Osteological and stable isotope ($\delta^{13}C$ and $\delta^{15}N$) analysis of faunal remains from Khami, Zimbabwe

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Abstract

This paper presents distribution patterns and stable carbon and nitrogen isotope measurements of recently excavated faunal remains from two middens at Khami, the UNESCO World Heritage site. The middens are dated to c. AD 1475–1650. The results indicate that food practices may have differed in the high- and low-lying areas of the site, as reflected in the two excavated contexts studied here. $\delta^{13}C$ values of serial samples of tooth dentine show that cattle and wild grazers consumed C_4 grasses year-round. The availability of rich natural grazing would have been a considerable attraction to the builders of the site.

Key Words: Late Iron Age, cattle husbandry; meat consumption; grazing seasonality; serial sampling; dentine collagen

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Introduction

Recent excavations at the UNESCO World Heritage site of Khami (Fig 1), dated to c. AD 1420–1820 (Chirikure *et al.* 2013) yielded a large assemblage of faunal remains. This article presents analyses of faunal material from two midden contexts at the site, North Platform Midden (NPM) and Midden 2 (M2) (Fig. 2). These are dated to AD 1475–1650 (Mukwende 2016: see Table 4.3). In our study, we aimed to investigate (1) possible differences in intra-site distribution of meat foods and (2) the nature of the animals' diets, as a proxy for local vegetation. As we accumulate more such data from different areas and time periods, we will be able to make inferences about local environments, and perhaps responses to events such as droughts. The analyses were done in two stages. The first consisted of morphological identification and quantification of the faunal material according to stratigraphic layers, and was done at the Natural History Museum of Zimbabwe in Bulawayo. This was followed by stable isotope ($\delta^{13}C$ and $\delta^{15}N$) analysis of selected specimens, conducted at the University of Cape Town.

Faunal remains at Khami: background and status

The Iron Age inhabitants at Khami were agropastoralists who grew crops and kept herds of cattle (*Bos taurus*), sheep and goats (Huffman 1996, 2007; Phillipson 1993). The site is located on the Zimbabwean plateau, in the summer rainfall zone, and is located at 1200–1350 metres above present sea level (Fig. 2). The modern vegetation consists of open savanna woodlands (acacia woodlands), including grass, shrubs and herbaceous plants (Hyde *et al.* 2016; Summers 1960: 269), thus providing fertile support for browser and grazer diets. The vegetation during the Iron Age settlement of Khami is expected to have been similar. Modern rainfall averages 450–650 mm per annum (Beach 1998; Thorp 1995; Mukwende 2016:12). Paleoenvironmental studies generally agree that precipitation declined after c. AD 1500, culminating in particularly problematic conditions for cultivation in the 17th century (Driscoll et al. 2009; Smith 2005; Smith et al. 2007; Smith et al. 2010; Smith et al. 2002; Stager et al. 2013; Thorp 1984a, 1995; Tyson et al. 2002; Woodborne et al. 2015).

The excavated area NPM was on a platform at the elevated area associated with the north wall of the central Hill Complex while M2 was located on the lower-lying flats to the NW of the Hill Complex. Previous excavations at Khami have identified a wide variety of animal species, including both wild and domesticated fauna. However, a predisposition towards cattle and caprines seems evident in settlement areas (see Robinson 1959: 166; Thorp 1984a, 1984b, 1995; van Waarden 1987, 1989). In her comparative analysis of faunal remains from Khami and Great Zimbabwe, Thorp demonstrated that a larger array of species, including more wild game, was consumed at Khami compared to Great Zimbabwe (Thorp 1995: 58). She also pointed out that fewer immature animals were consumed at Khami. This may be due to different animal management strategies (Thorp 1995: 65).

Discussion of possible intra-site differences must take into account the various factors that may have influenced the distribution patterns of faunal remains. Hughes (1997: 5–20) and Thorp (1995: 50–61) note that soil erosion is more prominent on lower settlement areas at Khami, and that preservation of deposit appears to be better at the precipice or elevated areas. Our study confirms previous observations by these scholars. The sediments contained more ash and showed less signs of erosion at NPM on the hill complex than at M2, and better preservation conditions on the elevation may explain the larger faunal assemblage found there. At both middens, 1m^2 pits were excavated, to a depth of 150 cm at M2 and 140 cm at NPM, yielding similar volumes of deposit.

All faunal remains excavated are curated at the Natural History Museum of Zimbabwe in Bulawayo (see Table 1 for a list). For the purposes of this study, a selection of the faunal remains was made for isotope analysis. In particular Thorp's study gave grounds for studying wild and domesticated fauna, in order to examine any discrepancies in space and time.

Stable isotopes in bone and teeth

Stable isotope analyses of animal tissues are now widely used, particularly for reconstructing diets and environments. For a recent review of applications in African archaeology, see Loftus *et al.* (2016). Briefly, stable carbon isotope ratios ($^{13}C/^{12}C$) in animals depend mainly on the photosynthetic pathways of plants at the base of the foodweb. In summer rainfall regions such as Zimbabwe, trees, shrubs and dicotyledonous plants use the Calvin-Benson or C_3 photosynthetic pathway, in which atmospheric carbon dioxide is fixed initially into three-carbon compounds. This is associated with strong discrimination against ^{13}C, so that the $^{13}C/^{12}C$ ratio in C_3 plant tissues is much lower than in atmospheric carbon dioxide. The mean $\delta^{13}C$ value[1] of C_3 plants world-wide is about -27‰. Grasses, on the other hand, use the Hatch-Slack or C_4 photosynthetic pathway. This does not discriminate as strongly against ^{13}C, so that the mean $\delta^{13}C$ value of C_4 plants is about -12‰. These ratios are carried through into the tissues of consumers, so that browsing animals that consume C_3 plants have bone (or dentine) collagen $\delta^{13}C$ of about -21‰, while grazers consuming only C_4 grasses have values of about -6‰. Mixed feeders have intermediate values, depending on the proportions of browse and graze consumed (see e.g. Ambrose 1993; O'Leary 1981; Zazzo et al. 2006).

Nitrogen isotope systematics are more complicated. Atmospheric N_2 gas is converted by nitrogen-fixing bacteria into ammonium, nitrite and nitrate, each reaction changing the $^{15}N/^{14}N$ ratio ("fractionating" the isotopes) to a different degree. These forms can inter-convert in soils, and fixed nitrogen can be reduced by denitrifying bacteria to N_2 and released back into the atmosphere – processes that are all dependent on the moisture content of the soil. Plant $\delta^{15}N$ values depend on the form of nitrogen taken up, on whether plants have associated mycorrhizae, and many other factors (for a summary, see Szpak 2014). There are, however, clear relationships between plant $\delta^{15}N$ and moisture, with lower $\delta^{15}N$ values in moister environments (Craine *et al*, 2009; Murphy and Bowman 2009). Nitrogen isotope ratios in animals depend largely on their food, and to some extent on metabolic processes within the animals' bodies.

In archaeological sites in which bone proteins are preserved, the preferred analytical material for stable isotope measurements is usually bone (or dentine) collagen, the major structural protein in these tissues. Teeth form incrementally from the occlusal surface to the root apex, and once formed, they do not remodel. The isotopic composition of a tooth therefore reflects diet during the individual's early life. Sequential or serial samples of dentine (or enamel) from the occlusal surface to the root apex provide a record of diet over the time of tooth formation. Bone, on the other hand, resorbs and re-forms throughout life, so its isotopic composition provides an average of the diet over a longer period of time.

Materials and methods

Faunal material from middens NPM and M2 was identified as far as possible at the Natural History Museum of Zimbabwe in Bulawayo, following Driver (1999). Specimens were labelled 'identifiable'(ID) when species, genus or bovid size could be determined. The other categories (see Table 2: bone fragments, ribs, vertebrae, cranial and unidentifiable bone) include bones without diagnostic features for species or genus determination. 'Cranial bones' can be determined as such due to their morphology. 'Bone fragments' are splinters and fragments indicating food preparation or consumption (see Driver 1999; Outram 2000, 2002), whereas 'unidentifiable bone' is bone material that does not fit the other categories. Bovid size class followed Brain (1974), and specimens were quantified using Number of Identifiable Specimens (NISP) and Minimum Number of Individuals (MNI). 27 faunal specimens were selected for measurement of $\delta^{13}C$ and $\delta^{15}N$ in bone and dentine collagen (Table 3). These consisted primarily of domesticated animals, i.e. *Bos taurus* and *Ovis/Capra*, in addition to a few wild species for comparative purposes. In order to avoid sampling the same animal more than once, lower second molars (M2s) were sampled from *Bos taurus,* as far as possible. For caprines, teeth and bone were sampled from the right mandible at NPM, and right maxilla from M2, the exception is KM1095, which was retrieved from a separate stratigraphic layer. The right mandible KNPM110 (NPM) with M1-M3 and the left mandible KM1095 (M2) with M1-M3, were sampled to compare bone and M1-M3 values.

All samples were cleaned by sanding away the outer surfaces of the bone or dental root. Teeth were removed from their sockets (if present) and ¼ of each tooth removed, preserving the entire height of the tooth and including the longest root preserved. The remaining ¾ of the sample was retained in the collection at the Natural History Museum of Zimbabwe.

Bone and dentine collagen were isolated following the standard procedure employed at the University of Cape Town (Sealy *et al.* 2014). All samples were soaked in 0.2M HCl at room temperature until completely decalcified. At this stage, enamel was removed from the teeth using tweezers and a scalpel. To remove humic and other contaminants all samples were treated with 0.1M NaOH for 24 hours. Next, all samples were soaked in distilled water for 24-48 hours. Dentine collagen was cut with a scalpel into 1mm thick slices (Balasse *et al.* 2001; Balasse & Tresset 2002; Makarewicz 2014), from the apex of the root to the occlusal surface, with the most apical sample labelled (a). Both bone and dentine samples were then freeze-dried. 0.45–0.65mg of each sample was weighed into a tin capsule. These were combusted in a Flash 2000 organic elemental analyser at 1020°C. The CO_2 and N_2 gases generated were purified and swept in a stream of helium gas through a Conflo IV interface into an isotope ratio mass spectrometer (Delta V Plus, Thermo Scientific, Germany). Results are expressed in the delta notation relative to Vienna Pee Dee Belemnite (for carbon) or air (for nitrogen), where $\delta^{13}C=({}^{13}C/{}^{12}C_{sample}/{}^{13}C/{}^{12}C_{standard} - 1) \times 1000‰$; $\delta^{15}N$ is calculated in the same way, using the isotope pair ${}^{15}N/{}^{14}N$. In-house standards were included in each run. Repeat analyses of these materials yielded standard deviations of less than 0.2‰ for both nitrogen and carbon.

Results

Faunal distribution

Table 1 shows the fauna identified from middens NPM and M2 in terms of NISP and MNI. In accordance with previous excavations, there are a variety of species present, both wild and domesticated. Among the 19 species positively identified, *Bos taurus* and *Ovis/Capra* dominate. NPM yielded more bone material than M2, although approximately the same volume of deposit was excavated at both middens.

The two middens yielded 6765 bones (c.41.1kg), of which 402 (c.8.4kg) were osteologically identified to species or as class category "bovid" (Tables 1 & 2). A total of 19 species were identified, of which cattle (*Bos taurus*) is the most numerous, followed by buffalo (*Syncerus caffer*) and caprines (*Ovis/Capra*).

Unfortunately, at the time of our identification, the Natural History Museum of Zimbabwe had only a single *Bos indicus* (heat adapted species of cow) and a single *Bos taurus* (common species of cow) skull available, with no complete comparative *Bos taurus* skeleton. This has affected the accuracy of the identification process, hence the uncertain (cf.) classification of some *Bos taurus*. The largest group from both middens is Bovid Size Class III, a category that includes *Bos taurus*, kudu and wildebeest (Plug 2014). We suspect that careful re-examination of this category and comparison with a good reference collection would reduce this group and enlarge the *Bos taurus* category. The *Bos taurus* specimens on which stable isotope analyses were carried out were positively identified to species by comparison with a complete *Bos taurus* skeleton at the Department of Archaeology at the University of Cape Town.

Among the species identified, domesticates dominate in both middens, however, *Bos taurus* is more prominent in NPM, and caprines are the largest identified group in M2. Note that category bov IV contain animals such as buffalo and eland, two huge animals that tend to be aggressive and difficult to hunt (Skinner and Chimimba 2005:624). Buffalo (*Syncerus caffer)* are common at NPM (NISP=34), and there is one bone at M2, in addition to 4 specimens identifiable only as bov IV. Given the difference in sample size from NPM compared to M2, the presence of bov IV in both middens may suggest that the entire society participated in hunting or trapping activities of this size category.

Approximately 25% of the identified faunal remains (108/402 specimens) had cut–, burn–, or gnaw marks, or had signs of being worked, or had unfused epiphyses indicating juveniles. If we concentrate on the age aspect, there is a larger proportion of unfused bones at M2 (14.3%) as opposed to NPM (6.5%). Given the small sample size and poor preservation conditions at M2, this may be a skewed picture. In Thorp's (1995: 61) study, Khami showed less evidence of culling of immature animals compared with Great Zimbabwe, which may suggest that maximising meat exploitation was more important at Khami. Another possible explanation is herd management, with herd managers or stock keepers inhabiting lower-lying ground with immediate access to the cattle kraals.

Stable isotope analysis

Collagen quality was evaluated according to the criteria of Ambrose (1990) and van Klinken (1999). Nearly all samples met these criteria (C/N ratio between 2.9-3.6, weight % C 26-47%, and weight % N11-17%), as reported in Table 3.

Table 3 reports $\delta^{15}N$ and $\delta^{13}C$ values for all specimens analysed. For teeth that underwent serial sampling, the values are means for that tooth. $\delta^{15}N$ values range from 3.7 to 9.1‰. These values are typical of those seen in relatively well-watered environments.

$\delta^{13}C$ values for different skeletal elements range from -4.8‰ to -17.6‰ (Table 3 and Fig. 3). The most positive values are found in grazers (*Syncerus caffer, Bos taurus, Connochaetes taurinus)*, and indicate diets that consisted entirely of C_4 grasses. The most negative values derive from *Ovis*/*Capra* and *Sylvicapra grimmia*, and indicate diets that consisted largely of C_3 browse.

Values for *Ovis/Capra* vary considerably, probably because this category includes both sheep and goats. Ovicaprines are mixed feeders but their dietary preferences vary, with sheep preferring to graze if grass is available, and goats to browse. In summer rainfall regions, this leads to more negative $\delta^{13}C$ values in goats compared with sheep (Balasse and Ambrose 2005). We suspect that in our sample, those specimens of *Ovis/Capra* with the most negative $\delta^{13}C$ values are likely to be goats, whereas those towards the positive end of the range are probably sheep.

In order to investigate possible seasonal variations in diet, we analysed serial samples of dentine collagen from a sub-set of teeth. The results are shown in Fig. 4a-c.

For *Bos taurus*, we have serial samples from one M1 and five M2s. Based on the archaeological context and stage of wear, these six teeth are likely to derive from different animals. The $\delta^{13}C$ and $\delta^{15}N$ profiles for the M1 do not differ noticeably from those for the M2s. In particular, there is no shift in the isotope values in the later-forming compared with the earlier-forming part of the tooth, as reported in some previous studies and interpreted as a signal of weaning (Balasse *et al.* 2001; Balasse & Tresset 2002, but see also Luyt and Sealy 2018). The M1 and M2s can therefore be directly compared. All show very consistent $\delta^{13}C$ and $\delta^{15}N$ values up the height of the tooth. Maximum intra-tooth variation is 2.4‰ for $\delta^{13}C$ (in KNPM224

M2) and 3.2‰ for δ^{15}N (in KNPM121 M2) (excluding a single outlying δ^{13}C value for KNPM274 M2). Mean intra-tooth variation is 1.6‰ for δ^{13}C and 2‰ for δ^{15}N. Given that different individuals raised on the same, isotopically-controlled diet show differences of 1-2‰ in their δ^{13}C and δ^{15}N values (DeNiro and Schoeninger 1983), the amount of variation seen here is very small. The mean δ^{13}C value of -6.1‰ (for all serial samples of all six teeth) indicates diets that consisted mostly of C_4 grasses throughout the period of formation of these teeth.

For *Ovis/Capra*, we have serial samples from nine teeth. For two individuals (KNPM110 and KM1095) we have mandibular M1, M2 and M3. In addition, we have a further M1, M2 and M3, probably from three different individuals. As for *Bos taurus*, the isotopic profiles of the M1s are no more variable than those of the M2s and M3s. Maximum intra-tooth variation is 5.4‰ for δ^{13}C (in KM1095M1) and 2.6‰ for δ^{15}N. Mean intra-tooth variation is 3.4‰ for δ^{13}C and 1.8‰ for δ^{15}N. For δ^{13}C, these values are influenced by four outliers (KNPM 222 M3 slices g and x, KNPM110 M1 slice i and KM1095 M1 slice d). Excluding these values, maximum intra-tooth variation in δ^{13}C is 3.8‰ and the mean 2.6‰. Regardless of whether the outliers are included or excluded, intra-tooth variation in δ^{13}C is somewhat greater in *Ovis/Capra* than in *Bos taurus*, as expected in species that show more dietary flexibility, incorporating both C_3 and C_4 plants. It is, however, remarkable how slight the increase in variation is, and how consistent the mix of C_3/C_4 foods remained throughout the period of mineralization of all three molars. This is true of both KNPM110, which was mainly a browser (very likely a goat), and KM1095, a mixed feeder (very likely a sheep). Similar consistency is seen in the three single teeth. Fig. 4b shows that the *Ovis/Capra* teeth with the most negative δ^{13}C values also have the highest δ^{15}N. Many factors contribute to δ^{15}N values in animals, but several previous studies in African savannahs have reported higher δ^{15}N in browsers compared with grazers (e.g. data from Kasungu in Sealy *et al.* 1987; Smith 2005).

The results of serial sampling of teeth from wild fauna (*Syncerus caffer, Connochaetes taurinus and Damaliscus lunatus*) are shown in Fig. 4c. All are grazers, but the isotope profiles display a degree of variation. Of the three *Syncerus caffer* teeth (KNPM151 M1, KNPM270 M2 and KNPM027 M3, probably all from different animals) the first and third molars have very similar mean δ^{13}C (-5.3 and -5.6‰) and δ^{15}N (5.2 and 4.8‰), while the second has more negative δ^{13}C (-7.3‰) and more positive δ^{15}N (8.9‰). This animal lived in a more arid environment, at least during the time that its second molar was forming. It ate more C_3 browse, and its δ^{15}N value is higher than any of the other grazers reported here. It may have lived during a drought episode. Values for a single tooth of *Connochaetes taurinus* (KNPM055 M2) and

Damaliscus lunatus (KNPM153 M2) indicate consistent grazing diets very similar to those of *Bos taurus*.

Discussion

The remarkable consistency of the δ^{13}C (and δ^{15}N) values in the serially sampled *Bos taurus* teeth shows that these animals had access to good grazing all year round. In *Bos taurus*, permanent second molars begin to form approximately one month after birth, and the roots complete their growth at 24-25 months of age. First molars begin to form in utero, and complete their growth at approximately 13 months (Brown *et al.* 1960). The second molars analysed here (five out of the six cattle teeth that were serially sampled) therefore preserve a record of diet over a period of up to two years (some of the earliest-forming dentine may have been lost due to tooth wear). In all cases, diet was dominated by C$_4$ graze. Cattle did not need to resort to browse during the dry season. Wild species (*Syncerus caffer, Connochaetes taurinus and Damaliscus lunatus*) were also able to graze throughout the year, showing that good year-round grazing could be obtained from wild grasses. There would have been no need to supplement the diets of cattle by feeding them crop residues, although this may have been done. It would be difficult to identify this practice using stable isotope measurements, since δ^{13}C values do not distinguish sorghum and millet from wild C$_4$ grasses.

Smith (2005) and Smith *et al.* (2007) reported δ^{13}C and δ^{15}N values for cattle from the Faure and Kolope sites in the Shashi-Limpopo River Basin, dated to 1475-1685 cal AD and therefore contemporary with Khami. Here, too, cattle were able to consume overwhelmingly (>90%) C$_4$ diets, and Smith noted that this differed from the pattern seen amongst modern herds in the region, which are forced to browse to obtain sufficient nutrition during the dry season (2005:166). Mean δ^{15}N for a combined sample of *Bos taurus* and *Ovis/Capra* from Faure was 8.3 ± 1.2‰ (n=15), while that from Kolope was 9.0 ± 1.6‰ (n=6). By comparison with modern fauna from the same region, Smith *et al.* inferred that these δ^{15}N values indicate rainfall of 350-500mm per annum at that time. Lower δ^{15}N values from Khami reported here might, at first glance, be taken to indicate higher rainfall than in the Shashi-Limpopo River Basin. However, given the multiple factors that influence soil (and hence plant and animal) δ^{15}N (Szpak 2014), this conclusion may not be warranted. Further studies are required to produce a well-documented local baseline before we can draw reliable inferences about past climates.

Concluding remarks

Our faunal analysis shows that a large number of species are present at Khami, consistent with earlier work by Thorp (1995). There is a wider range of species in the NPM midden on the elevated platform compared with the M2 midden on the flats. However, NPM contains a lower proportion of juveniles than M2 (6.5% vs 14.3%). It is, however, difficult to assess the possible effects of differential preservation, which may have created a skewed picture.

The isotope analyses show that *Bos taurus, Syncerus caffer, Connochaetes taurinus* and *Damaliscus lunatus* were able to graze on C_4 grasses throughout the year. Specimens classified as *Ovis/Capra* included both browsers (probably goats) and mixed feeders (probably sheep). The fact that wild grazers were also able to consume C_4 diets year-round is powerful evidence for the existence of rich natural grazing in the vicinity of the site. This was very likely a factor in the decision to build at Khami in the first place, and in the development of the site into a major regional centre. Further work of this kind is being done at other Zimbabwe culture sites, and as more evidence becomes available we will be able to develop a clearer picture of the role of ecological opportunities and constraints in the choices made by these farming communities.

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Note

1. Isotope abundances are reported in the δ notation, relative to international standards of known isotopic composition. Because the variations are slight, values are expressed in parts per thousand or per mille (‰) calculated as:

$$d^aX = \{R_{sample}/R_{standard} - 1\} \text{ x } 1000$$

where R_{sample} is the ratio of ^aX (the less abundant isotope) to ^bX of the sample material and $R_{standard}$ is that of a standard reference material. For carbon isotopes the standard is Peedee Belemnite (PDB), a marine fossil. Marine carbonates contain a relatively large proportion of ^{13}C compared with other biological materials, so the $\delta^{13}C$ values of most organic materials are negative. For nitrogen isotopes, the standard is atmospheric nitrogen gas (AIR).

References

Ambrose, S.H. 1990. "Preparation and characterization of bone and tooth collagen for isotopic analysis". *Journal of Archaeological Science* 17 (4): 431–451.

Ambrose, S.H. 1993. "Isotopic analysis of paleodiets: methodological and interpretive considerations". In *Investigations of ancient human tissue*, edited by Mary K. Sandford, 59–130. Amsterdam: Gordon and Breach Science Publishers.

Balasse, M. and Ambrose, S.H. 2005. "Distinguishing sheep and goats using dental morphology and stable carbon isotopes in C_4 grassland environments". *Journal of Archaeological Science* 32 (5): 691–702.

Balasse, M., Bocherens, H., Mariotti, A. and Ambrose, S.H. 2001."Detection of dietary changes by intra-tooth carbon and nitrogen isotopic analysis: an experimental study of dentine collagen of cattle (*Bos taurus*)". *Journal of Archaeological Science* 28 (3): 235–245.

Balasse, M. and Tresset, A. 2002. "Early weaning of Neolithic domestic cattle (Bercy, France) revealed by intra-tooth variation in nitrogen isotope ratios". *Journal of Archaeological Science* 29 (8): 853–859.

Beach, D.N. 1998. "Cognitive archaeology and the imaginary history of Great Zimbabwe". *Current Anthropology* 39 (1): 47–72.

Brain, C.K. 1974. "Some suggested procedures in the analysis of bone accumulations from southern African Quaternary sites". *Annals of the Transvaal Museum* 29 (1): 1–8.

Brown, W.A.B., Christofferson, P.V., Massler, M. and Weiss, M.B. 1960. "Postnatal tooth development in cattle". *American Journal of Veterinary Research* 21 (80): 7–34.

Chirikure, S., Manyanga, M., Pikirayi, I. and Pollard, M. 2013. "New pathways of sociopolitical complexity in Southern Africa". *African Archaeological Review* 30 (4): 339–366.

Craine, J.M., Elmore, A.J., Aidar, M.P., Bustamante, M., Dawson, T.E., Hobbie, E.A., Kahmen, A., Mack, M.C., McLauchlan, K.K., Michelsen, A. and Nardoto, G.B. 2009. "Global patterns of foliar nitrogen isotopes and their relationships with climate, mycorrhizal fungi, foliar nutrient concentrations, and nitrogen availability." *New Phytologist* 183 (4): 980–992.

DeNiro, M.J. and Schoeninger, M.J. 1983. "Stable carbon and nitrogen isotope ratios of bone collagen: variations within individuals, between sexes, and within populations raised on monotonous diets". *Journal of Archaeological Science* 10 (3): 199–203.

Driscoll, C.A. Macdonald, D.W., and O'Brien, S.J. 2009. "Wild animals to domestic pets, an evolutionary view of domestication". *Proceedings of the National Academy of Science of the United States of America* 106 (1): 9971–9978.

Driver, J.C. 1999. *Manual for Description of Vertebrate Remains.* Vancouver: Crow Canyon Archaeological Center.

Hughes, G. 1997. “Excavations Within the Peripheral Area of Settlement at Khami”. *Zimbabwea* 5: 3–21.

Huffman, T.N. 1996. *Snakes and Crocodiles. Power and Symbolism in Ancient Zimbabwe*. Johannesburg: Witwatersrand University Press.

Huffman, T.N. 2007. *Handbook to the Iron Age: The Archaeology of Pre-Colonial Farming Societies in Southern Africa*. Pietermaritzburg: University of KwaZulu-Natal Press.

Hyde, M.A. Wursten, B.T. Ballings, P.and Palgrave, C.M. 2016. “Flora of Zimbabwe: Location details: Khami Ruins, Bulawayo”. http://www.zimbabweflora.co.zw/index.php.

Loftus, E. Roberts, P. & Lee-Thorp, J.A. 2016. “An isotopic generation: four decades of stable isotope analysis in African archaeology”. *Azania: Archaeological Research in Africa* 51 (1): 88–114.

Luyt, J. & Sealy, J. 2018. “Inter-tooth comparison of $\delta^{13}C$ and $\delta^{18}O$ in ungulate tooth enamel from south-western Africa”. *Quaternary International*. https://doi.org/10.1016/j.quaint.2018.02.009

Makarewicz, C.A. 2014. “Winter pasturing practices and variable fodder provisioning detected in nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotopes in sheep dentinal collagen”. *Journal of Archaeological Science* 41 (1): 502–510.

Mukwende, T. 2016. “An archaeological study of the Zimbabwe culture capital of Khami, south-western Zimbabwe”. PhD diss., University of Cape Town.

Murphy, B.P. and Bowman, D.M. 2009. “The carbon and nitrogen isotope composition of Australian grasses in relation to climate.” *Functional Ecology* 23 (6): 1040–1049.

O’Leary, M.H. 1981. “Carbon isotope fractionation in plants”. *Phytochemistry* 20 (4): 553–567.

Outram, A.K. 2000. “Hunting meat and scavenging marrow? A seasonal explanation for Middle Stone Age subsistence strategies at Klasies River Mouth”. In *Consuming passions and patterns of consumtion,* edited by Preston Miracle and Nicky Milner. Cambridge, MacDonald Institute Monographs.

Outram, A.K. 2002. “Bone fracture and within-bone nutrients: an experimentally based method for investigating levels of marrow extraction”. Vol 5 of *Food, cuisine and society in prehistoric Greece*, edited by Paul Halstead and John C. Barrett, 16–44. Oxford, Sheffield Studies in Aegean Archaeology.

Phillipson, D.W. 1993. *African archaeology*. 2nd ed. Cambridge, Cambridge University Press.

Plug, I. 2014. “*What bone is that? A guide to the identification of southern African mammal bones”*. Pretoria: Rosslyn Publishers Press.

Robinson, K.R. 1959.*Khami ruins: report on excavations undertaken for the preservation of natural and historical monuments and relics, Southern Rhodesia 1947-1955*. Cambridge: Cambridge University Press.

Schapera, I. 1938. *A Handbook of Tswana Law and Custom*. London: Oxford University Press.

Sealy, J.C., van der Merwe, N.J., Lee-Thorp, J.A. and Lanham, J.L. 1987. “Nitrogen isotopic ecology in southern Africa: implications for environmental and dietary tracing”. *Geochimica et Cosmochimica Acta* 51 (10):2707–2717.

Sealy, J.C., Johnson, M., Richards, M. and Nehlich, O. 2014. “Comparison of two methods of extracting bone collagen for stable carbon and nitrogen isotope analysis: comparing whole bone demineralization with gelatinization and ultrafiltation.” *Journal of Archaeological Science* 47 (1): 64–69.

Skinner, J.D. and Chimimba C.T. 2005. *The Mammals of the Southern African Sub-region.* 3rd ed. Cambridge: Cambridge University Press.

Smith, J.M. 2005. “Climate change and agropastoral sustainability in the Shashe/Limpopo river basin from AD 900”. PhD diss., University of the Witwatersrand.

Smith, J., Lee-Thorp, J. and Hall, S. 2007. “Climate change and agropastoralist settlement in the Shashe-Limpopo river basin, Southern Africa: AD 880-1700”. *The South African Archaeological Bulletin* 62 (186): 115–125.

Smith, J.M., Lee-Thorp, J.A., Prevec, S., Hall, S. and Späth, A. 2010. “Pre-colonial herding strategies in the Shashe-Limpopo basin, Southern Africa, based on strontium isotope analysis of domestic fauna”. *Journal of African Archaeology* 81 (1): 83–98.

Smith, J.M., Lee-Thorp, J.A. and Sealy, J.C. 2002. “Stable carbon and oxygen isotopic evidence for late Pleistocene to middle Holocene climatic fluctuations in the interior of southern Africa”. *Journal of Quaternary Science* 17 (7): 683–695.

Szpak, P. 2014. “Complexities of nitrogen isotope biogeochemistry in plant-soil systems: implications for the study of ancient agricultural and animal management practices.” *Frontiers in Plant Science* 5: 288. https://doi.org/10.3389/fpls.2014.00288

Stager, J.C., Ryves, D.B., King, C., Madson, J., Hazzard, M., Neumann F.H. and Maud R. 2013. “Late Holocene precipitation variability in the summer rainfall region of South Africa”. *Quaternary Science Reviews* 67: 105–120.

Summers, R. 1960. “Environment and culture in Southern Rhodesia: a study in the "personality" of a land-locked country”. *Proceedings of the American Philosophical Society* 104 (3): 266–292.

Thorp, C. 1984a. “A cultural interpretation of the faunal assemblage from Khami Hill Ruin”. In *Frontiers: Southern African Archaeology Today*, edited by Martin Hall, Graham Avery, D.Margaret Avery, Michael L. Wilson and Anthony J.B. Humphreys, 266–276. Oxford, British Archaeological Reports International Series 207.

Thorp, C. 1984b. “Faunal remains as evidence for social stratification at Great Zimbabwe”. MA diss., University of the Witwatersrand.

Thorp, C. 1995. *Kings, commoners, and cattle at Zimbabwe tradition sites*. Museum Memoir (New Series) 1. Harare: National Museums and Monuments of Zimbabwe.

Tyson, P.D., Lee-Thorp, J., Holmgren, K. and Thackeray J. 2002. "Changing gradients of climate change in Southern Africa during the past millennium: implications for population movements. *Climate Change* 52 (1): 129–135.

van Klinken, G.J. 1999. "Bone collagen quality indicators for paleodietary and radiocarbon measurements". *Journal of Archaeological Science* 26 (6): 687–695.

van Waarden, C. 1987. "Matanga, a late Zimbabwe cattle post". *The South African Archaeological Bulletin* 42 (146): 107–124.

van Waarden, C. 1989. "The Granaries of Vumba: structural interpretation of a Khami period commoner site". *Journal of Anthropological Archaeology* 8 (2): 131–157.

Woodborne, S., Hall, G., Robertson, I., Patrut, A., Rouault, M., Loader, N.J. and Hofmeyr, M. 2015. "A 1000-year carbon isotope rainfall proxy record from South African baobab trees (*Adansonia digitata* L.)". *PlosOne* 10 (5): 1–18.

Zazzo, A., Balasse, M. and Patterson, W.P. 2006. "The reconstruction of mammal individual history: refining high-resolution isotope record in bovine tooth dentine". *Journal of Archaeological Science* 33(8): 1177–1187.