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The transitional climate of the late Miocene Arctic: Winter-dominated precipitation with high seasonal variability

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Stratigraphic Context and Palynology Analysis

Fossil wood was collected from the Upper Miocene Khapchansky horizon (Fig. DR1) at the Finish Stream site (modern coordinates: 68.724° N, 161.587° E; paleolatitude: 71–72° N, van Hinsbergen et al., 2015). The Khapchansky horizon contains ferruginous sands with rare pebbles and lenses of silt that have yielded abundant plant detritus and wood fragments, including *Pinus* (evergreen) and mixed deciduous species (Grinenko et al., 1997; Sher et al., 1977). These sampled layers are overlain by the Lower Pliocene Begunovsky horizon (Fig. DR1), which is dominated by very coarse-grained materials, including sand and gravel (pebbles to boulders) (Grinenko et al., 1997). A 50 g subsample of the sediment surrounding the fossil wood within the Upper Miocene Khapchansky horizon was prepared for palynological analyses by Global Geolab Limited (Medicine Hat, Alberta, Canada), and was examined at the LSU Center for Excellence in Palynology (CENEX) using an Olympus BX41 microscope and a 100x oil immersion objective in order to identify pollen, i.e., plant taxa. Examination of the subsamples revealed excellent preservation of the pollen and spore grains, suggesting that they represented *in situ* taxa with minimal transport and reworking. The most abundant palynomorphs were comprised of *Sphagnum* spores and contained little to no *Picea*, *Tsuga*, *Cedrus*, and *Abies* pollen, suggesting a lack of conifer tree species near the site. The dominant tree pollen was from the deciduous genus *Alnus*; an abundance of *Alnus* with little to no thermophilic angiosperm species (including *Juglans*, *Corylus*, *Quercus*, *Carpinus*, and especially *Fagus*) and no *Taxodiaceae* suggested the site did not span the Miocene Climate Optimum (17-15 Ma) and was consistent with the cooler climate of the late Miocene (Frolov et al., 1989; Grinenko et al., 1997). Therefore, the palynological analysis was consistent with the late Miocene age for the site (11.6 to 5.3 Ma), as suggested by the stratigraphy of the region (Grinenko et al., 1997; Nikitin, 2007).

Stable Carbon Isotope Analysis

All six fossil specimens showed distinctive rings in hand sample with discernable earlywood and latewood anatomy (Fig. DR1); therefore, the direction of growth was known. In total, 36 distinct rings were sampled from the six specimens, resulting in 445 subsamples. In addition, one specimen, Sib13, was measured across two distinct transects in order to assess intra-sample variability. On average, each growth ring was subdivided into 11 increments (mean slice thickness ±1σ: 54 ± 20 μm) to determine bulk $\delta^{13}C$ values (n = 445) across each growth ring.

Eight consecutive growth rings, representing the years A.D. 2005–2012, were identified from within both modern *Pinus* specimens; each of these sixteen rings was then subdivided by hand. On average, each of the modern rings was divided into 16 subsamples for a total of 107 subsamples collected from PINE01 and 148 subsamples collected from PINE02.

Bulk $\delta^{13}C$ values were determined for each intra-ring subsample using a Delta V Advantage Isotope Ratio Mass Spectrometer (Thermo Fisher) coupled to a Thermo Finnigan Elemental Analyzer (Flash EA1112 Series, Bremen, Germany) at the University of Louisiana at Lafayette and a Eurovector automated elemental analyzer (Eurovector Inc, Milan, Italy) coupled to an Isoprime isotope ratio mass spectrometer (Isoprime, Ltd, Cheadle Hulme, UK) at the University of Hawaii at Mānoa. Isotopic values are reported in δ-notation (‰) against Vienna standards (VPDB). The analytical uncertainty associated with each measurement, assessed using a quality assurance sample that was analyzed as an unknown within each batch run, was < 0.1‰.

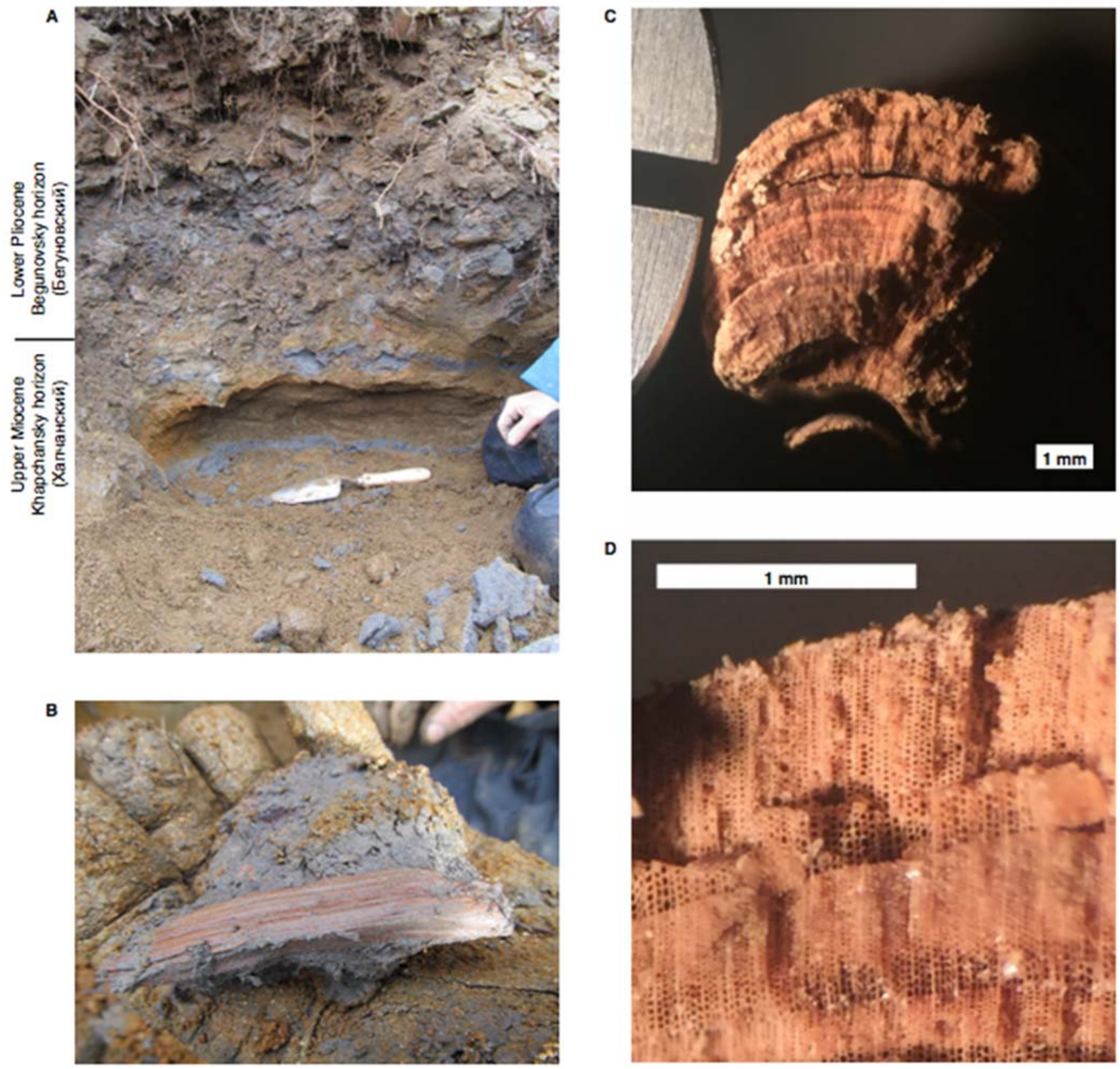

Figure DR1. Fossil wood collected from the Finish Stream site in far northeastern Siberia. (A) Outcrop view showing the coarse grained Lower Pliocene Begunovsky horizon above the fine-grained Upper Miocene Khapchansky horizon. Within the Khapchansky horizon, fossil wood was found in the silty layers (gray), but not within the oxidized sandy lenses. (B) Piece of fossil wood embedded in gray silt. (C) Photograph of sample Sib14-02 showing concentric growth rings. (D) Photograph of sample Sib13 showing well-preserved cellular structure. Because each of the six samples analyzed for this study represented distinct wood fragments with no obvious relationship to each other when discovered in situ, the fossils most likely represented six individuals and that none of the rings sampled represent overlapping time periods. The distinct earlywood and latewood anatomy and concentric curvature of the samples did allow for of the direction of growth (and thus direction of the progression of growing season) to be known.

Figure DR2. Modern *Pinus pumila* sampled for high-resolution intra-ring $\delta^{13}C$ analysis. Field photos of PINE01 (A) and PINE02 (B). (C-D) Cut discs of PINE01 (C) and PINE02 (D) showed annual growth bands. Scale bar is in centimeters.

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