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Ichnology of the Miocene Güneyce Formation (Southwest Turkey): Oxygenation and Sedimentation Dynamics

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Abstract: The Güneyce Formation is well exposed in the Lake District of southwestern Turkey. It was deposited in the early Miocene in the Neotethys ocean and contains a large variety of trace fossils. The following ichnotaxa were recognized: *Chondrites intricatus*, *C. targionii*, ?*Cosmorhaphe* isp., *Helminthopsis* isp., *Helminthorhaphe flexuosa*, *Lorenzinia* isp., *Naviculichnium marginatum*, ?*Nereites* isp., *Ophiomorpha rudis*, ?*Phycosiphon incertum*, *Planolites beverleyensis*, cf. *Rhizocorallium* isp. and *Thalassinoides suevicus*. There is a lateral trend from proximal turbiditic successions to distal low-oxygen shaly mudstone. *Ophiomorpha rudis* ichnosubfacies, *Paleodictyon* ichnosubfacies of the *Nereites* ichnofacies and *Zoophycos* ichnofacies were identified.

Key Words: trace fossils, turbidites, ichnofacies, oxygenation, Neotethys

Miyosen Yaşlı Güneyce Formasyonu (GB Türkiye) İz Fosilleri: Oksijenleşme ve Sedimantasyon Dinamiği

Özet: Güneyce Formasyonu çökel dizilimleri güneybatı Türkiye'de Göller Yöresinde önemli yüzeylenmeler vermektedir. Çökelim, Neotetis Okyanusu'nda erken Miyosen zamanında gerçekleşmiştir. Formasyon içerisinde belirlenen iz fosiller şunlardır: *Chondrites intricatus*, *C. targionii*, ?*Cosmorhaphe* isp., *Helminthopsis* isp., *Helminthorhaphe flexuosa*, *Lorenzinia* isp., *Naviculichnium marginatum*, ?*Nereites* isp., *Ophiomorpha rudis*, ?*Phycosiphon incertum*, *Planolites beverleyensis*, cf. *Rhizocorallium* isp. ve *Thalassinoides suevicus*. İstifte, yakınsak turbiditik istiflerden düşük oksijenli şeylli çamurtaşına yanal geçişler bulunmaktadır. Ayrıca, formasyonda *Ophiomorpha rudis*, *Paleodictyon* ve *Zoophycos* iknoaltfasiyesleri tanımlanmıştır.

Anahtar Sözcükler: İz fosiller, türbidit, iknofasiyes, oksijenleşme, Neotetis

Introduction

The geology of the Isparta Angle in southwestern Turkey is structurally complex. Various allochthonous (Antalya and Lycian nappes) and autochthonous units have been recognized (e.g., Poisson 1967; Gutnic *et al*. 1979; Poisson *et al*. 1983; Yalçınkaya *et al*. 1986, Yalçınkaya 1989; Şenel 1997). They comprise Mesozoic and Palaeogene successions of the Neotethys, which are commonly unconformably overlain by younger deposits (see Nielsen *et al*. 2010 and references therein). This is also recognized in the areas of Dereboğazı (Isparta), Ağlasun and Sagalassos (Burdur) (Figure 1). The Triassic to Early Cretaceous Isparta Çay Formation, comprising radiolarite chert and platy and turbiditic limestones, is erosively and unconformably overlain by Miocene formations: the Karabayır, Güneyce and Gökdere formations, which were formed in a regionally large basin. The siliciclastic successions of the Güneyce Formation are characterized by abundant trace fossils. In addition to the microfossil content, they can provide complementary data about the palaeoenvironment. For this reason, the Güneyce Formation is of particular interest because it extends laterally for

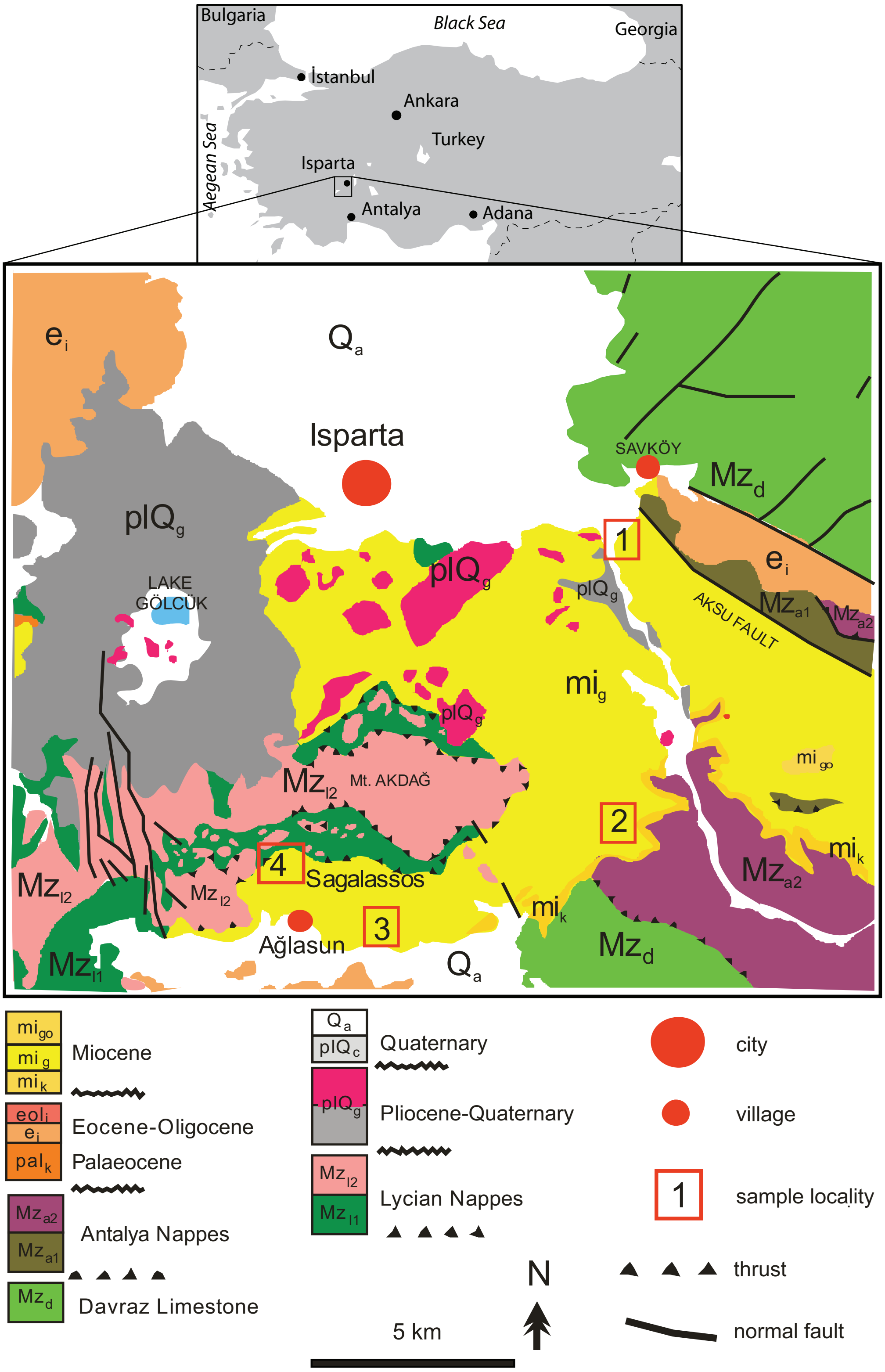

Figure 1. Geological map of the study area within the Isparta Angle, Turkey. Localities of the Miocene Güneyce Formation are indicated by numbers (1–4). Modified from Gutnic *et al.* (1979), Şenel (1997) and Nielsen *et al.* (2010).

many kilometres. The aim of this study is to provide the first overview of trace fossils from the Güneyce Formation. The presence of trace fossils is discussed in terms of palaeoenvironmental conditions in relation to sedimentation dynamics, substrate consistency, oxygenation and other parameters.

Geological Setting

In the study area, Miocene formations include the Karabayır, Güneyce and Gökdere formations (Akbulut 1980; Yalçın 1993; Görmüş & Hançer 1997). Among these, we only report the stratigraphical and ichnological data from the siliciclastic rocks of the Güneyce Formation (Figures 1 & 2). Previous records gave details of the other Miocene formations (Yalçınkaya *et al.* 1986; Yalçınkaya 1989; Yalçın 1993; Yağmurlu 1994; Görmüş & Hançer 1997; Şenel 1997; Görmüş *et al.* 2001; Poisson *et al.* 2003).

The name of the Güneyce Formation is derived from Güneyce village, southwest of Isparta

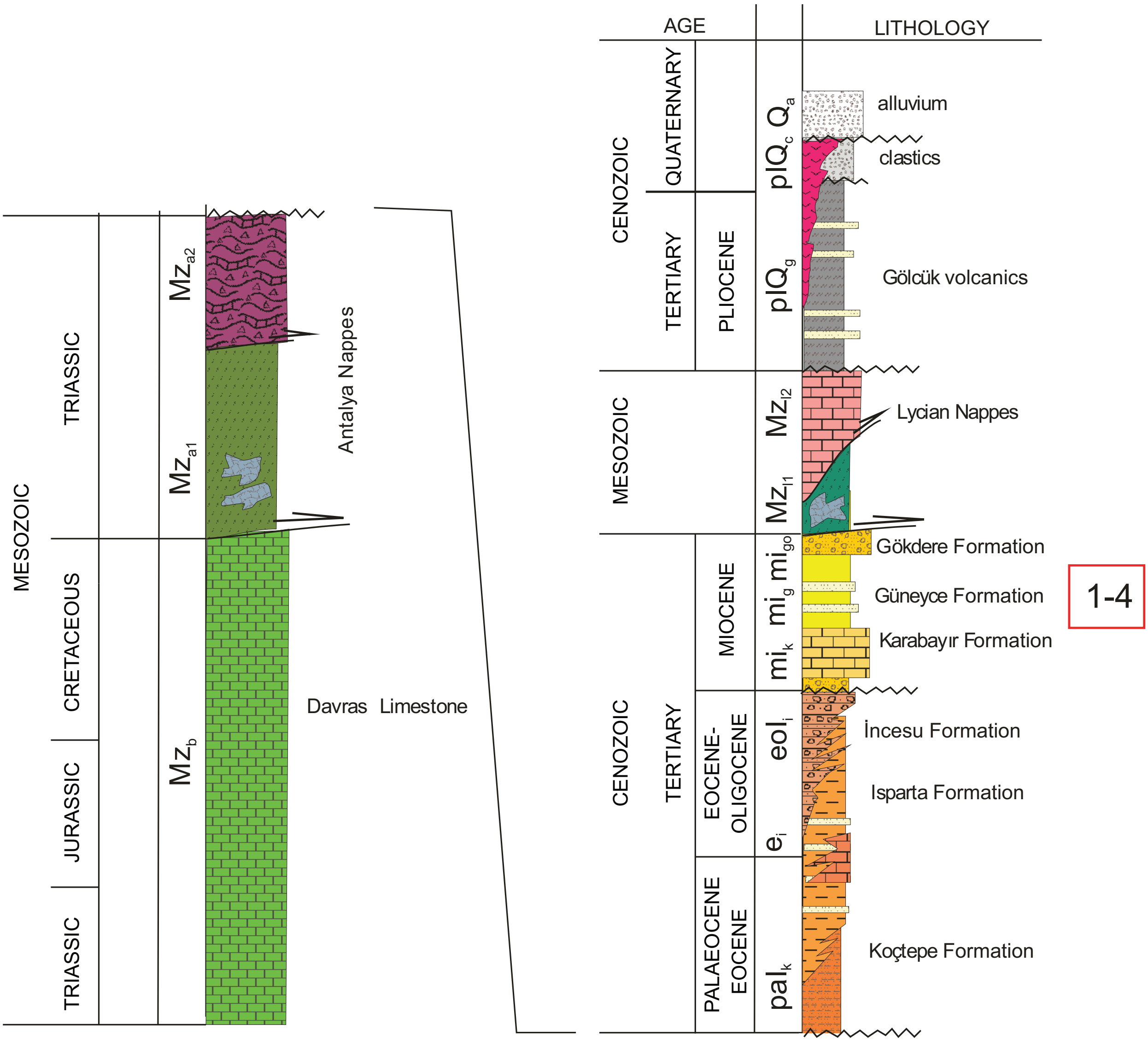

Figure 2. Stratigraphical overview of Mesozoic and Cenozoic formations exposed in the Burdur and Isparta regions. Structural nappes are indicated by older units on top of younger ones. Stratigraphical levels of localities are indicated by rectangular symbols. From Nielsen *et al.* (2010).

(Akbulut 1980). Rhythmical siliciclastic sediments were identified as 'the Burdigalian flysch' by Gutnic *et al*. (1979). The Ağlasun Formation is a more recent synonym of the Güneyce Formation (Yalçınkaya 1989; Karaman 1990). We prefer the original formation name given by Akbulut (1980) according to stratigraphical rules (Hedberg 1976). The Güneyce Formation is exposed widely around İmrezi, Kışla, Dariören and Güneyce villages. Siliciclastic sediments are dominant and include various sedimentary facies such as (1) mudstone-dominated facies; (2) sandstone-dominated facies; (3) olistostromal facies; (4a) rhythmic heterolithic facies of sandstone and mudstone; (4b) carbonate facies; (5) pure sandstone facies; (6) coarse clastic-conglomerate facies (Görmüş *et al*. 2001). The last two facies are distinguished as separate units: the Gökdere Formation (Yalçın 1993). The total thickness of the Güneyce Formation is between 500–750 m, according to our field observations. The underlying contact with the Karabayır Formation is conformable and interfingering is present. Pliocene and Quaternary volcanic rocks rest unconformably on the Miocene sediments, as in the palaeovalley located 2 to 3 km south of Savköy.

Microfossils and nannofossils of the Güneyce Formation are listed below. Details about nannofossils and their reworking are compiled from Görmüş *et al*. (2001, 2004). Planktonic foraminifera: *Globigerina* sp., *Globigerinoides* sp., *Globorotalia* sp., *G.* cf. *kugleri*, *Globoquadrina dehiscens,* reworked *Morozovella aequa*, *M. angulata*. Benthic foraminifera: *Amphistegina* sp., *Lepidocyclina (Eulepidina)* sp., *Lepidocylina (Nephrolepidina)* sp., *Miogypsina* sp., *Miogypsinoides* sp. and *Operculina* sp. Nannofossils: *Braarudosphaera bigelowii, Calcidiscus* sp., *Cyclicargolithus abisectus, C. floridanus*, *Coccolithus pelagicus*, *Discoaster deflandrei*, *D. druggii, Dictyococcites bisectus*, *Helicosphaera obliqua*, *Sphenolithus belemnos, S. conicus*, *S. compactus, S. dissimilis* and *S. moriformis.* Reworked nannofossils from Eocene: *Coronocyclus nitscens, Coccolithus pelagicus, Dictyococcites* sp., *Discoaster binodosus*, *D. diastypus, D. gemmifer, D. salisburgensis*, *D. multiradiatus, Ericsonia formosa*, *E. ovalis*, *Sphenolithus radians*, *S. editus*, *Toweius eminens*, *T. occultatus*, *T. pertusus*, *Tribrachiatus orthostylus*, *Triquetrorhabdus carinutus* and *Zygrhablithus bijugatus.* Reworked Cretaceous nannofossils: *Micula decussate*, from the Cretaceous/Palaeogene boundary: *Aspidolithus parcus constrictus*, *Briantolithus sparsus*, *Litraphidites quadratus*, *Microrhabdulus attenuatus, Micula decussata*, *Prinsius bisulcus*, *Stradneria crenulata*, *Thoracosphaera saxea* and *Watznaveria barnesae*. The fossils of the entire Güneyce Formation indicate an early Miocene age, i.e., Aquitanian–Burdigalian–?Langhian age (Görmüş *et al*. 2001, 2004). Lithological characteristics and fossil contents of the Güneyce Formation indicate a transgressive to regressive succession, from shallower to open sea and back to shallower palaeoenvironments.

Sedimentological Overview

Overall the Güneyce Formation contains primary sedimentary structures typical of turbidity current deposits. This chapter gives a generalised overview of these deposits. The divisions Ta, Tb, Tc, Td and Te by Bouma (1962) have been widely used to describe turbiditic beds (e.g., Komar 1985; Talling 2001; Sinclair & Cowie 2003; Bouma 2004; Schultz & Hubbard 2005; Warchoł & Leszczyński 2009). Walker (1978) and Mutti (1992) found the Bouma divisions to be insufficient for classification of coarse-grained beds, which may contain a broad spectrum of sediment types. For detailed facies analysis with genetic facies, Mutti (1992) recommended that the broadly descriptive divisions of Bouma (1962), Mutti & Ricci Lucchi (1972) and Walker (1978) should be abandoned. In the present study, we consider the Bouma divisions adequate to capture the common sediment types in the Güneyce Formation. The formation contains relatively well-sorted sandstones with a tabular and tapered geometry, which differentiate them from debrites (Amy *et al*. 2005).

Four localities, typical of the Güneyce Formation in the Dereboğazı (1), Ağlasun (2, 3) and Sagalassos (4) areas, have been chosen for this study (Figures 1 & 2). The sedimentary successions in these localities formed in an open-sea environment during maximum sea level. They cover approximately the central part of the formation (Figure 3). Detailed biostratigraphical studies are needed to verify whether the successions are exactly coeval with each other.

At locality 1 (Dereboğazı), the Güneyce Formation succession consists of grey laminated or

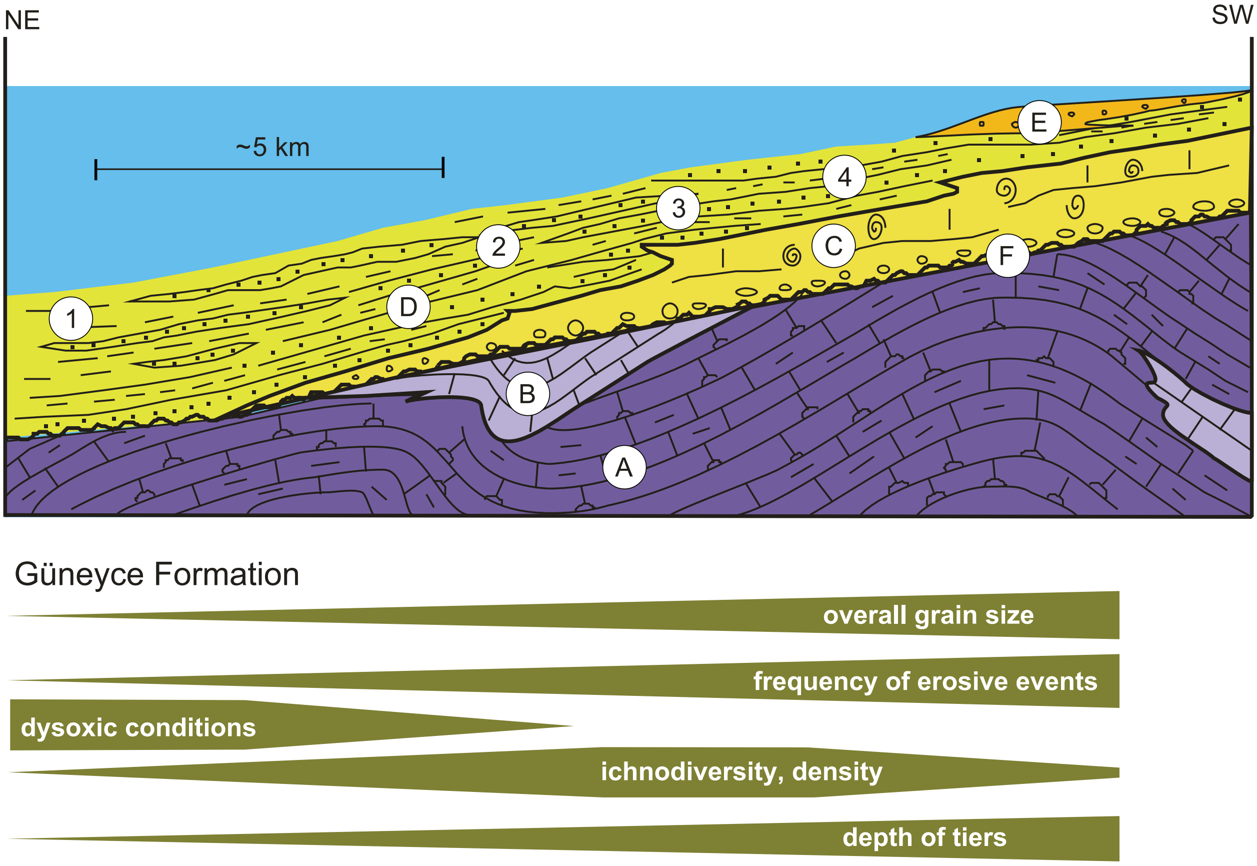

Figure 3. Palaeoenvironmental reconstruction of the Miocene Güneyce Formation. Isparta Çay Formation (A, B) including radiolarite chert (A) and turbiditic limestones (B). Karabayır Formation (C). Güneyce Formation (D). Gökdere Formation (E). Disconformity (F). The Güneyce Formation interfingers with the shallow-marine Karabayır Formation, and erosively superposes bedrocks of the Isparta Çay Formation. Localities indicated by numbers (1–4).

massive shaly mudstones. These can be interpreted as indicators of low density turbidity current deposition and hemipelagic sedimentation (division Tde).

At locality 2 (Ağlasun), the Güneyce Formation consists predominantly of sheet-like beds of coupled silty sandstones and mudstones. The sandstones are typically less than 5 cm thick, which is thinner than at locality 3. The mudstones are laminated or massive (divisions Td and Te).

At locality 3 (Ağlasun), the succession contains sandstone layers up to 10 cm thick, thicker than at locality 2. Plane parallel laminae (division Tb) and cross laminae (division Tc) are common. The latter may appear in silty sandstones. Flute casts may be present on bedding planes. Small wrinkle structures may rarely be present, indicating rapid loading and compaction. The sandstones may be overlain by laminated mudstone (division Td), forming couplets.

At locality 4 (Sagalassos), the beds consist commonly of sandstone and siltstone layers. The sandstone layers are massive or normal graded, typically 10–20 cm thick. Groove structures, which may be present on bedding planes, were formed by objects dragged along the sea floor. The graded sandstone layers represent the division Ta. These are overlain by parallel laminated sandstone layers less than 25 cm thick assigned to division Tb. Cross-laminated silty sandstone to siltstone (division Tc) may be present at the top of the beds.

As supported by laboratory experiments (e.g., Middleton 1967; Parsons *et al.* 2002), the coarse-grained sediment was preferentially deposited proximally in the fan system. The fine grains tended to travel further outwards. The overall grain size, bed thickness and sand/shale ratio (Walker 1978) indicate that the succession at locality 4 formed proximally in the depositional system (intermediate fan), while the other successions at localities 1, 2 and 3 formed more distally (outer fan). Nevertheless, the interpretation of proximality presumes a generalised fan system. The grain size and the bed thickness can vary laterally in local parts of the fan system.

Material and Methods

Road sections were studied during the fieldwork. Particular sections (localities 1 to 4) were investigated further for primary sedimentary structures and trace fossils. The scree material of these sections was also examined. Hand-picked samples were collected and a selection of them is housed at the Jeoloji Mühendisliği Bölümü, Süleyman Demirel University. Bertling *et al*. (2006) gave an overview of morphological features relevant to trace fossil identification, i.e. ichnotaxobases. Their recommendations for ichnotaxobases are followed here.

Ichnology

Bioturbation structures are absent to moderately frequent in the Miocene Güneyce Formation (Figures 4 & 5, Table 1). The ichnodiversity is low at localities 1 (Dereboğazı) and 4 (Sagalassos), whereas localities 2 and 3 (Ağlasun) are characterized by moderate ichnodiversity (Figure 3).

Cross-cuttings between the trace fossils are generally absent. The graphoglyptids are common at the localities 2 and 3, whereas they are rare at locality 4 (Table 1). They occur on the sole of sandstones and are preserved in convex hyporelief because of slight scouring and casting. Other trace fossils are preserved in full relief (see below).

Chondrites intricatus (Brongniart 1823)

Description – *Chondrites intricatus* is rare at locality 1 (Figure 4b). It is characterized by its branching burrow system composed of straight, unlined segments and consistent branching angle at 35 to 45°. The individual branches are 0.5 to 1 mm wide and up to 30 mm long. They are commonly horizontally or subhorizontally oriented to bedding and affected by compaction. The branches do not cross-cut each other.

Remarks – Fu (1991) revised the ichnogenus *Chondrites*, and here we follow her emendation of *C. intricatus*. In Turkey, the ichnospecies has been found in deep-sea fan fringe deposits within the western fan of the Miocene Cingöz Formation (Adana Basin), where the trace fossil assemblages are representative of the *Nereites* ichnofacies together with some features of the *Skolithos* and *Cruziana* ichnofacies (Uchman & Demircan 1999; Demircan & Yıldız 2007). Specimens of *C. intricatus* are also present in middle fan deposits of the late Eocene Korudağ Formation within the Thrace Basin, Turkey (Demircan & Uchman 2006; see Demircan 2008). *Chondrites* isp. has also been found in outer fan deposits of the middle–late Eocene Gaziköy Formation (Thrace Basin) (Demircan & Uchman 2006) and the Eocene Kırkgeçit Formation (Elazığ) (Özkul 1993). In the Sinop-Boyabat Basin, *C. intricatus* is present in the deep-marine flysch of the Maastrichtian–Palaeocene Akveren Formation and the Eocene Kusuri Formation (Uchman *et al*. 2004).

Chondrites targionii (Brongniart 1828)

Description – The burrow system of *C. targionii* is slightly winding and has commonly slightly curved branches. The individual branches are 2 to 4 mm wide. Branching angles are acute.

Remarks – *Chondrites targionii* differs from *C. intricatus* by its commonly curved branches. For discussion of this ichnospecies see Fu (1991) and Uchman (1998). The ichnospecies is known from the Akveren and Kusuri formations (Uchman *et al*. 2004).

?*Cosmorhaphe* isp.

Description – ?*Cosmorhaphe* isp. has apparently only one order of meanders. The trace fossil, which is preserved in convex hyporelief, is 2 mm wide and can be at least 18 cm long.

Remarks – The specimens are poorly preserved and are therefore left in open nomenclature (Figure 4d). *Cosmorhaphe* and its ichnospecies have been

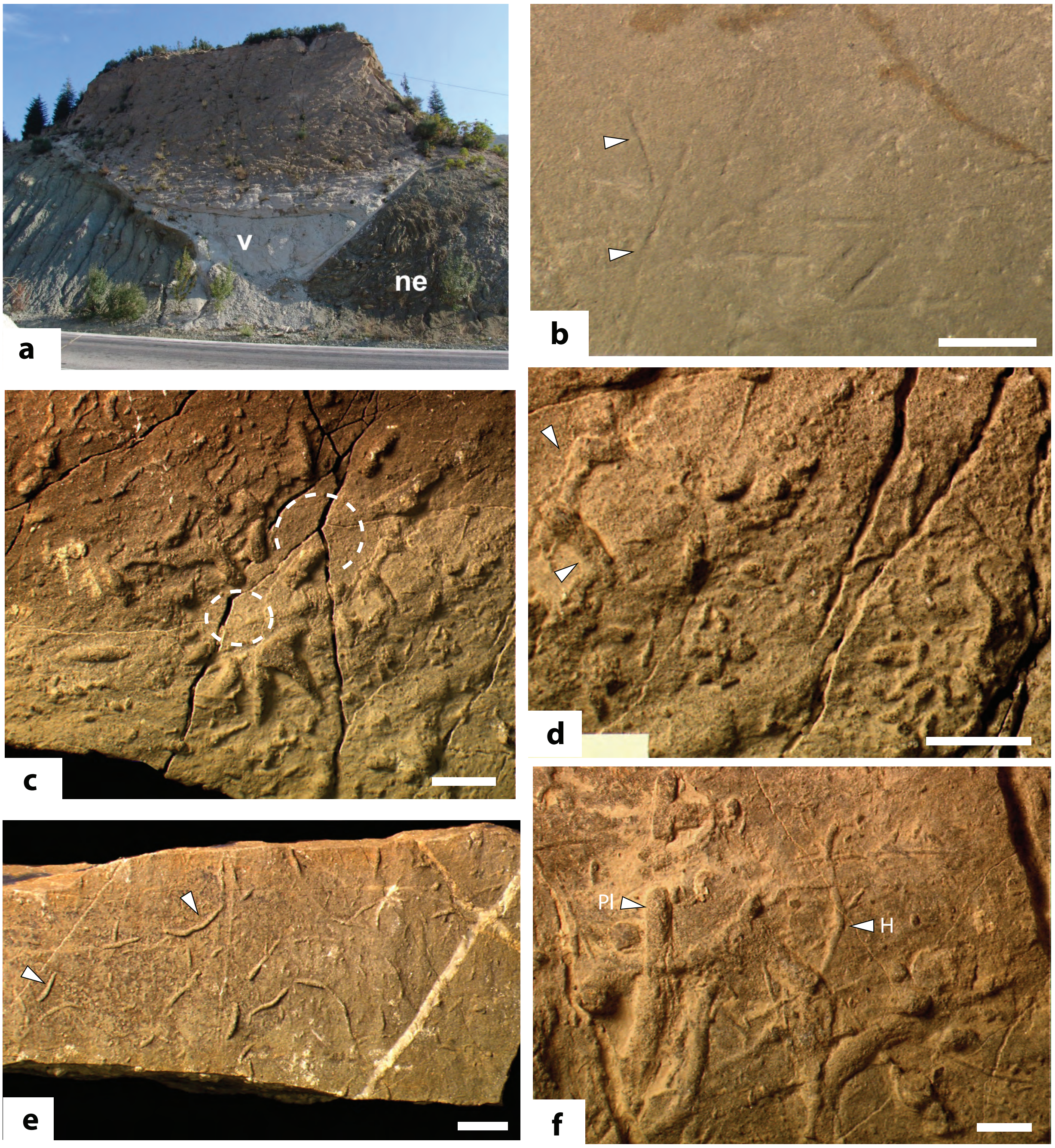

Figure 4. The Güneyce Formation. (**a**) Road section (locality 1) through the Güneyce Formation (ne) and volcanoclastic deposits (v), looking southwards. The section is about 15 m high. (**b**) *Chondrites intricatus* (triangles). Locality 1. (**c**) *Lorenzinia* isp., hyporelief. Centres of trace fossils indicated by dashed lines. Locality 2. (**d**) ?*Cosmorhaphe* isp., poorly preserved hyporelief (triangles). Locality 2. (**e**) ?*Helminthopsis* isp., hyporelief (triangles). Locality 2. (**f**) *Planolites beverleyensis* (Pl) and *Helminthopsis* isp. (H). Locality 3. Scale bars 1 cm.

summarized and discussed by Uchman (1998). *Cosmorhaphe sinuosa* (Azpeitia Moros 1933) is present in the outer fan depositional lobes (fan fringe) of the eastern and western fans of the Miocene Cingöz Formation (Uchman & Demircan 1999; Demircan & Toker 2003, 2004). *C. sinuosa* has also been found in the abyssal to lower slope palaeoenvironments of the Eocene Korudağ Formation (Demircan 2008).

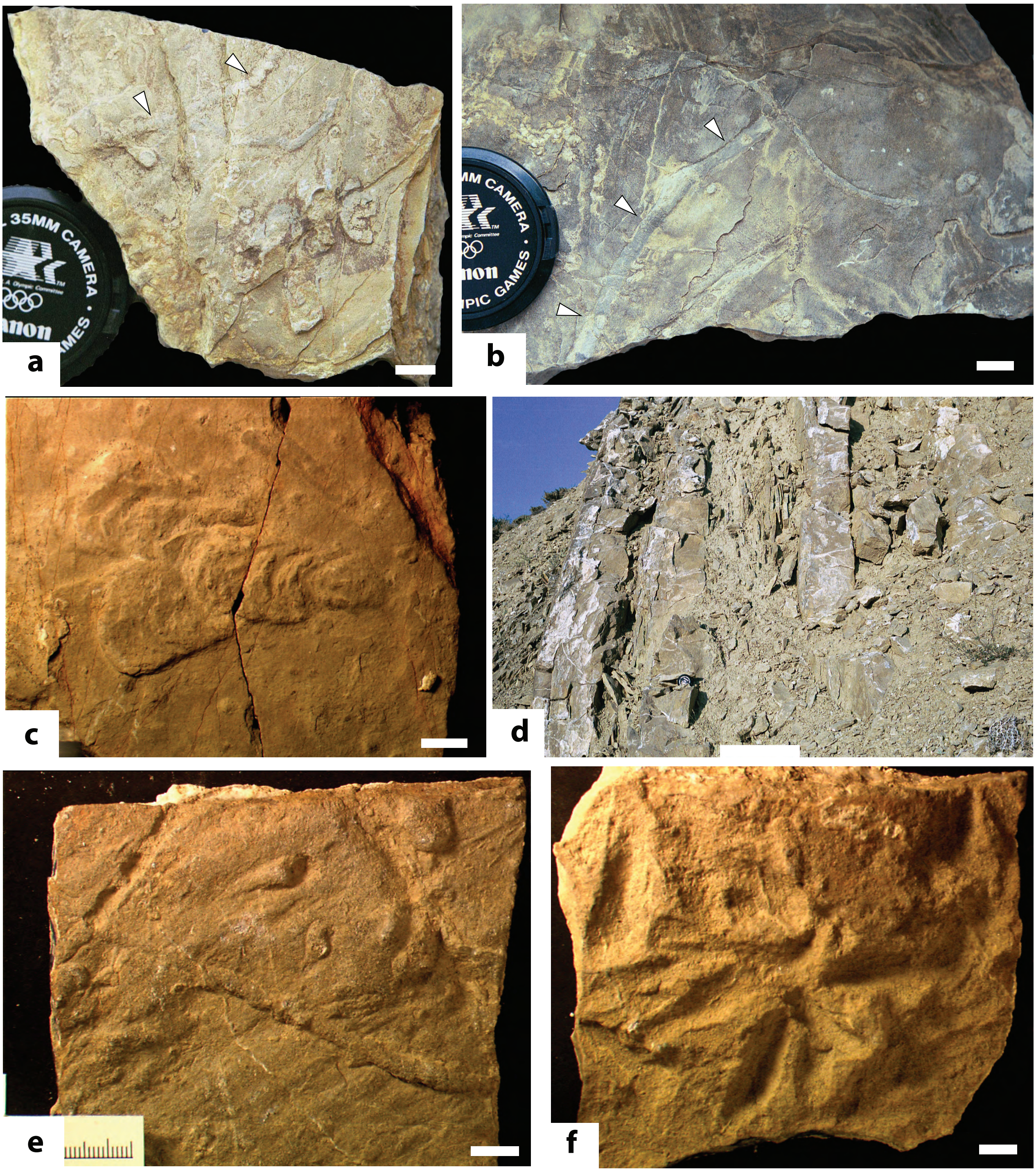

Figure 5. The Güneyce Formation. (**a**) ?*Nereites* isp., full relief (triangles). Locality 3. (**b**) *Thalassinoides suevicus*, full relief (triangles). Locality 3. (**c**) Cf. *Rhizocorallium* isp., hyporelief. Locality 3. (**d**) Road section through turbiditic deposits, looking northwards. Stratigraphical top is to the left. Locality 4. Scale bar 40 cm. (**e**) *Ophiomorpha rudis*, full relief. Locality 4. (**f**) *Naviculichnium marginatum*, epichnial relief. Locality 4. Scale bars 1 cm, except for (**d**) with scale bar 40 cm.

Table 1. Overview showing the distribution of trace fossils at localities of the Miocene Güneyce Formation in the Dereboğazı, Ağlasun and Sagalassos areas.

	Early Miocene			
	Güneyce Formation			
Localities:	1	2	3	4
Chondrites intricatus (Brongniart 1823)	+			
Chondrites targionii (Brongniart 1828)		+	+	
Cosmorhaphe isp.		?		
Helminthopsis isp.		++	+	+
Helminthorhaphe flexuosa Uchman 1995		+		
Lorenzinia isp.		++	+	
Naviculichnium marginatum Książkiewicz 1977				+
Nereites isp.		?	?	
Ophiomorpha rudis (Książkiewicz 1977)		+	+	++
Phycosiphon incertum Fischer-Ooster 1858		?		
Planolites beverleyensis Billings 1862		++	++	+
cf. *Rhizocorallium* isp.			+	
Thalassinoides suevicus (Rieth 1932)			+	

Note: +, few specimens; ++, common; +++, abundant.

Helminthopsis isp.

Description – Unbranched, irregularly winding horizontal burrows are preserved in convex hyporelief (Figure 4e, f). Crossings are absent. The width is about 0.5 cm and the length is at least 25 cm.

Remarks – In Turkey, the ichnogenus *Helminthopsis* has been described from the abyssal and slope deposits of the Eocene Korudağ Formation (Demircan 2008), and from the turbiditic fan deposits of the Eocene Cingöz Formation (Demircan & Toker 2003, 2004). *Helminthopsis* isp. is present in the Maastrichtian–Palaeocene flysch of the Akveren Formation, in the Sinop-Boyabat Basin (Uchman *et al.* 2004).

Helminthorhaphe flexuosa Uchman 1995

Description – *Helminthorhaphe flexuosa* is present as convex hyporeliefs on sandstones. It is horizontal and unbranched, 1 mm wide. Crossings are common. The curvature pattern shows high amplitude irregular meanders.

Remarks – The curvature pattern resembles that described by Uchman (1995). The bulging turns of *H. japonica* (Tanaka 1970) are absent. *Helminthorhaphe flexuosa* is known from the fan fringe deposits of the Eocene turbiditic Cingöz Formation (Uchman & Demircan 1999; Demircan & Toker 2004). The ichnospecies has also been described from the Eocene Kusuri Formation (Uchman *et al.* 2004).

Lorenzinia isp.

Description – *Lorenzinia* isp. is a radiating graphoglyptid trace fossil consisting of short ridges in hyporelief (Figure 4c). There may be about 10 ridges placed in a circle, about 30 to 40 mm in diameter. The ridges are of different length, up to 13 mm long. One specimen of *Lorenzinia* isp. is seen to overlap another specimen (Figure 4c).

Remarks – The ichnogenus *Lorenzinia* was discussed by Uchman (1998). Demircan & Toker (2003) recognized *Lorenzinia pustulosa* (Książkiewicz 1977) in middle and outer fan deposits of the Miocene Cingöz Formation. Uchman *et al*. (2004) recorded *Lorenzinia* in siliciclastic flysch of the Eocene Kusuri Formation, in the Sinop-Boyabat Basin.

Naviculichnium marginatum Książkiewicz 1977

Description – Elongate depressions in epichnial preservation (Figure 5f). The length is between 25 and 46 mm, while the width is up to 15 mm. A marginal rim is present.

Remarks – *Naviculichnium marginatum* has also been found in Eocene deep-sea turbiditic deposits of the Gorrondatxe section, North Spain (Rodríguez-Tovar *et al*. 2010).

?*Nereites* isp.

Description – Poorly preserved specimens of ?*Nereites* isp. occur as horizontal, loosely winding burrows (Figure 5a). The course is irregular and shows no overlap. Meniscate backfill is about 5 mm wide, while the enveloped zone is thin and hardly visible. The specimens are therefore determined only at the ichnogeneric level.

Remarks – The ichnogenus *Nereites* was revised by Uchman (1995). *Nereites* isp. was found by Demircan & Uchman (2006) in middle fan deposits of the Eocene Gaziköy Formation. Uchman & Demircan (1999) and Demircan & Toker (2004) observed *Nereites irregularis* (Schafhäutl 1851) in fan fringe deposits of the Miocene Cingöz Formation.

***Ophiomorpha rudis* (Książkiewicz 1977)**

Description – Specimens of *Ophiomorpha rudis* can be at least 55 cm long and 0.5–1.0 cm in diameter (Figure 5e). The branching angle ranges from 40 to 90°. The specimens, which are preserved as full relief, may cross-cut the packages of sandstones. Filling is structureless and sandy. Wall lining is discontinuous in places. The orientation of *O. rudis* is oblique to horizontal.

Remarks – *Ophiomorpha rudis* was revised by Uchman (2009). It has been recorded in the deep-sea fan fringe deposits of the Cingöz Formation within the Adana Basin, southern Turkey (Uchman & Demircan 1999; Demircan & Toker 2003). This ichnospecies is also known from the outer fan deposits of the middle–late Eocene Gaziköy Formation in the Adana Basin, and the middle fan deposits of the late Eocene Korudağ Formation (Thrace Basin) (Demircan & Uchman 2006). The ichnospecies is also present in turbiditic channel fill and proximal lobe facies of the early–middle Eocene Kusuri Formation in the Sinop-Boyabat Basin, northern Turkey (Uchman *et al*. 2004).

?*Phycosiphon incertum* Fischer-Ooster 1858

Description – The specimens are horizontal spreite structures of recurving U-lobes. The lobes consist of a dark core and surrounding pale mantle. The individual lobes are about 7 mm in size. The specimens are poorly preserved in full relief.

Remarks – The ichnospecies *Phycosiphon incertum* was discussed by Wetzel & Bromley (1994). Specimens of *P. incertum* occur in the Akveren Formation, in the Sinop-Boyabat Basin (Uchman *et al*. 2004). Specimens are also present in a diverse trace fossil assemblage within the middle fan deposits of the Korudağ Formation (late Eocene), Thrace Basin. The trace fossil assemblage is typical of the *Nereites* ichnofacies (Demircan & Uchman 2006).

Planolites beverleyensis Billings 1862

Description – *Planolites beverleyensis* is present as horizontal ridges in hyporelief (Figure 4f). The ridges, which are unbranched, are 3 to 5 mm wide. Transverse cross-sections are semi-circular in outline. The ridges are straight to slightly curved.

Remarks – The ichnogenus *Planolites* and its ichnospecies were revised by Pemberton & Frey (1982). Specimens of *P. beverleyensis* have also been recognized in the western turbiditic fan complex of the Miocene Cingöz Formation in the Adana Basin (Demircan & Toker 2003). *Planolites* isp. was recorded as a facies-crossing form in shelf and slope deposits of the Eocene Korudağ, Kešan and Yenimuhacir formations (Thrace Basin) (Demircan 2008). *Planolites* isp. occurs also in the

Barremian–Cenomanian Çağlayan Formation, the Coniacian–Campanian Yemişliçay Formation and the Maastrichtian–Palaeocene Akveren Formation in the Sinop-Boyabat Basin (Uchman *et al.* 2004).

cf. *Rhizocorallium* isp.

Description – Cf. *Rhizocorallium* isp. occurs rarely as hyporelief in the Güneyce Formation (Figure 5c). The trace fossil is characterized by a horizontal spreite with lobate outline. The trace fossil, which consists of a spreite of fairly regular U-shaped laminae, is horizontally retrusive and is 2.5 cm wide. The length is 7.5 cm. The marginal tunnel is not visible.

Remarks – The ichnogenus *Rhizocorallium* was revised by Fürsich (1974). Larger specimens of *Rhizocorallium* isp. occur in the western middle fan deposits of the Miocene Cingöz Formation (Demircan & Toker 2003).

Thalassinoides suevicus (Rieth 1932)

Description – *Thalassinoides suevicus* is preserved in full relief and displays mainly horizontally oriented galleries (Figure 5b). The width is 0.8 to 20 mm and the margin is unlined and smooth. The junctions between branches are Y-shaped and slightly enlarged.

Remarks – For discussion of *Thalassinoides suevicus* see Fürsich (1973), Frey *et al.* (1978), Howard & Frey (1984) and Schlirf (2000). *Thalassinoides* isp. has been described from the turbiditic proximal facies of the Maastrichtian–Palaeocene Samanlık Formation, in the Kalecik region (Yıldız *et al.* 2000), and from the turbiditic middle fan deposits of the Miocene Cingöz Formation in the Adana Basin (Uchman & Demircan 1999; Demircan & Yıldız 2007). It also occurs in the shelf and slope deposits of the Eocene Korudağ and Keşan formations in the Thrace Basin (Demircan 2008). *Thalassinoides suevicus* has been found in the Maastrichtian–Palaeocene turbidite deposits of the Akveren Formation as well as in the Eocene Kusuri Formation in the Sinop-Boyabat Basin (Uchman *et al.* 2004).

Discussion

The Miocene successions in the Dereboğazı, Ağlasun and Sagalassos areas show lateral variation in the lithology and the distribution of trace fossils within the Güneyce Formation (Table 1). The basinward part of the Güneyce Formation, which is the most fine-grained and distal to sediment source, is present at locality 1 (Figure 3). The bottom water had a low content of oxygen, that is dysoxic conditions. This is shown by the low diversity and density of trace fossils. Also, *Chondrites intricatus* is characterized by its small size (Figure 4b). Recognition of low oxygen levels by the presence of *Chondrites* in low-diversity assemblages and decreasing burrow size was shown by Bromley & Ekdale (1984) and Savrda & Bottjer (1986). Ekdale & Mason (1988) proposed an oxygen-controlled trace-fossil model, showing a transition from fodinichnia (e.g., *Chondrites*) through pascichnia to domichnia-dominated assemblages, with increasing oxygen concentration. The observed distribution of trace fossils in the Güneyce Formation conforms to this model. *Chondrites intricatus* in the Güneyce Formation may be common in places where the soft substrate was particularly rich in hydrogen sulphide or methane. Considering these sources for cultivating bacteria, *Chondrites* may be interpreted as an agrichnion (e.g., Fu 1991; Savrda 1992; Seilacher 2007), or specifically belonging to the tentative subcategory chemichnia (Bromley 1996). Seilacher (1990) proposed the 'deviated-well' hypothesis for interpreting such cases. Modern analogue traces are formed by thyasirid bivalves exploring chemosymbiotic sources (Dando & Southward 1986; Dufour & Felbeck 2003; Seilacher 2007). *Chondrites intricatus* of the Güneyce Formation comprises the only preserved tier of burrows at locality 1. They were formed in the sea floor under quiet conditions, without the impact from turbiditic deposition. The trace fossils are therefore interpreted as representative of the *Zoophycos* ichnofacies (see Seilacher 1967; Bromley & Asgaard 1991). *Chondrites intricatus* has previously been recognized as a deep tier trace fossil, for instance, in post-turbidite mud in the Upper Cretaceous of Schliersee (Bavaria) and the Eocene of Florence (Tuscany) (Seilacher 2007). *Chondrites* has been interpreted as reflective of both single-layer and multi-layer colonization, for example, in the Marnoso-arenacea Formation and associated shelf deposits (Uchman 1995). D'Alessandro *et al.* (1986) recognized *Chondrites* as an opportunistic form in the Eocene Saraceno Formation, Italy. The trace makers colonized the turbidite sediment and burrowed deeper into it over time. Wetzel & Uchman (2001) investigated ichnofabrics in the Eocene Beloveža Formation (Poland) and showed that post-event colonization of muddy turbidites occurred sequentially. The relative appearance of trace makers was particularly related to the re-established redox boundary. Trace makers of *Chondrites* penetrated down into turbiditic layers in the late stages of colonization, when oxygenation in pore waters became poor (Wetzel & Uchman 2001).

There is a higher diversity and density of trace fossils in localities 2, 3 and 4 at Ağlasun and Sagalassos (Figures 4 & 5, Table 1). Turbiditic sandy beds are common and reflect abrupt periods of increased sedimentation rate. The oxygenation of the bottom water was higher and various trace makers apparently thrived, as indicated by the number of pre-turbidite trace fossils. These structures are assigned to the *Paleodictyon* ichnosubfacies of the *Nereites* ichnofacies (see Seilacher 1974).

The turbiditic deposits at localities 2, 3 and 4 (Figure 5d) became colonized by trace makers, forming post-turbidite traces. For example, *Thalassinoides suevicus* formed as open burrow systems in the turbidite sand and became filled with fine-grained background sediment. Fodinichnia such as *Thalassinoides suevicus* represent depositional conditions typical of the *Cruziana* ichnofacies. *Thalassinoides suevicus* also occurs in other ichnofacies of the marine realm. *Ophiomorpha rudis* is also present. Its wall lining was built by the trace makers to stabilize the open burrow system. *Ophiomorpha rudis* is characteristic of the low-diverse *O. rudis* ichnosubfacies of the *Nereites* ichnofacies (Uchman 2001, 2009; Uchman *et al*. 2004; Nielsen *et al*. 2010). This ichnosubfacies may occur in channel and proximal lobe facies of deep-sea fans, or in thick beds formed in a deep-sea ramp setting. The trace fossil assemblage at locality 4 (Sagalassos) has a low diversity and is therefore assigned to the *O. rudis* ichnosubfacies. In addition, *O. rudis* can be present in fan fringe and overbank deposits of the *Paleodictyon* ichnosubfacies, with a higher diversity (Uchman 2009). A similar occurrence is recognized in the Güneyce Formation, at localities 2 and 3.

The occurrence of the *Ophiomorpha rudis* ichnosubfacies in the Kusuri Formation, Sinop-Boyabat Basin, is characterised by reduced trace-fossil diversity and abundant *O. annulata* and *O. rudis*. This occurrence is interpreted as related to plant detritus supplied from a large fluvio-deltaic system (Uchman *et al*. 2004). At present, there is not enough evidence to confirm or disprove that such a setting existed during the deposition of the Güneyce Formation.

Conclusions

The environments of the Güneyce Formation were characterized by differential variation in background sedimentation rates, rapid depositional events and oxygenation of bottom water. The trace fossils of the Güneyce Formation are representative of the *Zoophycos* ichnofacies as well as the *Paleodictyon* ichnosubfacies and the *Ophiomorpha rudis* ichnosubfacies of the *Nereites* ichnofacies. The deposits of the Güneyce Formation were produced in open-sea siliciclastic environments in the Neotethys Ocean. Lateral trends in the trace fossil distribution show that the influence of turbiditic currents and oxygenation varied with the proximity to sediment source.

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