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Hydraulic sediment penetration and seasonal growth of petalonamean basal discs from the Vendian of Ukraine

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ABSTRACT

Around the Ediacaran-Cambrian transition, about 540 million years ago, marine organisms began to dig in the sediment that has resulted in its better ventilation and further expansion of infaunal life. Few vertical infaunal burrows are known from the Precambrian and they are usually attributed to sea anemones. Here we show that the enigmatic Ediacaran petalonamean 'sea pens' were able to penetrate sediment for more than one centimetre depth while anchoring the body in the microbial mat. Their growth, as evidenced by numerous well-preserved basal discs from the late Ediacaran Lomoziv Member of the Mohyliv Formation in Podolia, Ukraine, was under control of rhythmic sedimentation events and periodic microbial mat development. Size frequency distribution in classes of both the final disc size and growth retention stages show that their size increase was stepwise. Each discrete stage corresponds to deposition of a thin sediment layer and development of the microbial mat at its top. Podolia was located near the South Pole in the Ediacaran (Vendian) and such rhythmic sedimentation was probably connected with the local climate seasonality.

1. Introduction

Exposures of the latest Precambrian strata in the Dniester River valley in Podolia, Ukraine, are among world localities richest in discoidal body fossils (Fedonkin, 1985; Fedonkin and Vickers-Rich, 2007; Ivantsov et al., 2015). Most of these fossils represent either attachment discs of the frond-bearing petalonameans or more or less compressed spherical microbial colonies (Narbonne and Hofmann, 1987, p. 666; Ivantsov et al., 2014). The microbial balls can be easily distinguished from metazoan body fossils owing to the pattern of their folding in result of the sediment compaction. The Podolian discs presumably representing petalonameans show neither chaotic oblique folding, typical for the microbial balls, nor finely distributed concentric increments characterizing some discoidal fossils from other Ediacaran localities. Their surface is smooth except for the concentric circular rings apparently corresponding to retentions in their growth. The first such ring marks the end of a juvenile stage in development of the disc that was of a finger-like appearance and deeply penetrated the sediment. These penetration marks resemble mysterious traces of short horizontal movements and vertical penetration of sediment attributed to cnidarians polyps that were reported from Podolia by Fedonkin (in Velikanov, 1985, p. 161, pl. 31:6). Similar structures are associated with minute discoidal fossils in the Fermeuse Formation in the Avalon Peninsula of Newfoundland (Menon et al., 2013). Longer trails have been described from the slightly older Mistaken Point Formation in the same region (Liu et al., 2010). Their relationship to the petalonameans was rejected and a cnidarian affinity was preferred by these authors, but the new Podolian material described here shows that the Ediacaran alleged 'sea pens' (see Antcliffe and Brasier, 2008) were truly able to penetrate sediment to a significant depth. This introduces a new aspect to the process of 'Agronomic Revolution' near the Precambrian-Cambrian transition (Seilacher et al., 2005; Dzik, 2005, 2007; Mángano and Buatois, 2014).

2. Material and methods

The studied specimens have been collected by the junior author in the quarry that operated for about 15 years, until 2015, on the northern bank of the Dniester River below the Novodnistrovs'k dam. There are several fossiliferous horizons in the Lomoziv Member of the Ediacaran Mohyliv Formation exposed in the quarry, represented by intercalations of sandy siltstone and thin arkosic sandstone lenses, as well as the

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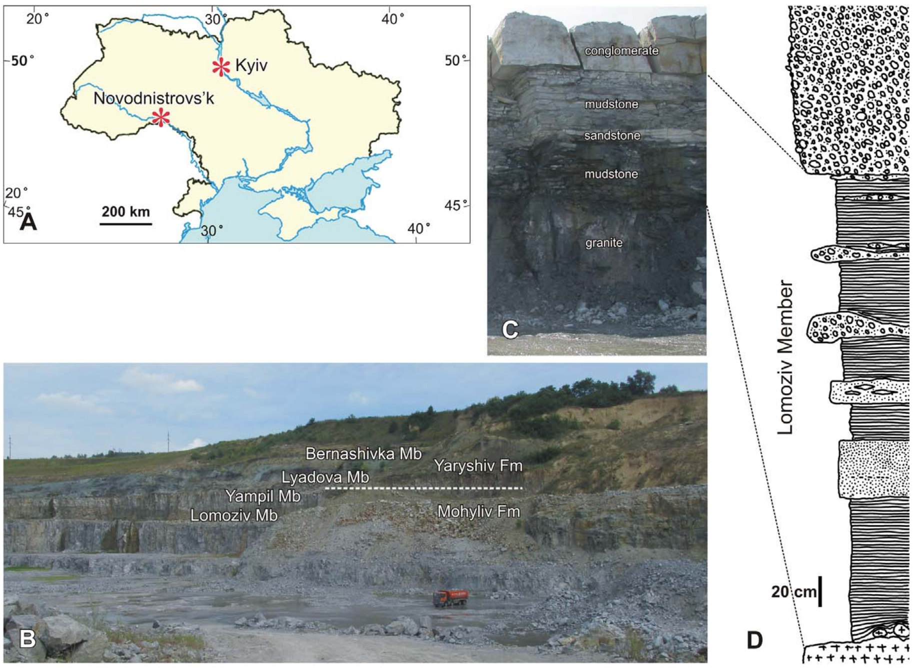

Fig. 1. Late Vendian strata exposed in the Novodnistrovs'k quarry, Podolia, Ukraine (modified after Dzik and Martyshyn (2015)). A. Location of the Novodnistrovs'k electric plant dam on the map of Ukraine. B. General view of the eastern wall of the quarry. C. View of the section exposed in the south-western corner of the quarry. D. Rock column of the fossiliferous lower Lomoziv Member of the Mohyliv Formation.

Yampil Member of the same Formation, consisting mostly thick-bedded sandstone (Fig. 1; Martyshyn, 2012; Dzik and Martyshyn, 2015). The bedding is horizontal and there is no tectonic deformation or metamorphism of the strata.

The fossiliferous thin-bedded mudstone of the Lomoziv Member occurs immediately above, and in continuity with, the basal conglomerate at the weathered granite surface. Conglomerate beds intercalate with the mudstone and cover the fossiliferous unit. No doubt that the environment was shallow marine water (Paliy et al., 1979; Fedonkin and Vickers-Rich, 2007; Tarhan et al., 2015). In this respect the conditions of life of petalonameans in Podolia contrasted with those in Newfoundland, interpreted as relatively deep-water (e.g., Laflamme et al., 2004).

The 'elephant skin' surfaces indicate profuse development of microbial mats in the Lomoziv Member, on which metazoan fossils are frequently encountered, mostly the petalonamean basal discs. The rock between such surfaces is irregularly laminated, as visible in thin sections (Dzik and Martyshyn, 2015, Fig. 2B). To some degree this is an aspect of the rock compaction but many of these laminae seem to have resulted from mineral grains trapping on the microbial slime. In result of compaction of the mudstone, the fossils are usually preserved in a low relief and mostly as replicas of imprints left by collapsed animal bodies on the microbial mat.

The countless fossils covering the sandstone slabs in the upper part of the Yampil Member represent more or less compacted moulds of spherical microbial (cyanobacterial?) colonies classified in *Beltanelliformis* (Leonov, 2007; Ivantsov et al., 2014). Occasionally also metazoan fossils, including petalonamean 'sea pens' holdfasts and fronds, occur among them providing closer approximation to their original three-dimensional geometry.

719 best-preserved specimens of the petalonamean basal discs have been selected, measured and photographed for the purpose of the present study. The illustrated specimens are stored in the Department of General and Historical Geology, Taras Shevchenko National University of Kyiv, Ukraine (abbreviated KSU).

3. Taphonomy

To explain fossilization of soft-bodied organisms one has to assume deposition of their dead bodies in an environment protecting them against decomposition. Either by steady sinking of such bodies in a toxic fluidised sediment blocking access to scavengers (which is unlikely to be the case with the Ediacaran fossil assemblages) or by a catastrophic sudden entombment under a burden of sand. The latter was apparently the case with the Ediacaran organisms at the Mistaken Point in Newfoundland, which were preserved after being smothered by volcanic ash, later covered by microbial mats. This preserves fossils on the upper surface of the beds that represent the seafloor before arrival of the entombing materials ("Conception-style" of Narbonne, 2005). In Australia, the "death mask" of Gehling (1999) preserved specimens at the bases of the entombing siliciclastic event beds, which were later sealed off supposedly by microbial mats or cementation with iron sulphates ("Flinders-style" of Narbonne, 2005; Dzik, 2003). Cementation with pyrite may preserve organic membranes three-dimensionally also within the sandstone bed. Such are preserved the stalks emerging from the basal discs attached to three-dimensionally entrained, current-aligned stalks illustrated by Tarhan et al. (2015, fig. 5B) from Ediacara. Their contours and the centrally located circular structure are preserved on the lower surface of the rock slab in positive relief (as a replica of depression in the microbial mat) but the margin represented by a narrow furrow may continue with the stem, three-dimensionally preserved within the sandstone. According to Tarhan et al. (2010, 2015) this results from a force from the current of suspended sediment drawing the frond and deforming the disc as well as the mat below, to which it was attached. As shown by Grazhdankin (2000) the pattern of deformation shows that the stalk was connected with the disc by randomly distributed fibres within the external wall of the disc but mostly with the central region of its base. In result, its middle was the first to be elevated together with the microbial mat (Grazhdankin, 2000). This is consistent with information offered by the three-dimensionally preserved specimen from the White Sea Ust-Pinega Formation illustrated by Steiner and Reitner (2001, fig. 4). This means that many fossil assemblages of sedentary Ediacaran organisms represent community structures frozen at the moment of a catastrophe. The termination of a community could have been caused by a sudden deposition of the sediment layer too thick to allow subsequent unearthing of the fronds. In such cases the bed above the microbial mat and the infill of imprints of the discs are of the same composition and of equal degree of compaction (Figs. 2D, 4).

Most of the discs from the Lomoziv Member and other localities are