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Lake bottom sediments as archives of paleo-climate changes on decade and millennium time scales of the Holocene-Pleistocene

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ABSTRACT. Undoubtedly, the study of the Planet's climate is one of the fundamental topics for elaboration of strategies for life support of the Earth's population. The following questions arise: i) what is the spatial pattern of intensity of these changes; ii) what is the response of the regions to climatic changes; iii) what is the critical line when changes in the ecosystem are irreversible; iv) what are causes and mechanisms of these changes; v) what is the human role in these processes; and vi) which tendencies should be expected in climate changes in the nearest future? After answering these questions, a logical question is put forward: how unique is "the climatic landscape" of the recent decades compared to the previous epochs, and are all regions similarly sensitive to climatic changes? The challenge is how to describe these changes and which methods to use in order to obtain more reliable data. More generally and despite some problems, the studies indicate the value of combining limnological and palaeolimnological records in reconstructing lake history and in disentangling the changing role of different pressures on lake ecosystems.

Keywords: Paleolakes, Climate changes, bottom sediments, the Holocene-Pleistocene

1. Discussion

Climate change has become one of the most important environmental concerns facing modern society (IPCC, 2007). The extent of natural climate variability is not yet fully understood, though understanding of this variability is crucial for predicting future trends.

Lacustrine sediment sequences can provide valuable archives of past environmental and climatological variability in terrestrial realms. To unravel the history of a lake and of lake's catchment, a profound understanding of the sedimentary processes is required. This encompasses the supply of allochthonous organic matter, nutrients and clastic material to the lake and the subsequent redistribution within the lake, as well as autochthonous organic matter and mineral deposition (Battarbee and Bennion, 2012).

Paleoclimate reconstruction can be qualitative (e.g. pollen or diatom records) or quantitative with a low, medium and high time-resolution (Fig. 1). Mechanisms of long-period, contrast and large-scale changes of the Earth's climate in the Pleistocene have been well studied. For the past decades, due to the studies of oceanic, marine and glacial cores, significant progress has been achieved in understanding of cause-effect factors that govern long-period (400, 100, 40, and 21 ka) changes of the climatic image of the Earth with a time interval of several millennia. Thus, the global climate of the Earth during the last several Ma was studied with a step in 0.5-1 ka (e.g. Berg et al., 1991; Lourens et al., 1996; Larrasoaña et al., 2003), a low time-resolution. The longest in time records were obtained from the sediment covers of the lakes Baikal (Russia), Khubsugul/Hovsgol (Mongolia) and Elgygytgyn (Russia). For example, Baikal and Khubsugul drill cores contain climate records for the past 8 and 1.3 Ma (BDP Members..., 2000; BDP-99..., 2005), respectively.

According to the Baikal records, it is suppose that weakly weathered material was delivered into the lake during the ice ages, perhaps from the nearest mountain glaciers in the northern or northeastern part of the catchment. In contrast, the mature and chemically weathered terrigenous material was transported from the river valleys during warm periods. The significant decrease of the relative contribution of the largest river input, the Selenga River, to the water budget of the paleo Lake Baikal (or possibly even its complete disappearance) during the global ice ages and deep regional cooling. As a direct result, a sharp decrease in the delivery of nutrients into Lake Baikal and the consequent decrease of its bioproductivity had to occur almost simultaneously (Grachev et al., 1997; Goldberg et al., 2008; 2010).

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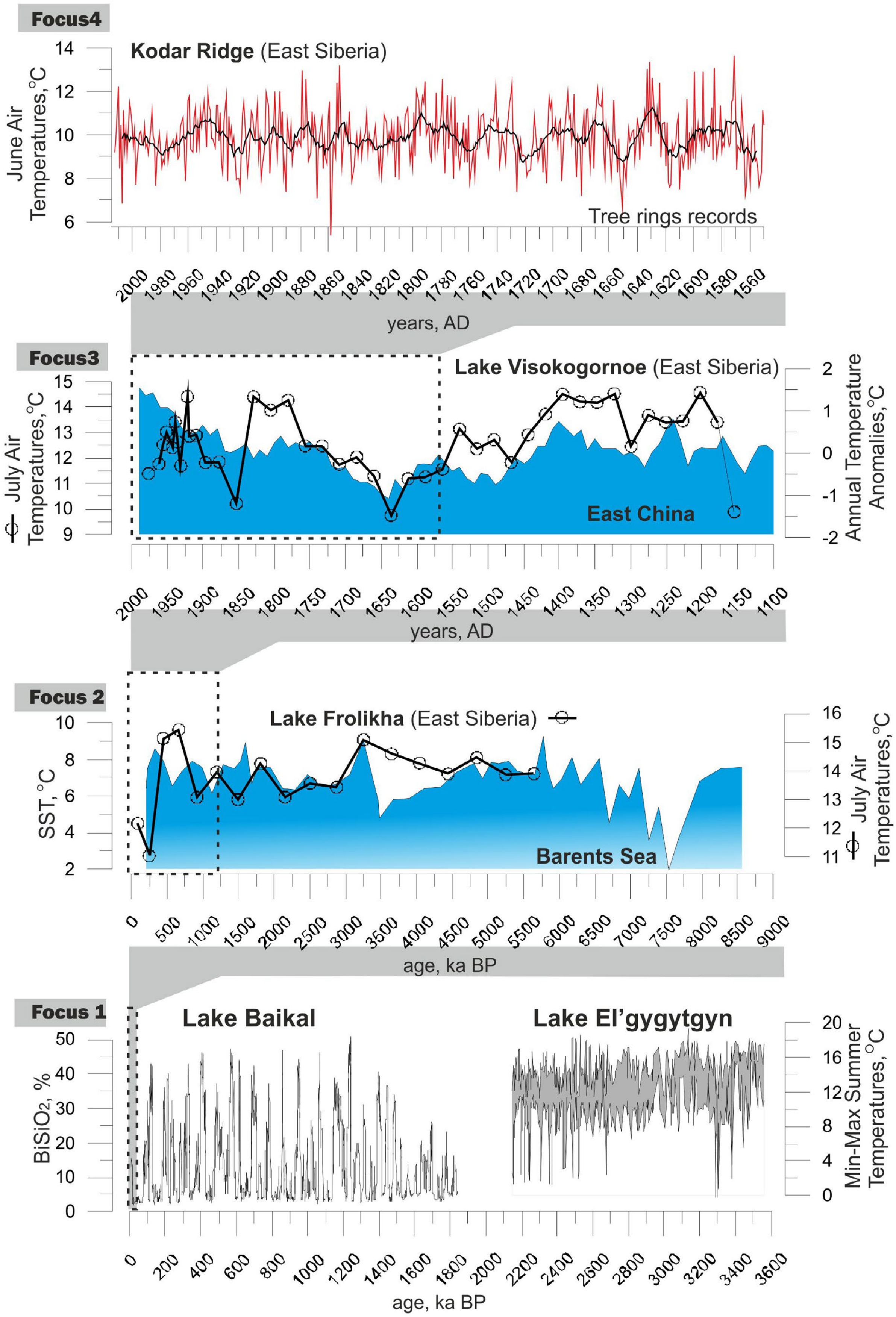

Fig. 1. Paleoclimate reconstruction at different time-frames. *Focus 1* – low-resolution records from bottom sediments of "old" lakes, Lake Baikal according to Prokopenko et al. (2006) (IGBP PAGES/World Data Center for Paleoclimatology), Lake Elgygytgyn according to Brigham-Grette et al. (2013) (IGBP PAGES/World Data Center for Paleoclimatology); *Focus 2* – meadle-resolution records of the Holocene, July air temperature was obtained base on chironomid analyses (Lake Frolikha, East Siberia), SST - Reconstruction of summer sea-surface temperatures of the Barents Sea (Voronina et al., 2001 (IGBP PAGES/World Data Center for Paleoclimatology)); *Focus 3* – high-resolution records of the last Holocene, Lake Visokogornoe according to Fedotov et al. (2015), Temperature variation in China according to Yang et al. (2002); *Focus 4* – high-resolution June temperatures inferred from tree-rings reconstruction (the Kodar Ridge, East Siberia)

In contrast to the Baikal records, a geochemical signal is main in Khubsugul pale-records (Fedotov et al., 2004). The formation of the Khubsugul isotopic and geochemical records depended on the change of the regional aridity level. The high aridity is determinate on abrupt increasing of values these records. During the aridity periods, the lake level was low, the lake water was of high salinity and the evaporation enriches determined δ18O composition of the lake waters. It assumes that the Khubsugul level was stable on ~100 m below what the modern level during ca. MIS-2 and the second half of MIS-3, at the evaporate/inflow ratio 2.7 (Fedotov et al., 2015).

Records from Lake Elgygytgyn (NE Arctic Russia) showsthat 3.6-3.4 million years ago, summer temperatures were ~8C warmer than today when pCO2 was ~400 ppm. Multiproxy evidence suggests extreme warmth and polar amplification during the Middle Pliocene, sudden stepped cooling events during the Pliocene-Pleistocene transition, and warmer than the present Arctic summers until ~2.2 Ma, after the onset of the Northern Hemispheric glaciation (Brigham-Grette et al., 2013).

Meanwhile, investigations of the European Holocene sections with high time resolution visualized that long-term climatic phases were extremely heterogeneous (e.g. Jones and Mann, 2004; Luterbacher et al., 2004; Osborn and Briffa, 2006; Mann et al., 2009). In addition, the Holocene climate changes were some triggers for socio-economic developments. For example, climate cooling in Central Asia can be seen as a triggering for the actions of peoples such as the Huns and Mongols in the history of the vast parts of Eurasia from China to Central Europe (Schlütz and Lehmkuhl, 2007). Therefore, it is currently important to obtain: i) information on climate changes with a time interval of a year-decade and ii) their quantitative parameters.

Fossils of chironomid larvae (non-biting midges) preserved in lake sediments are well-established palaeotemperature indicators, which can provide quantitative estimates of past temperature change using numerical chironomid-based inference models (transfer functions). This approach to temperature reconstruction relies on the strong relationship between air and lake surface water temperatures and the distribution of individual chironomid taxa (species, species groups and genera) that has been observed in different climate regions (arctic, subarctic, temperate and tropical) in both the Northern and Southern Hemispheres (Brooks and Birks, 2001; Brooks, 2006).

Climate changes in East Siberia for the past 5.5 ka can be described by four episodes based on chironomid analyses. Thus, maximum in regional moisture occurred at ca. 5.5-3.5 cal. ka BP and mean July temperatures was ca. 14°C. The following episode of 3.5-1.7 ka BP was characterized by a tendency to dry conditions and to temperature drop by 1°C. During the third episode (1.7-0.8 ka BP), dry conditions decreased, but the temperature change was negligible. In the fourth episode (0.8 ka BP to present), the climate changed significantly associated with the Medieval Warm Period. This event was characterized by warm and dry conditions, when the dry component was maximal for the past 5.5 ka.

More detailed chironomid, biogenic and geochemical lake records showed a clear decrease in summer temperatures occurred in East Siberia after ca. 1400. It was linked with the beginning of the Little Ice Age (Fedotov et al., 2015). The coldest summer occurred about ca. 1570-1700 and 1830-1900. It assumed that the most significant changes of the lake bio-productivity and the catchment area occurred about ca. 1160-1350, 1350-1590, 1590-1730, 1730-1900 and 1940 to the present. The most dramatic period with unfavorable climate conditions for the lake biota was during 1590-1730.

However, many questions about climate changes in Northern Eurasia are still open. If to compile a scheme on which the Holocene section of the Northern Hemisphere will be marked with a high precision, Europe and North America are the best studied regions, North and Central China are less studied areas, and only several regions have been sporadically investigated in Mongolia, Transbaikalye, East and Western Siberia. On the other hand, high contrast landscape zones (tundra, taiga, steppe, high-mountain areas and deserts) are located in Northern Eurasia, and regional features of climate changes can be well illuminated. In particular, why climatic regimes of various landscape zones were different under similar global conditions (orbital parameters, insolation level, evaporation from the oceans and movement of humid fronts). Comparing the obtained new records with those from Europe and Inter-Continental Asia, we can determine control factors and feedback inside the Eurasian climatic system, as well as its interaction with the global system at the inter-regional level. It is expected to widen information on how ecosystems of different landscape zones respond to climatic changes and which elements of these systems are more resistant or, vice versa, sensitive to short-period climatic fluctuations. In addition, the results of this study will enlarge information on the effect of global anthropogenic factor of the industrial period on the stability of regional ecosystems.

2. Conclusion

As future climate changes are expected to have a major impact on freshwater lake ecosystems, it is important to assess the extent to which changes taking place in freshwater lakes can be attributed to the degree of climate change that has already taken place. It is necessary to examine evidence spanning many decades by combining long-term observational data sets and palaeolimnological records. However, there is also evidence of climate influence related in some cases to natural variability in the climate system, and in others to the trend to higher temperatures over recent decades attributed to anthropogenic warming.

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