Testing Hypotheses for the Role of Climate Change in Hominin Evolution Using the Geochemistry of Carbonates from the East African Rift System

UCLA

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ABSTRACT

A series of major hominin speciation events that took place in East Africa during the Pliocene-Pleistocene epochs have been linked to landscape evolution. Previous studies examining the role of climatic and environmental pressures on hominin evolution have used either discontinuous outcrops exposed proximal to, or marine sediments distal from, hominid fossil sites. These sediments have been used to develop stable carbon and oxygen isotope (**$\delta^{13}C$, $\delta^{18}O$**) proxy-based reconstructions of ancient environments, showing evidence for a series of changes including a transition from woodland to savannah-dominated environments. This work has prompted researchers to hypothesize that speciation events coincided with cooling of the African climate and local aridification during times of glacial intensification. It is speculated that local environmental pressures led to an increase in brain size, breakthroughs in stone technology, and the migration of Homo sapiens out of Africa. However, recent clumped isotope reconstructions from soil carbonates (Passey et al., 2010) have challenged this hypothesis, depicting relatively high and stable temperatures during the past 4 My. To find resolution between these competing hypotheses, we are examining paleosols and lake sediments near hominin fossil sites, including recently recovered drill cores that provide access to an unweathered and continuous archive of past environmental change. Isotopic data (**$\delta^{13}C$, $\delta^{18}O$, and Δ_{47}**) are used to constrain past changes in vegetation, hydrology, and temperature.

METHODS

Drilled cores were collected >50 cm below preserved soil horizons. No extra preparation was required, as organic content was very low. Samples were weighed out in batches of 5.6-6.5 mg and dissolved in phosphoric acid to produce CO2 and water. Once water was separated out of this mixture, CO2 isotopic ratios were measured using a mass spectrometer. Using these isotopic ratios, paleoenvironment and paleotemperature were deduced.

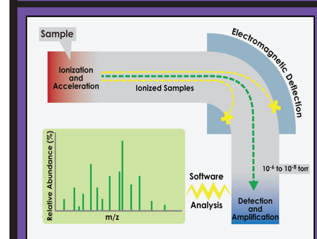


Figure 1 – A simplified depiction of mass spectrometry.

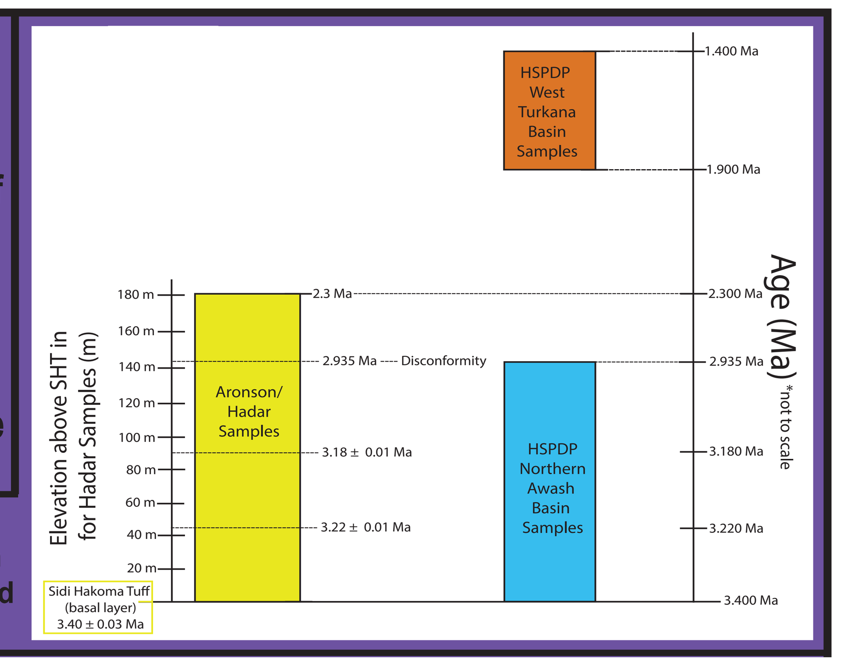


Figure 3 – Age relationships between the 3 localities analyzed in this study.

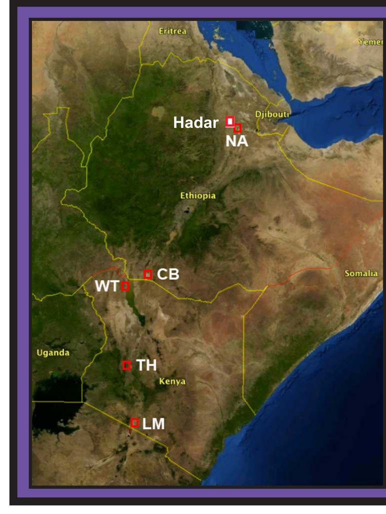


Figure 2 – The general localities of five of the six HSPDP drilling sites. HSPDP samples were collected from the Northern Awash (NA) and West Turkana (WT) regions. Aronson samples were collected from the Hadar region (in close proximity to the NA core).

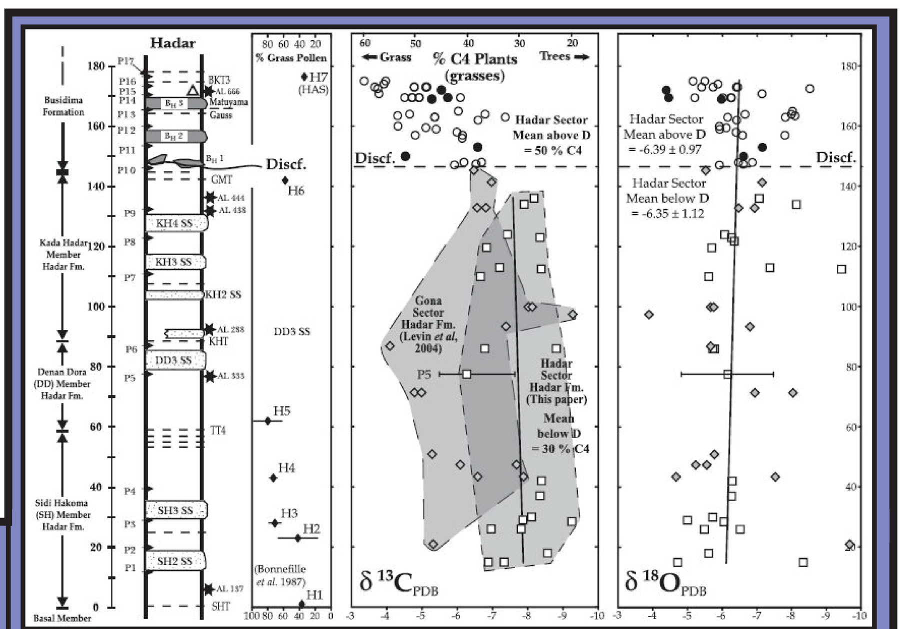


Figure 4A–From Aronson et al. (2008), the above plots depict vegetation and rainout trends using carbonate isotopic data.

HADAR PALEOSOLS

Given that confident conclusions are generally drawn from samples with 3-5 replicates each, the interpretation of these data are preliminary. Here, we only discuss trends defined by samples that have multiple replicates (i.e. data that are shown in filled data points).

C and O isotope systematics: δ13C and δ18O are particularly useful for paleoenvironment studies; more specifically, vegetation and rainout can be constrained with these stable isotope studies. More negative δ13C values can correspond to environments containing C3 plants (adapted to wetter environments), while less negative values can correspond to C4 plants (adapted to more arid environments)(Fig. 4A). Furthermore, in a pool of vapor that has experienced more rainout, heavier isotopes are preferentially removed while lighter isotopes remain, a process which, along with higher temperatures of carbonate precipitation, is reflected in progressively more negative values of water δ18O (Fig. 4A).

Findings: In the plot of δ13C of Hadar paleosols (Fig. 4B) we observe a trend of increasingly positive δ13C values both from ~3.4-2.9 Ma (underneath a disconformity present in this locality), and following the Hadar disconformity (~2.9-2.3 Ma). This observation is consistent with Ethiopian vegetation constraints (Aronson et al., 2008), and can be explained by this region of East Africa experiencing aridification, with paleoenvironment transitioning from biomes adapted to wetter environments, to biomes adapted to drier environments. Combined with the evolution seen over time in hominin fossil records, it can be assumed that this transition was one from woodland to savannah biomes as has previously been reported.

In the plot of carbonate δ18O for Hadar paleosols (Fig. 4B), we observe a trend towards more negative values pre-disconformity, and less negative post-disconformity. Carbonate d18O reflects both temperature and water d18O, which we deconvolve using clumped isotope measurements.

Our reconstruction of paleotemperature from clumped isotopes is still underway. Preliminary results (Figure 4B) show that from ~3.4-2.9 Ma, mean values are approximately 29 °C, and cool by about 2 °C to 27 °C above the disconformity (~2.9-2.3 Ma). Future work will include replication of sample values and assessing if this shift is in fact robust, as well as significance tests. It is worth noting the shift is synchronous with intensification in Northern Hemisphere glaciation, global cooling, and a reduction in atmospheric CO2 levels. We also note that variability in temperatures below the disconformity is reduced compared to above the disconformity, when temperature values exhibit a slightly wider range. This pattern is consistent with greater climate variability during times of intense glaciation post 2.9 Ma. These results and interpretations are tentative; however, we note the pattern is consistent with previous interpretations and essentially support cooling conditions in East Africa linked to aridity and vegetation changes from about 3 Ma onwards, coincident with turnover in the hominin fossil record.

Shown in Fig. 4B is a plot of water δ18O. Water δ18O is highly sensitive to changes in [1] ice volume changes in polar regions (~1 ppm) [2] temperature of tropical and subtropical source waters (~1 ppm) and [3] cloudmass trajectory and/or [4] rainout. Given that the Hadar samples depict a range of 1 ppm to -8 ppm, for the most part, ice volume and source water temperature fluctuations would not significantly contribute to such a large range of values. Hence, we presume that the large scatter of water δ18O values is a result of changes in the trajectory and/or rainout of the cloudmass' delivering the water from which carbonates precipitated. One possible explanation that has previously been suggested is that paleorainfall during the Pliocene-Pleistocene periods in Hadar was sourced from far-travelled, Atlantic air masses pulled eastwards towards the Tibetan Low, which would have resulted in isotopically heavier rainfall in Hadar (Aronson et al., 2008) as the region became more arid.This change in water isotopes could also be due to the development of rift shoulders and subsequent changes in elevation arising from magmatic and tectonic activity in the East African Rift System.

CLUMPED COMPARISON

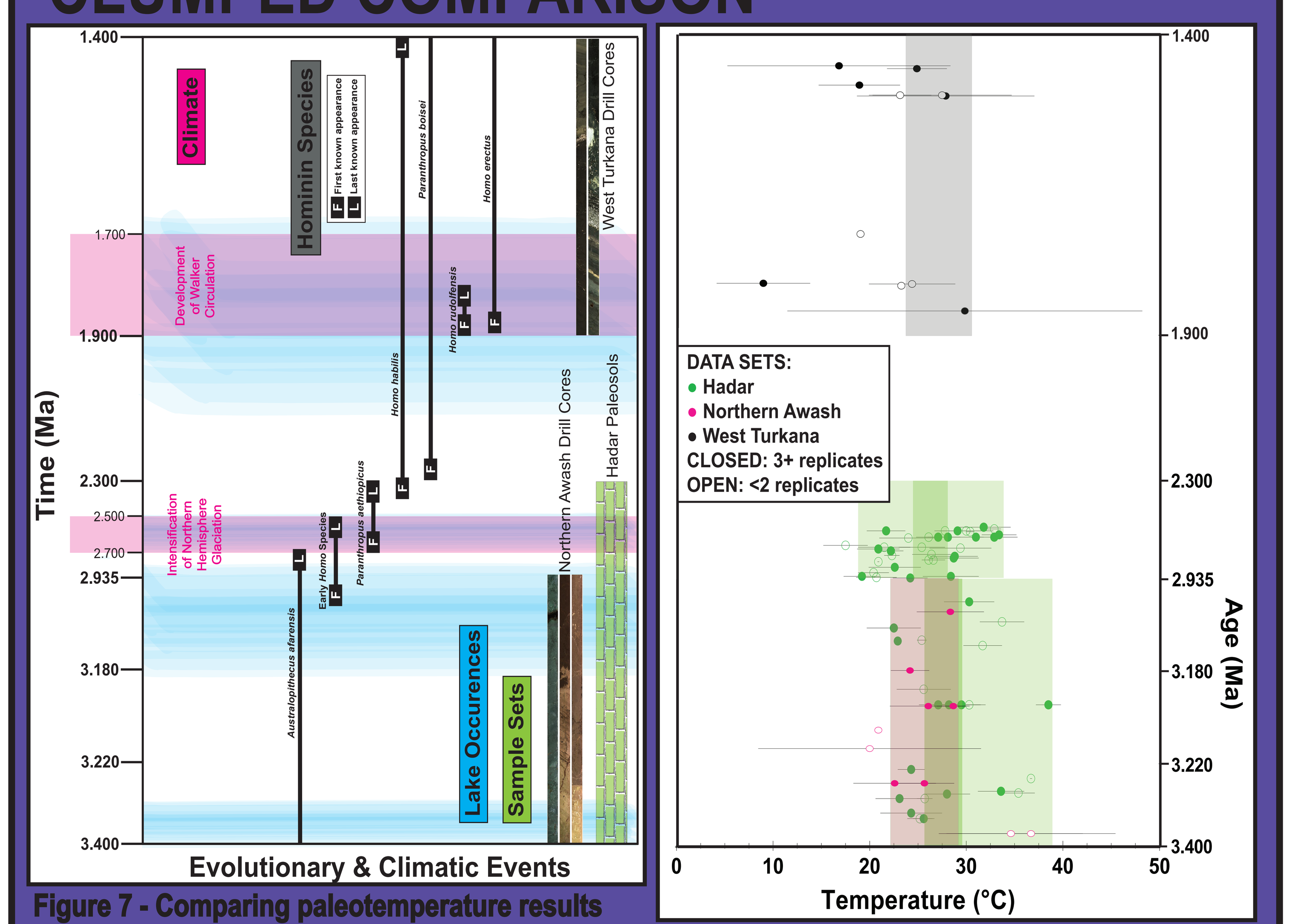


Figure 7 - Comparing paleotemperature results obtained in this study with evolutonary/climatic events of significance for the three studied basins.

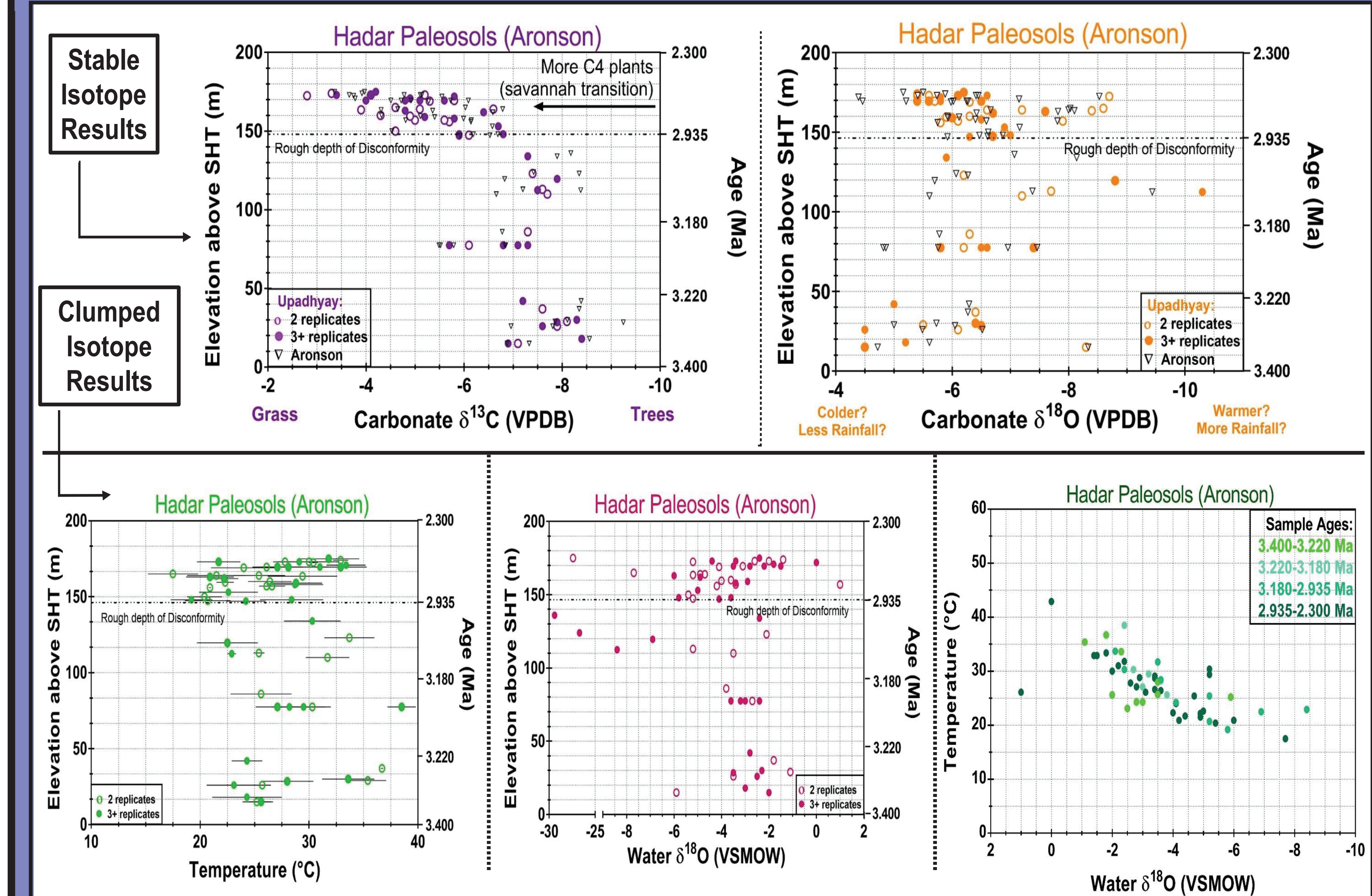
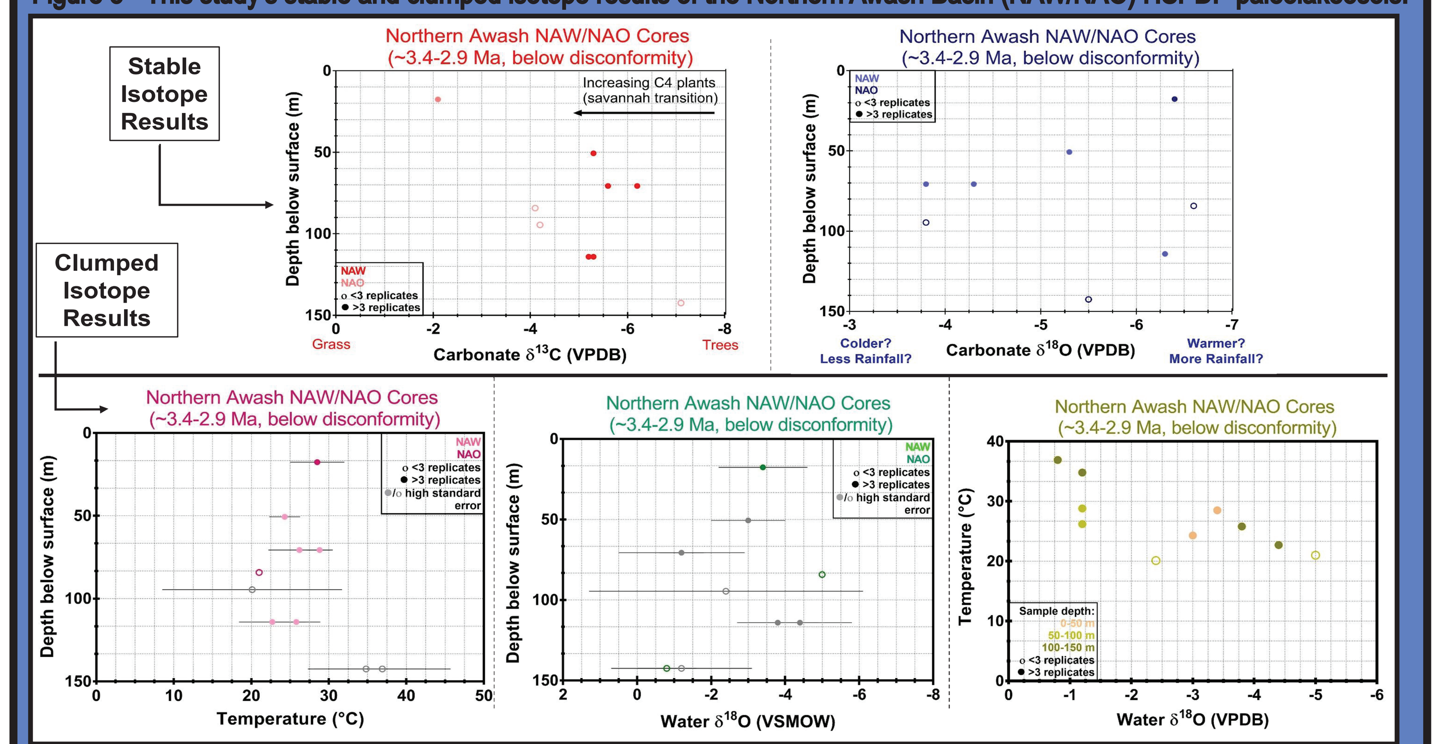


Figure 4B - This study's stable and clumped isotope results of Aronson's Hadar paleosols.

HSPDP NORTHERN AWASH DRILL CORES

Figure 5 - This study's stable and clumped isotope results of the Northern Awash Basin (NAW/NAO) HSPDP paleolakeosols.



Referencing Figure 5, **$\delta^{13}C$** values for the NA tend to center around -5 ppm. This value implies about 50% of the vegetation from ~3.4-2.9 Ma consisted of C4 grasses, while the majority of the vegetation of this area was comprised of C3 trees/shrubs (Aronson et al., 2008).

$\delta^{18}O$ values in the NA locality seem to portray a large amount of scatter. The same can be said concerning paleotemperature data; it appears as though temperatures remained relatively stable over time in Northern Awash (until 2.9 Ma),a conclusion which is, with reservation, consistent with the paleotemperature trend observed during the ~3.4-2.9 Ma period in Hadar (proximal to NA).

Regarding both the carbonate **$\delta^{18}O$** vs. temperature and water **$\delta^{18}O$** plots for NA, as with the stable isotopic measurements, scatter is significant enough that no reliable conclusion may be drawn without increasing the resolution at which we examine this region during this time period.

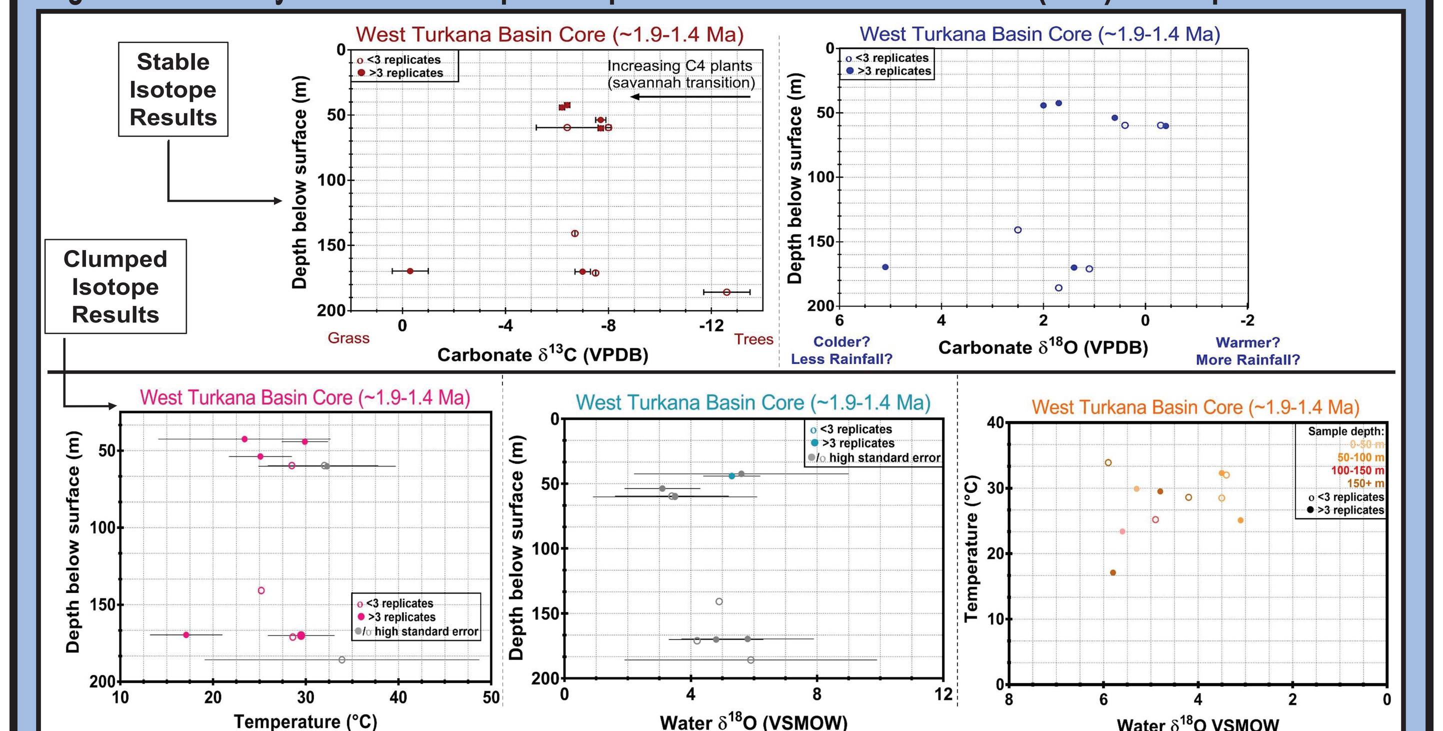
HSPDP WEST TURKANA DRILL CORE

Referencing Figure 6, it seems that **$\delta^{13}C$** tend to center around -7 ppm (impying about 35% of the Pleistocene vegetation in the area consisted of C4 grasses), while **$\delta^{18}O$** values for the WTK tend to encompass a wide range of scattered values.

It appears that paleotemperatures remained somewhat constant, centering between 20-30°C, tentatively matching our expectations of a cool Pleistocene Eastern Africa.

Again, no firm conclusion can be drawn without higher resolution.

Figure 6 - This study's stable and clumped isotoperesults of the WestTurkana Basin (WTK)HSPDP paleo-lakeosols.



CONCLUSIONS

Using $\delta^{13}C$, $\delta^{18}O$, and Δ_{47} data from Hadar paleosols, we are able to reconstruct paleoclimate and constrain vegetation of the Hadar region. We tentatively find the aridification and ***slight*** cooling of East Africa over time, a factor which led to a transition of vegetation from a C4 woodland biome towards a C3 savannah environment and which is hypothesized to be a major factor in hominin evolution. Regarding the HSPDP Northern Awash and West Turkana drill cores, we see no clearly defined trends and conclude that higher resolution is required to test whether the lack of a significant difference between populations is robust.

FUTURE PLANS

Further work upon this project includes analyzing the remaining Hadar samples for up to three replicates, and boosting the resolution of the HSPDP datasets in order to perform comparative isotopic analyses on both sets.

ACKNOWLEDGEMENTS

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