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GEOLOGY

Trace Fossils and the Upper Vendian Boundary in the Southeastern White Sea Region

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Among numerous localities of Late Proterozoic (Vendian) fossilized soft-bodied organisms, the southeastern White Sea region is the most informative one owing primarily to high taxonomic diversity of the biota and perfect preservation of its remains. The absence of paleontologically characterized Vendian–Cambrian boundary sections, a drawback of this region, hampers the correlation and restricts possibilities of paleontological studies. Based on lithological correlation between sections of the southeastern White Sea region and northwestern East European Platform, the existence of Cambrian sediments in the northeastern White Sea region was repeatedly suggested in the 1950s and 1960s [1–4]. However, this assumption could not be confirmed because of the poor geological knowledge of sediments attributed now to the Padun Formation that crowns the Valdai Group section in the southeastern White Sea region. Recently, we were able to solve this problem. In the Padun Formation, we detected trace fossils *Diplocraterion*, which indicate the Cambrian age of host sediments and allowed us to carry out a more reliable correlation of Vendian reference sections of the White Sea region with coeval sequences not only in the neighboring regions, but also beyond the East European Platform.

In 2004, we studied small isolated outcrops of red-brown and light gray fine-grained quartz sandstones partly bleached by surface weathering in the Bol'shaya Yura River, a right tributary of the Severnaya Dvina River (Fig. 1). The sections include numerous sandstone layers with thin horizontal lamination (Fig. 2) that form lenticular interbeds from 4–8 cm to 0.5 m thick. The thin lamination pattern is provided by alternation of millimeter-scale sandstone laminae that differ in grain-size and the shape of detrital material. Some interbeds are characterized by convolute lamination, probably related to water-saturation and deformation of finely laminated sediments. The sections enclose abun-

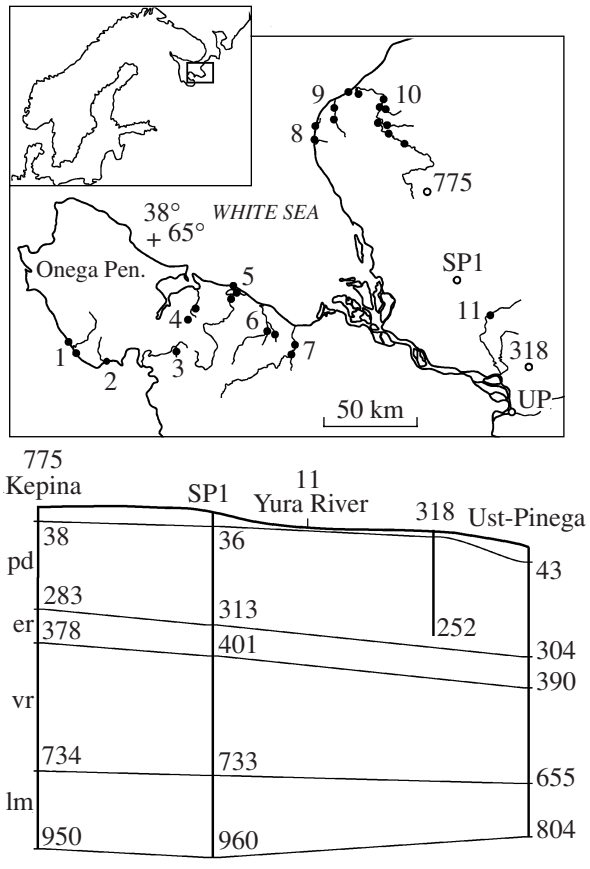

Fig. 1. (a) Location of examined sections of the Valdai Group in the southeastern White Sea region. (1) Lamtsa River; (2) Purnema River; (3) Agma River; (4) Kinzhuga River; (5) Suzma River; (6) Verkhovka River; (7) Solza River; (8) Winter Mountains; (9) Torozhma River; (10) Zolotitsa River; (11) Bol'shaya Yura River. (UP) Borehole Ust-Pinega; (b) geological section across examined outcrops along the Bol'shaya Yura River and Borehole 318. Formations: (lm) Lamtsa, (vr) Verkhovka, (er) Erga, (pd) Padun.

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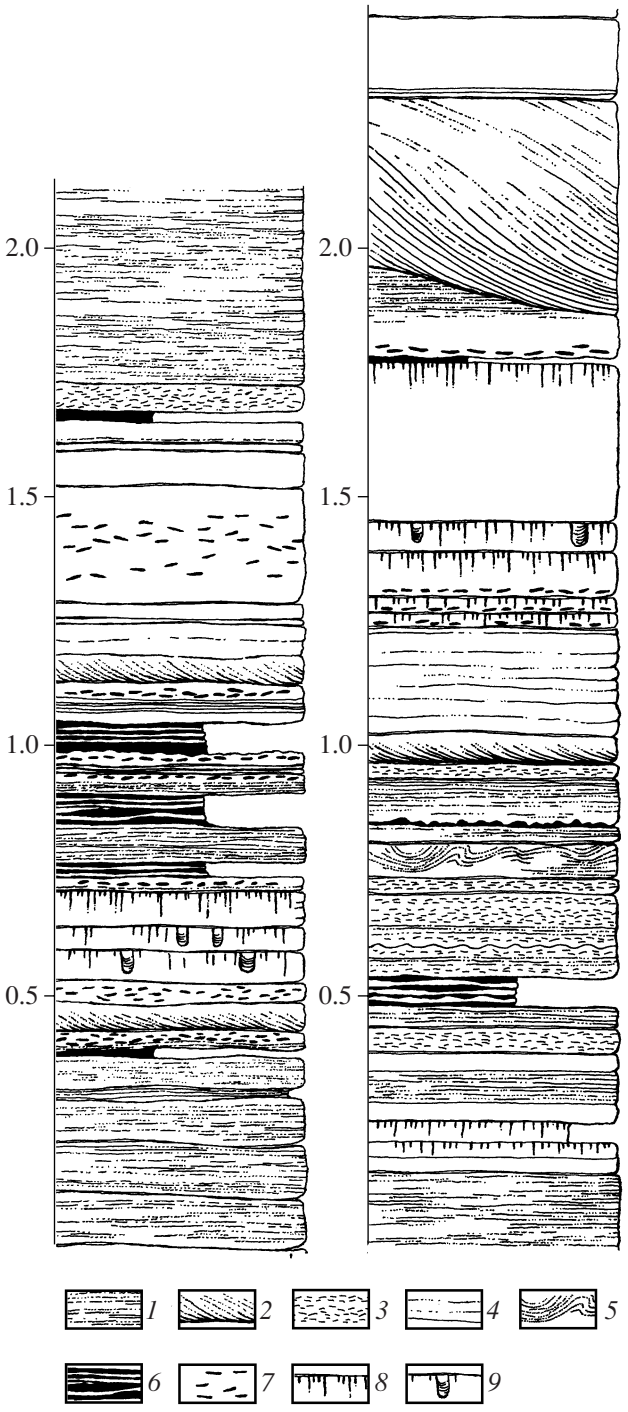

Fig. 2. Sections of the Padun Formation exposed along the Bol'shaya Yura River. (*1*) Fine even bedding; (*2*) cross-bedding; (*3*) flaser bedding; (*4*) coarse even bedding; (*5*) convolute bedding; (*6*) alternating siltstones and clays; (*7*) clayey pebbles; (*8*) *Scolithos*; (*9*) *Diplocraterion*.

dant sandstones with coarse cross-bedding. The sandstones form a thick (up to 0.4 m) series incised into underlying sediments and traceable through all the sections (Fig. 2). Some sections are characterized by unidirectional multistage cross bedding. Less common are sandstones with flaser lamination, which constitute interbeds 3–7 cm thick and often show ripple marks at the top (Fig. 2).

Of particular interest are sandstones with coarse horizontal bedding that constitute relatively thick (up to 0.9 m) members (Fig. 2). The thickness of separate beds ranges from 1 to 30 cm averaging usually 3–9 cm. The basal parts of these interbeds contain accumulations of flat clayey pebbles (Fig. 2). Their upper parts enclose abundant trace fossils: dominant simple vertical burrows *Scolithos* up to 1 cm in diameter; U-shaped vertical burrows *Diplocraterion* with abundant spreites (Fig. 3a) occurring at some levels. Some burrows penetrate the entire depth of interlayers. In the case of thin interlayers, the burrows crosscut the coarse horizontal lamination of host sediments. Sometimes, the density of burrows is so high that the rock resembles a sandy matrix of the complex maze in chocolate-red siltstones (Fig. 3b). Bedding surfaces often demonstrate horizontal unbranched burrows.

These sediments accumulated in the extended flat deltaic plain flooded by a shallow sea, which took river runoff from numerous channels. The flow branched off due to the formation of underwater channel bars, which expanded subsequently into sandy shoals. Sandstones with the multistage cross-bedding represent channel sediments, while sandstones with coarse cross-bedding characterize transverse channel bars. Thin-bedded sandstones can be interpreted as sediments of the peak runoff, and their coarse-bedded varieties with trace fossils can be understood as sediments of sandy shoals. The sandstones with flaser bedding characterize the most likely sediments of tidal shoals.

The stratigraphic position of the examined sections is reliably established owing to regional studies carried out by geologists from the ALROSA-Pomor'e enterprise in the Yura–Dvina area. The geological survey (scale 1 : 200 000) and data on eight additional relatively deep (up to 250 m) mapping boreholes drilled along the near-meridional approximately 30-km-long profile demonstrate that the Bol'shaya Yura valley is composed of the Padun Formation, which was recognized in 1986 in the Valdai Group without indicating the stratotype [5]. A layer-by-layer lithological description of the formation is absent. According to published data, the Padun Formation lacks paleontological remains. However, it is traditionally correlated with the Upper Vendian Kotlin Horizon [6]. The sections of new boreholes and outcrops along the Bol'shaya Yura River shed light on the structure and age of rocks of the Padun Formation in the southeastern White Sea region.

Borehole 318 recovered the most complete section (235 m) of the Padun Formation (Fig. 1). The section can be divided into three beds. The oldest bed is 61 m thick (Fig. 4, Bed 1, interval 191–252 m). It is com-

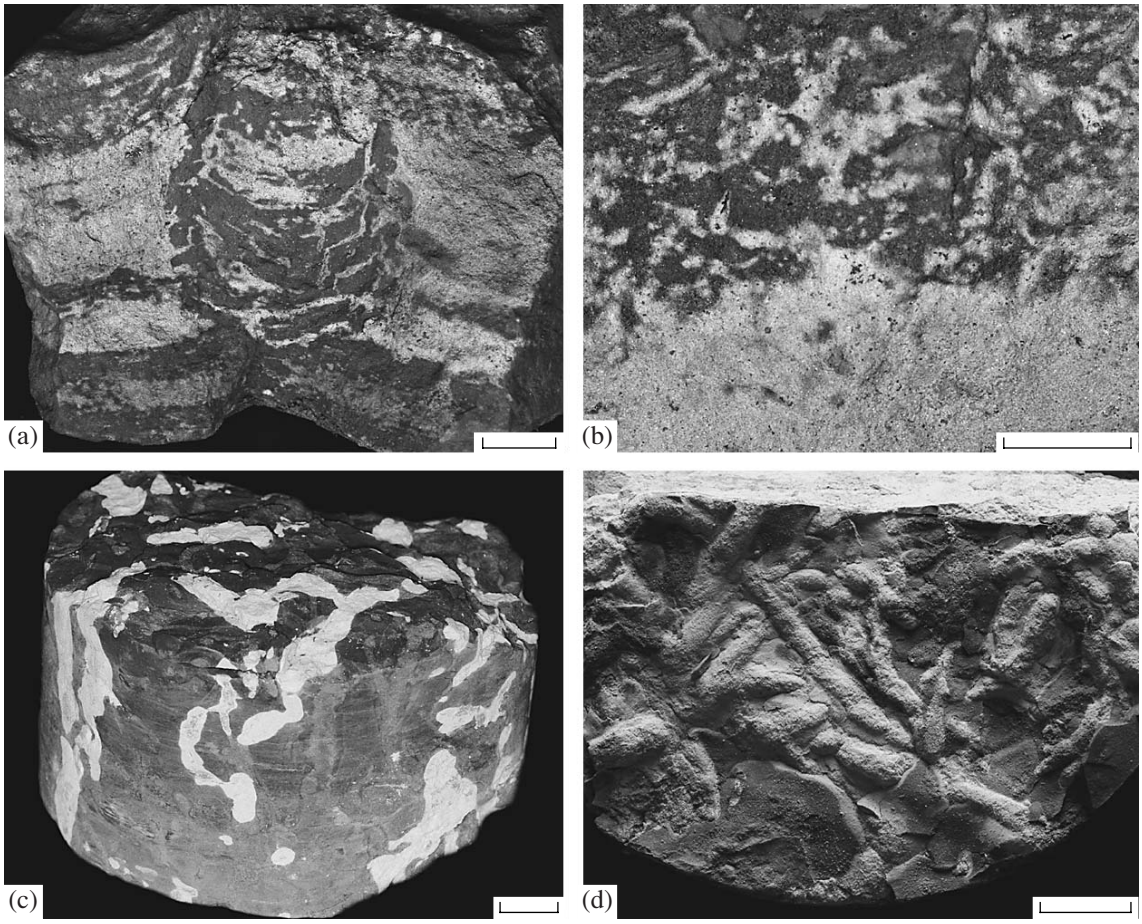

Fig. 3. Trace fossils in sediments of the Padun Formation: (a) *Diplocraterion* (Bol'shaya Yura River), (b) bioturbated sediment (Bol'shaya Yura River), (c) bioturbated sediment (Borehole 318), (d) horizontal unbranched burrows (Borehole 318). Collection is stored at the Paleontological Institute of the RAS (Moscow). Bar length 10 mm.

posed of violet-chocolate and cherry red, locally gray-brown fine-grained frequently friable sandstones. They contain brick-red and purple-red siltstone members (0.2–0.5 m) with light green spots and typical fine horizontal bedding. Such features are typical of the Zolotitsa Beds of the Padun Formation exposed in the Myandovo Ravine along the Zolotitsa River. These sandstones lack fossils.

They are overlain by a peculiar laterally sustained sequence (84.5–98.0 m) largely composed of finely alternating sandstones, siltstones, and clays (Fig. 4, beds 2–6, interval 191–100 m). This sequence with a less expressed red color encloses abundant brown and brownish gray sandstone and clay interbeds. The sandstones are characterized by alternation of flaser, knotty, and coarse horizontal bedding and accumulations of flat clayey pebbles. They are also marked by wide development of microbial structures that reflect processes of sediment biostabilization (chagrin structure), decomposition, and destruction of the microbial substrate (microfissures) (Fig. 4). The upper part of the interval encloses abundant trace fossils *Scolithos, Diplocraterion*, and horizontal unbranched burrows (Fig. 3d). Some beds are intensely bioturbated (Fig. 3c).

The section is crowned by a sequence of alternating fine-grained sandstones and siltstones. Borehole 318 penetrated this sequence in the interval of 100–17 m (Fig. 4). Precisely this sequence is probably exposed in outcrops along the Bol'shaya Yura River (Fig. 1). The lower part of the section (Fig. 4, beds 7–9) is dominated by vinous red or less common grayish brown and brown-gray sandstones with cross, flaser, fine horizontal, and convolute bedding. The upper part of the sequence (Bed 10) is composed of rhythmically alternating sandstone (1.0–1.5 to 4 m) and siltstone (0.5–1.5 m) members. The sandstones and siltstones are largely characterized by a red-brown and vinous red (less commonly, violet-chocolate) color and thin horizontal bedding. Beds 7–10 in neighboring boreholes differ in thickness and persistence, suggesting their facies variability. In addition, Borehole 314 drilled in the Bol'shaya Yura River valley penetrated a thick bed

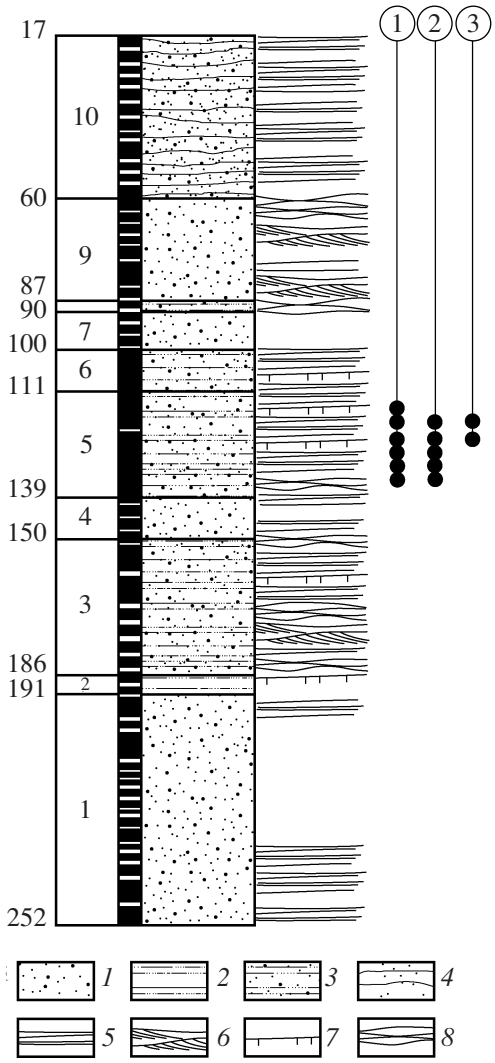

Fig. 4. Section of the Padun Formation recovered by Borehole 318 (ALROSA-Pomor'e). Stratigraphic ranges of trace fossils: (1) *Diplocraterion*, (2) *Scolithos*, (3) horizontal unbranched burrows. (*1*) Sandstones; (*2*) alternating siltstones and mudstones; (*3*) alternating sandstones, siltstones, and mudstones; (*4*) alternating sandstones and siltstones; (*5*) fine regular bedding; (*6*) cross-bedding; (*7*) microfissures; (*8*) flaser bedding.

of intensely bioturbated red-brown and chocolate-brown siltstones at 103–81 m.

Taking into consideration the obtained data, the vertical distribution of trace fossils through sections of the Valdai Group in the southeastern White Sea region demonstrates the gradual increase in their diversity, size, and complicated behavior of burrowing organisms. For example, the Lamtsa Formation encloses the first horizontal trace fossils with levees (*Archaeonassa*). The lower part of the Verkhovka Formation hosts the first curved trace fossils with backfill structure (*Nenoxites*), while its upper part contains small burrows (*Bergaueria*), meandering traces (*Gordia*), and fan-shaped scratches on the microbial substrate (*Radulichnus*). The lower part of the Erga Formation contains abundant large *Berguaeria* and subordinate *Scolithos, Astropolichinus*, and *Psammichnites*. The middle part of the Padun Formation is characterized by the abundance of trace fossils, increase in the diameter of burrows, intense bioturbation of some interbeds, and traces of *Diplocaterion.* The taxonomic composition and stratigraphic distribution of trace fossils indicate that the Valdai Group in the White Sea region includes the Vendian–Cambrian boundary strata.

According to available data, the first *Diplocaterion* ichnofossils appear in the Lower Cambrian. They are reported from Lower Cambrian sections of Australia, Spain, Canada, Sweden, and Norway [7]. On the southern slope of the Baltic Shield, such fossils were found in rocks of the Siverskaya Formation (Baltic Group, Lontova Horizon) and Tiskre Formation (Liivi Group, Lükati Horizon) of the Lower Cambrian [8–10]. *Diplocaterion* is also widespread in coeval sequences of the Zawiszyn and Kaplonosy formations in Poland [11]. Thus, we can suppose that the Padun Formation in the southeastern White Sea region is also an Early Cambrian unit.

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REFERENCES

1. A. I. Zoricheva, Materialy VSEGEI. Nov Ser., Issue 14, 153 (1956).
2. A. I. Zoricheva, in *Geology of the USSR* (Gosgeoltekhizdat, Moscow, 1963), Vol. 2, Part 1, pp. 79–99 [in Russian].
3. N. S. Igolkina, Materials VSEGEI. Nov. Ser., Issue 14, 169 (1956).
4. A. I. Krivtsov, Izv. AN SSSR. Ser. Geol., No. 4, 63 (1958).
5. *The Upper Cambrian of the European Northern USSR*, Ed. by V.A. Dedeev and B.M. Keller (Syktyvkar, 1986) [in Russian].

6. A. F. Stankovskii, E. M. Verichev, and I. P. Dobeiko, in *The Vendian System* (Nauka, Moscow, 1985), Vol. 2, pp. 67–76 [in Russian].
7. T. P. Crimes, I. Legg, A. Marcos, and M. Arboleya, Geol. J. Spec. Issue, No. 9, 91 (1977).
8. K. Mens and E. Pirrus, *Cambrian Stratotype Sections of Estonia* (Valgus, Tallinn, 1977) [in Russian].
9. V. I. Palii, E. Posti, and M. A. Fedonkin, in *Paleontology of Upper Precambrian and Cambrian Sediments in the East European Platform* (Nauka, Moscow, 1979), pp. 49–82 [in Russian].
10. K. Mens, Ya. Bergstrem, and K. Lendzen, *The Cambrian of the East European Platform* (Valgus, Tallinn, 1987) [in Russian].
11. J. Paczensa, Bull. Inst. Geol. **355**, 31 (1986).