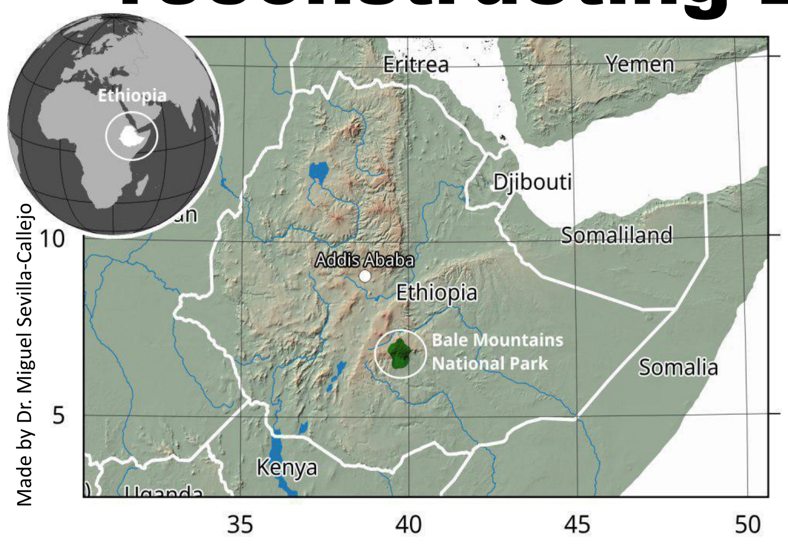
Revisiting Lake Garba Guracha, high altitude lake in the Bale Mountains, Ethiopia: reconstructing Late Glacial – Holocene lake level history using δ2H/δ18O biomarker analyses



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Introduction

The climate of East Africa is driven by the position of the Intertropical Convergence Zone (ITCZ). The intensity and position of the ITCZ related tropical rain belt changes depending on the interhemispheric temperature gradient (Broccoli et al., 2006). During the early Holocene boreal summer insolation maximum, the mean position of the tropical rain belt shifted north leading to increased precipitation across northern Africa (Gasse, 2000). Additionally, an increased land-ocean temperature gradient caused a strengthening of the West African Monsoon (WAM) and Indian Summer Monsoon (ISM) generating a water level rise in African lakes (Junginger et al., 2014; Lezine et al., 2014). This shift to a more pluvial early-mid Holocene (12-5 ka), termed African Humid Period (AHP) (DeMenocal et al., 2000), was particularly intense in North Africa and extended south until 10° S in East Africa (Gasse, 2000). While the general mechanisms for the orbitally-forced AHP are well understood the spatial and temporal patterns are highly debated.
As part of the Research Unit FOR 2358 'The Mountain Exile Hypothesis', we address the question of 'How humans benefited from and re-shaped African high-altitude ecosystems during Quaternary climate changes´. Therefore, we investigated the high-altitude, small catchment, cirque lake Garba Guracha at 3950 m asl. - an ideal sedimentary archive for reconstructing afro-alpine paleoclimate/-environment.
We show geochemical, biomarker and diatom isotope ($\delta^{18}O_{fucose}$ and $\delta^{18}O_{diatom}$) results for the Late Glacial and Holocene.

Specifically, we aim to:

1. **develop a robust chronology,**
2. **reconstruct the sedimentary history and**
3. **the climate and lake level history since the Last Glacial.**

Methods

We analyzed the sediments of Garba Guracha (15.5 m core)

- XRF analysis was performed at Aberystwyth University using the ITRAX™ core scanner.
- Total carbon (TC), total nitrogen (N) and stable carbon and nitrogen isotopic composition ($\delta^{13}C$ and $\delta^{15}N$, respectively) were determined for 110 mixed sediment samples covering roughly 10 cm intervals.
  - TC is equal TOC
- 88 samples were analyzed for $\delta^{18}O_{sugar}$ and $\delta^{2}H_{n\text{-}alkane}$
- 20 samples were analyzed for $\delta^{18}O_{diatom}$

Chronology

For radiocarbon dating, we took a total of **27** samples. Apart from 14 bulk sediment ages, we obtained ^{14}C ages from 8 bulk n-alkane and 5 charcoal samples from the organic-rich top 9 meters of the core.
All ^{14}C ages are in stratigraphic order. The bulk n-alkanes and the bulk sediments samples obtained from the same core centimeters yielded similar ages without any systematic age offset. Additionally, there is no age offset for the two charcoal ^{14}C ages. The surface core (top 70 cm) were ^{210}Pb dated. Tephra layers were analyzed and correlated.

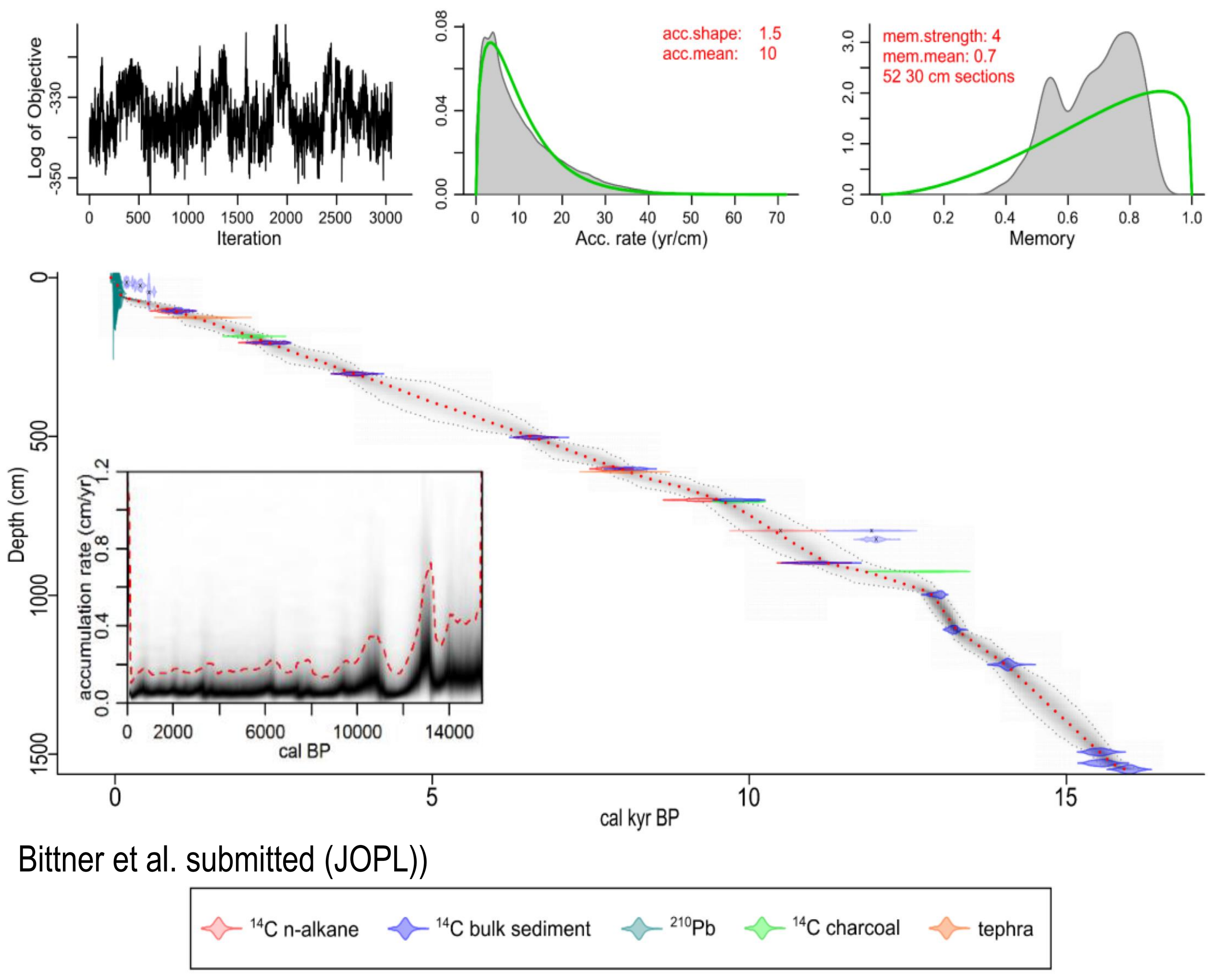

Fig. 1: Age-depth model for the Garba Guracha sedimentary record. The model was created using Bacon (Blaauw and Christen 2011). The main panel displays the depth (x-axis) and age (y-axis) scale. The probability distribution of the calibrated ages is represented as violin plots (modeled ages (blue), non-modeled ages (pink) and tephra ages (68 % probability) of Lake Tilo tephra TT1 and Lake Chamo tephra CHT2 (red). In the lower-left corner, the sedimentation rate with a mean sedimentation rate (dotted red line) is displayed.

Discussion

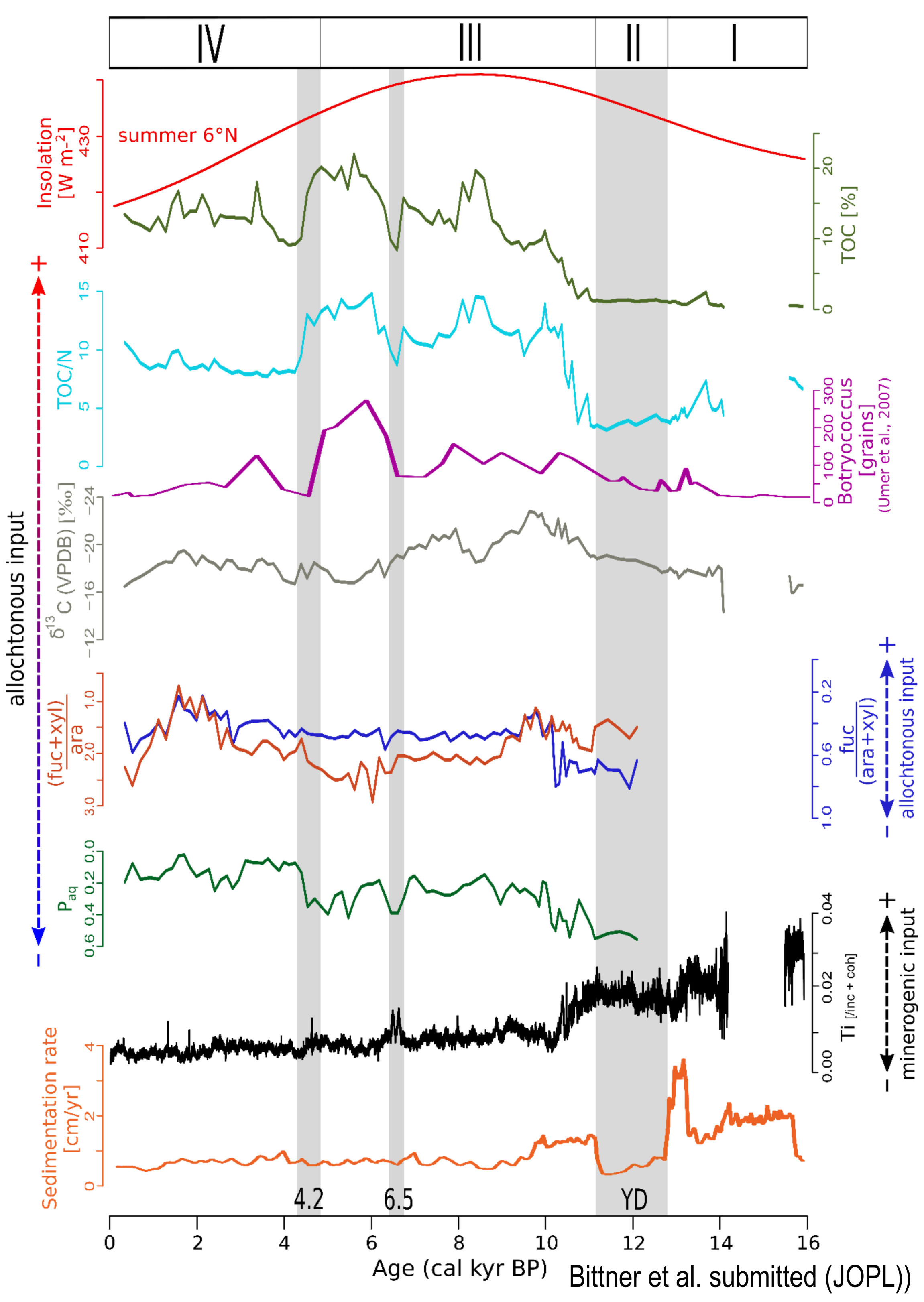

Fig. 2: Summer insolation (Laskar et al. 2011), TOC, TOC/N, Botryococcus braunii (Umer et al. 2007), $\delta^{13}C$, (fuc+xyl)/ara, fuc/(ara+xyl), P_{aq}, titan element and calculated sedimentation rate.

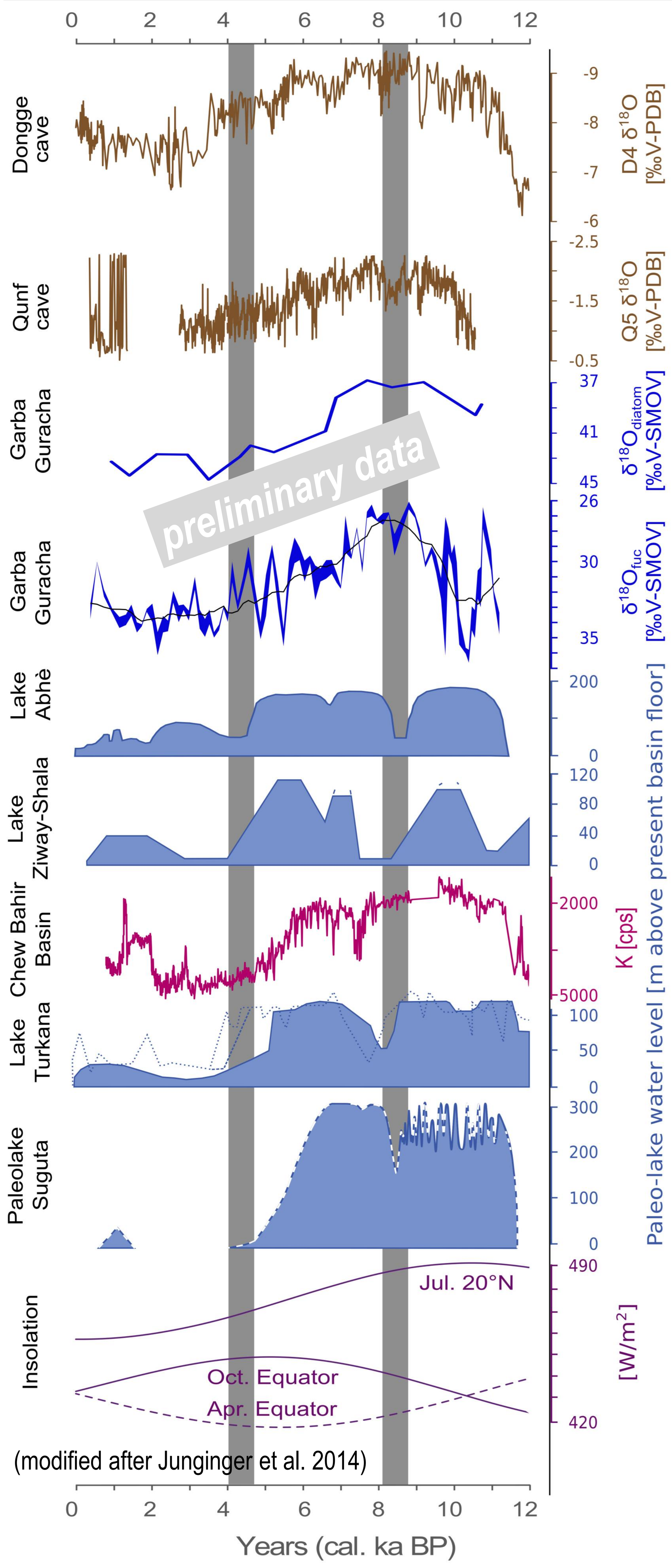

Fig. 3: Comparison of lake level reconstructions in Eastern Africa and $\delta^{18}O$ records for the past 12,000 years (Dongge caves - Dykoski et al., 2005; Qunf cave - Fleitmann et al., 2003; Garba Guracha - this study; Lake Abhè - Gasse, 2000; Ziway–Shala - Gillespie et al., 1983; Chew Bahir - Foerster et al., 2012; Turkana - Garcin et al., 2012 (filled curve), Johnson et al., 1991 (dotted curve), Brown and Fuller, 2008 (dashed curve); Paleolake Suguta - Junginger et al., 2014; and insolation variations (Laskar et al., 2004).

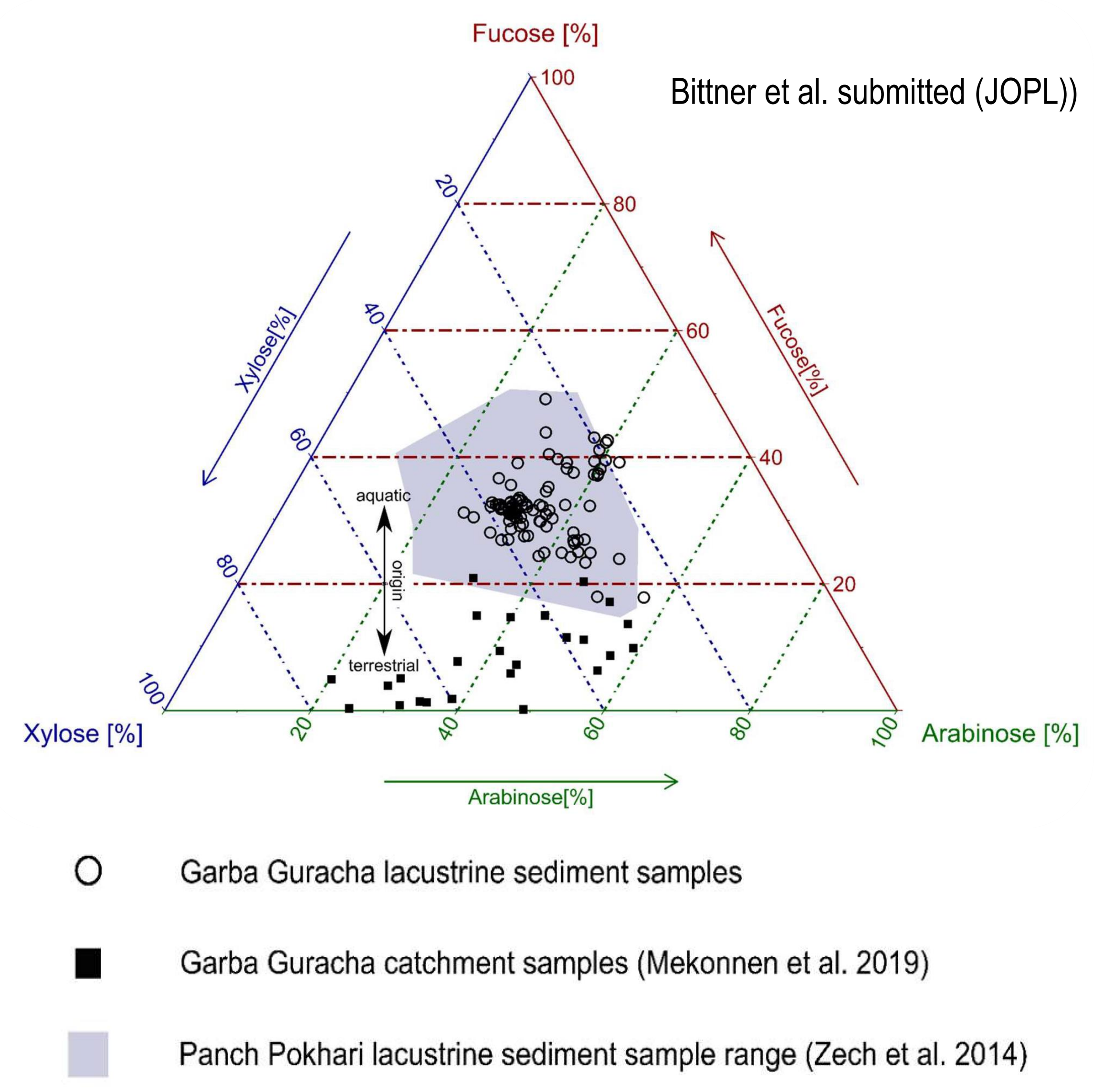

Fig. 4: Ternary diagram illustrating the relative contributions of ara, fuc and xyl in the GG sedimentary record. For comparision, plant, organic layer and topsoil samples from the GG catchment are included (Mekonnen et al., 2019).

Environmental implications

Phase 1 (Fig. 2): High sedimentation rates, high minerogenic input and low TOC values point to fast filling lake bed with a low vegetated catchment. Low TOC/N values and relatively positive $\delta^{13}C$ values point to aquatic algae as dominant organic matter source.

Phase 2: The time period of the northern hemisphere Younger Dryas (YD) is marked by a decrease in sedimentation rate by 80% indicating a dry or/and cold phase.

Phase 3: With increasing insolation TOC and TOC/N reach the highest values between the Holocene onset and 4.3 ka (ca. African humid period - AHP) pointing to a phase of favorable growth conditions. Most negative $\delta^{18}O$ values support high rainfall amounts (amount effect), a different moisture source (source effect) or/and a high P/E value and an overflowing lake. North-hemisphere cold spells (8.2 and 6.5 ka event) are visible in different proxies.

Phase 4: A rapid change in TOC, TOC/N concur with the 4.2 ka event known as a shift to dryer conditions.

Conclusions

- Dating of compound class *n*-alkanes is a valuable tool for lake sediment dating in small catchment areas
- The minimum age of deglaciation is ~16000 cal. yrs BP)
- $\delta^{18}O_{fucose}$ can be used as proxy for $\delta^{18}O_{lake\ water}$
  - $\delta^{18}O_{diatom}$ as aquatic signal supports this finding.
  - Most negative $\delta^{18}O$ values agree with other records from the region (Fig. 3) pointing to increased precipitation or/and a different moisture source.
  - Moreover, the range of $\delta^{18}O_{fucose}$ can not be explained by source and amount effect alone. Evaporative enrichment must be considered interpreting the $\delta^{18}O_{sugar}$ record.
- Most negative $\delta^{18}O$ values between 10 and 7 ka concurring with the AHP indicating a high P/E ratio and an overflowing lake.
- Northern hemisphere events (8.2, 6.5, and 4.2 ka) are visible in the Garba Guracha record

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