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GEOCHEMISTRY

In Search for Fingerprints of an Extraterrestrial Event: Trace Element Characteristics of Sediments from the Lake Medvedevskoye (Karelian Isthmus, Russia)[1]

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Abstract—Concentration and distribution of trace elements across the sequence of the Late Pleistocene sediments from the lake Medvedevskoye suggest the addition of materials other than those from a common source for the lake sediments of the region. The sediments of the lake Medvedevskoye carry some geochemical fingerprints which could be related the ET event that occurred at ca. 12.9 ka. Because such fingerprints are extremely subtle, the NW Russia can be considered to be the most remote eastern region of the extent of the Late Pleistocene airborne ET material. The sediments of the lake Medvedevskoye can also contain volcanic material from the eruption of the Laacher See (Germany) volcano and probably from other Late Pleistocene volcanoes of Western Europe and/or Iceland.

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The Late Pleistocene climate oscillation known as Younger Dryas (YD) cooling event is connected predominantly to a sharp decrease of thermohaline circulation in the Atlantic Ocean affecting the salinity in the areas where north Atlantic deep water is formed [1–3]. Recently, a hypothesis was proposed relating the YD cooling to an extraterrestrial (ET) bolide impact [4]. This hypothesis suggested that just before the onset of the YD cooling, 12.9 ka, a large bolide (up to 4 km in the diameter) exploded over the North American Laurentide Ice Sheet, The consequences of such a catastrophic event (so-called "meteorite impact winter") might have led to an abrupt climate change. This suggestion resulted in a widespread discussion, which has yet to result in a decisive conclusion. Detailed descriptions of arguments for and against the impact hypothesis are given in [5].

If the impact occurred over North America, transportation of the impact-related microparticles eastward by the dominating move of the air masses from west to east could have delivered such particles as far to the east as Western and East Europe [6], Some studies showed that the material that could be related to meteorite impact is present in the Late Pleistocene sediments of Western Europe [5]. Subaquatic sediments deposited in small basins may capture and preserve airborne particles. Authors proposed to apply modern geochemical analytical methods (inductively coupled plasma-mass spectrometry; ICP-MS) in order to check the presence of geochemical anomalies (in particular, ET-related) in Late Glacial lake sediments of East Europe.

Many lakes of NW Russia are known to exist as long as from 14–15 ka [3], i.e., continuing sedimentations started there before time of the suggested meteorite impact. Therefore, geochemical fingerprints of such an event could be preserved in such lake sediments. In a search for fingerprints of the ET impact, we chose to study Late Pleistocene sediments of the Lake Medvedevskoye (60°14′ N, 29°54′ E, 102.2 m a.s.l.) of the Karelian Isthmus of NW Russia (Fig. 1).

Because of its elevation and small watershed, this small shallow lake (0.44 km^2 surface, 0.55 km width, 1.18 km length, ~4 m the maximum depth), first of all, was never flooded by water of bigger water bodies after deglaciation of the Karelian Isthmus, and, second, is

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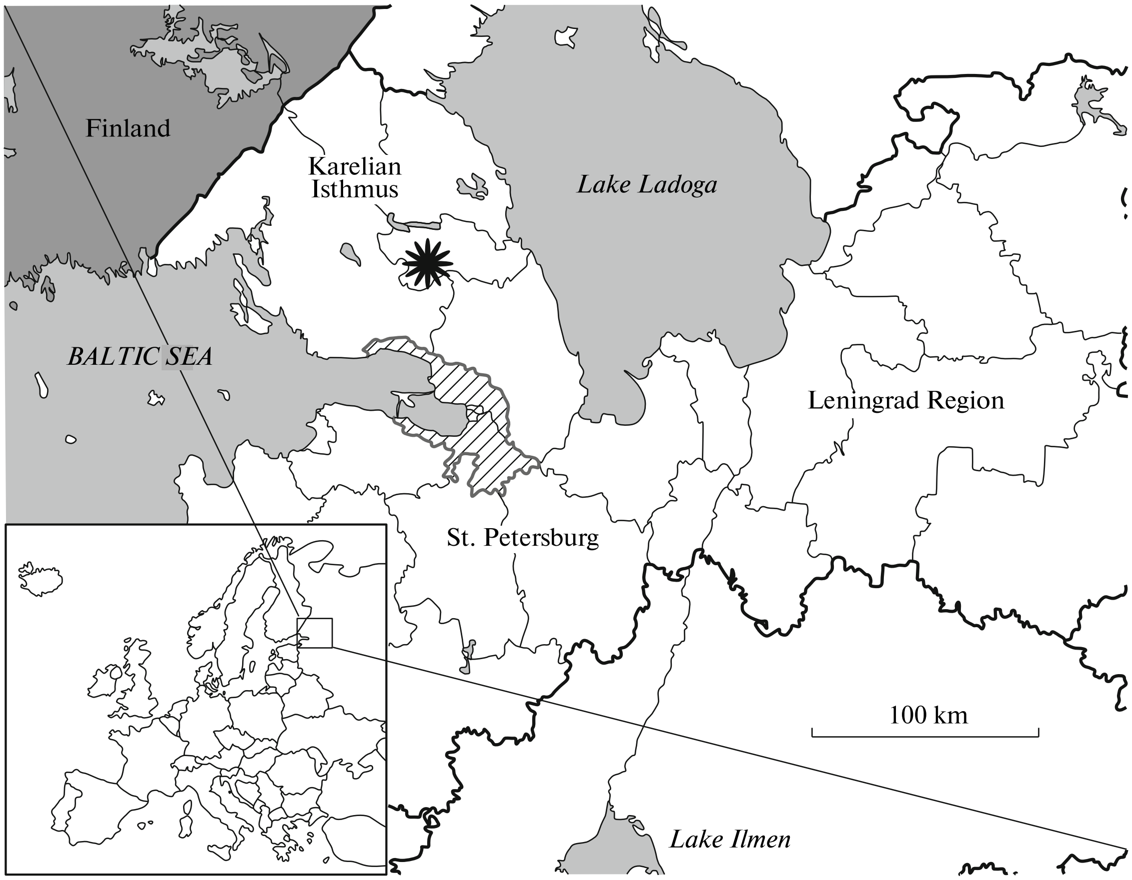

Fig. 1. A map showing the location of the lake Medvedevskoye (black asterisk) in Karelian Isthmus.

characterized by continuous sedimentation with dominating of allochthonous and eolian components in the sediments. As a result, a sequence of sediments of a maximum observed thickness of 3.5 m was formed. Such a sequence is represented by Late Glacial grey sand and clay, and by Holocene dark-brown organogenic silt (table). Earlier study of the sequence identified the presence of a thin layer of Vedde volcanic ash dated as 12 ka here [7, 8].

A sedimentary column from the lake Medvedevskoe located on the central plateau of the Karelian Isthmus was collected from ice in April 2011 for geochemical studies. We conducted correlation of the sedimentary column from the deepest part of the lake Medvedevskoye using well studied and dated sedimentary core from the peripheral part of the lake [3, 7]. The correlation was conducted with the use of three main stratigraphic markers (Fig. 2): lower boundary of the

A lithostratigraphic scheme of sediments from the lake Medvedevskoye (central and peripheral parts)

Centre	Periphery	Description
Depth from water surface (m)		
2.60–5.01	2.5–3.725	Dark-brown detritic organic gyttja, with a thin moss layer (at 3.71–3.69 m for a peripheral part, and at 5.0–5.01 m for the central part). The lower boundary is sharp, well distinguished by the color change
5.01–5.08	3.725–3.795	Greenish-brown clay gyttja with algae fragments
5.08–5.13	3.795–3.85	Light-brown aleuritic gyttja
5.13–5.53	3.85–3.91	Greenish-brown clay. The lower contact is sharp
5.53–5.90	3.91–4.52	Grayish-brown clayey silt with thin black layers of hydrotroilite (in the upper part)
5.90–6.15	4.52–4.695	Gray aleurite, sandy aleurite with micro-inclusions of organic particles
Deeper than 6.15	4.695–4.86	Gray aleurite sand with layers of coarse-grained sand

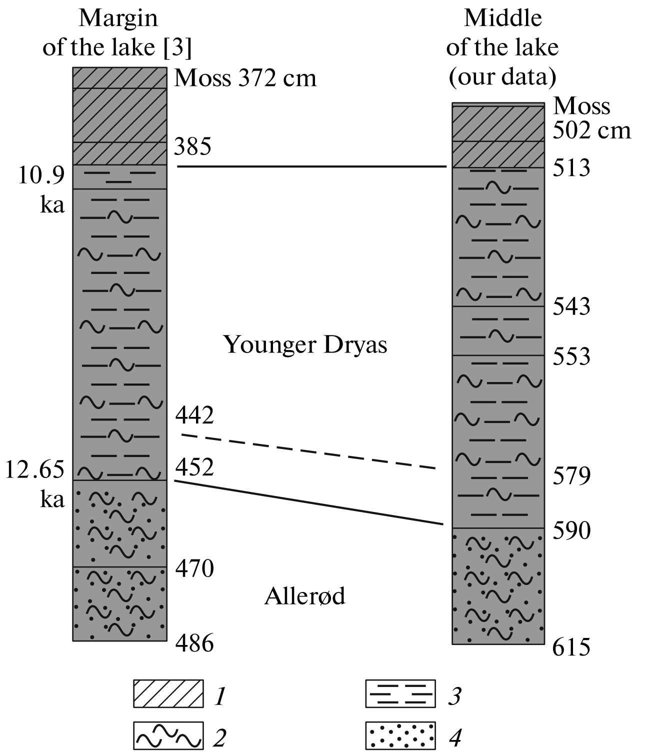

Fig. 2. Stratigraphic correlation of sedimentaiy sequences from the lake Medvedevskoye: (a) a sedimentary core recovered from the peripheral part of the lake [3]; (b) a sedimentary core recovered from the central part of the lake (present work). *1*—Sapropel; *2*—silt; *3*—clay ; *4*—sabd.

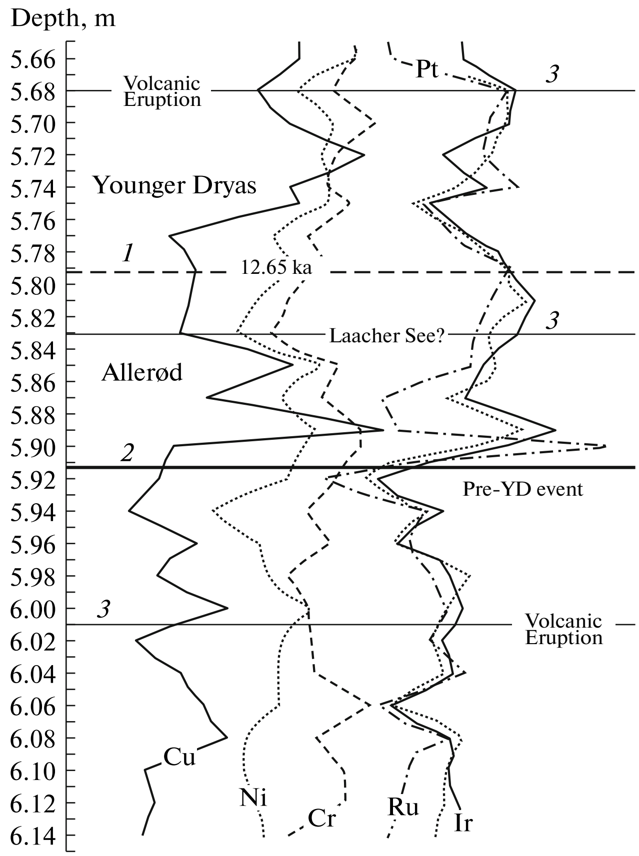

Fig. 3. Schematic distribution of selected "meteoritic" trace elements across the studied part of the sedimentary sequence of the lake Medvedevskoye: (*1*) the Allerød–Younger Dryas boundary [3]; (*2*) a sedimentary horizon corresponding to the suggested ET event occurred ca. around 12.9 ka; (*3*) horizons corresponding to the eruption of the Laacher See volcano (around 12.9 ka but shortly after the ET event) and two other suggested Late Pleistocene volcanic eruptions. The picture does not show an absolute concentration of the trace elements.

development of moss (372 and 502 cm; 10.25 ka; not in the studied part of the sequence), upper boundary of the development of clay (385 and 513 cm; 10.9 ka), and the upper boundary of the development of laminated silty sand (452 and 590 cm). A transition between the Allerød and the Younger Dryas biozones (a border between palinozones ME1 and ME2; 12.65 ka [3]) is located at the depth of 442 cm for the core from a peripheral part of the lake, and can be traced to the depth of about 580 cm for the core from the deepest part of the lake.

A sedimentation rate of ~0.3 mm per year for a studied period of time could be estimated [3]. We studied a core of lake sediments recovered from the depth interval 615 to 565 cm. This part of the core covers the age of 12.9 ka (Fig. 2), or the time of the suggested ET event [4]. Twenty eight samples were selected to be studied by the ICP-MS analyses. Details of the applied analytical technique are given in [9].

Total measured amounts of trace elements in the lake Medvedevskoye sediments are about 4,500 ppm that is comparable with those concentrations in the average continental crust (ACC) [10]. Such geochemical features as elevated relative to the ACC concentrations of Th–U, and lowered concentrations of Ta–Nb, Ti and Co-Ni are displayed by all studied samples, and could be due to the compositional features of the source for sedimentary material (metamorphic rocks of the Baltic Shield). Elevated concentrations of Pd observed for all studied samples can be due to the high mobility and redistribution of this element (an element from the platinum group elements or PGE) in aquatic environment [11]. Elevated concentrations of W in samples 3MD-7, 11, and 18 (horizons of 6.03–6.01 m, 5.95–5.93 m, and 5.67–5.65 m, respectively) are most likely also due to the high mobility and redistribution of these elements in aquatic environment. Because the lake Medvedevskoye belongs with a geochemical province with high concentrations of Fe and Mn [3], enrichment of some sediment horizons with W is not unexpected.

The studied sediments of the lake Medvedevskoye generally display pretty high concentrations and very

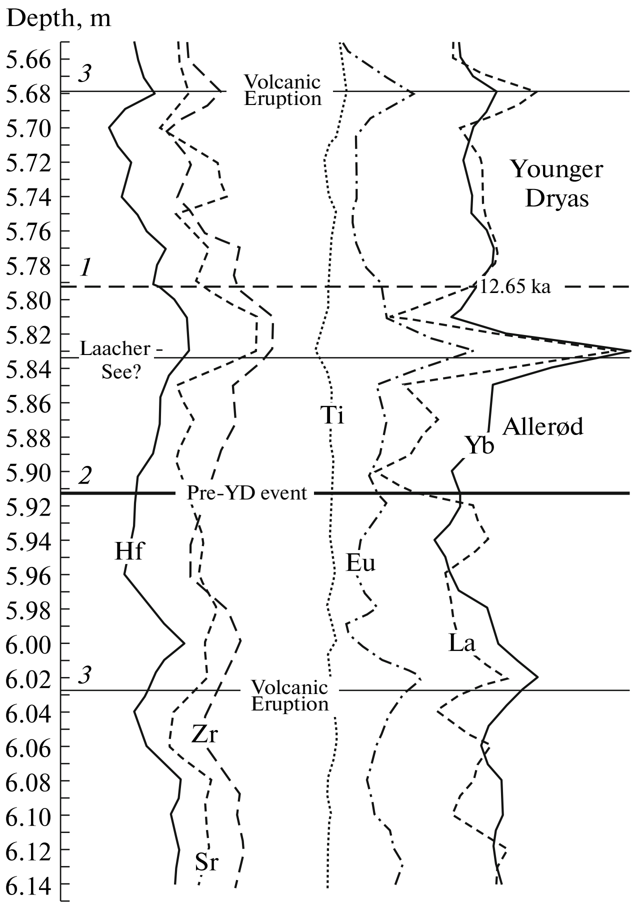

Fig. 4. Schematic distribution of selected "volcanic" trace elements across the studied part of the sedimentary sequence of the lake Medvedevskoye. *1–3*, correspond to those in Fig. 3. The picture does not show an absolute concentration of the trace elements.

uneven distributions of most trace elements across the sequence (Figs. 3, 4), and slight addition of trace element-rich material will be difficult to identify. Nevertheless, on the basis of trace element distributions in sediments of the lake Medvedevskoye, we suggest the presence of meteoritic and volcanic components in some horizons of the lake sediment sequence.

A meteorite component could be identified on the basis of concentrations of such elements as Ni, Cr, Cu and the PGE, which are known to be present in much higher concentrations in meteorites than in terrestrial sediments [11, 12]. The strongest indication for a possible presence of the ET component in a terrestrial environment is the presence of the elevated concentrations of the PGE [11] because concentrations of the PGE in meteoritic material are a few orders of magnitude higher than in the ACC (450 ppb and <0.1 ppb, respectively) [10, 12].

In studies related to meteorite impacts, an increase of Ir concentration, often together with enrichment in other (but not necessarily all) PGE, suggests to be a clear indicator of a contribution of meteoritic material to the terrestrial environment [11].

Features of distribution of trace elements in the lake Medvedevskoe sequence suggest that some event occurred leaving its fingerprints at the level of 5.90 m (sample 3MD-13). Sediments from this depth are characterized by a sharp and coherent increase of concentrations of such "meteoritic" elements as Ni, Cr, Cu, Ir, Pt and to a lesser extent, Ru (Fig. 3). Additionally, this level is characterized by a decrease of rare earth element (REE) concentrations (Fig. 4), i.e., the elements which are low in meteorites [12]. If enrichment (or depletion) in any of the mentioned elements alone could be explained by some terrestrial processes (like a change in a source of alochthonous sedimentary material or influence of a biotic component), simultaneous enrichment in all these elements should raise suspicion about the potential presence of the ET component. Signs of geochemical disturbances involving "meteoritic" elements can be traced upwards to the depth of at least 5.83 m, i.e., affected geochemical characteristics of sediments for at least 200 years that can tell about a global scale of the event. A geochemical marker "5.90 m" is located 11 cm below the Allerød-Younger Dryas boundary (12.65 ka) and should then correspond to the time of ca. 13 ka (Fig. 3). This is very close to the age of 12.9 ka suggested for a pre-YD meteorite impact [4]. It should be strongly emphasized, however, that because we do not know an exact rate of sedimentation at every stage of the lake evolution, the age estimates are just very approximate and, therefore, the difference in 100 years is quite within the error range.

The presence of the volcanic component can be identified not only by the presence of volcanic glass shards [7, 8], but also on the basis of concentrations and distributions of such elements as REE, Zr, Hf, Sr, and Ti which are very common in products of volcanic eruptions [13]. As well as in the case of the PGE, enrichment/depletion in each mentioned individual element-marker could just reflect features of local sedimentation whereas coherent behavior of the marker elements could point to a much wider event(s). Coherent enrichments in all mentioned "volcanic" elements accompanied by a slight depletion in Ti is detected at levels 6.00–6.02 m, (samples 3MD-07 and 08), 5.80–5.83 m (2MD-04), and 5.69–5.67 m (3MD-17) (Fig. 4) suggesting presence of the volcanic material in the sediments. The geochemical marker identified at the depths of 6.02–6.00 m is located approximately 22 cm below the Allerød-Younger Dryas boundary (12.65 ka) that corresponds to the age of 13.4–13.3 ka according to the suggested sedimentation rate. The marker at 5.83 m corresponds to ca. 12.78 ka, and the last marker at 5.68 m corresponds to the age of 12.3 ka.

The most pronounced geochemical marker (strong peaks at La, Eu, and Yb, and also enrichment at Zr, Sr, and Hf; Fig. 4) likely related to a volcanic eruption, roughly corresponds to the age of 12.8 ka. At approximately this time (12.88 ka [14]) the Laacher See volcano (Eifel, Germany) erupted explosively. This eruption was one of the most significant and largest volcanic events during the Late Pleistocene in the Northern Europe. The stratigraphic location of the layer enriched in some REE, and also in Zr, Sr, and Hf, and slightly depleted in Ti roughly corresponds to the time of the Laacher See eruption. That may suggest that the enrichment of the lake Medvedevskoye sediments at the depth of 5.80–5.83 m was related to the Laacher See volcano eruption.

Geochemical marker at a depth interval of 6.00–6.02 m displays enrichment in some REE, and such elements as Zr, Hf and Sr with slightly elevated concentrations of Ni and Cr accompanied by lowered concentrations of Ti (Fig. 4). Such characteristics are consistent with the presence of minute amounts of volcanic material which is somewhat different from the material suggested for sample 2MD-04 (5.80–5.83 m). The third marker (3MD-17; 5.69–5.67 m) displays geochemical features similar to those from the sample 2MD-04, but at a smaller scale. Because volcanoes of Western Europe and Iceland were very active during the Late Pleistocene [7, 13–15], we can relate the presence of the volcanic material at the horizons of 6.00–6.02 m (ca. 13.4–13.3 ka) and 5.69–5.67 m (ca. 12.3 ka) with eruptions of such volcanoes. The presence of the Vedde volcanic ash (12.0 ka) in sediments of two lakes of the Karelian Isthmus and, in particular, in sediments of the lake Medvedevskoye [3, 7, 8] could be in favor of such a suggestion.

Therefore, concentration and distribution of trace elements across the sequence of the Late Pleistocene sediments from the lake Medvedevskoye display features consistent with the addition of materials other than those from a common source for the lake sediments of the region. Although there are still no decisive data about the connection between the beginning of the Younger Diyas cooling and the possible ET event [4], we suggest that sediments of the lake Medvedevskoye carry microparticles related to the ET event that occurred at ca. 12.9 ka. Because the enrichments of the lake Medvedevskoye sediments in the trace element-markers are extremely subtle, the NW Russia can be considered to be the most remote eastern region of the extent of the Late Pleistocene airborne ET material. In addition to the earlier found layer of the Vedde volcanic ash (Katla volcano, Iceland), sediments of the lake Medvedevskoye can also contain volcanic material from the eruption of the Laacher See volcano and probably from other Late Pleistocene volcanoes of Western Europe and/or Iceland.

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