Paleoenvironmental Reconstruction of the Turkana Basin through Pedogenic Carbonate Analyses

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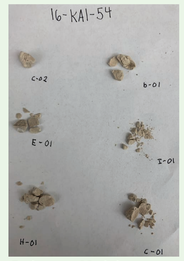
Abstract

Eastern Africa contains a well-preserved pedogenic carbonate record, useful for contextualizing the paleoenvironment associated with key fossil and archeological evidence. One significant paleoanthropological discovery from the Turkana Basin in Kenya was Nariokotome Boy, one of the most complete examples of Homo erectus discovered to date. This site is directly associatedwith a paleo-Vertisol and the Natoo tuff, enabling stratigraphic correlation into outcrop records. Leveraging this opportunity, we analyzed stable isotopes of pedogenic carbonates (n=74) to study the paleoenvironmental conditions in the Turkana Basin for three time slices between 1.9 and 1.2 Ma. We interpret that the narrow range of δ18O values implies the presence of one main water source throughout the time interval. Variation in δ13C, with a standard deviation of 1.5‰ and range of 6.9‰, can thus be considered a function of landscape heterogeneity rather than changing water source. Woody cover estimates from the paleosols within this study interval suggest this area was a wooded grassland despite a significant first-order paleoenvironmental change from a marginal lacustrine environment to a fluvially-dominated one. While our record cannot resolve variability on a millennial scale, the lack of significant long term trends in percent woody cover suggest that Nariokotome Boy and other hominin communities inhabited a paleoenvironment which was relatively stable in terms of vegetation composition despite a major lacustrine regression.

Methods

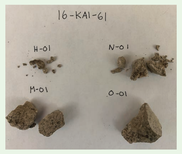
Fresh surfaces of individual pedogenic nodules were drilled for powder. One sample was drilled per nodule. The powders were weighed out on a microbalance, within a range of 200-300 µg. The samples were run through a mass spectrometer and were compared with a set of standards to measure $\delta^{18}O$ and $\delta^{13}C$. These values were then used to calculate the percent woody cover, following the equation of Cerling et al. (2011):

$$f_{WC}=\{\sin(-1.00688-0.08538*(\delta^{13}C_{carbonate}-14‰)\}^2$$



Carbonate Nodules

Labeled Carbonate Samples



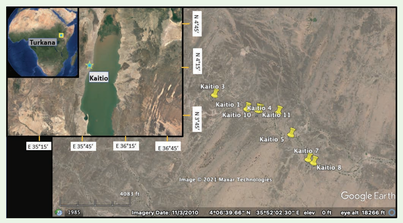
Carbonate Nodules


Mass Spectrometer

Geologic Context

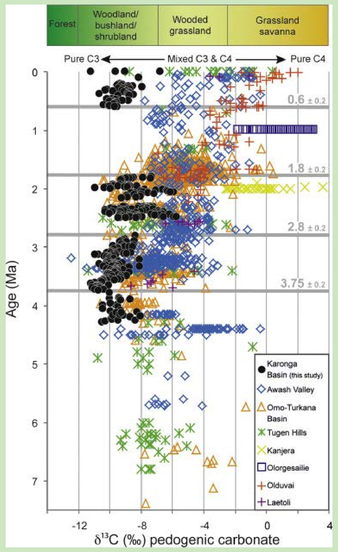
Study Area

Pedogenic carbonate samples were collected in the Turkana Basin (Kenya) within the East African Rift System. The Nachukui Formation, a section of the Omo Group, preserves a geological record of dynamically changing environments. The carbonate samples we analyzed belong primarily to the Kaitio, Natoo, and Nariokotome Members of the Nachukui Formation.



Map of sampling location. The African continent is depicted on the top left corner. The Turkana Basin is shown in the middle image, with the West Turkana Kaition designated by a blue star. Individual sampling locations are marked by yellow pins in the rightmost image. From Google Earth.

Compilation of Pedogenic Carbonate $\delta^{13}C$ Data



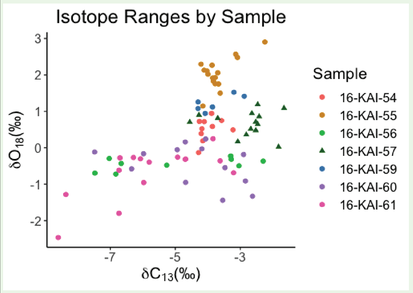
Ludecke et al., 2016

Pedogenic Carbonates

Pedogenic carbonates form when inorganic calcium carbonate is leached downwards in the soil and then precipitates (Zamanian et al., 2016). They exist in a wide range of forms, including rhizoliths, calcretes, and nodules.

$\delta^{18}O$ and $\delta^{13}C$ values from pedogenic carbonates are used in paleoclimate reconstruction to estimate the relative composition of C_3/C_4 vegetation and precipitation. An extensive record of pedogenic carbonate isotope values has been compiled across East Africa (Ludecke et al., 2016). The carbonates analyzed within this study fall into the 1.9-1.2 Ma range.

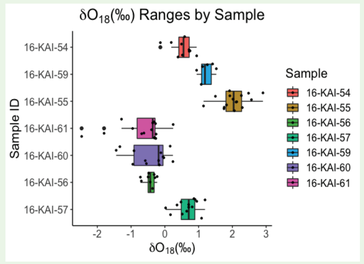
Results

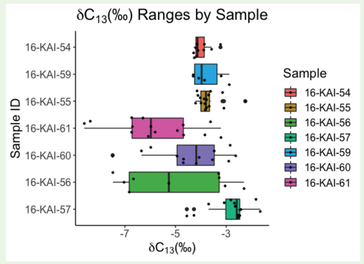


Scatterplot of $\delta^{18}O$ vs $\delta^{13}C$ of pedogenic carbonate samples. Rhizolith samples are represented by triangles.

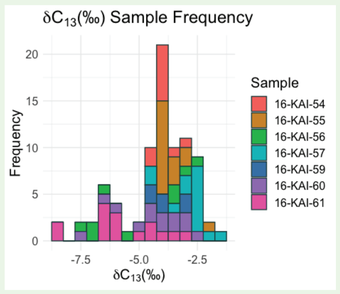
Oxygen-18

The range of all $\delta^{18}O$ values is between -2.5 to 2.9 ‰. Within each sample, the maximum data spread was roughly 1 ‰. The mean of all $\delta^{18}O$ data is 0.42 ‰ and the standard deviation is 1.1 ‰. Assuming a constant temperature, the isotope values are primarily influenced by water source and evaporation rate. The data does not indicate the presence of varying water sources.





Box and whisker plots of pedogenic carbonate $\delta^{18}O$ vs $\delta^{13}C$ values. Samples are in stratigraphic order.

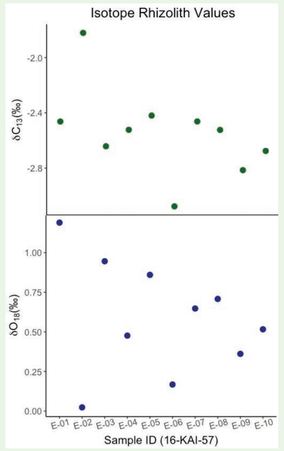


Frequency histogram showing distribution of $\delta^{13}C$ values across sampled carbonates

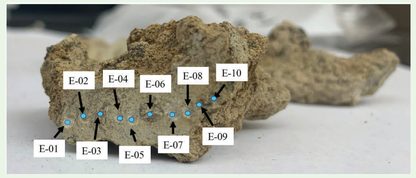
Carbon-13

The range of all $\delta^{13}C$ values is between -8.6 to -1.7 ‰. Within each sample, the maximum data spread was roughly 5.2 ‰. The mean of $\delta^{13}C$ data is -4.2 ‰ and the standard deviation is 1.5 ‰. The most variable $\delta^{13}C$ values were reported for sample 16-KAI-56. The corresponding $\delta^{18}O$ range is relatively narrow, leading to the interpretation that the wide variability in vegetation was a result of landscape heterogeneity rather than precipitation patterns.

Discussion



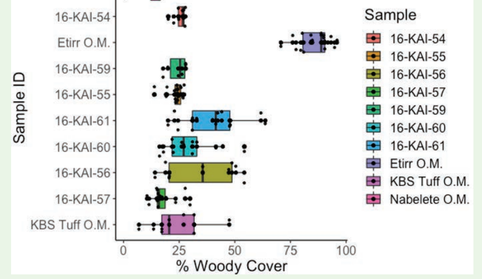
Scatterplots of rhizolith $\delta^{18}O$ vs $\delta^{13}C$ values



Drilled Rhizolith

For the time range represented by the rhizolith, the paleoenvironment was relatively consistent, as represented by the small variation in isotope values ($\delta^{18}O$: 0.0 to 1.2, $\delta^{13}C$: -3.1 to -1.8). The more depleted carbon-13 value in the dark, circular center of the rhizolith may be a function of higher organic matter content.

The majority of percent woody cover estimates fall in the range of 10-50% and can be classified as wooded grasslands. Carbonates (16-KAI) and organic matter from the KBS Tuff and Nabelete yield a consistent range of % woody cover. The Etirr soil organic matter acts as an outlier. Mean annual precipitation calculated from the organic matter samples is 762 mm (CalMag weathering index) and 813 mm (CIA-K weathering index)



Box and whisker plots of percent woody cover from sampled carbonates (16-KAI), estimated using the equation from Cerling et al. (2011). Plotted data is in stratigraphic order and includes organic (O.M.) matter percent woody cover estimates from Manning (2021). Analog scale representing paleovegetation in the tropics taken from Sikes and Ashley (2007).

Modern Habitats

Modern day habitats in Kenya classified by C_3/C_4 composition from Cerling et al. (2014). (b) Woody grassland in Samburu National Preserve, 20% woody cover. (c) Riparian grassy woodland in Tsavo East National Park, 40% woody cover.

Conclusions

- A narrow range of $\delta^{18}O$ values indicates that there was one fixed water source in the area from 1.9 to 1.2 Ma. $\delta^{13}C$ variation cannot be attributed to changing water source, but rather environmental heterogeneity.
- Samples with a wider range of $\delta^{13}C$ represent a more heterogeneous landscape. The region experienced a decrease in % woody cover and a transition to more stable vegetation composition. With the exception of the Etirr soil, this is the general trend.
- Due to the 68.2 ‰ difference in means between 16-KAI-59 and Etirr O.M. (same stratigraphic layer), we hypothesize that the Etirr O.M. measurements were skewed by inorganic carbonate and thus should be reanalyzed.