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Palaeoecological significance of the trace fossil *Circulichnis* Vyalov, 1971 from the Carboniferous of the Donets Basin, Ukraine

Paleoekološki pomen fosilne sledi *Circulichnis* Vyalov, 1971 iz karbona Doneškega bazena v Ukrajini

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Abstract

The ichnogenus *Circulichnis* Vyalov is a horizontal a ring- or ellipse-shaped burrow and/or locomotion trace of an unknown producer, most likely an annelid or a "worm", preserved on the bedding plane. This ichnogenus is known over a wide age interval (Ediacaran–Oligocene). *Circulichnis* demonstrates a wide ecological range and has been found in continental (Mermia ichnofacies), shelf, and relatively deep-water (turbidites) deposits. It is commonly interpreted as a sediment feeding trace, but the peculiarities of its formation remain somewhat mysterious, as it is unclear how the tracemaker reached the sediment surface, as lateral branches of the ring-shaped traces are extremely rare and have only been observed by a few researchers. A rather large specimen of *Circulichnis montanus* Vyalov, 1971 with a preserved lateral branch was found in the Mospyne Formation (upper Bashkirian, Lower Pennsylvanian) of the Donets Basin. This discovery confirmed the assumption made by Alfred Uchman and Bruno Ratazzi regarding the peculiarities of formation of *Circulichnis*. According to these authors, a single ring-shaped *Circulichnis* indicates an attempt to forage at a specific level in the sediment, while the lateral branches of *Circulichnis* are part of a vertical shaft leading to another level within the sediment. The study of *Circulichnis montanus* from the Donets Basin has confirmed that at least variant C of the *Circulichnis* formation scheme proposed by Uchman and Ratazzi is correct, i.e. the lateral branch is a horizontal or subhorizontal part of a generally vertical shaft. However, it is important to note that the correctness of variants A and B of the Uchman and Ratazzi scheme cannot be excluded. To answer this question unequivocally, new finds of well-preserved *Circulichnis* are necessary.

Izvleček

Ihnofosilni rod *Circulichnis* Vyalov, 1971 je vodoravna, obročasto ali elipsasto oblikovana sled vrtanja in/ali premikanja neznanih organizmov, najverjetneje anelidov ali "črvov", ki so se ohranili na površini plasti. Ta ihnofosilni rod je poznan v širokem starostnem intervalu (ediakarij–oligocen). *Circulichnis* izkazuje širok ekološki razpon in je bil najden v kontinentalnih (Mermia ihnofacies), šelfnih in razmeroma globokomorskih (turbiditnih) sedimentih. Običajno ga tolmačijo kot sled prehranjevanja s sedimentom, vendar posebnosti njegovega nastanka ostajajo nekoliko skrivnostne, saj ni jasno, kako je organizem, ki je pustil sled, dosegel površino sedimenta, saj so stranske veje obročastih sledi izjemno redke in jih je opazilo le nekaj raziskovalcev. V formaciji Mospyne (zgornji baškirij, spodnji pennsilvanij) v Doneškem bazenu je bil najden precej velik primerek vrste *Circulichnis montanus* Vyalov, 1971. Na tem primerku je ohranjena stranska veja, kar je, kot je navedeno zgoraj, precej redko. To odkritje je potrdilo domnevo Alfreda Uchmana in Bruna Ratazzija o posebnostih nastanka rodu *Circulichnis*. Po tej domnevi je posamezen obroč *Circulichnis* poskus prehranjevanja na določeni ravni v sedimentu, medtem ko so stranske veje *Circulichnis* del vertikalnega rova, ki vodi na drugo raven v sedimentu. Raziskava *Circulichnis montanus* iz Doneškega bazena je pokazala, da je pravilna vsaj varianta C sheme nastanka rodu *Circulichnis*, ki sta jo predlagala Uchman in Ratazzi, tj. stranska veja je horizontalni ali subhorizontalni del sicer vertikalnega rova. Vendar to ne izključuje pravilnosti variant A in B Uchmanove in Ratazzijeve sheme. Nedvoumen odgovor na to vprašanje bodo lahko dale le nove najdbe dobro ohranjenih primerkov rodu *Circulichnis*.

Introduction

Circulichnis Vyalov, 1971 is a burrow or trail of enigmatic producers, most likely annelids or "worms", in the form of a ring or ellipse preserved on bedding surfaces (Pickerill & Keppie, 1981; Pickerill et al., 1988; Blissett & Pickerill, 2004; Uchman & Rattazzi, 2018). This ichnogenus ranged from the Ediacaran to the Oligocene (Uchman & Rattazzi, 2018; Morgan et al., 2023). *Circulichnis* shows a wide environmental range, from continental (Mermia ichnofacies) via shelf to deep-sea (turbiditic) deposits (e.g., Pickerill & Keppie, 1981; Fillion & Pickerill, 1984; McCann & Pickerill, 1988; Buatois & Mángano, 1993; Buatois et al., 1998a). *Circulichnis* is generally considered to be a fodinichnion (Pickerill & Keppie, 1981; Mángano et al., 1997; Buatois et al., 1998a, b; Buatois et al., 2006).

Carboniferous trace fossils from the Donets Basin have not yet been studied sufficiently. However, they are of great palaeoecological importance, since the Carboniferous carbonate platform (Tournaisian–Viséan (part)), paralic coal-bearing (Serpukhovian–Kasimovian (part)), and continental red-bed (Kasimovian (part)–Gzhelian) strata in the Donets Basin were formed under different depositional conditions, from relatively deep-water shelf areas to lowland land, located in humid and arid climates (Logvinenko, 1953; Feofilova & Levenshtein, 1963; Novik, 1974; Kozitskaya &

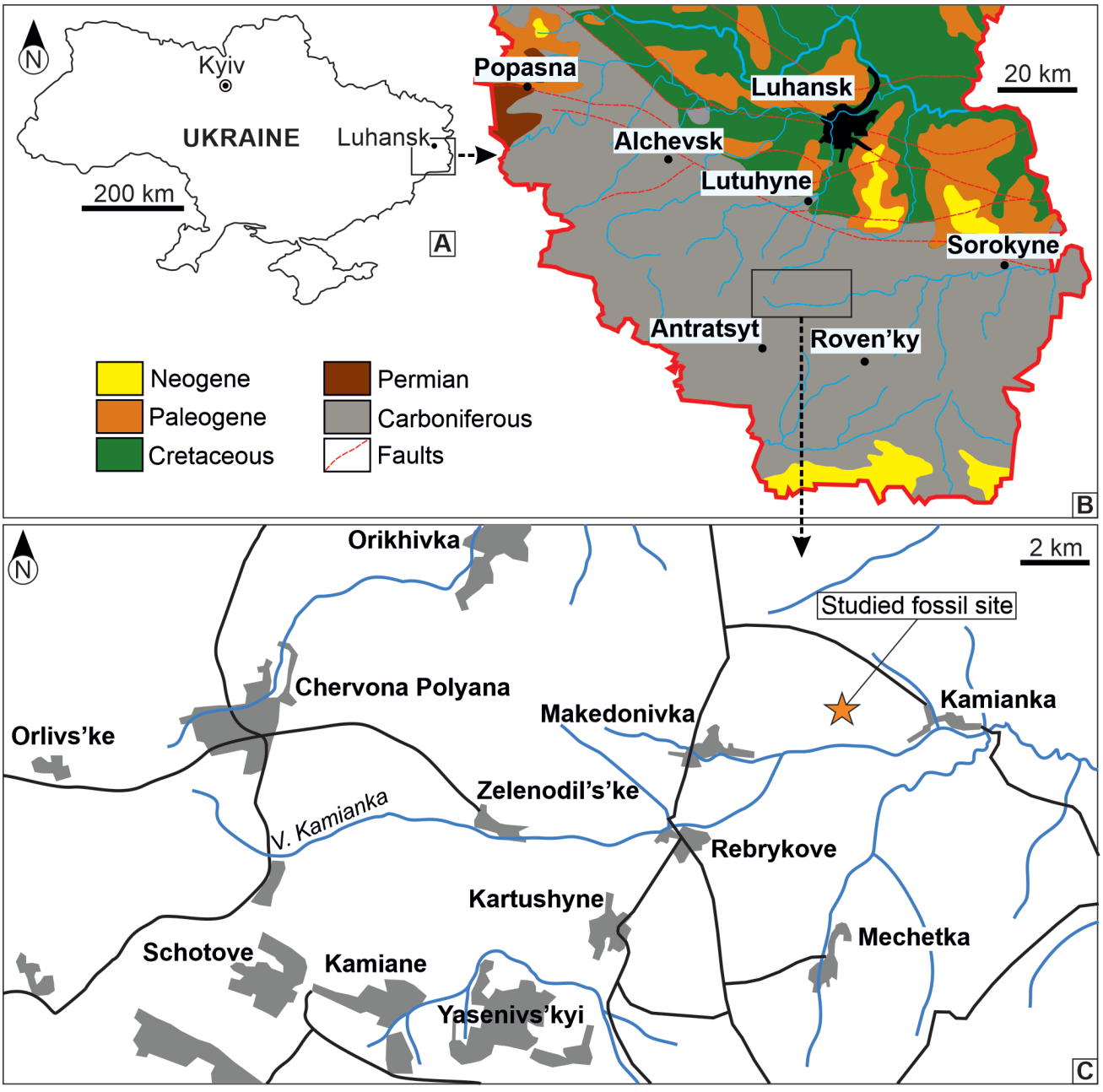

Fig. 1. Geographical location of the fossil site with *Circulichnis montanus* Vyalov, 1971. Abbreviation: V. Kamianka – Velyka Kamianka River. Geological map in Fig. 1B modified after Fissunenko (2004).

Schegolev, 1993). As a result, they characterised different habitat conditions for animals and plants.

This paper describes the ichnospecies *Circulichnis montanus* Vyalov, 1971 from the upper Bashkirian (Pennsylvanian) Mospyne Formation of the Donets Basin (Ukraine), which is important for clarifying the ethology of its tracemakers. In Ukraine, the trace fossils *Circulichnis* have been recorded in the Ediacaran deposits of Podillia (Gureev, 1983), in the Triassic and Jurassic deposits of Crimea (Dmitrieva et al., 1963; Shalimov, 1978) and in the sandstone bed below the G_1^2 limestone layer of the Mospyne Formation in the study area (author's unpublished data), i.e. about 300 m below the sandstone bed from which the trace fossil described here originates. Therefore, this study is also a documentation of the new record of *Circulichnis* in Ukraine.

Geological setting and material

Bashkirian-aged coal-bearing deposits in the Donets Basin were accumulated mainly in a large alluvial-deltaic plain, which was flooded periodically by the epicontinental seas. Only the central part of the Donets Basin was characterized by a continuous regime of marine sedimentation in the Bashkirian.

The sandstone bed with *Circulichnis montanus* Vyalov, 1971 lies in the upper part of the Mospyne Formation (Fig. 2A, B), which is a 315 to 730 m-thick sequence of mudstone, siltstone, sandstone, limestone, and coal (Feofilova & Levenstein, 1963; Dunaeva, 1969; Aisenverg et al., 1975; Poletaev et al., 2011; Nemyrovska & Yefimenko, 2013). These rocks were deposited in shallow marine, lagoonal, lacustrine, prodeltaic, deltaic, peat and clastic swamp environments (Logvinenko, 1953; Feofilova & Levenshtein, 1963). The Mospyne Formation corresponds to the lower part of the Zuyivkian Horizon (lower half of the Kayalian Regional Stage) of the Regional Stratigraphic Scheme of the Dnipro-Donets Downwarp (Poletaev et al., 2011; Nemyrovska & Yefimenko, 2013). This formation contains remains of typical Langsettian terrestrial plants (Novik, 1974; Dernov & Udovychenko, 2019a) and

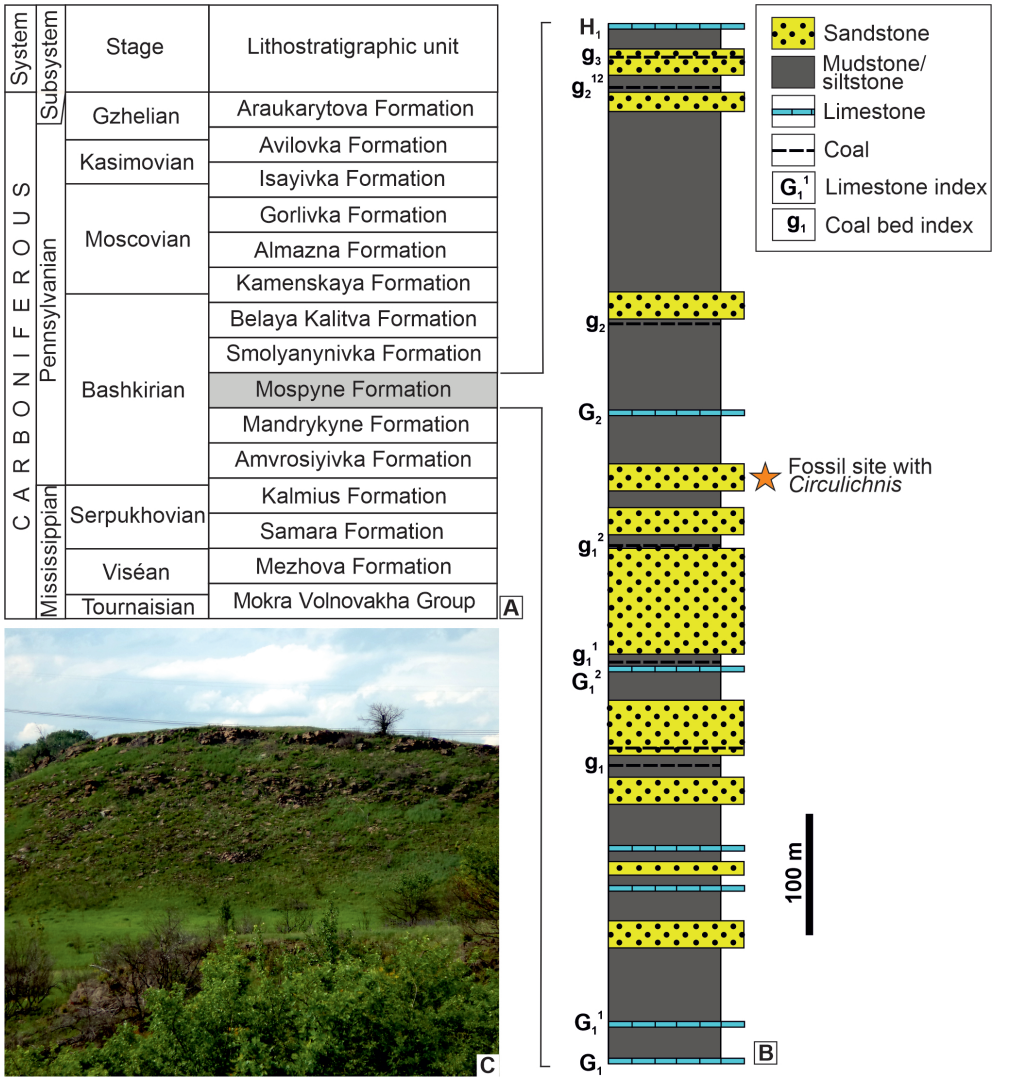

Fig. 2. Stratigraphic position (A, B) and the general view of the *Circulichnis*-bearing fossil site (C).

ammonoids (Popov, 1979; Dernov, 2022b), the non-marine bivalves of the upper part of the *lenisulcata* Zone and the lower part of the *communis* Zone (Dernov, 2022a), the late Bashkirian conodonts (Nemyrovska, 1999), and other marine and terrestrial biota, such as miospores, foraminifers, corals, bryozoans, brachiopods, scaphopods, gastropods, horseshoe crabs, millipedes, insects and fishes.

Some trace fossils from the Mospyne Formation, such as the ichnospecies of the ichnogenera *Arborichnus, Arenicolites, Avetoichnus, Archaeonassa, Aulichnites, Bergaueria, Chondrites, Cochlichnus, Conichnus, Cyclopuncta, Diplichnites, Diplocraterion, Diplopodichnus, Gordia,* ?*Halopoa, Helminthopsis, Kouphichnium, Lockeia,* ?*Lophoctenium, Mammillichnis, Monocraterion, Monomorphichnus, Paleophycus, Phycodes, Phycosiphon, Planolites, Ptychoplasma, Protovirgularia, Rhizocorallium, Rogerella, Rusophycos, Saerichnites, Scolithos, Selenichnites, Treptichnus* and evidences of arthropod-plant interaction have been previously described or figured by the author (Dernov, 2019a, b; Dernov & Udovychenko, 2019b; Dernov, 2021, 2022c, 2023).

The studied specimen GMLNU-15/01 is a single trace fossil *Circulichnis montanus* Vyalov, 1971 on a slab of fine-grained, polymictic, horizontally-bedded, grey sandstone. It was collected by the author from the sandstone bed in the upper part of the Mospyne Formation. This sandstone bed is exposed in the Dubova Ravine, located 2 km west of the village of Kamianka (Ukraine, Luhansk Region: 48°14'54.8"N 39°20'48.0"E; Fig. 1). The section is poorly exposed here (Fig. 2C), but in the neighbouring Sukha Ravine and near the village of Makedonivka, it has been exposed in small quarries. No *Circulichnis* has been found at these other sites, but numerous other trace fossils, such as *Archaeonassa*, *Aulichnites, Bergaueria, Planolites,* and *Treptichnus* are present. The specimen GMLNU-15/01 is housed in the Geological Museum of the Luhansk Taras Shevchenko National University (Poltava, Ukraine).

Systematic ichnology

Ichnogenus *Circulichnis* Vyalov, 1971

Type ichnospecies: *Circulichnis montanus* Vyalov, 1971; by original designation.

Diagnosis: Horizontal, approximately circular to oval, cylindrical ring (after Uchman & Rattazzi, 2018).

Remarks: Keighley & Pickerill (1998) proposed to change the spelling of the ichnogenus from *Circulichnis* to *Circulichnus*, arguing that in the original description of this ichnotaxon by Vyalov (1971), there was a mistake in the spelling of its ending. I see no reason for such a decision, because nowhere is it officially stated that the names of ichnogenera should end in *-ichnus*. Moreover, in the text of the work of Vyalov (1971), the spelling *Circulichnis* is used everywhere, so the ending *-ichnis* cannot be a typographical error. This opinion is shared by many other researchers (for example, Uchman & Rattazzi, 2018; Morgan et al., 2023).

Occurrence: Ediacaran–Oligocene (Palaeogene); worldwide distribution.

Circulichnis montanus Vyalov, 1971

Fig. 3

(See Uchman & Rattazzi (2018, pp. 4, 5) for synonymy)

Material: One well-preserved specimen (GMLNU-15/01).

Description: Horizontal, smooth, unlined, ring-shaped and subcylindrical burrow, 10 to 15 mm wide and 12.5 cm and 10.0 cm in external diameters, preserved as a concave epirelief on the upper bedding plane. The width of the burrow varies considerably, which may be a taphonomic artefact caused by the fact that it is exposed to different depths. A much narrower, slightly curved burrow, about 50 mm long and 8–9 mm wide, extends from the ring at an acute angle. The burrow fill is identical to the host rock.

Remarks: In addition to the type species, several ichnospecies have been described under the name *Circulichnis/Circulichnus*, such as *Circulichnus ngariensis* Yang & Song, 1985, *Circulichnis spiralis* Li, 1993, and *Circulichnis sinensis* Yang, 1990, but they are not related to *Circulichnis* or are synonymous with *Circulichnis montanus* (Uchman & Rattazzi 2018). However, Fan et al. (2021) have reviewed *C. sinensis* as a valid ichnospecies, despite the fact that this ichnospecies, as well as *Circulichnis leomonti* Morgan, Juntunen, Scott & Landreth, 2023, differs from *Circulichnis montanus* in its segmental structure. *Circulichnis montanus* described above differs from *Circulichnis ligusticus* Uchman & Rattazzi, 2018 by the regular elliptical course of the burrow.

The specimen GMLNU-15/01 differs somewhat from the holotype of *Circulichnis montanus* figured by Vyalov (1971, pl. 1, fig. 1) and Uchman & Rattazzi (2018, fig. 2), namely: (1) the holotype is much smaller (the large diameter is about three times smaller than that of the specimen GMLNU-15/01; (2) the holotype is represented by a convex hyporelief, whereas the specimen GMLNU-15/01 is preserved as a concave epirelief; (3)

the holotype is composed by a cylindrical annular ridge, whereas the specimen GMLNU-15/01 is either a partially destroyed cylindrical or subcylindrical burrow. However, the morphology of the specimen GMLNU-15/01 does not contradict the diagnosis of *Circulichnis montanus* given in the revision by Uchman & Rattazzi (2018, p. 5), namely: "horizontal, cylindrical burrow, which shows a course along a regular circle or ellipse". The specimen GMLNU-15/01 is much larger than the holotype of *Circulichnis montanus*, but the size is not of ichnotaxonomic significance (Pickerill, 1994). From the Cretaceous deposits of Alaska, McCann & Pickerill (1988) described specimens of *Circulichnis montanus* similar in size to *Circulichnis montanus* described above.

Locality: Ukraine, Luhansk Region, left slope of the Dubova Ravine, 2 km west of the village of Kamianka; upper part of the Mospyne Formation (late Bashkirian, Early Pennsylvanian).

Fig. 3. *Circulichnis montanus* Vyalov, 1971 from the Mospyne Formation of the Donets Basin (specimen GMLNU-15/01). Scale bar = 10 mm.

Discussion and concluding remarks

Vyalov (1971) and Keighley & Pickerill (1998) suggested that *Circulichnis* could not be unbranched, as its tracemaker could not have appeared from nowhere and had to somehow got to the area of the seabed where it subsequently formed the trace. Probably, in most cases, the incoming (and outgoing) branch could not be preserved, since, for example, it could be located in a different plane relative to the main part of the trace (Vyalov, 1971; Pickerill & Keppie, 1981).

Pickerill & Keppie (1981), suggested that *Circulichnis* and *Helminthopsis* from the Cambrian–Ordovician deposits of Nova Scotia (Canada) were produced by the same producers, most likely annelid worms. This conclusion was supported by the fact that these traces occur on the same bedding surfaces and sometimes overlap (Häntzschel, 1975, fig. 2a on p. W71; Pickerill & Keppie, 1981, fig. 3c).

Uchman & Rattazzi (2018) proposed a model for the function of *Circulichnis*, according to which, *Helminthoidichnites, Gordia*, and *Helminthopsis* are burrows or trails used for feeding, locomotion, or both. The trace makers probably used these structures to explore the environment at different sediment depths, primarily for feeding, and often along bedding interfaces. According to this model, the rejoining of the shaft can occur at the point where the vertical to subvertical shaft connects with the ring, or with the shaft bent to a horizontal position near the ring, or with the shaft diverging in the lower part and transitioning to an imperfect ring that is not closed on the same level.

However, a vertical or subvertical shaft hypothetically connecting *Circulichnis* to another level within the sediment has never been observed, but only documented cases of a horizontal short branch of the *Circulichnis* ring (Uchman & Rattazzi, 2018), as in the specimen GMLNU-15/01. The lateral branch of the specimen GMLNU-15/01, if found in isolation from the ring, could be assigned to the ichnogenus *Planolites* or *Palaeophycus*, so there is good reason to believe that the producers of these ichnogenus, as well as *Helminthoidichnites, Gordia*, and *Helminthopsis*, could also produced *Circulichnis*.

The studied material suggests that at least the variant of the *Circulichnis* ethological model proposed by Uchman & Rattazzi (2018, fig. 6A, B – variant C; see fig. 4) is correct. However, it is not yetclear whether it is the only possible one.

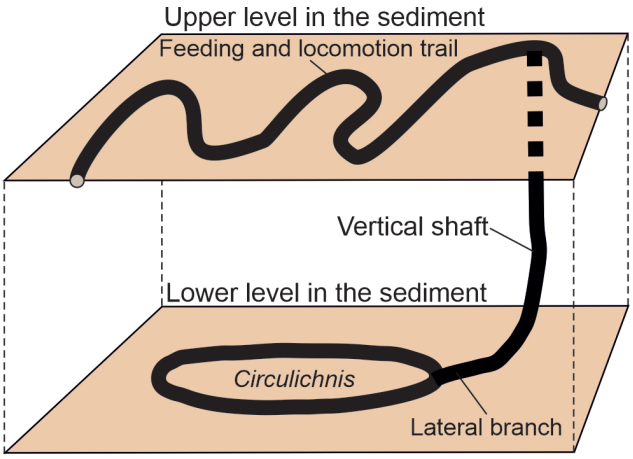

Fig. 4. Model of *Circulichnis*. Modified from Uchman & Rattazzi (2018, fig. 6).

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