ARCTIC CLIMATE DURING THE EOCENE AS VIEWED FROM A PRISTINE KIMBERLITE PIPE ARCHIVE

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Introduction

During the Eocene epoch, high levels of atmospheric pCO_2 (ca. 700-1000 ppm) maintained a climate with no substantial land ice and extraordinarily warm sea-surface temperatures[1]. Understanding the climate dynamics of such greenhouse climates is relevant given our current climate change trajectory. However, our view of terrestrial climate during the Eocene is challenged by the paucity of suitable archives. In particular, resolving temperatures on high latitude landmasses is key to quantifying the magnitude of polar amplification.

Here, we utilize a unique archive to reconstruct climate during the Eocene: the post-eruptive sedimentary fill of kimberlite pipes from the Northwest Territories (Canada). These pipes were mainly emplaced during the Paleogene, and in unique cases were subsequently filled with organic-rich maar lake sediments, after which they were capped by glacial till from late Cenozoic glaciations. The till and absence of tectonic activity or deep burial in this region fosters extraordinary preservation. The microfossils and biomarkers in these pipe deposits are unusually pristine, with little to no evidence for alteration. These pipe sediments therefore offer a remarkable glimpse of high-latitude climate during a greenhouse interval.

Results

We analysed biomarker distributions in an exploration core sample taken from Giraffe Pipe (64˚48'N, 110˚04'W) spanning approximately 38 to 45 Ma. Chronological control comes from the Rb/Sr date of kimberlite emplacement, and glass fission-track and zircon U-Pb ages from distal tephra in the post-eruptive sedimentary fill. Sediments during this interval have total organic carbon concentrations of up to 50%. An initial biomarker survey revealed an exceptionally high abundance of higher plant-derived biomarkers including long-chain *n*-alkanes, *n*-acids, *n*-alkanols; diterpenoids and pentacyclic triterpenoids; and lignin phenols, indicating substantial allochthonous input of organic matter from a heavily forested environment. In addition, the sediments contained isoprenoidal and branched glycerol dialkyl glycerol tetraethers (GDGTs) typical of a productive lake environment. To infer past changes in temperature, lake pH, and the regional hydrologic cycle, we focused on measuring the concentration and abundance of brGDGTs as well as hydrogen isotopes on *n*-alkanes.

Our results reveal a warm, variable climate during the middle Eocene in the North American Arctic (Fig. 1). Mean annual temperatures according to the brGDGTs range from 10-20˚C and the δ^2H values of *n*-alkanes span ca. 60 per mil. The brGDGT temperatures, which are approximately 20-30˚C warmer than present-day, are in good agreement with independent estimates from leaf margin analysis and pollen conducted on the same core sequence. The δ^2H data indicate that in spite of warmer temperature, the isotopic composition of precipitation is roughly similar to modern. This suggests that the climate was substantially wetter, such that heavier rain-out compensated for warmer temperatures. The brGDGT and *n*-alkane δ^2H data indicate an exceptionally warm and wet interval occurred between 77-87

meters. Interestingly, the relative cyclization of the brGDGTs (CBT' index) suggests that the lake was acidified during this time. A "peat-like" isoGDGT distribution and elevated occurrences of acidophile diatoms during this interval provides independent confirmation of acidic conditions. The sedimentary facies of this interval are finely laminated, with no apparent tephra, precluding a local volcanic eruption as the cause of the acidification. We therefore hypothesize that this warm, wet "Mystery Acid Interval" represents a regional climatic event resulting in perturbation of the pH balance of the maar lake system.

Conclusions

Overall, the biomarker evidence from the Giraffe kimberlite pipe indicates the middle Eocene climate in the North American Arctic was warm, wet, and heavily forested. Quantitative estimates from brGDGTs indicate mean annual temperatures 20-30˚C warmer than modern. Considering that middle Eocene temperature estimates from the tropics are ca. 5˚C degrees warmer, this indicates substantial polar amplification during the middle Eocene.

The exceptional preservation of organic matter and wealth of biomarker information recovered from the Giraffe site demonstrates that Canadian kimberlite pipes are unique and valuable archives of terrestrial Arctic paleoclimate. Future efforts to sample and drill neighbouring pipes offer the potential for a high-resolution, continuous record of high-latitude climatic conditions during the Cenozoic greenhouse.

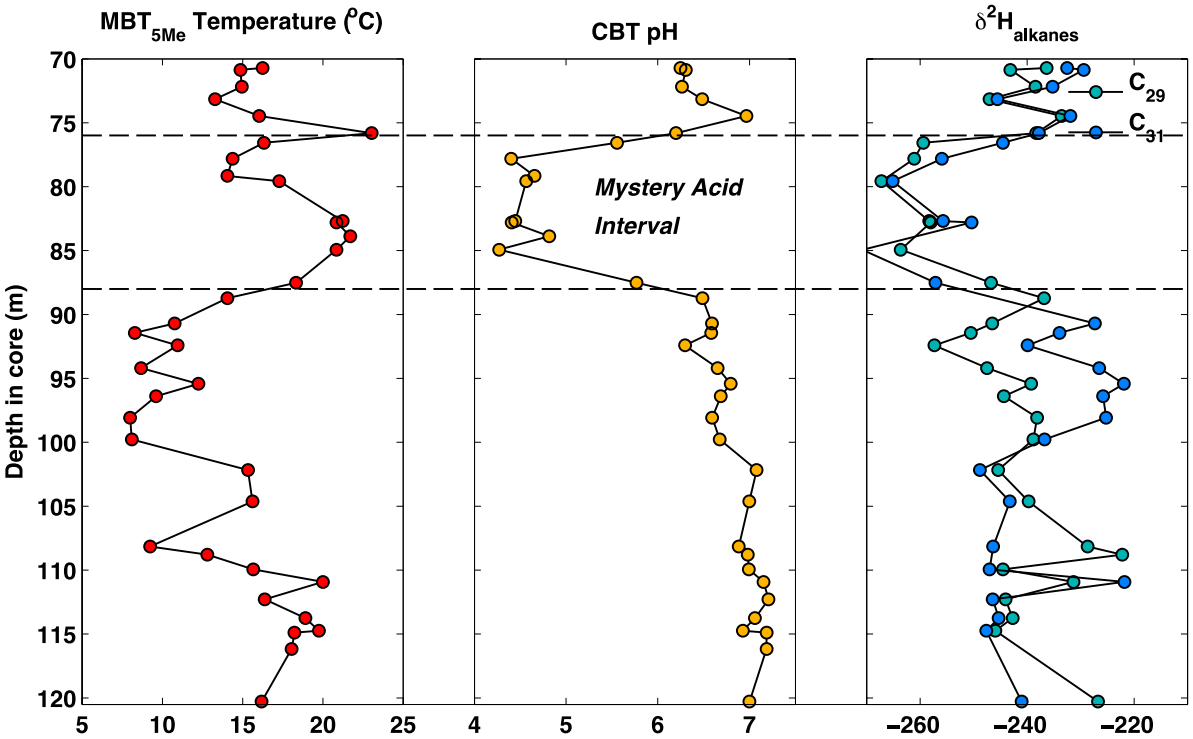

Figure 1 *Biomarker proxy data from the Giraffe pipe from the middle Eocene, including brGDGT-derived temperature and lake pH, and the δ^2H of higher-plant alkanes. Dotted lines denote the "Mystery Acid Interval" (see main text).*

References

[1]Bijl, P. K., Schouten, S., Sluijs, A., Reichart, G. J., Zachos, J. C., & Brinkhuis, H. (2009). Early Palaeogene temperature evolution of the southwest Pacific Ocean. *Nature*, *461*(7265), 776-779.