Gazelle Tooth Enamel Stable Isotope as a Paleoclimate Proxy at Kharaneh IV, Jordan

https://escholarship.org/uc/item/12g379hm

White, AJ

2022-11-01

GAZELLE TOOTH ENAMEL STABLE ISOTOPES AS A PALEOCLIMATE PROXY AT KHARANEH IV, JORDAN

Stahl Research Report
2022, Archaeological Research Facility, UC Berkeley
http://escholarship.org/uc/item/12g379hm

AJ White
Department of Anthropology, University of California, Berkeley
adam_white@berkeley.edu

Kharaneh IV is a large, Epipaleolithic hunter-gatherer aggregation site located in eastern Jordan that was occupied from approximately 19,900 to 18,600 BP (Macdonald et al., 2018; Maher et al., 2012; Richter et al., 2013). Multiple studies have investigated the environmental events that occurred leading up to the site's initial occupation (Besancon et al., 1989; Garrard et al., 1985; Jones et al., 2016), but there is no sedimentological archive to reconstruct the paleoenvironment during the site's occupation due to the erosion of contemporary sedimentary features (Jones et al., 2016). The absence of concurrent paleoclimatic and archaeological data complicates our understanding of human-environmental relations at Kharaneh IV.

To address this problem, I investigated the use of gazelle tooth enamel O and C isotopes as proxies of paleoclimatic conditions at Kharaneh IV. While the site's dense habitation layers lack naturally deposited strata useful for traditional paleoenvironmental studies, they contain the remains of many butchered goitered gazelle (*Gazella subgutturosa*). Gazelle teeth are prevalent throughout the site's occupation deposits as isolated teeth no longer within a mandible, but I chose to focus on third mandibular molars (M_3) in this study because they are most easily identifiable and best preserved due to their large size (Figure 1). Third molar enamel in modern gazelle populations form between the first 9 and 18 months of an individual's life, and thereby reflect close to a year of seasonal change as the organism incorporated isotopic signatures of its surroundings (Davis, 1980; Henton et al., 2017).

The oxygen isotopic composition ($\delta^{18}O$) of tooth enamel reflects the $\delta^{18}O$ values of ingested water, which in turn corresponds to regional temperature and precipitation conditions (Dansgaard, 1964; Henton et al., 2017; Iacumin and Longinelli, 2002; Naito et al., 2022). The carbon isotopic composition ($\delta^{13}C$) of tooth enamel is derived from dietary carbon, which ultimately relates to the $\delta^{13}C$ of vegetation and their photosynthetic pathways (C_3, C_4, CAM) (DeNiro and Epstein, 1978; Hoppe et al., 2006; Zazzo et al., 2010). The interpretation of gazelle tooth enamel isotopes is complex because gazelle are nonobligate drinkers that may migrate large distances, requiring $\delta^{18}O$ values to be understood within the context of plant tissue $\delta^{18}O$ and possibly meaning that their isotopic signature reflects regional, not local, conditions. However, Henton et al. (2017) demonstrated that gazelle tooth $^{87}Sr/^{86}Sr$ values from Kharaneh IV remains are consistent with $^{87}Sr/^{86}Sr$ values of local soils, suggesting that gazelle stayed near the site year-round.

For this study, I compared the range of $\delta^{18}O$ and $\delta^{13}C$ gazelle tooth enamel values reported by Henton et al. (2017) and new data from this project from Kharaneh IV's Area A, a younger part of the site dated to 18,850-18,600 cal BP, with data I obtained from Area B, an older part of the site dated to 19,830 and 18,730 cal BP (Maher et al., 2016), to determine if there is diachronic variation in gazelle tooth isotope values and to assess if this variation is related to changes in local climate.

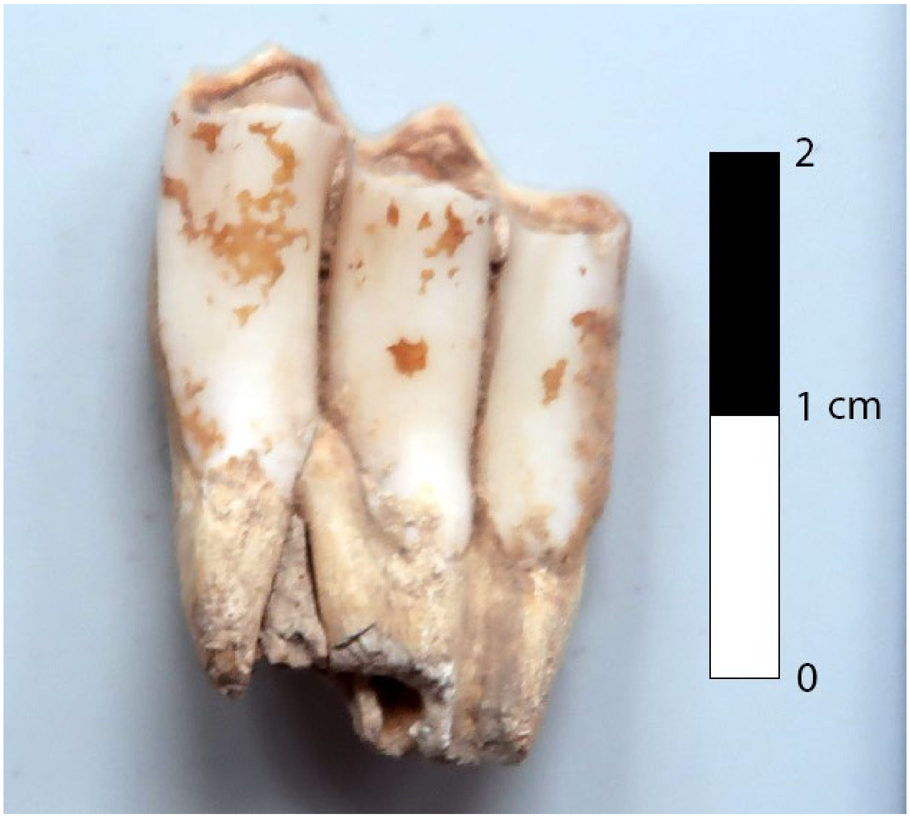

Figure 1. Third mandibular gazelle molar prior to cleaning and sample preparation.

A brief methods summary is provided here; the study's full methodology will be described in a later publication. I obtained 14 Area B M_3 specimens and 7 Area A M_3 specimens from bulk > 4 mm material collected over multiple field seasons by the Epipaleolithic Foragers in Azraq Project (EFAP). Specimens were originally washed in the field; I removed remaining dirt and plaque using a dental pick and brush. I used a handheld Foredom rotary tool with a diamond coated drill bit to sample enamel at 5 mm increments beyond the enamel:root junction (ERJ). Due to size differences, the number of samples yielded per tooth ranged from 1-4 (5-20 mm from ERJ). I bathed the samples in 1 mL of sodium hypochlorite for 24 hours, rinsed them with 1 mL of ultrapure water, bathed the samples in 1 mL of 0.1 M hydrochloric acid for 12 hours, then rinsed them with water 10 times to remove latent salts that initially disrupted mass spectrometer analysis (Yang et al., 2005). Following drying in an oven at 60° C for 4 hours, I submitted the samples to the Center for Stable Isotope Biogeochemistry at UC Berkeley for analysis.

The results of the study show that Area A $\delta^{18}O$ samples range from -2.81 to 7.14‰ and Area B $\delta^{18}O$ samples range from -3.31 to 6.53‰ (Figure 2). Area A $\delta^{13}C$ samples range from -10.78 to -3.56‰ and Area B $\delta^{13}C$ samples range from -11.40 to -3.15‰. The $\delta^{18}O$ and $\delta^{13}C$ envelopes for Area A and Area B samples are notably similar, with less than 1‰ difference in their maximum and minimum extents. The Area A samples from this study are slightly more positive than those reported in 6 comparable Area A M_3 specimens by Henton et al. (2017), which range from -4.24 to 4.92‰ $\delta^{18}O$ and -10.79 to -5.85‰ $\delta^{13}C$ (Figure 2). This discrepancy could be due to low sample sizes in comparable data from Henton et al. ($M_3 = 6$) and this study ($M_3 = 7$), quantitative differences arising from different analytical equipment, or reflect actual diversity within Area A samples. The Area A samples selected for this study are stratigraphically higher (Loci 002-035; locus number generally increases with depth at Kharaneh IV) than those presented in Henton et al. (Loci 034-178), and therefore represent later and earlier Area A occupation levels, respectively.

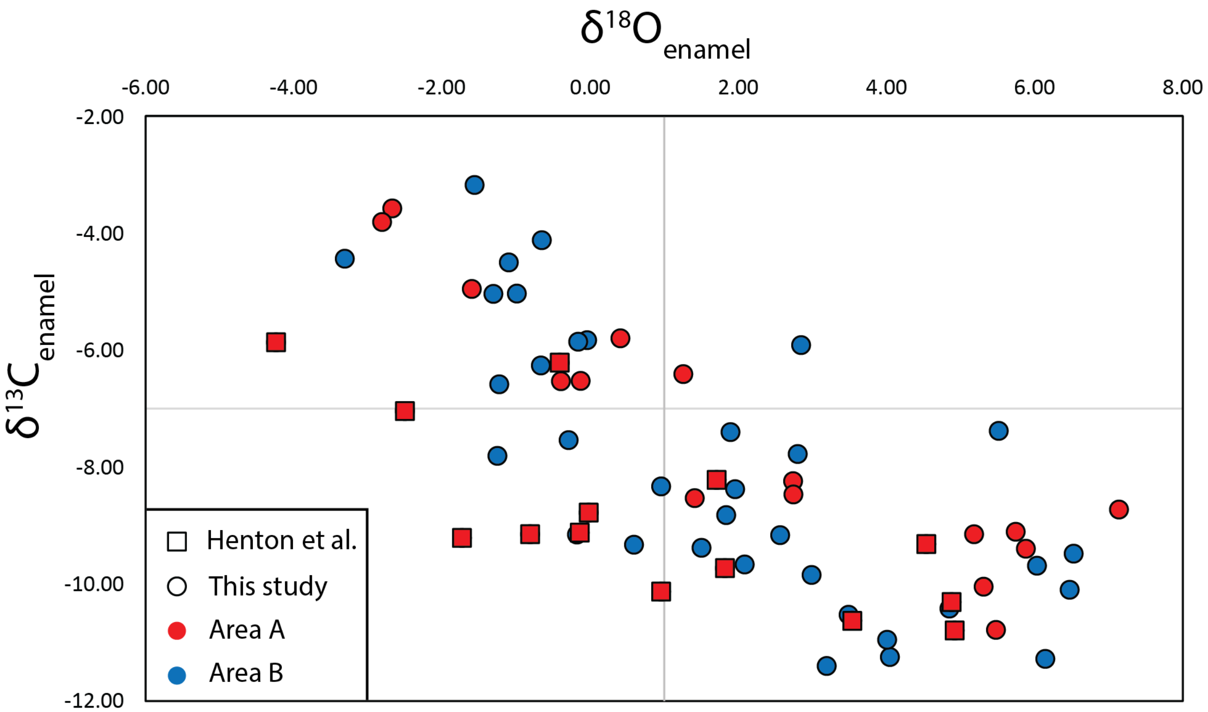

Figure 2. Range of $\delta^{18}O$ and $\delta^{13}C$ values in Area A (red) and Area B (blue) samples. Area A data points include relevant samples from Henton et al. 2017 (squares) along with data from this study (circles).

If the gazelle tooth enamel isotope record presented here reflects local meteoric water and vegetation isotopic values, then either there was little environmental change between the occupations of Area A and Area B, with perhaps a moment of cooler or wetter conditions interpreted from the Henton et al. (2017) data, or the envelope of values displayed in each area (Area A = 11.38‰ $\delta^{18}O$, 7.23‰ $\delta^{13}C$; Area B = 9.84‰ $\delta^{18}O$, 8.25‰ $\delta^{13}C$) is too wide to capture changes in climate. However, meteoric water in the Azraq Basin averages between 0.33‰ $\delta^{18}O$ in September and -6.36‰ $\delta^{18}O$ in January, with maxima over 6‰ and minima under -12‰ over the past 50 years, representing an average annual $\delta^{18}O$ envelope of 6.69‰ (Henton et al., 2017; IAEA/WMO, 2022). The $\delta^{18}O$ envelope of each area of Kharaneh IV is within the maximum and minimum range of modern meteoric water $\delta^{18}O$ variation over a period of just 50 years (IAEA/WMO, 2022), indicating that the gazelle tooth enamel record is not too wide to record changes in climate.

In both this study and Henton et al. (2017), gazelle enamel $\delta^{18}O$ values are highest at 5 mm from the ERJ and lowest at 15-20 mm from the ERJ, mirroring the local modern meteoric water $\delta^{18}O$ high in the summer and low in the winter. Because the gazelle tooth enamel record closely parallels seasonal changes in modern meteoric water $\delta^{18}O$, it would likely be sensitive to large swings in local hydroclimate had they occurred. However, the close similarity of the Area A and Area B enamel records suggests that local climatic conditions were mostly stable over the course of Kharaneh IV's occupation. A stable local environment is supported by regional climate datasets from Lake Lisan (Bartov et al., 2003), Soreq Cave, Israel (Bar-Matthews et al., 2003; Grant et al., 2012), and Sofular Cave, Turkey (Fleitmann et al., 2009) which show little change during this period. The slight offset between the Henton et al. (2017) Area A dataset and this study suggests a period of climatic instability, which may relate to a brief negative excursion in speleothem δ^{18}O values from Soreq Cave centered on 18,800 BP (Figure 3) (Grant et al., 2012). Despite this possible interruption and assuming gazelle populations remained local year-round, the continuity in δ^{18}O and δ^{13}C gazelle tooth enamel values between Area A and Area B suggests that climatic conditions were largely similar at the start and end of the site's occupation. The implications of this finding on Kharaneh IV's site history will be explored in a later publication.

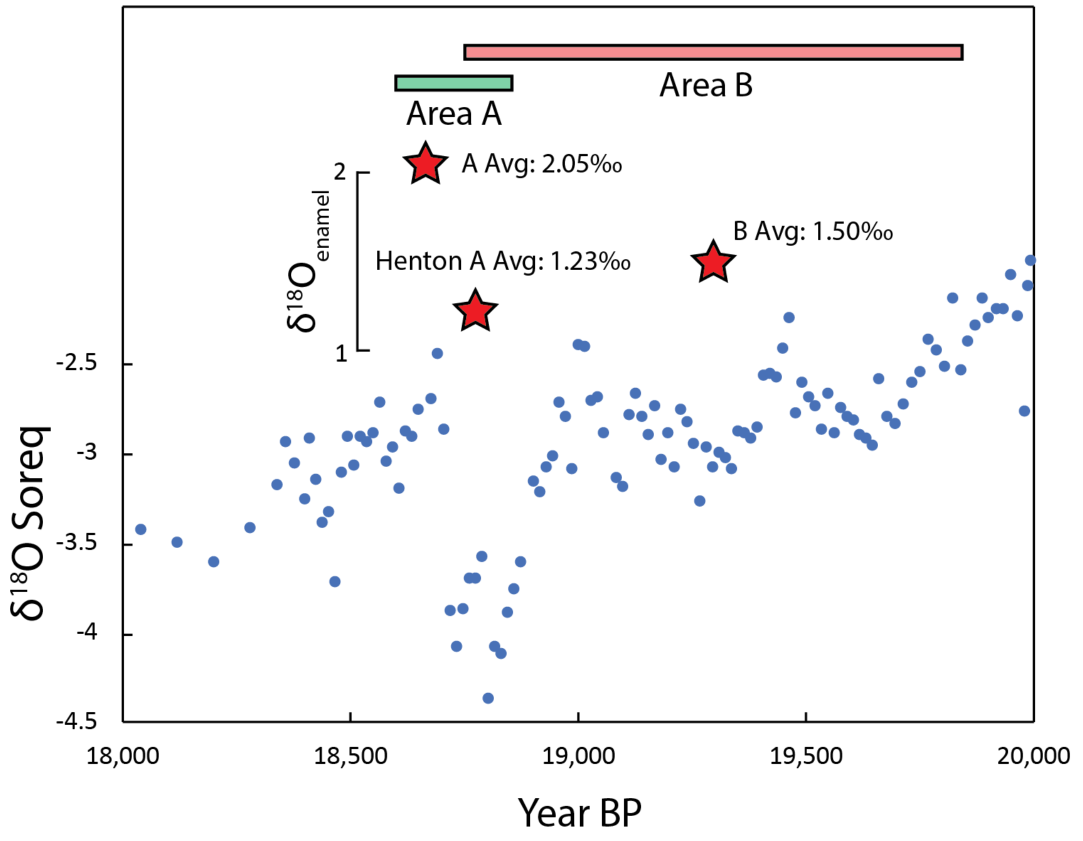

Figure 3. Soreq Cave speleothem δ^{18}O values (blue circles; Grant et al., 2012) and averaged Kharaneh IV gazelle tooth enamel δ^{18}O values across Area A (Henton et al. 2017 and this study) and Area B (red stars). The occupation dates for Area A and B are shown above as colored bars (Maher et al., 2016).

Acknowledgements: Funding from the Stahl Foundation covered the analytical costs of this work. The Archaeological Research Facility at UC Berkeley provided laboratory space and equipment. I thank Lisa Maher for providing access to samples, research funds, and project guidance, Melanie Miller for sampling training and materials, and Todd Dawson, Louise Martin, and Wenbo Yang for consultation.

References

Bar-Matthews, M., Ayalon, A., Gilmour, M., Matthews, A., Hawkesworth, C.J., 2003. Sea–land oxygen isotopic relationships from planktonic foraminifera and speleothems in the Eastern Mediterranean region and their implication for paleorainfall during interglacial intervals. Geochimica et Cosmochimica Acta 67, 3181–3199.

Bartov, Y., Goldstein, S.L., Stein, M., Enzel, Y., 2003. Catastrophic arid episodes in the Eastern Mediterranean linked with the North Atlantic Heinrich events. Geology 31, 439–442. https://doi.org/10.1130/0091-7613(2003)031<0439:CAEITE>2.0.CO;2

Besancon, J., Geyer, B., Sanlaville, P., 1989. Contribution to the study of the geomorphology of the Azraq Basin, Jordan, in: Copeland, L., Hours, F. (Eds.), The Hammer on the Rock: Studies in the Early Palaeolithic of Azraq, Jordan. B.A.R., pp. 7–63.

Dansgaard, W., 1964. Stable isotopes in precipitation. Tellus 16, 436–468. https://doi.org/10.3402/tellusa.v16i4.8993

Davis, S.J., 1980. A note on the dental and skeletal ontogeny of Gazella. Israel Journal of Ecology and Evolution 29, 129–134.

DeNiro, M.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. Geochimica et cosmochimica acta 42, 495–506.

Fleitmann, D., Cheng, H., Badertscher, S., Edwards, R.L., Mudelsee, M., Göktürk, O.M., Fankhauser, A., Pickering, R., Raible, C.C., Matter, A., 2009. Timing and climatic impact of Greenland interstadials recorded in stalagmites from northern Turkey. Geophysical Research Letters 36.

Garrard, A., Byrd, B., Harvey, P., Hivernel, F., 1985. Prehistoric environment and settlement in the Azraq Basin. A report on the 1982 survey season. Levant 17, 1–28.

Grant, K.M., Rohling, E.J., Bar-Matthews, M., Ayalon, A., Medina-Elizalde, M., Ramsey, C.B., Satow, C., Roberts, A.P., 2012. Rapid coupling between ice volume and polar temperature over the past 150,000 years. Nature 491, 744–747. https://doi.org/10.1038/nature11593

Henton, E., Martin, L., Garrard, A., Jourdan, A.-L., Thirlwall, M., Boles, O., 2017. Gazelle seasonal mobility in the Jordanian steppe: The use of dental isotopes and microwear as environmental markers, applied to Epipalaeolithic Kharaneh IV. Journal of Archaeological Science: Reports 11, 147–158. https://doi.org/10.1016/j.jasrep.2016.11.031

Hoppe, K.A., Paytan, A., Chamberlain, P., 2006. Reconstructing grassland vegetation and paleotemperatures using carbon isotope ratios of bison tooth enamel. Geology 34, 649–652.

Iacumin, P., Longinelli, A., 2002. Relationship between δ18O values for skeletal apatite from reindeer and foxes and yearly mean δ18O values of environmental water. Earth and Planetary Science Letters 201, 213–219. https://doi.org/10.1016/S0012-821X(02)00635-0

IAEA/WMO, 2022. Global Network of Isotopes in Precipitation. The GNIP Database. URL https://nucleus.iaea.org/wiser (accessed 10.20.22).

Jones, M.D., Maher, L.A., Macdonald, D.A., Ryan, C., Rambeau, C., Black, S., Richter, T., 2016. The environmental setting of Epipalaeolithic aggregation site Kharaneh IV. Quaternary International, Late Pleistocene Eastern Levant: Landscape Strategies in Open Spaces 396, 95–104. https://doi.org/10.1016/j.quaint.2015.08.092

Macdonald, D.A., Allentuck, A., Maher, L.A., 2018. Technological Change and Economy in the Epipalaeolithic: Assessing the Shift from Early to Middle Epipalaeolithic at Kharaneh IV. J. Field Archaeol. 43, 437–456. https://doi.org/10.1080/00934690.2018.1504542

Maher, L.A., Macdonald, D.A., Allentuck, A., Martin, L., Spyrou, A., Jones, M.D., 2016. Occupying wide open spaces? Late Pleistocene hunter–gatherer activities in the Eastern Levant. Quaternary International, Late Pleistocene Eastern Levant: Landscape Strategies in Open Spaces 396, 79–94. https://doi.org/10.1016/j.quaint.2015.07.054

Maher, L.A., Richter, T., Macdonald, D., Jones, M.D., Martin, L., Stock, J.T., 2012. Twenty Thousand-Year-Old Huts at a Hunter-Gatherer Settlement in Eastern Jordan. PLOS ONE 7, e31447. https://doi.org/10.1371/journal.pone.0031447

Naito, Y.I., Hirose, M., Belmaker, M., Henry, D.O., Osawa, M., Nakazawa, T., Habinger, S.G., Tung, P., Bocherens, H., Massadeh, S., Kadowaki, S., 2022. Paleoenvironment and human hunting activity during MIS 2 in southern Jordan: Isotope records of prey remains and paleosols. Quaternary Science Reviews 282, 107432. https://doi.org/10.1016/j.quascirev.2022.107432

Richter, T., Maher, L.A., Garrard, A.N., Edinborough, K., Jones, M.D., Stock, J.T., 2013. Epipalaeolithic settlement dynamics in southwest Asia: new radiocarbon evidence from the Azraq Basin. Journal of Quaternary Science 28, 467–479. https://doi.org/10.1002/jqs.2629

Yang, W., Lowenstein, T.K., Krouse, H.R., Spencer, R.J., Ku, T.-L., 2005. A 200,000-year δ18O record of closed-basin lacustrine calcite, Death Valley, California. Chemical Geology 216, 99–111.

Zazzo, A., Balasse, M., Passey, B.H., Moloney, A.P., Monahan, F.J., Schmidt, O., 2010. The isotope record of short-and long-term dietary changes in sheep tooth enamel: implications for quantitative reconstruction of paleodiets. Geochimica et Cosmochimica Acta 74, 3571–3586.