Influence of the African Megadrought on Vegetation in East Africa

Brett Light[1], Allix Baxter[1], Dirk Verschuren[2], Jaap Sinninghe Damsté[1,3], and Francien Peterse[1]

1 Utrecht University, the Netherlands
2 Ghent University, Belgium
3 Royal NIOZ and Utrecht University, the Netherlands
Contact : b.t.w.light@students.uu.nl

Introduction

- Much of Earth's climate history has been derived from marine sediment cores or ice sheet cores from high latitudes. Detailed records of the continental response to climate change, particularly from low latitudes, are either relatively short (Johnson et al., 2002) or punctuated (Trauth et al., 2005).
- Lake Chala has permanently anoxic bottom waters, which leads to the high preservation of organic material in the sediments, including fossil leaf wax lipids (*n*-alkanes). Leaf wax lipids can serve as proxy to reconstruct the continental vegetation that biosynthesized them.
- Here we use long and mid-chain *n*-alkanes present in the sedimentary record of Lake Chala during the interval 170 to 60 ka, covering Marine Isotope Stage 5 (MIS5) and the last interglacial period, to reconstruct the regional vegetation variability, by identifying the predominant means of terrestrial carbon fixation.
- Seismic surveying of the lake sediments (Moernaut et al., 2010); (Verschuren et al., 2009); indicates a period of intense aridity between 98 - 115 kyrs ago, corroborating previous studies that identified the so-called 'African Megadrought' in Africa's lower latitudes at that time (Scholz et al., 2007).
- The aim of this study, was to find out to what extent the vegetation of the Lake Chala region was impacted by this event.

ICDP project DeepCHALLA

- In 2016, a 215 m core of finely laminated lake sediment (dating back almost 250 kyrs) was recovered from Lake Chala in eastern equatorial Africa (Figures 2 & 3).
- The unique location of Lake Chala just below the equator (Figure 1) makes it a suitable for the reconstruction of tropical vegetation because its located within an area where the Intertropical Convergence Zone (ITCZ) passes overhead twice each year following the migration of peak insolation.
- The twice-yearly passage of the ITCZ, drives the Indian monsoon and delivering moisture to the region. The rainy periods are separated by a dry and windy period during which the oxycline extends deeper into the lake.
- The bottom waters of the lake are permanently anoxic leading to great preservation of organic material.
- A recent vegetation survey of the area, revealed around half of the local vegetation is grassland, one third dry forest and one quarter by moist forest.

Figure 1: Location of Lake Chala, East Africa

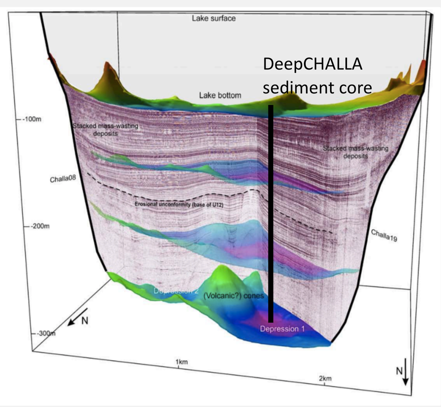


Figure 2: A 3D representation of Lake Chala's sedimentary infill, also showing the coring location (Moernaut et al., 2010).

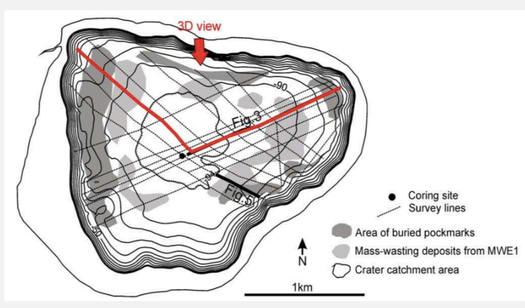


Figure 3: A bathymetry map showing the coring location and seismic survey lines (Moernaut et al., 2010).

Methods

- Long-chain *n*-alkanes are associated with the waxy protective coatings on leaf cuticles (Figure 5) and provide protection from infection, physical damage, and desiccation (Eglington and Hamilton, 1967).

Gas Chromatography (GC)
Relative quantification
→
Gas Chromatography Mass Spectrometry (GC-MS)
Identification of organic compounds
→
Gas Chromatography Isotope Ratio Mass Spectrometry (GC-IRMS)
Measurement of the $\delta^{13}C$ of the n-alkanes

Figure 4: Laboratory instruments used in this investigation.

Proxies used in this investigation

C_3 + C_4 Plants

C_3 plants are typically more temperate species (i.e. trees/shrubs) and C_4 plants are typically more drought adapted species (i.e. grasses).

Average Chain Length (ACL) = $\Sigma(C_n \times n) / \Sigma(C_n)$

The fundamental assumption of this proxy is that woody plants produce leaf waxes with shorter ACL values than non-woody plants (Wang et al, 2015).

Branched and Isoprenoid Tetraether (BIT) index $\mathrm{BIT} = \dfrac{\mathrm{I} + \mathrm{II} + \mathrm{III}}{\mathrm{I} + \mathrm{II} + \mathrm{III} + \mathrm{cren}}$

The BIT index, is based on the relative abundance of terrestrially derived tetraether lipids versus crenarchaeol and used to determine the relative inputs of aquatic autochthonous and terrestrial allochthonous organic matter into lacustrine environments.

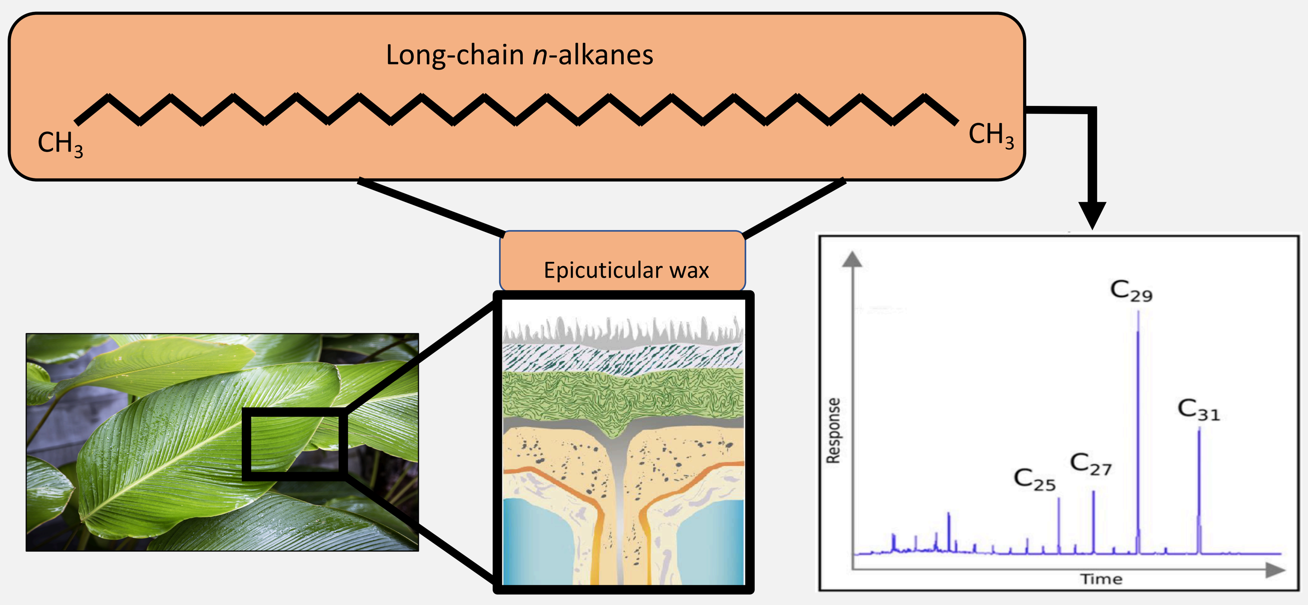
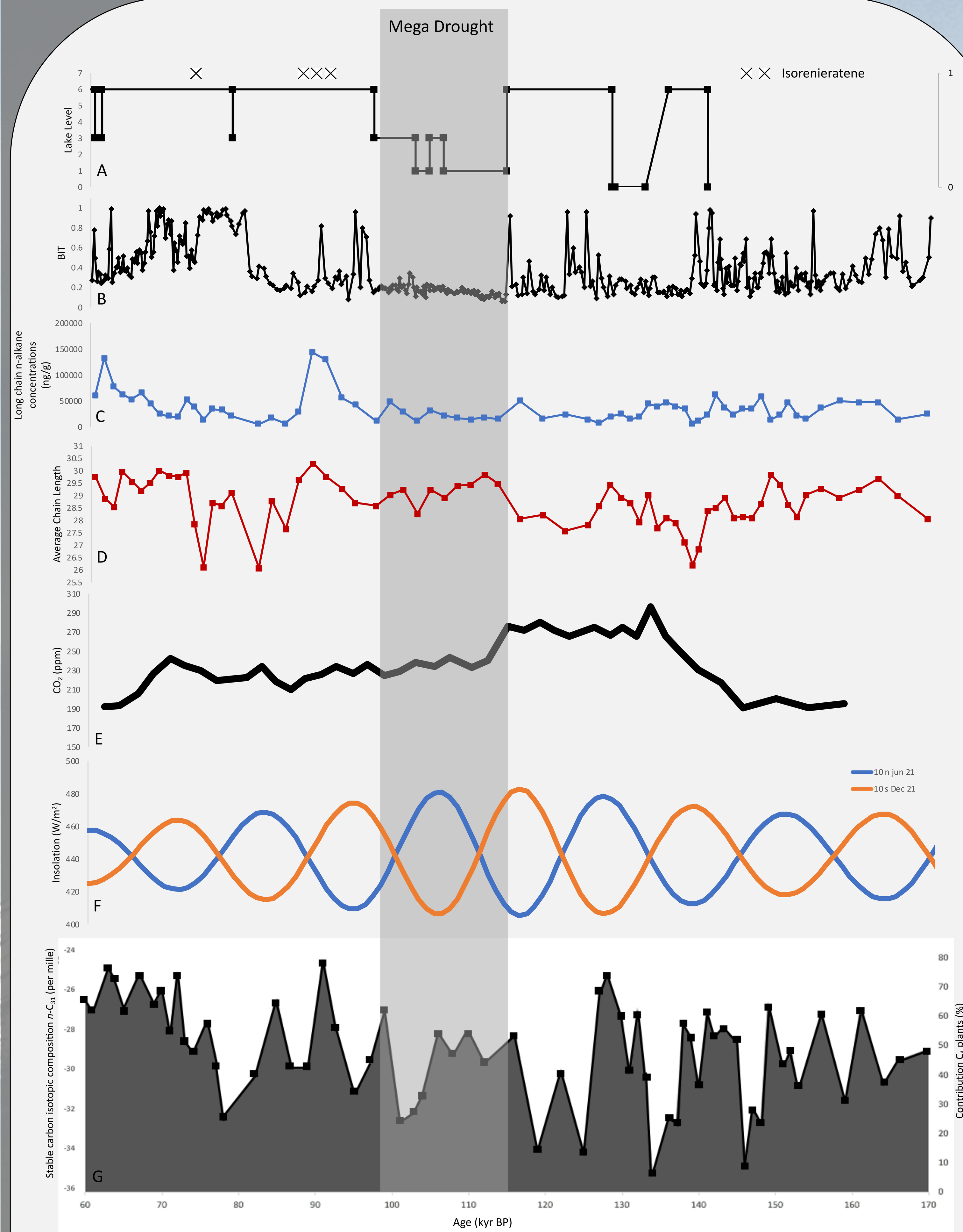


Figure 5: An example of plant epicuticular wax alkanes, and their typical GC traces.

- Higher plants use two fundamentally different pathways for CO_2 fixation; the C_3 (Calvin-Benson) and the C_4 (Hatch-Slack) cycles. The Hatch-Slack cycle pre-concentrates CO_2 before it is fixed by the enzyme Rubisco, culminating in an ecological advantage in arid, hot or low pCO_2 conditions.
- A simple two-member mixing model was used to estimate the %C_4 plant contribution to the sedimentary *n*-C_{31}, based on the average $\delta^{13}C$ values for *n*-C_{31} in C_3 plants (-35.2‰) and C_4 plants (-21.7‰) from a compilation of literature data (Castañeda et al., 2009).

Results



- Seismic surveying of Lake Chala indicates a substantial lake level lowering between 96 – 115 kyr ago (Figure 6a), this is also seen in the BIT record (Figure 6b).
- Complete anoxia in the water column was not achieved during the identified drought because the presence of Isorenieratene a biomarker for green sulphur bacteria found commonly in highly stratified lakes was not found in the analysed sediments. This could possibly due to cooler and more windy conditions at that time promoting a deeper lake mixing regime (figure 6a).
- Despite this considerable change in lake conditions, the concentration of the long chain *n*-alkanes (Figure 6c) remains relatively constant throughout this period, as does the average chain length of the *n*-alkanes (Figure 6d).
- Comparison of the *n*-C_{31} $\delta^{13}C$ record with the BIT rainfall record (Figure 6g) shows little similarity in long-term trends, this suggests that despite considerable hydrological change, it does not seem to have affected the higher plants within this region.
- It appears that rainfall variation by itself is not the single-most important driver in long-term vegetation change in this region of tropical Africa.
- The relative invariant C_3/C_4 ratio during this sampled interval, resembles the main long-term trend in atmospheric CO_2, suggesting substantial control.

Conclusion

- The contribution of C_3/C_4 plants is highly variable (from as much as 85% C4 plants to as little as 10%) throughout the measure time interval (60 – 170 kyr ago).
- Higher plant contribution is relatively stable throughout the lengthy drought period identified in the seismic surveying and BIT record, indicating that C_3 plants were able to cope at this time, despite major hydrological changes.
- The C_3/C_4 ratio used to estimate the relative contributions of more temperate species compared to more drought adapted species, appears to follow the global trend in CO_2.
- Water column mixing in Lake Chala still occurred even despite significant lake level lowering during the recognised drought period.
- The mostly invariant C_3/C_4 ratio, in the period (60 - 75 kyr BP), coincides with diminished insolation variation.

References

- Castañeda, I.S., Caley, T., Dupont, L., Kim, J.H., Malaizé, B. and Schouten, S., 2016. Middle to Late Pleistocene vegetation and climate change in subtropical southern East Africa. *Earth and Planetary Science Letters*, *450*, pp.306-316.
- Eglinton, G., R.J. Hamilton. 1967. Leaf Epicuticular Waxes. Science 156(3780): 1322-1335.
- Johnson, T. C., Werne, J. P., Brown, E. T., Abbott, A., Berke, M., Steinman, B. A., ... & Scholz, C. A. (2016). A progressively wetter climate in southern East Africa over the past 1.3 million years. *Nature*, *537*(7619), 220.
- Moernaut, J., Verschuren, D., Charlet, F., Kristen, I., Fagot, M. and De Batist, M., 2010. The seismic-stratigraphic record of lake-level fluctuations in Lake Challa: Hydrological stability and change in equatorial East Africa over the last 140 kyr. *Earth and Planetary Science Letters*, *290*(1-2), pp.214-223.
- Scholz, C.A., Johnson, T.C., Cohen, A.S., King, J.W., Peck, J.A., Overpeck, J.T., Talbot, M.R., Brown, E.T., Kalindekafe, L., Amoako, P.Y. and Lyons, R.P., 2007. East African megadroughts between 135 and 75 thousand years ago and bearing on early-modern human origins. *Proceedings of the National Academy of Sciences*, *104*(42), pp.16416-16421.
- Trauth, M.H., Maslin, M.A., Deino, A. and Strecker, M.R., 2005. Late cenozoic moisture history of East Africa. Science, 309(5743), pp.2051-2053.
- Van Bree, L.G.J., Peterse, F., Van der Meer, M.T.J., Middelburg, J.J., Negash, A.M.D., De Crop, W., Cocquyt, C., Wieringa, J.J., Verschuren, D. and Damsté, J.S., 2018. Seasonal variability in the abundance and stable carbon-isotopic composition of lipid biomarkers in suspended particulate matter from a stratified equatorial lake (Lake Chala, Kenya/Tanzania): Implications for the sedimentary record. *Quaternary Science Reviews*, *192*, pp.208-224
- Verschuren, D., Sinninghe Damsté, J.S., Moernaut, Kristen I., Blaauw, M., Fagot, M., Haug, G., CHALLACEA project members, 2009. Half-precessional dynamics of monsoon rainfall near the East African equator. Nature 462, 637–641.
- Wang, Y., Zhou, W., Xie, S. and Yu, X., 2015. A comparative study of n-alkane biomarker and pollen records: an example from southern China. *Chinese Science Bulletin*, *54*(6), pp.1065-1072.

Utrecht University
icdp
DeepCHALLA
NAC NEDERLANDS AARDWETENSCHAPPELIJK CONGRES