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The Upper Cretaceous calciclastic submarine fan deposits in the Eastern Pontides, NE Turkey: facies architecture and controlling factors

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Abstract: The Tonya Formation, which represents the uppermost part of the Mesozoic sequence in the Eastern Pontides, consists of calciturbidites in Trabzon and its surrounding region. Two stratigraphic sections of the unit were measured in the Hacımehmet and Gürbulak areas to decipher the distribution of rock types, facies architecture, sediment textures and depositional environment. The grain size, channels, suprafan lobes and slump structures of the sediments suggest that calciclastic sequences were deposited in a submarine fan system. Calcarenites/calcirudites and hemipelagic rocks, comprising an alternation of marls and mudstones, are the two dominant lithologies described in the studied calciclastic submarine fan system. Calciclastic facies, which are identified as middle fan deposits, indicate high-concentration turbidity currents in the sequences. The hemipelagic rocks, which are delineated as outer fan deposits, suggest low-energy, deep-marine conditions. The microfacies description and fauna determinations propose the gravity origin for these calciclastic submarine fan deposits. Rudstones, grainstones and packstones are the dominant carbonate textures in the calcarenites. Pelagic marls and mudstones are characterised by a planktonic, foraminifera-bearing, wackestone-mudstone texture. Biogene parts of the calciclastics are fragments of benthonic foraminifers, algae, rudists, echinoids, bryozoa, inoceramids and neritic and pelagic carbonate lithoclasts, which suggest a close contemporaneous shallow marine carbonate depositional environment as their source during their deposition. Palaeocurrent directions, measured from the base of the calciturbidites, show that the components of the calciturbidites were transported from a shallow marine environment lying to the E or SE. The lateral and vertical facies organisation of these calciturbidites favours a deposition of the calciclastic submarine fan model. These deposits were fed by material derived from a shallower water carbonate depositional environment in the Eastern Pontides during the Late Campanian. All the sedimentological properties, combined with the regional data, suggest that the Late Campanian sedimentation in the Eastern Pontides formed in a back-arc environment.

Key words: Late Campanian, calciturbidites, calciclastic submarine fan, microfacies, Eastern Pontides

1. Introduction

Calciclastic submarine fan (CSF) systems are less well documented than their siliciclastic counterparts. However, CSF systems have economic importance due to hydrocarbon-rich fluids migrating to shelf host rocks (Coniglio & Dix 1992). As they are mostly sourced from coeval carbonate platforms, they may provide information about the sedimentary nature and depositional evolution of the adjacent shallow-water setting (e.g., Reijmer & Everaars 1991; Reijmer *et al.* 1991). Reijmer *et al.* (1991) suggested that variations in the grain composition of calciclastic submarine deposits are useful markers of the stratigraphy and sea-level fluctuation in their source carbonate platform areas. Additionally, Reijmer *et al.* (2012) argued that all types of gravity-induced carbonate deposits, calciturbidites and calcidebrites were deposited in response to global eustatic sea-level variations. These sea-level variations may be climate-induced or related to tectonic processes, or a combination of both. The geometric analysis of carbonate turbidite systems resulted in two main models of deposition: the slope and base-of-slope apron model, fed by a multiple linear source (Mullins & Cooks 1986), and the calciclastic submarine fan model, involving a localised source through a main feeder channel system (Payros & Pujalte 2008).

The Upper Cretaceous sequences in the northern part of the Eastern Pontides mainly consist of back-arc volcaniclastic deposits (Şengör & Yılmaz 1981; Okay & Şahintürk 1997; Okay & Tüysüz 1999; Dokuz & Tanyolu 2006). The uppermost part of the volcaniclastic deposits

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is characterised by calciclastic-dominated submarine fan deposits. These sediments mainly consist of an alternation of allochthonous calcarenite and rare calcirudites, including volcanic clasts, hemipelagic sediments that include pelagic marls, claystone and mudstone (Yılmaz *et al.* 2002; Kırmacı & Akdağ 2005; Aydin *et al.* 2008). At present, many calciclastic deposits still match the classical submarine fan models better (Payros & Pujalte 2008). Payros and Pujalte (2008) proposed that CSFs are accumulations of carbonate sediment in gravity flow deposits at the base of a slope fed by a single feeder channel and mostly consist of calciturbidites and debrites, commonly with other types of calciclastic gravity flow deposits and even hemipelagic sediments.

Calciclastic rocks are not widespread throughout the northern part of the Eastern Pontides; the Hacımehmet (south of Trabzon) and Gürbulak (west of Trabzon) areas appear, due to well-preserved Upper Cretaceous outcrops, to be the best localities in which to describe the sedimentological features of the calciclastic successions (Figure 1). Although the calciclastic deposits were extensively studied in the western parts of Turkey by Leren (2003), in the Eastern Pontides detailed microfacies, palaeoenvironmental analyses and sedimentological works are still lacking. The origin of dolomites in the Hacımehmet section was studied by Kırmacı and Akdağ (2005). Another study of the sedimentary properties and biostratigraphy of the Upper Cretaceous sections in the Eastern Pontides was conducted by Özer *et al.* (2008). However, detailed microfacies and depositional properties have rarely been conducted, and so no definite depositional models have been proposed until now. This study aims to document the detailed facies architecture, microfacies analysis and depositional controls of the uppermost Cretaceous Tonya Formation. This study provides a small contribution to our knowledge of carbonate gravity and calciclastic systems and the development of predictive geological models.

2. Regional geological setting and stratigraphy

Turkey is one of the major components of the Alpine-Himalayan orogenic system. Turkey comprises four major tectonic blocks separated by three main high pressure belts (Okay & Tüysüz 1999; Figure 1A). North of the İzmir-Ankara-Erzincan suture in Turkey are three tectonic units, the Strandja Massif, the İstanbul Zone and the Sakarya Zone, which were assembled at different times (Okay & Tüysüz 1999). The Eastern Pontides is used as a geographical representative for the eastern portions of the Sakarya Zone, which is one of the major tectonic blocks of Turkey (Figure 1A). The Eastern Pontides can be basically divided into northern and southern parts, defined by different lithological and tectonic properties (Özsayar *et al.* 1981; Okay & Şahintürk 1997). The main differences between the southern and northern parts of the Eastern Pontides occur in the Late Cretaceous and Middle Eocene volcanic and volcaniclastic rocks, respectively, covering much of the pre-Late Cretaceous geology (Figure 2). The Late Cretaceous corresponds to the time at which a volcanic arc was initiated on the northern shelf of the Neotethys Ocean due to the northward subduction of Neotethyan oceanic crust along the southern border of the Sakarya Zone (e.g., Akin 1979; Şengör & Yilmaz 1981; Okay & Şahintürk 1997; Okay & Tüysüz 1999; Şengör *et al.* 2003; Çinku *et al.* 2010; Karsli *et al.* 2011; Karsli *et al.* 2012; Temizel *et al.* 2012). The subsequent convergence between Gondwana and Laurasia resulted in the formation of a collisional orogenic belt and transformation of the earlier volcanic arc into a magmatic arc throughout the Palaeocene and into the Eocene. The Pontide magmatic arc mainly comprises volcanic and volcaniclastic rocks, and alternating clastic and carbonate rocks, all cut by intrusions. The northern part of the magmatic arc is characterised by a volcano-sedimentary sequence more than 2 km thick (Okay & Şahintürk 1997).

In the northern part of the Eastern Pontides, Mesozoic sedimentation began with the Early-Middle Jurassic Şenköy Formation (Yılmaz & Kandemir 2002) (Figure 2). The Formation unconformably overlies Late Palaeozoic metamorphic basement rocks (Kandemir 2004; Topuz *et al.* 2007, 2010; Dokuz *et al.* 2011) and consists of basaltic and andesitic lithic tuffite, volcanogenic sandstone, shale, basaltic and andesitic lavas, conglomerate (Kandemir 2004; Dokuz & Tanyolu 2006) and Ammonitico-rosso limestone horizons (Kandemir & Yılmaz 2009). In the Late Jurassic, after the deposition of the Şenköy formation, the block topography of the basin evolved into a platform as a result of a decrease in the tectonic activity and filling of the rift basins (Yılmaz & Kandemir 2006), on which was deposited the Upper Jurassic-Lower Cretaceous Berdiga Formation (Pelin 1977), largely characterised by platform-type carbonates. These two formations are not exposed within the study areas. Until the Late Cretaceous, the lithostratigraphic development in the northern part of the Eastern Pontides was very similar to that in the southern part. The Late Cretaceous is dominated by volcanic-sedimentary sequences and comprises four units, namely the Çatak, Kızılkaya, Çağlayan and Tonya formations, distinguished by their rock associations (Figure 2).

The Çatak Formation consists of andesite, basalt and tuffs intercalated with clayey limestones, sandy limestones, tuffite and red *Globotruncana*-bearing pelagic limestones. This formation also contains large limestone boulders of the Late Jurassic-Early Cretaceous Berdiga Formation. The Kızılkaya Formation is composed of rhyodacitic–dacitic lavas and pyroclastic rocks with minor clayey and sandy limestone intercalations. The Çağlayan

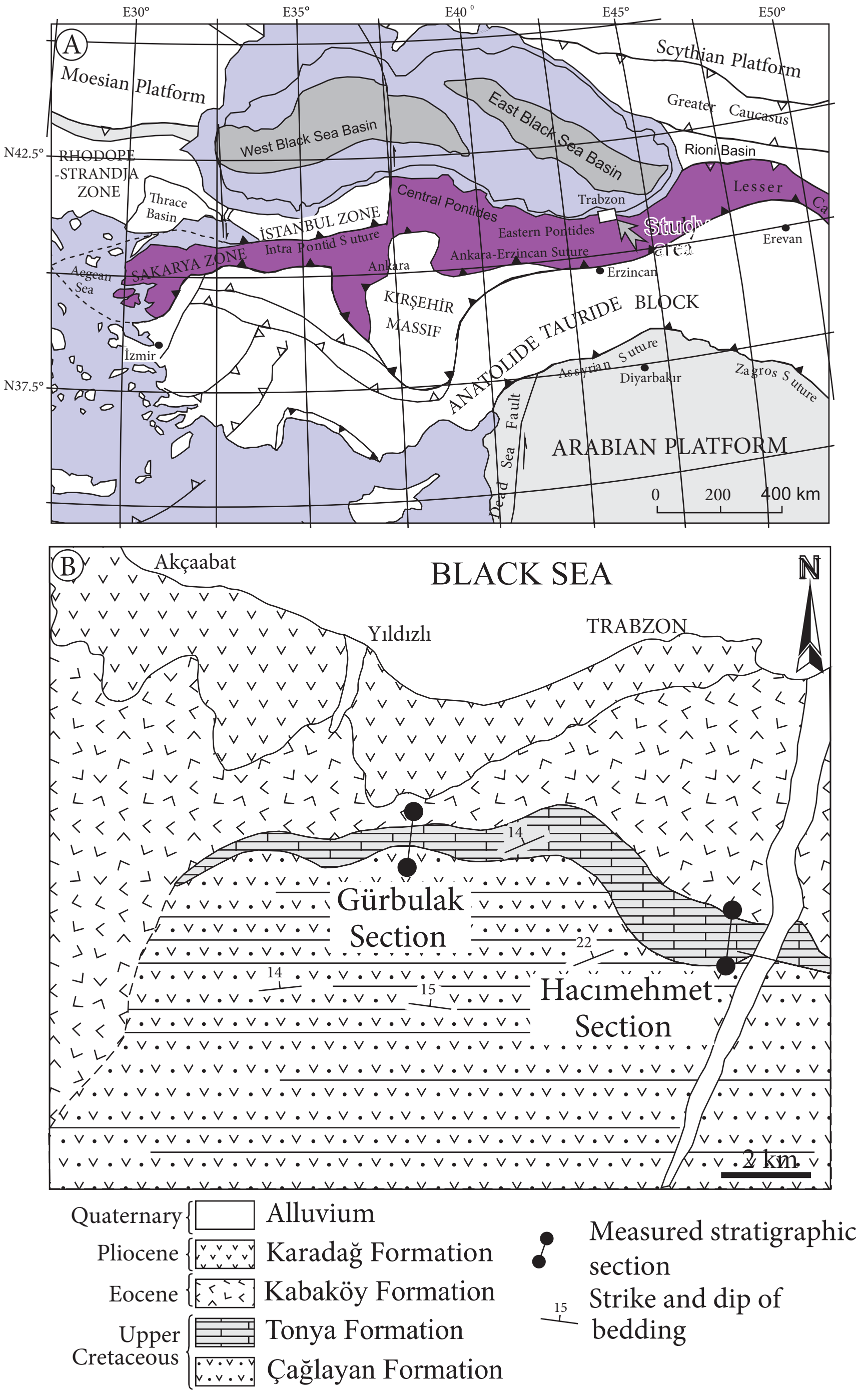

Figure 1. (A) Regional tectonic setting of Turkey with main blocks in relation to the Afro-Arabian and Eurasian plates (modified from Okay & Tüysüz 1999). (B) Simplified geological map of the Gürbulak and Hacımehmet areas and surroundings (modified from Güven 1993).

Formation is composed mainly of marls, sandstones and sandy limestones, locally alternating with spilitic basalts, andesites and associated pyroclastics (Kırmacı & Akdağ 2005). It also contains red *Globotruncana*-bearing pelagic limestone intercalations. The Tonya Formation, which represents the uppermost part of the Mesozoic sequence, has hemipelagic rocks and calciclastic deposits containing shelf-derived carbonate clasts, such as fragments of bivalves,

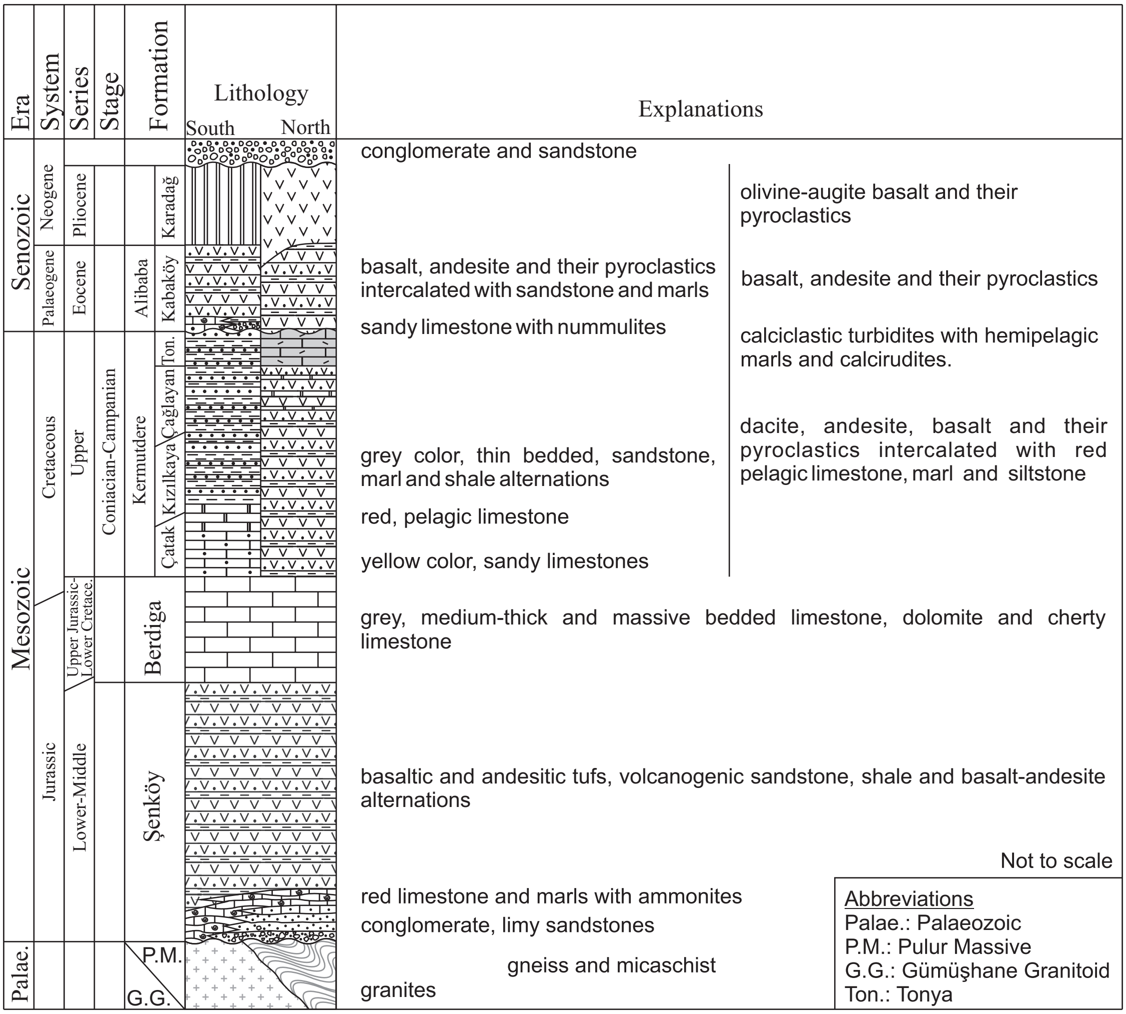

Figure 2. Generalised stratigraphic column of the northern and southern parts of the Eastern Pontides (northern part simplified and modified after Güven 1993, south zone simplified from Yılmaz & Kandemir 2006).

rudists, echinoderms, benthonic foraminifers, red algae, corals and bryozoa, as well as intrabasinal lithoclasts and extrabasinal pebbles and boulders of basaltic and rhyolitic volcanic rocks (Yılmaz *et al.* 2002; Kırmacı & Akdağ 2005, Özer *et al.* 2008). A Late Cretaceous-Palaeocene age has been assigned to the Tonya Formation based on outcrops in the Düzköy area (Korkmaz 1993). However, some researchers (Kırmacı & Akdağ 2005; Aydin *et al.* 2008) claimed a Campanian-Maastrichtian age for the formation outcrops south of Trabzon. Özer *et al.* (2008) revised this age to be early late Campanian in the Hacımehmet area, based on inoceramids and planktonic foraminifers. The Palaeocene mostly appears to be absent in the northern parts of the Eastern Pontides, although a Palaeocene age for the limestones at the top of the Tonya Formation in the Tonya-Düzköy area was reported by Korkmaz (1993) and İnan *et al.* (1999). The Eocene Kabaköy Formation, which rests unconformably on top of the Late Cretaceous and older units, is widely exposed in the northern zone of the Eastern Pontides. The Kabaköy Formation consists of andesite and basalt and associated pyroclastics, with lesser amounts of sandstone, sandy limestone and tuffite (Figure 2). Limestone patches, including nummulite, are located at the bottom of the formation. The Pliocene Karadağ Formation comprises olivine-augite basalt and various pyroclastic rocks (Aydin *et al.* 2009).

3. Materials and methods

The sedimentological data have been acquired by detailed lithostratigraphic logging and petrographic analysis of the Tonya Formation, which is well-exposed in two abandoned quarries in the Hacımehmet and Gürbulak areas near the city of Trabzon (Figure 1B). The samples were collected for both microfacies and biostratigraphical analyses. The Hacımehmet section, located in an abandoned quarry south of the Trabzon city centre, has a thickness of 93 m

(Figure 3). The Gürbulak section, located in an abandoned quarry west of Gürbulak, approximately 7 km west of the Trabzon city centre, is 260 m thick (Figure 4). This study is based on both facies descriptions in the field and microfacies descriptions from thin sections of 160 samples. Uncovered and unpolished thin sections were studied by optical microscopy with a magnification from 15× to 200×. The textures of the samples were defined by following the classification schemes of Dunham (1962) and Embry and Klovan (1971). In the field, sedimentary sequences were distinguished based on their sedimentary structures and granulometry.

4. Facies architecture

The uppermost unit of the Cretaceous sequence has been studied in two localities by measuring the stratigraphic sections in detail to the south of the city of Trabzon (Figures 3 and 4). The Tonya Formation is composed of calciclastics and hemipelagic deposits. The calciclastic components range from fine to coarse sand size. Sand-size grains are the most common, and therefore most calciclastic beds were classified as calcarenites, although rudite-size calcirudites or rudstones, with a grain diameter larger than 2 mm, were locally abundant in these sections, which are channel-like deposits. Mixtures of different-sized calciclastic grains are very common. Hemipelagic rocks are composed of either pure carbonate or are mixed with very fine-grained siliciclastic sediment (marl). These hemipelagic deposits are interbedded with calciclastic deposits. The hemipelagic deposits usually occur as alternating couplets of bioturbated marls, marly limestones and mudstones, 5-40 cm thick. The beds have gradational bounding surfaces and extensive continuity. They contain a rich and diversified planktonic foraminiferal association, including thin-walled, spherical and keeled forms. All of these features attest to an open low energy marine environment for the upper part of the Tonya Formation. Payros *et al.* (2007) suggested that the sedimentation water depth of these type sediments is approximately 400-500 m, based on the planktonic/benthonic foraminifer ratio and bathymetry in present day and Eocene oceans. The calciclastic deposits studied are mainly composed of bioclasts and carbonate lithoclasts. Bioclasts, ranging from fine sand to pebble size, are fragmented tests of shallow water organisms such as red algae, rudists and larger foraminifers (mainly orbitoids). Lithoclasts are the fragments of sedimentary rocks ranging from sand to gravel size. Most of these components were derived from a contemporaneous shallow water carbonate depositional environment, but exotic extraclasts, such as well-rounded different volcanic rock fragments, containing pyroxene, biotite and quartz, also occur. The interlayers of calciclastic deposits within the hemipelagic deposits suggest the resedimentation of shallow water material in deeper water. Seven calciclastic and sedimentary facies are summarised in the Table. They are distinguished by their bed thickness and geometry, sedimentary structures and textural parameters, such as the framework nature, grain size, sorting and grading. Two major facies assemblages, or associations, have been recognised based on the calciclastic and sedimentary facies listed in the Table.

5. Sedimentary petrography

5.1. The Hacımehmet section

The Hacımehmet section starts with channel-like fill deposits at the bottom. The thickness of this level exceeds 5 m (Figure 3; Figures 5A and 5B). It is filled by coarse-grained calcarenites and calcirudites. Rudstone is the dominant texture, represented by sand- to gravel-sized transported skeletal grains (mainly fragments of rudists, echinoids, benthonic foraminifers, algae, bryozoa and rare planktonic foraminifers), neritic and pelagic carbonate lithoclasts (Figure 6B) and volcanic extraclasts of various sizes (Figure 3; Figure 6A). These constituents are especially abundant in the lower part of the beds. This section is composed of a basal bioclastic rudstone with normal grading. The basal rudstone passes up to a finer-grained packstone/grainstone. The lower parts of the beds indicate rapid sedimentation from a high-concentration turbidity current. Dolomitisation at these levels is common. The detrital components are widely cemented by sparry calcite (Figure 6A). Some of the echinoid fragments, which show syntaxial overgrowth and stylolitic contacts, may also occur between these fragments. This section continues upward with calcarenites and rare calcirudites to a hard ground (Figure 3; Figure 5C). Additionally, moderately to poorly sorted rudstones and grainstones are the dominant lithologies, formed from earlier-mentioned components. Rudist fragments are the dominant component in these beds. Algal detritus similar to *Lithotamnium* sp. and *Lithophyllum* sp. are fairly abundant (Figure 3). The 70-m-thick upper part of the Hacımehmet section mainly consists of an alternation of allochthonous calcarenite/calcirudite beds and planktonic foraminifera-bearing hemipelagics, represented by marls and mudstones (Figure 5F). The upper part of the Hacımehmet section starts with a 5-m-thick calcarenite (Figure 3). Rudist and inoceramid fragments are abundant in the upper surfaces of these layers (Figure 5D). Fragments of rudists, echinoids and crinoids dominate the thin sections of these samples, and abundant amounts of algae and bryozoa have also been observed. Inoceramid fragments are first observed in this level (Figure 6D). The upper part of the Hacımehmet section is dominated by grainstones and packstones. These rocks are characterised by the presence of planktonic foraminifers and fragments of undifferentiated algae. The fragments of algae first occur from the 33rd metre

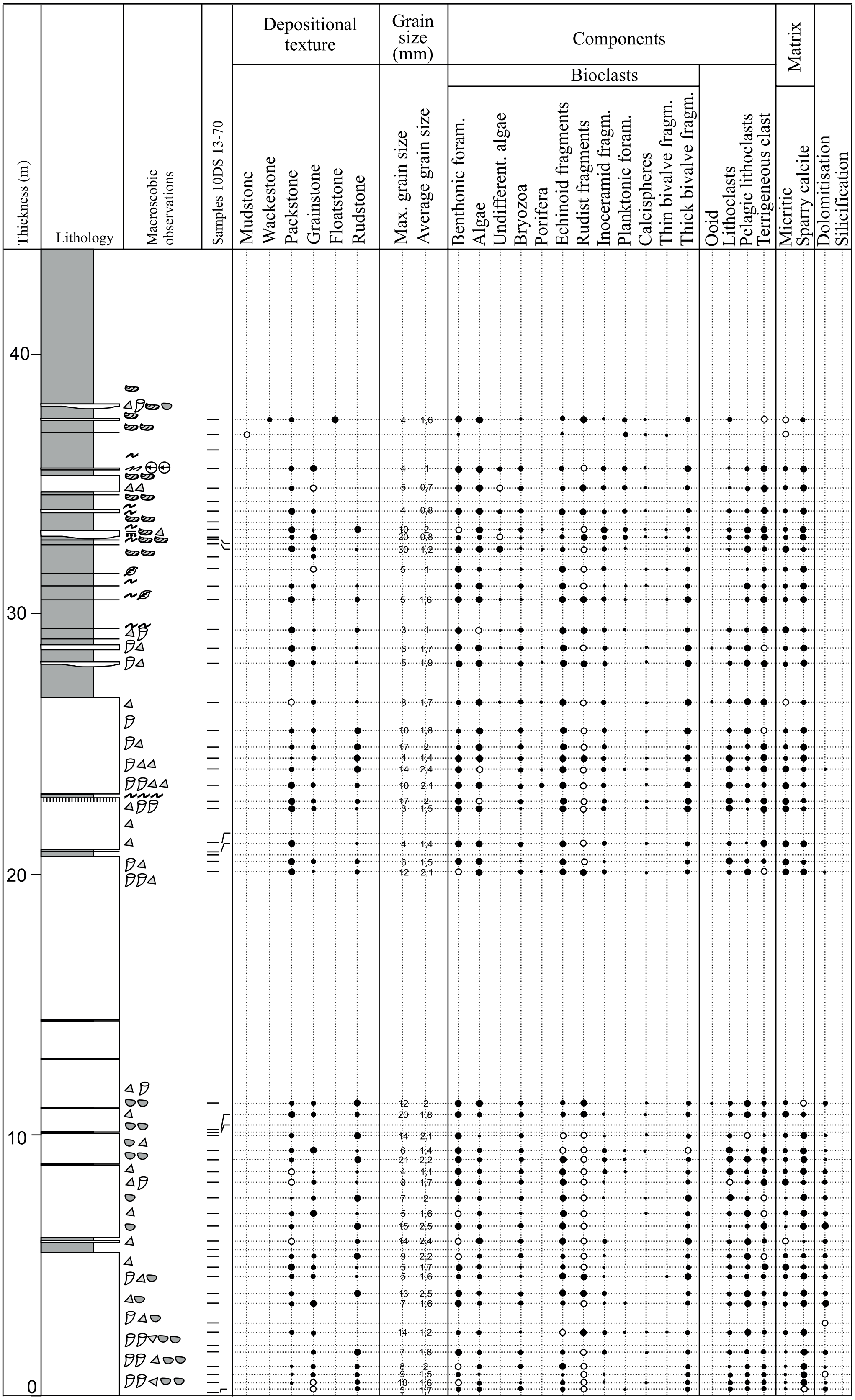

Figure 3. Details of CSF deposits in the Hacımehmet stratigraphic section.

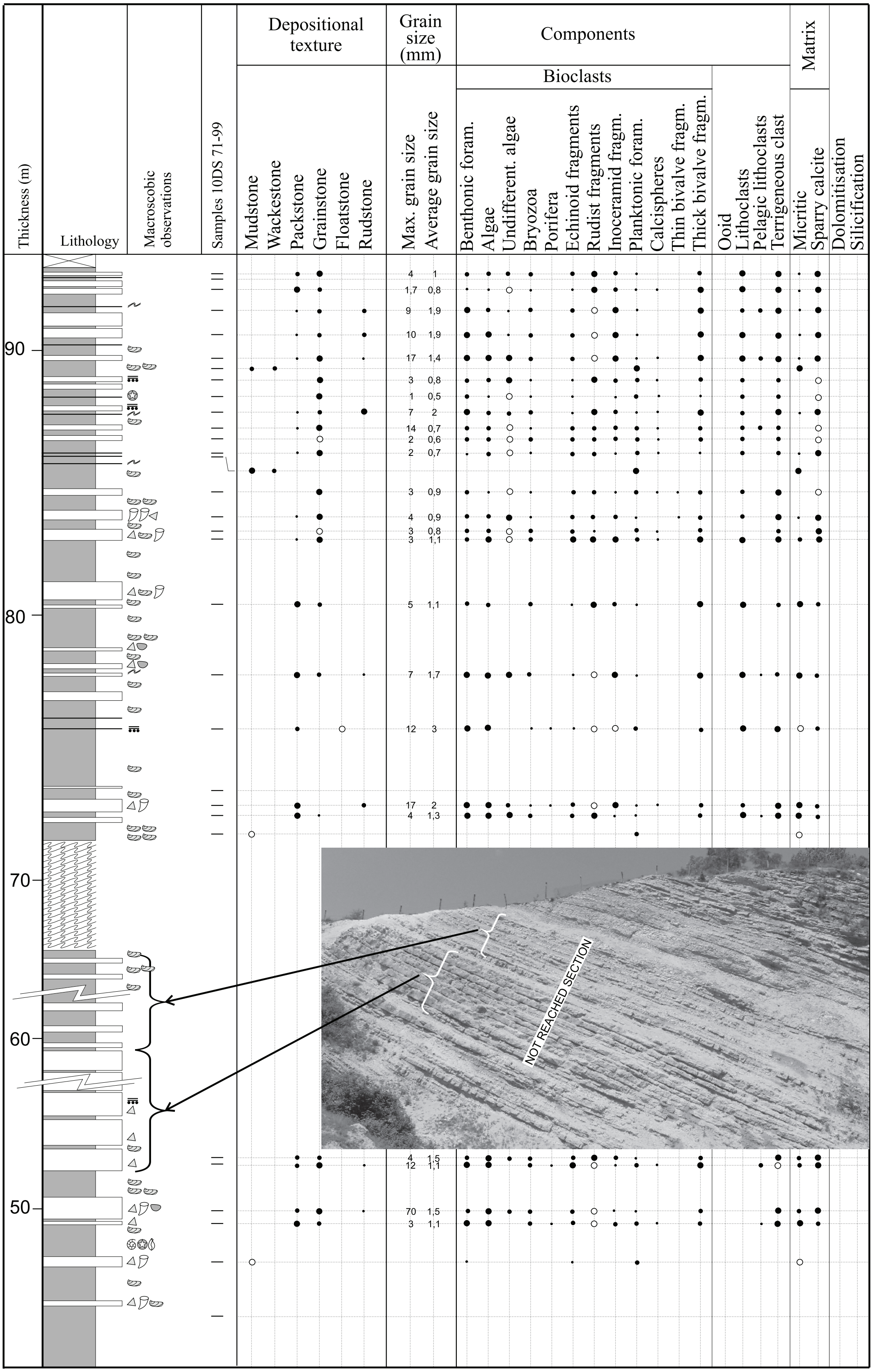

Figure 3. Continued

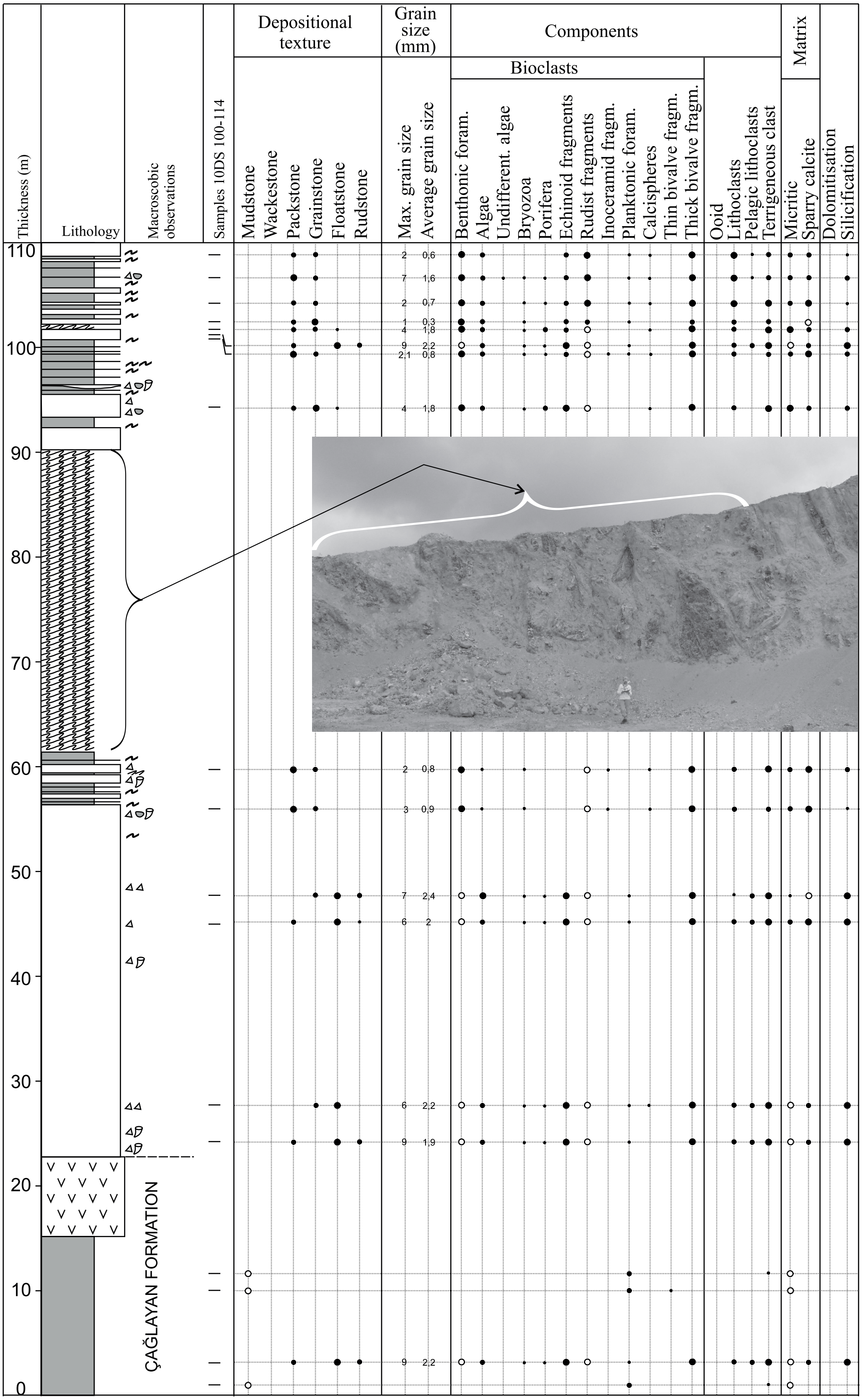

Figure 4. Details of CSF deposits in the Gürbulak stratigraphic section.

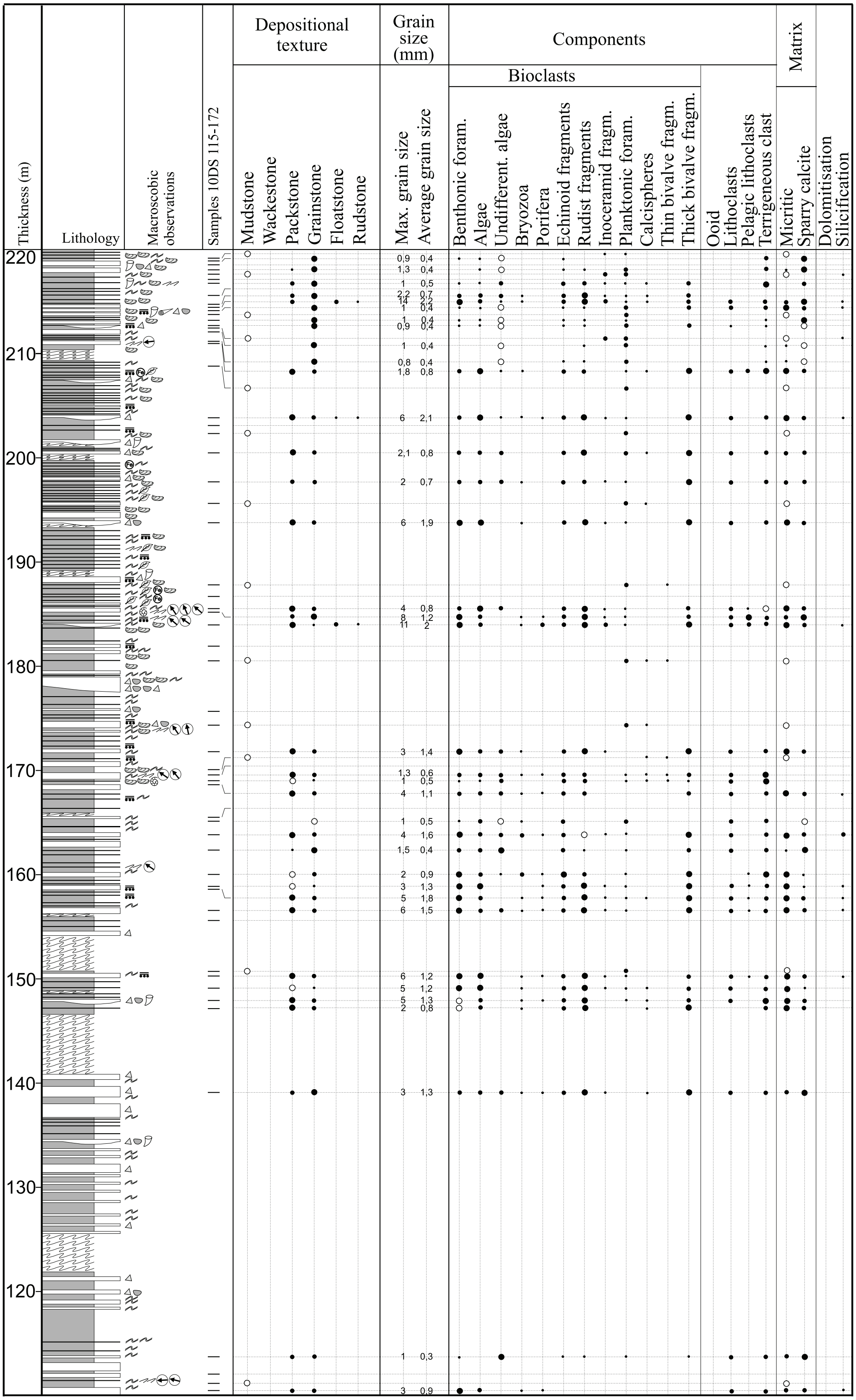

Figure 4. Continued

Figure 4. Continued

Table. Summary of sedimentary facies in the Tonya Formation.

Facies	Lithology and texture	Bedding geometry and thickness	Interpretation
Clast-supported calcirudites	Chaotic, poorly sorted conglomerate with sand to boulder-sized extraclasts and intraclasts derived from neritic in pack-to-rudstone matrix.	Irregular bedding with scoured based, consisting of rapid lateral changes in thickness.	High-concentration turbidity current, distributor channel in proximal-middle fan deposits.
Calcirudites	Poorly sorted orthoconglomerate passing up first into bioclastic rudstone and then into bioclastic grainstone. They consist of abundantly rounded volcanic rock fragments.	Irregular bed with common basal scours and graded into coarse-grained calcarenites.	High-concentration turbidity current.
Massive calcarenites	Bioclastic pack- or grainstone with one or more irregular, discontinuous strings of granule-sized bioclasts (commonly orthophragmanids and rudists) and neritic skeletal components.	Erosive based and laterally continuous thick composite, commonly amalgamated. Normal graded intrabed layers with gradational transitions with scattered volcanic pebbles.	Sandy debris flow followed by suspension sedimentation from genetically related high-concentration turbidity currents.
Stratified/graded calcarenites	Bioclastic rudstones and coarse-grained grainstones passing up to finer grained pack- and/or grainstone.	Medium to thick planar parallel stratification with normal grading, amalgamated, with erosional bases (mostly flute marks) and often undulatory tops.	Grain suspension deposition from a high-concentration turbidity current.
Thin-bedded calcarenites	Well-sorted, fine-grained bioclastic pack- or grainstone, capped with a mud layer gradational into hemipelagic deposits.	Thin beds, generally stratified and laterally continuous. These beds mostly alternate with thin-bedded marl and mudstone. Beds are mostly bioturbated.	Suspension deposition from a low-concentration turbidity current.
Marlstone	Fine-grained bioclastic wackestone composed of calcispheres and planktonic foraminifers. Beds are some with a silty, faintly parallel lamination, commonly grading upwards into mudstones.	Sheet-like and mainly tabular beds, pale grey, some with a slightly undulatory base and/or top.	Suspension fall-out deposition from a low concentration turbidity current.
Mudstone	Sheet-like layers, capping calcarenites, calcilutites or marlstone beds. Beds consist of mudstone to sparse wackestone.	Massive, bioturbated and mainly grey; occasionally whitish to greenish, or olive green with sporadic coaly plant detritus.	Fall out of “background” pelagic suspension; hemipelagic capping of calcarenites.

of the section and are very dominant in thin sections of samples collected from the 83rd metre of the section (Figure 6E). All of the components are mostly cemented by sparry calcite. Hemipelagic rocks, consisting of an alternation of marls and mudstones in these levels, are dominated by mudstones and wackestones (Figure 6J). In wackestones and mudstones, all components are embedded within micritic mud. The microfacies details of these deposits are described in Figure 3. The components represent a foraminiferal carbonate facies (Lees & Buller 1972) and are derived from a contemporaneous shallow-marine environment. A detailed biostratigraphy of the Hacımehmet section was first reported by Özer *et al.* (2008). They reported a late Campanian age, based on the inoceramids and planktonic foraminifers.

5.2. The Gürbulak section

The Gürbulak section has two groups of sediments comprising a 33-m-thick sequence of calcarenites/calcirudites and a 205-m-thick hemipelagic section consisting abundantly of an alternation of marls and

Figure 5. Field appearances of the CSF deposits from the Gürbulak and Hacımehmet sections. (A) General view of the bottom level of the Hacımehmet section indicating middle fan deposits. (B) Close view of the channel deposits at the bottom of the Hacımehmet section and boulders of volcanic rock in the channel deposits. (C) Field photograph of hardground, represented by trace fossils at the Hacımehmet section (the scale is the pen with a length of 14 cm). (D) Close-up view of a calcirudite bed containing very coarse sand to granule-sized abundantly rudist bioclasts and carbonate lithoclasts are clearly seen at the surface of the bed in the Hacımehmet section. (E) Erosive based channel-like calcirudite bed including abundantly bioclast fragments and rounded volcanic rock granules in the Hacımehmet section. (F) Hemipelagic deposits in the Hacımehmet section. (G) Erosive base of the calcarenite bed in the hemipelagic deposits in the Gürbulak section. (H) General view of the hemipelagic deposits in the Gürbulak section and slumped horizon (rectangle). (I) Close-up view of flute marks and bioturbations at the base of a calcarenite bed in the Gürbulak section, arrows indicating palaeocurrent direction. (J) Stack of inoceramid shells in the hemipelagic deposits in the upper level of the Gürbulak section.

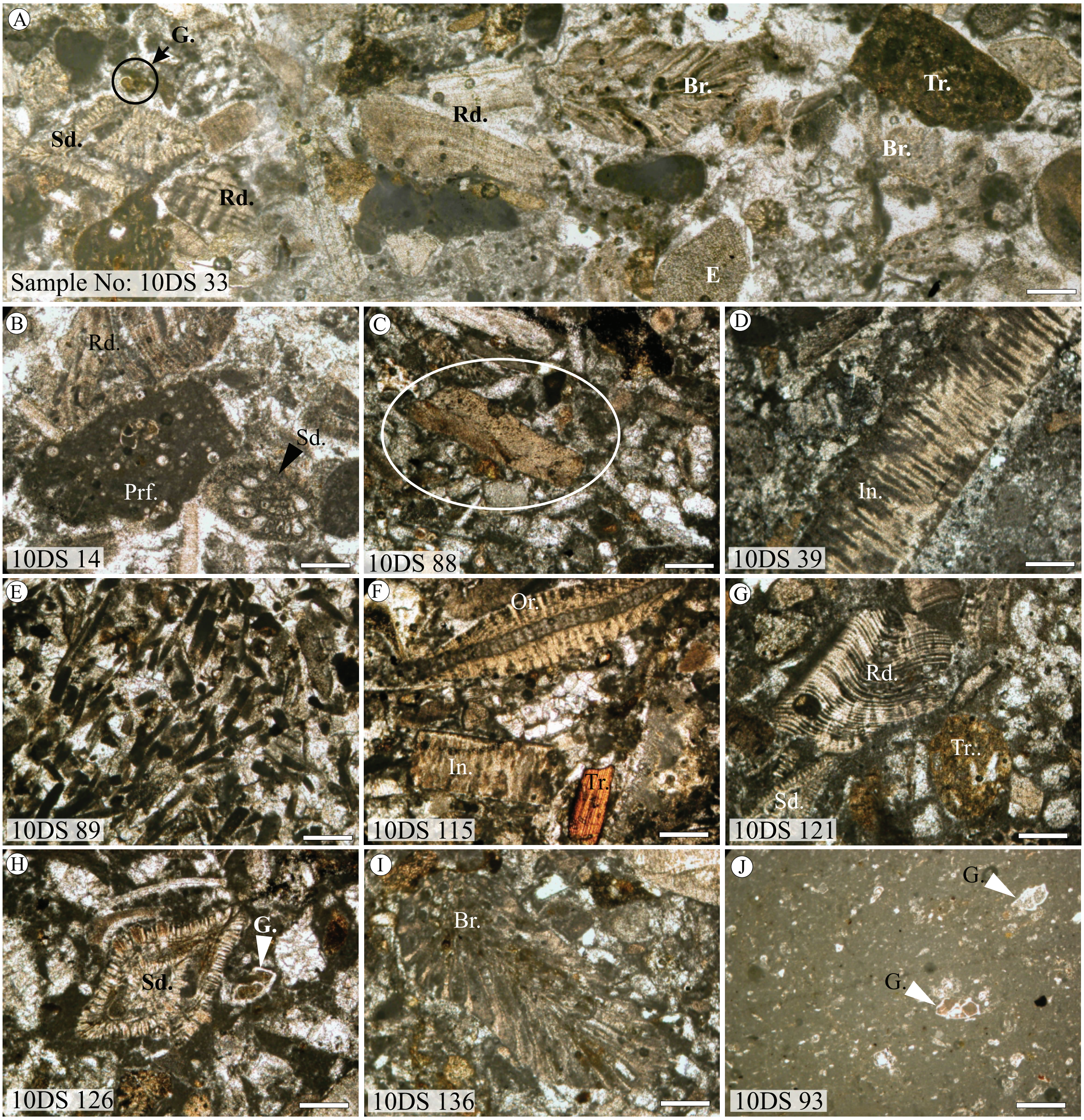

Figure 6. Microfacies photographs of CSF deposits in the Hacımehmet and Gürbulak sections. (A) Rudstone from the lower part of a concentrated density flow deposit in the Hacımehmet section. Bioclastic rudstones rich in benthonic foraminifers (*Siderolites* sp. (Sd.)), differently sized rudist fragments (Rd.), echinoids (E), bryozoa fragments (Br.), terrigeneous volcanic rock fragments (Tr.) and planktonic foraminifers (G). (B) Bioclastic rudstone rich in pelagic lithoclast fragment (Prf.) including planktonic foraminifera and radiolarian, benthonic foraminifer fragments (*Siderolites* sp. (Sd.)) and rudist fragments (Rd.). (C) Bioclastic packstone rich in *Polystrata alba* (in ellipse line). (D) Silicified inoceramid shell in a bioclastic grainstone. (E) Bioclastic grainstone rich in abundant undifferentiated algae fragments, which is generally observed in upper level of the sections. (F) Packstone rich in benthonic foraminifers (*Orbitoides* sp. (Or.)), inoceramid shells (In.) and terrigeneous biotite fragment (Tr.). (**G**) Bioclastic floatstone rich in rudists (Rd.), benthonic foraminifers (*Siderolites* sp. (Sd.)) and terrigeneous particles (Tr.). (H) Bioclastic packstone rich in both planktonic foraminifer (*Globotruncanita* (G.)) and benthonic foraminifers (*Pseudosiderolites vidali* (Sd.)) from the Gürbulak section. (I) A bryozoa fragment in a packstone from Gürbulak section. (J) A mudstone contains abundant planktonic foraminifers (*Globotruncana* sp. (G.)) from hemipelagic rocks (scale bars are 500 µm).

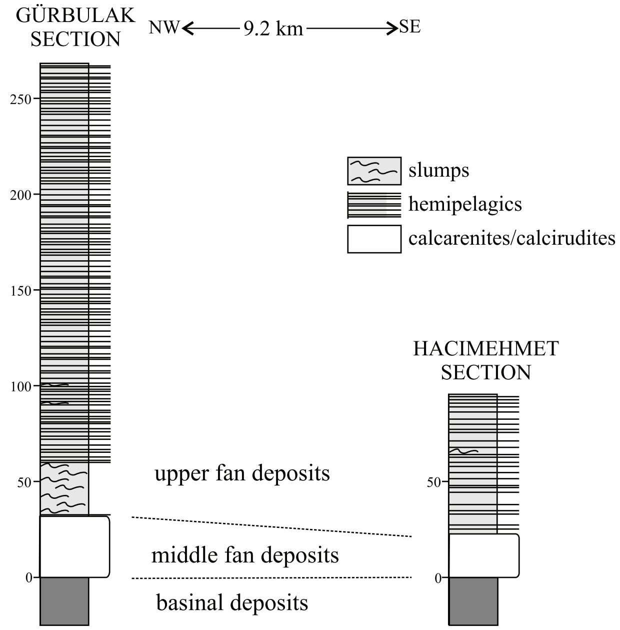

Figure 7. Correlation of simplified lithologies of the Gürbulak and Hacımehmet measured stratigraphic sections.

mudstones (Figure 4; Figures 5G and 5H). The calcareous turbidites are generally poorly sorted with respect to their siliciclastic counterparts (Eberli 1991), and a similar composition is observed in the coarse to medium-grained sediments of the Tonya Formation. The coarse and very coarse material is essentially composed of grain-supported rudstones and rare grainstones lying at the bottom of the section (Figure 4). The rudstones and grainstones consist of transported skeletal grains (fragments of benthonic foraminifers, inoceramids, rudists, bryozoans and red algae), neritic and pelagic carbonate lithoclasts and volcanic extraclasts (Figure 4). The medium calcarenites are generally represented by packstones to grainstones, dominated by echinoids and benthonic foraminifers with rudists and some orbitolinids (Figures 6F-6I). The finest calcarenitic material corresponds to packstones or packstones–grainstones dominated by the above mentioned components. Floatstones are also observed at the top of the hemipelagic part of the section (Figure 6G). The floatstones are less sorted, and their grain granulometry reaches up to a maximum of 11 mm. Shallow-water and deep-water bioclasts in these rocks are the identifiable components. Interparticle pores of calcarenites are mainly filled by sparry calcite cement and a minor amount of micrite matrix (Figure 4). Benthonic foraminifer fragments are also found in some pelagic marls and mudstones. The algae are very abundant in the 205th metre of the section (Figure 6E). Planktonic foraminifers are more abundantly seen in the hemipelagics than those of the Hacımehmet section (Figure 6H). Silicification is common in the hemipelagic part of the Gürbulak section, which is observed especially over echinoid plates and inoceramid shell fragments. Silicification is the most characteristic diagenetic feature of calcareous turbidites, which is probably coeval with lithification (Eberli 1991). Turbidite sedimentation favours silicification because the rapid burial of transported siliceous tests prevents silica from the dissolution of the tests passing into overlying sea water (Bustillo & Ruiz-Ortiz 1987). The microfacies properties of the deposits are described in detail in Figure 4. A detailed biostratigraphy, fossil content and age of the Hacımehmet succession were presented in detail by Özer *et al.* (2008) and Sarı *et al.* (2009). Obviously, the Gürbulak section is the lateral equivalent of the Hacımehmet succession and thus can be biostratigraphically correlated with it.

6. Discussion

6.1. Facies description and associated facies

Basin facies deposits: This facies, observed in both the Hacımehmet and Gürbulak areas, constitutes the upper level of the Çağlayan Formation, located immediately beneath the Tonya Formation (Figure 7). The Çağlayan Formation is a volcano-sedimentary sequence dominated by volcanic rocks originating from arc magmatism. It comprises a series of pyroclastic flows, lithic tuffs, andesites and spilitic basalts alternating with shales, marls and volcaniclastic sandstones as well as red pelagic limestone interlayers. The pelagic limestone horizons of the Çağlayan Formation are red, pink or whitish and thinly bedded. The bedding is smooth, parallel and well-exposed in most places, but some undulose bedding surfaces were also observed. The total thickness of the limestone levels varies between 3 and 8 m, and the thickness of individual beds is approximately 5-30 cm. In thin sections, well-preserved microfossils appear to be scattered within the micritic matrix. Wackestones were also observed. Hematite concentrations along the laminae surfaces and scattered hematite fragments are common. Minor amounts of quartz and feldspar fragments were also observed. In the Hacımehmet area, Özer *et al.* (2008) suggested that the uppermost level of the Çağlayan Formation is composed of an alternation of allochthonous calcarenite/calcirudite beds, conglomerates with mainly volcanic clasts and planktonic foraminifera-bearing red pelagic limestone and mudstone beds. Additionally, Özer *et al.* (2008) described three conglomerate levels consisting of volcanic lithoclasts of pebble to boulder size from the uppermost level of the Çağlayan Formation. The presence of subordinate conglomerates in the upper part of the formation indicates the occasional presence of channels that brought coarse clastic sediments into the basin from the adjacent shelf or shallow environments. Red pelagic interlayers show a planktonic foraminifera-bearing mudstone depositional texture and indicate a Late Campanian age. The occurrence of planktonic foraminifers within these levels involves an open-marine environment and accumulation in the deepest part of the basin. Robinson *et al.* (1995) suggested that the Upper Cretaceous units, including planktonic foraminifera-bearing levels in the northern zone of the Eastern Pontides, were deposited in a deep-marine environment.

Middle fan deposits: The depositional architecture of these deposits is comparatively simple, mostly comprising two facies associations. Volumetrically, the most important deposit is formed by calcarenites/calcirudites with occasional intercalations of thin-bedded hemipelagic rocks composed of marl and mudstones. The average calcarenite/mud ratio is 11.5 (92% calciturbidite and 8% hemipelagic) in both the Hacımehmet and Gürbulak sections in the middle fan deposits. This ratio is obtained when the channel deposits at the bottom of the Hacımehmet section are added. If the deposits of the channel level are extracted, the ratio is reduced to 2.33 (67% calcarenite and 33% hemipelagic).

The middle fan deposits are 17 m thick in the Hacımehmet section and 33 m thick in the Gürbulak section (Figures 3 and 4). In the Hacımehmet section, they are mostly composed of amalgamated, regularly bedded, graded, clast-supported, coarse-grained, abundantly calciclastic and calcirudite deposits up to 1 m thick, with large amounts of cobble-sized volcanic clasts (Figure 5B). Most of the beds in the middle part of the middle fan deposits have commonly tabular, basal surfaces with erosive, plane-parallel geometries exceeding 60 m along the depositional strike and show no remarkable thickness variations. The upper intervals of these deposits are composed mostly of graded calciturbidites, including abundant large bioclastic detritus, intraclasts and basement volcanic rocks. Bioturbation is scarce in both the lower and upper intervals.

In the Gürbulak section, the middle fan deposits are composed of abundant regular-bedded, coarse-grained calcarenites. The lower part consists of a chaotic, 10-m-thick conglomerate with abundant boulder-sized hemipelagic clasts in a calcarenitic matrix. The large hemipelagic/mud clasts and conglomeratic calciturbidites suggest basal plucking of semiconsolidated interbedded muds and calciturbidites by highly erosive sediment gravity flows (Savary 2005). The section has a thick slump horizon between the 62nd and 92nd metres in the Gürbulak section. This horizon was not observed in the Hacımehmet section. It also has coarse-grained calcarenites arranged in channel-like bodies up to 1 m thick, with erosive bases that cut down the calciturbidite and hemipelagic interlayers (Figure 5G). Bioturbation was generally observed and burrows attributable to *Thalassinoides* sp. and *Ophiomorpha* sp. have been identified.

The calcarenitic bodies are the dominant deposits of the middle fan/upper slope. The abundance and frequent amalgamation of turbidite beds implies a high frequency of turbiditic events. Data from the facies suggest that most outcrops are proximal. The calciruditic horizons capping the proximal lobe bodies correspond to small, slightly erosive channels that are interpreted as distributary channels. The occurrence of high-concentration calciturbidites within the lobe deposits suggests proximity to the major provenance. Payros *et al.* (2007) suggested that the flat-based calcarenitic bodies in more distal areas may be interpreted as unconfined, distal equivalents of the channelised lobe bodies. The alternation between distal calcarenitic lobes and mostly hemipelagic horizons could be a response to a lateral shift of the main depositional zones over time. Hence, thick-bedded calcarenitic turbidites accumulated when frequent high-concentration gravity flows reached a particular zone, whereas interlobe hemipelagic deposition is dominant in the same area when high-concentration gravity flows trended elsewhere.

Outer fan deposits: The outer fan deposits are 70 m thick in the Hacımehmet section and 205 m thick in the Gürbulak section (Figure 7). The average calcarenite/mud ratio is 0.51 (34% calciturbidite and 66% hemipelagic) in both sections. In the Gürbulak section, slump beds also occur, accounting for ~18% of the succession. In the Hacımehmet section, the uppermost part of the calcarenite/calcirudite beds of the middle fan deposits is truncated by a hardground (Figure 5C). The hardground is easily recognisable as it is a prominent surface and forms a high relief in the outcrop profile, as first described by Özer *et al.* (2008). The outer fan deposits start with a calcirudite bed that contains abundant fragments of rudists, echinoids, benthonic foraminifers and volcanic rock fragments in the Hacımehmet section (Figure 3). Above this level, the deposits are dominated by hemipelagic rocks. The upper intervals of this sequence are characterised by an alternation of calciturbidites and hemipelagic rocks (marls and mudstones). The calcarenite beds are mostly graded and comprise abundant large bioclastic detritus. The base of the calcarenite beds is mostly erosive, whereas the upper surface boundaries with the hemipelagic rocks are gradational. The hemipelagic rocks consist of an alternation of marls and mudstones in this section and are represented by abundant inoceramids. Bioturbation is generally seen, and burrows attributable to *Ophiomorpha rudis*, *Ophiomorpha* sp. and *Thalassinoides* isp. have been identified.

The Gürbulak section has a dominance of hemipelagic deposits. In the upper part of the section, the dominant facies are highly bioturbated hemipelagic deposits with intercalations of thin-bedded (5-10 cm in thickness), laminated calcarenites (Figures 5G and 5H). The calcarenitic bodies are separated from each other by up to 5- to 7-m-thick intervals of alternations of hemipelagic marls and mudstones with thin-bedded calcarenites. The thin-bedded calciclastics are represented by well-sorted, fine-grained bioclastic pack-/grainstone with a subtle normal grading and are capped by a mud layer. Erosional sole marks (mostly flute marks) are seen at the base of many of the calcarenitic beds (Figure 5I). The bed thickness is less than 10 cm, and the bed-shape is commonly tabular with parallel-sided planar boundaries. The beds are commonly laterally continuous. These intervals correspond to the T_{bc} intervals of Bouma (1962). This facies was formed by suspension deposition from a low-concentration turbidity current. This alternation of fine-grained intervals comprises 40% of the outer fan deposits. The facies association is composed of comparatively medium-bedded calcarenites randomly scattered within the hemipelagic deposits. Most of these calcarenitic bodies are composed of irregularly amalgamated, stratified and graded calciturbidites. These calcarenitic bodies have channel-like erosive bases (Figure 5G). These fining-upward lensoid packages are considered to represent small- to medium-sized intralobe channels corresponding to distributary channels. In the Gürbulak section, some of these small channel-like calcarenites are presumably related to the minor lobes developed in the outer fan deposits. The channel-like, coarse-grained calcarenitic bodies consist of abundant rudist bioclasts and volcanic rock fragments (Figure 4). Calcarenitic bodies are characterised by well-developed grading, typically from coarse calcarenites to calcilutite. The upper parts of the individual graded deposition units are typically planar laminated. The sedimentary structures as a whole are indicative of deposition by turbidity currents (Bouma 1962). However, complete A to E divisions of the Bouma sequence are not always present. Inoceramid shells are abundant further above the 168th metre of the Gürbulak section (Figure 5J). Rare ammonite moulds were observed in various levels of the section (Figure 4). Palaeocurrent indicators, including flute marks, are abundant, showing that the calciclastic gravity flows in the outer fan deposits might be derived from the E-SE. Bioturbation is generally common, and burrows attributable to *Thalassinoides* sp., *Scolocia* sp., *Ophimorpha* sp., *Halopoa* sp. and *Paleodictyon* sp. have been identified (Figure 4).

The position and facies of these deposits demonstrate that they represent the lower part of the CSF deposits. The dominant facies association within these deposits indicates a low-energy environment with the occasional influx from low-concentration turbidity currents. The sedimentological features indicate a dominance of the hemipelagic settling. The upper interval, comprising fine-grained hemipelagic intervals separated by channel-like calcarenitic bodies, indicates less energetic conditions with a predominance of hemipelagic settling. Although calcarenitic bodies are characterised by more energetic environments, fine-grained hemipelagic intervals may represent comparatively quiet periods during which sediment influx into the system was reduced and no channelling occurred. However, the presence of slumps in the sequence, especially in the Gürbulak area, is clear proof of syn-sedimentary instability (Figure 5H). Beds with slump folds predominate in the outer fan deposits of the Gürbulak section, where beds reach more than 2 m thick. Typical slump beds display predominantly disrupted, folded, originally laminated hemipelagic strata with or without very rare silt and finer calciclastic beds (Figure 5H). The folded beds grade into marly beds with a chaotic structure and massive appearance. Gradations to pebbly mudstones and block-bearing mud flows were also observed. The upper and lower boundaries of the beds appear to be planar, although the lateral control of these surfaces is poor, due to poor outcrop. Locally, marlstone packages with lenses rich in well-preserved macrofossils (mainly inoceramid bivalves) are also incorporated into the slumps. The laminated appearance and planktonic-rich foraminiferal assemblages of the deposits indicate an upper slope origin for the greater part of the slumped material. The slump structures in the sequences do not show a clear orientation. Keeling & Stanley (1976) suggested that the increasing pore pressures induced by this rapid accumulation and the accompanying rapid subsidence are considered to be the principal factors causing slumping. In addition, volcanic tremors and a high general seismicity associated with volcanic regions may have contributed to the formation of slumps.

Channel and lobe systems: The channel was observed at the bottom of the Hacımehmet sequence (Figures 5A and 5B). Although the channel margin is not exposed, the lateral accretion architecture itself provides compelling evidence of channel-fill deposits. The covering package of the alternation of dominant calcarenites and calcareous mudstones indicates channel abandonment. This channel is more than 5 m deep, but its width was not observed due to vegetation cover (Figure 5B). It is filled by calcarenites and calcirudites containing shelf-derived carbonate clasts, such as fragments of bivalves, echinoderms, benthonic foraminifers, red algae, rudists and bryozoa, as well as intrabasinal limestone clasts and extrabasinal pebbles/boulders of basaltic and rhyolitic volcanic rocks. Volcanic clasts have various sizes, from sand to boulder, in this part of the section (Figure 5B). The centre of the channel is composed of coarse calcarenites and calcirudites that grade upwards to medium calcarenites, which, in turn, spill over the channel. Microfacies of these calciclastics are represented by grainstones and rudstones dominated by rudist fragments, echinoids, large benthonic foraminifers, red algae, rare planktonic foraminifers and coarse-grained pelagic and neritic lithoclasts (Figure 3).

The clast-supported calcirudites and pebbly calcarenites consist of thick- to thin-bedded, coarse- to medium-grained and normally graded beds in the upper part of the Hacımehmet sequence. These beds show bioturbation, amalgamation and channel structures as well as load marks. The classic turbidites are characterised by medium- to thin-bedded, medium- to fine-grained, normally graded beds, alternating with medium- to thin-bedded marls. Channel fillings have been observed in the Hacımehmet section and particularly in the outer fan deposits of the Gürbulak section (Figure 5E). A large volume of sediment has been removed from the platform or shallowest area and transported into the adjacent basin through these channels. During this process, coarse-grained sediment was selectively deposited, filling the channel. The coarsest clasts of volcanic rocks are derived from the older formations that include volcanic rocks.

The lobe-shaped bodies, found in the carbonate fans, are interpreted as lobes of sediment deposited relative to the channel. Sediments within the lobes originate from turbidity flows. Most of these lobes are still preserved as features resistant to weathering (Figure 3). They show many characteristics typical of turbidites, such as a well-developed, conspicuous internal parallel lamination and occasionally positive grading. Nevertheless, other important turbidite structures, such as scour marks, ripples and convolute lamination, are absent or rare. This situation is presumably due to the extremely coarse grain size of the deposits. A significant part of the mobilised skeletal particles derived from the shallow carbonate platform are granules to coarse grains. When sediments are finer than medium size, they can be maintained in suspension by fluid turbulence to give low-density turbidity currents. The deposits of these currents are characterised by graded beds showing well-developed Bouma sequences. High-density turbidity currents can transport a large amount of coarse sediment. In the Hacımehmet section, this fining-upward package between the 52nd and 67th metres is considered to have small- to medium-sized lobe deposits (Figure 3). Additionally, minor lobes and channel-like levels formed in the outer fan deposits in the Gürbulak sequence (Figure 4). In the upper part of the Gürbulak sequence, horizons of calciclastics with irregular bases are considered to be distributary channels. Some of the small channels were presumably related to the minor lobes developed in the outer fan deposits of the Gürbulak section. In the studied successions, feeder channels for the lobes have not been identified.

6.2. Depositional properties of the CSFs

The calciclastics studied were clearly deposited by turbidity currents, as indicated by their texture, internal structure, sole marks and depositional periodicity. These features indicate that the sediments were removed, remobilised and redeposited in CSF systems. Sediments in the CSF consist of turbiditic carbonates (calcarenites and calcirudites) and hemipelagic deposits (Figure 7). The middle fan deposits are characterised mostly by calcarenites and calcirudites, whereas the outer fan deposits are characterised mostly by hemipelagic deposits composed of muddy beds (Figure 7). Structures indicating slumping and sliding processes are abundant, and shallow-water bioclastic sediments, which were transferred downslope through the channels, are abundant in these deposits. The calciclastic rocks with these features are classified as 'limestone turbidites' (Flügel 2004) or 'calciclastic submarine fan deposits' (Payros & Pujalte 2008). As these allochthonous or redeposited beds are bounded by and alternate with the background sediments, their components should have been transported from adjacent shallow marine and slope environments to the deeper basinal conditions by turbidity currents. Therefore, the investigated calciclastics and hemipelagic deposits appear to be part of the CSF system. Payros and Pujalte (2008) emphasised that two main lithologies are generally coeval in CSFs: calciclastic sediments and muds. Braga *et al.* (2001), Payros *et al.* (2007) and Payros and Pujalte (2008) suggested that major components of calciclastic beds in fans are loose carbonate allochems derived from shallow-water areas. The most common grain type is skeletal, but ooids and peloids also occur. The investigated calciturbidites do not contain a significant amount of non-skeletal grains. The non-skeletal grains mainly comprise peloids and ooids.

The proportion of calciclastic to muddy sediment varies considerably down the depositional dip (coarser-grained sediments in the proximal parts, finer-grained in the distal parts) and along the depositional strike (Van Konijnenburg *et al.* 1999). Wright and Wilson (1984) provided calciclastic/mud values that range from 1:2 to 4:1 in different slices of the succession studied in the Portuguese Cabo Carvoeiro Formation. The most detailed information on the calciclastic sediment content and distribution in CSFs was provided by Payros *et al.* (2007) from the Pyrenean Anotz Formation. They showed that the calciclastic content varies from 20% to 90% in the different environments of the Anotz CSF systems. According to their content of calciclastic and hemipelagic sediments, the Hacımehmet and Gürbulak sections can be divided into two parts, the middle and outer fan deposits, which contain varying proportions of calciclastic and hemipelagic deposits. The two lithologies described above show two major groups of facies. The hemipelagic deposits generally contain the remains of open-marine benthonic and/or planktonic organisms and hence indicate low-energy deep-marine conditions, and these deposits are considered to be the result of background hemipelagic sedimentation. These deposits, characterised by random alternations of unconfined thin-bedded calciturbidites and fan fringe deposits, are recognised in most CSFs. Calciclastic facies are highly variable and composed of different-sized components, such as calcarenites and calcirudites. They indicate high-concentration turbidity currents in the sections.

CSFs are much smaller than siliciclastic submarine fans and are thus commonly referred to as small-sized systems (Payros & Pujalte 2008). The width of the CSF is variable and generally shorter than the length. The thickness of an individual CSF system varies from tens to hundreds of metres (Payros & Pujalte 2008). From the investigations of the Hacımehmet and Gürbulak sections, making an inference about the exact dimensions of the CSF system appears impossible. However, the presence of outcrops of Late Campanian calciclastic deposits along a line parallel to the Black Sea side suggests a regional scale for the dimensions of the studied CSF system. Palaeocurrent data showing component derivation from E-SE for the sections suggest that the source area should be linear, similar to that of basin margin-derived sediments and unlike major point sources. Palaeostructures useful for the determination of the palaeoslopes were frequently observed. Well-developed erosional sole marks were observed at the base of many calcarenite beds throughout the region, occurring more commonly in the thinner beds (3-30 cm), especially in the Gürbulak section. The most abundant erosional sole marks in these sections are flute casts (Figure 5I). The predominant trends of the palaeocurrents are towards the south and south-east. Most of the bioclastic carbonate detritus is derived from intrabasinal sources, such as reefs that possibly grew at the edge of the marginal shelf and platform. The continuous erosion of these regions may have supplied significant amounts of material to the sediments deposited in the deeper part of the basin. The volcanic-derived components were transported partly from outside the basin and partly from internal sources by coeval erosion, which documents the existence of these units in the source areas.

The hemipelagic deposit comprises alternating couplets of highly bioturbated marls and marly limestones, several decimetres thick, with gradational transition intervals and usually great lateral continuity, although marly limestone beds are occasionally nodule-shaped. These hemipelagic deposits are rich in planktonic foraminifers with a high specific diversity, indicating an open-marine, low-energy environment, characteristic of the outer fan deposits of the Tonya Formation. Redeposited bioclastic materials (algae, bryozoa etc.) are very diversified and derived from a shallow marine carbonate production environment. Bioclasts are found in the submarine lobes and channels at the CSF deposits of the Tonya Formation. Bryozoa are small colonial organisms with little tolerance for strong waves, commonly present in shallow to moderately deep seawater of normal salinity (Tucker 2001; Flügel 2004). Red coralline algae are encrusting, coating, cementing and binding organisms common in high-energy, shoal-water reef or bank-edge setting (Adams & McKenzie 1998; Tucker 2001); they prefer clear, low-turbidity, generally shallow water (Adey 1986). The red coralline, algae and bryozoan colonies probably increase the latter's tolerance of wave action and allow the bryozoa to live in relatively shallower water. *Polystrata alba* is a peyssoneliacean algal species observed in all levels of the two sections (Figure 6C), suggesting temperate and tropical to subtropical water depths from a few metres to more than 100 m, and its distribution is controlled by the light intensity, current regime and sediment input (Flügel 2004). Rudist fragments, which are a significant bioclastic component of deposits, are also inhabitants of shallow water environments. This composition of bioclastic sediments may indicate a foramol-type source (temperate carbonates) involving warmer climatic conditions for the Pontides than that of the present. According to the palaeomagnetic data (Kissel *et al.* 2003), the Pontides was located at approximately 20°N in the Late Cretaceous to Early Palaeocene period. This palaeogeographic position may be compatible with the palaeontological data acquired by this study because the definition of temperate carbonates is based on both water temperature and salinity (Lees & Buller 1972; James 1997). Temperate carbonates are typically unlithified or only weakly lithified on the seafloor prior to burial (Nelson 1988; James 1997), which makes them prone to syn-sedimentary removal, transport and redeposition. Braga *et al.* (2001) emphasised that this lack of stabilisation provides sediment with a loose characteristic and that the skeletal particles are easily mobilised as individual grains. In these calciclastic sediments, once removed, the skeletal particles are placed into suspension and transported downslope in turbidity flows, together with siliciclastic grains that behaved in a similar manner.

6.3. Triggering mechanism of calciclastic deposits

Redeposited carbonate deposits can be triggered by a number of mechanisms, including earthquakes, tsunamis, relative falls in the sea level, oversteepening of a platform margin, differential compaction and even bolide impacts (Sandberg & Warme 1993). Most of the CSFs were formed in tectonically active areas, and therefore seismic activity is thought to be the most common triggering mechanism to form resedimented carbonates (Bice *et al.* 2007; Spalluto *et al.* 2007). Turbidites are commonly reported as a major component of the slope, toe-of-slope and basin environments. In the modern Bahamas, turbidity currents appear to be the primary process responsible for transporting shallow-water debris into the deep basins (Mullins 1983; Mullins *et al.* 1984). Turbidity currents can be maintained as long as the energy lost to friction is compensated by gravity (Middleton & Hampton 1973), and thus, they can be transported down slopes of less than 0.5 degrees (Stow 1986). In this respect, several studies in the surrounding areas and studied deposits have originated from the same source due to a phase of instability and resedimentation during the Late Cretaceous. For several of these gravity sediments, tectonism has been evoked as a triggering factor (Borgomano 2000; Casabianca *et al.* 2002; Drzewiecki & Simo 2002; Savary & Ferry 2004; Savary 2005; Bice *et al.* 2007; Heba & Prichonnet 2009; Rubert *et al.* 2012), which is mirrored by a series of genetically related formations into which the Tonya Formation can be incorporated. This tectonism was probably associated with the beginning of the convergence between the Anatolian-Tauride block and Pontide block in the Late Cretaceous period (Karsli *et al.* 2011). The vertical evolution of gravity systems is also dependent on the eustatic fluctuations of sea level and sediment supply (Eberli 1991).

The sedimentation of carbonate gravity deposits is favoured during highstand sea-level periods when carbonate production is high (Eberli 1991). Nevertheless, the influence of the global eustatic sea level might be obliterated by local sea-level changes induced by tectonic instabilities. The occurrence of marly intervals between the calciclastic bodies of the studied CSF complex can be regarded as evidence of some intervals, during which the resedimentation processes were essentially halted. To better explain this stop-and-go behaviour, two main allocyclic factors caused by eustatic sea-level changes and tectonism, acting alone or in combination, can be envisaged. Pujalte *et al.* (2000, 2002) showed that the intervals between active calciclastic resedimentation correspond to the periods in which vast areas of the inner carbonate ramp remained subaerially exposed and the production of shallow-water carbonates became restricted to a comparatively narrow belt in the outer ramp. In contrast, the hemipelagic units separating the calciclastic bodies correspond to periods in which the carbonate ramp was completely flooded and the outer ramp area was drowned. In this respect, the calciclastic members and hemipelagic units of the Tonya Formation are attributed, respectively, to relative sea-level lowstand and highstand periods.

Despite the shallow origin of most components in the CSF deposits of the Tonya Formation, the petrological and sedimentological features described above are clearly proof of their resedimentation by different energy types of gravity flows, mostly turbidity currents. The calciclastic beds are commonly amalgamated in the middle fan deposits, showing that resedimentation processes were very frequent and almost continuous.

Sea-level changes and tectonic processes play a major role in shaping the carbonate submarine fan systems (Reijmer *et al.* 2012). The dominance of skeletal grains in the studied calciturbidites characterises the sea-level lowstands. However, the presence of non-skeletal grains, although in insignificant amount, suggests that the sea level during the deposition of these calciclastics was occasionally at a highstand level. Reijmer *et al.* (2012) suggested that non-skeletal grains will only be produced and exported when the shallow water realm of the flat-topped carbonate platform is flooded and that glacial calciturbidites will almost be completely devoid of these types of non-skeletal grains. Hence, the composition of the calciclastics is dominated by skeletal grains derived from the margin and upper slope of the carbonate platform. The investigated calciclastics contain significantly higher amounts of skeletal grains compared with non-skeletal grains. This situation is seen not only in these calciclastic deposits of the periplatform components at the Eastern Pontides but also in the sediment export patterns of the Triassic calciturbidites at the Eastern Alps in Austria (Reijmer *et al.* 1991; Reijmer 1998), Cretaceous slope and slope apron deposits (Everts & Reijmer 1995; Everts *et al.* 1999; Savary & Ferry 2004) and Miocene slope deposits of the Bahamas (Betzler *et al.* 2000). Calciturbidites include neritic skeletal grains such as algae, benthonic foraminifers, bivalves and rudists. These constituents occur at the edge of the platform and on the platform margin (Reijmer *et al.* 2012). Reijmer *et al.* (2009) also imply that the reduced occurrence of micrite within these deposits, to some extent, supports their origin from the edge of the platform in which grainstones dominate.

7. Conclusions

Microfacies within the sedimentation display the presence of planktonic foraminifers, which is a marker of slope or deeper environments. The petrographic descriptions show a mixture of shallow-water and deep-water faunas, such as rudists and benthonic and planktonic foraminifers. This mixing, together with the sedimentological field study, supports a gravity origin for the calciclastic deposits of the Hacımehmet and Gürbulak areas in Trabzon. These density-flow deposits are dominated by calcarenites and calcirudites, which mainly constitute grainstones and rudstones, which are accumulated into sequences with granulometry variations, thickness variations, sedimentary structures, microfacies properties and other features (bioturbation etc.) that are assumed to be the result of gravity currents. All of the facies and features described suggest a CSF system deposited during the Late

Campanian period. The calciclastic deposits delineated by this study are characterised by seven different calciclastic and sedimentary facies. They appear to have been accumulated in an upper and a lower slope environment of a CSF. Such a CSF environment is also indicated by several other features, e.g., channels, suprafan deposits, alternations, erosive bottom marks, grading and lateral variations. Redeposited bioclastic materials are very diverse and derived from a shallow-marine carbonate production environment. The calciclastic and hemipelagic components of the Tonya Formation record relative sea-level lowstand and highstand periods, respectively. The calciclastics and hemipelagic deposits, which are the two major lithologies described in this study, show two major groups of facies. The hemipelagic deposits generally contain open-marine benthonic and/or planktonic organisms and hence indicate low-energy deep-marine conditions; therefore, these deposits are considered to be the result of background hemipelagic sedimentation. The calciclastic facies are highly variable and composed of different-sized components, such as calcarenites and calcirudites. They indicate high-concentration turbidity currents in these sections. Palaeontological and sedimentological data obtained from the studied sequences suggest that a Late Campanian shallow-marine depositional environment existed in the northern part of the Eastern Pontides. This shallow-marine environment was suitable, despite volcanism, for the deposition of calciclastics and living organisms, as demonstrated by the many fossil groups, such as benthonic foraminifers, rudists, bryozoa, crinoids and red algae. This sedimentological and palaeontological evidence appears to indicate for the studied sections a geometry of submarine fan systems, fed from coeval shallow-water environments.

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References

Adams, A.E. & MacKenzie, W.S. 1998. A Colour Atlas of Carbonate Sediments and Rocks under the Microscope. Manson Publishing, London.

Adey, W.H. 1986. Coralline algae as indicators of sea-level. *In*: Van De Plassche, O. (ed), *Sea-Level Research: A Manual for the Collection and Evaluation of Data*. Free University of Amsterdam, Amsterdam, 229-279.

Akın, H. 1979. Geologie, magmatismus und Lagerstattenbildung im ostpontischen Gebirge/Türkei aus der Sicht der Plattentektonik. *Geology Rundschau* **68**, 253-283.

Aydin, F., Karsli, O. & Chen, B. 2008. Petrogenesis of the Neogene alkaline volcanics with implications for post-collisional lithospheric thinning of the Eastern Pontides, NE Turkey. *Lithos* **104**, 249-266.

Aydin, F., Karslı, O. & Sadıklar, M.B. 2009. Compositional variations and zoning types of low-pressure clinopyroxene phenocrysts in Neogene alkaline volcanic rocks with petrogenetic implications, NE Turkey. *Turkish Journal of Earth Sciences* **18**, 163-186.

Betzler, C., Pfeiffer, M. & Saxena, S. 2000. Shedding patterns and sedimentary cyclicities in periplatform deposits of a Neogene carbonate platform (Miocene, Great Bahama Bank). *Geologische Rundschau* **89**, 140-153.

Bice, D.M., Montanari, A. & Rusciadelli, G. 2007. Earthquake-induced turbidites triggered by sea level oscillations in the Upper Cretaceous and Paleocene of Italy. *Terra Nova* **19**, 387-392.

Borgomano, J.R.F. 2000. The Upper Cretaceous carbonates of the Gargano–Murge region southern Italy: a model of platform-to-basin transition. *AAPG Bulletin* **84**, 1561-1588.

Bouma, A. 1962. Sedimentology of Some Flysch Deposits. Elsevier, Amsterdam.

Braga, J.C., Martin, J.M. & Wood, J.L. 2001. Submarine lobes and feeder channels of redeposited, temperate carbonate and mixed siliciclastic–carbonate platform deposits (Vera Basin, Almeria, southern Spain). *Sedimentology* **48**, 99-116.

Bustillo, M.A. & Ruiz-Ortiz, P.A. 1987. Chert occurrences in carbonate turbidites: examples from the Upper Jurassic of the Betic Mountains (southern Spain). *Sedimentology* **34**, 611-621.

Casabianca, D., Bosence, D. & Beckett, D. 2002. Reservoir potential of Cretaceous platform-margin breccias, central Italian Apennines. *Journal of Petrology and Geology* **25(2)**, 179-202.

Coniglio, M. & Dix, G.R. 1992. Carbonate slopes. *In:* Walker, R.G. & James, N.P. (eds), *Facies Models: Response to Sea-Level Changes*. Geological Association of Canada, St John's, Newfoundland, 349-374.

Çinku, M.C., Ustaömer, T., Hirt, A.M., Hisarli, M., Heler, F. & Orbay, N. 2010. Southward migration of arc magmatism during latest Cretaceous associated with slab steepening, East Pontides, N Turkey: new paleomagnetic data from the Amasya region. *Physics of the Earth and Planetary Interiors* **182**, 18-29.

Dokuz, A. & Tanyolu, E. 2006. Geochemical constraints on the provenance, mineral sorting and subaerial weathering of Lower Jurassic and Upper Cretaceous clastic rocks of the Eastern Pontides. *Turkish Journal of Earth Sciences* **15**, 181-209.

Dokuz, A., Uysal, I., Kaliwoda, M., Karsli, O., Ottley, C.J. & Kandemir, R. 2011. Early abyssal- and late SSZ-type vestiges of the Rheic oceanic mantle in the Variscan basement of the Sakarya Zone, NE Turkey: implications for the sense of subduction and opening of the Paleotethys. *Lithos* **127**, 176-191.

Drzewiecki, P.A. & Simo, J.A. 2002. Depositional process, triggering mechanism and sediment composition of carbonate gravity flow deposits: examples from the Late Cretaceous of the south-central Pyrenees, Spain. *Sedimentary Geology* **146**, 155-189.

Dunham, R.J. 1962. Classification of carbonate rocks according to depositional textures. *In*: W.E. Ham (ed), *Classification of Carbonate Rocks*. American Association of Petroleum Memoir 1, 108-121.

Eberli, G.P. 1991. Calcareous turbidites and their relationship to sea-level fluctuations and tectonism. *In*: Einsele, G., Ricken, W. & Seilacher, A. (eds), *Cycles and Events in Stratigraphy*. Springer Verlag, Berlin, 340-359.

Embry, B.D. & Klovan, J.E. 1971. A Late Devonian reef tract on Northeastern Banks Island, N. W. T. *Bulletin of Canadian Petroleum Geology* **19**, 730-781.

Everts, A.J.W. & Reijmer, J.J.G. 1995. Clinoform composition and margin geometries of a Lower Cretaceous carbonate platform (Vercors, SE France). *Palaeogeography, Palaeoclimatology, Palaeoecology* **119**, 19-33.

Everts, A.J.W., Schlager, W. & Reijmer J.J.G. 1999. Carbonate platform-to-basin correlation by means of grain-composition logs: an example from the Vercors (Cretaceous, SE France). *Sedimentology* **46**, 261-278.

Flügel, E. 2004. Microfacies of Carbonate Rocks. Springer, Berlin.

Güven, İ.H. 1993. Doğu Pontidlerin Jeolojisi ve 1/250.000 Ölçekli Kompilasyonu. MTA Yayınları, Ankara.

Heba, G. & Prichonnet, G. 2009. L'instabilité fini-Crétacé-Éocène de la marge passive d'Apulie en Albanie (plate-forme carbonatée de Kruja) et ses impacts sur la sédimentation. *Bulletin de la Societe Geologique de France* **180(5)**, 431-448 [in French with English abstract].

İnan, N., İnan, S. & Kurt, İ. 1999. Doğu Pontidler'de Uyumlu Bentik K/T Geçişi: Tonya Formasyonunun (GB Trabzon) Şahinkaya Üyesi. *Türkiye Jeoloji Bülteni* **42/2**, 63-67.

James, N.P. 1997. The cool-water carbonate depositional realm. In: James, N.P. & Clarke, J.A.D. (eds), *Cool-Water Carbonates*. SEPM Special Publication **56**, 1-20.

Kandemir, R. 2004. *Sedimentary Characteristics and Depositional Conditions of Lower-Middle Jurassic Şenköy Formation in and around Gümüşhane*. PhD Thesis, Karadeniz Technical University, Trabzon, Turkey [unpublished].

Kandemir, R., & Yılmaz, C. 2009. Lithostratigraphy, facies, and deposition environment of the lower Jurassic Ammonitico Rosso type sediments (ARTS) in the Gümüşhane area, NE Turkey: implications for the opening of the northern branch of the Neo-Tethys Ocean. *Journal of Asian Earth Sciences* **34**, 586-598.

Karsli, O., Uysal, I., Ketenci, M., Dokuz, A., Aydin, F., Chen, B., Kandemir, R. & Wijbrans, J. 2011. Adakite-like granitoid porphyries in Eastern Pontides, NE Turkey: potential parental melts and geodynamic implications. *Lithos* **127**, 354-372.

Karslı, O., Dokuz, A., Uysal, İ., Ketenci, M., Chen, B. & Kandemir, R. 2012. Deciphering the shoshonitic monzonites with I-type characteristic, the Sisdağı pluton, NE Turkey: magmatic response to continental lithospheric thinning. *Journal of Asian Earth Sciences* **51**, 45-62.

Kelling, G. & Stanley, D.J. 1976. Sedimentation in canyon slope and base of slope environments. *In*: Stanley, D.J. & Swift, D.J.P. (eds), *Marine Sediment Transport and Environmental Management*. Wiley, New York, 379-435.

Kırmacı, Z. & Akdağ, K. 2005. Origin of dolomite in the Late Cretaceous-Paleocene limestone turbudite, Eastern Pontides, Turkey. *Sedimentary Geology* **181**, 39-57.

Kissel, C., Laj, C., Poisson, A. & Görür, N. 2003. Paleomagnetic reconstruction of the Cenozoic evolution of the Eastern Mediterranean. *Tectonophysics* **362**, 199-217.

Korkmaz, S. 1993. Tonya-Düzköy (GB-Trabzon) Stratigrafisi. *Türkiye Jeoloji Bülteni* **36**, 151-158.

Lees, A. & Buller, A.T. 1972. Modern temperate-water and warm-water shelf carbonate sediments contrasted. *Marine Geology* **13**, 67-73.

Leren, L.S.B. 2003. *Late Cretaceous to Early Eocene Sedimentation in the Sinop-Boyabat Basin, North-Central Turkey: Facies Analysis of Turbiditic to Shallow-Marine Deposits*. MSc thesis, University of Bergen, Norway.

Middleton, G.V. & Hampton, M.A. 1973. Sediment gravity flows: mechanics of flow and deposition. *In*: G.V. Middleton & A.H. Bouma (eds), *Turbidites and Deep-Water Sedimentation*. Pacific Section SEPM, Los Angeles, California, 1-38.

Mullins, H.T. 1983. Modern carbonate slopes and basins of the Bahamas. *In*: Cook, H.E., Hine, A.C. & Mullins, H.T. (eds), *Platform Margin and Deep Water Carbonates*. SEPM Short Course No. **12**, 4.1-4.138.

Mullins, H.T., Heath, K.C., Van Buren, H.M. & Newton, C.R. 1984. Anatomy of a modern open-ocean carbonate slope: northern Little Bahama Bank. *Sedimentology* **31**, 141-168.

Mullins, H.T. & Cook, H.E. 1986. Carbonate slope apron models: alternatives to the submarine fan model for paleoenvironmental analysis and hydrocarbon exploration. *Sedimentary Geology* **48**, 37-79.

Nelson, C.S. 1988. An introductory perspective on non-tropical shelf carbonates. *Sedimentary Geology* **60**, 3-12.

Okay, A.I. & Şahintürk, Ö. 1997. Geology of the Eastern Pontides. *In*: Robinson, A.G. (ed), *Regional and Petroleum Geology of the Black Sea and Surrounding Region*. AAPG Memoir **68**, 292-311.

Okay, A.I. & Tüysüz, O. 1999. Tethyan sutures of Northern Turkey. *The Mediterranean Basins: Tertiary Extension within the Alpine Orogen*. Geological Society of London, Special Publication **156**, 475-515.

Özer, S., Sarı, B., Yılmaz, C., Görmüş, M., Kandemir, R. & Akdeniz, N. 2008. *Kampaniyen-Mastrihtiyen İstiflerinin Rudist-Foraminifer Biyostratigrafisi, Fasiyes Analizi ve Paleobiyocoğrafik Özellikleri, Pontidler-Kuzey Türkiye*. TÜBİTAK Project No: 106Y144 [unpublished].

Özsayar, T., Pelin, S. & Gedikoğlu, A. 1981. Doğu Pontidler'de Kretase. *Karadeniz Teknik Üniversitesi Yer Bilimleri Dergisi* **1/2**, 65-114.

Payros, A., Pujalte, V. & Orue-Etxebarria, X. 2007. A point-sourced calciclastic submarine fan complex (Eocene Anotz Formation, Western Pyrenees): facies architecture, evolution and controlling factors. *Sedimentology* **54**, 137-168.

Payros, A. & Pujalte, V. 2008. Calciclastic submarine fans: an integrated overview. *Earth-Science Reviews* **86**, 203-246.

Pelin, S. 1977. Alucra (Giresun) Guneydoğu Yöresinin Petrol Olanakları Bakımından Jeolojik İncelemesi. Karadeniz Technical University Publication No. 87, Trabzon, Turkey.

Pujalte, V., Robles, S., Orue-Etxebarria, X., Baceta, J.I., Payros, A. & Larrizea, I.F. 2000. Uppermost Cretaceous-Middle Eocene strata of the Basque-Cantabrian region and western Pyrenees: a sequence stratigraphic perspective. *Revista de la Sociedad Geológica de España* **13**, 191-211.

Pujalte, V., Baceta, J.I. & Payros, A. 2002. Western Pyrenees and Basque-Cantabrian region. *In*: Gibbons, W. & Moreno, T. (eds). *The Geology of Spain*. Geological Society, London, 293-301.

Reijmer, J.J.G. 1998. Compositional variations during phases of progradation and retrogradation of a Triassic carbonate platform (Picco di Vallandro/Dürrenstein, Dolomites, Italy). *Geologische Rundschau* **87(3)**, 436-448.

Reijmer, J.J.G. & Everaars, J.S.L. 1991. Carbonate platform facies reflected in carbonate basin facies (Triassic, northern calcareous Alps, Austria). *Facies* **25**, 253-278.

Reijmer, J.J.G., Palmieri, P. & Groen, R. 2012. Compositional variations in calciturbidites and calcidebrites in response to sea-level fluctuations (Exuma Sound, Bahamas). *Facies* **58**, 493-507.

Reijmer, J.J.G., Swart, P.K., Bauch, T., Otto, R., Reuning, L., Roth, S. & Zechel, S. 2009. A re-evaluation of facies on Great Bahama Bank I: new facies maps of western Great Bahama Bank. *International Association of Sedimentologists Special Publication* **41**, 29-46.

Reijmer, J.J.G., Ten Kate, W.G.H.Z., Sprengrer, A. & Schlager, W. 1991. Calciturbidte composition related to exposure and flooding of a carbonate platform (Triassic, Eastern Alps). *Sedimentology* **38**, 1059-1074.

Robinson, A.G., Banks, C.J., Rutherford, M.M. & Hirst, J.P.P. 1995. Stratigraphic and structural development of the Eastern Pontides, Turkey. *Journal of Geological Society of London* **152**, 861-872.

Rubert, Y., Mohamed, J., Loisy, C., Cerepi, A., Foto, G. & Muska, K. 2012. Sedimentology of resedimented carbonates: facies and geometrical characterization of and upper Cretaceous calciturbidite system in Albania. *Sedimentary Geology* **257-260**, 63-77.

Sandberg, C.A., & Warme, J.E. 1993. Conodont dating, biofacies, and catastrophic origin of Late Devonian (early Frasnian) Alamo Breccia, southern Nevada. *Geological Society of America Abstracts with Programs* **25**, 3, 77.

Sarı, B., Kandemir, R., Özer, S., Görmüş, M., Lopez, G., Martínez, R., Yılmaz, C. & Demircan, H. 2009. Upper Campanian limestone turbidite sequences from Hacımehmet village (south of Trabzon, Eastern Pontides, Turkey): biostratigraphy, age revision, microfacies analysis. *2nd International Symposium on the Geology of the Black Sea Region*, Ankara. Abstracts, p. 177.

Savary, B. 2005. Calcareous turbidity current emplacement as an initiation mechanism for substrate brecciation and deformation. *In:* Hodgson, D.M. & Flint, S.S. (eds), *Submarine Slope Systems: Processes and Products. Geological Society of London Special Publications* **244**, 207-220.

Savary, B. & Ferry, S. 2004. Geometry and petrophysical parameters of a calcarenitic turbidite lobe (Barremian–Aptian, Pas-de-la-Cluse, France). *Sedimentary Geology* **168**, 281-304.

Şengor, A.M.C. & Yılmaz, Y. 1981. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics* **75**, 181-241.

Şengör, A., Özeren, S., Genç, T. & Zor, E. 2003. East Anatolian high plateau as a mantle supported, north-south shortened domal structure. *Geophysical Research Letters* **30**, 24 .

Spalluto, L., Moretti, M., Festa, V. & Tropeano, M. 2007. Seismically-induced slumps in Lower-Maastrichtian peritidal carbonates of the Apulian platform (southern Italy). *Sedimentary Geology* **196**, 81-98.

Stow, D.A.W. 1986. Deep clastic seas. *In*: Reading, H.G. (ed), *Sedimentary Environments and Facies*. Blackwell Scientific Publications, Oxford, 399-444.

Temizel, İ., Arslan, M., Ruffet, G. & Peucat, J.J. 2012. Petrochemistry, geochronology and Sr–Nd isotopic systematics of the Tertiary collisional and post-collisional volcanic rocks from the Ulubey (Ordu) area, eastern Pontide, NE Turkey: implications for extension-related origin and mantle source characteristics. *Lithos* **128**, 126-147.

Topuz, G., Altherr, R., Schwarz, W.H., Dokuz, A. & Meyer, H.P. 2007. Variscan amphibolite-facies rocks from the Kurtoğlu metamorphic complex, Gümüşhane area, Eastern Pontides, Turkey. *International Journal of Earth Sciences* **96**, 861-873.

Topuz, G., Altherr, R., Siebel, W., Schwarz, W.H., Zack, T., Hasözbek, A., Barth, M., Satır, M. & Şen, C. 2010. Carboniferous high-potassium I-type granitoid magmatism in the Eastern Pontides: the Gümüşhane pluton (NE Turkey). *Lithos* **116**, 92-110.

Tucker, M.E. 2001. *Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks*. Blackwell Science, Oxford.

Van Konijnenburg, J.H., Bernoulli, D. & Mutti, M. 1999. Stratigraphic architecture of a Lower Cretaceous–Lower Tertiary carbonate base-of-slope succession: Gran Sasso d'Italia (Central Apennines, Italy). *In*: Harris, P.M., Saller, A.H. & Simo, J.A. (eds), *Advances in Carbonate Sequence Stratigraphy: Application to Reservoirs, Outcrops and Models*. SEPM Special Publication **63**, 291-315.

Wright, V.P. & Wilson, R.C.L. 1984. A carbonate submarine-fan sequence from the Jurassic of Portugal. *Journal of Sedimentary Petrology* **54**, 394-412.

Yılmaz, C. & Kandemir, R. 2002. Şenköy Formasyonu: Yeni bir formasyon adlaması. *3. Stratigrafi Çalıstayı Bildiri Özleri*, Ankara, 14.

Yılmaz, C. & Kandemir, R. 2006. Sedimentary records of the extensional tectonic regime with temporal cessation: Gümüşhane Mesozoic Basin, NE Turkey. *Geologica Carpathica* **57**, 3-13.

Yılmaz, C., Aydın, F., Sadıklar, M.B. & Kandemir, R. 2002. Carbonate turbidite sequences deposits: Upper Cretaceous sedimentary records of the Pontian Volcanic Arc (Trabzon, NE Turkey). *1st International Symposium of the Faculty of Mines (İTÜ) on Earth Sciences and Engineering*, İstanbul.