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Cover Page Footnote

I would like to thank Kevin Takashita-Bynum, Gary Stinchcomb, Naomi Levin, Jay Quade, Nels Iverson, William McIntosh, Nelia Dunbar, Lee Arnold, Mathieu Duval, Michael Rogers, Sileshi Semaw, Javus Yandal, and Margaret Peck for their help in the lab as well as the National Museums of Ethiopia, the Afar people, and ARCCH. This project was made possible in part by the National Geographic Society (Grant EC-52923R-18), the Geological Society of America, the Watershed Studies Institute, and the Office of Research and Creative Activity at Murray State University.

STEEPLECHASE ORCA Student Journal Research Snapshot

Evidence of variable climate and resources during the Late Pleistocene and Holocene at Gona, Ethiopia

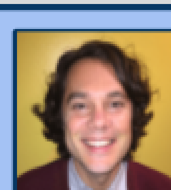
Marie White
BSc in Geosciences, Earth Science Area
Class of 2020

I didn't know what I was in for when joining the Stinchcomb lab or just how much dirt could teach you. I fell in love with soil science – especially ancient soils. Paleontology, archaeology, and geology have always intrigued me, but getting to tie them all together and recreate past environments at famous hominin sites is a dream come true. A whole new world has been opened up to me, and I've found that I'm passionate about this particular field of science, the field in Africa, and sharing my research and talking about science with other people. Additionally, I'm the president of Murray State's GeoClub and Dressage Club. I hope to continue studying paleosols and paleoenvironment when I start my Master's degree in the Fall of 2020.

Abstract

The African Humid Period (AHP) spanned a period of approximately 15 to 5 thousand years ago (ka) and resulted in Northern and Eastern Africa being wetter than today. This climate change event impacted flora, fauna, and humans to an unknown extent. Much of the work on the AHP across Eastern Africa utilizes lacustrine and marine proxies rather than river-based (fluvial). Gona, located in the Afar region of Ethiopia, is known for its extensive archaeological and fossil records in fluvial deposits. However, the paleoenvironment of the AHP at Gona has not been investigated. This study uses stratigraphy, geochronology, and paleopedology to reconstruct the Late Pleistocene and AHP paleoenvironments. We examine two paleosols, the Odele and Erole paleosols, located in the Asbole study region of Gona. The Odele paleosol is between the Korina Tuff (<39 ka) and the Kilaitoli Tuff (~25.7 ka) and weathered during late-stage MIS-3 and MIS-2 during the Late Pleistocene. The Erole paleosol, a relict soil that weathered during the AHP, is ~15 m above the Kilaitoli Tuff and immediately above a calibrated 14C age of 12 ka. Both paleosols formed along paleo-tributaries of the ancestral Awash River, as only matrix-supported gravels are found. The Erole paleosol is darker and may have more organic matter than the Odele paleosol. Average strain calculations using paleosol geochemistry show a volumetric collapse on the order of 34 ± 4% in the Erole paleosol and little to no dilation/collapse in the Odele paleosol, 0 ± 2%. Calculations of open-system mass transport of elements through the profiles (Tau) show an 18 ± 7% loss of SiO_2 and a 69 ± 5% loss of CaO in the Erole paleosol, which are greater than the 2 ± 1% loss of SiO_2 and 1 ± 3% loss of CaO in the Odele paleosol. These strain and tau results suggest more intense weathering and elemental loss in the Erole paleosol. The geochemistry is consistent with recent paleoclimate reconstructions, where an increase in collapse and elemental loss from the Odele to the Erole paleosol coincides with increased rainfall from the Late Pleistocene to the AHP. Specific paleoenvironmental indicators, as well as the evident increase of rainfall and the presence of grasslands, provide more abundant and diverse resources to Homo sapiens living in Gona during AHP time.

Gary Stinchcomb is an Assistant Professor in the Watershed Studies Institute and Department of Geosciences at Murray State University. He holds a BA from Penn State (2001), MS from Temple University (2006), and a Ph.D. from Baylor University (2012). He served as a postdoctoral fellow at Penn State, focusing on soil geochemistry. His research interests include studying soil geomorphic response to environmental change. He currently studies soils in Ethiopia, Kenya, and the USA. Some of his current work focuses on buried soils and paleoflood deposits along the Middle Tennessee and Delaware Rivers with the aim of reconstructing relative flood magnitudes and frequencies during the Holocene. He's also interested in the processes involved in the burial and storage of carbon along river valleys.



Gary Stinchcomb
Assistant Professor

Introduction

East Africa is a focal point of many hallmark events in the history of human evolution and migration with evidence linking these events to climate change (deMenocal, 1995). This region records millions of years of hominin evolution, from *Ardipithecus ramidus* to anatomically modern *Homo sapiens*, in sedimentary deposits. Fossil and archaeological deposits are well-dated due to the volcanic nature of the East African Rift System, as tephra and ash deposits are readily dated and correlated across sites (Feibel, 1999; Roman et al., 2008). Climate reconstructions using dust and pollen deposits in marine sediment cores, as well as paleolimnology (lake levels and cores) in the region, suggest a gradual shift towards aridity since 2.8 million years ago (Ma), with oscillations being attributed to orbital forcings driving non-linear, rapid, and large-amplitude climate change. In the case of the AHP, increased levels of insolation resulted in the intensification of the African monsoon, which led to a series of positive ocean and vegetation-related feedbacks (deMenocal, 1995; deMenocal et al., 2000).

An important locality that holds clues to the story of human evolution and climate change in East Africa is Gona, Ethiopia, with six million years of sedimentary, fossil, and archaeological records (Quade et al., 2004,2008; Wynn et al., 2008). The most recent period of climate change in this area, the African Humid Period (AHP), is present at Gona and spanned 15 to 5 thousand years ago (ka), according to lacustrine and marine proxies (Beck et al., 2018; Costa et al., 2014; Foerster et al., 2015; Mercone et al., 2000). Yet, few reconstructions using paleosols have been performed for the AHP, despite deposits present in the Busidima formation at Gona and nearby Dikika (Wynn et al., 2008). The use of fossil soils, known as paleosols, provides a direct environmental analysis of the location where a soil formed (Beverly et al., 2018), providing a more localized view of past environments. These paleosols are useful to anthropologists and archaeologists working at hominin sites in East Africa as they provide paleoenvironmental context of artifacts and fossils. Conversely, marine and lacustrine paleoenvironmental proxies are limited in offering a localized view of as they integrate over a larger spatial area.

This study uses sedimentology, stratigraphy, and paleosols to examine how the wetter African Humid Period affected past environments at Gona compared to a drier Late Pleistocene interval. The results are discussed in terms of potential resources available to those hominins during two unique climate intervals.

Methods

Field sites and location: The study area is the Gona paleoanthropological project area in the Afar regional state of Ethiopia, encompassing ~130 km^2 (Figure 1). The project area is known for the fossil presence of *Ardipithecus* sp., *Australopithecus* sp., and *Homo* sp. (Quade et al., 2004, 2008), as well as some of the oldest known stone tools, dating from ~2.6 Ma (Semaw at al., 2003).

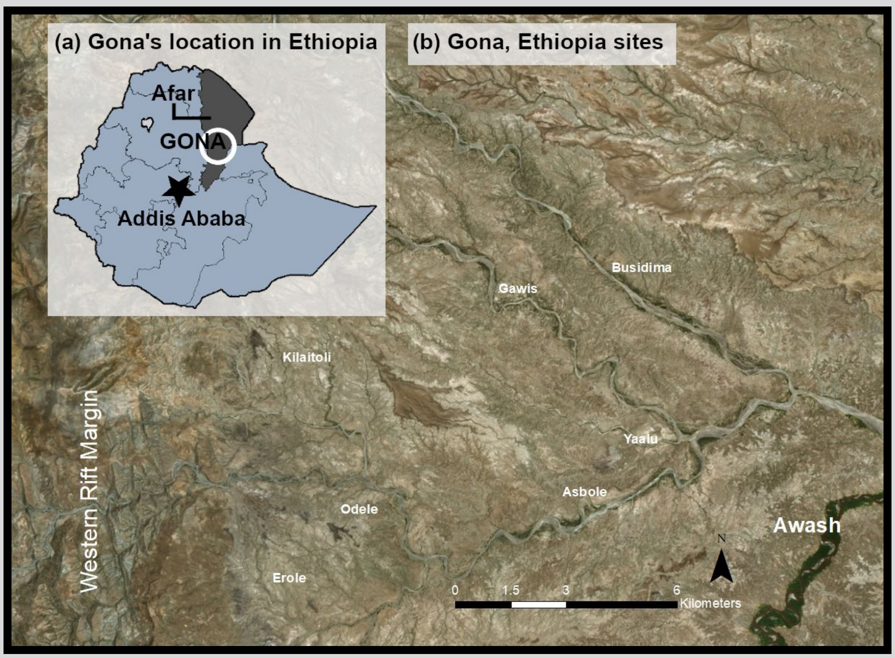


Figure 1. The Gona Paleoanthropological Project Area (in the Afar regional state) with drainages, along which archaeological sites are noted. Labelled drainages are ephemeral tributaries that drain into the perennial Awash River to the east.

Paleosols were sampled in the field, with attention paid to the level of soil development and the presence of vertic features. Soils form due to the interaction of the *cl*imate, *o*rganisms, *r*elief, *p*arent material, and *t*opography in a given area, as detailed below (Jenny, 1941):

soil = *f (cl, o, r, p, t)*

Vertic features such as slickensides are indicative of paleo-Vertisols and are desired due to known landscape positions. Since soils will form due to landscape position (relief) and parent material, controlling for these factors allow us to attribute differences in soil properties to changes in other soil-forming characteristics. Thus, these paleo-Vertisols likely formed in a distal floodplain setting from tributary sediments.

Laboratory methods:

Geochemistry: All samples were processed for bulk geochemistry via X-ray fluorescence spectroscopy (XRF) and evaluated using a mass-balance approach as detailed by Brimhall et al. (1991). These calculations use soil horizon geochemistry normalized to the parent material geochemistry to quantify weathering throughout each soil profile, using immobile index elements such as titanium (Ti) and zirconium (Zr). Titanium was chosen as the immobile index element, as Ti is more abundant in the fine silt and clay-size fraction, which is the dominant size class in these paleosols (Stiles et al., 2003).

Strain ($\varepsilon_{i,w}$) uses soil bulk density (Bd, or ρ) to quantify volumetric changes in a soil profile relative to the parent material (otherwise known as the C horizon) and is calculated as follows:

$$\varepsilon_{i,w} = \frac{\rho_p}{\rho_w}\frac{C_{i,p}}{C_{i,w}} - 1$$

In which ρ_p represents the bulk density of the parent material (in g/cm^3), ρ_w represents the bulk density of the weathered horizon (in g/cm^3), $C_{i,p}$ represents the concentration of the immobile index element in the parent material, and $C_{i,w}$ represents the concentration of the immobile index element in the weathered horizon (Brimhall et al., 2001). A positive number represents dilation, or addition of volume, while negative numbers represent collapse, the loss of volume. Changes in strain are due to weathering and bioturbation resulting in soil expansion through mass addition and pore development or soil collapse due to mass loss and compaction.

The open-system, mass-transport function, Tau, ($\tau_{j,w}$) uses the same concept as strain to quantify elemental gain and/or loss throughout the profile, relative to the parent material. It is calculated as follows, according to Brimhall et al. (2001):

$$\tau_{j,w} = \frac{C_{j,w}}{C_{j,p}} \frac{C_{i,p}}{C_{i,w}} - 1$$

In which $C_{j,w}$ and $C_{j,p}$ represent the concentration of the mobile element in the weathered horizon and the parent material. As illustrated above, a positive value indicates the accumulation of a mineral or element while a negative value indicates loss during weathering.

Results

Stratigraphy, geochronology, and sedimentology

Stratigraphy was mapped throughout the study areas, with tephra layers correlated dated (Figure 2a). Two paleosols, an AHP paleosol in the Erole drainage and a Last Glacial Period (LGP) paleosol in the Odele drainage, are also sampled (Figure 3b-c) and given a temporal context via chronologic work. The Erole AHP paleosol formed during the terminal Pleistocene and into the Early Holocene (Stinchcomb et al., in prep). The Odele LGP paleosol (Figure 2c) likely weathered during late stage MIS-3/MIS-2 (Lisiecki and Raymo, 2005).

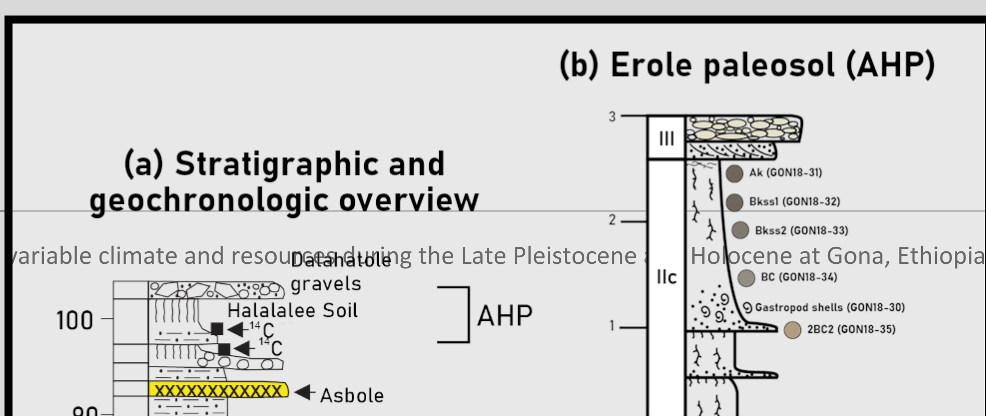


Figure 2a-c. Composite stratigraphy (a) and sampled paleosol profiles from (b) Erole (AHP) and (c) Odele (LGP). Tuffs (yellow) have been dated via Ar-Ar dating and Profiles are broken up by the stratigraphic unit. Grain size (clay, silt, sand, and gravel), sedimentary features and structure, soil horizonation, and color (via NIX colorimeter and Munsell Color System) are shown for each paleosol.

The black to very dark gray color of the Erole AHP paleosol (Figure 2b) and other AHP deposits is likely associated with an increase in soil organic carbon, consistent with on-going work (Takashita-Bynum, 2019). Slickensides (in horizons containing “ss”) are well-developed and indicate shrinking and swelling of the soil, due to (1) the fine-grained particle size and (2) periodic water moving through the soil profile. Gastropod shells of the genus *Melanoides* require perennial water and are found across these AHP deposits at Odele, Erole, and Kilaitoli. At Erole, the shells are found in dense concentrations (Figures 3b, 3c), including at the base of the sampled paleosol profile. Carbonized wood (Figure 3d) and tufa deposits (Figure 3e) were also found at Erole, indicating the presence of woody plants and freshwater springs in the area.

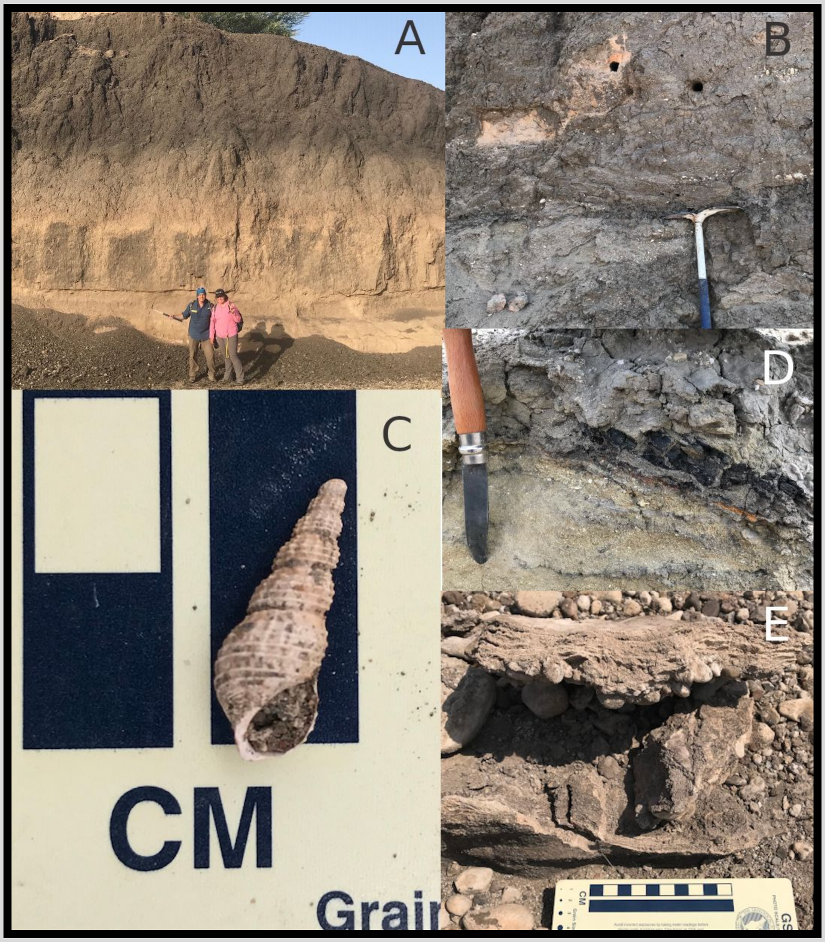


Figure 3a-e. Sedimentary indicators of the African Humid Period. Image A shows the dark AHP deposit at Kilaitoli, people for scale. Images B and C show Melanoides sp. shells, occurring in concentrations across AHP sites (above pick head). Image D shows a piece of carbonized wood with a knife for scale at Erole, likely deriving from a riparian woodland. Image E shows a tufa deposit, having formed from a freshwater spring at Erole.

In contrast to the Erole AHP paleosol, the Odele LGP paleosol (Figure 2c) is consistently lighter in color than the AHP paleosol. While the Odele paleosol also exhibits slickensides, they are less developed. Field mapping of nearby Odele stratigraphy shows that correlative layers are also lighter in color. Gastropod shells belonging to the genus *Pupilla* were observed along layers equivalent to the Odele LGP paleosol. No *Melanoides* shells were observed. The Kilaitoli Tuff, which outcrops immediately above the LGP Odele paleosol, shows exceptional preservation of volcanic glass with little evidence of weathering.

Paleosol geochemistry

Geochemistry from the Erole AHP paleosol and the Odele LGP paleosol show collapse in both soils (negative strain), but a greater amount in the Erole AHP paleosol (Figure 4). Erole collapsed by 39 ± 8 %, losing up to 46 % of its original estimated volume in the uppermost horizon. The Odele LGP paleosol exhibited little to no strain (-5 ± 4 %).

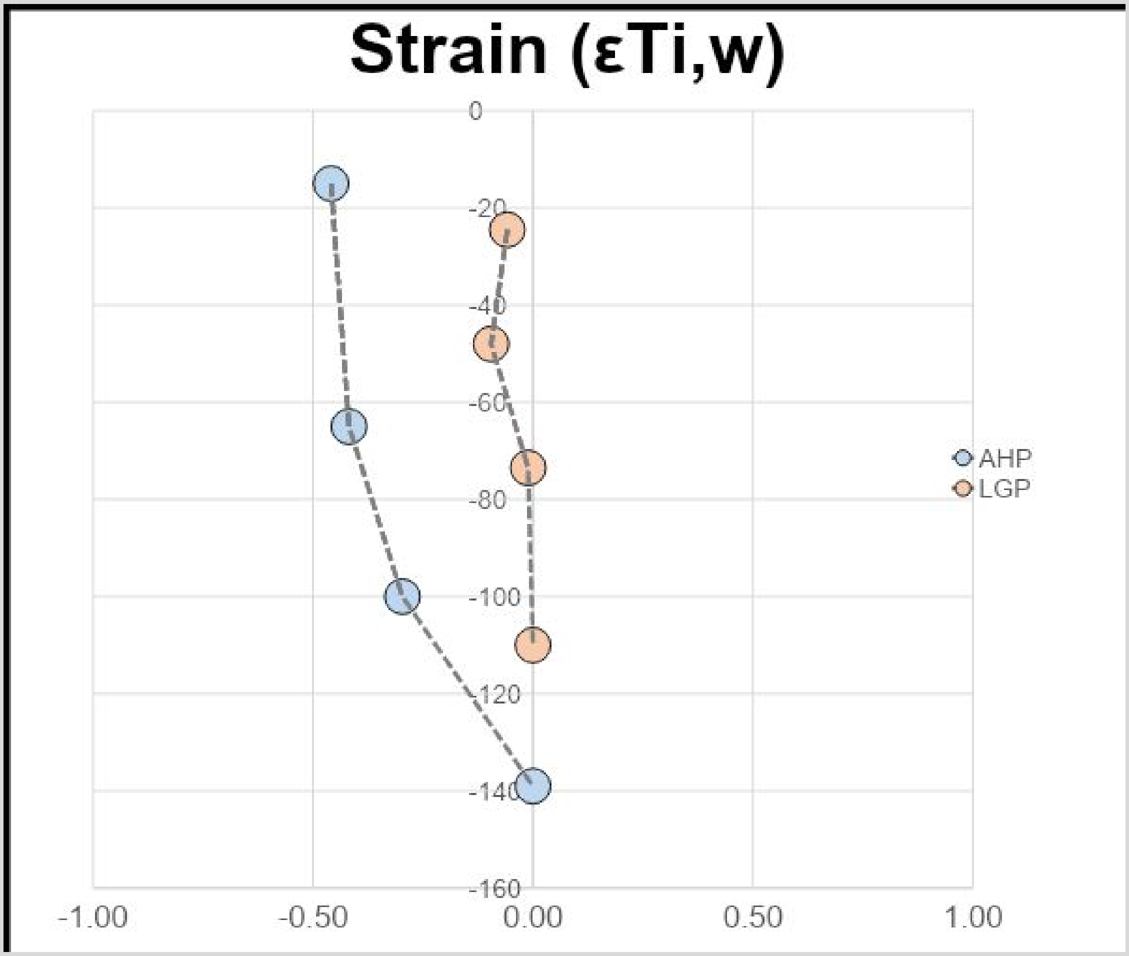


Figure 4. Strain of paleosols using bulk geochemistry. Both paleosols exhibit collapse, indicating a loss of volume relative to the parent material. Titanium was used as the immobile index element.

Similar to that of strain, the tau calculations show mass loss with respect to SiO_2 and CaO in both profiles, but more so in the Erole AHP paleosol (Figure 5). The Erole AHP paleosol lost 25 ±

13 % of SiO_2 and 71 ± 6 % of CaO (Figure 5). The Odele paleosol exhibits much less loss than Erole, with a 8 ± 4 % loss of SiO_2 and 7 ± 3 % loss of CaO.

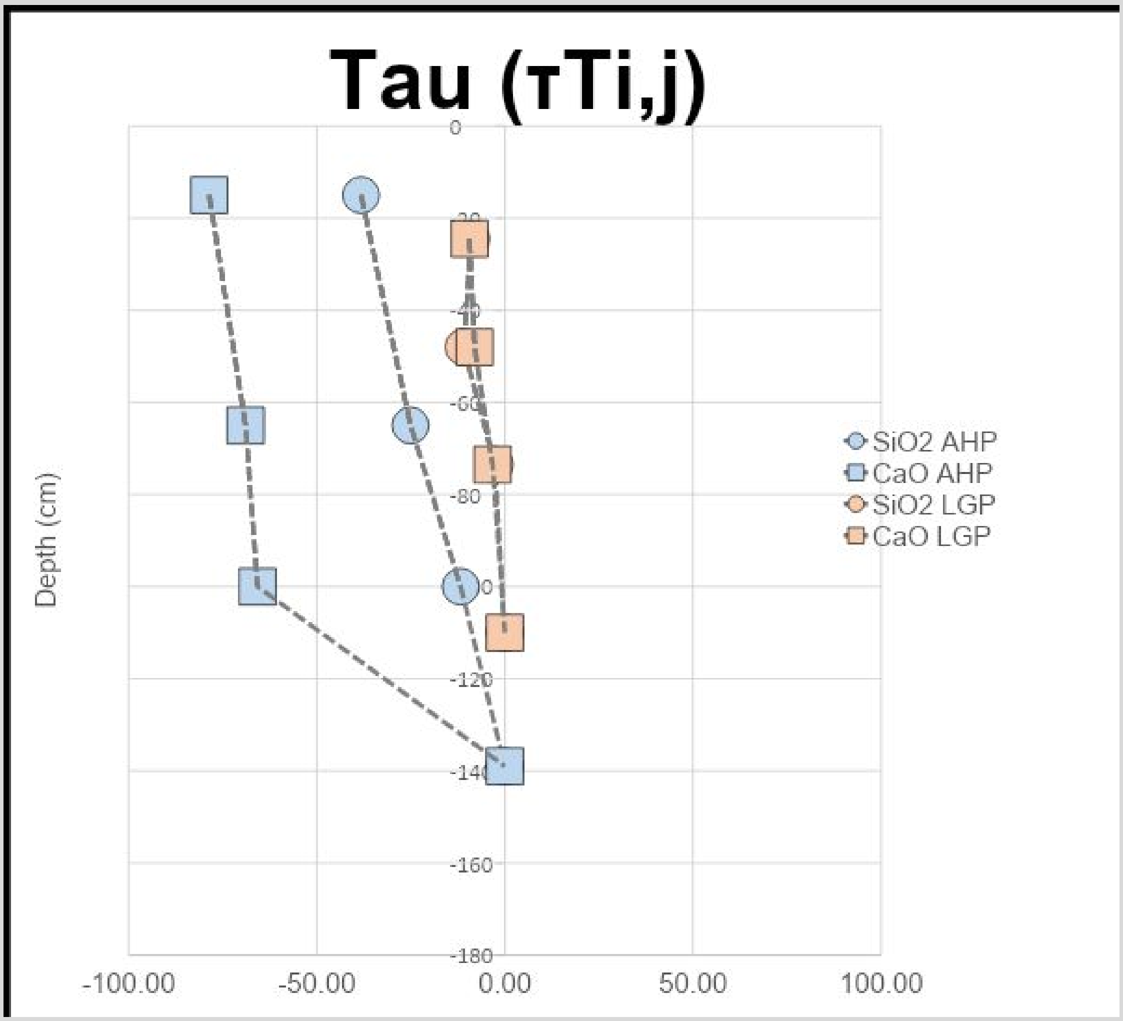


Figure 5. Elemental mass-balance (Tau) of paleosols using bulk geochemistry. Both soils exhibit a net loss of both silica and calcium. Titanium was used as the immobile index element.

Discussion

Field observations suggest the presence of perennial water at Gona during the AHP. The presence of the gastropod genus Melanoides indicates wetter, pluvial conditions when these sediments were deposited. These shells are also found at the base of the Erole paleosol and require perennial water. Carbonized wood found at Erole suggests woody plants occurring in the landscape in the form of gallery forest. These are evident today along the perennial Awash river. Tufa deposits during the AHP suggest that freshwater springs in the area were fed with sufficient amounts of groundwater. Groundwater present in a large enough quantity to sustain springs—as the tufa deposit indicates—suggests waterlogged soil and the relative increase of water moving through the surface and subsurface. This is further reflected by more negative strain and tau values. Combined, these paleoenvironmental indicators suggest that the AHP environment at Gona had ample vegetation and water.

Consistent with these observations, the paleosol geochemistry shows more net loss in volume and mass during the AHP than during the LGP. Both soils are formed through the weathering of unconsolidated sediments into more stable forms (the soil), but differential volumetric and elemental loss suggest differences in rates and intensities of weathering.

Strain and tau values are consistently more negative based on the AHP (Erole) geochemistry than the LGP (Odele) geochemistry. The increased collapse during the AHP suggests an increase in pore space within the soil, likely due to more precipitation flowing throughout the system as well as an increased amount of bioturbation. This bioturbation is potentially due to more flora and fauna living at the land surface and within the soil, sustained by more habitable conditions. Gastropod shells found at the AHP sites may have contributed to this, as Melanoides and other gastropods burrow (Beeston and Morgan, 1979). Both soils exhibit slickensides, created by the shrinking and swelling of the soils during wet-dry periods, leading to the formation of soil structure and pores, likely driving collapse.

Both deposits show elemental losses, with the AHP paleosol at Erole having more loss in both elements analyzed than the LGP paleosol at Odele. Silica is more susceptible to leaching and removal in alkaline soils, especially when there is (1) an increase in temperature and (2) an increase in available water (Sommer et al., 2006). This suggests that there was a likely increase in precipitation and temperature during the AHP, relative to the LGP at Odele. Dissolution and loss of Ca from calcite and volcanic glass likely occurred when soils were wet and respired CO_2 was high, driving acidity (e.g., Van Den Berg and Loch, 2000). Slickensides in the soil also support the notion that these soils underwent repeated wet-dry cycles, where Ca-rich waters were drained and resulted in Ca loss. Lastly, soil color is darker in the AHP paleosol than the previous LGP paleosol, which may suggest an increase in soil organic matter (OM) as seen in the increase of TOC at Kilaitoli, another AHP paleosol (Takashita-Bynum, 2019).

An uncertainty in our work is the lack of knowledge of parent material uniformity in the two paleosols examined. It is well known that hydrodynamic size sorting of grains during flood deposition likely affected the textural and mineralogical composition of the sediments. As immobile elements in minerals are sometimes found more frequently in discrete particle-size classes, the sorting of sediment during deposition may alter the chemistry of the parent material vertically within a profile. We are exploring this uncertainty by examining the silt-size geochemistry and results are forthcoming.

Conclusion

Sedimentological features seen in the field agree with our geochemical calculations, suggesting that there was an increase in precipitation, water availability, and vegetation during the African Humid Period at Gona, Ethiopia. The presence of spring deposits and organisms indicating year-round water may explain the increased amount of calcium and silica leached from minerals seen in the AHP paleosol at Erole relative to the LGP at Odele. Desilication, in particular, is driven by increased precipitation and temperature (Sommer et al., 2006). Gona likely experienced increased desilication as the environment transitioned from an arid environment into one with semi-arid conditions. Collapse of the soil during AHP weathering suggests increased amounts of precipitation and water moving throughout the system in addition to increased bioturbation and shrink-swell activity.

Paleosols provide the direct, localized reconstruction of environments and past climates that are particularly useful in archaeological contexts. The availability of water, vegetation, and organisms in the Gona area during the AHP would have provided a more hospitable environment for human occupation than during the prior dry and semi-arid LGP.

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