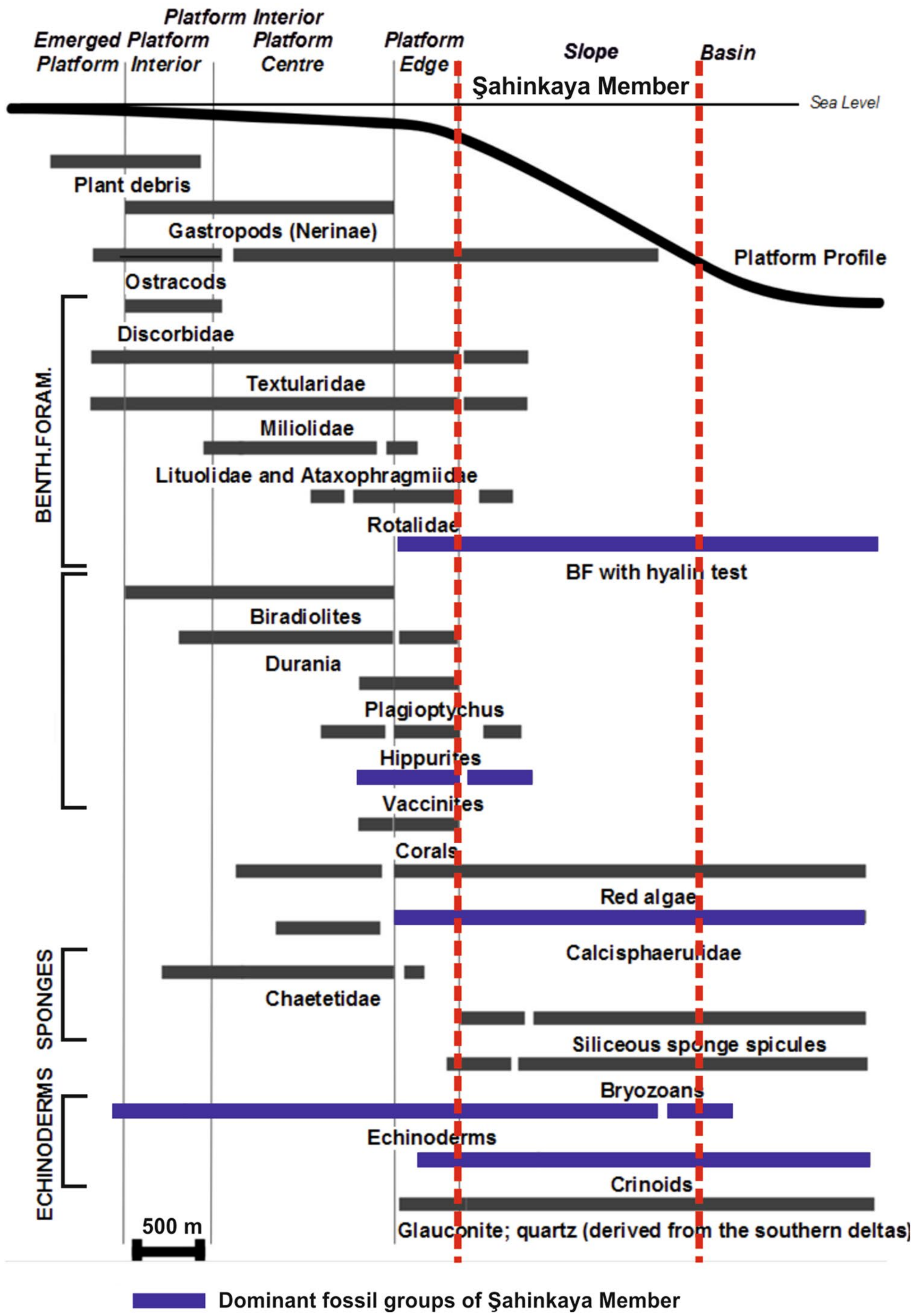

Fig. 8 Distribution of various biota along the Şahinkaya Member of Maastrichtian (Late Cretaceous)-aged platform edge-to-basin transect environment (modified from Reijmer et al. 2015)

stratigraphically during the Late Cretaceous period. The reasons for these differences are the regional dissemination mechanism of the product closing processes of the Neotethyan Ocean. The basin conditions showed that from the end of the Cretaceous period an environment of deposits of pelagic and neritic sediments was formed. In this period, the region can be interpreted as a back-arc basin environment. As the age of the magmatic activity during the latest Cretaceous ascended to the early to late Campanian, the marine sedimentary rocks during this period can be taken up to the timing of Turonian age. Regional geodynamic events indicate that magmatic products and marine sediments are deposited in the same environment. When looking at the age range in which magmatism ended, the region may be characterized by a partly stable tectonic setting during the late Campanian and Maastrichtian stages. Dokuz et al. (2019) pointed out that the time span from the early Maastrichtian to early Thanetian corresponds to a stagnation in terms of

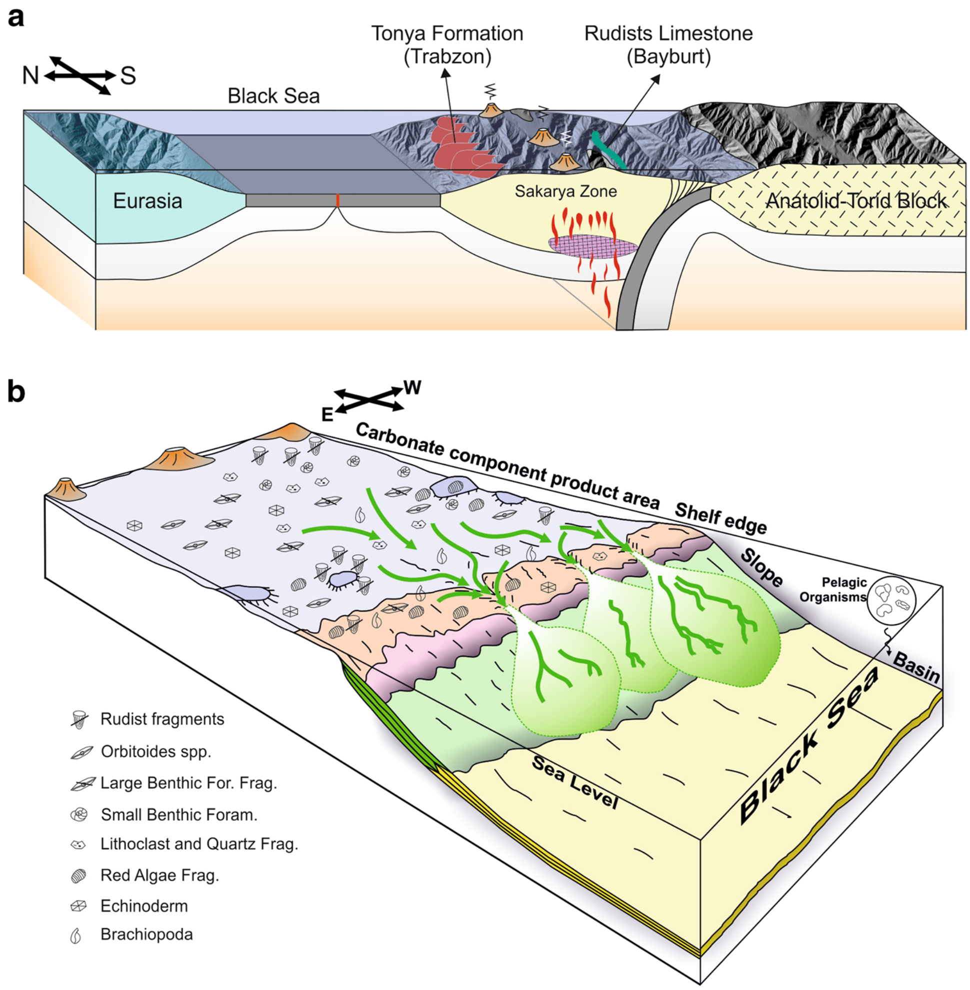

Fig. 9 Depositional model of the Campanian–Maastrichtian (Late Cretaceous) time span of the Tonya Formation. **a** During the Late Cretaceous tectonic setting of the Eastern Pontides region (modified from Şengör and Yılmaz 1981; Karsli et al. 2010, 2018; Aydin 2014; Aydin et al. 2016; Dokuz et al. 2019). **b** At the end of Late Cretaceous, the Black Sea opened as a marginal back-arc basin; the sedimentation environment of resedimented carbonate rocks that deposited to the north of the arc parallel to E–W line

magmatic activity. The Şahinkaya Member accumulated in this stagnation period in the north of the eastern Sakarya Zone (Fig. 9).

The Late Cretaceous of the Tonya Formation is characterized by calciclastic turbidites, intercalated with pelagic limestones, white color limestones, pelagic marls, mudstones and conglomerates with volcanic lithoclasts–pebbles. The allochthonous unit beds are composed of transported benthic and planktonic organisms, including main foraminifers, rudists, red algae, crinoids, bryozoans, bioclast fragments and neritic and pelagic carbonate lithoclasts. early to late Campanian–Maastrichtian–Paleocene range of age is suggested by planktonic foraminifera definition the Tonya Formation, a Maastrichtian age by benthic foraminifera's definition the Şahinkaya Member and nannoplankton biostratigraphy (Korkmaz 1993; Özkar and Kırcı 1997; Hippolyte et al. 2015; Türk-Öz and Özyurt 2018).

Larger benthic foraminifera biostratigraphy indicates that the Maastrichtian stage is biostratigraphically complete in the Şahinkaya Member. In spite of the reasonable thin section examination of the foraminifera, index species defining the Maastrichtian biozones were identified. The basal part of the measured section constrained at the level of biozones because of the rarity of the planktonic foraminifera species with the relation to facies control. The measured section is quite a bioclast, having larger benthic foraminifera, mollusc shells, echinoderm spines, bryozoans, and red algae. The characteristics of these fossil forms were utilized in the determination of the environment of deposition in addition to texture-fabric properties of carbonate rocks. We believe that there was a relative sea-level change of the Eastern Pontides basin-related to regional tectonically movement. Regional tectonic events and sea-level change, and fossil groups and depositional setting reflect the general character of the environment (Sofracıoğlu and Kandemir 2013). When the depths of the life of fossil groups and rock units in the environment are examined, it is expected that facies transitions are directly related to sea level, which is similar to the trend proposed by Haq (2014). Especially, it has been pointed out in many studies that the sea level in Maastrichtian stage changed nearly 75 m towards the end of the Late Cretaceous (Haq 2014). This might indicate that sea-level changes in the Black Sea basin north zone were mainly controlled by sea-level changes together with tectonic activity in the eastern Sakarya Zone.

The comparison of the surrounding areas of the Trabzon (Hacımehmet, Gürbulak, and Araklı) calciturbidites shows that the sediment composition triggered the tectonic event and tempest movement in the depositional environment. However, the studies in these areas are given as early to late Campanian in the range of sediment age (Sofracıoğlu and Kandemir 2013; Sari et al. 2014). Both the sedimentary composition and the range of age Şahinkaya Member, whose fossil contents are different, are Maastrichtian–Paleocene (Korkmaz 1993; İnan et al. 1999; Hippolyte et al. 2015). Based on the obtained paleontological data, the Şahinkaya Member Orbitoidal fossil forms as the unit of late Maastrichtian age are identified. It also shows the presence of conglomerate level within the Şahinkaya Member, which is not in other areas, and different age and depositional environmental conditions.

The role of the conglomerates in the geological evolution of Çayırbağı–Çalköy (Düzköy) area: a key level as the identified member of age, stratigraphic position and the tectonic setting provenance of all the fragment materials. As a concern about the age and matrix ingredients of the conglomerate level, the matrix has been found in the reworked microfauna with planktonic foraminifera and pelagic limestone fragments. Our consequence focused on field evidence and only this conglomerate level within the Şahinkaya Member. It has been observed on the field their contact with the bottom and upper levels of the units. The Şahinkaya Member within the conglomerate level to late Maastrichtian skeletal limestone with *Orbitoides* spp. and rudist fragments yields clasts ranging in age from the planktonic foraminifera and pelagic limestone fragments. Our interpretation of the Şahinkaya Member, the position of the conglomerate level, and the tectonic movement connected to uplift was continuous in time. The oligomictic conglomerates shown are proximal mass-flow deposits. Okay and Şahintürk (1997) suggested that the Sakarya Zone during Late Cretaceous period was affected by major complex geodynamic events and results in the region evolution. In their interpretation of the magmatic arc and the major tectonic events in the region, the K–Pg transition corresponds to carbonate to marly–clayey sedimentation in the northern part of the Sakarya Zone, whereas the conglomerate levels show characteristics of the late Maastrichtian stage, a hiatus in sedimentation. Sofracıoğlu and Kandemir (2013) proposed that the occurrence of deposits in the early to late Campanian age was defined as platform derivation facies sequence "Calciclastic Submarine Fan system (CSFs)" depositional system suggesting a primary control of tectonic or storm related. Then, Nikishin et al. (2015a, b) reported a calciturbidite sedimentation setting located further south than the current location of the region during Campanian stage. According to Nikishin et al. (2015a, b), the region is shallow marine from the end of Campanian towards Maastrichtian stage. The K–Pg transition corresponds to the start of deep-water marl–clay and on-going to neritic carbonate sedimentation in the eastern Sakarya Zone. We have identified the Şahinkaya Member as common resedimented deposits, consisting mainly of numerous reefal derived fauna, bioclastic, lithoclasts, and oligomictic conglomerate. All the materials originated from the platform margin, shelf, and terrestrial realm. The Şahinkaya Member has defined the conglomerate deposits composed of a variety of transport mechanism to major tectonic events and reworked shallow-water materials. The unit also shows the presence similar to a breccias bed with thin-to-thick limestone beds largely consisting of resedimented carbonate (bioclastic and lithoclastic) material originating from the slope/toe of the slope environment. Therefore, based on the conglomerate-level age, the origin of the conglomerate seems related to the major tectonic events affecting the magmatic arc in response to northward subduction of Neotethyan Oceanic Lithosphere.

The youngest of the Maastrichtian event, KMa5 (66.8 Ma), is also of medium amplitude (~ 75 m) sea-level change and is seen in Western Europe, on the Arabian Platform. The presence of Maastrichtian Hayrat gabbroic intrusion (ca. 66–68 Ma; Eyuboglu et al. 2018) emplaced into the sedimentation environment in the region. This study also supports that age is one of the events affecting the sedimentation processes of the region as magmatic intrusion. In such case, the sedimentological and paleontological findings rule out the possibility of the southward subduction model proposed by Eyuboglu et al. (2018). Since the proposed subduction model is not evaluated together with all the geological records, it is evaluated as an incomplete and biased model.

We infer that the paleo-tectonic period of our region is the closing of the ocean and the opening of its new branches. The subduction-related volcanism during these periods has a thick cover. Late Cretaceous volcanic and volcano-sedimentary sequences (> 2000 m thickness) were deposited throughout the northern part of the eastern Sakarya Zone (Okay and Şahintürk 1997). The youngest magmatic rocks in the Sakarya Zone are attributed to early Campanian. Towards early Campanian, a calm tectonical turn was introduced to the environment. It is thought that different sedimentary facies and environmental dynamics in the basin environment developing on the paleotopography are formed by thick volcanic and volcano-sedimentary rocks. Our studies appoint clues for these findings and detail the description of the sediment composition of both calcidebrites and calciturbidites as markers of tectonically movements or sea-level changes.

Conclusions

Two measured stratigraphic sections, SB and SK, were studied to establish the stratigraphic framework of the Şahinkaya Member in the Tonya Formation (Fig. 4). Our sedimentological and paleontological results show the sediment compositional changes of carbonate deposits in a restricted neritic carbonate setting in the Sakarya Zone. Therein, they highlight the differences in the sediment composition of the Şahinkaya Member. The neritic sediment composition is analyzed for the K–Pg transition in two sections in the Düzköy area. Based on stratigraphic distributions of the benthic foraminifera, the Şahinkaya Member succession is constrained to have been deposited in Maastrichtian time span. The Şahinkaya Member carbonates consist of six microfacies reflecting a range of depositional environments from slope to toe of slope (Figs. 5, 6).

It shows that the Şahinkaya Member deposited in the slope/toe of slope carbonate platforms displays differences in sediment composition ranging in accordance with the depositional setting in sea-level change. However, the neritic deposits present in the Çayırbağı–Çalköy areas show a relatively unstable composition of platform-edge or reefal derived fauna. The Şahinkaya Member composition likely seems to relate to major changes in eustatic sea-level fluctuations, not only sea-level rises but also sea-level falls and unstable sedimentary environments at the edge of the reefal carbonate platform. The Şahinkaya Member deposits with reefal-derived sediments evolving like shallow-water redeposited skeletal carbonates accumulated in the active tectonic setting of the Sakarya Zone basin. The Şahinkaya Member shows sediment compositions that differ from the sediment compositions found within Hacımehmet, Gürbulak, and Araklı (Trabzon) regions. The three above-mentioned areas consisted of mixed-type rock and fossil fauna. We can also show the carbonate platform distance, which controls the tilt and spread mechanism of the beds. The redeposited sedimentary carbonate, mixed fauna, and conglomerate deposits exhibited a mixed type of grains to clasts derived from all facies belts present along the neritic carbonate platform to basin transect. This scenario is supported by Haq (2014). The Şahinkaya Member has defined the conglomerate deposits composed of a variety of transport mechanism to major tectonic events and reworked shallow-water materials. The conglomerate levels have been defined within the member and together with angular differences in the layers corresponding to an unconformity surface or hiatus, developing due to regional tectonic events such as erosion/uplift and magmatic intrusions.

The sea-level change transformed carbonate sedimentary rocks together with upper bioclastic carbonate on the slope facies. The most particular feature of this slope is the occurrence, at the toe of slope, displays in both the conglomerate and carbonate beds. This conglomerate-level accretion explains the lateral accretions seen in erosion positioned in the slope direction. The transition from conglomerate level to carbonate beds shows sequence in which accumulated conglomerate level constitutes a core that is blanketed by carbonate level spreading laterally in direction with different bed thickness. The angular unconformities accompanying the existence of the conglomerate level indicate that the Şahinkaya Member is an unconformable sequence. To summarize, sediment composition variations are not related to a specific area on the platform, at the same time, and they are influenced by sea-level changes in the Black Sea. The sediment compositional analysis and regional geology observe this sedimentological process depending on both tectonical events and sea-level changes. In the study area, the depositional environment is attributed to a deposit of back-arc setting of Şahinkaya Member (Fig. 9).

Acknowledgements The authors sincerely thank Orhan Karsli and Utku Avcı (Recep Tayyip Erdogan University), Muhittin Görmüş (Ankara University), Abdurrahman Dokuz (Gümüşhane University) and Merve Özyurt (Karadeniz Technical University) for their constructive comments and language editing. In addition, we are so thankful to Mesut Köroğlu, Semih Köroğlu, Mehdi İlhan and Z. Samet Güloğlu for their help with the transportation to study area and logistics. We are grateful to Lorenzo Consorti (Trieste University) for his helpful remarks on the benthic foraminifers in thin sections.

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