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Ichnological aspect of fossiliferous nodules of the Šárka Formation (Ordovician, Llanvirnian, Czech Republic)

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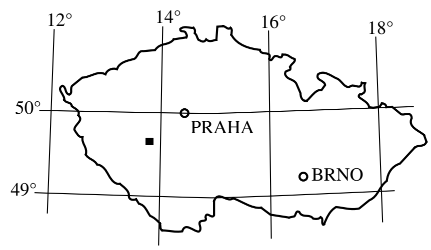
Abstract. In the muddy, oxygen-deficient sediments of the Llanvirnian of the Prague Basin, chemical disequilibrium between burrows and the host substrate were a common reason for the origin of nodules. As the ichnofossils are well preserved in the nodules, without deformation, the origin of the nodules during very early diagenesis is likely, in some cases possibly contemporaneous with the existence of the open burrow. The steepest chemical gradient can be expected close to the openings of the burrows. Therefore, these parts of burrows may have had the highest fossilization potential. The ichnogenera of *Skolithos*, *Planolites*, *Rhizocorallium* and *Glockerichnus* were recognized as possible agents of the nodule-forming process.

Key words: Ordovician, Llanvirnian, Prague Basin, ichnofossils, nodules, diagenesis



Introduction

Richly fossiliferous nodules of the Šárka Formation (Ordovician; Llanvirnian Stage; Barrandian area) belong to the well-known palaeontological (e.g. Havlíček and Vaněk 1966, Chlupáč 1993, Havlíček 1998) and sedimentological (Kukal 1962) phenomena of the Czech Republic. Not only body fossils but also trace fossils are commonly preserved in the nodules (Mikuláš 1991). The question that has not been solved yet is to what degree are the biogenic sedimentary structures (i.e. ichnofabric) of the substrate involved in the formation and shape of the nodules. A particular problem of this study is the difficulty in obtaining representative material because of the present state of localities and outcrops. Temporary exposures (such as that reported by Slavíčková and Budil 2000) usually provide a limited number of nodules. Traditional sites of exposure on the soil surface were exploited a long time ago. Therefore, the nodules preserved *in situ* have undergone through a selection by fossil collectors, who prefer – according to their previous experience – certain shapes. Large amount of previously non-sorted nodules has been obtained at the locality Díly near Rokycany (Fig. 1) during the construction of a speedway in early 90s' of 20th century by P. Kraft and J. Kraft (P. Kraft *pers. comm.* 2001), but this material has not yet been thoroughly investigated.

In the 1980, Mr. Pavel Šlehofer (formerly the Institute of Geology, Academy of Sciences of the Czech Republic, Prague) collected the nodules at several sites of the Šárka Formation. Part of the material obtained by him was processed in a usual way, i.e. by splitting the nodules and selecting those having well-preserved or rare fossils. However, 200 nodules from the locality of Osek (Fig. 1) were kept in the depository of the Institute of Geology without further preparation and selection. The character of the collected material (partly broken concretions are also present, no size and shape selection is seen) indicates the intentional non-selectivity of the collection. I find this material appropriate for the evaluation of the role of ichnofabric during the formation of the nodules, which is the aim of the present contribution.

Geological settings

Ordovician sediments in the Barrandian area (central Bohemia, Czech Republic) represent a continuous succession from the Tremadocian through the late Ashgillian (Kosovian Stage of the local subdivision) continuing to the Silurian. During the Llanvirnian, sedimentation was influenced by the tensional regime in the basin. A rapidly deepening central depression was filled with grey to black clays, with sand admixture in places. Fossils in the black shales are poorly preserved and deformed in contrast to the fossils from siliceous nodules where preservation is often remarkable. The benthic community consists of a few species of articulate brachiopods, the inarticulate brachiopods *Palaeoglossa* and *Paterula* and very diversified, presumably vagile elements (trilobites, ostracods, gastropods etc.) (e.g. Havlíček 1998 and references therein). In the western part of the basin, well-preserved trace fossils occur in siliceous nodules, including *Chondrites, Palaeophycus, Rhizocorallium,* strongly lined *Arenicolites,* and *Brdichnus*, which might represent uppermost parts (i.e. openings of vertical shafts) of extraordinarily large *Zoophycos*. In the eastern part of the basin, the nodules did not yielded this ichnoassemblage; instead, *Spirophycus* and *?Urohelminthoida* were found in the shales. Degree of bioturbation of the shales is usually difficult to estimate as the primary lamination is usually poorly ob-

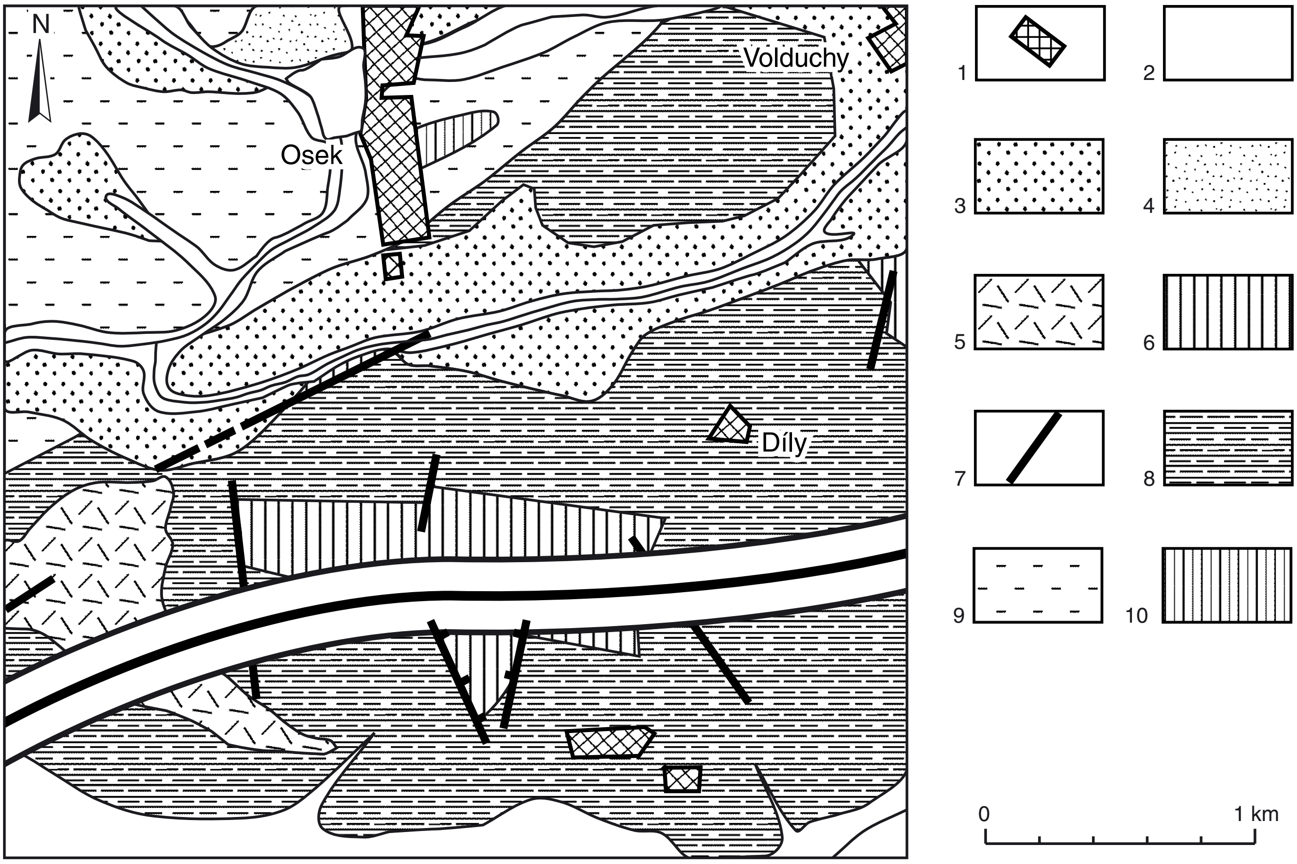


Figure 1. Generalized geology of the Osek area. 1. Anthropogenous deposits; 2. Colluvial and fluvial Holocene sediments; 3. Colluvial and fluvial Pleistocene sediments; 4. Pleistocene loess; 5. Miocene fluvial sediments; 6. Šárka Formation (Ordovician); 7. Faults; 8. Klabava Formation (Ordovician); 9. Proterozoic greywackes and shales; 10. Proterozoic cherts. The locality "Osek" comprises the area between the speedway and both eastern and western surroundings of the village. Adapted from Slavíčková and Budil (2000).

servable because of the compaction and re-crystallization. However, the shales locally provide sequences, which allow us to measure the Ichnofabric Index (i.i.; cf. Droser and Bottjer 1986). The exposure at Praha-Červený vrch shows i.i. = 1–2 in the lower part of the outcrop; the biogenic structures belong almost exclusively to the ichnogenus *Pilichnus*. In the upper part, i.i. reaches locally, in thin layers, the value 3–5; otherwise, the "background" is poorly reworked by in-fauna (i.i. = 1–2). In conclusion, the probability that the growing nodule had randomly picked-up a trace fossil is low in most of the horizons of the Šárka Formation.

The Osek locality is situated in the western part of the presently preserved sedimentary fill of the Prague Basin. Ichnofossils such as *Chondrites* isp. ("thin form"), *Palaeophycus* cf. *sulcatus* (Miller et Dyer), *P.* cf. *striatus* Hall, *Zoophycos*-like trace *Brdichnus*, *Rhizocorallium* isp. and *?Arenicolites* isp. have been described from Osek and adjacent localities from the nodules (Mikuláš 1991).

Table 1. Quantitative assessment of the ichnofabric-bearing nodules from Osek.

Description of ichnofabric	Number of finds
Straight cylindrical shafts or tunnels (*Skolithos, ?Planolites*, ? upper parts of U-tubes)	4
Clusters of straight to moderately curved tunnels (*Planolites*)	7
Flat, simple spreiten-structures (*?Rhizocorallium*)	4
Star-like structures (*?Glockerichnus*)	2
Combination of two approximately perpendicular shafts/tunnels (*Skolithos-Planolites*)	1

Description of the material

Among the studied 200 nodules, surfaces or fracture planes of 31 bear marked features of ichnofabric (i.e. the remaining 169 nodules show no observable ichnofabric or only indistinct, isolated cross-sections of tunnels). Among these 169 nodules, ovoid-shaped ones highly prevail. Ca 20% of them contains well-preserved body fossils (e.g. pygidia of trilobites), orientated symmetrically to the "host" nodules. Out of the 31 selected nodules, 13 showed no clear shape relation of the concretion body to the ichnofabric, and the remaining 18 ones do allow to presume such relation. The latter finds are included in Table. 1.

From the above mentioned data, it can be estimated that ca. 10% of the nodules were probably formed as a result of ichnofabric. More specifically, ca. 5% of the nodules originated along probably vertical tubes (Pl. I, figs 7, 8; Pl. II, fig. 3), approximately 10% around clusters of subhorizontal tunnels (Pl. I, figs 3, 5, 6; Pl. II, figs 2, 7) and 5% on subhorizontal spreiten laminae (Pl. I, fig. 4; Pl. II, fig. 5, 8), bushy or star-like traces (Pl. I, figs 1–2) or on a combination of horizontal and vertical tubes (Pl. II, fig. 1).

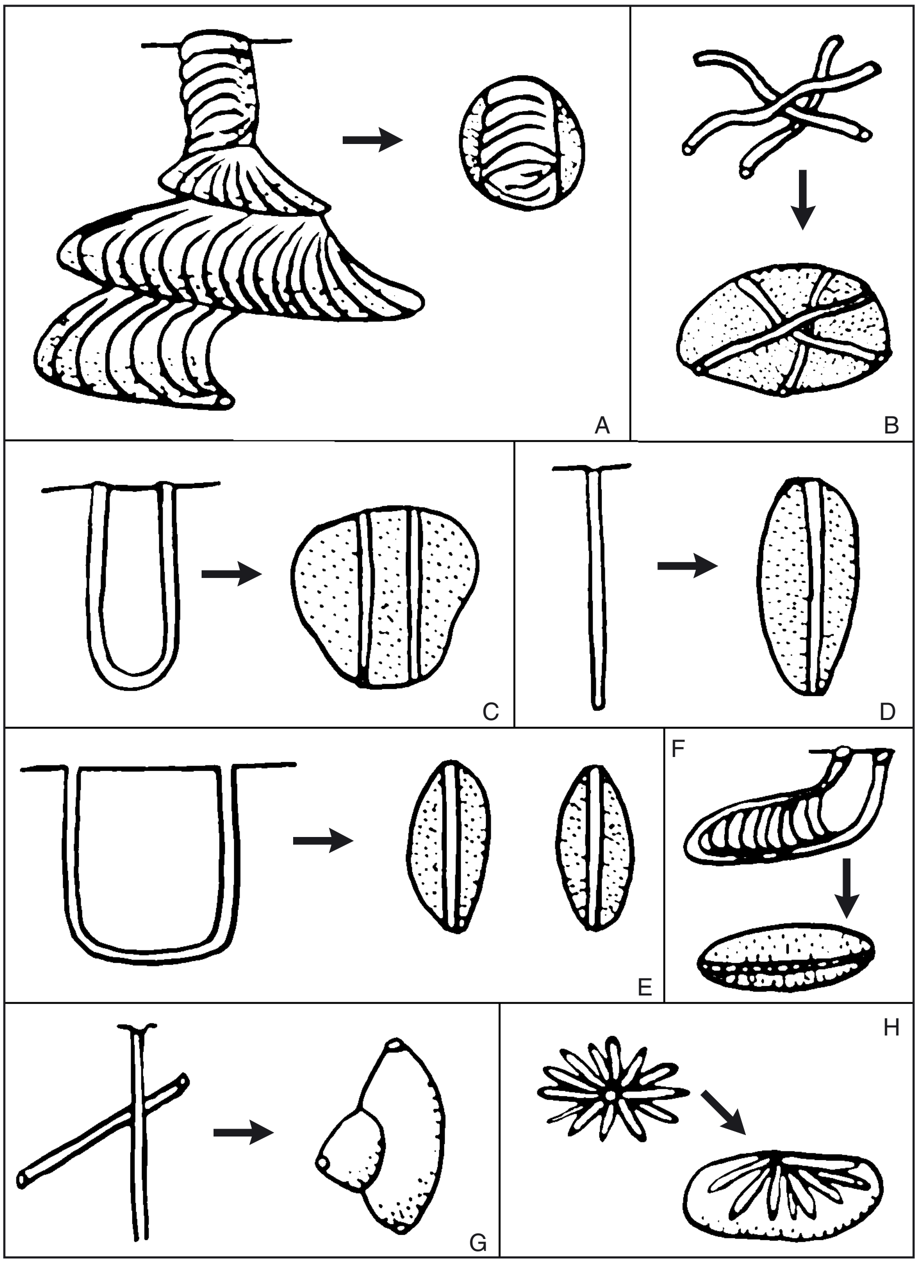


Figure 2. Presumed nodule-forming processes resulting from ichnofabric. Specimens suggesting processes A and C were figured by Mikuláš (1991), the remaining examples are illustrated herein on Pl. I and II. A. *Zoophycos*; B. *Planolites*; C. *Arenicolites*; D. *Skolithos*; E. *Arenicolites*; F. *Rhizocorallium*; G. *Skolithos* and *Planolites*; H. *Glockerichnus*. Approximately 1/3 of natural size.

Interpretation and ichnological consequences

All burrows represent chemical inhomogeneities in the substrate (e.g. Frey 1971) and have been often reported as nodule-forming agents (e.g. Kennedy 1970). Especially feeding traces and those used for a permanent dwelling or the "chemichnia" (Bromley 1996) may include in their ethological purpose a change in the chemical composition of the substrate. Chemical disequilibrium between the burrows and the host substrate was, as previously shown, a common cause for the origin of a nodule. As the fossils and ichnofossils are well preserved in the nodules, showing no deformation, the origin of the nodules must be presumed very early, in some cases probably contemporaneously with the existence of the open burrow.

The steepest chemical gradient can be expected close to the openings of the burrows. Therefore, these parts of burrows may have had the highest fossilization potential. Examples of nodules formed probably around burrow openings are figured herein on Pl. I, figs 7–8; Pl. II, figs 1, 3.

Besides these clear examples (where the ichnofossil is observable inside the nodule as well as it influences its external shape), we may often find nodules showing more-or-less ordered system of protuberances and ridges on their surfaces but no ichnofabric is visible in the nodule substrate. This situation deserves a special attention as an example of frequently expounded dilemma of a "fossilization barrier" of trace fossils (e.g. Bromley 1996). Some traces (especially uniphase feeding probes and locomotion burrows) may be filled with the material extremely similar to the surrounding rock. As a result, it is impossible to recognize the ichnofabric either in the unconsolidated substrate or in the substrate that passed through diagenesis and re-crystallization processes. However, early diagenetic processes, namely penetration of fluids and precipitation of cement from them, might be extremely responsive for slim (and subsequently disappearing) differences in substrate porosity and chemism controlled by bioturbation. Therefore, the protuberances and ridges on the surface of nodules are interpreted herein as ichnofabric features (e.g. Pl. I, figs 5, 6). Plausibility of this explana-

Figure 3. A nodule showing a branching pattern of ridges (which corresponds to the ichnogenus *Chondrites*) on its surface. Ordovician, Šárka Formation, Praha – Červený vrch.

tion is supported by a find from the Praha – Červený vrch locality where a nodule showing a branching pattern of ridges (which corresponds to the ichnogenus *Chondrites*) on its surface was found (Figure 3).

The presumed ichnologic influences to nodule-forming processes are summarized in Fig. 2.

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Plate I ⇒

Siliceous nodules of the Šárka Formation (locality Osek) showing a prominent ichnofabric. 1–2: ?*Glockerichnus* isp.; 3, 5, 6: clusters of *Planolites* isp.; 4: ?*Rhizocorallium* isp. and *Planolites* isp.; 7–8: *Skolithos* isp. 1 – × 1.3; 2 – × 1.6; 3 – × 1.4; 4 – × 1.5; 5 – × 1.0; 6 – × 1.4; 7 – × 2.8; 8 – × 1.4.

Plate II ⇒⇒

Siliceous nodules of the Šárka Formation (locality Osek) showing a prominent ichnofabric. 1: ?*Skolithos* isp. and *Planolites* isp.; 2, 8: ?*Planolites* isp.; 3: *Skolithos* isp.; 4–5: ?*Rhizocorallium* isp.; 6–7: ?*Rhizocorallium* isp. and ?*Planolites* isp. 1 – × 1.3; 2 – × 1.3; 3 – × 1.4; 4 – × 1.4; 5 – × 1.4; 6 – × 1.0; 7 – × 1.1; 8 – × 1.0.

Plate I


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Plate II