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Millennial-scale vegetation changes in the north-eastern Russian Arctic during the Pliocene/Pleistocene transition (2.7–2.5 Ma) inferred from the pollen record of Lake El'gygytgyn

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A B S T R A C T

The sediment record of Lake El'gygytgyn (67°30′N, 172°05′E) spans the past 3.6 Ma and provides unique opportunities for qualitative and quantitative reconstructions of the regional paleoenvironmental history of the terrestrial Arctic. Millennial-scale pollen studies of the sediments that accumulated during the Late Pliocene and Early Pleistocene (ca. 2.7 to 2.5 Ma) demonstrate orbitally-driven vegetation and climate changes during this transitional interval. Pollen spectra show a significant vegetation shift at the Pliocene/Pleistocene boundary that is, however, delayed by a few thousand years compared to lacustrine response. About 2.70–2.68 Ma the vegetation at Lake El'gygytgyn, currently a tundra area was mostly dominated by larch forests with some shrub pine, shrub alder and dwarf birch in understory. During the marine isotope stages G3 and G1, ca. 2.665–2.647 and 2.625–2.617 Ma, some spruce trees grew in the local larch-pine forests, pointing to relatively warm climate conditions. At the beginning of the Pleistocene, around 2.588 Ma, a prominent climatic deterioration led to a change from larch-dominated forests to predominantly treeless steppe- and tundra-like habitats. Between ca. 2.56–2.53 Ma some climate amelioration is reflected by the higher presence of coniferous taxa (mostly pine and larch, but probably also spruce) in the area. After 2.53 Ma a relatively cold and dry climate became dominant again, leading to open steppe-like and shrubby environments followed by climate amelioration between ca. 2.510 and 2.495 Ma, when pollen assemblages show that larch forests with dwarf birch and shrub alder still grew in the lake's vicinity. Increased contents of green algae colonies (*Botryococcus*) remains and *Zygnema* cysts around 2.691–2.689, 2.679–2.677, 2.601–2.594, 2.564–2.545, and 2.532–2.510 Ma suggest a spread of shallow-water environments most likely due to a lake-level lowering. These events occurred simultaneously with dry climate conditions inferred from broad distribution of steppe habitats with *Artemisia* and other herbs.

1. Introduction

The transition from the late Pliocene into the earliest Pleistocene is an interval of dynamic environmental changes. During this transition glacioeustatic sea-level changes markedly increased in amplitude in response to intensification and increased fluctuation of Northern Hemisphere glaciation (Bailey et al., 2012). Generally, this interval at about 2.588 Ma covers the termination of the Pliocene, the most recent geological epoch with global temperatures several degrees higher than today, and the onset of the Pleistocene, the epoch of increasing climate extremes.

The high Arctic is particularly sensitive to climate changes. Recent studies have shown that during the last few decades the Arctic has experienced significant warming, more dramatic than in other parts of the globe (e.g. Sundqvist et al., 2010 and references therein). The rate of temperature increase of 2 °C since 1961 significantly exceeds that of the global mean (IPCC, 2007). With further temperature rise, the permafrost-dominated Siberian Arctic will likely turn from a main methane sink into a significant source of greenhouse gases (e.g. Schuur et al., 2009; Nisbet et al., 2014).

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For a better understanding of climate and environmental processes in the Arctic long, high-resolution paleoenvironmental records are required. Such records are also an important prerequisite for the validation and improvement of climate simulation scenarios. Unfortunately, long-term, continuous records are extremely rare in the Arctic. It took until 2009 for the first terrestrial sediment record that continuously penetrates beyond the Pliocene/Pleistocene boundary to become available from Lake El'gygytgyn, which was drilled under the auspices of the International Continental Scientific Drilling Program (ICDP) (Melles et al., 2011, 2012; Brigham-Grette et al., 2013).

Lake El'gygytgyn was formed following a meteorite impact 3.58 ± 0.04 Ma ago (Layer, 2000), in an area of northeastern Russia that remained afterwards free of continental glaciations, despite its location approximately 100 km to the north of the Arctic Circle (67°30′N, 172°05′E, Fig. 1). The unique, 318-m thick, sedimentary record of Lake El'gygytgyn provides excellent opportunities for time-continuous reconstructions of past environments. Multi-proxy results from the upper part (back to 2.8 Ma) of the lake sediment succession have provided a complete record of glacial/interglacial changes in the Arctic throughout the Pleistocene (Melles et al., 2012). A first compilation of data and paleoenvironmental interpretations obtained from the lower part of the record (~3.6–~2.2 Ma ago) was published by Brigham-Grette et al. (2013). More detailed results have recently become available in a special issue of the journal Climate of the Past: *Initial results from Lake El'gygytgyn, western Beringia: first time-continuous Pliocene-Pleistocene terrestrial record from the Arctic* (http://www.clim-past.net/special_issue48.html).

Amongst the large number of sediment proxies applied to the El'gygytgyn record, palynological proxies turned out to be of particular importance (Melles et al., 2012; Andreev et al., 2012, 2014; Brigham-Grette et al., 2013; Lozhkin and Anderson, 2013; Tarasov et al., 2013). Modern pollen studies indicate that the lake record provides reliable insights into regional and/or even over-regional vegetation changes, since the lake traps pollen from a source area of several thousand square-kilometers (Lozhkin and Anderson, 2013 and references therein). Taking the sensitivity of the vegetation to climate, the pollen assemblages can also be used to reconstruct climate parameters and to validate and improve climate model scenarios.

According to initial palynological results, the Pliocene/Pleistocene boundary (at 2.558 Ma during Marine Isotope Stage (MIS 103) marks an important change in vegetation at Lake El'gygytgyn from generally interglacial to glacial environmental conditions (Andreev et al., 2014). However, the understanding of the vegetation and climate change at this globally important boundary was hampered by the rather low temporal resolution of ca. 2000 yr/sample of the preliminary palynological data. Here, we present a more detailed reconstruction of climatically and environmentally driven vegetation changes in the northeastern Russian Arctic between ~2.7 and ~2.5 Ma, based upon palynological data from the Lake El'gygytgyn record in a temporal resolution of ca. 800 yr/sample in average.

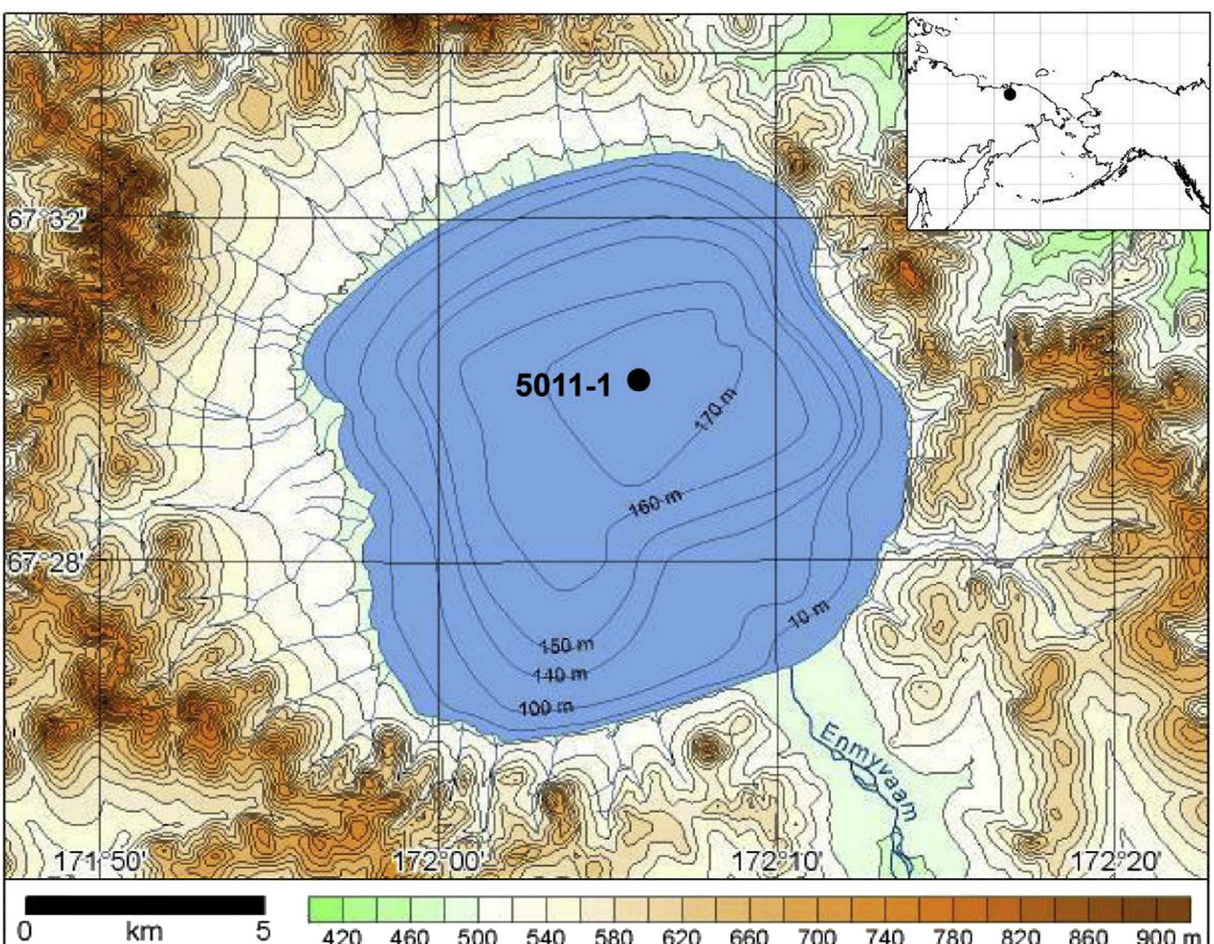

Fig. 1. Map of Lake El'gygytgyn showing the location of ICDP Site in the central, deepest part of the lake (for location of the lake in north-eastern Russia see inserted map).