Testing the methodological utility of trace element analysis for detecting dietary differences in fossil fauna from Turkana

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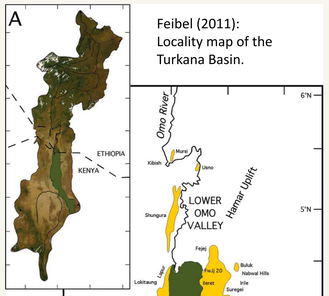
Introduction

Trace element analysis (Sr/Ca, Ba/Ca, Mg/Ca) has been utilized to gauge diet in fossil hominins[1,2,3,4,5]. Biopurification of Sr, Ba, Mg, relative to Ca, increases with trophic space and consequently carnivores exhibit trace element ratios lower than sympatric herbivores[6,7,8,9]. Previous work has characterized South African ecosystems and has been used to infer meat consumption in *Australopithecus* and *Paranthropus*[2,4,5]. Trace element ratios successfully parsed out trophic level in an eastern African modern mammalian ecosystem (Laikipia, Kenya)[10]. Previous work found browsers (a diet comprised of Sr, Ba depleted leaves) display low Sr/Ca, Ba/Ca dietary values relative to sympatric grazers[1,2,3]. Yet contrary to previous work[4], our modern study in eastern Africa found no significant separation among herbivorous taxa. **Here we present a pilot study in eastern Africa assaying the relationship between Sr/Ca, Ba/Ca values in herbivorous fossil taxa to determine if the modern faunal pattern found in Laikipia, Kenya persists through time.**

Nachukui Formation, West Turkana, Kenya



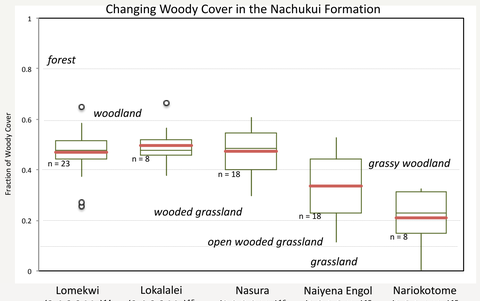
Feibel (2011): Locality map of the Turkana Basin.

The Nachukui Formation, one of three main formations in the upper part of the Turkana Basin, is situated west of Lake Turkana and encompasses sediments dating to the Plio-Pleistocene[11]. The Nachukui Formation is comprised of eight members and ranges in age from 4 Ma to 0.7 Ma.

Numerous hominin-bearing archaeological sites are found within the Nachukui Formation including Lokalalei 1a (early *Homo*)[12], Naiyena Engol (*Homo*)[13], and Kalokodo 6 (*Paranthropus boisei*)[13]. Fauna included in the study are from eleven sites: Lomekwi 3, Nasura 1, Nasura 2, Nasura 3, Lokalalei 1, Lokalalei 2C, Naiyena Engol 1, Naiyena Engol 2, Nadung'a 3, Nachukui 6, Kalokodo 6. Site dates from Roche (2011) and Chris Lepre (pers. comm).

Site	Abbreviation	Age (Ma)
Lomekwi 3	LOM-3	3.4 – 3.2
Lokalalei 1	LA1	2.4 – 2.2
Lokalalei 2C	LA2C	2.4 – 2.2
Nasura 1	NAS1	2.3 – 2.0
Nasura 2	NAS2	2.3 – 2.0
Nasura 3	NAS3	2.3 – 2.0
Kalokodo 6	KLD6	1.8 – 1.6
Naiyena Engol 1	NY1	1.8 – 1.6
Naiyena Engol 2	NY2	1.8 – 1.6
Nachukui 6	NK6	1.3 – 1.1
Nadung'a 3	NAD3	0.9 – 0.7

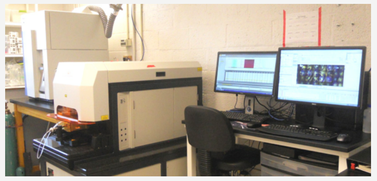
Vegetation Structure of the Nachukui Formation



Pedogenic carbonate $\delta^{13}C$ values (Quinn et al., 2013, unpublished; Harmand et al., 2015) were used to calculate the fraction of woody cover[17] through time in the Nachukui Formation.

Despite change in the vegetative structure in the Nachukui Formation, the relative Sr/Ca and Ba/Ca ratios amongst fossil taxa do not vary by site, implying that trace elements may be useful at gauging dietary differences amongst time-transgressive faunal assemblages and vegetation community changes.

Mass Spectrometry



Enamel samples were analyzed at the Department of Earth and Planetary Sciences at Rutgers University. Trace elements were analyzed on a Thermo iCapQc ICP-MS under the direction of Jake Setera; $\delta^{13}C$ values were analyzed on a FISIONS IRMS under the direction of Jim Wright and Rick Mortlock.

NSF provided funding for student training in anthropological isotopic methodologies (to RQ, NSF-BCS 1455274). Seton Hall University Research Council provided travel funds to RQ for sample collection.

Sample Collection and Pretreatment

Reduncini LM^3 from LA1

Faunal samples analyzed here were excavated by the West Turkana Archaeological Project and are housed in the Archaeology Department of the Kenya National Museums in Nairobi.

Enamel was sampled with a diamond-tipped rotary tool (Foredom Series) from clean surfaces of whole teeth. We preferentially sampled late-forming teeth depending on species known eruption sequences. Half of the samples (n=45) were pretreated with 0.1 M acetic acid for ten minutes then rinsed three times with distilled deionized water. **No significant differences exist between pretreated or unpretreated samples[18]**.

Next, between 1.0-1.5 mg of enamel powder from each specimen was weighed and treated with 0.5 mL of 65% HNO_3 in Teflon beakers. The solution was evaporated to dryness on a hotplate. Residue was dissolved, according to standards of the lab, into 5 mL of 2% HNO_3 to be analyzed. Two modern zebra samples were analyzed multiple times to serve as an internal standard between runs. NIST SRM 1400 (bone ash) was used as the external standard. Error is estimated as ±3%.

Diet Categories

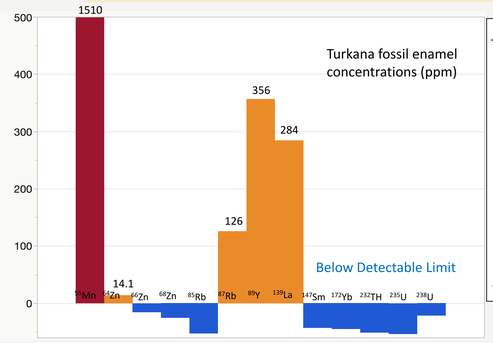
Family	Tribe	Diet*	N	$\delta^{13}C$ range
Camelidae		Browser	3	-11.6 to -10.2 ‰
Deinotherioidea		Browser**	1	
Giraffidae		Browser**	1	
Felidae		Carnivore	1	-4.5 ‰
Bovidae	Bovini	Grazer	3	-0.9 to .02 ‰
Bovidae	Tragelaphini	Grazer	3	-1.5 to 2.4 ‰
Bovidae	Aepycerotini	Grazer (Mixed Feeder)	8	-1.6 to 0.6 ‰
Bovidae	Alcelaphini	Grazer (Mixed Feeder)	8	-4.8 to 1.6 ‰
Bovidae	Antilopini	Grazer (Mixed Feeder)	4	-2.9 to 0.6 ‰
Bovidae	Reduncini	Grazer (Mixed Feeder)	4	-3.8 to 1.0 ‰
Bovidae		Grazer (Browser)	5	0.0 to -8.6 ‰
Hippopotamidae		Grazer (Mixed Feeder)	8	-5.6 to -1.2 ‰
Cercopithecoidae	Papionini	Grazer (Omnivore)	5	-2.1 to -1.9 ‰
Equidae		Grazer	4	-0.6 to 0.2 ‰
Rhinocerotidae		Grazer	3	-0.9 to -0.5 ‰
Proboscidea		Grazer (Browser)	16	-10.1 to 0.6 ‰
Suidae		Omnivore	10	-2.1 to 0.1 ‰

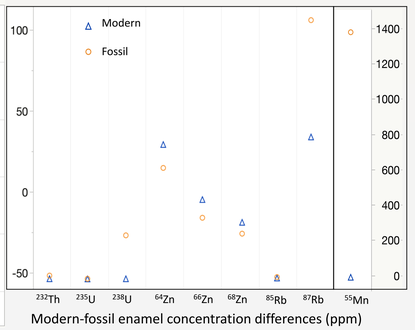
Dietary classification for each specimen was confirmed by a $\delta^{13}C$ value. Above, the most common diet is listed for each taxon, and the less common diet is in parentheses.
**$\delta^{13}C$ values unavailable

Aepycerotini LM_3 from LOM-3

We analyzed Sr/Ca and Ba/Ca from bulk enamel of 87 individuals with thirty-nine and forty-eight specimens identified at the tribe and family level, respectively. Diet categories include C_4 grazers, C_3 browsers, mixed C_3-C_4 feeders, carnivores, and omnivores.

Monitoring Diagenesis

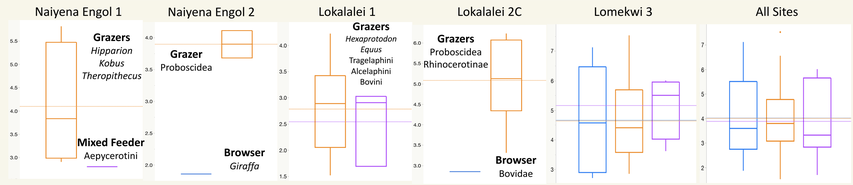




Modern-fossil enamel concentration differences (ppm)

We gauged diagenesis in the Turkana fossil enamel samples by measuring Mn, Zn, Rb, Y, La, Sm, Yb, Th, and U. Concentrations of ^{55}Mn and ^{87}Rb are significantly higher in the fossil enamel samples than in the modern assemblage. We interpret that the Turkana fossil enamel sample has undergone element-specific diagenetic effects, but still holds promise for traces element analysis for inferring trophic level.

Results: Sr/Ca Herbivore Site Comparisons



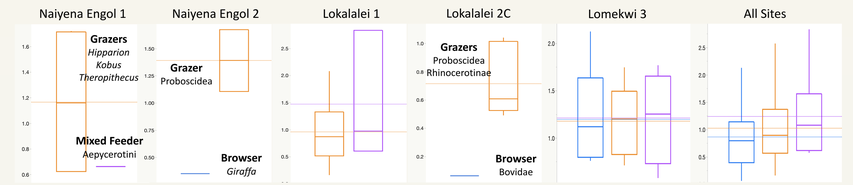
Sites with a minimum of two herbivorous diet groups (browser, grazer, mixed feeder) are presented with boxplots in the above figure.

One-way ANOVA

Site	Difference	Test Statistic	p-level
NY1 (Grazer-Mixed Feeder)	1.2971	0.7646	0.4463
NY2 (Browser-Grazer)	2.0389	29.9327	0.1151
LA1 (Grazer-Mixed Feeder)	0.2432	0.2120	0.6523
LA2C (Browser-Grazer)	3.0420	1.4647	0.2717
LOM-3 (Browser-Grazer-Mixed Feeder)		0.2480	0.7822
All Sites(Browser-Grazer-Mixed Feeder)		0.0286	0.9718

We found no significant difference in Sr/Ca among herbivorous taxa at individual sites (NY1, NY2, LA1, LA2C, LOM3) or when all sites were combined. **Similar to the findings in Laikipia, Kenya, Nachukui fossil C_3 browser and C_4 grazer Sr/Ca ratios do not differ from one another**.

Results: Ba/Ca Herbivore Site Comparisons



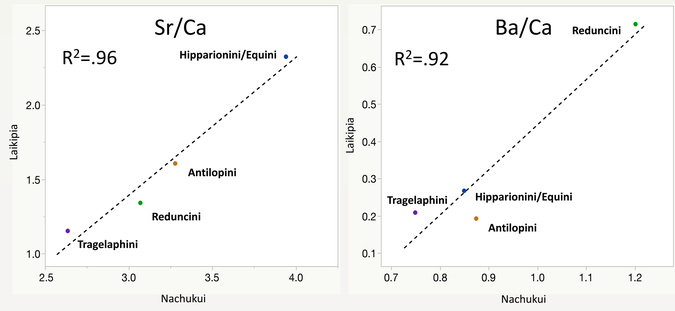
Sites with a minimum of two herbivorous diet groups (browser, grazer, mixed feeder) are presented with boxplots in the above figure.

One-way ANOVA

Site	Difference	Test Statistic	p-level
NY1 (Grazer-Mixed Feeder)	0.5042	0.5227	0.5220
NY2 (Browser-Grazer)	1.0401	4.4634	0.2814
LA1 (Grazer-Mixed Feeder)	0.5122	1.4199	0.2532
LA2C (Browser-Grazer)	0.9681	1.0887	0.3370
LOM-3 (Browser-Grazer-Mixed Feeder)		0.0139	0.9862
All Sites(Browser-Grazer-Mixed Feeder)		0.8468	0.4333

We found no significant difference in Ba/Ca among herbivorous taxa at individual sites (NY1, NY2, LA1, LA2C, LOM3) or when all sites were combined. **Similar to the findings in Laikipia, Kenya, Nachukui fossil C_3 browser and C_4 grazer Ba/Ca ratios do not differ from one another**.

Results: Sr/Ca and Ba/Ca Modern-Fossil Comparisons

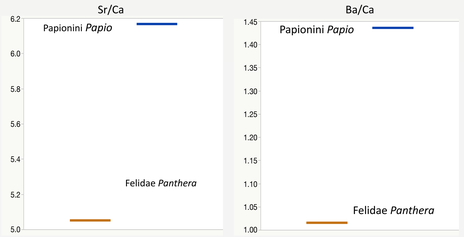


We found good agreement between fossil and modern Sr/Ca (R^2=0.96) and Ba/Ca (R^2=0.92) ratios of tragelaphini, antilopini, reduncini and hipparionini/equini.

Notably for Ba/Ca, the distribution of data prohibits a meaningful interpretation.

Future Directions: Indicators of trophic level

Kalokodo 6



In Laikipia, predators showed lower Sr/Ca and Ba/Ca than their prey. In the Nachukui sample, one *Panthera* specimen from Kalokodo 6 was the only terrestrial carnivore available for analysis. Here we compare the *Panthera* to one specimen of *Papio* available from Kalokodo 6. Major conclusions cannot be derived from a single carnivore, yet the lower Sr/Ca and Ba/Ca ratios of *Panthera* (carnivore) relative to *Papio* (omnivore) is intriguing and warrants further research.

All references denoted by superscript numbers are provided on handout.