The oxygen isotope record from diatoms at Lake El'gygytgyn – Quaternary Far East Russian Arctic palaeo-temperature and talik dynamics

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Background & Location

In the Arctic, long terrestrial records for paleoclimate reconstructions are rare. In 2003, a 16.5 m sediment core (Lz1024) was drilled at Lake El'gygytgyn (Fig. 1), NE Russia. It dates back to 250 ka in an area which has never been glaciated in the Quaternary. Samples from MIS 11 originate from the ICDP core 5011-1 (Fig. 1).

The oxygen isotope composition from biogenic silica, i.e. diatoms, is used as proxy for reconstructing past climate changes i.e. mean annual air temperatures (MAAT):

$\delta^{18}O_{diatom}$ -> $\delta^{18}O_{lake\ water}$ -> $\delta^{18}O_{precipitation}$ -> MAAT

Here, we present the first continuous terrestrial >250 ka $\delta^{18}O$ record from the Arctic directly reflecting palaeo precipitation changes.

Lake level changes have played a role in the past for sediment delivery and talik dynamics. To account for that, we studied permafrost core 5011-3 with isotope geochemical methods.

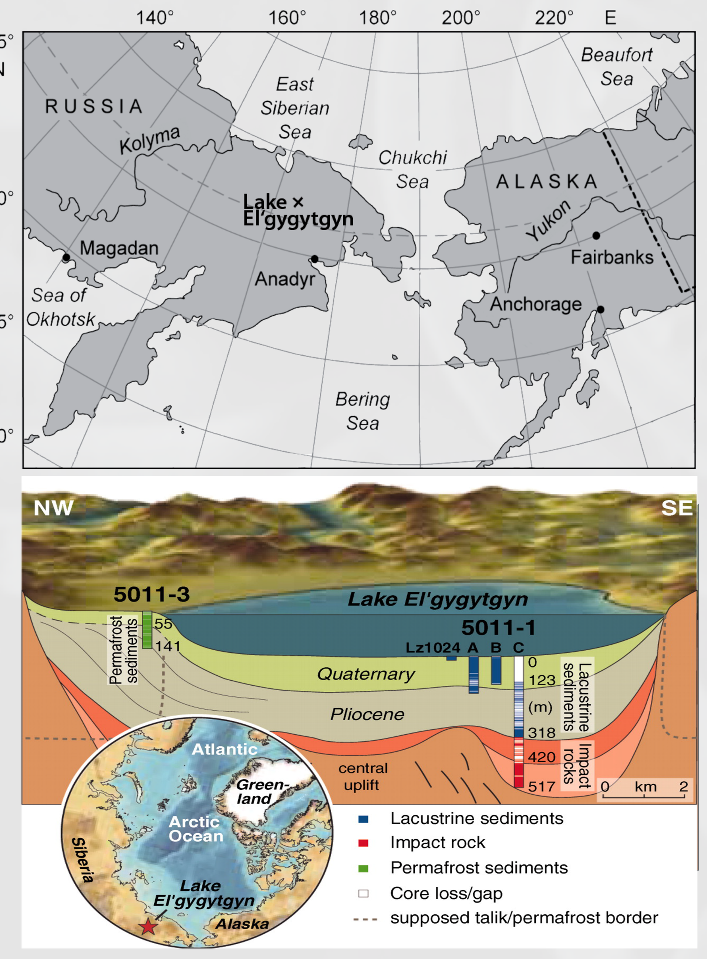

*Fig. 1: Lake El'gygytgyn was formed after a meteorite impact 3.6 Ma ago. It is about 12 km in diameter, 170 m in depth and located in Chukotka, NE Russia. Samples from sediment cores from the drilling locations Lz1024 and ICDP site 5011-1 were used for the $\delta^{18}O_{diatom}$ study *.*

Methods & Material

Various preparation steps have been performed in order to gain the cleanest diatom sample possible from the original sediment: (1) drying, (2) H_2O_2/HCl treatment, (3) wet sieving, (4-7) heavy liquid separation and (8) $HClO_4/HNO_3$ treatment. The inert Gas Flow Dehydration (iGFD) was used for removing all exchangeable oxygen from the structure. The isotope analysis was performed with a PDZ-Europa 2020 mass spectrometer. The oxygen was liberated from the sample by laser-fluorination under BrF5 atmosphere.

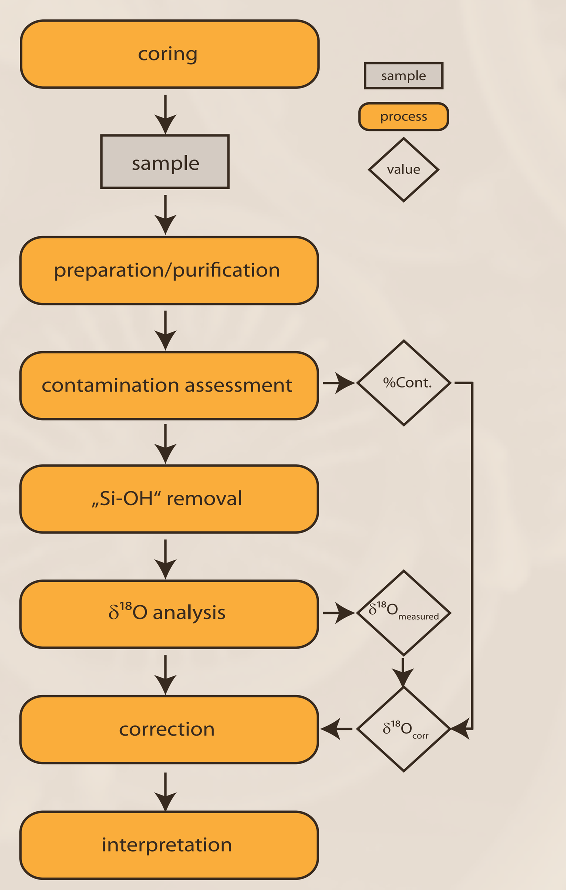

Fig. 2: Method outline from coring to interpretation.

250 ka climate history

Around 100 samples were analysed with a standard deviation of $1\sigma < \pm 0.3$ ‰. Contamination assessment of the pure samples show SiO_2 mostly >97 % and Al_2O_3 <2.5 % determined by EDS. Downcore variations in $\delta^{18}O$ values show that glacial-interglacial cycles are present throughout the core (Fig. 3) and $\delta^{18}O_{diatom}$ values are mainly controlled by $\delta^{18}O_{precipitation}$. Changes reflect the Holocene Thermal Maximum, the Last Glacial Maximum and the interglacial periods corresponding to MIS 5.5 and MIS 7 with a peak-to-peak amplitude between LGM and MIS 5.5 of $\delta^{18}O$= 5.3 ‰. This corresponds to a mean annual air temperature difference of about 9 °C. The record correlates well with the $\delta^{18}O$ benthic stack LR04 (r = 0.58) and the dD EPICA Dome-C record (r = 0.69).

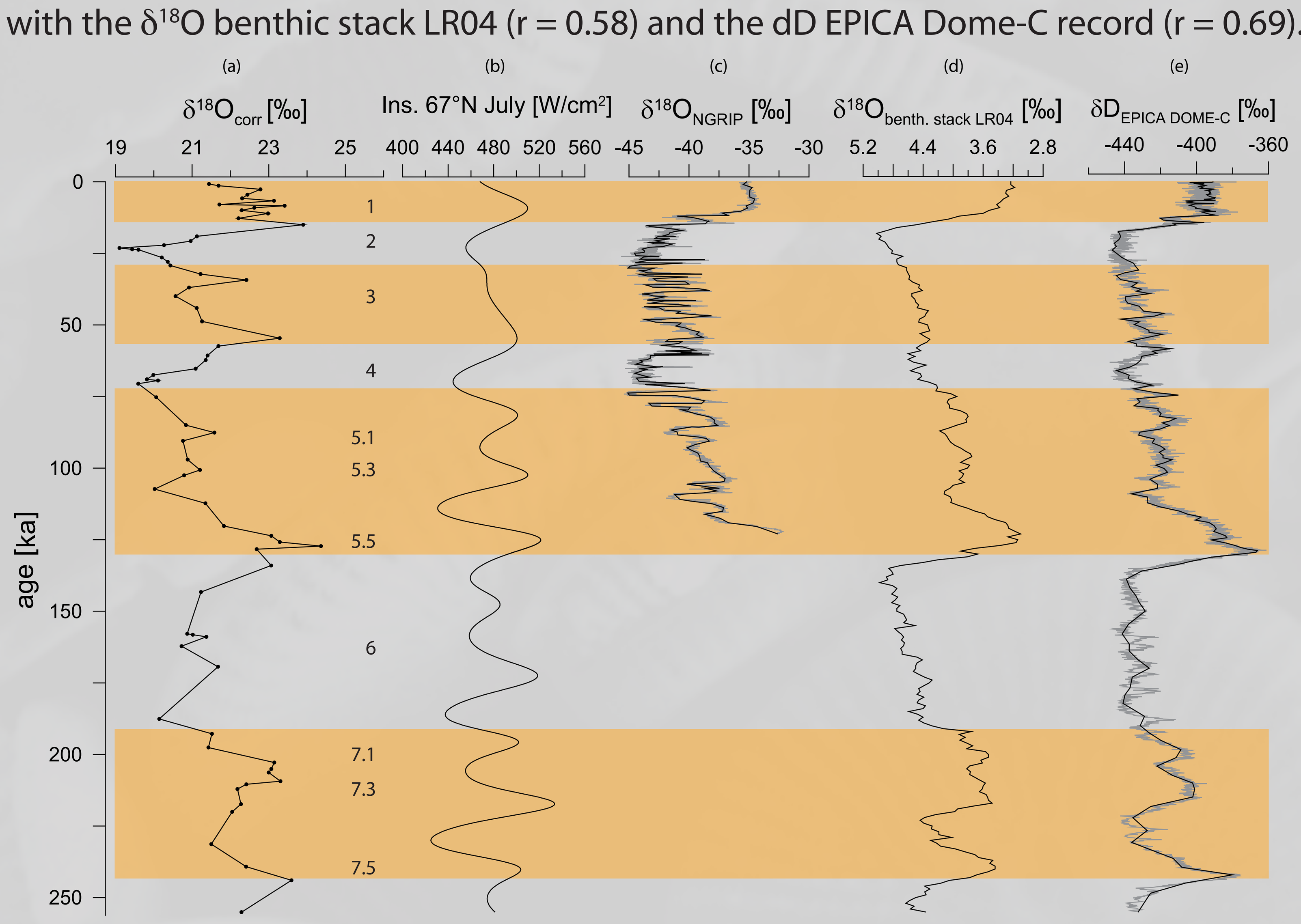

Fig. 3: (a) Lake El'gygytgyn $\delta^{18}O$ results for the last 250 ka after contamination correction clearly show climate- related isotope variations. Warmer periods corresponding to MIS 1, MIS 3, MIS 5 and MIS 7 are marked in orange, interglacials and some interstadials are labelled. (b) The summer insolation at 67°N and ice-core records (c) NGRIP ($d^{18}O$), (e) EPICA Dome-C (δD) plotted for comparison (grey: all data, black: spline smoothing to 50 points) as well as (d) LR04 benthic stack (Lisiecki and Raymo, 2005).

Investigation of warm stages

Comparing interglacials/interstadials (MIS 1, MIS 5e and MIS 11) similar average $\delta^{18}O$ values were recorded for the HTM and MIS 7. MIS 5.5 was warmer than the Holocene and MIS 11 the warmest interglacial of this record (Tab. 1, Fig. 4a). The average values between HTM/MIS 7 and MIS 5.5 differ by about 1-1.5°C in mean annual air temperature (MAAT; Lake El'gygytgyn 1995-2009: -9.1°C, deviation from recent MAAT: Fig. 4b). The reconstructed MAAT from MIS 11 is about 1°C warmer than for MIS 5e, ~2°C warmer than for the HTM and ~4-5°C warmer than recent values. This amplitude is roughly in the range of the pollen spectra temperature reconstructions by Melles et al. (2012)* (Fig. 4c, modified) who found the MIS 5.5 to be slightly warmer (MTWM, i.e. July) as compared to the HTM data and MIS 11 to be the warmest period - a „super-interglacial".

Stage	$d^{18}O$ [‰]	Age [ka]
Recent	21.4	0.8
HTM	22.8	9.6
MIS 3	21.9	49.1
MIS 5e	23.6	125.6
MIS 7	22.6	218.0
MIS 11	24.2	419.8

Tab. 1: Comparison of $\delta^{18}O$ values from warm periods (average $d^{18}O$ values and average age shown).

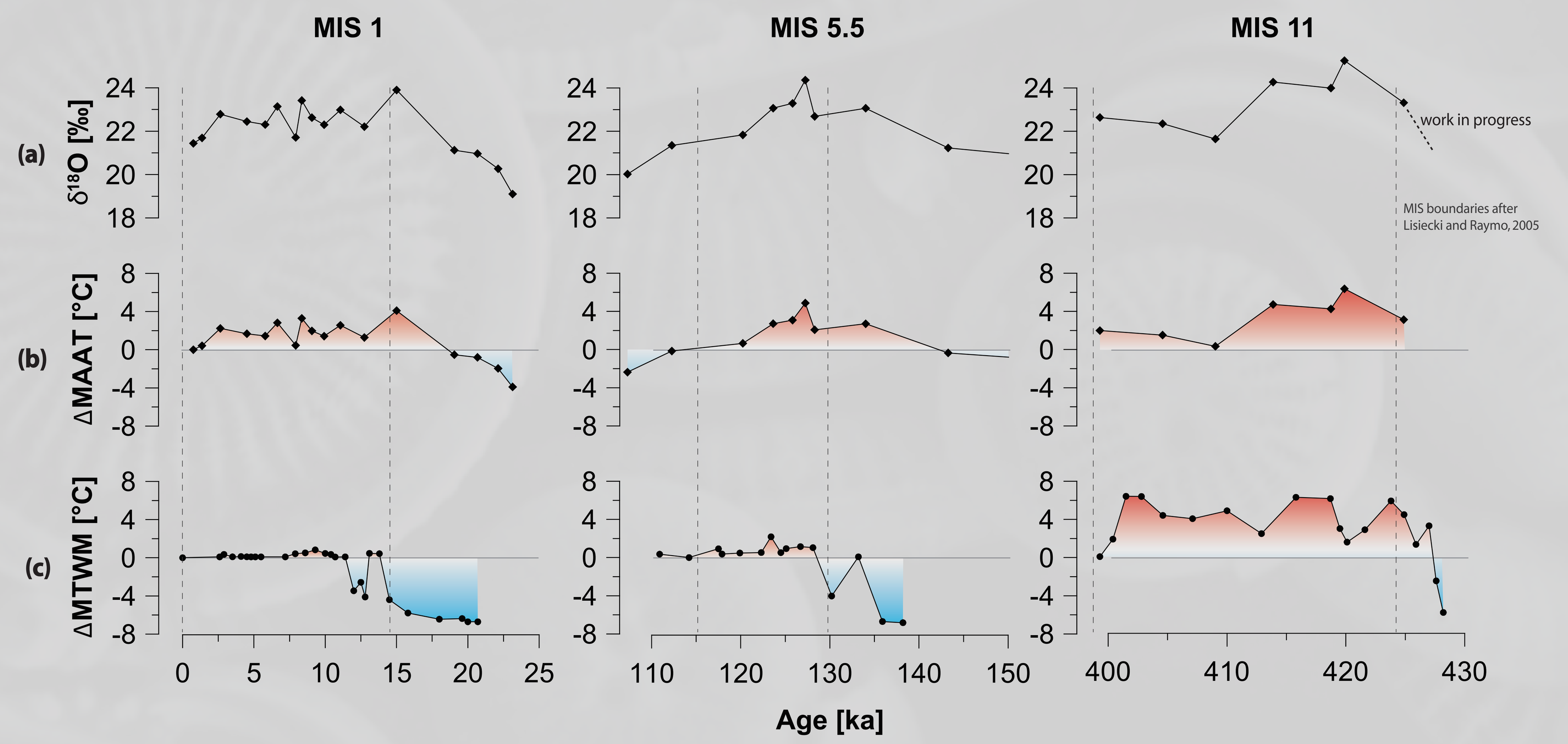

Fig. 4: Comparison of MIS 1, MIS 5e and MIS 11. (a) $\delta^{18}O$ record from diatoms (b) reconstructed relative mean annual air temperature (MAAT) from $\delta^{18}O$ values (variations to the most recent value which was set to 0°C). (c) reconstructed relative mean temperature of the warmest month (MTWM), modified from Melles et al. 2012 (variations to the most recent value (8.8°C) which was set to 0°C).*

* Melles et al. (2012): 2.8 Million Years of Arctic Climate Change from Lake El'gygytgyn, NE Russia, Science, 337, 315–320, doi:10.1126/science.1222135

Lake E talik dynamics

Lake El'gygytgyn lake dynamics are recorded in ground ice within permafrost core 5011-3 taken in the catchment of the lake. The upper 9.1 m of ground ice are synsedimentary and reflect mostly palaeo-precipitation since the Allerød. The deeper layers (to 141 m) are indicative for climate-induced lake-level changes that caused expansion of the Lake E talik. Changes in the hydrochemical characteristics reflect at least three repeated freeze-thaw cycles of the talik associated with lake-level highstands of Allerød (+4 m) and of pre LGM age (+10 m and + 40 m terraces) likely the Eemian and MIS 11.

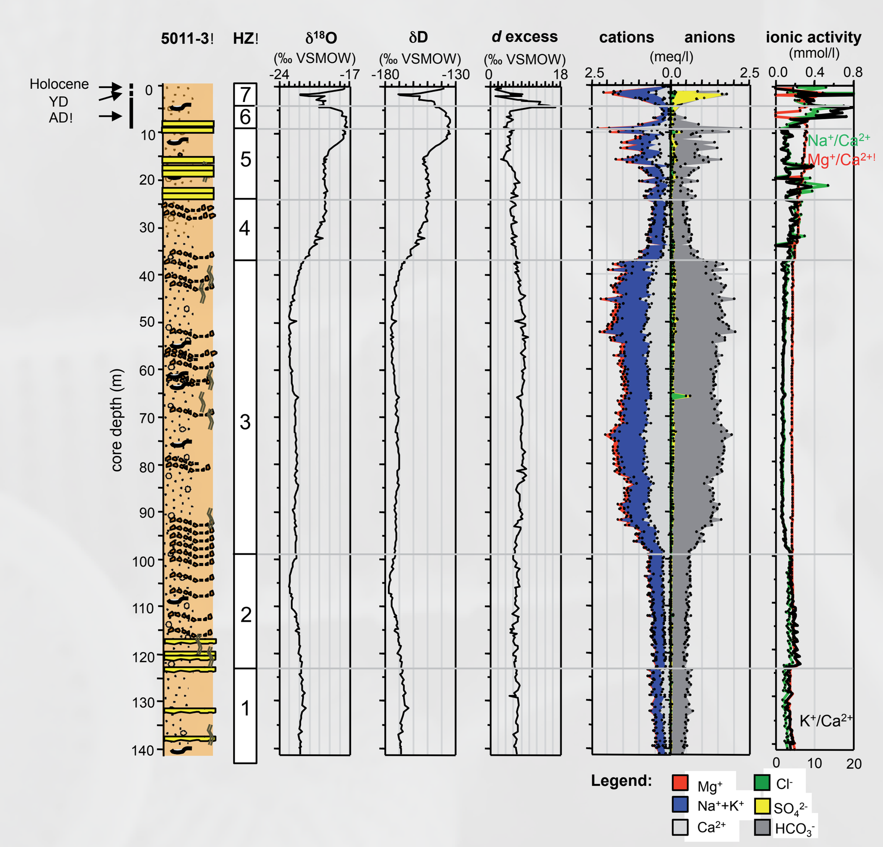

Fig. 5: Lake El'gygytgyn hydrochemical data from core 5011-3

Conclusions

About 120 samples from sediment cores Lz1024 and 5011-1 drilled at Lake El'gygytgyn (NE Russia) were analysed and show diatom $\delta^{18}O$ variations (MAAT) that **reflect glacial-interglacial cycles** including HTM, LGM, the Eemian, MIS 7 and MIS 11.

The correlations of the $\delta^{18}O$ record with the $\delta^{18}O$ benthic stack LR04 (r = 0.58) and the δD EPICA Dome-C record (r = 0.69) **are significant** and show the sensitivity of Lake El'gygytgyn and the wider Arctic climate system to global climate conditions.

Comparing the warm stages, similar reconstructed MAAT occured during HTM and MIS 7, whereas **MIS 5.5 was about 1.5°C and MIS 11 about 2.5°C warmer than the HTM.** The average MAAT from **„super-interglacial" MIS 11 was ca. 4-5°C warmer than today**.

Hydrological changes in permafrost ice near Lake E reflect **lake-level dynamics** and changes of the **talik expansion** with at least three highstands during Allerød, and potentially MIS 5 and MIS 11 (as derived from the diatom isotope record).

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Further reading (see QR codes for direct link):
1) Chapligin et al. (2010): A high-performance, safer and semi-automated approach for the $\delta^{18}O$ analysis of diatom silica and new methods for removing exchangeable oxygen, Rapid Comm. Mass Spectrom., 24, 2655-2664.
2) Chapligin et al. (2011): Inter-laboratory comparison of oxygen isotope compositions from biogenic silica, Geochim. Cosmochim. Acta, 75, 7242-7256.
3) Chapligin et al. (2012): Assessment of purification and contamination correction methods for analysing the oxygen isotope composition from biogenic silica, Chem. Geol., 300-301, 185-199.
4) Chapligin et al. (2012): A 250 ka oxygen isotope record from diatoms at Lake El'gygytgyn, far east Russian Arctic. Clim. Past 8, 1621-1636.

1 Method development
2 Inter-lab comparison
3 Contamination correction
4 250 ka $\delta^{18}O_{diatom}$ record (Lake El'gygytgyn)

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