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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

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Abstract: Trace fossils collected from the best outcrop of the Kamchia Formation have been analysed. There are thirteen ichnotaxa (*Curvolithus simplex*, *Gyrochorte* isp., ?*Helminthoidichnites tenuis*, *Multina minima* [second occurrence], *Palaeophycus tubularis*, ?*Palaeophycus* isp., *Phycodes bilix*, *Phycosiphon incertum*, *Planolites* cf. *reinecki*, *Spongeliomorpha* ?*chevronensis*, *Squamodictyon tectiforme*, *Thalassinoides suevicus*, *Zoophycos* isp.) representing different ethologic, toponomic and preservational types, and produced at different depths in the sediment. The ichnoassemblage 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 ichnoassemblage 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. *Olcostephanus* 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

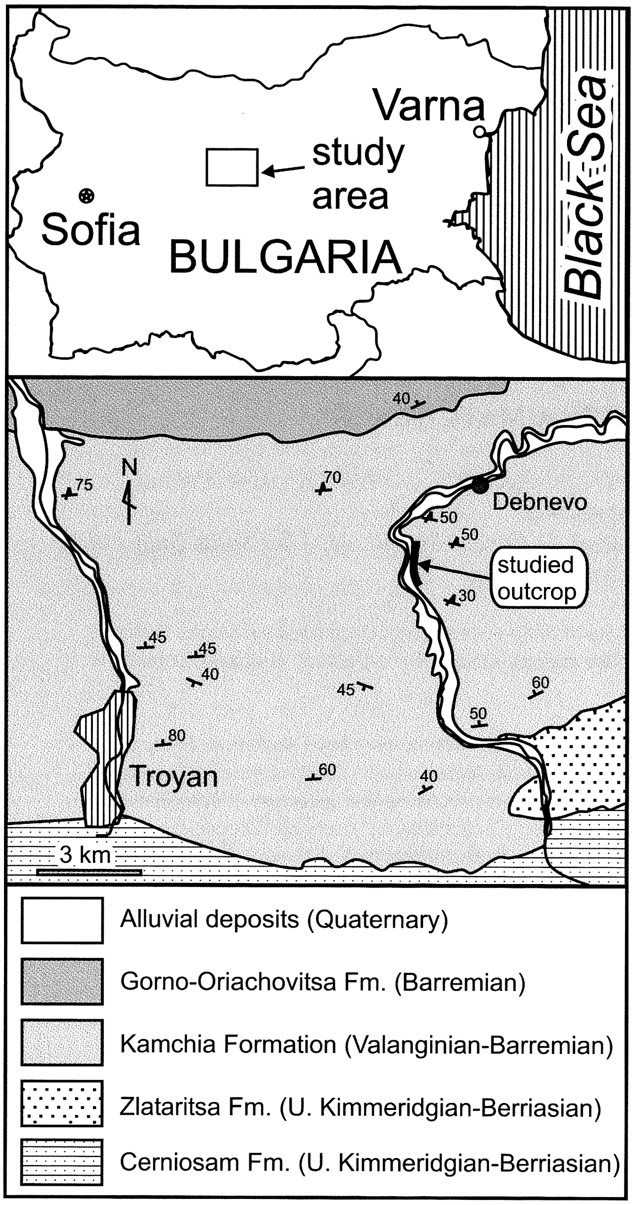

Fig. 1. Location map. Based on Cheshitev (1994)

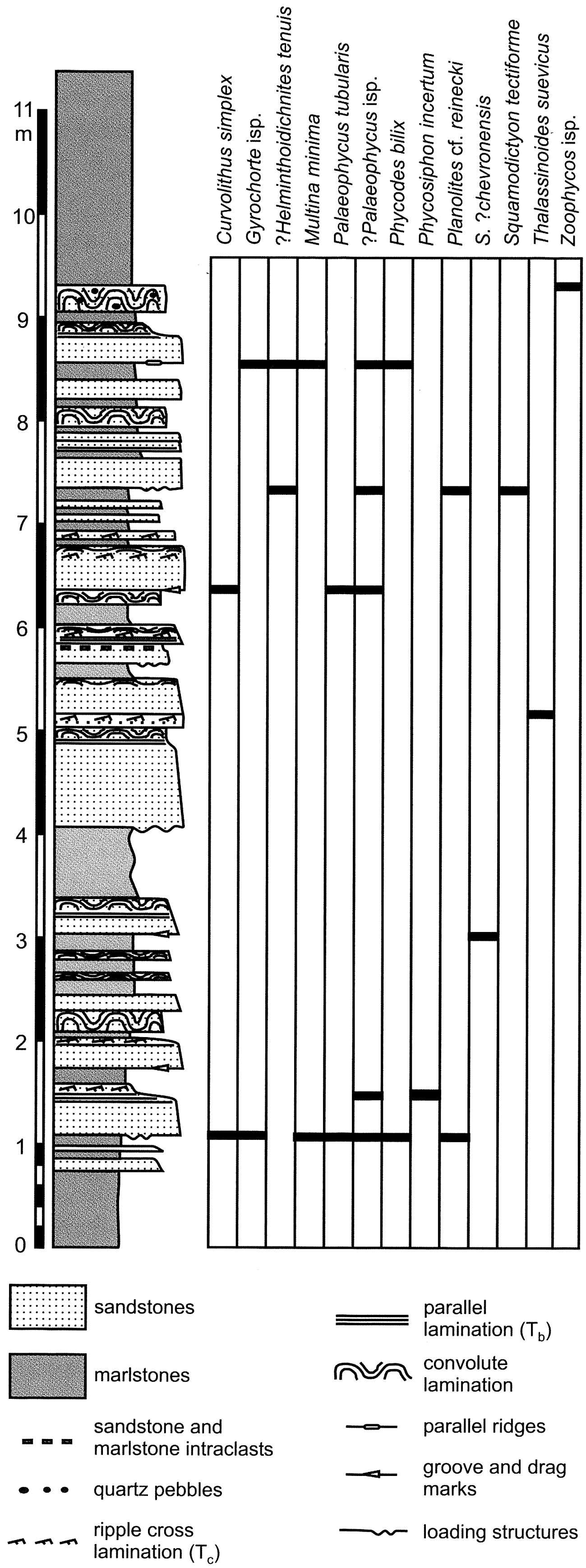

Fig. 2. Lithological log of the investigated section with ranges of the described trace fossils

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,

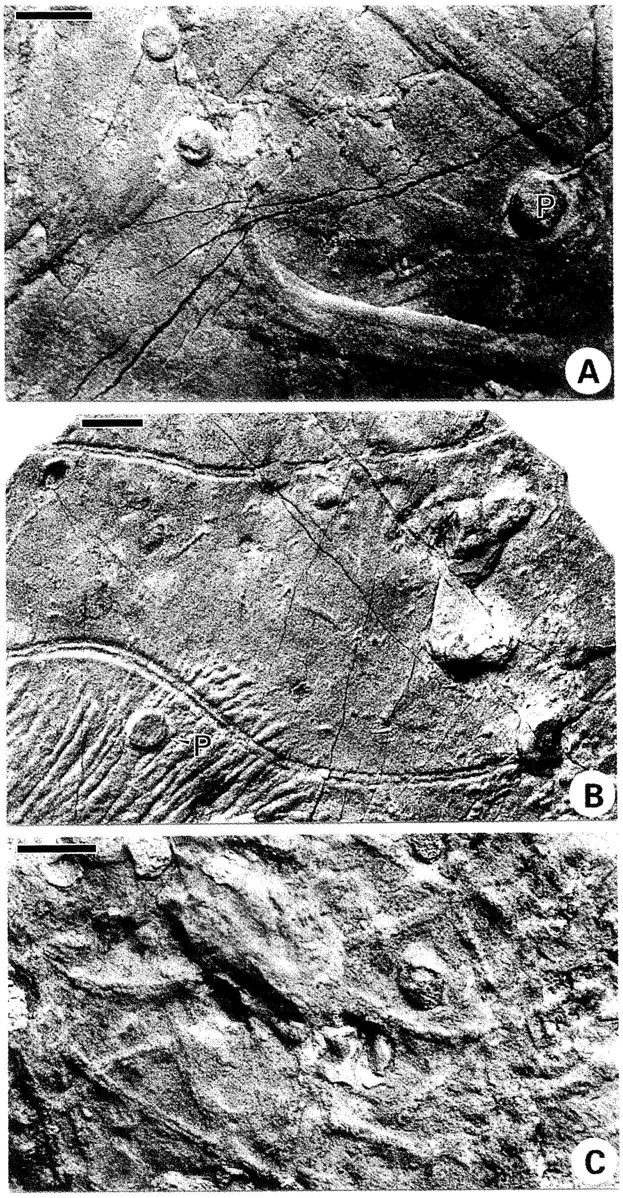

Fig. 3. Trace fossils from the Kamchia Formation. **A.** *Curvolithus simplex* and ?*Palaeophycus* isp. (P), hypichnial convex full-reliefs, F.1.2002.1.1. **B.** *Gyrochorte* isp., hypichnial concave form, and ?*Palaeophycus* isp. (P), hypichnial convex full-relief, F.1.2002.1.9. **C.** *Gyrochorte* isp., epichnial convex full-relief, F.1.2002.1.7. Scale bars – 1 cm

horizontal to inclined, smooth, trilobate band-like trace fossil, 8–10 mm wide. Its lower surface is composed of a central, flat or slightly convex zone and two convex, rounded side lobes. A single side lobe is 1–3 mm wide. According to the revision of Buatois et al. (1998), *Curvolithus* has only two ichnospecies, the other being *C. multiplex* Fritsch, which is easily recognisable by its quadrilobate lower surface. *Curvolithus* is interpreted as a locomotion trace (repichnion), made most probably by carnivorous gastropods (Seilacher, 1954; Heinberg, 1973) similar to recent members of the Cephalaspidea (Heinberg & Birkelund, 1984). Buatois *et al.* (1998) added that not only carnivorous but also scavenging gastropods are probable trace makers, and that turbellarian or nemertean worms cannot be excluded. Seilacher (1990) earlier suggested flatworms (turbellarians) as tracemakers of *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).

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. *Gyrochorte* is represented mostly by *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 & Birkelund, 1984), but Schlirf (2000) criticised this view and regarded it as the feeding trace of an arthropod.

Gyrochorte burtani Książkiewicz, *G. obliterata* Książkiewicz, and *Gyrochorte imbricata* Książkiewicz have been described from the Polish Carpathian Flysch (Książkiewicz, 1977), but Uchman (1998) included these within *Protovirgularia* McCoy. A very similar trace fossil was described by Tunis & Uchman (1996) as ?*Gyrochorte* isp. from the Eocene flysch of Istria in Slovenia, and by Plička (1987) as *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 *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.

?*Helminthoidichnites 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 *Helminthoidichnites* and *Gordia* have been confirmed by computer analysis (Hofmann, 1990). *Helminthoidichnites* ranges from the Precambrian (Narbonne & Aitken, 1990) to the Lower Cretaceous (Fregenal Martinéz et al., 1995) in marine and nonmarine settings.

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. *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 *M. minima* from Valanginian to Eocene.

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-

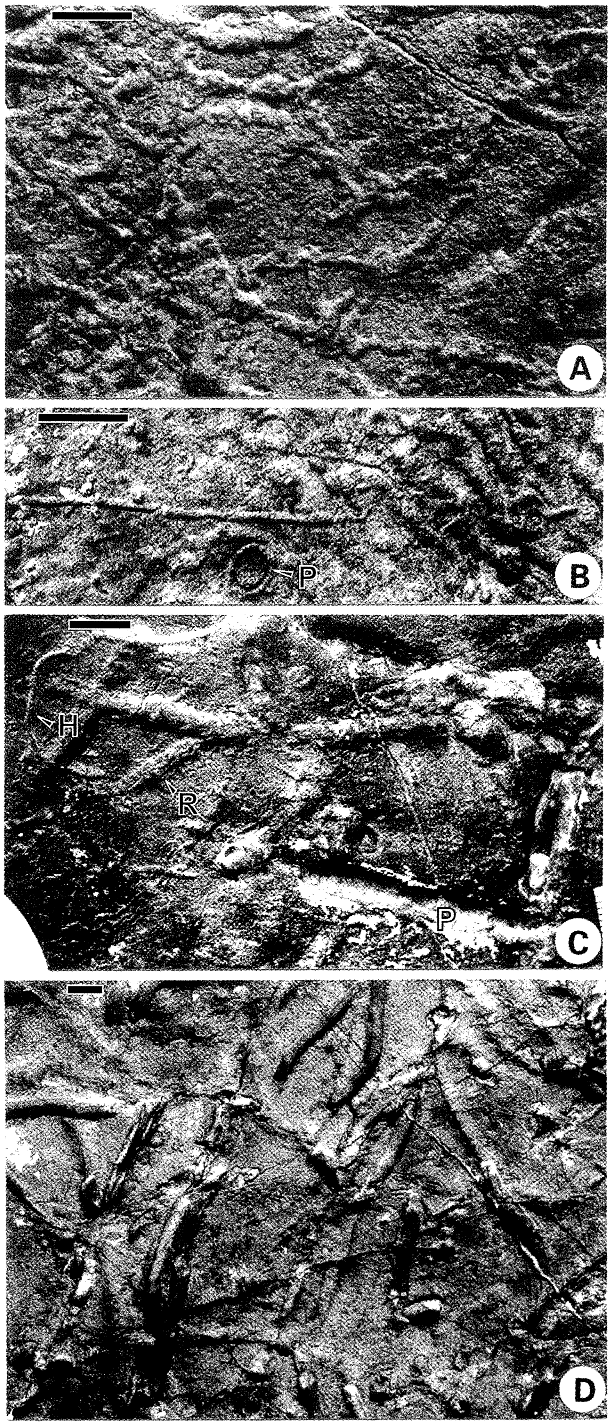

Fig. 4. Other trace fossils from the Kamchia Formation. **A.** *Multina minima,* hypichnial convex full-relief, F.1.2002.1.6. **B.** ?*Helminthoidichnites tenuis*, hypichnial convex semi-relief, and *Palaeophycus tubularis* (P), hypichnial convex full-relief, F.1.2002.1.12. **C.** ?*Helminthoidichnites tenuis* (H), hypichnial convex semi-relief, *Planolites* cf. *reinecki* (R), hypichnial convex full-relief, and *Palaeophycus tubularis* (P), hypichnial concave and convex full-reliefs, F.1.2002.1.10. **D.** *Palaeophycus tubularis*, hypichnial convex full-reliefs, F.1.2002.1.7. Scale bars – 1 cm

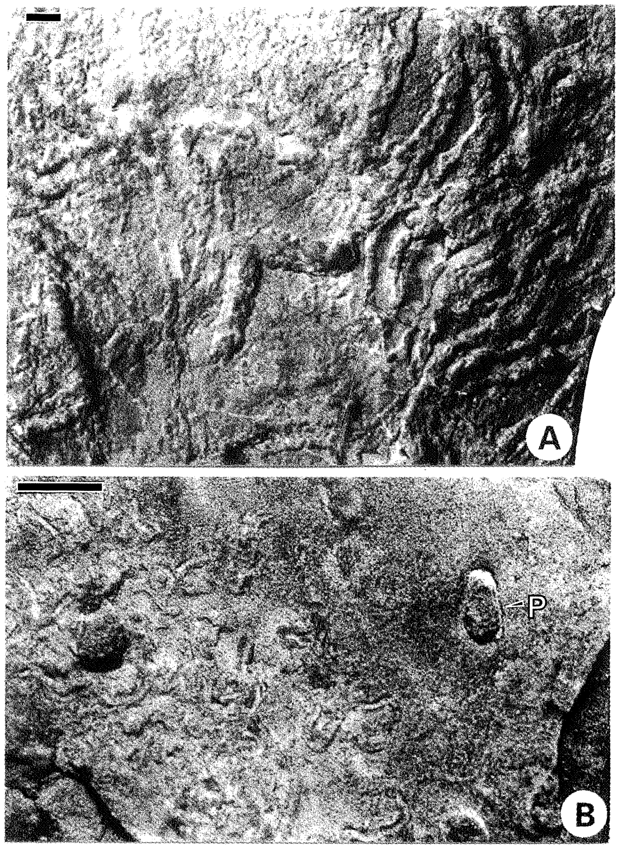

Fig. 5. Other trace fossils from the Kamchia Formation. **A.** *Phycodes bilix,* hypichnial convex full-relief, F.1.2002.1.6. **B.** *Phycosiphon incertum* and ?*Palaeophycus* isp. (P), epichnial full-reliefs, F.1.2002.1.8. Scale bars – 1 cm

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 *Buthotrephis 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 information about *Phycosiphon* can be found in Wetzel and Bromley (1994).

Planolites cf. *reinecki* Książkiewicz (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 constriannulatus* 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 ranges from 60° to 70°. The ridges are casts of scratch marks. This trace fossil may represent the same kind of burrow systems 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 other ichnotaxa of *Spongeliomorpha.*

Squamodictyon tectiforme (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 (Seilacher, 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).

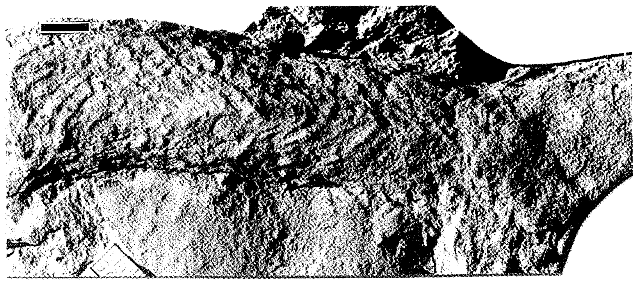

Fig. 6. *Spongeliomorpha ?chevronensis*, full-relief, F.1.2002.1.4

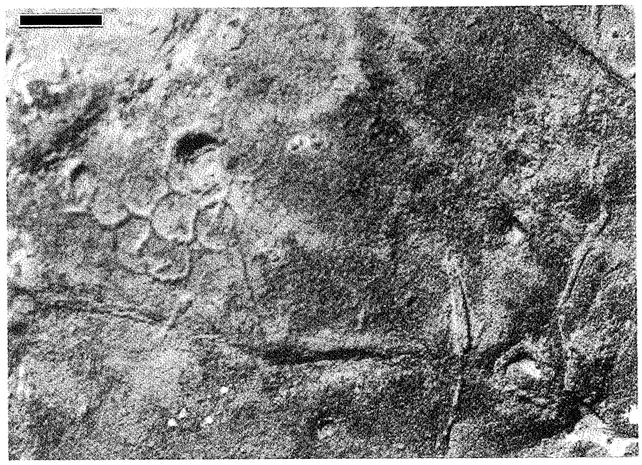

Fig. 7. *Squamodictyon tectiforme*, hypichnial convex semi-relief, F.1.2002.1.10. Scale bar – 1 cm

Fig. 8. *Thalassinoides suevicus*, full-relief, F.1.2002.1.3. Scale bar – 1 cm

DISCUSSION

The Kamchia trace fossil association contains forms of diverse ethology. Traces include forms ascribed to deposit feeders (e.g., *Phycosiphon*, *Gyrochorte*), 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 tracemaker 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 *Gyrochorte* isp. occur in full-relief on the lower surfaces. *Squamodictyon* and ?*Helminthoidichnites* occur as semi-reliefs on the lower

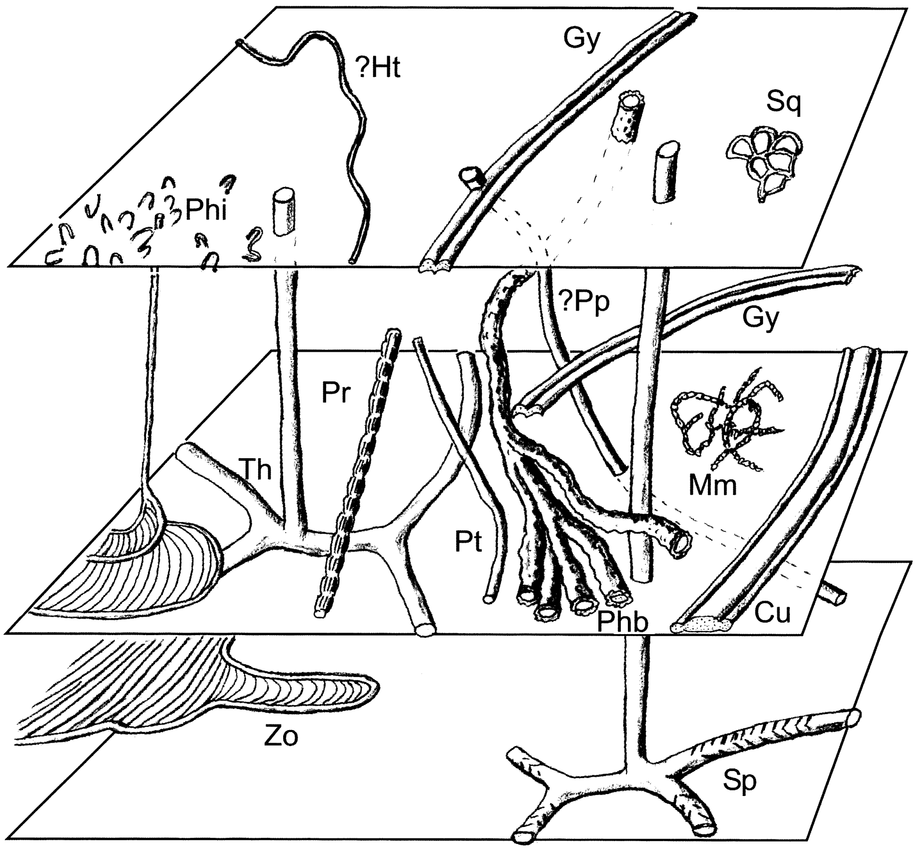

Fig. 9. Collective tiering pattern of trace fossils from the Kamchia Formation. Only some of the illustrated trace fossils occur together in particular beds. Cu – *Curvolithus simplex*; Gy – *Gyrochorte* isp.; ?Ht – ?*Helminthoidichnites tenuis*; Mm – *Multina minima*; Pt – *Palaeophycus tubularis*; ?Pp ?*Palaeophycus* isp.; Phb – *Phycodes bilix*; Phi – *Phycosiphon incertum*; Pr – *Planolites* cf. *reinecki*; Sp – *Spongeliomorpha* ?*chevronensis*; Sq – *Squamodictyon tectiforme*; Th – *Thalassinoides suevicus*; Zo – *Zoophycos* isp. Trace fossils not to scale

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 *Cruziana* 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 rippled. 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. Häntzschel (1964) described an ichnoassemblage 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 ludwigae*, 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 *Scolicia* 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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Streszczenie

MIESZANY ZESPÓŁ GŁĘBOKOMORSKICH I SZELFOWYCH SKAMIENIAŁOŚCI ŚLADOWYCH W DOLNOKREDOWEJ (WALANŻYN) FORMACJI KAMCZIJA W REJONIE TROJANU, CENTRALNY PREBAŁKAN, BUŁGARIA

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W centralnym Prebałkanie w okręgu Trojan (Fig. 1) znajduje się najlepsze odsłonięcie dolnokredowej formacji Kamczija datowanej tam na walanżyn. Formacja ta, uznawana za „post-fliszową", zdominowana jest przez szare i zielonkawe margle przeławicone z ławicami kwarcowych i szarogłazowych piaskowców o erozyjnych spągach (Fig. 2). W badanym odsłonięciu, w ławicach piaskowców, rozpoznano 13 ichnotaksonów. Są to (Fig. 3–8): *Curvolithus simplex*, *Gyrochorte* isp., ?*Helminthoidichnites tenuis*, *Multina minima* (drugie występowanie na świecie), *Palaeophycus tubularis*, ?*Palaeophycus* isp., *Phycodes bilix*, *Phycosiphon incertum*, *Planolites* cf. *reinecki*, *Spongeliomorpha* ?*chevronensis*, *Squamodictyon tectiforme*, *Thalassinoides suevicus* i *Zoophycos* isp.

Omawiane skamieniałości śladowe reprezentują różne grupy etologiczne, w tym osadożerców (*Phycosiphon*, *Gyrochorte*), drapieżników i wszystkożerców (*Curvolithus*, *Palaeophycus*) oraz farmerów (*Squamodictyon*). Powstawały one w miękkim podłożu z wyjątkiem *Spongeliomorpha*, która produkowana była przez skorupiaki w głębiej pogrzebanym, stwardniałym w wyniku odwodnienia osadzie. Pozycja toponomiczna i relacje przecinania się pozwoliły na określenie piętrowości i sukcesji czasowej badanych skamieniałości śladowych (Fig. 9).

Asocjacja omawianych skamieniałości śladowych zawiera formy fliszowe (*Squamodictyon*), typowe dla ichnofacji *Nereites*, oraz formy szelfowe (*Curvolithus*, *Gyrochorte*), typowe dla ichnofacji *Cruziana*. Współwystępowanie tych form prowokuje do pytań o środowisko sedymentacji badanych utworów. Prawdopodobnie, ławice piaskowca były deponowane przez sztormy do basenu z sedymentacją marglistą, o głębokościach większych od szelfowych, a mniejszych od równi basenowej. Dane z literatury na temat podobnych ichnoasocjacji (Häntzschel, 1964; Ernst & Zander, 1993) oraz występowania *Paleodictyon* w utworach niefliszowych jury i kredy (Hantzpergue & Branger, 1992; Pek *et al.*, 1994) sugerują podobne środowiska.

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