A MIXED ASSEMBLAGE OF DEEP-SEA AND SHELF TRACE FOSSILS FROM THE LOWER CRETACEOUS (VALANGINIAN) KAMCHIA FORMATION IN THE TROYAN REGION, CENTRAL FORE-BALKAN, BULGARIA

Alfred UCHMAN¹ & Platon TCHOUMATCHENCO²,

¹ Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, 30-063 Kraków, Poland, e-mail: fred@ing.uj.edu.pl
² Geological Institute, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl. 24, 1113 Sofia, Bulgaria, e-mail: platon@lark.vmei.acad.bg


Abstract: Trace fossils collected from the best outcrop of the Kamchia Formation have been analysed. There are thirteen ichnotaxa (Curvolithus simplex, Gyrochorte isp., Helminthoidichnites tenax, Multina minima [second occurrence], Paleophycus tubularis, Palaeophycus isp., Phylocodes bilix, Phycosiphon incuratum, Planolites cf. reincki, Spongeliomorpha ?chevronensis, Squamodictyon testiforme, Thalasstichnus suevicus, Zoophycos isp.) representing different ethologic, toponomic and preservational types, and produced at different depths in the sediment. The ichnossemblage contains a mixture of forms typical of flysch (Squamodictyon) and shelf deposits (Curvolithus, Gyrochorte). Probably, sediments of the Kamchia Formation were deposited in an offshore or deeper basin with storm deposition of sand beds and background marly sedimentation. It is possible that storm currents transported trace makers of the shelf trace fossils to the deeper sea. It is not excluded that the trace maker of Gyrochorte migrated to the deep-sea after the Jurassic. However, the simplest explanation is that the Kamchia ichnofauna represents an ecological transition between shelf and slope communities.

Key words: Trace fossils, ichnology, Lower Cretaceous, Fore-Balkan, Bulgaria.

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INTRODUCTION

Some lithostratigraphic units of the Cretaceous deposits of the Fore-Balkan region display abundant trace fossils that have never previously been investigated. One of the units is the Kamchia Formation. The senior author collected twelve sandstone slabs with representative trace fossils from the best outcrop of this formation located along the road paralleling the eastern side of the Vidima River, 4 km south of Debnevo Village in the Troyan District (Fig. 1). The trace fossils form an atypical ichnossemblage that contains both typical deep-sea flysch and shelf ichnotaxa. Their description and interpretation are the main aims of this paper. The trace fossils are housed at the Geological Institute of the Bulgarian Academy of Sciences (acronym and catalog number F.1.2002).

GEOLOGICAL SETTING

The Lower Cretaceous sediments of the region of the Central Fore-Balkan, Bulgaria, have been studied by numerous Bulgarian geologists, including Lanjev (1940), Nikolov and Khrischev (1965) and Pimpirev (1984, 1987).

The Kamchia Formation, containing the studied ichnofossils, is a 900–2000 m thick unit composed of alternating beds of grey calcareous, fine- to medium-grained quartz sandstones to greywackes and grey-green to greenish marlstones. The sandstones slightly dominate over marlstones, except at the very base of the formation, which is composed mostly of marls. The beds of sandstones and marlstones are 50–60 cm thick. The ammonite Kilianella sp. collected from the section of the studied outcrop indicates a middle Valanginian age. Olocsteyphatus sp., found 100 m above the studied section, indicates the transition between Valanginian and Hauterivian (Nikolov, 1994, p. 60). Thus, the studied trace fossils are middle to late Valanginian in age.

The source of clastic material is located to the south in the Tracian Massif, which has recently been included within the Rhodope Massif. The Kamchia Formation is considered as a regressive non-turbiditic “post-flysch” unit. It is underlain by “normal” distal flysch of the Cerniosam Formation (latest Kimmeridgian–Berriasian), which is replaced to the
south by coarse flysch deposits of the Zlataritsa Formation, and by predominantly conglomeratic flysch deposits of the Kostel Formation. The Kamchia Formation is overlain by the Gorno-Oriachovitsa Formation (Barremian), which is composed of relatively thick marlstones alternating with minor sandstones.

The studied locality contains a 150–200 m thick Valanginian section, stratigraphically slightly below the middle part of the formation. It occurs in a gently folded area in the overturned limb of a Palaeogene anticline. The trace fossils were collected from 15 beds of fine to medium-grained calcareous sandstone (Fig. 2).

**TRACE FOSSILS**

*Curvolithus simplex* Buatois, Mangano, Mikuláš et Maples (Fig. 3A) is a hypichnial, straight to slightly winding,

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**Fig. 1.** Location map. Based on Cheshitsev (1994)

**Fig. 2.** Lithological log of the investigated section with ranges of the described trace fossils
but also scavenging gastropods are probable trace makers, and that turbellarian or nemertean worms cannot be excluded. Seilacher (1990) earlier suggested flatworms (turbellarians) as trace makers of \textit{Curvolithus}. The genus occurs from Precambrian (Webby, 1970) to Miocene (Keij, 1965) in different shallow marine or even brackish environments from distal fan deltas, tidal flats to offshore settings (see Buatois et al., 1998 for review).

\textit{Gyrochorte} isp. (Fig. 3B–C) is preserved in two ways. A. An epichnial, convex, horizontal, gently curved, bilobate ridge, about 2 mm wide. The lobes are smooth or display indistinct perpendicular striation, and are separated by a narrow groove. The trace occurs on a rippled sandstone surface. B. A hypichnial, gently winding furrow, 2.5–3.0 mm wide, divided in two bilobate gutters separated by a narrow crest. \textit{Gyrochorte} is represented mostly by \textit{G. comosa} Heer, which typically is larger and occurs in Jurassic shelf siliciclastics (Weiss, 1940; Schlirf, 2000). It was regarded as a trace of a polychaete-like worm (Heinberg, 1973) or aplacophoran mollusc (Heinberg & Birkeland, 1984), but Schlirf (2000) criticised this view and regarded it as the feeding trace of an arthropod.

\textit{Gyrochorte burtani} Książkiewicz, \textit{G. obliterata} Książkiewicz, and \textit{Gyrochorte imbricata} Książkiewicz have been described from the Polish Carpathian Flysch (Książkiewicz, 1977), but Uchman (1998) included these within \textit{Protovirgularia} McCoy. A very similar trace fossil was described by Tunis & Uchman (1996) as \textit{?Gyrochorte} isp. from the Eocene flysch of Istria in Slovenia, and by Plška (1987) as \textit{Aulichnites parkerensis} Fenton et Fenton from the Paleogene flysch of the Inner Carpathians in Slovakia. These trace fossils are smooth, but this is one of the preservational variants of \textit{G. comosa} (Schlirf, 2000). The Slovenian and Slovakian forms display the same morphological features as the Bulgarian material, but are larger. Although the trace fossil described here may represent a new ichnospecies, material is insufficient for diagnosis.

\textit{?Helmintidichnites tenuis} Fitch (Fig. 4B–C) is a hypichnial, horizontal, smooth, curved, irregularly winding or occasionally straight ridge, 0.7 mm wide, preserved in semi-relief. The differences between \textit{Helmintidichnites} and \textit{Gordia} have been confirmed by computer analysis (Hofmann, 1990). \textit{Helmintidichnites} ranges from the Pre cambrian (Narbonne & Aitken, 1990) to the Lower Cretaceous (Fregenal Martínéz et al., 1995) in marine and non-marine settings.

\textit{Multina minima} Uchman (Fig. 4A) is a very irregular hypichnial net whose meshes are less than 30 mm across. The gallery, 1.5–2.0 mm wide, is composed of actively formed pads of sediment, with common small turns and constrictions. \textit{M. minima} was previously described only from the Eocene flysch of the Hecho Group in northern Spain. Meshes in the holotype are smaller, but it is expected that this ichnospecies displays large morphometric variability. This trace fossil was produced probably by a small deposit feeder. The Bulgarian material extends the stratigraphic range of \textit{M. minima} from Valanginian to Eocene.

\textit{Palaeophycus tubularis} Hall (Fig. 4D) is a hypichnial, cylindrical, horizontal, gently curved, smooth trace fossil having a distinct margin, and a diameter of 4–7 mm. Lo-
cally, burrows are collapsed. *P. tubularis* is a facies-crossing form produced by carnivorous or omnivorous animals, mostly polychaetes (Pemberton & Frey, 1982). For discussion of *Palaeophycus* see also Keighley and Pickerill (1995).

*Palaeophycus* isp. (Figs. 3A–B, 5B) is an oblique tubular form with a lining, a width of 4–5 mm, and preserved in full relief plunging into beds. It was observed in oblique cross-sections at the top and base of sandstone beds.

*Phycodes bilix* (Książkiewicz) (Fig. 5A) is a hypichnial, horizontal to oblique trace fossil composed of strongly flattened, branched, walled cylinders, 9–10 mm wide, which display a granulate exterior, smooth interior, and distinct central collapse. The branches diverge concordantly, forming a bundle. The granulate wall and collapse suggest an open burrow similar to *Ophiomorpha* Lundgren. However, the horizontal development and arrangement in bundles is atypical of *Ophiomorpha*. *Phycodes bilix* occurs also in the Lower Cretaceous “pre-flysch” deep-sea deposits of the Silesian unit in the Polish Carpathians, from which it was described as *Buthotrophis bilix* (Książkiewicz, 1977) and later included in *Phycodes* (Uchman, 1998).

*Phycosiphon incertum* Fischer-Ooster (Fig. 5B) is preserved as small, horizontal lobes up to 5 mm wide, encircled by a narrow marginal tunnel less than 1 mm thick. They occur on the upper, nonerosive surface of sandstone beds. This trace fossil, produced by a deposit-feeder, is common in fine-grained deep-sea and deeper shelf deposits. More infor-
mation about Phycosiphon can be found in Wetzel and Bromley (1994).

Planolites cf. reinecki Ksiażekiewicz (Fig. 4C) is a hypichnial, tubular, straight to slightly winding, horizontal trace fossil lacking wall, 2.5–3.5 mm wide, preserved in full-relief. It displays shallow constrictions every 2–3 mm, and is covered with indistinct, thin longitudinal striae. Uchman (1998) included Planolites constriammlatus Stanley et Pickerill in P. reinecki. Stanley and Pickerill (1994) regarded this trace fossil as produced by a mobile setaceous annelid. It is known from the Late Ordovician storm-dominated shallow shelf siliciclastics of Ontario, Canada (Stanley & Pickerill, 1994) and the Senonian flysch of the Polish Carpathians (Książkiewicz, 1977).

Spongeliomorpha †chevronensis Muñiz et Mayoral (Fig. 6) is a hypichnial, horizontal, cylindrical, branched trace fossil, 25–30 mm wide. Its surface is smooth or covered with small ridges arranged in a chevron pattern. The angle between the ridges varies from 60° to 70°. The ridges are casts of scratch marks. This trace fossil may represent the same kind of burrow system as Thalassinoides suevicus (see Schlirf, 2000). Spongeliomorpha is produced by crustaceans in firm-ground substrates (e.g., Frey et al., 1984). S. chevronensis was described from shallow-marine Neogene deposits of southern Spain by Muñiz and Mayoral (2001), who discussed also ichnotaxa of Spongeliomorpha.

Squamodictyon textiforme (Sacco) (Fig. 7) is a hypichnial regular net of which the meshes are scale-like. The meshes are maximum 6 mm across, and the string is less than 1 mm wide. This typical graphoglyptid trace fossil, produced probably by an unknown farming animal, is known from Cretaceous and Tertiary flysch deposits (Selacher, 1977).

Thalassinoides suevicus (Rieth 1932) (Fig. 8) is a large, mostly horizontal, smooth tubular trace fossil preserved in full-relief, with Y-shaped branches and with distinct enlargement at the branching points. It is 25 mm wide, and the enlargement is about 50 mm across. Thalassinoides was produced by crustaceans, mostly decapods (Frey et al., 1984). For further discussion of this ichnogenus see Ekdale (1992). Schlirf (2000) followed Fürsich (1973) and included Thalassinoides in Spongeliomorpha. This problem is a matter of debate, and therefore we apply here the usual ichnotaxonomy (Bromley & Frey, 1974).

**DISCUSSION**

The Kamchia trace fossil association contains forms of diverse ethology. Traces include forms ascribed to deposit feeders (e.g., Phycosiphon, Gyrocorte), carnivores and scavengers (Curvolithus, Palaeophycus) and farmers (Squamodictyon). They were produced in soft, well-oxygenated substrate, except for Spongeliomorpha, which indicates a firm-ground substrate. Its trace maker burrowed deeply into partly dewatered sediments.

Cross-cutting relationships and toponomy indicate a complex tiering pattern of burrows. Trace fossils occurring on the base of sandstone beds were dug more deeply than those at the top of the beds, except in cases where the trace maker burrowed into buried sandy beds. The cross cutting relationships can also help to determine tiering (the deeper form crosscutting the shallower one) and succession (the later form crosscutting earlier forms). In the Kamchia slabs, Curvolithus, Planolites, †Palaeophycus isp., Palaeophycus tubularis, Spongeliomorpha, Multina and Gyrocorte isp. occur in full-relief on the lower surfaces. Squamodictyon and †Helminthoidichnites occur as semi-reliefs on the lower
surfaces. *Phycosiphon*, *Palaeophycus* isp., and *Gyrochorte* occur as full-reliefs on the upper surfaces. The trace fossils preserved in full-relief are post-depositional forms that were dug in sand or at the sand-marl interface after deposition of the sandy bed. The hypichnial semi-reliefs represent background fauna burrowed in marls (cf. Kern, 1980). Only a few cross-cuttings occur in the examined slabs. *Curvolithus* is crosscut by *Planolites* cf. *reinecki* and *Palaeophycus* isp. *Gyrochorte* is crosscut by *Palaeophycus* isp. These examples indicate that *Palaeophycus* isp. was produced by late, deep colonizers. The relationships discussed in this paragraph allow us to reconstruct a collective tiering pattern (Fig. 9), but only some of the illustrated trace fossils have been found together in the same bed.

The discussed trace fossil assemblage contains flysch forms (*Squamodictyon*) typical of the *Nereites* ichnofacies, and shelf forms (*Curvolithus*, *Gyrochorte*) typical of the *Craizana* ichnofacies, bringing the paleoenvironment into question. The Kamchia Formation is considered as a “post-flysch non-turbidite” unit, but its sediments do not fit slope or offshore models of sedimentation. Unfortunately, we do not have enough data for a more detailed sedimentological analysis. Lower and upper surfaces of sandstone beds are both sharp, soles are erosive and tops of some beds are ripped. Thus, the sandstone beds were probably deposited by storms in an environment characterized by background marly sedimentation at depths greater than outer shelf but less than basin plain.

In the literature, only a few examples of similar problems can be found. Hántzschel (1964) described an ichnocoassemblage that among others includes *Paleodictyon* and *Curvolithus* from Campanian deposits of the Beckum Basin in Westphalia, Germany. Those deposits are composed of intercalations of marlstones and calcarenitic beds with erosive bases, graded bedding and flute casts. *Paleodictyon* occurs in Oxfordian calcarenitic beds intercalating with marlstones in the Aquitaine Basin in France, which were referred to the “lower slope” environment (Hantzpergue & Branger, 1992). A few graphoglyptid ichnotaxa are present in Upper Cretaceous deposits composed of alternating marls and sandstones in southern Tanzania, deposited probably in an intrashelf basin affected by tempestites (Ernst & Zander, 1993). A Coniacian *Paleodictyon* has been found in intercalations of claystones and sandstone tempestites of the Bohemian Basin in the Czech Republic (Pek et al., 1994). A similar interpretation is possible for the investigated deposits. *Megagrapton?* isp. occurs in the deepest-water storm-generated turbidite beds of the Silurian Red Mountain Formation of southeastern Tennessee (USA), along with *Dictyodora major*, *Asterosoma ludwiga*, and other shelf ichnotaxa (Rindsberg & Frey, 1981).

In general, mixture of deep-sea and shelf trace fossils
can be caused by transportation of trace makers by storm currents from the shelf to the deep sea. Such an hypothesis was applied to explain the occurrence of "shallow-water" trace fossils, mostly Ophiomorpha and Thalassinoides, in deep-sea sediments (Crimes, 1977; Wetzel, 1984; Föllmi & Grimm, 1990). Curvolithus has never been reported from the deep-sea (Buatois et al., 1998), and its occurrence in the deposits of the Kamchia Formation can be explained in this way. In the case of Gyrochorte (see description of this taxon) it is not impossible that its trace maker migrated to the deep-sea environment after the Jurassic, as the producers of Ophiomorpha and Sclocchia have done (Tchoumatchenco & Uchman, 2001). However, the simplest explanation is that the Kamchia ichnofauna represents an ecotone (ecological transition) between shelf and deeper (slope) communities. Transitions between the communities are expected to occur somewhere, also in the geological record.

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REFERENCES


Streszczenie

MIESZANY ZESPÓŁ GŁĘBOKOMORSKICH I SZELFOWYCH SKAMIALNOŚCI ŚLADOWYCH W DOLNOKREDOWEJ (WALANŻYN) FORMACJI KAMCZIIJA W REJONIE TROJANU, CENTRALNY PREBALKAN, BULGARIA

Alfred Uchman & Platon Tchoumatchenco

W centralnym Prebalkanie w okresie Trojan (Fig. 1) znajduje się najlepsze odsłonięcie dolnokreduwej formacji Kamczija datowanej tam na walanżyn. Formacja ta, uznawana za „post-fliszo-wą”, zdominowana jest przez szare i zielonkawe margle przełalone z ławkami kwarcowymi i szaroglazowymi piaskowców o erozyjnych spachach (Fig. 2). W badanym odsłonięciu, w ławiach piaskowców, rozpoznano 13 ichnotaksonów. Są to (Fig. 3–8): Curvolithus simplex, Gyrochorte, isp., ?Helmithoidichnites temnis, Multina minima (drugie występowanie na świecie), Palaeophycus tubularis, ?Palaeophycus isp., Ptychodrilus bilix, Ptychosphon incertum, Planolites cf. reinecki, Sphenolithus sp., ?Cheironomis, Squamodictyon textiforme, Thalassinoides suvecius, i Zoophycus isp.

Oznawiane skamienialności śladowe reprezentują różne grupy etologiczne, w tym osadażerów (Phycosiphon, Gyrochorts), drańników i wszystkożerców (Curvolithus, Palaeophycus) oraz farmerów (Squamodictyon). Powstały one w miękkim podłożu z wyjątkiem Sphenolithus, która produkowana była przez skorupiaki w głębokie pogrzebanym, stwardnialnym w wyniku odwodnienia osadzanie. Pozycja toponomastyczna i relacje przecinania się pozwoliły na określenie pietrności i sukcesji czasowej badanych skamienialności śladowych (Fig. 9).

Asocjacja oznawianych skamienialności śladowych zawiera formy fliszowe (Squamodictyon), typowe dla ichnofacji Nerites, oraz formy szelfowe (Curvolithus, Gyrochors), typowe dla ichnofacji Czucziana. Współwystępowanie tych form prowokuje do pytania o środowisko sedimentacji badanych utworów. Prawdopodobnie, ławice piaskowca były deponowane przez sztormy do basenu z sedimentacją marglistą, o głębokościach większych od szelfowych, a mniejszych od równie basenowej. Dane z literatury na ten temat podobnych ichnoassocjacji (Häntzschel, 1964; Ernst & Zander, 1993) oraz występowania Paleodictyon w utworach niefliszowych nur i kredy (Hantzpergu & Branger, 1992; Pek et al., 1994) sugerują podobne środowiska.

Obecność form szelfowych w głębszym środowisku może być powodowana transportem zwierząt płotkarskich przez płyty sztormowe i zawiesinowe. Taka interpretacja może tłumaczyć obecność Curvolithus. Ta skamienialność śladowa nigdy dotąd nie była opisana ze środowisk głębokomorskich (Buuotois et al., 1998). W przypadku Gyrochorte jest możliwe, że produkujące ten ichnorojdcz zwierzę zaczęło po jurze zasiedlać środowiska głębszego morza. Najprostszym wytłumaczeniem jest jednak istnienie strefy przejściowej pomiędzy ichnozespółmi szelfowymi i głębszymi, gdzie występują skamienialności śladowe typowe dla szelfu i głębszych środowisk.