

## The oldest evidence of bioturbation on Earth

Vladimir Rogov, Vasily Marusin, Natalia Bykova, Yuriy Goy, Konstantin Nagovitsin, Boris Kochnev, Galina Karlova, and Dmitry Grazhdankin

Institute of Petroleum Geology and Geophysics, Koptyug Avenue 3, Novosibirsk 630090, Russia

Brasier et al. (2012) raise concerns over our interpretation of the meniscate structure in the late Ediacaran carbonates of the Khatyspyt Formation of Siberia (Rogov et al., 2012). Although serial sectioning or CT scanning would no doubt reveal the three-dimensional morphology of the structure, we believe observations we've made in the field, polished hand specimens, and petrographic thin-sections including the elemental mapping are sufficient to claim that it is the oldest evidence of bioturbation.

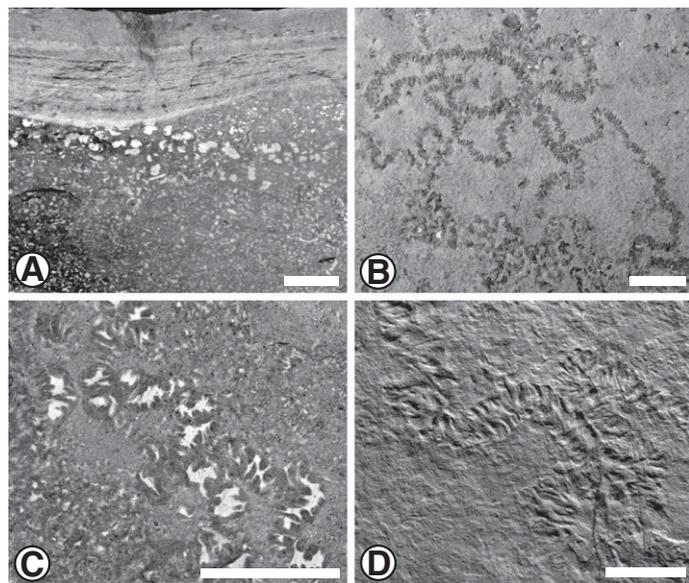
We disagree that the meniscate structures in the Khatyspyt Formation resemble coquina of skeletal fossils. Unlike coquina, the structures are never preserved as a lag deposit nor show any graded bedding. Instead, the structures are prone to erosion, suggesting that they represent trace fossils rather than fragmented parts of body fossils (Fig. 1A). Brasier et al. noted the irregular shape of the menisci and the presence of irregularly distributed bridges between them, and argue that these features are "inconsistent with a meniscate mode of formation"; but this is precisely how backfilled burrows are preserved in flint (Bromley and Ekdale, 1984). An

individual meniscate structure in the Khatyspyt Formation can be long and meandering, but never overlapping itself (Fig. 1B); however, we disagree that the lack of cross-cutting relationship is anomalous. The principle of self-avoidance is a key element in the formation of meandering and spiral trails, strip mining burrow systems, and probing behavior: worms do not waste effort grazing in territory that had already been traversed (Seilacher, 2007). For example, chondritid burrows produce a similarly dense ichnofabric with a distinct phobotactic behavior, where the primary rule is to avoid contact with any other burrow.

Just because the base of the Cambrian is defined as the first appearance of the trace fossil *Treptichnus pedum* in southeastern Newfoundland, doesn't mean that complex trace fossils and even ichnofabric cannot be found in older strata elsewhere in the world (Gehling et al., 2001; Jensen and Runnegar, 2005). As our article went to press, we discovered Khatyspyt-type meniscate structures in the Bronnitsy Member of the Yaryshev Formation (Mogilev-Podolsky Group, Vendian) of Podolia in Ukraine (Figs. 1C and 1D). Volcanic tuff in the underlying Bernashevka Member of the Yaryshev Formation has a U–Pb zircon age of 553 Ma (obtained by S.A. Bowring, Massachusetts Institute of Technology, in 2004), which could be coeval with tholeiitic basalts (Rb–Sr isochron date of  $552 \pm 53$  Ma) and volcanic tuff (U–Pb zircon date of  $551 \pm 4$  Ma) of the Volyn–Brest Igneous Province (Compston et al., 1995; Nosova et al., 2008). Similar to the Khatyspyt Formation, the meniscate structures in Podolia are confined to low-energy shoreface sediments and preserved in tuffaceous argillite by early diagenetic silicification. Even if the meniscate structures in Siberia and Ukraine are to be regarded as earliest Cambrian, they still remain the oldest record of bioturbation on Earth.

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**Figure 1. Taphonomy of the meniscate structure. A, B: Vertical cross section of a sedimentary layer with the meniscate structure cut by an erosional scour (A), and bedding surface with a long and meandering structure (B), Khatyspyt Formation, arctic Siberia. C, D: Meniscate structure in cross section (C) and on a bedding surface (D), Yaryshev Formation, Ukraine. Scale bar: 10 mm.**