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Upper Campanian calciclastic turbidite sequences from the Hacımehmet area (eastern Pontides, NE Turkey): integrated biostratigraphy and microfacies analysis

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ABSTRACT:

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The upper Campanian (Cretaceous) of the Hacımehmet area (south of the city of Trabzon; Eastern Pontides) is mainly composed of calciclastic turbidites. The basinal unit of the 119 m thick succession includes thin red pelagic limestone interlayers and conglomerates dominated by volcanic clasts. The overlying upper slope and lower slope units of the sequence consist of an alternation of allochthonous calcarenite/calcirudite beds and pelagic marls and mudstones. Calcarenite/calcirudite beds dominate the upper slope unit of the succession and are composed of transported material, including benthic foraminifers, red algae, bryozoan, crinoid and rudist fragments, inoceramid bivalve prisms and neritic and pelagic carbonate lithoclasts. The occurrence of *Helicorbitoides boluensis* (Sirel) extracted from the calcarenite/calcirudite beds indicates a Campanian age. Identifiable rudists such as *Joufia reticulata* Boehm*, Bournonia* cf. *anatolica* Özer, *Biradiolites* cf. *bulgaricus* Pamouktchiev and ?*Biradiolite*s sp. from the upper slope unit of the succession indicate a late Campanian–Maastrichtian age. The planktonic foraminifers within the red pelagic limestone beds, marls and mudstones throughout the succession consist mainly of Campanian–Maastrichtian forms and suggest mainly basinal depositional conditions. The presence of *Radotruncana* cf. *calcarata* (Cushman) accompanied by *Globotruncanita elevata* (Brotzen) in the basinal unit of the succession indicates an early late Campanian age for the lower part of the succession. Inoceramid bivalves have been collected from the upper part of the succession. The fauna is dominated by '*Inoceramus*' *tenuilineatus* Hall and Meek, 1854 and *Cataceramus haldemensis* (Giers, 1964); other taxa recognised are: '*Inoceramus*' *algeriensis* Heinz, 1932, *Platyceramus vanuxemi* (Meek and Hayden, 1860), '*Inoceramus*' cf. *nebrascensis* Owen, 1852, *Cataceramus* aff. *barabini* (Morton, 1834), *Cataceramus gandjaensis* (Aliev, 1956), and '*Inoceramus*' sp.; the assemblage indicates the '*Inoceramus*' *tenuilineatus* Zone; corresponding to the middle–late Campanian boundary interval. The uppermost part of the succession is characterized by the presence of the trace fossils *Scolicia strozzii* and *Scolicia* isp., indicating a mixed *Skolithos-Cruziana* ichnofacies. This ichnofacies suggests a well-oxygenated environment.

Keywords: Late Campanian; Calciclastic Turbidite; Biostratigraphy; Eastern Pontides.

INTRODUCTION

The Upper Cretaceous sequences of the northern Eastern Pontides are composed mainly of back-arc volcaniclastics (Şengör and Yılmaz 1981; Okay and Şahintürk 1997; Okay and Tüysüz 1999; Dokuz and Tanyolu 2006; Topuz *et al*. 2007; Karslı *et al*. 2010) (Text-figs 1 and 2). These are deposits related to the closure of the northern branch of the Neotethys Ocean and northward subduction of its oceanic crust (Şengör and Yılmaz 1981; Okay and Şahintürk 1997; Yılmaz *et al.* 1997; Okay and Tüysüz 1999; Şengör *et al.* 2003; Çinku *et al.* 2010; Karslı *et al.* 2010). The volcaniclastics are followed by a calciclastics-dominated sedimentary sequence (Text-fig. 2) dominated by an alternation of allochthonous calcarenites/calcirudites, conglomerates with volcanic clasts, red pelagic limestone interlayers, and pelagic marls and mudstones (Yılmaz *et al.* 2002; Aydın 2003; Kırmacı and Akdağ 2005; Ersoy 2007). Such deposits may be referred to as the calciclastics (Braunstein 1961): allochthonous, detrital carbonate sediments, transported and redeposited as calciturbidites or limestone turbidites (Meischner 1964). Calciclastics were initially considered to be submarine fan deposits with a point source and channelized sedimentation, similar to their siliciclastic counterparts (Price 1977; Bosellini *et al.* 1981). Alternatively, many calciclastic deposits were generally line sourced rather than point sourced (Colacicchi and Baldanze 1986), and were interpreted according to carbonate apron models with a line source and sheetflow sedimentation (Mullins and Cook 1986; Eberli 1987). It now appears that many calciclastic deposits still fit classic submarine fan models better (Payros and Pujalte 2008).

As calciclastics are usually sourced from coeval carbonate platforms, they provide useful information about the sedimentary nature and depositional evolution of the adjacent shallow water settings (e.g., Reijmer and Everaars 1991; Reijmer *et al.* 1991). Payros and Pujalte (2008) have suggested that calciclastic submarine fans are accumulations of carbonate sediment gravity flow deposits at the base of a slope fed by a single feeder channel. Calciclastics consist usually of calciturbidites and debrites, but other types of gravity flow deposits and even hemipelagic sediments are commonly present.

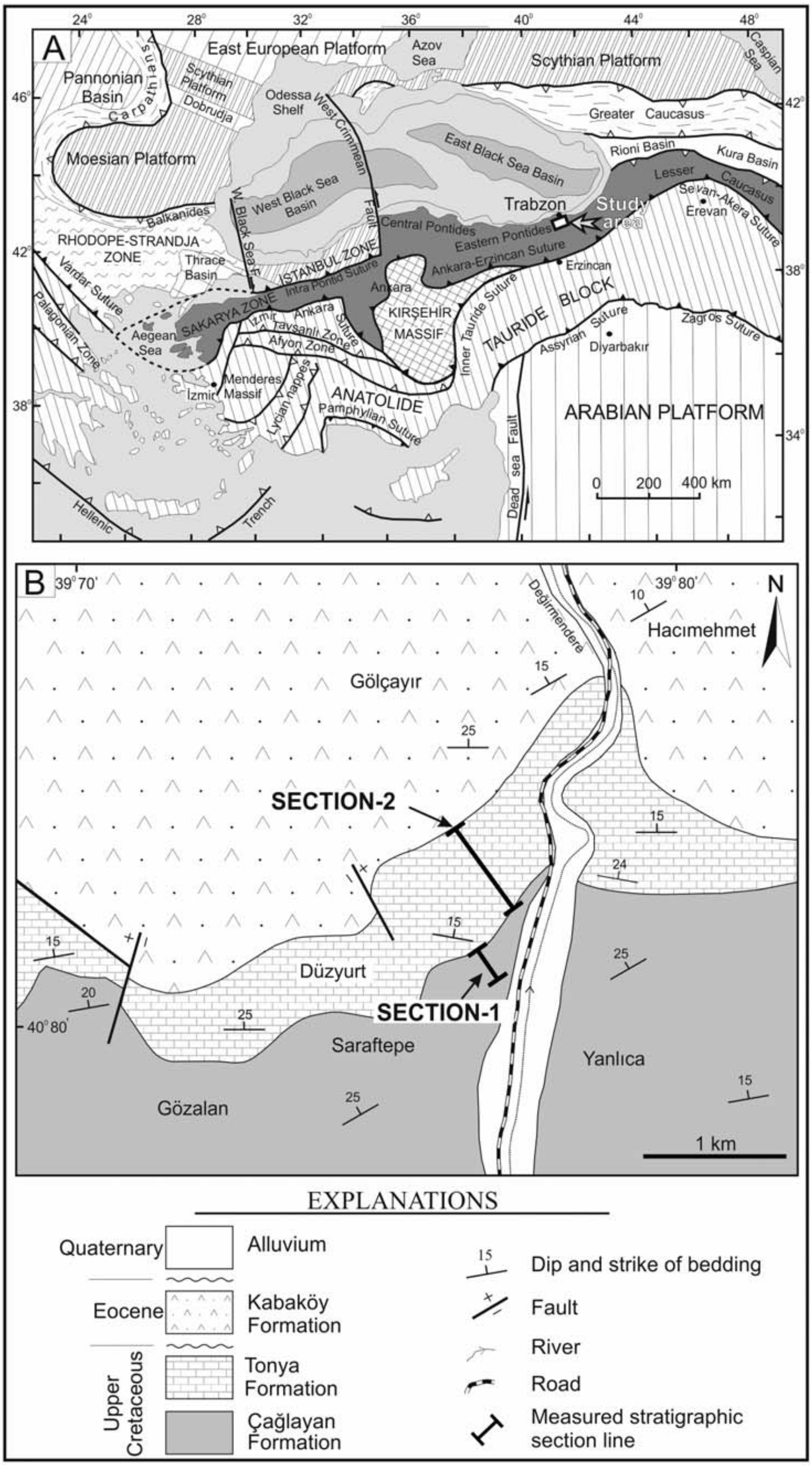
Well-represented and easily available sections with calciclastic sequences are relatively rare in the northern part of the Eastern Pontides. The best exposures are in the Hacımehmet area, south of the town of Trabzon (Text-figs 1B, 2 and 3). This area has been the subject of many investigations (Özsayar 1971; Güven 1993; Korkmaz 1993; Ayaz *et al.* 1996; Yılmaz *et al*. 2002; Aydın 2003; Kırmacı and Akdağ 2005; Ersoy 2007; Sofracıoğlu and Kandemir 2013). In spite of this, however, many aspects of the calciclastic sequences remained poorly recognized. The present paper concentrates on the biostratigraphy and sedimentology of the calciclastic successions, based on selected sections of the area. In lithostratigraphic terms, the interval studied spans the uppermost part of the Çağlayan Formation and Tonya Formation (Text-figs 1B and 2). The biostratigraphy integrates the results based on macro- and microfossils, including inoceramid bivalves, ammonites, rudists, and planktonic and benthic foraminifers. The presence of numerous pelagic interlayers within the calciclastic sequences allows for a reliable dating. The analysis of trace fossils provides valuable data concerning the sedimentary environment.

REGIONAL GEOLOGICAL SETTING

Turkey is geologically composed of four major tectonic blocks, separated by high pressure belts (Okay and Tüysüz 1999; Text-fig. 1A). The Eastern Pontides belong to the Sakarya Zone, which is one of the major tectonic blocks (Text-fig. 1A).

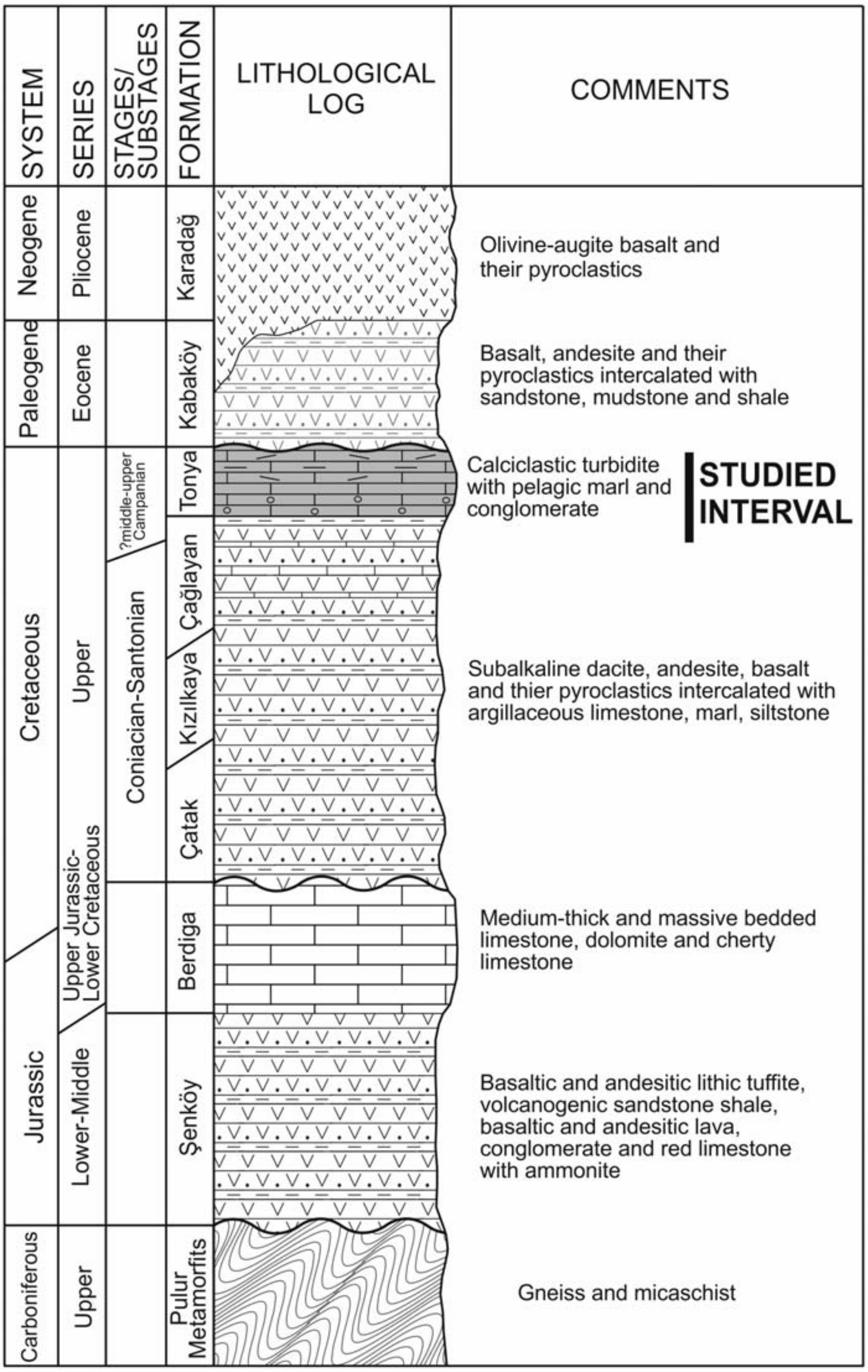
Until Early Cretaceous time, the whole area of the Eastern Pontides records relatively uniform tectonic and sedimentary conditions. Starting with the Late Cretaceous, however, the Eastern Pontides evolve into two tectonically distinct units, referred to as their northern and southern parts (Özsayar *et al*. 1981; Okay and Şahintürk 1997). The northern part evolved into the magmatic arc, whereas the southern part was incorporated into a fore-arc basin, characterized by sedimentation of siliciclastic turbidites. The arc of the northern zone developed due to the ongoing convergence between Laurasia and Gondwana, with northward subduction of the Neotethys crust along the southern margin of the Sakarya Zone (e.g., Akin 1979; Şengör and Yilmaz 1981; Okay and Şahintürk 1997; Yilmaz *et al*. 1997; Okay and Tüysüz 1999; Şengör *et al*. 2003; Topuz *et al.* 2007; Çinku *et al*. 2010; Karslı *et al.* 2010; Dokuz *et al*. 2010). The

Text-fig. 1. A – Regional tectonic setting of Turkey in relation to the Afro-Arabian and Eurasian plates, based on Okay and Tüysüz (1999). B – Geological map of the study area and surroundings (simplified after Ersoy 2007). The map shows the geographic distribution of the studied interval and the location of the stratigraphic sections. Section-1 corresponds to the uppermost part of the Çağlayan Formation and includes the basinal unit of the measured section. Section-2 is represented by rocks of the Tonya Formation and forms the upper slope and lower slope units of the measured section


24°
28°
32°
36°
40°
44°
48°
A
East European Platform
Azov Sea
Scythian Platform
Caspian Sea
Pannonian Basin
Carpathians
Scythian Platform
Dobrudja
Odessa Shelf
West Crimmean Fault
Greater Caucasus
East Black Sea Basin
Rioni Basin
Kura Basin
Moesian Platform
West Black Sea Basin
Lesser Caucasus
Sevan-Akera Suture
Erevan
Trabzon
Study area
Balkanides
W. Black Sea F.
Central Pontides
Eastern Pontides
RHODOPE-STRANDJA ZONE
Thrace Basin
ISTANBUL ZONE
Intra Pontid Suture
Ankara-Erzincan Suture
Erzincan
Vardar Suture
Ankara
TAURIDE BLOCK
SAKARYA ZONE
İzmir
Ankara Suture
KIRŞEHIR MASSIF
Inner Tauride Suture
Assyrian Suture
Zagros Suture
Palagonian Zone
Aegean Sea
Tavşanlı Zone
Afyon Zone
Diyarbakır
Menderes Massif
İzmir
Lycian nappes
ANATOLIDE
Pamphylian Suture
ARABIAN PLATFORM
Dead sea Fault
Hellenic
Trench
0 200 400 km
46°
42°
38°
42°
38°
34°
B
39° 70'
39° 80'
40° 80'
N
Değirmendere
Hacımehmet
Gölçayır
SECTION-2
SECTION-1
Düzyurt
Saraftepe
Yanlıca
Gözalan
1 km
10
15
25
15
24
15
25
15
20
25
25
15
EXPLANATIONS
Quaternary
Alluvium
Eocene
Kabaköy Formation
Upper Cretaceous
Tonya Formation
Çağlayan Formation
15
Dip and strike of bedding
Fault
River
Road
Measured stratigraphic section line

arc activity is recorded by a more than 2-km thick volcano-sedimentary sequence (Okay and Şahintürk 1997).

A composite stratigraphic section for the The Mesozoic–Cenozoic succession of the northern Eastern Pontides is shown in Text-fig. 2. The succession starts with the Early–Middle Jurassic Şenköy Formation (Yılmaz and Kandemir 2002), which overlies unconformably its Palaeozoic metamorphic basement. The formation consists of basaltic and andesitic lithic tuffite, volcanogenic sandstone, shale, basaltic and andesitic lavas, conglomerates and Ammonitico-rosso



Text-fig. 2. Stratigraphic column of the northern zone of the Eastern Pontides (simplified and modified after Güven 1993). This study focuses on the uppermost Cretaceous; explanation for lithology, fossils and stratigraphic sections see Text-fig. 4

limestone, yielding ammonites, brachiopods, bivalves, gastropods, belemnites, crinoids and foraminifers (Kandemir and Yılmaz 2009). The Şenköy Formation represents typical rift-related sediments (Kandemir 2004; Yılmaz and Kandemir 2006; Dokuz and Tanyolu 2006). These are followed by thick-bedded, shallow-marine Late Jurassic–Early Cretaceous platform carbonates of the Berdiga Formation (Pelin 1977) deposited during a period of tectonic quiescence. The Şenköy and Berdiga formations are not exposed in the study area.

The Upper Cretaceous is characterized by heterogeneous volcanic-sedimentary sequences, variable laterally and vertically due to syn-sedimentary tectonism and arc magmatism (Aydın *et al*. 2008), deposited in a deep-marine environment (Robinson *et al*. 1995). The Upper Cretaceous succession is subdivided into the Çatak, Kızılkaya, Çağlayan and Tonya formations. The Çatak Formation is composed of andesites and tuffs, intercalated with argillaceous limestones, sandy limestones, tuffites and red pelagic limestones, and with large boulders of Late Jurassic–Early Cretaceous limestone. The Kızılkaya Formation is composed of rhyodacite–dacite and their pyroclasts with few intercalations of argillaceous and sandy limestones. The Çağlayan Formation is composed mainly of deep-water limestones, marls, sandstones and sandy limestones, alternating locally with spilitic basalts and andesites (Kırmacı and Akdağ 2005). The Tonya Formation, at the top of the Mesozoic sequence (Text-fig. 2), consists of an alternation of pelagic marls and calciclastic turbidites (Korkmaz 1993; Yılmaz *et al*. 2002; Kırmacı and Akdağ 2005). In the Tonya-Düzköy area (approximately 20 km SW of the city of Trabzon), the Tonya Formation has been dated variously as Late Cretaceous–Palaeocene (Korkmaz 1993; Tansel-Özkar and Kırcı 1997), Campanian–Maastrichtian (Özsayar 1971; Yılmaz *et al*. 2002; Aydın 2003; Ersoy 2007) and early–middle Maastrichtian (Kaya and Sipahi, 1999).

The Palaeocene is mostly absent from the northern Eastern Pontides (Korkmaz 1993; İnan *et al*. 1999), and the Cretaceous is overlain unconformably by the Eocene Kabaköy Formation (Text-fig. 2).

THE LATEST MESOZOIC SEDIMENTARY SUCCESSION OF THE HACIMEHMET AREA

The two sections studied herein are located south of the city of Trabzon (Text-fig. 1B). The succession exposed in section-1 represents the uppermost part of the Çağlayan Formation, and represents the basinal unit of the succession studied herein. Section-2 exposes the Tonya Formation, which represents the upper slope and lower slope units of the studied succession (Text-figs 1B, 2 and 3). Brief characteristics of the three units, distinguished within the studied succession are given below.

Basinal unit

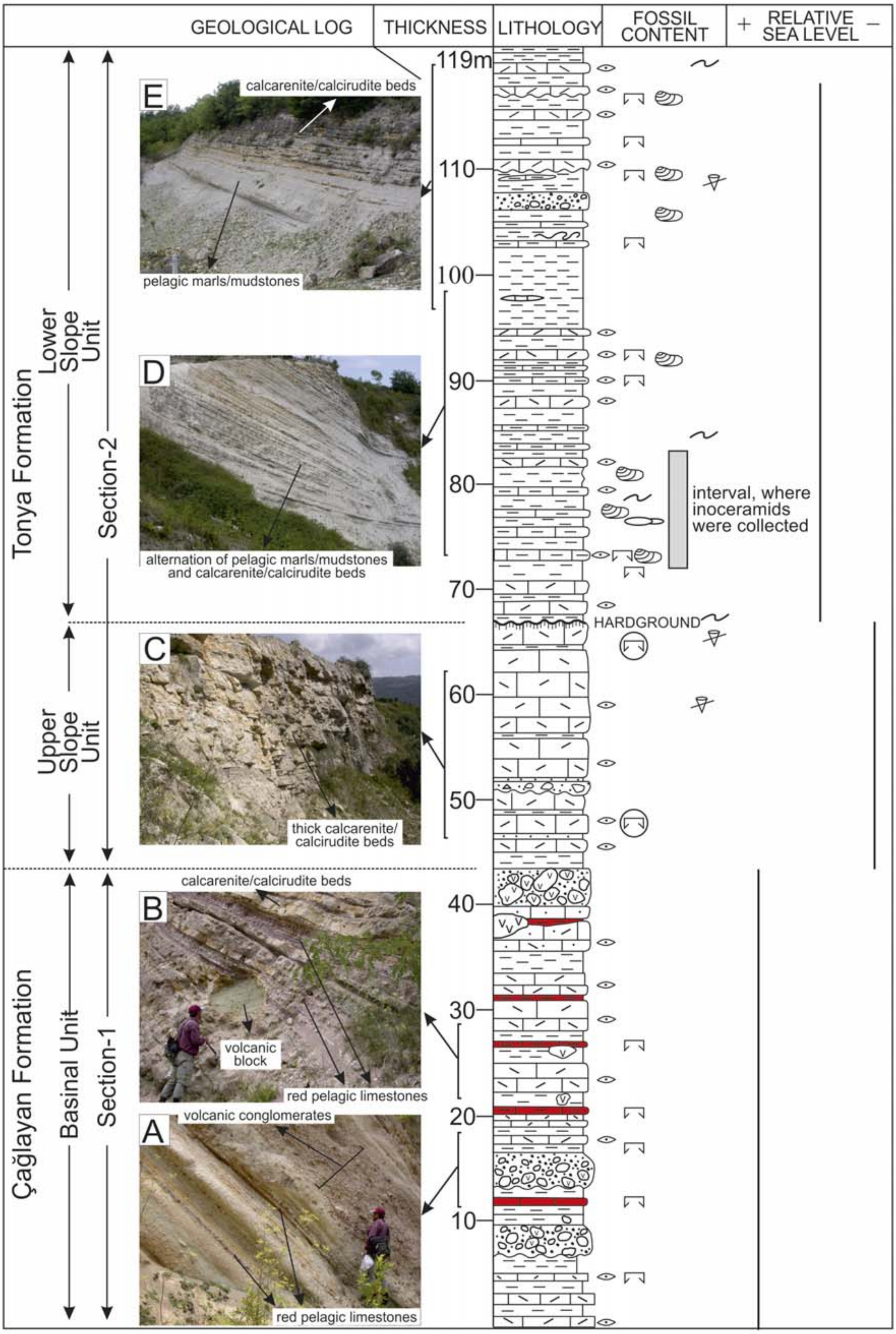
The 43 m thick basinal unit consists of alternating allochthonous calcarenite/calcirudite beds, conglomerates and foraminiferal (planktonic) red pelagic limestone and mudstone beds (Text-fig. 3). The three conglomerate horizons (0.5 m to 4 m thick) consist mainly of pebble- to boulder-size volcanic lithoclasts (Text-fig. 3A) and, subordinately, of neritic and pelagic carbonate lithoclasts. Granule- to boulder-size volcanic lithoclasts are also noted within the pelagic mudstones (Text-fig. 3B).

Upper slope unit

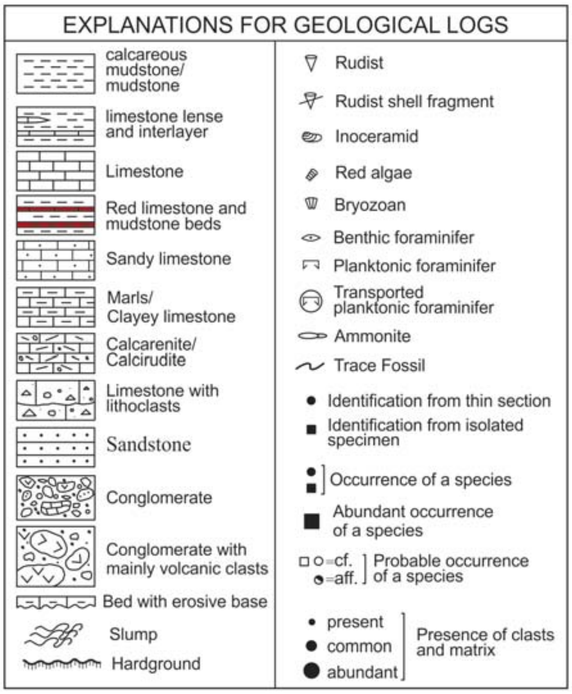
The 24 m thick upper slope unit is characterized by thick-bedded allochthonous calcarenite/calcirudite beds, intercalated with thin mudstone and sandstone beds (Text-fig. 3C). Some beds exhibit an erosional basal surface and show lateral thickness changes. The calcarenite/calcirudite-dominated unit is capped by a prominent hardground, with numerous trace fossils (Text-fig. 3).

Lower slope unit

The 52 m thick lower slope unit consists mainly of alternating allochthonous calcarenite/calcirudite beds and foraminiferal (planktonic) pelagic marls and mudstones (Text-fig. 3). The marls and mudstones dominate the uppermost part of the succession (Text-fig. 3D). The calcarenite/calcirudite beds are generally thin (5 to 30 cm thick), and some pinch out laterally. Some of the beds exhibit an erosional basal surface while passing gradually upward into marls and mudstones. Rare conglomerate horizons (0.7 to 1 m thick), consisting mainly of volcanic clasts and exhibiting an erosional bases, are also present. Slumped marly beds were noted at the 103 m level of the sequence. Inoceramids are abundant throughout this part. Rare ammonites and trace fossils are also noted (Text-fig. 3).



GEOLOGICAL LOG
THICKNESS
LITHOLOGY
FOSSIL CONTENT
+ RELATIVE SEA LEVEL –
Tonya Formation
Lower Slope Unit
Upper Slope Unit
Section-2
Çağlayan Formation
Basinal Unit
Section-1
119m
110
100
90
80
70
60
50
40
30
20
10
E
calcarenite/calcirudite beds
pelagic marls/mudstones
D
alternation of pelagic marls/mudstones and calcarenite/calcirudite beds
C
thick calcarenite/ calcirudite beds
B
calcarenite/calcirudite beds
volcanic block
red pelagic limestones
A
volcanic conglomerates
red pelagic limestones
HARDGROUND
interval, where inoceramids were collected



Text-fig. 4. Explanation for lithology, fossils and stratigraphic sections

BIOSTRATIGRAPHY

Data from planktonic and benthic foraminifers, inoceramids and rudists were integrated to construct the biostratigraphic framework. This is the first detailed biostratigraphy presented for the study area. Details on each group are presented below.

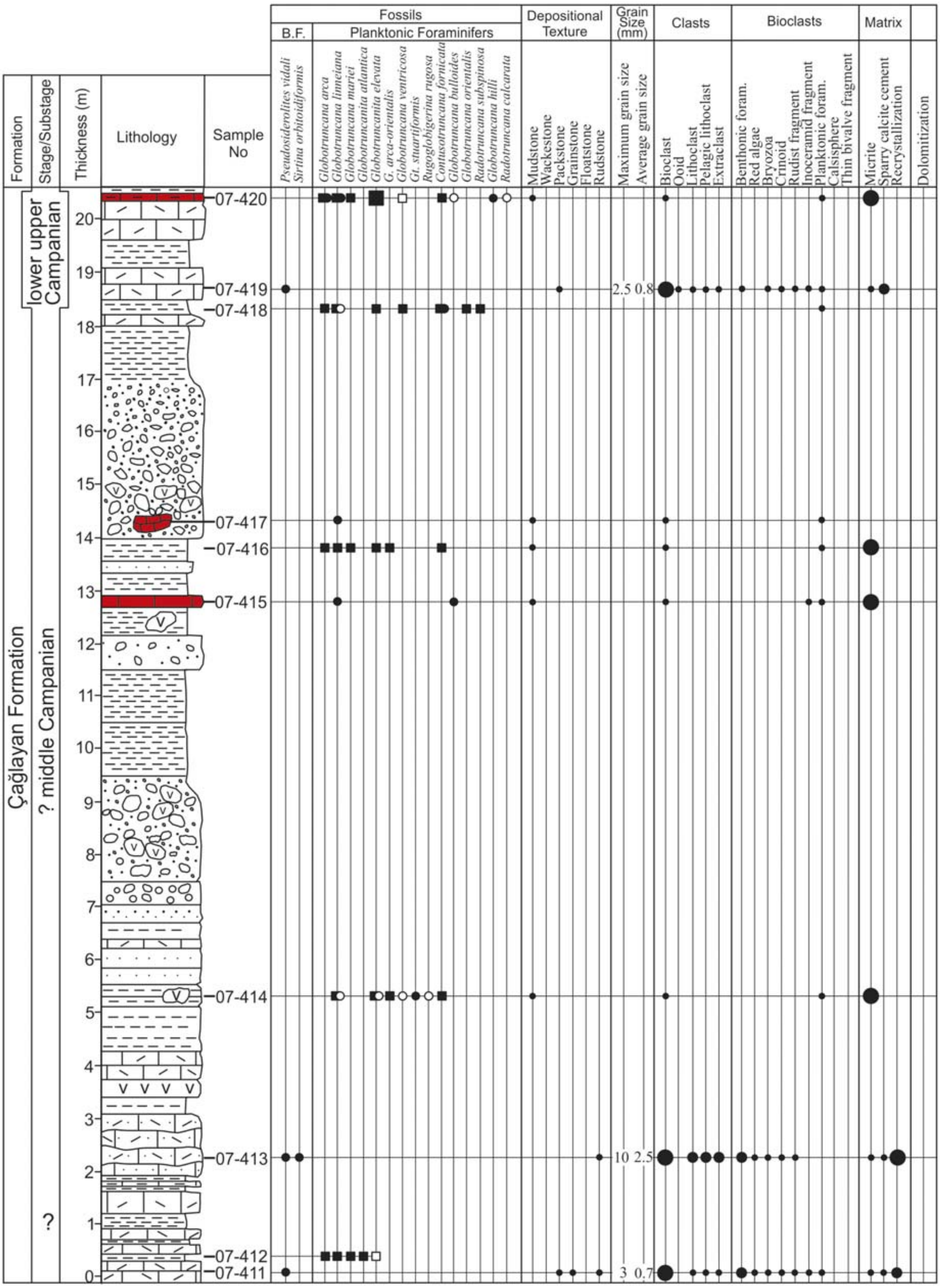
Planktonic foraminifers

Planktonic foraminifers were found in red pelagic limestone and mudstone interlayers in the basinal part and within pelagic marls, calcareous mudstones and mudstones in the upper part of the succession (Text-figs 5 and 6). Planktonic foraminifers are not diverse in thin sections of hard lithologies. However, some stratigraphically important forms were documented (Text-figs 5–7). Isolated specimens were also obtained from soft lithologies (Text-figs 5, 6, 8) using standard washing methods. *Radotruncana* cf. *calcarata* (Cushman) is known from a single specimen, from the middle part of the basinal unit of the succession (Text-fig. 5, sample 07-420; Text-fig. 7K). This species is the zonal marker of the *Radotruncana calcarata* Zone, of early late Campanian age (Premoli Silva and Sliter 1994; Robaszynski and Caron 1995; Sliter 1999; Robaszynski *et al.* 2000; Premoli Silva and Verga 2004; Sarı 2006, 2009; Gradstein *et al*. 2012). *Globotruncanita elevata* (Brotzen) is another important taxon that is common in the lower part of the sequence (Text-figs 5, 7I and 8J). *Gt. elevata* spans the latest Santonian to the middle Campanian according to Premoli Silva and Sliter (1994) and Premoli Silva and Verga (2004). However, the probable occurrence of the species within the lower upper Campanian (within the *R. calcarata* Zone) was documented in central Tunisia (Robaszynski *et al*. 2000). The abundance of *Gt. elevata* in sample 07-420, accompanied by *R.* cf. *calcarata*, supports the report of Robaszynski *et al*. (2000). *Radotruncana subspinosa* (Pessagno) is documented in a sample (sample 07-418) located two metres below the level with *R.* cf. *calcarata* (Text-fig. 5). It is a known late middle to latest Campanian species (Premoli Silva and Verga 2004). The upper part of the succession is generally characterized by long-ranging Campanian–Maastrichtian species, such as *Archaeoglobigerina* cf. *cretacea* (d'Orbigny), *Contusotruncana fornicata* (Plummer), *Contusotruncana patelliformis* (Gandolfi), *Contusotruncana plummerae* (Gandolfi), *Globotruncana arca* (Cushman), *Globotruncana arca-orientalis, Globotruncana bulloides* Vogler, *Globotruncana* cf. *esnehensis* Nakkady, *Globotruncana falsostuarti* Sigal, *Globotruncana falsostuarti-dupeublei*, *Globotruncana hilli* Pessagno, *Globotruncana linneiana* (d'Orbigny), *Globotruncana mariei* Banner and Blow, *Globotruncana orientalis* El Naggar, *Globotruncana rosetta* (Carsey), *Globotruncana ventricosa* White, *Globotruncanita* cf. *stuarti* (de Lapparent), *Globotruncanita atlantica* (Caron), *Globotruncanita stuartiformis* (Dalbiez), *Rugoglobigerina* cf. *pennyi* Brönnimann, and *Rugoglobigerina rugosa* Plummer (Text-figs 6, 7 and 8). The age of the succession below the level with *R.* cf. *calcarata* could be middle Campanian.

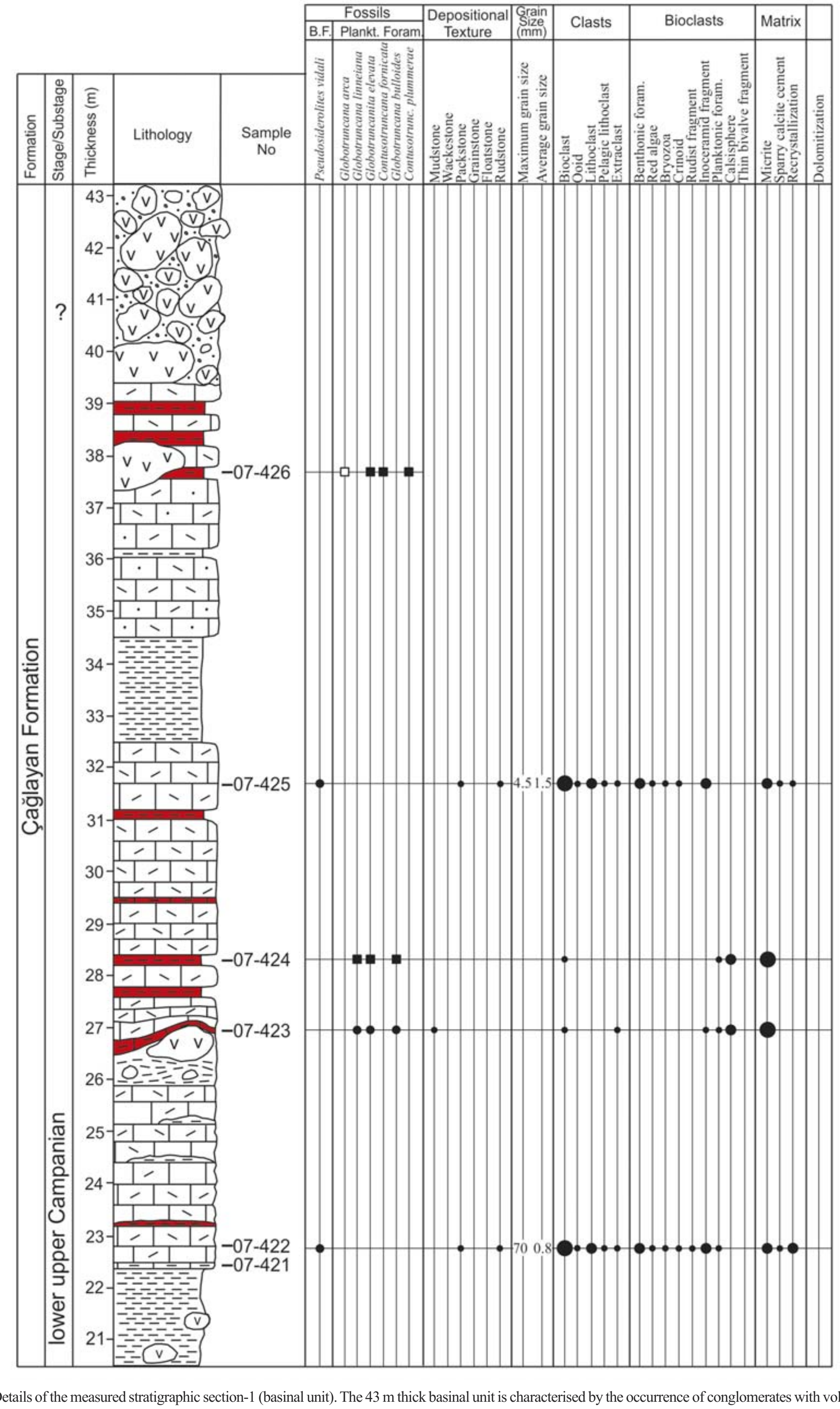
Benthic foraminifers

The benthic forms from the measured sections include *Pseudosiderolites vidali* (Douvillé), *Orbitoides tissoti* Schlumberger, *O. medius* (d'Archiac), *Helicorbitoides boluensis* (Sirel), *Sirtina orbitoidoformis* Brönnimann, *Saracenaria* sp., *Textularia* sp., Miliolidae, and Textulariidae (Text-figs 5, 6). *Pseudosiderolites*

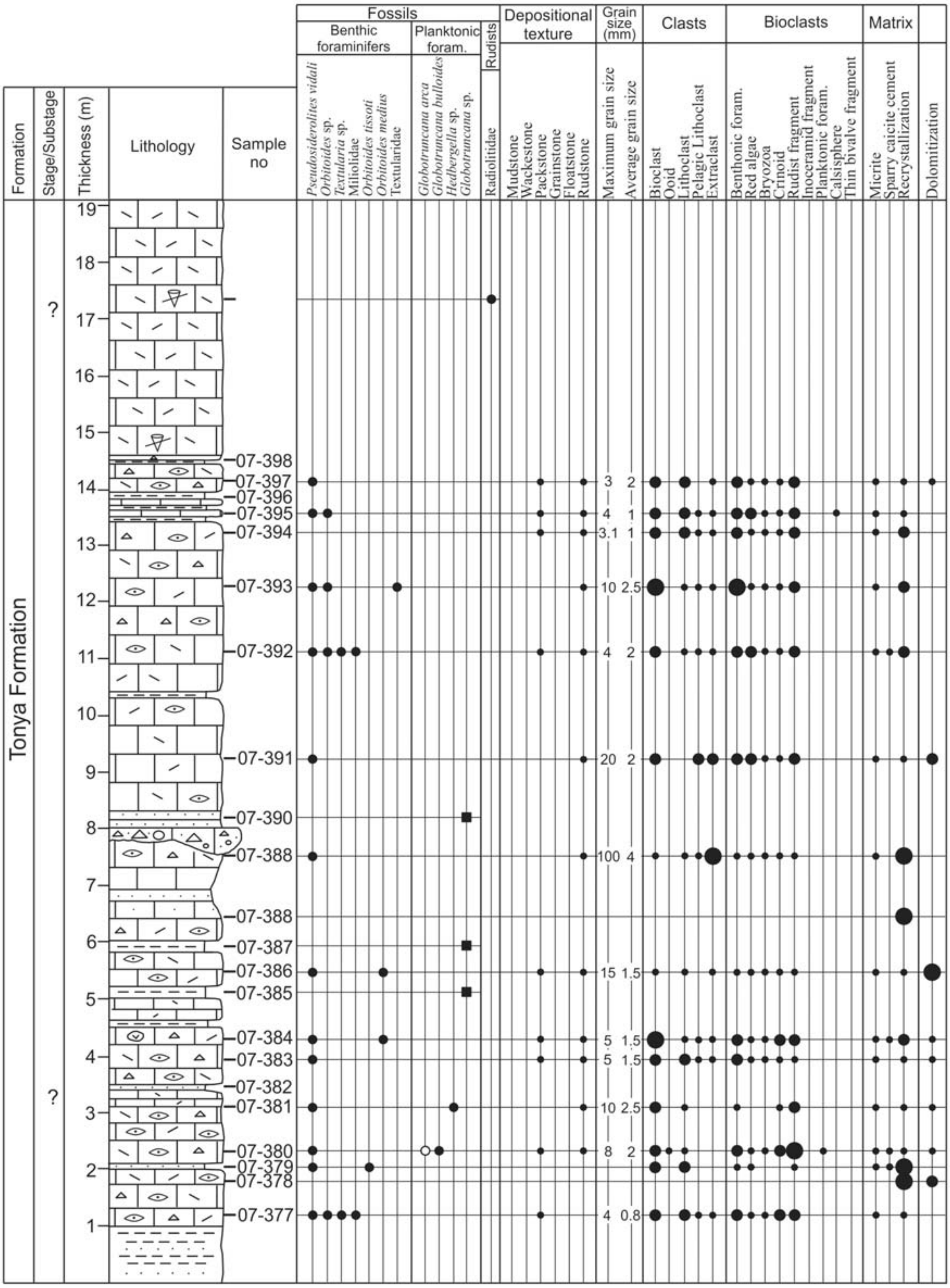
Text-fig. 3. Composite stratigraphic section showing the lithology, field photographs, the fossil content and the relative depositional depth of the three units of the succession. The stratigraphic section is comprised of three units (see Text-fig. 4 for explanations and Text-figs 5 and 6 for details regarding the lithologies and microfacies characteristics). (Note that the metre levels do not correspond to those in the detailed stratigraphic sections 1 and 2); explanation for lithology, fossils and stratigraphic sections see Text-fig. 4



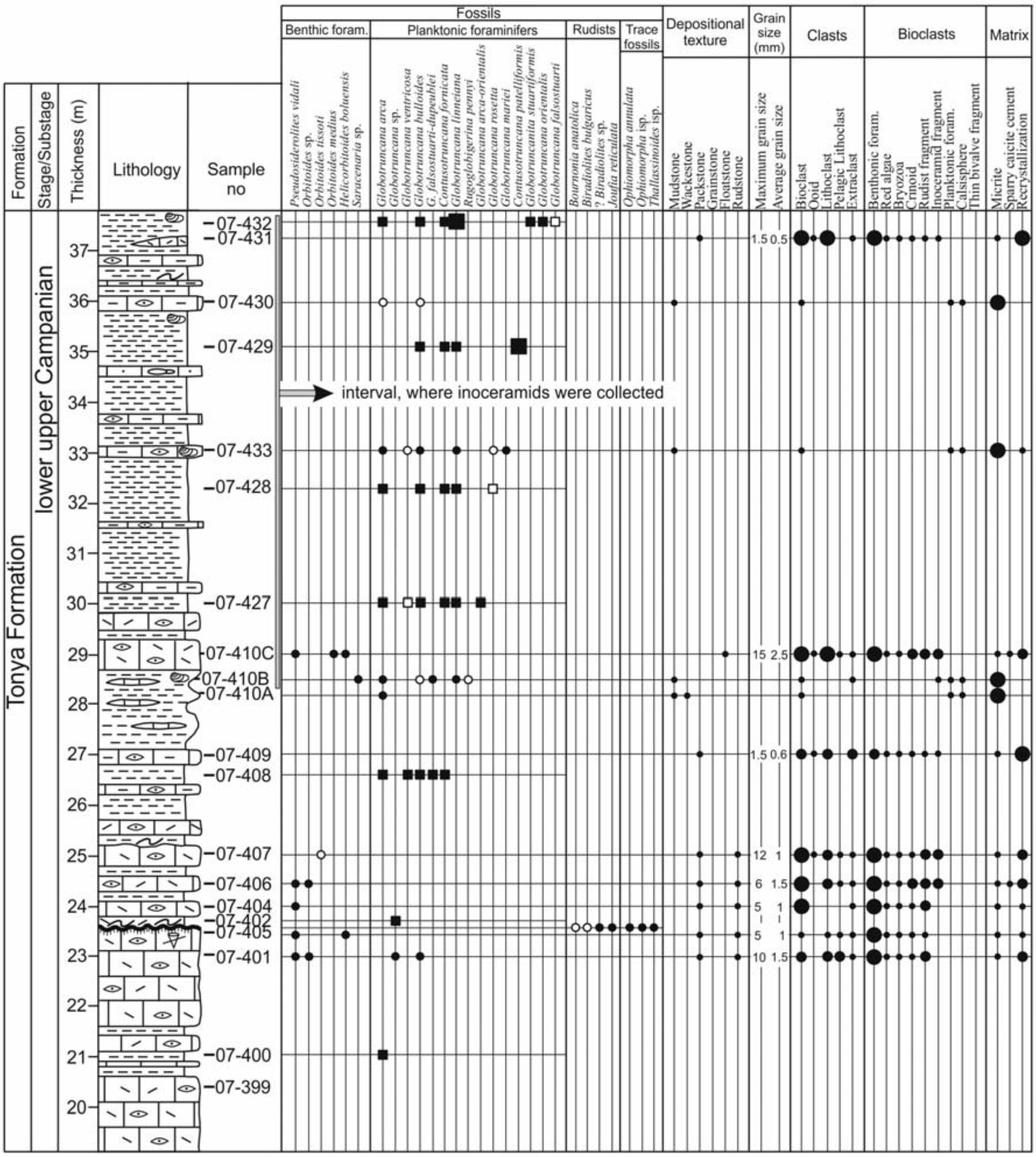
Text-fig. 5a. Details of the measured stratigraphic section-1 (basinal unit). The 43 m thick basinal unit is characterised by the occurrence of conglomerates with volcanic clasts, which alternate with red pelagic limestone and mudstone beds and allochthonous calcarenite/calciridite beds; explanation for lithology, fossils and stratigraphic sections see Text-fig. 4



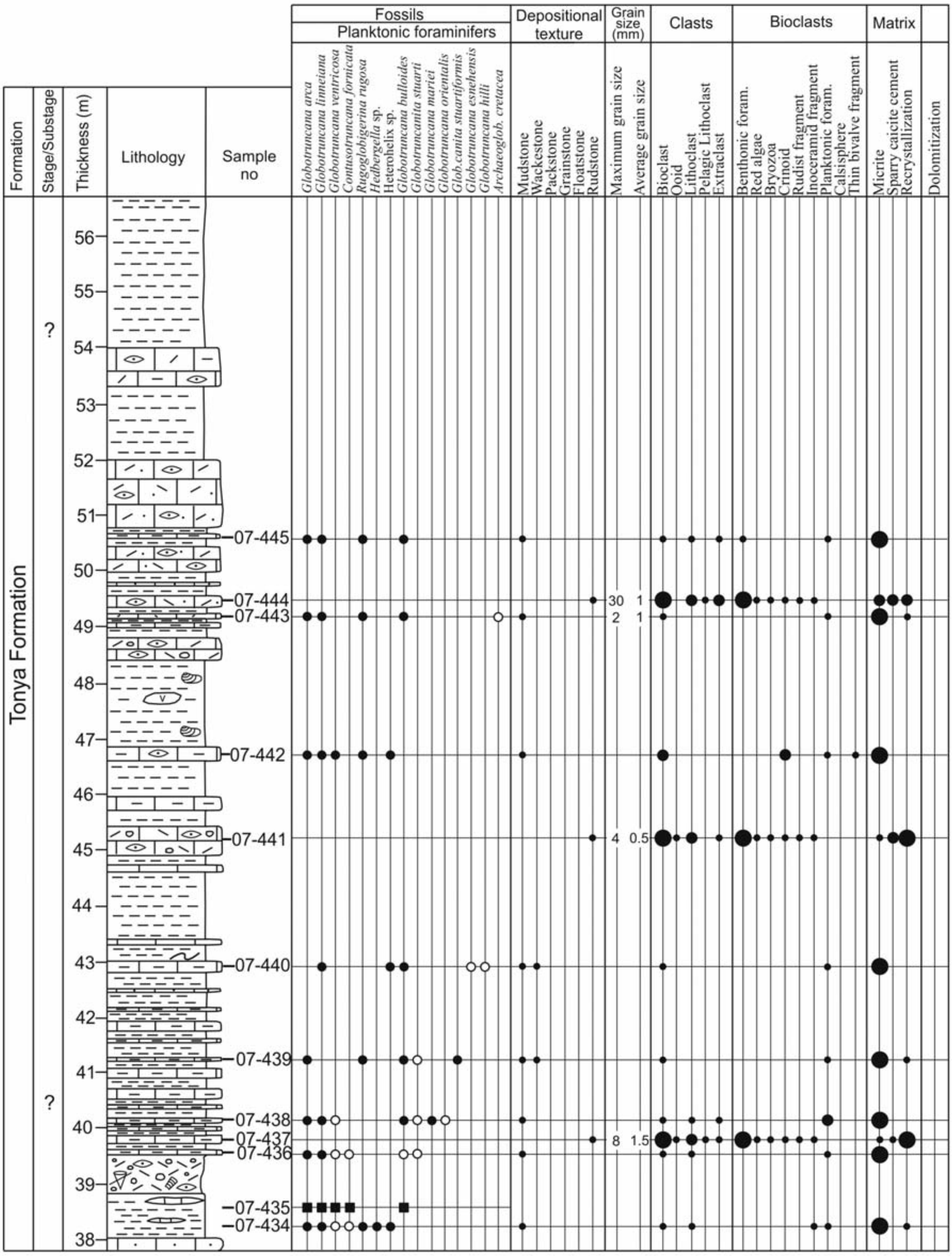
Text-fig. 5b. Details of the measured stratigraphic section-1 (basinal unit). The 43 m thick basinal unit is characterised by the occurrence of conglomerates with volcanic clasts, which alternate with red pelagic limestone and mudstone beds and allochthonous calcarenite/calcirudite beds; explanation for lithology, fossils and stratigraphic sections see Text-fig. 4



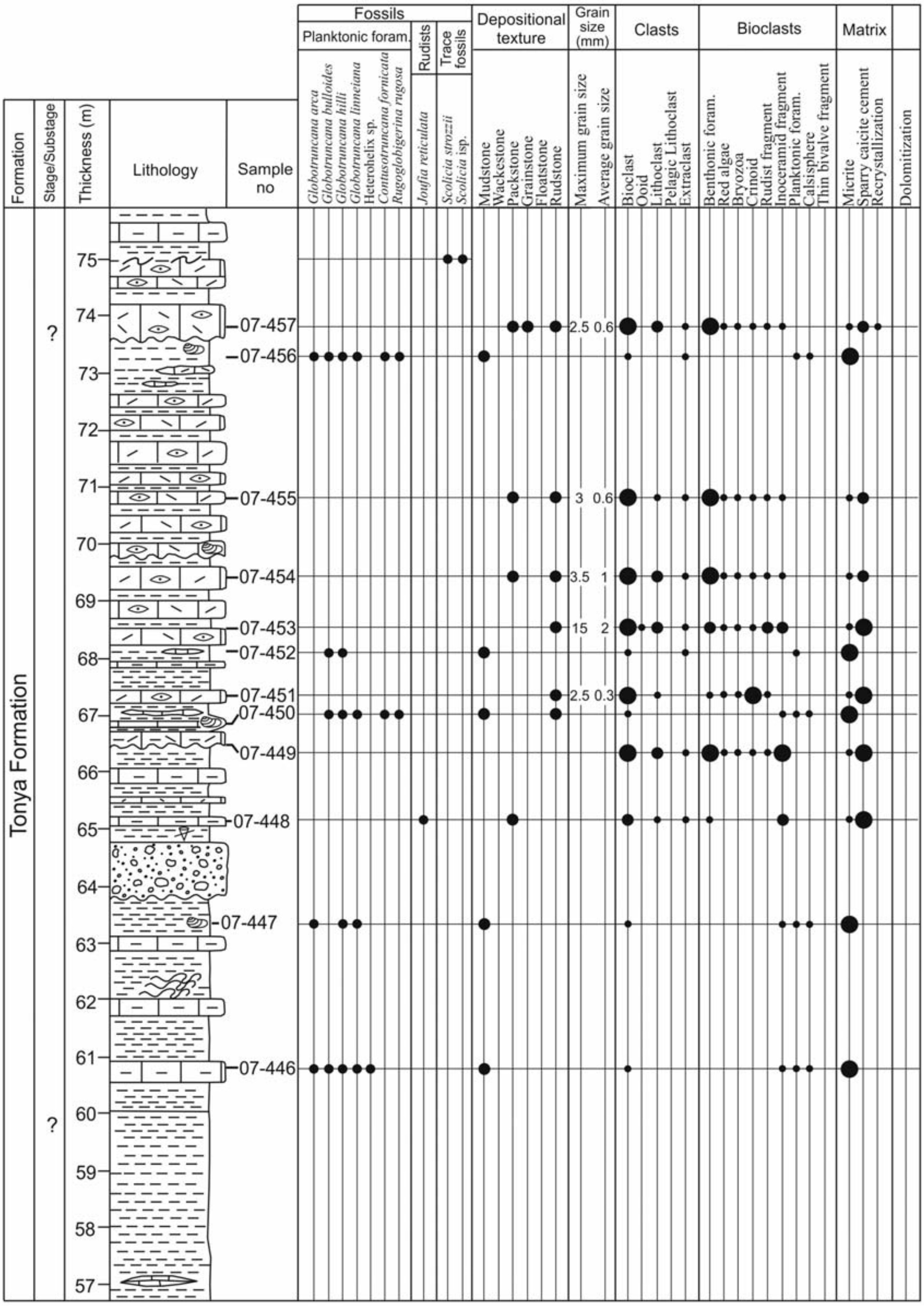
Text-fig. 6a. Details of the measured stratigraphic section-2 (upper slope and lower slope units). The 24 m thick upper slope unit is dominated by thick allochthonous calcarenite/calcirudite beds and truncated by a hardground. The 52 m thick lower slope unit is characterised by dominance of planktonic foraminifera and inoceramid-bearing marls, clayey limestones and mudstones, which are intercalated with allochthonous calcarenite/calcirudite beds; explanation for lithology, fossils and stratigraphic sections see Text-fig. 4



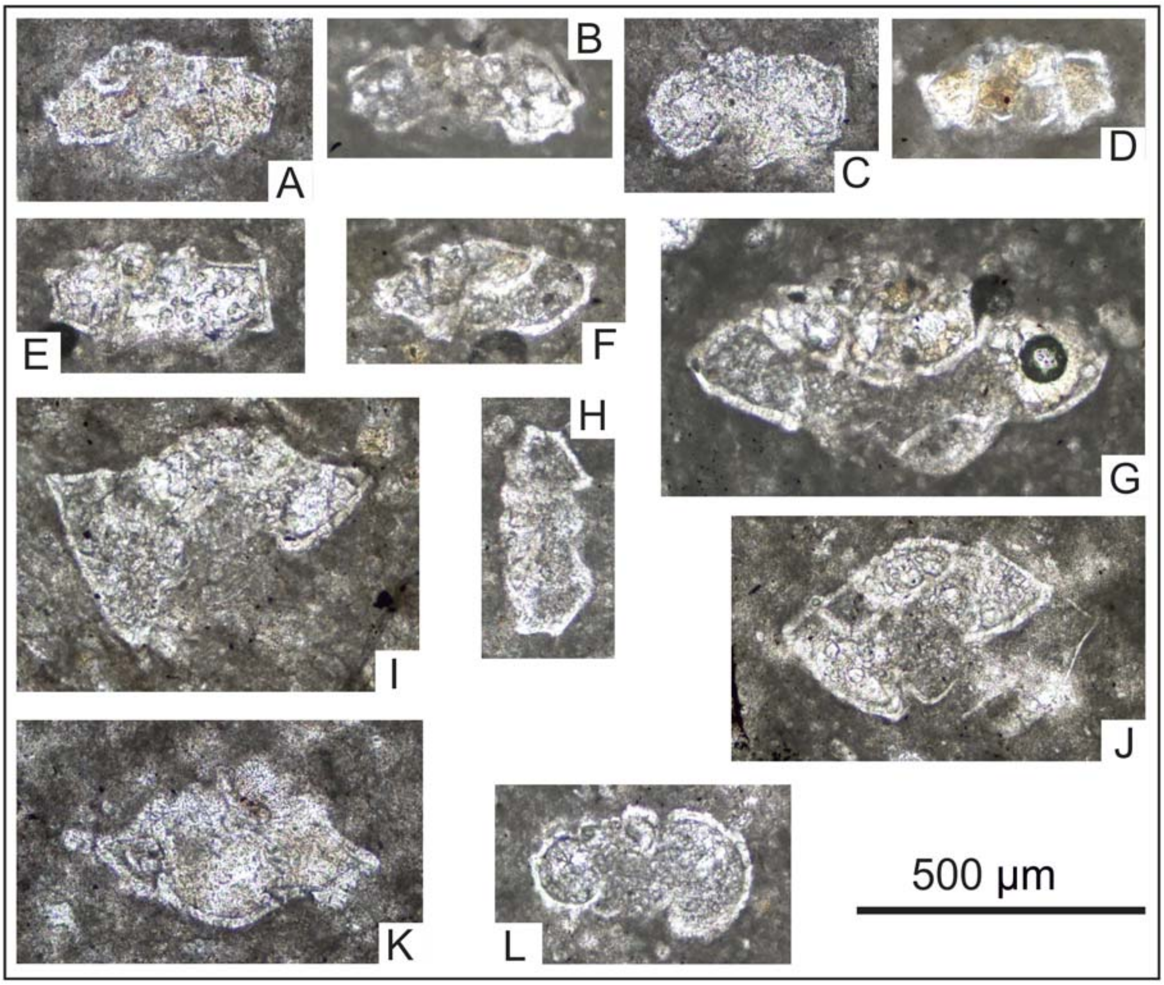
Text-fig. 6b. Details of the measured stratigraphic section-2 (upper slope and lower slope units). The 24 m thick upper slope unit is dominated by thick allochthonous calcarenite/calcirudite beds and truncated by a hardground. The 52 m thick lower slope unit is characterised by dominance of planktonic foraminifera and inoceramid-bearing marls, clayey limestones and mudstones, which are intercalated with allochthonous calcarenite/calcirudite beds; explanation for lithology, fossils and stratigraphic sections see Text-fig. 4



Text-fig. 6c. Details of the measured stratigraphic section-2 (upper slope and lower slope units). The 24 m thick upper slope unit is dominated by thick allochthonous calcarenite/calcirudite beds and truncated by a hardground. The 52 m thick lower slope unit is characterised by dominance of planktonic foraminifera and inoceramid-bearing marls, clayey limestones and mudstones, which are intercalated with allochthonous calcarenite/calcirudite beds; explanation for lithology, fossils and stratigraphic sections see Text-fig. 4



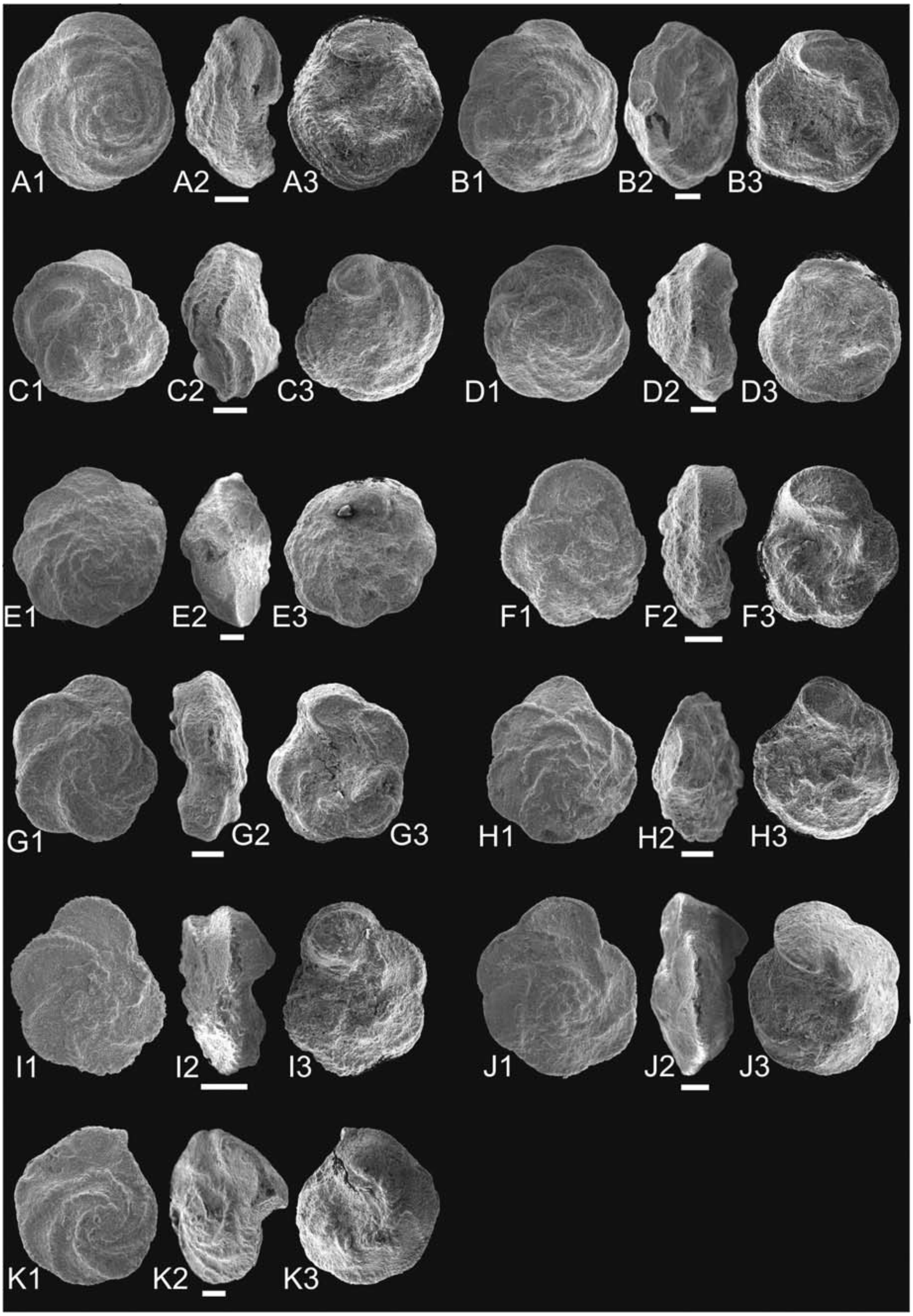
Text-fig. 6d. Details of the measured stratigraphic section-2 (upper slope and lower slope units). The 24 m thick upper slope unit is dominated by thick allochthonous calcarenite/calcirudite beds and truncated by a hardground. The 52 m thick lower slope unit is characterised by dominance of planktonic foraminifera and inoceramid-bearing marls, clayey limestones and mudstones, which are intercalated with allochthonous calcarenite/calcirudite beds; explanation for lithology, fossils and stratigraphic sections see Text-fig. 4



Text-fig. 7. Thin section photomicrographs of planktonic foraminifera observed throughout the succession. A – *Globotruncana arca* (Cushman), sample 07-420; B – *Globotruncana bulloides* Vogler, sample 07-438; C – *Globotruncana hilli* Pessagno, sample 07-420, D – *Globotruncana linneiana*, (d'Orbigny), sample 07-415; E – *Globotruncana linneiana* (d'Orbigny), sample 07-445; F – *Globotruncana mariei* Banner and Blow, sample 07-438; G – *Globotruncana* cf. *orientalis* El Naggar, sample 07-438; H – *Globotruncana ventricosa* White, sample 07-442; I – *Globotruncanita elevata* (Brotzen), sample 07-423; J – *Globotruncanita* cf. *stuarti* (de Lapparent), sample 07-436; K – *Radotruncana cf. calcarata* (Cushman), sample 07-420; L – *Rugoglobigerina rugosa* Plummer, sample 07-450.

vidali was yielded by all of the sparitic and dolomitic limestone samples from the entire succession (samples 377 to 410; Text-fig. 9A). It is a larger species from the Campanian to the lower Maastrichtian of the central regions of the Tethys (Zakrevskaya 2009). This species has been reported from Campanian to lower Maastrichtian localities in Turkey (Meriç 1988; Özcan 1993; Meriç *et al*. 1995; Meriç and Görmüş 1997; Yıldız and Gürel 2005). *Helicorbitoides boluensis* is a Campanian form reported from the Bolu region (Sirel 2004). This species occurs in the upper parts of the succession and is characterized by lateral chamberlets and nepionic stage chamber arrangement (Text-fig. 9C). *Orbitoides tissoti* and *O. medius* are also larger species that were

Text-fig. 8. Three-dimensional SEM views of washed specimens of planktonic foraminifera observed throughout the succession. A – *Contusotruncana fornicata* (Plummer), sample 07-420; A1) spiral view, A2) lateral view, A3) umbilical view; B – *Contusotruncana patelliformis* (Gandolfi), sample 07-429; B1) spiral view, B2) lateral view, B3) umbilical view; C – *Contusotruncana plummerae* (Gandolfi), sample 07-426; C1) spiral view, C2) lateral view, C3) umbilical view; D – *Globotruncana arca* (Cushman), sample 07-418; D1) spiral view, D2) lateral view, D3) umbilical view; E – *Globotruncana arca-orientalis*, sample 07-416; E1) spiral view, E2) lateral view, E3) umbilical view; F – *Globotruncana bulloides* Vogler, sample 07-427; F1) spiral view, F2) lateral view, F3) umbilical view; G – *Globotruncana linneiana* (d'Orbigny), sample 07-416; G1) spiral view, G2) lateral view, G3) umbilical view; H – *Globotruncana orientalis* El Naggar, sample 07-432; H1) spiral view, H2) lateral view, H3) umbilical view; I – *Globotruncana ventricosa* White, sample 07-408; I1) spiral view, I2) lateral view, I3) umbilical view; J – *Globotruncanita elevate* (Brotzen), sample 07-416; J1) spiral view, J2) lateral view, J3) umbilical view; K – *Globotruncanita stuartiformis* (Dalbiez), sample 07-432; K1) spiral view, K2) lateral view, K3) umbilical view. Scale bar equals 100 µm for all images.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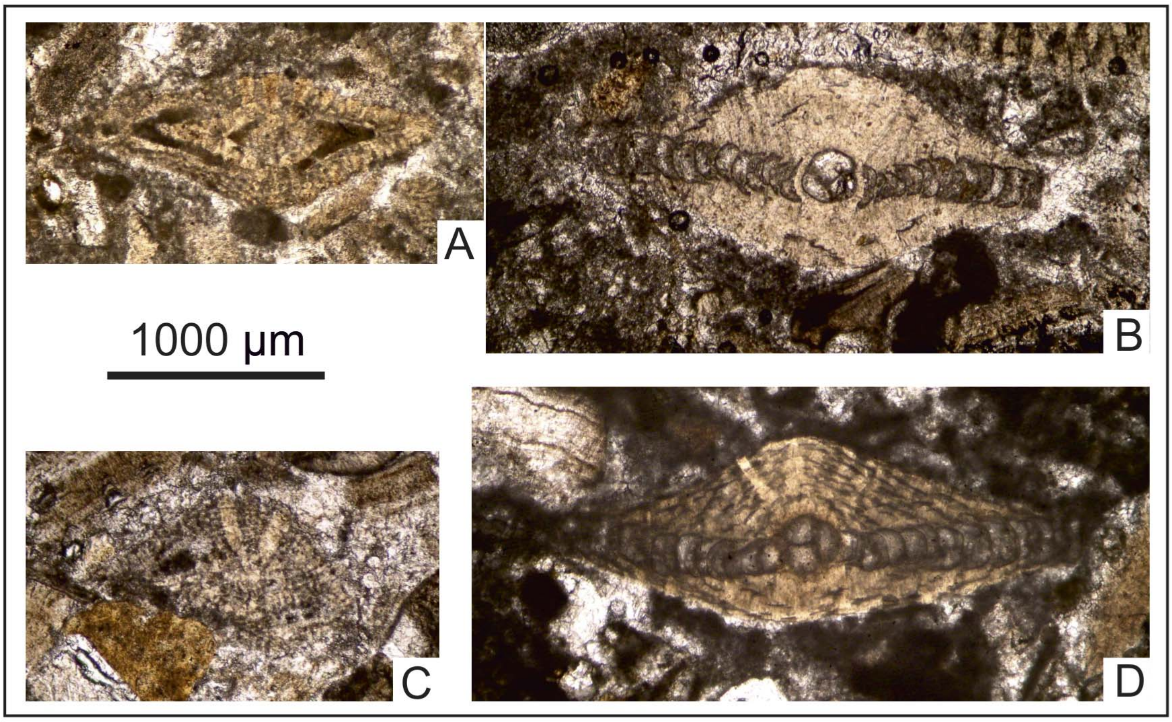
widespread from the Campanian to the lower Maastrichtian in Turkey (Görmüş 1998). Internal views of their embryos, embryo sizes, test shapes, and lateral chamberlets can clearly be seen in axial sections (Text-fig. 9B, D). The benthic foraminiferal association indicates a shallow water palaeoenvironment. The presence of *Helicorbitoides boluensis* in the lower part of the lower slope unit indicates a Campanian age for that level.

Inoceramid bivalves

The inoceramid bivalves are relatively rich taxonomically; eight species-level taxa are identified in the studied material. Best represented are '*Inoceramus*' *tenuilineatus* Hall and Meek, 1854 and *Cataceramus haldemensis* (Giers, 1964); also represented are '*Inoceramus*' *algeriensis* Heinz, 1932, *Platyceramus vanuxemi* (Meek and Hayden, 1860) and *Cataceramus gandjaensis* (Aliev, 1956) (Text-figs 10 and 11). Four other taxa, rather poorly preserved, are left in open nomenclature: '*Inoceramus*' cf. *nebrascensis* Owen, 1852, *Cataceramus* aff. *barabini* (Morton, 1834), strongly compressed '*I.*' cf. *tenuilineatus* Hall and Meek, 1854, and '*Inoceramus*' sp. The inoceramids were not collected bed by bed. They were collected loose from the base of the lower slope unit of the succession (stratigraphical interval between the 73 and 83 metre levels of the section-2) (Text-fig. 3). The actual composition and species richness of the original 'assemblages' therefore remain unknown.

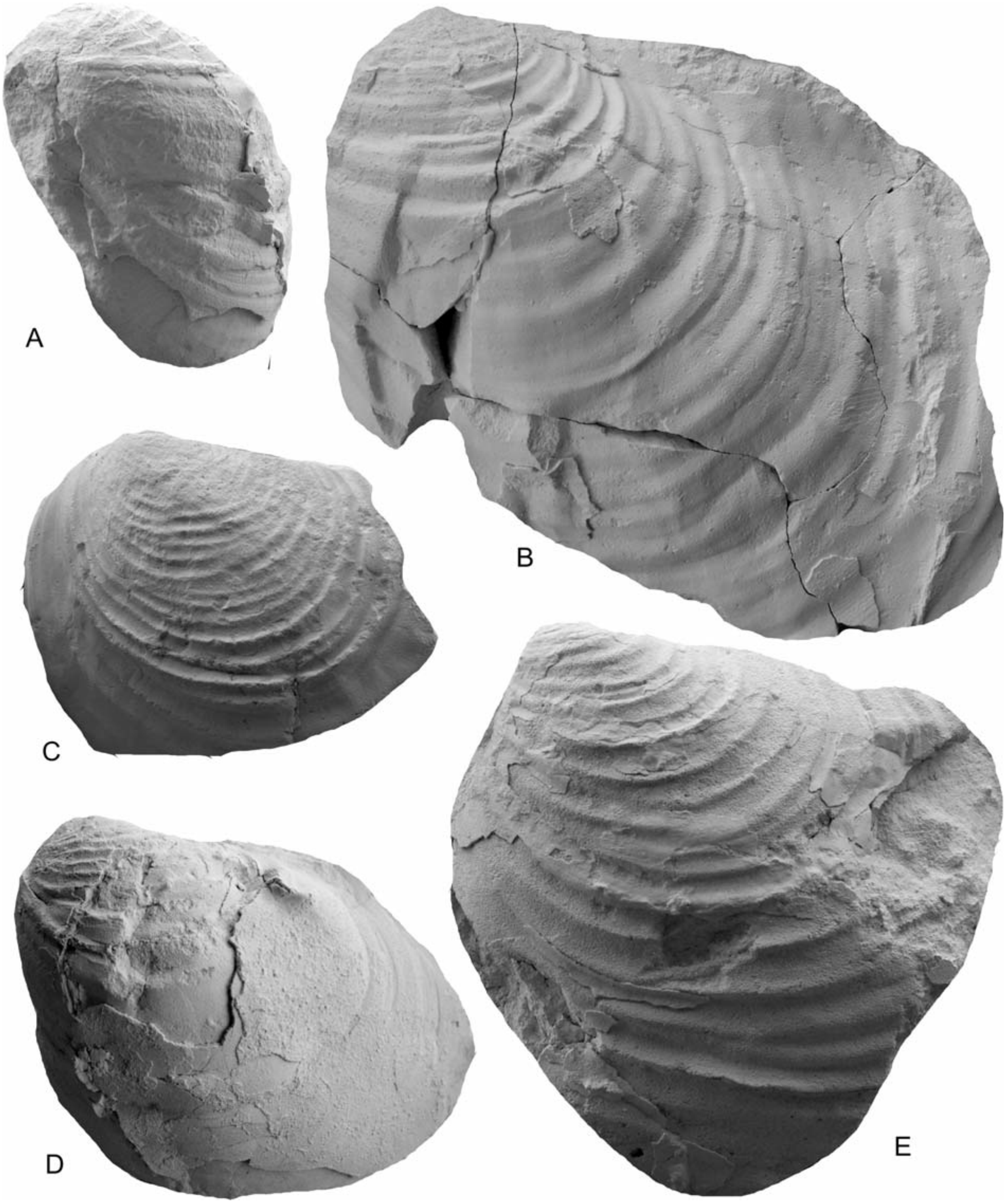
Chronostratigraphically, the assemblage characterizes the middle/upper Campanian boundary interval, as defined in the North American Western Interior (e.g. Cobban 1994; Walaszczyk *et al*. 2001; Cobban *et al*. 2006; Ogg and Hinov 2012). In inoceramid terms this is the *Inoceramus tenuilineatus* Zone (compare Walaszczyk *et al*. 2001, 2002; Walaszczyk 2004). *Cataceramus haldemensis* characterizes mostly slightly older parts of the middle Campanian (see e.g., Kennedy *et al*. 2007); however, it ranges up to the top of the substage. Nothing specific concerning the age may be said about '*Inoceramus*' *algeriensis*; Voûte (1951) writes broadly about the upper part of the upper Campanian, which may possibly mean upper Campanian in the sense as used herein. '*I.*' *algeriensis* is very similar to *C. haldemensis* (see illustrations of the former in Voûte 1951, and also in Walaszczyk 1997) and both species may possibly be synonymous, in which case, the earlier Heinz species name *algeriensis* would have priority and '*I.*' *algeriensis* would be of late middle Campanian age in the tripartite subdivision of the stage. *Cataceramus gandjaensis* appears in the latest middle Campanian and ranges high into the late Campanian and probably as high as the earliest Maastrichtian (e.g. Walaszczyk 2004).



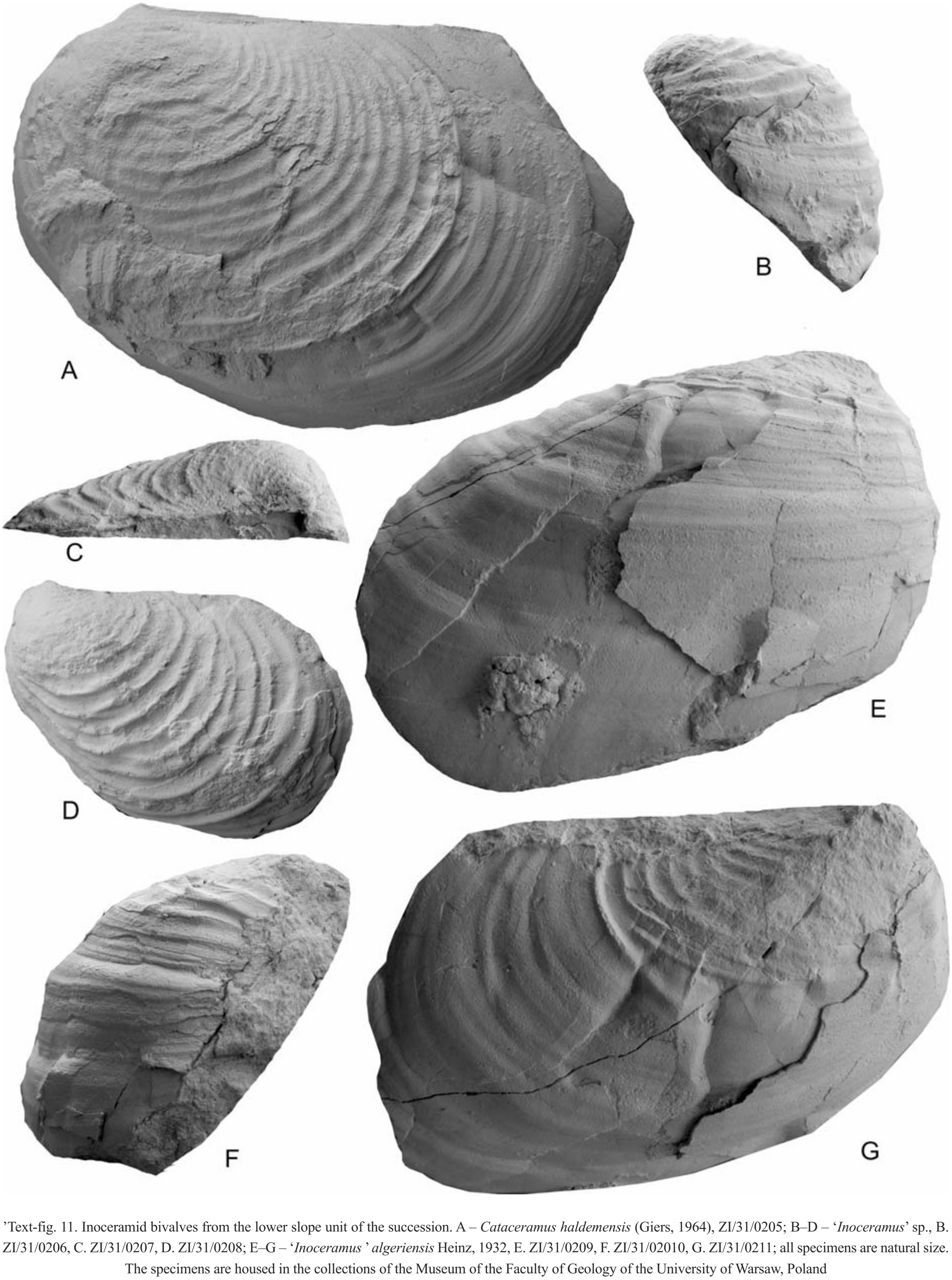
Text-fig. 9. Benthic foraminiferal association obtained from allochthonous calcarenite/calcirudite beds. A – *Pseudosiderolites vidali* (Douvillé), sample 07-377; B – *Orbitoides medius* (d'Archiac), sample 07-384; C – *Helicorbitoides boluensis* (Sirel), sample 07-405; D – *Orbitoides* cf. *tissoti* Schlumberger, sample 07-407.

Rudists

Rudist bivalves are rare throughout the succession. The calcarenite/calcirudite beds include abundant transported fragments (mostly radiolitids). Recognisable incomplete specimens were found at two levels: (1) the hardground with redeposited fragments of *Joufia reticulata* Boehm*, Bournonia* cf. *anatolica*

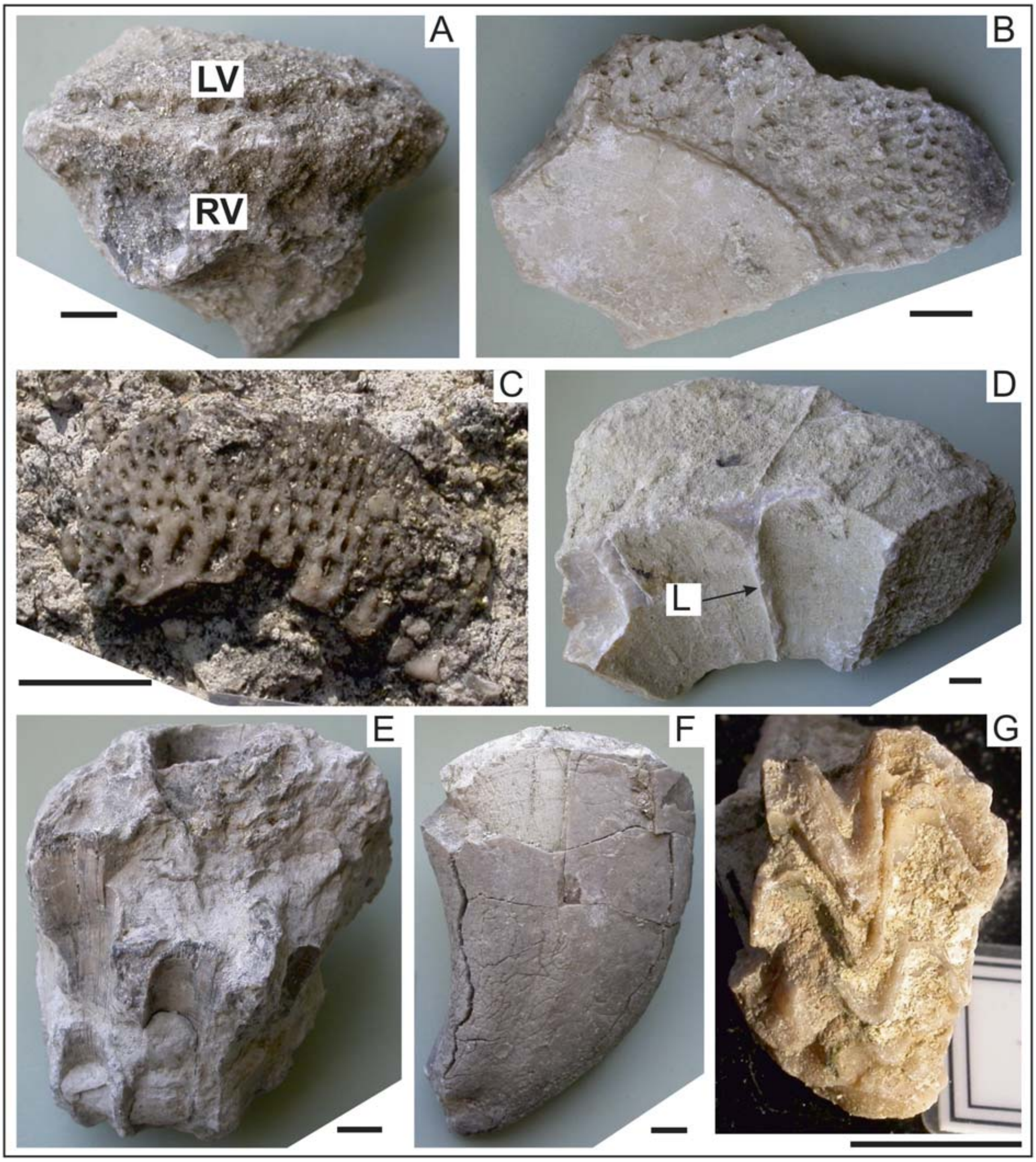


Text-fig. 10. Inoceramid bivalves from the lower slope unit of the succession. A, D – *Cataceramus haldemensis* (Giers, 1964), A. ZI/31/0200, D. ZI/31/0201; B – '*Inoceramus*' *tenuilineatus* Hall and Meek, 1854, ZI/31/0202; C – *Cataceramus gandjaensis* (Aliev, 1956), ZI/31/0203; E – *Platyceramus vanuxemi* (Meek and Hayden, 1860), ZI/31/0204; all specimens are natural size. The specimens are housed in the collections of the Museum of the Faculty of Geology of the University of Warsaw, Poland



'Text-fig. 11. Inoceramid bivalves from the lower slope unit of the succession. A – *Cataceramus haldemensis* (Giers, 1964), ZI/31/0205; B–D – '*Inoceramus*' sp., B. ZI/31/0206, C. ZI/31/0207, D. ZI/31/0208; E–G – '*Inoceramus* ' *algeriensis* Heinz, 1932, E. ZI/31/0209, F. ZI/31/02010, G. ZI/31/0211; all specimens are natural size. The specimens are housed in the collections of the Museum of the Faculty of Geology of the University of Warsaw, Poland

Özer, *Biradiolites* cf. *bulgaricus* Pamouktchiev and ?*Biradiolite*s sp. (Text-fig. 12A, C–G); and (2) at the 65 m level of the upper part of the sequence, with a fragment of a left valve of *J. reticulata* (Text-figs 6 and 12B). *J. reticulata* exhibits a wide geographic distribution in the upper Campanian–Maastrichtian of Turkey (Karacabey 1959, 1969, 1974; Özer 1983, 1988; 2002; Özer *et al.* 2008, 2009) and Bosnia-



Text-fig. 12. Rudists observed from the upper slope unit of the stratigraphic section-2. A, B, C are images of *Joufia reticulate* Boehm. A – both valves, LV; left valve, RV: right valve; B – left valve fragment showing its characteristic numerous canal sections; C – high-magnification view of the canal sections; D – right valve fragment of a radiolitid with a thick prismatic outer shell layer, probably belonging to *Joufia*. Note the preservation of the ligamental ridge (L). E – *Biradiolites* cf. *bulgaricus* Pamouktchiev, radial bands; F – *Bournonia* cf. *anatolica* Özer, note the very simple structure of the radial bands. G – ?*Biradiolite*s sp. Scale bar equals 10 mm for all images. (See Fig. 6 for stratigraphic positions of the rudists; A, C, D, E, F and G are from the hardground at the 23.5 metre level of the section-2, and B is from the 65.2 metre level of the same section)

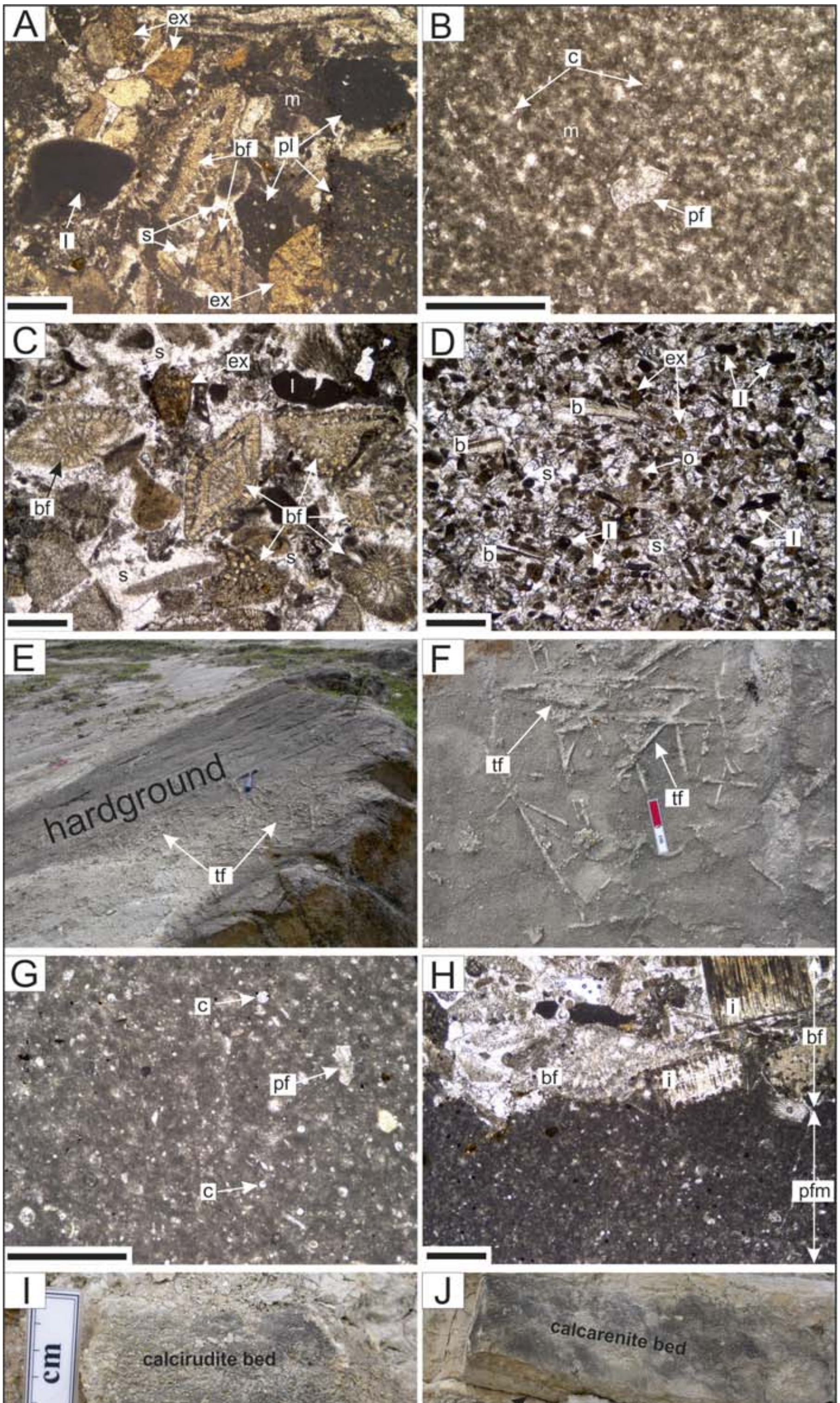
Herzegovina, Croatia, Serbia, Montenegro, Bulgaria, Romania, Greece, Italy and Spain as well (Steuber 2002). *B. anatolica* has been described from Maastrichtian limestones of central Anatolia (Özer, 1983) and the uppermost Campanian–Maastrichtian of the Eastern Pontides (Özer *et al*. 2008, 2009). Recently, this species was found in the Maastrichtian Tarbur Formation in the Zagros region in south-west Iran (Khazaei *et al.* 2010). *B. bulgaricus* has been reported from the Campanian of Bulgaria (Pamouktchiev 1967; Swinburne *et al.* 1992), Somalia (Pons *et al*. 1992) and the Maastrichtian of Turkey (Özer 1983). The identified rudists suggest a late Campanian–Maastrichtian age.

MICROFACIES AND DEPOSITIONAL ENVIRONMENT

The red pelagic beds of the basinal unit are foraminiferal mudstones (Text-fig. 13B). The presence of planktonic foraminifers within these levels and facies indicate a basinal environment or a slope-basin transition. The calcarenite/calcirudite beds of this unit contain mainly transported benthic foraminifers, red algae, crinoid, bryozoan and rudist fragments, neritic and pelagic carbonate lithoclasts and volcanic extraclasts. These limestones are mainly rudstones, with grain-supported fabric and sparry calcite cement, with subordinate amounts of micrite matrix (Text-figs 5 and 13A, C). The sparry calcite cement and micrite matrix are recrystallized to a different degree. Packstones are also present (Text-figs 5, 13D). The term ‘allochthonous bed’ is applied to these beds, as they are composed entirely of transported grains (Braunstein 1961). These types of rocks are classified as ‘limestone turbidites’ (Flügel 2004) or ‘calciclastic submarine fan deposits’ (Payros and Pujalte 2008). Considering that these allochthonous beds are bounded by and alternate with the background (in situ) red pelagic limestones, marls and mudstones, the grains are expected to have been transported to the basin from adjacent shallow marine and slope environments by turbidity currents. Hence, this part of the succession is suggested to have been deposited in the deepest part of the basin (Text-figs 3 and 15). Similar sediments were described as ‘basin floor’ deposits by Mullins (1983).

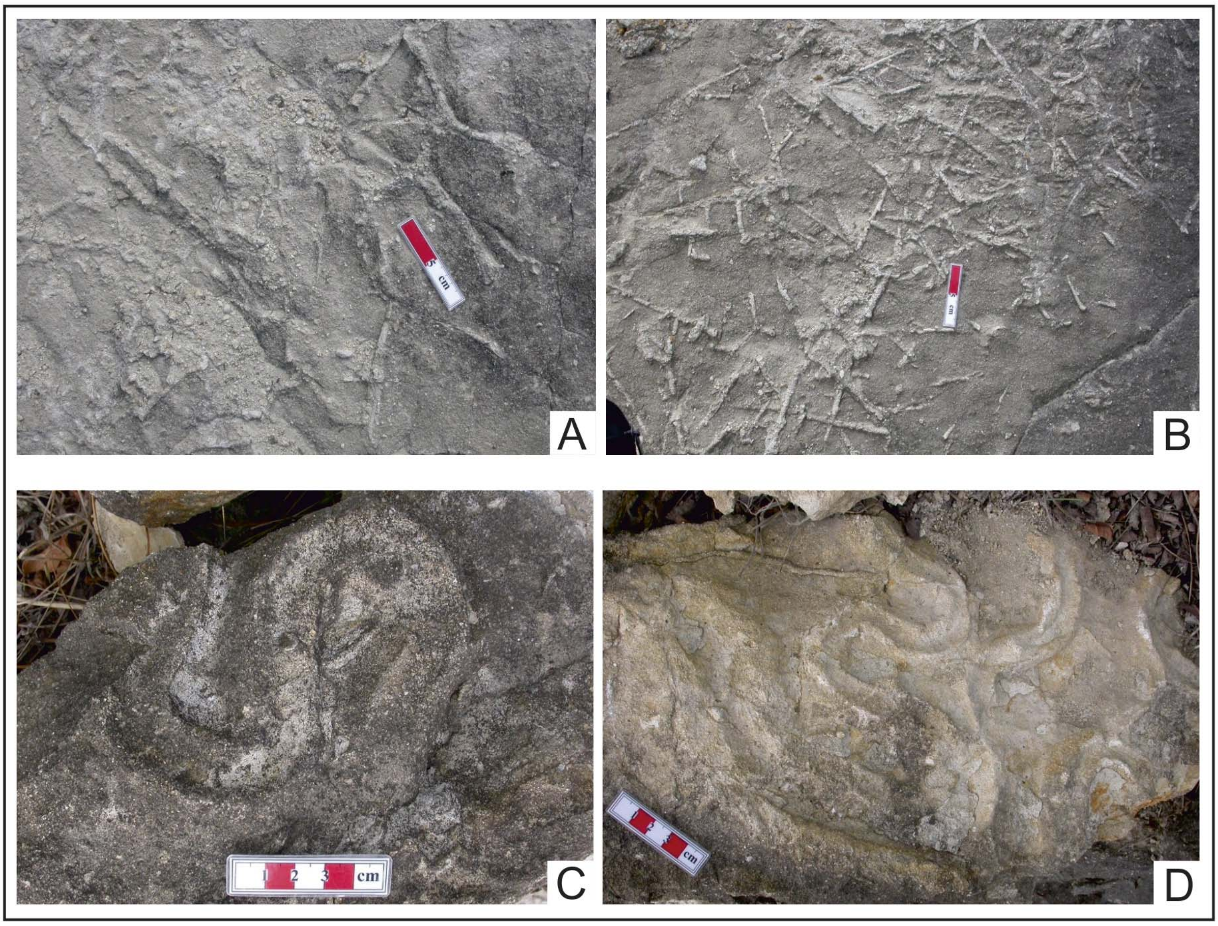
The upper slope unit is dominated by medium- to thick-bedded and massive allochthonous calcarenite/calcirudite beds (Text-fig. 6), often with sharp erosional basal surfaces. These limestones are dominantly rudstone in texture, represented by silt- to sand-sized transported skeletal grains (benthic foraminifer, bivalve, bryozoan, crinoid, rudist and rare planktonic foraminifer fragments), neritic and pelagic carbonate lithoclasts and volcanic extraclasts of various sizes (Text-figs 6, 13C). The dominance of thick allochthonous calcarenite/calcirudite beds in the upper slope unit indicates a more proximal depositional environment (Text-figs 3 and 15) (Flügel 2004). These deposits correspond more or less to the ‘upper slope’ facies of Mullins (1983). Dolomitization in these levels is common. The upper slope unit is truncated by a hardground forming a prominent ledge that is easily recognizable in the studied sections (Text-figs 6 and 13E). The hardground surface exhibits abundant trace fossils, which form horizontal and vertical branching burrows (the *Ophiomorpha* group) (Text-fig. 13F). The *Ophiomorpha* group encompasses large horizontal and vertical branching burrows. Ethologically these ichnogenera display dwelling and feeding activities of infaunal organisms (Text-fig. 14). *Ophiomorpha annulata*, *Thalassinoides* isp. and *Ophiomorpha* isp. are abundant throughout the surface (Text-fig. 14A, B). They may present in transitional zones from shallow to deeper water environments such as proximal part of submarine fans.

The allochthonous calcarenites/calcirudites intercalated with pelagic marls and mudstones through the lower slope unit are generally characterized by grain-supported rudstones with transported skeletal grains (benthic foraminifer, inoceramid, rudist, bryozoan and red algae fragments), neritic and pelagic carbonate lithoclasts and volcanic extraclasts. The interparticle pores are filled mainly by sparry calcite cement and subordinately by micrite matrix (Text-fig. 13H). Medium- to coarse-grained clasts dominate some beds (Text-fig. 13D). Fragments of benthic foraminifers are found in some pelagic marls and mudstones (Text-fig. 6). Rare ammonites were found at the 34.6 m level of the section-2 (Text-fig. 6). The thickness of the allochthonous beds in this part is reduced and varies from 3–5 cm to 50 cm. The bases of these beds are mostly sharp and erosional, whereas they pass gradually upward into marls and mudstones (Text-figs 6 and 13H-J). The pelagic marls and mudstones dominating this part of the succession are characterized by inoceramids, planktonic foraminifers and a calcisphere-bearing wackestone-mudstone texture (Text-figs 5 and 13G). This kind of microfacies is the result of deposition in mainly basinal conditions, which is also demonstrated by the fossil content. The dominance of pelagic marls and reduced thickness of the allochthonous beds in the lower slope unit suggest a more distal depositional environment (Text-figs 3 and

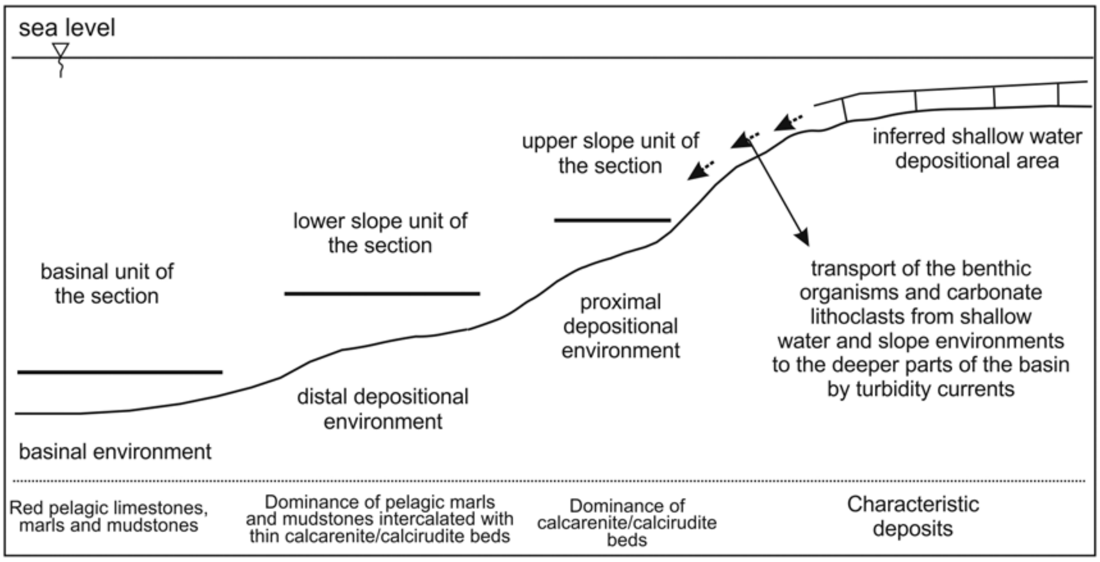


Text-fig. 13. Thin section and field photographs of various levels of the studied sequence. A – Bioclastic-lithoclastic rudstone with abundant benthic foraminifera (bf) and rare volcanic extraclasts (ex) (l: lithoclasts; sample 07-413). B – Planktonic foraminifera (pf) mudstone with rare calcispheres (c). Rare bioclasts are embedded within micrite matrix (m) (sample 07-414). C – Benthic foraminifera (bf) rudstone with rare lithoclasts (l) and extraclasts (ex) (sample 07-392). Interparticle pores are filled with sparry calcite cement (s). D – Bioclastic-lithoclastic packstone with medium to coarse sand-sized lithoclasts (l), bioclasts (b), rare extraclasts (ex) and ooids (o) (sample 07-409). Interparticle pores are filled with sparry calcite cement (s). E – Field photograph of the hardground. The prominent hardground is represented by trace fossils (tf) (the length of the hammer in the middle of the photograph is 30 cm). F – Close-up view of the hardground showing abundant trace fossils (tf), which consist of large horizontal and vertical branching burrows (*Ophiomorpha* group) (the length of the scale bar equals 10 cm). G – Planktonic foraminiferal wackestone with rare calcispheres (c) (sample 07-440). H – Thin section photograph of a sharp and erosive contact between a planktonic foraminiferal mudstone (pfm) and a bioclastic rudstone with benthic foraminifera (bf) and inoceramid fragments (i) (sample 07-449). I – Close-up view of the 10-cm thick fining-upward calcirudite bed, which pinches out laterally. Very coarse sand- to granule-sized bioclasts and carbonate lithoclasts are clearly seen at the weathered surface of the bed (the length of the scale bar equals 10 cm; 73 metre level of the section-2), J – Field photograph of the calcareous mudstone-calcarenite contact. The base of the allochthonous calcarenite bed is sharp and erosive. Inoceramids (in) are common in calcareous mudstones (74 metre level of the section-2; the length of the hammer is 30 cm).

The black bar at the left bottom corner of the photographs equals 1 mm



Text-fig. 14. Trace fossils obtained from two different levels of the succession. A – *Thalassinoides* isp. Endichnial full relief in calcarenites. Scale bar equals 10 cm. From the hardground at the top of the middle part of the sequence, B – *Ophiomorpha annulata*. Endichnial full relief in medium-fine-grained sandstone. Scale bar equals 10 cm. Slope–Middle fan. From the hardground at the top of the middle part of the sequence, C – *Scolicia strozzii*. Hypichnial semi-relief in calcarenites. Scale bar equals 5 cm. Middle fan–Outer fan. 75 m from the base of the sequence, D – *Scolicia strozzii*. Hypichnial semi-relief in calcarenites. Scale bar equals 5 cm. (See Fig. 6 for stratigraphic positions of the trace fossils)



Text-fig. 15. Simplified depositional model for the studied stratigraphic interval

15) (Flügel 2004). Similar facies was described as 'lower slope' deposits by Mullins (1983).

The second trace fossil group (the *Scolicia* group) observed at the top of the sequence consists of winding and meandering structures (Text-fig. 14C, D). This group encompasses bilobate and trilobate traces that have been related to Mesozoic and Cenozoic echinoid burrows. The presence of *Scolicia strozzii* and *Scolicia* isp. (Text-fig. 14C, D) indicate a mixed *Skolithos-Cruziana* ichnofacies, which suggests a deep marine, well-oxygenated environment.

The palaeontological and sedimentological data obtained from the studied sequence suggest that a deep marine environment existed in the northern part of the Eastern Pontides during the late Campanian (Text-fig. 15). The data from the allochthonous beds also imply that most of the material was derived from an adjacent shallow marine environment. This shallow marine environment was favourable for life, despite the existence of volcanism, as demonstrated by the presence of many benthic fossil groups, such as benthic foraminifers, rudists, bryozoans, crinoids and red algae in the allochthonous beds.

CONCLUSIONS

The upper Campanian of the Hacımehmet area is characterized by calciclastic turbidites (calcarenite/calcirudite beds), intercalated with red pelagic limestones, pelagic marls, mudstones and conglomerates with volcanic clasts. The allochthonous calcarenite/calcirudite beds are composed of transported benthic organisms, including foraminifers, rudists, red algae, crinoids, bryozoans and neritic and pelagic carbonate lithoclasts. The pelagic marls and mudstones include inoceramids, ammonites and planktonic foraminifers.

An integrated biostratigraphic study based on benthic and planktonic foraminifers, rudist and inoceramid bivalves is presented. An early late Campanian age is suggested by planktonic foraminifers; a Campanian age by benthic foraminifers and a late Campanian–Maastrichtian age by rudists. Inoceramid bivalves, collected from the pelagic marls of the lower slope unit of the succession, indicate the "*Inoceramus*" *tenuilineatus* Zone, the interval corresponding to the late middle and earliest late Campanian. Consequently, an earliest late Campanian age for the middle part of the basinal unit and lowermost part of the lower slope unit is herein suggested. The age of the lower part of the basinal unit could be middle Campanian. No index taxa indicating a Maastrichtian age were documented in any part of the succession. Hence, the biostratigraphic data obtained by this study are not in accordance with some of the former age determinations such as Campanian–Maastrichtian (Özsayar 1971; Yılmaz *et al*. 2002; Aydın 2003; Ersoy 2007) and early–middle Maastrichtian (Kaya and Sipahi 1999).

Based on the results obtained in this study, the existence of a shallow marine depositional environment adjacent to the deep marine environment in the Eastern Pontides during the late Campanian is inferred.

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