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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^{1,2,4,5}. 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*^{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^{11,12}. Yet contrary to previous work⁴, 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.

Nachukul Formation, West Turkana, Kenya

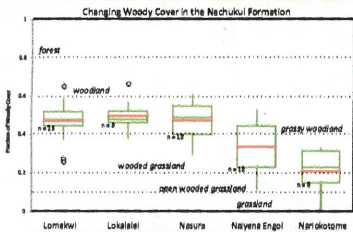


The Nachukul Formation, one of three main formations in the upper part of the Turkana Basin, is situated west of Lake Turkana and encompasses sediments dating to the Pliocene-Pleistocene¹³. The Nachukul Formation is comprised of eight members and ranges in age from 4 Ma to 0.7 Ma.

Numerous hominin-bearing archaeological sites are found within the Nachukul Formation including Lokalelei 1a (early Homo)¹⁴, Nalyena Engol (*Homo*)¹⁵, and Kalokodo 6 (*Paranthropus boisei*)¹⁶. Fauna included in the study are from eleven sites: Lomekwi 3, Nasura 1, Nasura 2, Nasura 3, Lokalelei 1, Lokalelei 2C, Nalyena Engol 1, Nalyena Engol 2, Nadung'u 3, Nachukul 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
Lokalelei 1	LA1	2.4 - 2.2
Lokalelei 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	1.6 - 1.6
Nalyena Engol 1	NY1	1.6 - 1.6
Nalyena Engol 2	NY2	1.6 - 1.6
Nachukul 6	NK6	1.3 - 1.1
Nadung'u 3	NAD3	0.9 - 0.7

Vegetation Structure of the Nachukul Formation



Pedogenic carbonate $\delta^{13}C$ values (Quinn et al., 2013, unpublished; Harmand et al., 2015) were used to calculate the fraction of woody cover¹⁷ through time in the Nachukul Formation.

Despite change in the vegetative structure in the Nachukul 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.

Sample Collection and Pretreatment



Reduncini LM1 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 untreated samples¹⁸.



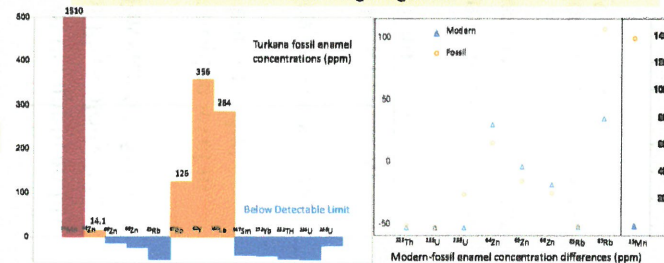
Aepycerotini LM1 from LOM-3

Diet Categories

Family	Tribe	Diet ^a	N	$\delta^{13}C$ range
Camelidae		Browser	3	-11.6 to -10.2 ‰
Deinotheriidae		Browser ^{a*}	1	
Giraffidae		Browser ^{a*}	1	
Felidae		Carnivore	1	-4.3 ‰
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 ‰
Cercopithecidae	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 ‰

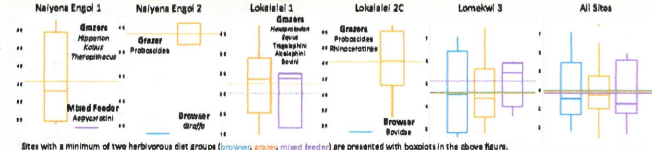
Dietary classification for each specimen was confirmed by a $\delta^{13}C$ value. Above, the most common diet is listed for each taxon, and the less common diet is in parentheses. ^a $\delta^{13}C$ values unavailable

Monitoring Diagenesis



We gauged diagenesis in the Turkana fossil enamel samples by measuring Mn, Zn, Rb, Y, La, Sm, Yb, Th, and U. Concentrations of ⁵⁵Mn and ⁸⁷Rb 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 trace element analysis for inferring trophic level.

Results: Sr/Ca Herbivore Site Comparisons



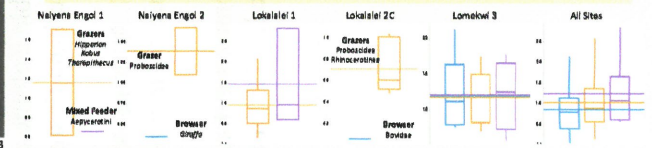
Sites with a minimum of two herbivorous diet groups (browsers, grazers, mixed feeders) are presented with boxplots in the above figure.

One-way ANOVA

Site	Difference	Test Statistic	p-level
NY1 (Grazer/Mixed Feeder)	1.2975	0.7646	0.4663
NY2 (Browser-Grazer)	2.0389	29.9327	0.1151
LA1 (Grazer/Mixed Feeder)	2.2432	0.3120	0.6823
LA2C (Browser-Grazer)	3.0420	1.4847	0.2717
LOM-3 (Browser-Grazer-Mixed Feeder)	0.3480	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, Nachukul fossil C₃ browser and C₄ grazer Sr/Ca ratios do not differ from one another.

Results: Ba/Ca Herbivore Site Comparisons



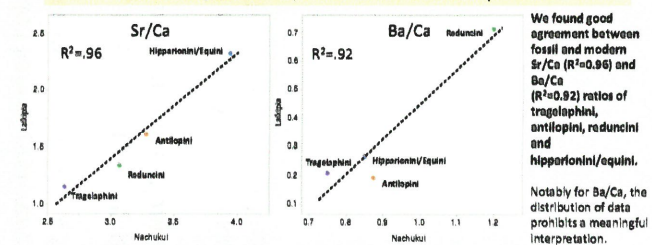
Sites with a minimum of two herbivorous diet groups (browsers, grazers, mixed feeders) are presented with boxplots in the above figure.

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	0.2914
LA1 (Grazer/Mixed Feeder)	0.5122	1.4199	0.2532
LA2C (Browser-Grazer)	0.9481	1.0887	0.3370
LOM-3 (Browser-Grazer-Mixed Feeder)	0.0139	0.0862	
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, Nachukul fossil C₃ browser and C₄ grazer Ba/Ca ratios do not differ from one another.

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

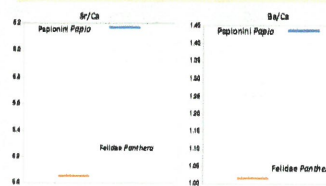


We found good agreement between fossil and modern Sr/Ca (R²=0.96) and Ba/Ca (R²=0.92) ratios of tragelaphini, antilopini, reduncini and hippopotamini/equini.

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 Nachukul 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.