TRACE FOSSILS FROM THE ABAZINSKAYA FORMATION (UPPER PALEOCENE; SOUTHERN CISCAUCASUS)

Trace fossils are sensitive indicators of the depositional environment, and their new findings in the Upper Paleocene deposits of the Abazinskaya Formation in the Southern Ciscaucasus allow some new interpretations. Urohelminthoidea isp., Chondrites intricatus, and Ophiomorpha isp. have been identified from the diagenetically-altered diatomites in the Yutsa section. The presence of Urohelminthoidea favors recognition of the Nereites ichnofacies in the Abazinskaya Formation. It indicates to deep-water environment of the basin slope or floor, where bacterial gardens were grown up extensively. Such depositional environment coincided with subsidence of the Greater Caucasus Basin during Late Paleocene.

Key words: trace fossils, agrichnia, fodinichnia, ichnofacies, depositional environment, basin depth, diatomites, Paleocene, Ciscaucasus.

Introduction

A careful investigation of trace fossils is one of the crucial tools for a precise reconstruction of depositional environment. Ichnofacies analysis, which is based upon the characteristics of recurring trace fossil assemblages, has been proven in numerous studies as a valuable instrument for environmental interpretations (e.g., Seilacher, 1964, 1967, 2007; Ekdale et al., 1984; Pemberton et al., 1992; McCann, 1993; Bromley, 1996; Hasiotis, 2006). This has led to recognition of archetypical ichnofacies in shallow- to deep-water deposits. A certain combination of diagnostic parameters of basin bathymetry recorded in trace fossil assemblages might be used as an indicative feature of relative sea level change (Ekdale, 1988). The relationship between ichnofacies and bathymetry is passive and, therefore, there might be local exceptions to the general distribution of marine ichnofacies (Seilacher, 1967; Frey et al., 1990). Transitions between ichnofacies may be gradual (Osgood, 1970). Still, the importance of trace fossils for sequence stratigraphic constraints has been demonstrated for marine sedimentary successions (e.g., Savrda, 1991). As trace fossils occur commonly in situ within the fossil records, they provide a valuable clue to understanding of different settings colonized by different groups of organisms and their behavioral activity.

It appears to be urgent the usage of trace fossils to broaden our knowledge on the geological development of the Caucasian sector of the northern Neotethyan margin. New findings...
in the Upper Paleocene of the Southern Ciscaucasia give us a valuable opportunity. This paper is presenting the results from our studies of Upper Paleocene ichnofacies from Southern Ciscaucasia aimed on reconstructions of depositional setting. The Paleocene geographical setting of this region was reviewed by Jasamanov (1978), but it remains somewhat questionable. Trace fossils are known as *in situ* well-preserved indicators of depositional history and, therefore, a study of the trace fossils is likely a useful tool in filling up the existing gaps in knowledge.

**Geological Setting**

The Southern Ciscaucasia is a large region in the south of European Russia. It is located between the Russian Platform in the north and the fold-and-thrust belt of the Caucasus in the south. The study area lies to the south from the Podkumok River (Fig. 1). The Paleocene deposits are represented widely there. Among three formations recognized within the Paleocene succession, the Abazinskaya Formation has been chosen as an object for our study. It is dominated by the diagenetically-altered diatomites and shales, which total thickness varies between 20 and 50 m (Mironova, 1982) (Fig. 1). The other lithological types are represented by clastic, volcaniclastic, and carbonate rocks (Milanovskij and Khain, 1963). This formation is underlain conformably by the Goryatchij Klyutch Formation, and it is overlain transgressively by Eocene Georgievskaya Formation. The late Paleocene age of the Abazinskaya Formation has been determined on the basis of its microfaunal assemblages (Milanovskij and Khain, 1963; Mironova, 1982).

The deposits of the Abazinskaya Formation were accumulated on the margin of the Greater Caucasus Basin, which stretched along the southern periphery of the Russian platform, i.e., it was situated on the northern Neotethyan margin (Golonka, 2004) (Fig. 1). The marine basin was warm with a normal salinity (Jasamanov, 1978). However, diatom growth indicates to, predominantly, cool-water conditions (Crosta and Koç, 2007).

**Materials and methods**

A number of samples of diagenetically-altered diatomites have been taken from the outcrop - the Yutsa section of the Abazinskaya Formation in the vicinity of the Yutsa village (Fig. 1). In addition to field observations representative samples have been analyzed carefully to identify particular ichnogenera (Figs. 2-4). The conceptual guidelines by Bertling et al. (2006) for ichnotaxonomy have been kept in the present study. We followed the present taxonomical overview of trace fossils summarized by Uchman (1998) and Seilacher (2007). Identification of the trace fossils enables determination of ichnofacies, which can be used as clear indicators of depositional environment (e.g., Seilacher, 1967, 2007; Ekdale et al., 1984; Bromley, 1996; Boggs, 2006; Catuneanu, 2006).

**Ichnotaxa**

Three ichnogenera were identified from the diagenetically-altered diatomite of the Abazinskaya Formation in the Yutsa section. They are *Urohelminthoida*, *Chondrites*, and *Ophiomorpha*. These ichnotaxa are briefly characterized below taking into account their morphological characteristics by Uchman (1998) and Seilacher (2007).

**Urohelminthoida isp.** (fig. 2) is a grapho-glyptid trace fossil characterized by deep hypichnial meanders, with appendages protruding laterally outward from the meanders (Uchman, 1995, 1998). The thin strings are interconnected and greenish-grey in color. The size of this trace fossil in our samples is up to 5 cm. The length of individual strings is between 0.2 and 2.0 cm. The maximum diameter of strings reaches 1 mm. The lateral distance between strings within an individual specimen is less than 1.0 cm.
Urohelminthoidae can be interpreted as an agrichnion, constructed by animals of unknown taxonomic affinity. They are tunnel systems of bacterial gardens, whose purpose was to accumulate oxygen for oxidation of H₂S and CH₄ by chemosynthetic bacteria (Seilacher, 2007). *Urohelminthoidae* is well known from numerous flysch occurrences (Uchman, 1998).

*Chondrites intricatus* (Brongniart, 1823) *emend. Uchman, 1998* (Fig. 3) is a chondritid trace fossil. It produces a regularly branched burrow system of radial shafts and tunnels with greenish-grey fill. The angle of branching is typically less than 45°. Diameter of the markedly flattened tunnels, which are elliptical in cross-section, is up to 0.5 mm. The size of individual specimens is less than 0.5 cm.

A systematic revision of *Chondrites* ichnotaxa was conducted by Fu (1991) and resulted in determination of four distinctive ichnospecies, i.e., *Chondrites intricatus*, *C. targionii*, *C. patulus* and *C. recurvus*. These have been recognized and confirmed by subsequent studies (e.g., Uchman, 1998). Specimens of *C. intricatus*, which are

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**Fig. 1.** Geographic location of the Yutsa section (A), the composite lithologic section (based on Mironova, 1982) (B), and the Paleogene setting of the Southern Ciscaucassus (adapted from Golonka, 2004) (C). Lithologies: 1 - sandstones, 2 - siltstones, 3 - shales, 4 - marlstones, 5 - diagenetically-altered diatomites.
similar to those in the Abazinskaya Formation, have been found in other regions, for example, Turonian siliceous flysch marls of the Polish Carpathians (Uchman, 1998).

Chondrites has been interpreted as a fo-dinichnion related to deposit feeders (Simpson, 1956; Osgood, 1970), or as an agrichnion formed by chemosymbiotic animals (Seilacher, 1990; Fu, 1991). The trace fossil formed in deep tiers by animals having large tolerance of low oxygen levels, i.e., within the oxygen-depleted zone (Bromley and Ekdale, 1984). The animals' behavior is linked to the hydrogen sulphide in the porewater used for feeding of bacterial symbionts (Dufour and Felbeck, 2003; Seilacher, 2007). These animals might have been lucinid bivalves (Thyasira) as noted in observations of both modern (Seilacher, 2007) and ancient (Zuschin et al., 2001) occurrences. Organic detritus-feeders such as endobenthic abyssal nematodes are also potential trace-makers (Bromley and Ekdale, 1984).

Ophiomorpha isp. (figs. 3, 4) is an ophiomorphid trace fossil. It consists of relatively thick branches with a diameter of maximum 5 mm. The branches are joined at triple junctions into scarcely developed boxwork burrow systems. The color is greenish-grey. The individual branches are up to several centimeters in length.

Resembling ophiomorphids have been found in Late Cretaceous and younger turbidities (flysch facies). They can generally be characterized as branching sparse, angles less than 120°, and diameter like a pencil (Seilacher, 2007). They occur...
typically as long probes along turbidite soles, apparently mining nutrient-rich bases of new sandy turbidites. Seilacher (2007) assigned such deep-water ophiomorphs to *Granularia* and described them further as miniaturized specimens, probably galleries formed by small crustaceans. However, the taxonomic status of *Granularia* is poorly defined and cannot be recommended for further use. *Granularia* is at least partially a junior synonym to *Ophiomorpha* (Uchman, 1995, 1998). For the present we therefore assign our specimens to the ichnogenus *Ophiomorpha*.

**Discussion**

To recognize the depositional environment of the Abazinskaya Formation, we have conducted an ichnofacies analysis of the trace fossils described above. According to Seilacher (2007), *Urohelminthoidea* is characteristic for *Nereites* ichnofacies. This ichnofacies is common for deposits formed in deep-water environment of the bathyal and abyssal zones (e.g., Uchman et al., 2005; Wetzel et al., 2007). *Chondrites* is a facies-breaking ichnogenus and may suggest low oxygen level (e.g., Bromley and Ekdale, 1984; Seilacher, 2007). The presence of *Chondrites* cannot further specify paleobathymetry of the Abazinskaya Formation. Although ophiomorphs are common in *Cruziana* ichnofacies, miniaturized specimens similar to *Ophiomorpha* isp. Herein are common in turbiditic deposits (Seilacher, 2007). The presence of *Chondrites* cannot further specify paleobathymetry of the Abazinskaya Formation. Although ophiomorphs are common in *Cruziana* ichnofacies, miniaturized specimens similar to *Ophiomorpha* isp. Herein are common in turbiditic deposits (Seilacher, 2007). The presence of dominant *Urohelminthoidea* is a crucial criterion for identification of ichnofacies in our case. On this basis, we may conclude that the trace fossil assemblage within the Abazinskaya Formation belongs to the *Nereites* ichnofacies.

Typical trace fossils of the *Nereites* ichnofacies are reflective of highly organized behavior. The trace fossils are complex meandering and spiral structures (pascichnia), in addition to patterned structures (agrichnia) (see Seilacher, 2007; Wetzel et al., 2007). Importantly, the occurrence of the *Nereites* ichnofacies depends on both taphonomic bias and ecological factors (Bromley and Asgaard, 1991). The *Nereites* ichnofacies, which may be found in deposits of the abyssal and bathyal zones, is common in Cretaceous and Cenozoic flysch successions (Seilacher, 1962, 2007; Frey et al., 1990). The flysch successions consist characteristically of interbedded deep-water shale, clastics, and sometimes carbonates, which altogether are turbidite beds. Because the Abazinskaya Formation is composed of diagenetically-altered diatomites, it does not represent a classical flysch succession. A number of environmental parameters affected the development of the *Nereites* ichnofacies, e.g., availability of food, hydrodynamic conditions and oxygenation (see Seilacher, 1967; Wetzel, 1984; Ekdale, 1988; Bromley, 1996). Current activity similar to turbiditic flows is an important factor affecting the preservation of typical trace fossils in the *Nereites* ichnofacies (e.g., Crimes et al., 1981; Bromley and Asgaard, 1991; Leszczyński and Seilacher, 1991; Seilacher, 2007; Fürsich et al., 2007; see also Simpson, 1956). The preservation is closely associated with slight erosion followed by immediate casting of the traces on the sole of the overlying turbidite. Subsequent bioturbation by deep burrowers have not obliterated them. This restricts graphoglyptid trace fossils such as *Urohelminthoidea* to deep-water settings with episodic erosion and sedimentation.

The presence of the *Nereites* ichnofacies in the Upper Paleocene of the Southern Ciscaucasus improves the understanding of the general depositional conditions. A distribution of the Abazinskaya Formation within the Southern Ciscaucasus (Milanovskij and Khain, 1963; Mironova, 1982; Khardikov, 2005) allows us to outline a large zone with deep-water environment, which persisted within this territory during the late Paleocene (Fig. 5). The present study of trace fossils from the Abazinskaya Formation does not confirm an existence of a relatively shallow basin in the Southern Ciscaucasus in the late Paleocene, which was depicted by Jasamanov (1978). However, our results correspond well to the basin model by Ershov et al. (2003), who suggested an overall subsidence of the Ciscaucasus during the Late Cretaceous-Eocene time interval. This subsidence was especially intense in the south of the Northern Caucasus, which includes the study area.
A wide distribution of deep-water environment within the Southern Ciscaucasus (fig. 5) indicates, undoubtedly, to an existence of the Greater Caucasus Basin in the late Paleocene. One may hypothesize that this was a deep back-arc basin. The presence of volcaniclastics in the Abazinskaya Formation (Milanovskij and Khain, 1963) may suggest an activity of island arcs located southwards from the study area, where major subduction zones existed during the Paleocene-Eocene (Golonka, 2004). These subduction zones appeared on the northern Neotethyan margin after multiple collisions of relatively small Caucasian, Turkish, and Iranian terranes together with a closure of the Neotethys Ocean (Golonka, 2004). Not only some subduction zones, but also a large landmass, were formed by this way. The accretion of the terranes might have changed the nature of the Greater Caucasus Basin from a typical back-arc basin to a foreland basin, which culminated, however, only with the beginning of the Caucasian orogeny some when in the Neogene.

Conclusions

This study led to the identification of three ichnogenera, namely *Urohelminthoidea*, *Chondrites*, and *Ophiomorpha*, from the Upper Paleocene deposits of the Southern Ciscaucasus. They indicate to the presence of the *Nereites* ichnofacies, occurring in deep-water environment of basin slope or floor, where the siliceous deposits of the Abazinskaya Formation were accumulated. These results confirm an ongoing subsidence of the Greater Caucasus Basin throughout the Paleocene. Further studies should aim at extending the knowledge on trace fossils from all Paleocene strata in the study region. This will help to interpret depositional environment: for example, to reveal changes in oxygenation and salinity over a longer time range.

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