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Cambrian trace fossil *Zoophycos* from the Czech Republic

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Abstract: Lobate and helical ichnofossils attributable to *Zoophycos* found in Middle Cambrian shales of the Palác Hill in the Železné Hory Mountains (eastern Bohemia) represent the oldest occurrence of this ichnogenus. Such a complex *Zoophycos* became frequent during the Mesozoic but has been never recorded in strata older than the Ordovician. As such, they represent the oldest occurrence of helical *Zoophycos*. Besides *Zoophycos* isp. there is also a 15 cm thick sandy siltstone layer which is strongly bioturbated by *Planolites* isp., which seems unusual in a Lower Cambrian ichno-association.

Key words: Cambrian, Bohemian Massif, Železné hory, ichnology, marine settings, *Zoophycos*.

Introduction

The early Paleozoic, especially the Cambrian and Ordovician periods, was a time of very important and intensively studied paleobiological events, which are reflected not only by body fossils but also by trace fossils (for a review see Buatois & Mangano 2011, p. 269–274). These events are known as the Cambrian Explosion (Conway Morris 2000) and the Agronomic Revolution (Seilacher & Pflüger 1994).

The ichnogenus *Zoophycos* Massalongo, 1855, is among the first ichnotaxa to occur in the critical earliest Paleozoic time (e.g. Sappenfield et al. 2012). It is an extremely complex trace fossil with broad potential for behavioural interpretation (e.g. Bromley 1991; Löwemark et al. 2007). For these reasons, early Paleozoic occurrences of *Zoophycos* should be thoroughly documented. Only a few reports of *Zoophycos* in Cambrian strata have been published.

On a regional scale, the study of trace fossils can aid in the interpretation of geological units that lack well preserved body fossils. The paucity of body fossils may be caused by partial metamorphism which is usually less destructive for trace fossils than for body fossils (cf. Chlupáč 1997). This is also the case for the lower Paleozoic of the Železné hory Mountains, which are located in eastern Bohemia, about 100 km east of Prague (Chlupáč et al. 2002 — Fig. 1). These rocks were intensively metamorphosed in places; at other sites they were only anchimetamorphosed. As most of the rock exposures are metamorphosed, though weakly, in addition to a smaller number of exposures, few biostratigraphic data are available. Until now, paleo-ichnological data from the Paleozoic complexes of the Železné hory Mountains had not been systematically documented and interpreted. However, it appears that the present record may play an important role in the understanding of the paleo-environment of this region.

The aim of this work is to describe and interpret the most interesting ichnological finds observed so far: the morphologically complex trace fossils of the ichnogenus *Zoophycos* in anchimetamorphosed Cambrian siltstones.

Geology of the study area

The Železné hory Mountains belong to the Bohemian Massif which is a part of the Variscan (Hercynian) orogen (Fatka & Mergl 2009). In the currently accepted conception, the Lower Paleozoic formations of the Železné hory Mts are seen as the continuation of the well-known, intensively studied Barrandian area to the east, showing a strong affinity to the eastern part of the Barrandian area and also to the so-called "metamorphic islets" of the Central Bohemian Pluton (Chlupáč et al. 2002). In contrast to the faintly metamorphosed to unmetamorphosed rocks of the Barrandian area, the Lower Paleozoic rocks of the Železné hory Mountains have undergone faint contact and regional metamorphism (Mikuláš 1996). Recently, an alternative view on the geological context of the Paleozoic of the Železné hory Mountains has appeared; suggesting greater affinity with the Saxo — Thuringian region (V. Kachlík, *personal communication*, 2010).

Historically, the Paleozoic complex of the Železné hory Mountains is divided into two structural zones, called here synclinoria, namely the Podol synclinorium in the south, and the Přelouč synclinorium in the north. Recently, Vodička (1997) put forth the idea that especially the Podol zone is structurally close to a nappe structure and that therefore the term synclinorium is inappropriate.

The age of deposits of the two so-called synclinoria is considerably different. In the northern Přelouč synclinorium, the stratigraphic sequence starts with the Seník Beds; these are composed of silty and sandy shales, greywackes and conglomerates of Middle Cambrian age. The age of the sequence is confirmed only near the town of Heřmanův Městec, where Havlíček (1949) found a trilobite fauna. Fiala & Svoboda (1956) subsequently distinguished the so-called "Sub-Cambrian complex" (currently ranked as Ediacaran) and "Cambrian complex" in the Seník Beds. Quartz sandstones with intercalated silty shales of Ordovician (Tremadocian) age, the Lipoltice Beds (Burda 1989), overlie the Cambrian strata there.

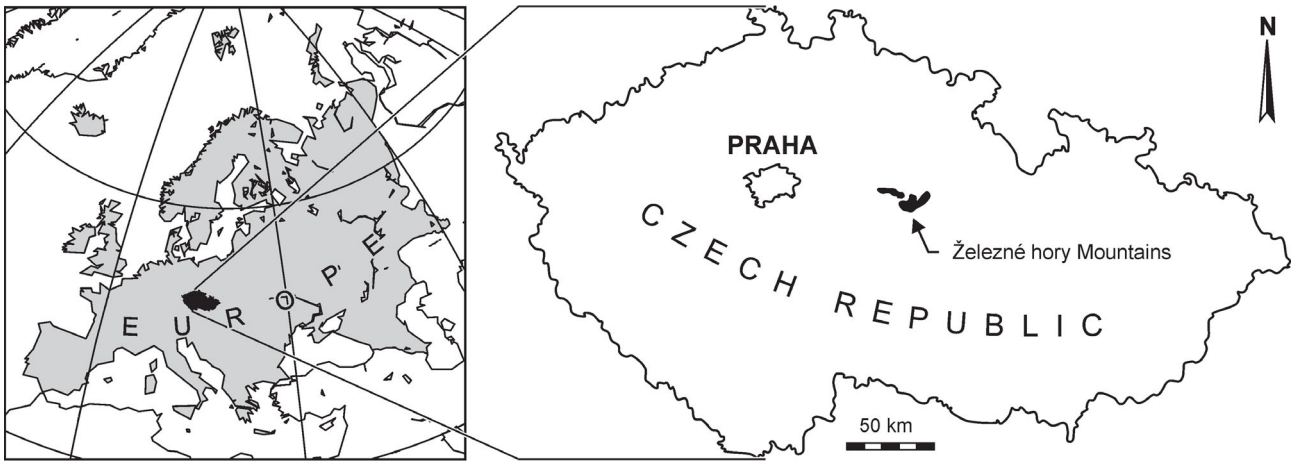


Fig. 1. Schematic map of Europe showing the location of the Czech Republic and the Lower Paleozoic of the Železné hory Mountains.

The Podol synclinorium provides a stratigraphically more complete set of strata. Ordovician, Silurian and Lower Devonian deposits overlie the probable Cambrian rocks that were discovered during uranium exploration (Urban 1972). The Ordovician rocks are represented by very thick complexes (Burda 1989). The Silurian sequence is represented by graphitic schists and orthoceras limestones that belong to the upper Llandovery to Ludlow; some authors place the upper parts of these limestones in the Přídolí Stage (Schmidt et al. 1967; Vodička 1985). The youngest rocks (limestones) of the Podol synclinorium are dated as early Devonian.

The locality

Palác Hill, near the town of Heřmanův Městec, from which the described finds come, is located at the southeastern margin of the Přelouč synclinorium. The bulk of the hill is made of the Cambrian Seník Beds; only its northeastern margin is built of Ordovician monomictic quartzites (Tremadocian Lipoltice beds — Burda 1989). The Seník Beds predominantly consist of siltstones (at the small quarry 280 m west-northwest of the spot height of 382 m — N 49°56′0″, E 15°40′48″), sandy siltstones or sandstones. These pass upward to quartz conglomerates.

Palác Hill, as a geological locality, was mentioned for the first time by Havlíček (1949), who assigned its Middle Cambrian trilobite fauna to the Acadian Stage, which was used at that time. He mentioned the following species: *Ellipsocephalus vetustus*, *Conocoryphe sulzeri, Ptychoparia* sp., *Paradoxides minor*, *Lobocephalus marginatus*, *Lobocephalina carinata* and *Skreiaspis spinosus*. These finds confirmed the Cambrian age of the eastern part of the Seník Beds. Havlíček & Šnajdr (1951) subsequently depicted the specimens. The existence of this trilobite fauna was later mentioned by numerous authors who partly revised the faunal list according to contemporary knowledge and understanding of the taxa (e.g. Fatka & Mergl 2009).

In addition to debris and occasional small outcrops, three small inactive quarries and five shallow boreholes with

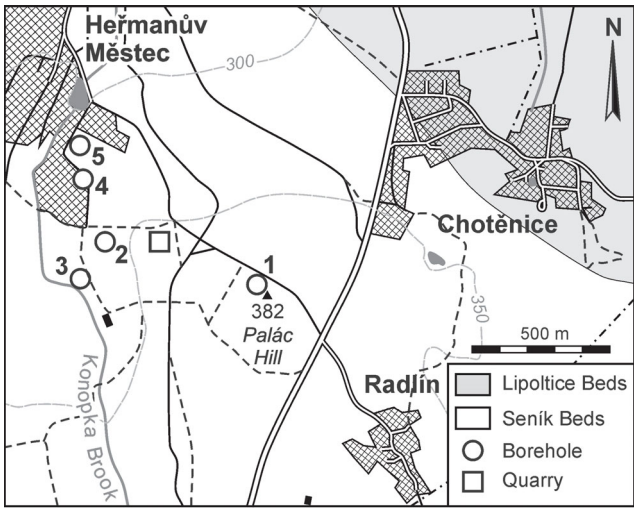


Fig. 2. Location map. Position of boreholes: 1 — U Kóty, 2 — Pod Lůmkem, 3 — Hájovna, 4 — Úvoz, 5 — Lavičky.

core diameter 185 mm provided information on the geological setting of Palác Hill. The most prominent quarry approximately 15 m long and 1.5 m high is located at N 49°56′02″, E 15°40′28″. It is elongated in a north-south direction; the inclination of bedding is 50° to east-south-east. Of the five boreholes, three provided ichnological data. The Hájovna borehole (N 49°56′01″, E 15°40′16″) revealed several specimens of *Zoophycos* from the depth interval 6.0–7.4 m, together with signs of plastic deformation (boudins up to 4 cm in size) in the same interval. Lithologically, it is composed of grey to greyish-green siltstones, finely fissured, and in places strongly limonitized. The Úvoz borehole (N 49°56′61″, E 15°40′12″) exposed sandy siltstones and fine-grained sandstones alternating at centimetric intervals that grade upward to quartzose sandstones and greywackes. *Planolites* isp. was discovered in the drill core. The Lavičky borehole (N 49°56′11″, E 15°40′13″) was drilled in an area where Havlíček (1949) found a trilobite fauna of Cambrian age. However, the borehole did not yield

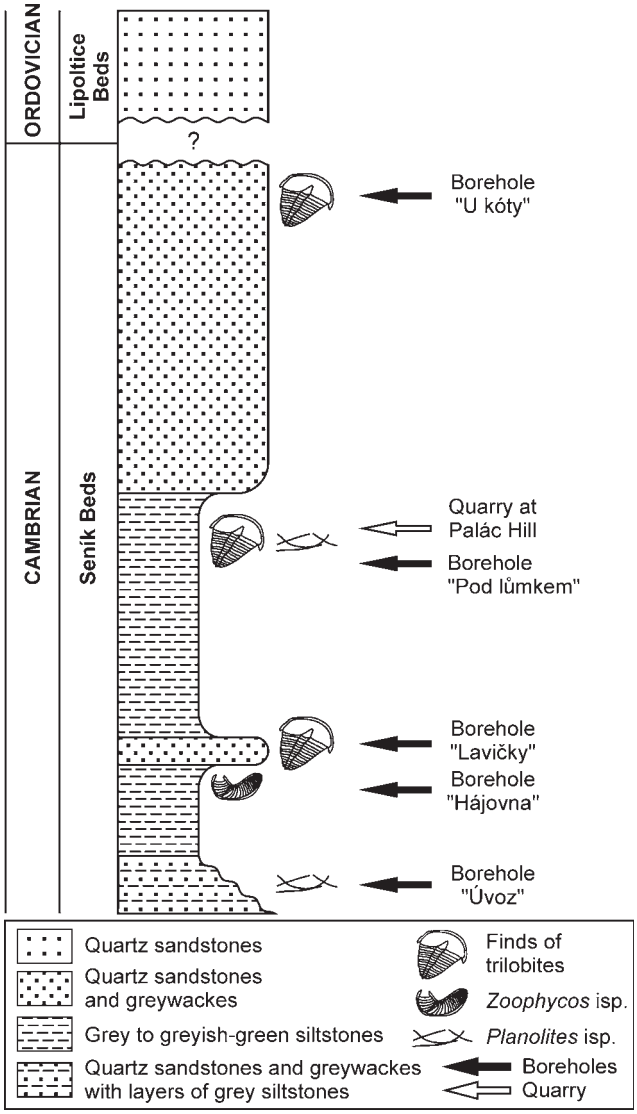


Fig. 3. Tentative lithostratigraphic profile on the rocks of Palác Hill based on geological mapping, outcrops and cores. Overall thickness of the depicted profile is more than 500 m.

any new finds of body fossils. Greenish siltstones contain layers of fine-grained bioturbated sandstones up to one centimeter thick.

From the cores and outcrops it is possible to reconstruct the schematic lithostratigraphic profile of Palác Hill (Fig. 3). The Seník Beds are heterolithic; they are represented by greenish grey siltstones, which are overlain by anchimetamorphosed silty shales and greywackes, quartzose sandstones and conglomerates. In the lower part of the profile, sandy siltstones with varying proportions of sand occur. Rocks of the Seník Beds, attributable to the Cambrian, are overlain by the monomictic, quartz-cemented conglomerates of the Lipoltice Beds (Tremadocian — Burda 1989).

To summarize, the rocks studied on Palác Hill represent several stratigraphic levels and different depositional environments. Except in the sandy greywackes to conglomerates in the upper part of the section, primary sedimentary structures are well-preserved. The structures in the siltstones in the middle part of the section (coarse, irregular parallel laminae; bioturbation) suggest deposition below the storm wave base. The lower and upper parts of the section represent shallow water, probably a shoreface environment with a sandy bottom.

Systematic ichnology

Zoophycos Massalongo, 1855

Zoophycos isp.
Fig. 4–6

Material: 3 specimens, Seník Beds, Hájovna Borehole; depth: 6.0 to 7.5 m.

Description: Fragments of horizontal to subhorizontal laminae of spreiten that repeat vertically in the sediment, suggesting the helical shape of the whole structure. The lobes may be connected with horizontal or subhorizontal tunnels showing a meniscate fill. Spreite structures are composed of the same material as the surrounding rock or with slightly darker material with higher clay admixture.

Sample P1H displays two specimens. Specimen No. 1 (Fig. 4) has six oblique laminae that are 3.0–4.0 mm thick; width of primary lamellae ranges from 0.3 to 0.5 mm. The diameter of the specimen cannot be precisely measured be-

Fig. 4. *Zoophycos* isp. (specimen No. 1) in sample P1H; oblique section. Scale bar = 1 cm.

cause the cross-section of the specimen obviously does not reach its central portion. The presumable depth can be estimated as several centimeters; more precise estimation would be speculative.

The specimen No. 2 from the P1H sample (Fig. 6) consists of two aligned subhorizontal lamellae, 2.5 to 3.0 mm thick. Measurable horizontal extent is 51.0 mm. The specimen from the P2H sample (Fig. 5A) consists of three or four presumably lobed, subhorizontal structures. Width of each lobe is approximately 55.0 mm; laminae are 2.3 to 3.9 mm thick. Individual lamellae, 0.5 to 0.6 mm thick, are easily visible in places. Spreite-structures are mostly composed of the same material as the surrounding rock; only in places are they darker, with the clay admixture.

The specimen from the P3H sample (Fig. 5B) is also observable in a transverse section steeply oblique to bedding. The three subhorizontal, joined or tightly aligned laminae are 3.6 to 4.8 mm thick; lamellae are 0.4 to 0.9 mm thick. Spreite-structures are composed of the same material as the surrounding rock.

Remarks: Using specimen No. 1 on sample P1H (Fig. 4), which is best accessible for observation, we can identify which morphotype of the ichnogenus *Zoophycos* is probably present. The described specimen evidently has a helical spreite and reaches the depth of several centimeters. This description fits the morphotype described by Olivero & Gaillard (2007) well. The specimen in the sample P3H enables the determination of the spiralling direction of the spreite-structure; this can be described as sinistral-upward.

Planolites Nicholson, 1873

Planolites isp.
Fig. 7–8

Material: Several dozen specimens. Seník Beds, Úvoz and Lavičky Boreholes, and outcrops at the Palác Hill.

Description: In the cores, the material attributable to *Planolites* consists of flattened, originally presumably circular to oval cross-sections of horizontal to subhorizontal tun-

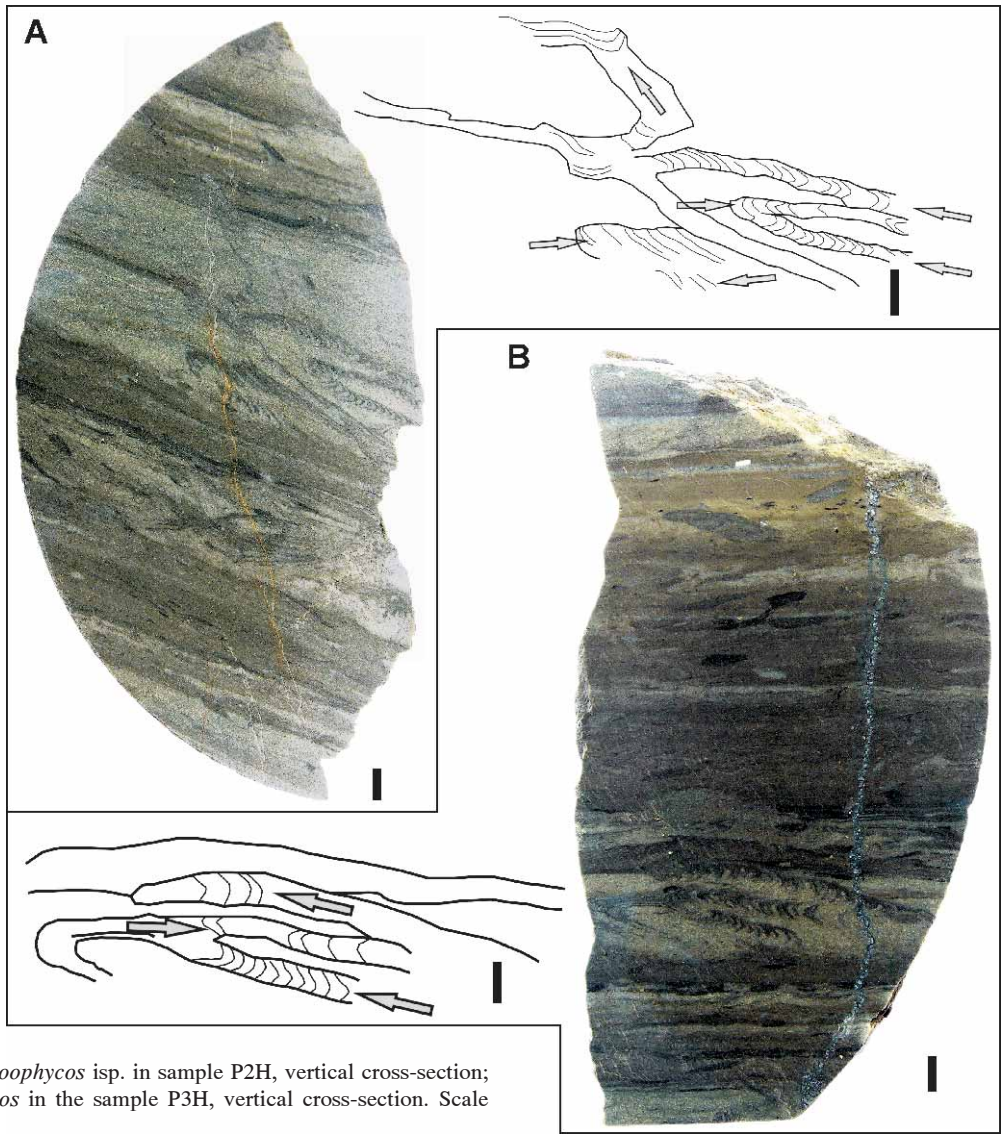
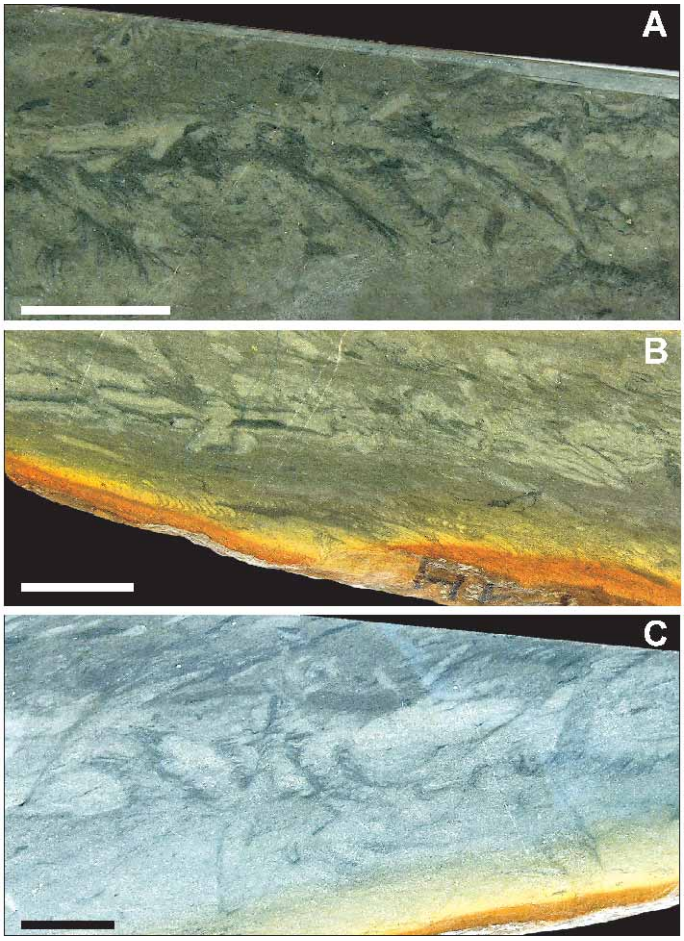


Fig. 5. A — *Zoophycos* isp. in sample P2H, vertical cross-section; **B** — *Zoophycos* in the sample P3H, vertical cross-section. Scale bar = 1 cm.



nels, 2.0–4.0 mm in diameter. The fill contrasts with the surrounding rock that is sandy or clayey. The material from the outcrop shows predominantly simple horizontal tunnels with diameters of 0.7–1.5 mm. The tunnels are unlined, unbranched, straight or more often curved (exceptionally even strongly curved to twisted), commonly intersecting each other. In comparison to the surrounding rock, the fill is finer, more clayey and more greenish.

Occurrence: The burrows were recorded in the Úvoz and Lavičky boreholes (depth 5.5 and 4.0 m, respectively). The highest amount of specimens was found in a fox hole (N 49°56′ 04″, E 15°40′ 48″) next to the largest quarry, in a 15 cm thick layer. All the occurrences belong to the lower part of the Seník Beds (Fig. 3).

Discussion and conclusions

Finds of helical *Zoophycos* from the Hájovna borehole on Palác Hill are unique in regard to their age. Thus far, the oldest specimens of *Zoophycos* come from the lower Cambrian member of the Wood Canyon Formation in California (Sappenfield et al. 2012) and from the Early Cambrian *Rusophycus avalonensis* trace fossil zone from Sweden (Jensen et al. 2001). The oldest known

Fig. 6. *Zoophycos* isp. (specimen No. 2) in sample P1H (lower left); oblique cross-section. Scale bar = 2 cm.

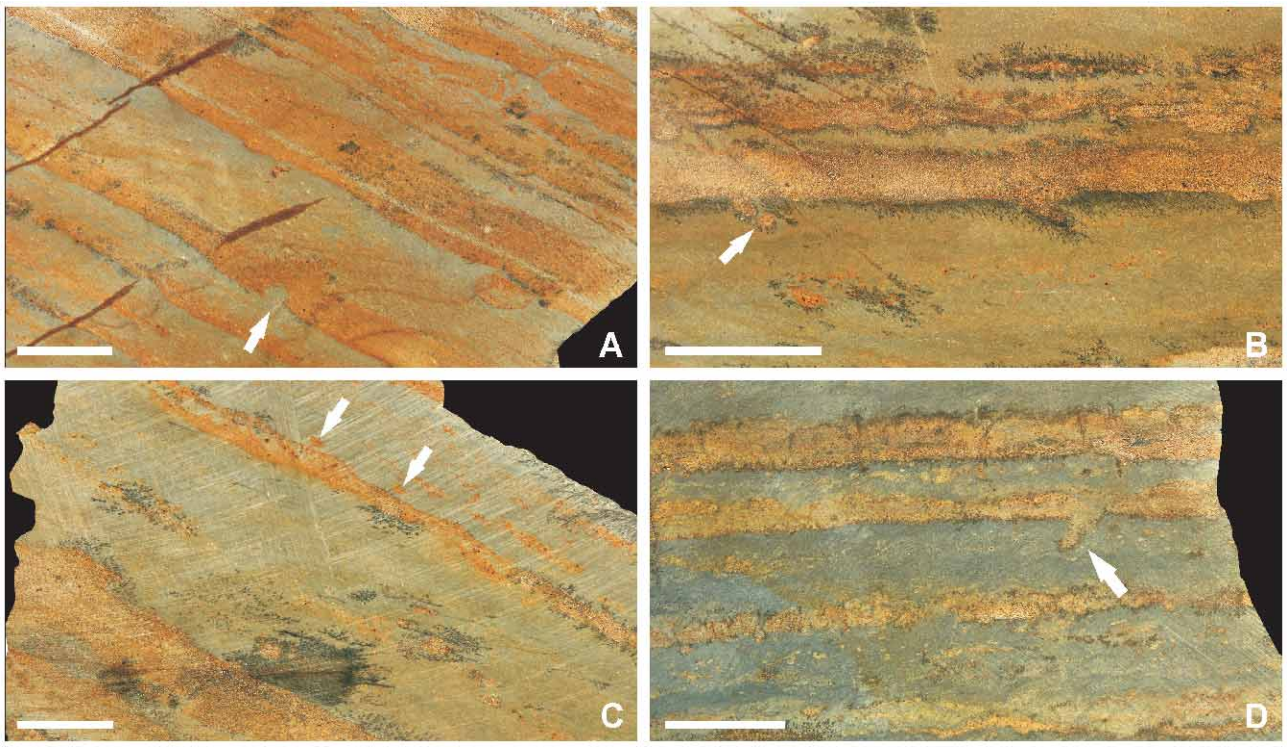


Fig. 7. Cross-sections of *Planolites* isp. **A, B, D** — Úvoz borehole, **C** — Lavičky borehole. Scale bar = 2 cm.

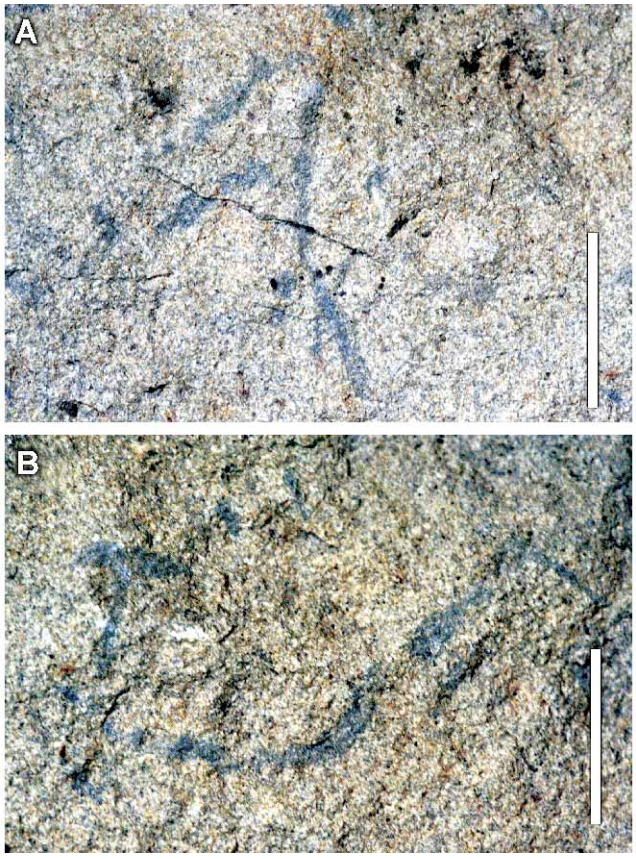


Fig. 8. *Planolites* isp. from the fox hole near the small quarry. Scale bar = 1 cm.

Zoophycos is a shallow burrow, constructed about 1–2 cm deep in the mixed layer (Sappenfield et al. 2012).

Among other notable finds of early *Zoophycos*, one comes from the Buen Formation of North Greenland (Bryant & Pickerill 1990). Stratigraphically, it is placed in the second Stage of the Cambrian Series. The morphology of this trace is simple: a straight tunnel 52 mm long and 3–6 mm wide, showing internal lamination. Laminae are alternately light and dark (Bryant & Pickerill 1990). Its architecture and structure indicate that it is a simple sinistral morphotype of *Zoophycos* (Olivero & Gaillard 2007).

All other specimens so far reported from the Cambrian are similar, planar forms. Jensen (1997) described such a find from the Lower Cambrian Mickwitzia Sandstone of Sweden. Yang & Wang (1991) described a planar *Zoophycos* from the Middle Cambrian beds of the North China Platform. De (1993) reported *Zoophycos* from the Lower Cambrian strata of Kashmir, India. Goldring & Jensen (1996) noted *Zoophycos* from Cambrian Stage 2(?) in western Mongolia. Potentially the oldest find of *Zoophycos*, as reported by Alpert (1977) from the Campito Formation of southern California, probably does not represent the ichnogenus *Zoophycos*; moreover, its stratigraphic position is questionable (S. Jensen, *personal communication* 2012).

The above data show that *Zoophycos* from the Železné hory Mts is unique among the Cambrian occurrences of the ichnogenus for its complex, non-planar, probably helical structure. No examples of helically coiled *Zoophycos* have previously been reported before the Ordovician (e.g. Mikuláš 1995).

Planolites is, in its most typical form, a horizontal to subhorizontal tunnel which can be common on bedding planes as semi-reliefs or within a substrate in full relief (Häntzschel 1975). In the Cambrian, dense *Planolites* ichnofabric is notably rare. The layer described here shows such an infrequent case, namely a modest mixed layer showing an even degree of bioturbation throughout its thickness of ~15 cm; the ichnofabric index (Droser & Bottjer 1986) is 3. Surrounding layers show no bioturbation. It can be presumed that *Planolites* represents in this case a true feeding trace; the bioturbated bed might have been well oxygenated and rich in nutrients.

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