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Mesoproterozoic Lakhanda Lagerstätte, Siberia: Paleoecology and taphonomy of the microbiota

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ABSTRACT

The preservation of the organic-walled microbiota of the Lakhanda Lagerstätte in the Kumakha mudstone succession of the late Mesoproterozoic Lakhanda Group (Uchur-Maya region, southeast Siberia) is a result of unusually favorable paleoecologic, taphonomic, and diagenetic conditions. Well known for its marked taxonomic diversity and exquisite preservation, the biota inhabited a warm, shallow, epicontinental basin rich in nutrients into which were dispersed clay minerals, from weathering of continental crust, and minor amounts of volcanic detritus. The fossils were preserved by compression in fine-grained smectite–illite–kaolinite mudstones deposited in a sulfur-deficient disoxic and anoxic environment. Subsequently, the long-term (~1 Ga) tectonic stability of the southeast margin of the Siberian platform has provided an exceptional environment for the preservation of the microfossil assemblage without significant diagenetic alteration. Conclusions drawn here from studies of the paleoecology, taphonomy, and diagenesis of the Lakhanda Lagerstätte may provide a globally useful model in the search for additional evidence of the Precambrian rise to dominance of eukaryotes in the Earth's biosphere.

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1. Introduction

Numerous Precambrian Lagerstätten, deposits that stand out because of the exceptionally well-preserved and highly diverse microfossil assemblages they contain, are now known (Schopf, 1968, 1992; Butterfield, 1990, 1995, 2003; Butterfield and Chandler, 1992; Butterfield et al., 2007; Xiao and Knoll, 1999; Javaux et al., 2004; Yin et al., 2005). One such example is the late Mesoproterozoic Lakhanda microbiota of the Uchur-Mayai region of southeast Siberia (Timofeev et al., 1976; German, 1979, 1990; Veis, 1988; Schopf, 1992; Woods et al., 1998; Hermann and Podkovyrov, 2002, 2006, 2007), the focus of this paper (see also the immediately following article in this special issue of *Precambrian Research* by German and Podkovyrov). Each such exceptionally preserved fossil assemblage requires more or less unusual pre- and post-depositional circumstances for fossilization (Allison, 1988; Butterfield, 1995, 2003), although there broad agreement that the taxonomic diversity of such microbiotas increases from coastal–marine and lagoonal settings to open-sea environments (Knoll, 1992; Petrov and Veis, 1995; Veis et al., 1998; Sergeev et al., 2007). The study of the Lakhanda-type fossil biota and its preservational environment presented here is based on a bed-by-bed description of the shallow-shelf Kumakha Subformation succession in the Itirinda type section (Maya River, Fig. 1) of the Lakhanda sediments. In order to constrain the marine redox and burial conditions of these units, redox-sensitive elements were measured both in microfossil-rich and -barren mudstones. The main objectives of this study are to investigate the relationships between the biotic population and the water redox conditions in its depositional environment, and the taphonomic and diagenetic effects that resulted in the exceptional fidelity of preservation of the Lakhanda microorganisms.

2. Geological setting and description of the microfossiliferous Itirynda section

The Lakhanda Group, of latest Mesoproterozoic age (1025–1010 Ma; Semikhatov et al., 2000), outcrops in the central part of the Maya depression (Fig. 1) where it is divided into two formations: the lower Neruen Formation and the upper Ignikan Formation (Nuznov, 1967; Semikhatov and Serebryakov, 1983). The Neruen succession is composed of multicolored silty–clayey sediments (the Kumakha and Nelkan Subformations) interbedded with stromatolitic and clastic limestones and dolomites (the Milkon Subformation), that were deposited in epicratonic shallow marine and upper-shelf environments (Kornev et al., 1980; Sklyarov, 1981; Cullers and Podkovyrov, 2000). Well-preserved fossils occur throughout much of the Maya sequence, but the

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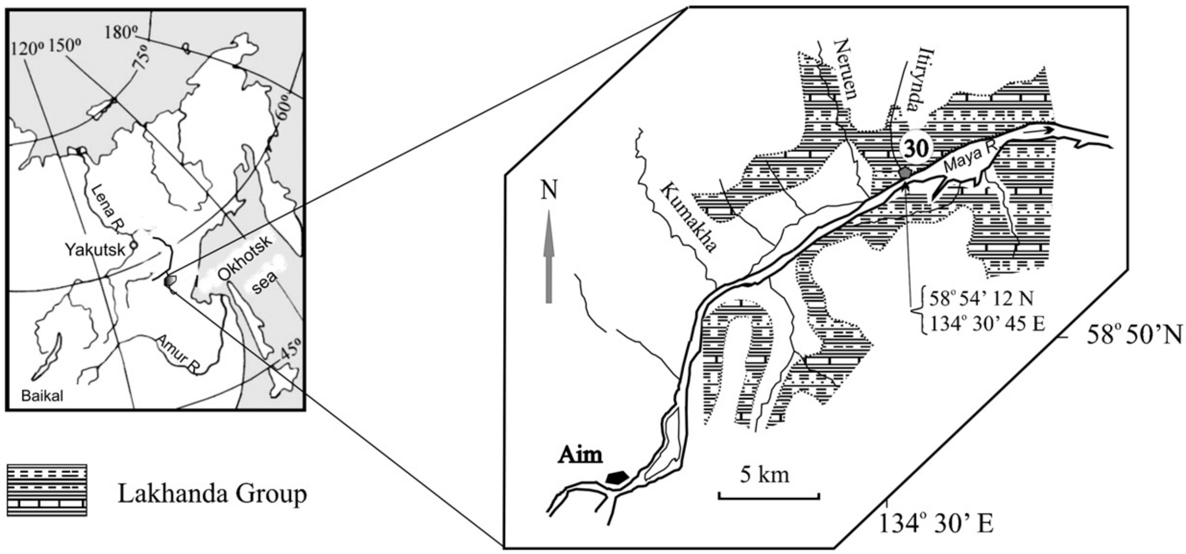

Fig. 1. Schematic geological map of the Lakhanda Group in the middle Maya River showing the location of the Itirynda section (outcrop. No 30, T.N. German, 1974).

most prominent fossil-bearing localities occur in the Kumakha Subformation (Timofeev et al., 1976; German and Timofeev, 1985; German, 1990).

The Lakhanda biota was first discovered, near the town of Itirynda on the left bank of the Maya River (Fig. 1), by B.V. Timofeev and T.N. German (Timofeev et al., 1976; German, 1979, 1990). Here, the basal part of upper Kumakha succession (up to 23 m-thick) includes gray, black, bluish-gray mudstones, containing siderite lenses and concretions, and rare siltstones and Fe-dolomite layers (Fig. 2, beds 1–4). Strata of the succession consist of thin-bedded mudstone and interbedded clayey siltstone/mudstone that exhibit fine graded-bedding, defined by brown organic films, that have sharp lower boundaries, sometimes comprised of exceedingly thin layers. Thin, horizontal, wavy- and cross-lamination are common, ranging from 5 to 40 mm in thickness. Brown-gray and gray mudstones predominate in beds 1 and 4 of the succession (Fig. 2, sample 77-2) where they occur together with bluish-gray mudstones and dark-brown siderite concretions that are partly replaced by hematite. Such strata are devoid of microfossils. Beds 2 and 3 of the Kumakha succession (Fig. 2) are composed mainly of dark gray (Fig. 2, samples 7-74, 8-74 and 77-3) and black mudstones. Numerous microfossils occur in these strata, typically of limited taxonomic variety (German, pers. comm.).

The upper part of the Kumakha succession (Fig. 2, beds 5–11) is composed of multicolored mudstones having non-uniformly distributed layers and concretions of brown hematitized siderite and rare dolomite. Studies of petrographic thin sections show that the mudstones are finely laminated (1–3 mm), having thin, horizontal, wavy- and cross-lamination made evident by organic films and, occasionally, by the occurrence of large microfossils (300–1000 μm in diameter). Within these beds occur dark gray (Fig. 2, samples 13-74, 22-74, 27-74 and 17-76), grayish- and bluish-black (samples 4-76, 18-76, 77-6, and 77-10), green-gray (sample 10-76) and red-brown horizons (samples 77-7and 77-8). The color of these horizons is defined party by their iron content and the degree of its oxidation – at low contents of total Fe (<2–2.5%, $Fe_2O_3/FeO = 2.5–5.9$; Table 1, Fig. 2, samples 77-3, 77-6, 77-10 and 77-12) the mudstones are dark gray to black, depending on the amount of carbonaceous matter they contain. In contrast, mudstones having high iron content (>7–23%; Table 1) are a red-brown to dark-brown due to high degree of iron oxidation (Table 1, Fig. 2, samples 77-7, 77-8). The most rich and taxonomically diverse microfossil assemblage of the upper Kumakha succession (Timofeev et al., 1976; Timofeev and German, 1979) is preserved in the dark gray (Fig. 2, sample 17-76) and bluish-black parts of bed 10 (Fig. 2, sample 22-74) and in black mudstones of beds 10 (Fig. 2, sample 18-76) and 5 (Fig. 2, sample 4-76).

The particularly fossiliferous upper part of the Kumakha Subformation was deposited in a transgressive marine environment (Semikhatov and Serebryakov, 1983; Veis et al., 1998), most likely a tidal flat to littoral near-shore setting that is consistent with the enrichment in these mudstones of heavy minerals, especially zircon and rutile (Cullers and Podkovyrov, 2000; Podkovyrov et al., 2002). Microfossils are essentially unknown from the reddish-brown mudstones of the sequence, so the organic remains in this Lagerstätte are not uniformly distributed. Indeed, most of the fossils, including those of relatively large size, are preserved in organic films at laminar interfaces or in unlaminated mudstones, but an appreciable part of the smaller (5–20 μm) microfossils of the assemblage occur in interstices between grains of the mudstone matrix.

3. Mineralogy of the samples studied

The samples studied were washed thoroughly in distilled water to remove surface contamination. Of each selected sample, half was used for the preparation of standard petrographic thin sections or of polished sections for microprobe analysis, and the other half, for chemical analysis (Cullers and Podkovyrov, 2000).

The chemical composition of the Lakhanda rocks was analyzed by X-ray fluorescence spectroscopy (Allrussian Geological Institute (VSEGEI), St. Petersburg). Concentrations of rare earth and trace elements (Sr, B, Ga, Ba, Zr, V, Co, Ni, Th, Hf, Cr, Mo, Re) were determined using the ICP-MS (inductively coupled plasma mass spectrometry) method at the Institute of Geology and Geochemistry Uralian branch of the Russian Academy of Sciences (Element-2, Ekaterinburg) and USGS standards that yield an uncertainty of 5–10%. The mudstone samples were examined with scanning (SEM), transmission (TEM), analytical (AEM) electron microscopy and X-ray diffraction by M.D. Tolkachev and T.L.Turchenko at the Institute of Precambrian Geology and Geochronology of the Russian Academy of Sciences in St. Petersburg.

TEM analysis revealed that fossil-bearing kaolinite- and smectite-rich Kumakha shallow-buried mudstones without identifiable fabric (isotropic microstructure) are dominated by high angle

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