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Contributions to the Archaeology of Egypt, Nubia and the Levant

CAENL

Edited by
Manfred Bietak, Robert Rollinger, Rahim Shayegan
and Willeke Wendrich

Volume 17

2024
Harrassowitz Verlag · Wiesbaden

Landscape and resource management in Bronze Age Nubia:

Archaeological perspectives on the exploitation of natural resources and the circulation of commodities in the Middle Nile

Edited by
Julia Budka and Rennan Lemos

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Harrassowitz Verlag · Wiesbaden

Cover photo: C. Geiger, © MUAFS Project, LMU.

The research leading to these results has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 865463).

European Research Council
Established by the European Commission

Diverse Nile

This publication has undergone the process of international blind peer review.

Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über https://dnb.de abrufbar.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at https://dnb.de

For further information about our publishing program consult our website https://www.harrassowitz-verlag.de

Printed on permanent/durable paper.
Typesetting and layout: Kim-Denise Uhe, u.ni medienservice, Hönze
Printing and binding: Hubert & Co., Göttingen
Printed in Germany

ISSN 2627-8022 e ISSN 2701-5831
ISBN 978-3-447-12137-8 Ebook ISBN 978-3-447-39498-7

Chapter 8

Isotopic and skeletal approaches to diet and mobility in ancient Nubia

Sarah Schrader[1] and Michele Buzon[2]

Abstract

In this chapter, we discuss previous isotopic research that has focused on diet and mobility in the ancient Nile Valley, with particular focus on Nubia. While dietary interpretations from carbon and nitrogen from bone collagen have been discussed elsewhere, carbonate in the Nile Valley has not been fully appreciated. We present new carbon and nitrogen data from carbonate tissues coupled with strontium to examine if and how childhood diet and migration status are related. We assess isotopic data from Tombos, Qurneh, Saqqara, Amara West, as well as the Scandinavian Joint Expedition's Pharaonic and C-Group samples. Our analysis suggests dietary practices were different between these samples. Tombos, Pharaonic, and C-Group all have markedly varied carbon values, which may suggest a more Nubian C_4-based diet. The other samples, Qurneh, Saqqara, and Amara West, are all much more similar, which may reflect a stricter Egyptian C_3-diet, or may be the effect of a small sample size. At Tombos, there does appear to be a difference between individuals who have a local strontium isotope signature and those that do not. However, this needs to be explored further as strontium should be coupled with other isotopes to confirm migration. This chapter illustrates the important contribution isotopes have made to dietary and migration studies in the Nile Valley while simultaneously highlighting the potential for future isotope analysis in the region.

Keywords:

Carbonate, strontium, carbon, nitrogen, foodways, migration, Nubia

Introduction

The human history of the Nile Valley spans millennia; during this time, there was a plethora of complex human interactions, as populations moved, boundaries changed, and people intermingled. Archaeologically, this is very fruitful ground as countless questions can be asked regarding but not limited to, sociopolitical change, everyday life, and the exploitation of resources. Using isotope science to address these questions is not only popular, but highly informative. Within the Nile Valley, there is a long history of isotope studies that have addressed topics such as human and animal diet, migration, climate change, and weaning.[3] The field is continuously developing as new archaeological sites are discovered and state-of-the-art isotopic methods are established.

However, isotopic studies are not always the ideal methodological approach and these techniques do come with limitations. For example, while the hot and arid environment of the Nile Valley macroscopically preserves bones, on a microscopic level there is often significant destruction to biomolecules. Several studies report limited to no success with such analyses, which is likely due to diagenetic, or post-depositional, processes associated with the extreme environment.[4]

In this contribution, we discuss previous isotopic research in the Nile Valley, with a particular focus on dietary and mobility isotopes. We discuss the various human tissues (e.g., bone collagen, dental enamel carbonate) that have been isotopically examined and pay particular attention to those tissues that are more resilient to diagenetic alteration. We review previous publications that have used these approaches and document methodological and topical trends in the field. Additionally, new carbon and strontium data from dental enamel are presented from Tombos, Qurneh, Saqqara, Amara West, and the Pharaonic as well as C-Group populations (Scandinavian Joint Expedition to Lower Nubia, discussed further below). We use carbon to infer dietary practices and strontium to elucidate possible scenarios of migration, both at the individual and population levels. Through this multi-isotope approach, we aim to elucidate the intersection of locality and diet in diverse Nubian populations, spanning the C-Group through Napatan Periods (c. 2300–664 BC). While many isotopic studies have been conducted in the Nile Valley, this chapter makes a unique contribution by comparing dental enamel carbon and strontium isotope data from these Nile Valley samples.

1 Faculty of Archaeology, Leiden University, The Netherlands; s.a.schrader@arch.leidenuniv.nl.

2 Department of Anthropology, Purdue University, USA; mbuzon@purdue.edu.

3 Buzon and Richman 2007; Buzon and Simonetti 2013; Buzon, Smith and Simonetti 2016; Buzon and Bowen 2010; Eerkens et al. 2018; Iacumin et al. 1996; Schrader 2019; Stantis et al. 2019; Stantis et al. 2020; Stantis et al. 2021.

4 For examples see Schrader 2019; Stantis et al. 2021; Thompson, Chaix and Richards 2008.

Dietary and mobility isotopic studies in the Nile Valley

Before discussing our new dataset and interpretations, we present a brief explanation of isotopes and previous applications to archaeological contexts. We focus specifically on carbon and strontium, as these are the isotopes examined in this chapter. There are other resources that discuss other isotopes applied to the Nile Valley, including nitrogen, oxygen, lead, and others.[5]

The foundations of isotope archaeology

Isotopes have been studied archaeologically for decades, providing an excellent basis for paleodietary studies and continued research.[6] Originally stemming from an interest in carbon-14 dating methods, research in this area gradually developed into broader applications including dietary reconstruction as well as mobility, life history, demography, disease, and paleoenvironmental studies.[7] With the development of mass-spectrometry technology, refined measurements of specific isotopes and their relative abundances became possible. Protocol to identify postmortem degradation have also been developed, increasing the reliability of the method.

In addition to the examination of various isotopes, multiple human tissues began to be assessed. Bone is composed of both organic and inorganic materials; the former, bone collagen, makes up approximately 30% of dry bone and the latter, bone carbonate, composes the other 70% of dry bone.[8] Controlled feeding studies have indicated that collagen isotope ratios reflect dietary proteins, whereas carbonate isotope ratios are derived from the total diet.[9] One integral component of bone is that it remodels throughout the life course. The speed with which a bone remodels depends on the bone; ribs are said to remodel approximately every two to five years, whereas the femur can take ten years or more to completely turnover.[10] Teeth also contain both organic as well as inorganic material. Dentine, the inner portion of the tooth extending from the crown to root, is approximately 30% organic.[11] Dental enamel, located on the crown surface, is largely composed of inorganic carbonate hydroxyapatite, making it particularly resistant to degradation.[12] Primary dentine, deposited during tooth formation, does not remodel during life; however, secondary and sometimes tertiary dentine do remodel.[13] Conversely, dental enamel does not change during life, but rather is essentially locked in at the time of production (*in utero*-15 years, depending on the tooth).[14]

Carbon

By analysing the ratio of the isotopes ^{13}C to ^{12}C, expressed as $\delta^{13}C$, archaeologists are able to infer broad patterns of plant consumption. More specifically, scientists can differentiate a predominately C_3-based plant diet (e.g., wheat, rice, many vegetables and fruits) from a C_4-based plant diet (e.g., sorghum, millet).[15] There is an approximate 5‰ enrichment between plant $\delta^{13}C$ values of plants and those of human bone collagen, and a further 5-6‰ enrichment between collagen and carbonate tissues.[16] Thus, we can expect bone collagen $\delta^{13}C$ values for C_3 diets to range from -33‰ to -23‰ (mean collagen approximately -19‰; mean carbonate approximately -12‰) and bone collagen $\delta^{13}C$ values for C_4 diets to range from -14‰ to -9‰ (mean collagen approximately -8‰; mean carbonate approximately -1‰).[17] There is a third photosynthetic pathway, CAM plants, that have $\delta^{13}C$ values intermediary to C_3 and C_4; however, they are not common in the Nile Valley and likely were not consumed as foods. Going beyond C_3/C_4 foods, it is also possible to use carbon isotopes to distinguish between marine and terrestrial diets. Because the main source of carbon for marine animals is dissolved carbonate ($\delta^{13}C$=0‰), which differs from atmospheric CO_2, ($\delta^{13}C$= -7‰), we can expect a 7‰ difference between terrestrial and marine environments.[18] Carbon values, primarily from dental enamel carbonate, can also be used to assess when weaning from breastmilk to solid foods occurred. Studies comparing dental enamel from multiple teeth have shown a dietary shift at the time of weaning, namely a general enrichment in $\delta^{13}C$ increasing with age.[19] For example, at the Dakhleh Oasis (Roman Egypt), there is a significant difference between preweaning and postweaning teeth, and it is estimated that complete weaning occurred by the age of 3 years old.[20]

Nitrogen values provide information on trophic level, wherein nitrogen is accumulated through steps in the food chain. Each step results in an approximately

5 See Buzon and Bowen 2010; Dupras and Schwarcz 2001; Iacumin et al. 1996; Iacumin et al. 1998; Schrader 2019; Simonetti et al. 2021; Thompson et al. 2005; Thompson, Chaix and Richards 2008; Touzeau et al. 2013; White 1993; White, Longstaffe and Law 2004.

6 See Britton 2018.

7 Katzenberg and Waters-Rist 2019.

8 Note that a small percentage of non-collagenous proteins, proteoglycans, lipids, and trace element substitutions are also present in bone; Katzenberg and Waters-Rist 2019.

9 Ambrose and Norr 1993; Kellner and Schoeninger 2007; Tieszen and Fagre 1993.

10 Hedges et al. 2007; Parfitt 2002; Xia et al. 2018.

11 Pilloud and Heim 2018.

12 Plomp et al. 2020

13 Cox and Sealy 1997; Hillson 1996.

14 Dupras and Tocheri 2007; Hillson 1996.

15 Smith and Epstein 1971.

16 Ambrose and Norr 1993; Passey et al. 2005.

17 DeNiro and Epstein 1978; Dupras and Tocheri 2007; Lee-Thorp, Sealy and van der Merwe 1989; Schoeninger and DeNiro 1984.

18 Katzenberg and Waters-Rist 2019.

19 Wright and Schwarcz 1998.

20 Dupras and Tocheri 2007.

3-5‰ increase, or enrichment, of $\delta^{15}N$ values.[21] For example, legumes have a $\delta^{15}N$ of 0‰; $\delta^{15}N$ values for herbivores are variable, but usually fall within 3-6‰; carnivores living in the same environment would then have $\delta^{15}N$ values greater than 6‰. In addition to trophic levels, nitrogen isotopes can also speak to freshwater fish consumption. As we might expect, the consumption of freshwater fish results in a more enriched $\delta^{15}N$ value, but also, will be accompanied by an increase in $\delta^{13}C$ values. The increase of $\delta^{13}C$ is markedly variable, given that, even within the same body of water, freshwater plants have various resources of carbon (e.g., atmospheric CO_2, water CO_2, soil bicarbonate and carbonate, organic carbon from plants and animals).[22] For example, Katzenberg and colleagues found that $\delta^{13}C$ values of fish bones ranged from -8.1 to -27.0‰ within the same body of water (little Sea of Lake Baikal).[23]

Previous studies of carbon and nitrogen from bone collagen in the Nile Valley have illustrated variation in diet across time and space. Differences between Egyptian and Nubian populations, with the former having a predominately C_3 diet and the latter having a mixed C_3/C_4 diet, have been put forward.[24] For example, Saqqara, Abydos, and Asyut samples all have strong C_3 isotopic values, suggesting a diet including wheat, barley, vegetables, and fruits.[25] Whereas, Kerma individuals have a mixed C_3/C_4 diet, suggesting they consumed sorghum or millet, or ate animals who were foddered on C_4 plants.[26] However, it should be noted that results from bone collagen have been limited due to poor preservation, as collagen is vulnerable to diagenesis.

While previous publications have summarised carbon and nitrogen collagen values from the Nile Valley, carbonate values have largely been overlooked.[27] However, several isotopic studies using carbonate tissues, abbreviated here as $\delta^{13}C_{CARB}$, have been conducted using Nile Valley samples. Iacumin and colleagues examined both bone collagen and bone carbonate from Gebelein (Predynastic 4950–2950 BC and First Intermediate Period 2120–1990 BC) and Asyut (First Intermediate Period) as well as unknown samples (probably from the Dynastic Period) and unknown mummy samples (bone carbonate n = 24).[28] The values between sites and time periods were markedly similar and reflect a largely C_3 diet ($\delta^{13}C_{CARB}$ -15.3‰ to -13.2‰; = -14.38 ± 0.48). Later, Buzon and Bowen examine the feasibility of using oxygen isotopes in the Nile Valley and in doing so, also present dental enamel carbonate data from the Nubian site of Tombos (n = 30).[29] Carbonate values from this sample were much more varied ($\delta^{13}C_{CARB}$ -13.4‰ to -7.4‰; = -11.81 ± 1.0), indicating a stronger C_4 component to the Nubian diet, which is congruent with other regional isotopic studies.[30]

Touzeau and colleagues examined carbon in bone and dental enamel carbonate, in addition to other tissues and isotopes (sulfur, hair, and soft tissue), in Egyptian mummies dating from 2500 BC–500 AD (n = 36).[31] Carbonate in bone and dental enamel both suggested a predominately C_3 diet (bone $\delta^{13}C_{CARB}$ -15.68‰ to -11.50‰; = -14.3 ± 0.9; enamel $\delta^{13}C_{CARB}$ -13.20‰ to -10.74‰; = -11.6 ± 0.7); these values are markedly similar to those reported above[32] and the authors also note a notable continuity in carbonate values over thousands of years of Egyptian history. Dental enamel carbonate was also less negative than bone carbonate (both within and between individuals, on average 2.7‰ less negative), which the authors suggest may be due to weaning practices. It is possible that milk, originating from C_4 fed animals, or millet gruel was introduced to infants and toddlers as part of the weaning process.[33]

Stantis and colleagues examined both mobility and dietary practices via strontium, oxygen, and carbon from dental carbonate at the site of Tell el-Daba in the Nile Delta (n=75).[34] Tell el-Daba is important as it is the capital city of the Hyksos, who are thought to have originated in the Near East and ruled Lower Egypt from the Delta during the Second Intermediate Period (c. 1638-1530 BC). Carbon values reported here are largely C_3, like other Nile Valley studies (enamel $\delta^{13}C_{CARB}$ -13.5‰ to -9.6‰; = -11.4 ± 0.7). Interestingly, there was no significant difference in carbon values between locals and non-locals, suggesting similar dietary patterns during childhood. Stantis and co-authors note a wider variety of foods consumed in non-locals, as illustrated by a broader $\delta^{13}C$ range (non-locals $\delta^{13}C_{CARB}$ -13.5‰ to -9.6‰, locals $\delta^{13}C_{CARB}$: -12.1‰ to -10.3‰).[35] These findings may also speak to the abundance of C_3 vegetation in both Egypt and the Near East during the Bronze Age.

Strontium

The movement of people across the landscape can provide important information to understand how resources were accessed and utilised through time.

21 Bocherens and Drucker 2003; O'Connell et al. 2012; Schwarcz and Schoeninger 1991.
22 Katzenberg and Waters-Rist 2019.
23 Katzenberg et al. 2012.
24 Schrader 2019.
25 Iacumin et al. 1996; Thompson et al. 2005.
26 Iacumin et al. 1998; Thompson, Chaix and Richards 2008.
27 See Schrader 2019.
28 Iacumin et al. 1996.
29 Buzon and Bowen 2010.
30 Ciesielska et al. 2021; Iacumin et al. 1998; Schrader 2019; Thompson, Chaix and Richards 2008.
31 Touzeau et al. 2014.
32 See Iacumin et al. 1996.
33 Touzeau et al. 2014.
34 Stantis et al. 2021.
35 Stantis et al. 2021.

For instance, in Bronze Age Nubia, the control of land by Kerma or Egyptians may have resulted in the relocation of individuals. Markers of geographic origin, such as isotopic signatures, are often used to investigate if migration, defined as one-way, long-term, permanent relocation, has occurred. However, mobility, understood as movement across shorter distances within more limited cultural or political boundaries, may also have occurred.[36] The ability to trace these transfers depends on particulars of the isotope system being used and the documented variability between regions of interest.

Isotope analyses can be used to identify first-generation immigrants who spent time in another location while their dental tissues were developing during childhood, or more recently though skeletal tissues if tissues are intact. Strontium isotope analysis ($^{87}Sr/^{86}Sr$) has been used in many global locations to trace movements across the landscape. Geological variability in the age and composition of bedrock is needed between a particular site and a likely place of origin for immigrants. Younger rocks and rocks with low Rb content generally have lower $^{87}Sr/^{86}Sr$ values with older, Rb-rich rocks, such as granite, that are characterised by higher values.[37] It is also important that local foods are being consumed, which would reflect the local geology; the importation of nonlocal foods as well as the consumption of sea salt can override local signatures.[38]

The Nile Valley provides some geological differences along the river, which are the basis for this method. Below the First Cataract, formations are characterised by Dakhla chalk, Esna shale and Theban limestone; Nubia generally consists of pre-Cambrian Basement Complex covered with Nubian Sandstone complex, with outcrops of granite at the cataracts.[39] The determination of a local $^{87}Sr/^{86}Sr$ signature is usually accomplished by analysing local small animals with local home ranges in order to characterize the biologically available strontium.[40]

Strontium isotope research in the region over the last two decades beginning with Buzon and colleagues[41] has established some consistency ($^{87}Sr/^{86}Sr$ with other archaeological indications of identity) in the documentation of individuals who may have originated in Egypt and moved to Nubia during the colonial activities of the Egyptian empire, particularly at the Third Cataract site of Tombos. Very little research has been done on samples in Northeast Africa outside of the Nile River Valley. However, as more samples are analysed by various researchers at numerous sites in the region,[42] it has become clear that there is much overlap in $^{87}Sr/^{86}Sr$ values.[43] The addition of other isotope systems may provide a sharper picture of movements. For example, variability in Pb ($^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$, $^{208}Pb/^{206}Pb$ $^{207}Pb/^{206}Pb$) and Nd ($^{143}Nd/^{144}Nd$) isotope can be used to corroborate the interpretations based on Sr isotope ratios.[44]

Oxygen isotope analysis ($\delta^{18}O$) has also been used in this region. Oxygen isotopes vary in relation to hydrological, geographical, and climatological factors such as temperature, humidity, rainfall, latitude, elevation and distance from the coast.[45] These values are complicated by isotopically variable groundwater (wells) and river water as well as water use strategies such as irrigation, storage, and boiling.[46] However, this method has proven valuable in distinguishing individuals from desert oases from the river valley[47] and may provide a useful method to explore the movement of people in Nubia into and from the Eastern and Western Deserts.

Materials and methods

Here we present new carbonate data, paired with previously published strontium data, from various ancient sites, including: Tombos, Qurneh, Saqqara, Amara West, Pharaonic, and C-Group (the last two of which are composed of various sites, excavated as part of the Scandinavian Joint Expedition to Sudanese Nubia; *N*=104; Fig. 1).

Materials

Tombos

Tombos is located at the Third Cataract of the Nile in Sudan. Remains in the nearby town reveal structure foundations and a wall/dry moat system that outlined a large, fortified area, which may have been the ancient fortress of Taroy.[48] Excavations and analyses since 2000 have revealed three main burial areas: North (middle-class chamber tombs and pits primarily dating to the New Kingdom Period), East (tumulus graves that begin in the late New Kingdom and continue into the early Napatan Period), and West (pyramid, chapel, and chamber tombs along with pit tombs primarily dating to

36 Gregoricka 2021.
37 Faure 1977.
38 Fenner and Wright 2014.
39 Burke et al. 1982; Whiteman 1971.
40 Price, Burton and Bentley 2002.
41 Buzon, Simonetti and Creaser 2007.
42 Buzon, Simonetti and Creaser 2007; Buzon, Smith and Simonetti 2016; Buzon and Simonetti 2013; Kozieradzka-Ogunmakin 2021; Osypinska et al. 2021; Retzmann et al. 2019; Schrader et al. 2019; Simonetti et al. 2021; Stantis et al. 2020; Touzeau et al. 2013.
43 Buzon, Guilbault and Simonetti 2023.
44 Simonetti et al. 2023.
45 Longinelli 1984
46 Buzon and Bowen 2010; Buzon, Schrader and Bowen 2018.
47 Dupras and Schwarcz 2001.
48 Smith and Buzon 2018.

the New Kingdom with some reuse in the early Napatan). The skeletal remains are curated at Purdue University. Previous research has indicated a possible local strontium range, based off small mammals, to be 0.70710-0.70783.[49] However, as discussed above, using strontium alone only provides preliminary evidence of mobility; additional testing, including further isotopic studies are necessary, to substantiate these data.

Qurneh
The site of Qurneh is located in the necropolis at Thebes and the individuals included are associated with a New Kingdom date. The remains are curated in the Duckworth Collection at the University of Cambridge. Note that no local strontium range has been determined.

Saqqara
The remains from the Saqqara necropolis, near Cairo, are associated with a New Kingdom date. They are curated in the Duckworth Collection at the University of Cambridge (labelled as Memphis in the collection). A local strontium range has yet to be established.

Amara West
Amara West is a site located between the Second and Third Cataracts in Sudan that contains burials dating to the New Kingdom and early Napatan Periods (~1300 BC–800 BC). The remains are curated at The British Museum. A tentative local strontium range is 0.70633-0.70802, which was also developed using small mammals.[50]

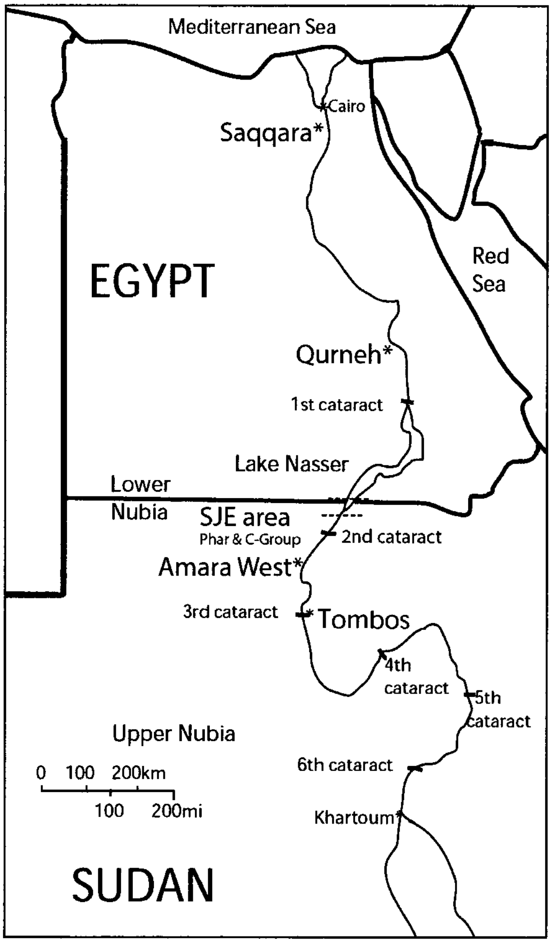

Fig. 1 Locations of samples examined.

Pharaonic
The collection marked 'Pharaonic' comes from the Scandinavian Joint Expedition to Nubia sites located from the modern Egyptian border to ~60km south. These individuals were buried in Egyptian style, date to 1650–1350 BC, and are curated in the Biological Anthropology Laboratory at the University of Copenhagen. At this time the local strontium range for the First to Second Cataract region is unclear; although faunal data have been published, the complicated geology makes the utility of migration studies – using strontium alone – limited.[51] The application of additional isotopes to the study of migration may clarify this issue.

C-Group
The C-Group remains come from cemeteries associated with this culture excavated by the Scandinavian Joint Expedition to Nubia (2000–1600 BC) in the region from the modern Egyptian border to ~60km south. They are curated in the Biological Anthropology Laboratory at the University of Copenhagen. For notes on local strontium range, please see information above regarding Pharaonic sample, as both the C-Group and Pharaonic populations inhabited the same region.

Methods

Sex and age-at-death in adults were estimated according to accepted bioarchaeological techniques, namely pelvic and cranial morphology.[52] Age-at-death for non-adults was estimated according to bone fusion and dental eruption, both of which are widely used in bioarchaeology.[53] Age at tooth formation was estimated using well-documented dental development data and later categorised in four

49 Buzon and Simonetti 2013.
50 Spencer et al. in review.
51 Buzon and Simonetti 2013.
52 Brickley and McKinley 2004; Buikstra and Ubelaker 1994.
53 AlQahtani, Hector and Liversidge 2010; Brickley and McKinley 2004; Buikstra and Ubelaker 1994.

	FEI	IEC	MC	AD	Total
Tombos	1	12	30	5	48
Qurneh	0	0	12	0	12
Saqqara	0	0	14	0	14
Amara West	2	3	1	0	6
Pharaonic	0	0	9	0	9
C-Group	0	0	13	0	13
Total	3	15	79	5	102

Table 1 Demographic distribution.

groups: Foetal/Early Infancy (FEI), Infancy and Early Childhood (IEC), Middle Childhood (MC), and Early Adolescence (AD).[54]

Best practices for destructive isotope sampling were followed at all stages of research and publication.[55]

*Carbonate_*

The enamel surface was burred to remove any adhering contaminants. Approximately 10mg of dental enamel was taken from the crown of the tooth, using a Dremel fitted with a diamond blade. These samples were then treated with 5% NaOCl (Sodium hypochlorite), then rinsed. A 0.1 mol acetic acid solution was added. This process was repeated for three days. Samples were rinsed and dried prior to analysis.[56] Dental carbonate was analysed using a TermoFinnigan Delta V Isotope Ratio Mass Spectrometer (Purdue Stable Isotope Facility, Department of Earth and Atmospheric Sciences, Purdue University).

Strontium

The strontium data presented in this study comes from published sources.[57] The analyses were completed at the Radiogenic Isotope Facility in the Department of Earth and Atmospheric Sciences, University of Alberta and the University of Notre Dame Midwest Isotope and Trace Element Research Analytical Center (MITERAC). Samples were prepared in a class 1000 cleanroom facility and prepared using previously published methods.[58]

Statistical analysis

Shapiro-Wilk tests and Q-Q plots were used to test for normality. Due to the fact that dental enamel is formed at various times in the life course (*in utero* to young adolescence) depending on the tooth, we also statistically examined age distribution based on tooth formation between sites; this was done via a Kruskal-Wallis test. Pearson's *t*-tests were used to compare strontium and carbonate values. ANOVA was employed to examine dental enamel carbonate values between all samples. LSD post-hoc tests were conducted, following the ANOVA, to better understand the relationship between strontium and carbon at specific sites. Statistical analyses were conducted in SPSS (version 29.0) and plots were made in R version 4.2.0[59] with the ggplot2 package.[60]

Results

Initial statistical testing confirmed that data were normally distributed. A Kruskal-Wallis test confirmed that there are no differences in the distribution of age at dental enamel formation between sites ($H[5] = 4.224, p=0.518$).

Results of the dental carbonate isotope analysis were markedly variable. Across the six sample populations included here, carbon values ranged from -13.85‰ to -6.22‰ and strontium values ranged from 0.70658 to 0.70912 (Table 2; Fig. 2). An ANOVA, comparing carbonate values from each of the samples, indicates that these populations had significantly different carbon values ($F(5), 98) = [3.007], p = 0.014$).

Carbon values from Tombos have a wide range and likely include both C_3 and C_4 consumers. As reported elsewhere, there is also a relatively wide range of

54 AlQahtani, Hector and Liversidge 2010; Hillson 1996; Turner et al. 2009; Table 1.
55 Vaiglova et al. 2023
56 Koch, Tuross and Fogel 1997.
57 For full description of methods see Buzon, Simonetti and Creaser 2007; Buzon and Simonetti 2013; Buzon, Smith and Simonetti 2016; Schrader et al. 2019.
58 Buzon, Simonetti and Creaser 2007; Buzon and Simonetti 2013.
59 R Core Team 2020.
60 Wickham 2016.

Site	n	$\delta^{13}C_{CARB}$			$^{87}Sr/^{86}Sr$		
		Min/Max		SD	Min/Max		SD
Tombos	49	-13.85 to -7.42‰	-12.22‰	1.15	0.70661-0.70912	0.70767	0.00045
Saqqara	12	-12.93 to -11.38‰	-12.27‰	0.55	0.70745-0.70807	0.70774	0.00022
Qurneh	14	-13.29 to -10.89‰	-12.37‰	0.72	0.70731-0.70798	0.70777	0.00018
Pharaonic	9	-13.23 to -6.22‰	-11.27‰	2.61	0.70658-0.70764	0.70740	0.00033
C-Group	13	-13.12 to -7.05‰	-11.01‰	1.75	0.70735-0.70807	0.70764	0.00020
Amara West	7	-13.30 to -11.94‰	-12.66‰	0.43	0.70741-0.70763	0.70753	0.00007

Table 2 Dental enamel carbon and strontium results.

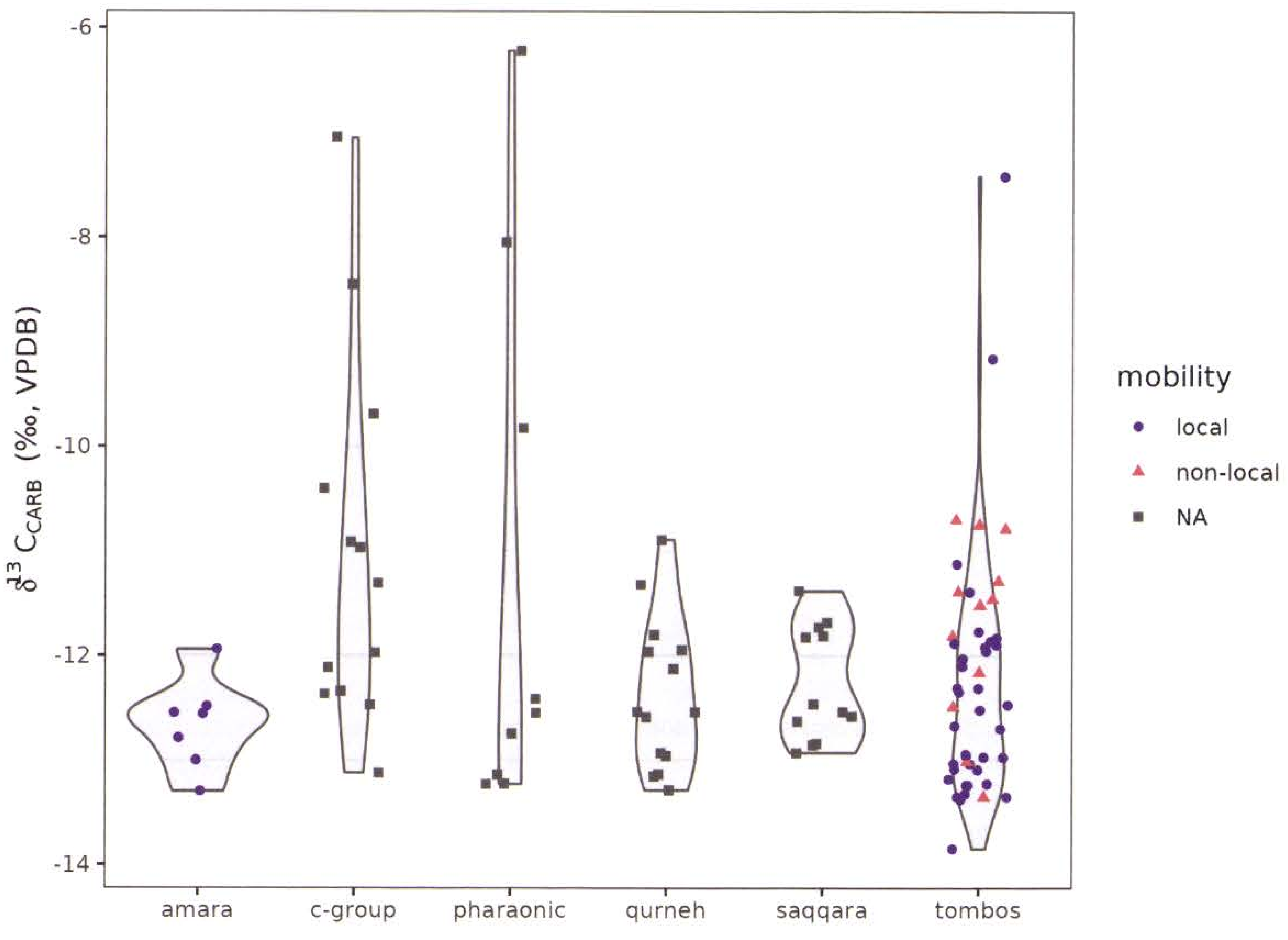

Fig. 2 Carbonate values for all samples.

strontium values.[61] There are two carbon outliers: TOM-24 and TOM-111 (discussed further below). When carbon and strontium are contrasted (outliers removed), there is a significant positive relationship ($r[47] = 0.345$, $p = 0.018$). If we compare carbon results between those individuals whose strontium values fall within the local range, versus those individuals whose strontium values are outside the local range (i.e., possible first-generation migrants), there is also a significant difference between these groups (t [47] = -1.764, $p = 0.042$; Table 3; Fig. 3). As noted above, further research needs to be done to confirm that these individuals are in fact migrants; however, the strontium data do suggest this. The two

61 Buzon, Simonetti and Creaser 2007; Buzon and Simonetti 2013.

Site	n	$\delta^{13}C_{CARB}$			$^{87}Sr/^{86}Sr$		
		Range		SD	Range		SD
Non-Local	11	-13.35 to -10.70‰	-11.69‰	0.90	0.70705-0.70912	0.70823	0.00054
Local	38	-13.85 to -7.42‰	-12.37‰	1.18	0.70661-0.70781	0.70751	0.00024

Table 3 Tombos local versus non-local carbon and strontium results

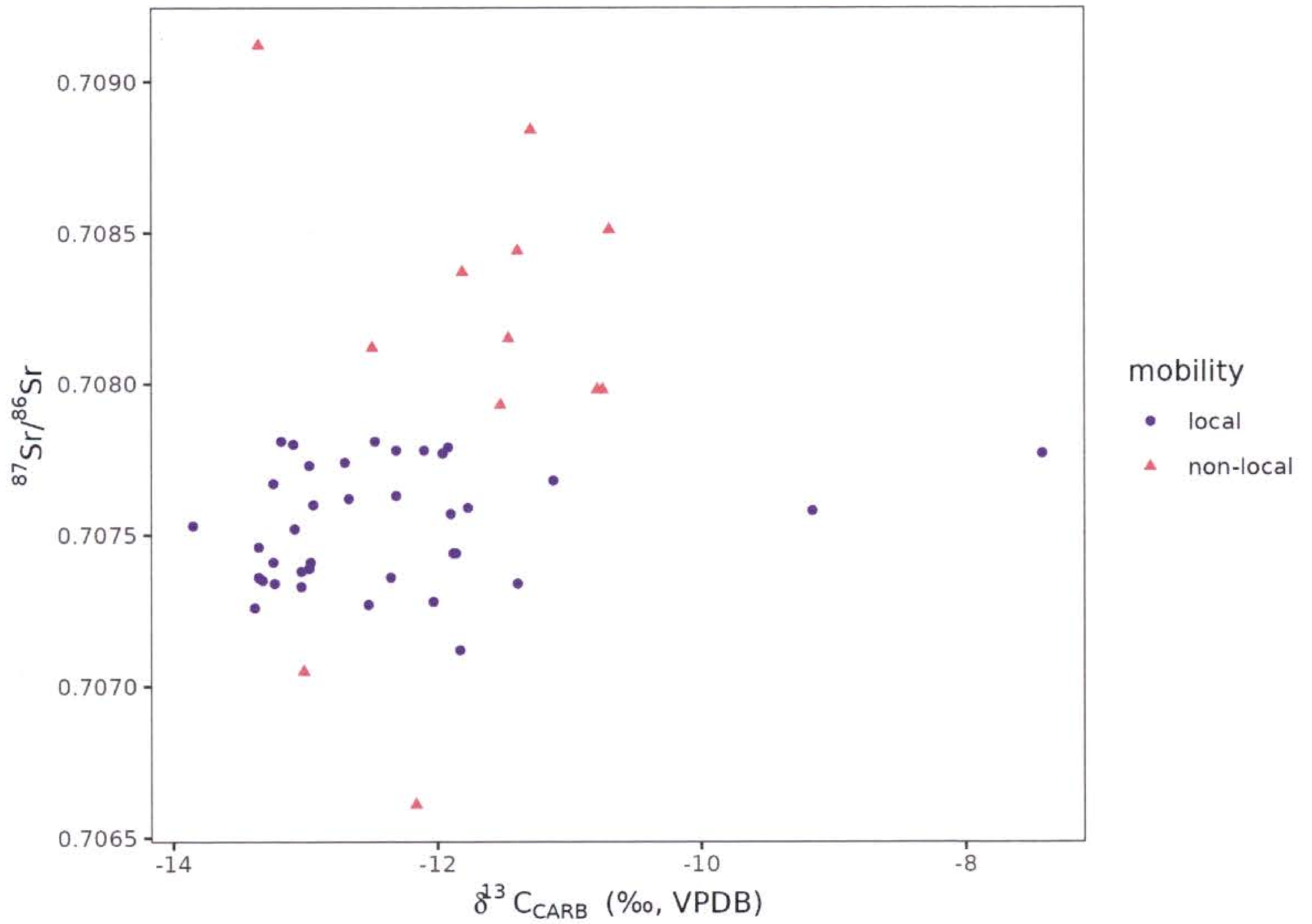

Fig. 3 Tombos locals versus non-locals carbon values compared.

carbon outliers, TOM-24 and TOM-111, have enriched carbon values ($\delta^{13}C_{CARB}$ -7.42 and -9.16, respectively), suggesting a stronger C_4 component to their diet to the rest of the Tombos sample. Both individuals have what can tentatively be interpreted as local strontium values (0.70777 and 0.70758, respectively). LSD post-hoc tests revealed that carbon values from the Tombos sample significantly differed from both Pharaonic and C-Group samples (p = 0.047, 95% C.I. = [-1.89, -0.01]; p = 0.004, 95% C.I. = [-2.01, -0.40], respectively). Interestingly, if Tombos 'locals' are differentiated from 'non-locals,' the same LSD post-hoc tests indicates that only the Tombos locals actually differ from Pharaonic and C-Group (p = 0.024, 95% C.I. = [-2.05, -0.15]; p =0.002, 95% C.I.= [-2.18, -0.53]), while the Tombos non-locals are not statistically significantly different (p = 0.472 , 95% C.I. = [-1.57, 0.73]; p = 0.206, 95% C.I. = [-1.73, 0.38]).

The Pharaonic and C-Group samples also have wide carbon ranges (7.01‰, 6.07‰), similar to that of Tombos (6.43‰). There is no significant correlation between carbon and strontium in either the Pharaonic or C-Group samples (r[9]= -0.615, p=0.078; r[13]= 0.190, p=0.535). LSD post-hoc tests indicate that the Pharaonic sample is significantly different than the Tombos locals, Qurneh, and Amara West samples (p=0.024, 95% C.I. = [-2.05, -0.15]; p=0.049, 95% C.I. = [-2.20, -0.01]; p=0.035, 95% C.I. = [0.10, 2.69]). Similarly, the C-Group is significantly different from Tombos local, Saqqara, Qurneh, and Amara West samples when a LSD post-hoc was conducted (p=0.002, 95% C.I. = [-2.18, -0.53]; p=0.017, 95% C.I.

= [-2.29, -0.23]; p=0.008, 95% C.I. = [-2.35, -0.37]; p=0.008, 95% C.I. = [0.45, 2.85]).

Dental enamel carbon from Saqqara, Qurneh, and Amara West are all relatively similar with less than 2.5‰ range within each sample (1.55‰, 2.4‰, 1.36‰, respectively). Carbon and strontium values for Saqqara and Amara West are not correlated (r[12]= -0.157, p=0.627; r[7]= -0.528, p=0.224); however, for Qurneh, carbon and strontium have a statistically significant negative relationship (r[14]= -0.624, p=0.017). While a local strontium range has been estimated for Amara West, all individuals with carbon data were deemed to be local—thus, more refined comparison of local versus non-local, as was done with the Tombos sample, is not possible here.

Discussion

The data presented here suggest a complex relationship between locality, chronology, and dietary practices during the second to first millennia BC in the Nile Valley. Statistical testing does suggest that there was a difference between carbon consumption between the six samples examined here. It is important to remember that, for the most part, this reflects childhood dietary practices as the enamel that was isotopically tested was formed in utero to young adolescence. Strontium values are also complicated because recent research has shown that strontium alone cannot establish first generation migrant status in the Nile Valley, but rather must be coupled with additional isotopes.[62] Nonetheless, these new carbonate data do suggest that diets varied across the Nile Valley.

The carbon values per site suggest that all six samples likely regularly consumed C_3 foods, including wheat, and barley, as well as common Nile Valley fruits and vegetables (e.g., onions, leaks, lentils, peas, dates). The Tombos, Pharaonic, and C-Group samples have a wide range of carbon values, indicating that at least some individuals were consuming C_4 foods (e.g., sorghum, millet) or were consuming the products of animals (e.g., milk, blood, meat) that were foddered on C_4 foods. One could make the argument that this is a geographic or environmental byproduct (i.e., C_4 foods grow in hotter climates). While this is certainly true, exceptions include Amara West, which has a distinctly C_3 dental enamel carbonate range and is south of the C-Group/Pharaonic area of occupation. We therefore argue, as others have done before us, that foods consumed are socially meaningful decisions that are made by agents, rather than passive selection of foods that are available.[63]

At Tombos, we found a positive relationship between carbon values and strontium values. Stantis et al. found similar results in their study of Tell el-Daba.[64] However, given that strontium geology is so complex, particularly in the Nile Valley, it is difficult at this time draw to conclusions about how these two values might be influencing one another.[65] If we use small mammal strontium values to estimate locality, we found that dental enamel carbon values between 'locals' and 'non-locals' did significant differ, with the former eating a higher proportion of C_3 foods and the latter consuming more C_4 foods. Within the complex colonial sphere of Tombos, this dietary juxtaposition is particularly interesting. Schrader has made the argument that C_4 foods were culturally selected by Nubians whereas C_3 foods were a more Egyptian food.[66] This doesn't preclude that Nubians consumed C_3 foods, as they were readily available and composed vegetables and fruits, which were certainly a sizeable portion of the Egyptian and Nubian diet. But, millet and sorghum possibly played an important cultural role in distinguishing Nubians from Egyptians, which may have been particularly relevant in a colonial sphere. Non-locals potentially moving to Tombos from other areas in Nubia may have consumed C_4 foods in childhood, while people who lived at Tombos in an Egyptian colonial environment, much like Amara West, may have consumed predominately C_3 foods in their childhood. It is equally possible that the non-locals were consuming a C_4-based gruel or animal by-products from C_4-fed animals.[67] Bone collagen data suggests this may have been the case throughout the life course.[68]

The wide carbon ranges found in both the C-Group and Pharaonic samples may also be explained by this Nubian cultural selection of C_4 foods argument. The C-Group were an indigenous Nubian group, occupying Lower Nubia from c. 2300–1800 BC. Given this Nubian heritage, they may also have consumed more C_4 and fed their children a higher proportion of C_4 foods than Egyptian counterparts. The Pharaonic sample is a bit more difficult to assess; these are individuals who were buried in the First-Second Cataract region in an Egyptian burial style—however, there is still debate as to whether they were Egyptians who migrated into this colonial space during the New Kingdom, or whether they were locals (e.g., C-Group, Nubian) who took on an Egyptian identity to survive and possibly advance within a colonial environment.[69] It is possible that the data presented here support the latter; that the Pharaonic samples were biologically Nubian and were thus raised

62 Buzon, Guilbault and Simonetti 2023.

63 Bourdieu 1977; Bourdieu 1984; Löfgren 2015.

64 Stantis et al. 2021.

65 Buzon, Guilbault and Simonetti 2023.

66 Schrader 2019.

67 Dupras 2001; Dupras and Tocheri 2007; Touzeau et al. 2014.

68 Schrader 2019.

69 Smith 1998; Smith and Buzon 2014.

on Nubian C_4 foods during childhood and then as they grew older decided to take on Egyptian identity, thereby explaining their burial status. However, additional research is needed to confirm this hypothesis.

Saqqara, Qurneh, and Amara West carbonate values are all markedly similar. There is limited variation within the samples, although this may be due to a limited sample size. It is also quite possible that these samples simply reflect carbon values of an Egyptian-based diet. If we compare the $\delta^{13}C$ ranges of Saqqara, Qurneh, and Amara West, they are all very similar to previous research conducted on dental enamel carbonate tissues discussed above.[70] Based on these results, we can tentatively conclude that, for these samples, nearly all of the foods consumed by these individuals were C_3. This is perhaps not surprising given the strong C_3 dietary practices of Egyptians. As mentioned above, the case of Amara West is particularly interesting, given the colonial nature of the site. There are meaningful differences between Amara West and Tombos, both of which are Egyptian colonial outposts in colonised Nubia, that might explain these findings. First, Amara West was founded and occupied much later than Tombos (Ramesside Period, ~1300–1100 BC, versus initial colonization, ~1450 BC). It is possible that the dietary distinctions between Nubian and Egyptian no longer existed by the Ramesside Period. Secondly, the strontium data suggest that all individuals that we have carbonate data for are local. Perhaps a similar pattern that we see at Tombos, where the non-local individuals have a more C_4 signal and the local individuals have a more C_3 signal, would also be visible at Amara West, but is currently obscured by the small sample size. Lastly, it is also possible that the community of Tombos nurtured a transcultural space where eating Egyptian and Nubian foods was accepted. Previous research by Buzon and Smith has suggested that life at Tombos was relatively peaceful, that Nubians and Egyptians living in this space were healthy, and that a certain coexistence was encouraged as a way to promote the success of the empire.[71]

Lastly, it is important to again highlight that because we are examining dental enamel tissues here, we are discussing childhood dietary practices, which may include breastfeeding and/or weaning. While more research needs to be done on this topic in the region, we do acknowledge that this variable could be impacting our results and subsequent interpretations. The fact that age-at-enamel formation did not differ significantly between sites, lends credence to the argument that these patterns might in fact reflect dietary differences. It is quite possible that, because Egyptians and Nubians identified with the foods they consumed in a meaningful way, in feeding these foods to their children they were instilling this very identity into future generations.

Conclusion

The new carbon data presented here suggests a dynamic social landscape where individuals and communities used food as a way to define and maintain identities. These data can be used as a springboard for additional research into dietary and migration practices in ancient Nubia and the Nile Valley. For example, additional carbonate data from other sites would help to support or refute our interpretations of Egyptian/Nubian dietary practices. We have mentioned the poor preservation of collagen in the region, likely due to the harsh environment. However, hair keratin has been shown to be a viable alternative to bone collagen.[72] Additional carbon and nitrogen studies from hair would provide more substantive interpretations of ancient dietary practices through the life course.

As discussed above, strontium should be coupled with other isotopes to confirm or refute migration.[73] If these multi-isotope studies were conducted on all samples discussed here, we would be able to more thoroughly examine the intersection of migration and diet as was preliminarily done here with the Tombos sample. Local ranges are also needed for several samples as well as the Nile Valley more broadly.

These isotopic contributions, in addition to the excavation and analysis of new archaeological sites, will certainly advance our understanding of Nubian and Nile Valley diet and migration. As has been argued elsewhere, isotope analysis has made a profound impact on the field and will continue to do so.

Acknowledgements

The authors wish to acknowledge our collaboration with co-Director Stuart Tyson Smith on the Tombos archaeological project and the support and assistance provided by the Sudanese National Corporation for Antiquities and Museums and the town of Tombos in our many seasons of excavations. The University of Copenhagen, University of Cambridge Duckworth Collection, and The British Museum generously allowed the sampling of materials from their collections for this study. The isotopic research was supported National Science Foundation grant BCS-0917815, Dutch Research Council (NWO VI.Vidi.201.153), National Geographic Society, American Philosophical Society, American Association of Physical Anthropologists, Purdue Alumni Association and Purdue University College of Liberal Arts Research Incentive grant. Sample preparation and analysis was completed in collaboration with Gabriel Bowen and Antonio Simonetti.

70 See Touzeau et al. 2014.

71 Smith 2003; Buzon and Richman 2007.

72 Schrader and Smith 2022.

73 Buzon, Guilbault and Simonetti 2023.

Bibliography

AlQahtani, S.J., Hector, M.P. and Liversidge, H.M.
2010 Brief communication: The London atlas of human tooth development and eruption, *American Journal of Physical Anthropology* 142, 481–490.

Ambrose, S.H. and Norr, L.
1993 Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate, in: B. Lambert and G. Grupe (eds.), *Prehistoric Human Bone: Archaeology at the Molecular Level*, Berlin, 1–37.

Bocherens, H. and Drucker, D.
2003 Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems, *International Journal of Osteoarchaeology* 13, 46–53.

Bourdieu, P.
1977 *Outline of the Theory of Practice*, Cambridge.
1984 *Distinction: A Social Critique of the Judgement of Taste*, Cambridge.

Brickley, M.B. and McKinley, J.I.
2004 *Guidelines to the Standards for Recording Human Remains*, IFA Paper No. 7, Reading.

Britton, K.
2017 A stable relationship: Isotopes and bioarchaeology are in it for the long haul, *Antiquity* 91 (358), 853–864.

Buikstra, J. and Ubelaker, D.
1994 *Standards for Data Collection from Human Skeletal Remains*, Fayetteville.

Burke, W.H., Denison, R.E., Hetherington, E.A., Koepnick, R.B., Nelson, H.F. and Otto, J.B.
1982 Variation of seawater $^{87}Sr/^{86}Sr$ throughout Phanerozoic time, *Geology* 10 (10), 516–519.

Buzon, M.R. and Bowen, G.J.
2010 Oxygen and carbon isotope analysis of human tooth enamel from the New Kingdom site of Tombos in Nubia, *Archaeometry* 52, no. 5, 855–868.

Buzon, M.R. and Richman, R.
2007 Traumatic injuries and imperialism: The effects of Egyptian colonial strategies at Tombos in Upper Nubia, *American Journal of Physical Anthropology* 133 (2), 783–791.

Buzon, M.R., Schrader, S. and Bowen, G. J.
2018 Isotopic approaches to mobility in northern Africa: A bioarchaeological examination of Egyptian/Nubian interaction in the Nile Valley, in: M.C. Gatto, D. Mattingly, N. Ray and M. Sterry (eds.), *Burials, Migration and Identity in the Ancient Sahara and Beyond*, Cambridge, 223–246.

Buzon, M.R., Simonetti, A. and Creaser, R.A.
2007 Migration in the Nile Valley during the New Kingdom Period: A preliminary strontium isotope study, *Journal of Archaeological Science* 34 (9), 1391–1401.

Buzon, M.R. and Simonetti, A.
2013 Strontium isotope ($^{87}Sr/^{86}Sr$) variability in the Nile Valley: Identifying residential mobility during ancient Egyptian and Nubian sociopolitical changes in the New Kingdom and Napatan Periods, *American Journal of Physical Anthropology* 151 (1), 1–9.

Buzon, M.R., Smith, S.T. and Simonetti, A.
2016 Entanglement and the formation of the ancient Nubian Napatan state, *American Anthropologist* 118 (2), 284–300.

Buzon, M.R., Guilbault, K.A. and Simonetti, A.
2023 Exploring intersectional identities and geographic origins in ancient Nubia at Tombos, Sudan, *Bioarchaeology International*, https://doi.org/10.5744/bi.2022.0029.

Ciesielska, J.A., Stark, R.J., Obłuski, A., Boivin, N. and Roberts, P.
2021 Multi-isotope analysis of dietary variation among the Early Christian communities of northern Sudan, *Journal of Archaeological Science: Reports* 37, 103016.

Cox, G. and Sealy, J.
1997 Investigating identity and life histories: Isotopic analysis and historical documentation of slave skeletons found on the Cape Town Foreshore, South Africa, *International Journal of Historical Archaeology* 1 (3), 207–224.

DeNiro, M.J. and Epstein, S.
1978 Influence of diet on the distribution of carbon isotopes in animals, *Geochimica et Cosmochimica Acta* 42 (5), 495–506.

Dupras, T.L. and Schwarcz, H.P.
2001 Strangers in a strange land: Stable isotope evidence for human migration in the Dakhleh Oasis, Egypt, *Journal of Archaeological Science* 28 (11), 1199–1208.

Dupras, T.L. and Tocheri, M.W.
2007 Reconstructing infant weaning histories at Roman period Kellis, Egypt using stable isotope analysis of dentition, *American Journal of Physical Anthropology* 134 (1), 63–74.

Eerkens, J.W., de Voogt, A., Dupras, T.L., Francigny, V. and Greenwald, A.M.
2018 Early childhood diets on the Nile: $\Delta^{13}C$ and $\Delta^{15}N$ in serial samples of permanent first molars in an elite Meroitic population from Sai Island, Sudan, *International Journal of Osteoarchaeology* 28 (5), 552–562.

Faure, G.
1977 *Principles of Isotope Geology*, New York.

Fenner, J.N. and Wright, L.E.
2014 Revisiting the strontium contribution of sea salt in the human diet, *Journal of Archaeological Science* 44, 99–103.

GREGORICKA, L.A.
2021 Moving forward: A bioarchaeology of mobility and migration, *Journal of Archaeological Research* 29, 581–635.

HEDGES, R.E.M., CLEMENT, J.G., THOMAS, D.L. and O'CONNELL, T.C.
2007 Collagen turnover in the adult femoral mid-shaft: Modelled from anthropogenic radiocarbon tracer measurements, *American Journal of Physical Anthropology* 133, 808–816.

HILLSON, S.
1996 *Dental Anthropology*, Cambridge.

IACUMIN, P., BOCHERENS, H., MARIOTTI, A. and LONGINELLI, A.
1996 An isotopic palaeoenvironmental study of human skeletal remains from the Nile Valley, *Palaeogeography, Palaeoclimatology, Palaeoecology* 126 (1–2), 15–30.

IACUMIN, P., BOCHERENS, H., CHAIX, L. and MARIOTH, A.
1998 Stable carbon and nitrogen isotopes as dietary indicators of Ancient Nubian populations (northern Sudan), *Journal of Archaeological Science* 25 (4), 293–301.

KATZENBERG, M.A., MCKENZIE, H.G., LOSEY, R.J., GORIUNOVA, O.I. and WEBER, A.
2012 Prehistoric dietary adaptations among hunter-fisher-gatherers from the Little Sea of Lake Baikal, Siberia, Russian Federation, *Journal of Archaeological Science* 39 (8), 2612–2626.

KATZENBERG, M.A. and WATERS-RIST, A.
2019 Stable isotope analysis: A tool for studying past diet, demography, and life history, in: M.A. KATZENBERG and A.L. GRAUER (eds.), *Biological Anthropology of the Human Skeleton*, Oxford, 469–504.

KELLNER, C.M. and SCHOENINGER, M.J.
2007 A simple carbon isotope model for reconstructing prehistoric human diet, *American Journal of Physical Anthropology* 133 (4), 1112–1127.

KOCH, P.L., TUROSS, N. and FOGEL, M.L.
1997 The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hydroxylapatite, *Journal of Archaeological Science* 24 (5), 417–429.

KOZIERADZKA-OGUNMAKIN, I.
2020 Isotope analysis and radiocarbon dating of human remains from El-Zuma, in: M. EL-TAYEB and E. CZYŻEWSKA-ZALEWSKA (eds.), *Early Makuria Research Project. El-Zuma Cemetery*, Leiden, 220–227.

LEE-THORP, J.A., SEALY, J.C. and VAN DER MERWE, N.J.
1989 Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet, *Journal of Archaeological Science* 16, no. 6, 585–599.

LÖFGREN, O.
2015 Anthropology of everyday life, in: J.D. WRIGHT (ed.), *International Encyclopedia of Social & Behavioral Sciences*, Amsterdam, 323–326.

LONGINELLI, A.
1984 Oxygen isotopes in mammal bone phosphate: A new tool for paleohydrological and paleoclimatological research?, *Geochimica et Cosmochimica Acta* 48, 385–390.

O'CONNELL, T.C., KNEALE, C.J. TASEVSKA, N. and KUHNLE, G.G.C.
2012 The diet-body offset in human nitrogen isotopic values: A controlled dietary study, *American Journal of Physical Anthropology* 149 (3), 426–434.

OSYPINSKA, M., OSYPINSKI, P., BELKA, Z., CHLODNICKI, M., WIKTOROWICZ, P., RYNDZIEWICZ, R. and KUBIAK, M.
2021 Wild and domestic cattle in the ancient Nile Valley: Marks of ecological change, *Journal of Field Archaeology* 46, 429–447.

PARFITT, A.M.
2002 Misconceptions (2): Turnover is always higher in cancellous than in cortical bone, *Bone* 30 (6), 807–809.

PASSEY, B.H., ROBINSON, T.F., AYLIFFE, L.K., CERLING, T.E., SPONHEIMER, M., DEARING, M.D., ROEDER, B.L. and EHLERINGER, J.R.
2005 Carbon isotope fractionation between diet, breath CO_2, and bioapatite in different mammals, *Journal of Archaeological Science* 32 (10), 1459–1470.

PILLOUD, M.A. and HEIM, K.
2018 Dental development, in: S.L. LÓPEZ VARELA (ed.), *The Encyclopedia of Archaeological Sciences*, Chichester, 1–4.

PLOMP, E., VON HOLSTEIN, I.C.C., KOOTKER, L.M., VERDEGAAL-WARMERDAM, S.J.A., FOROUZANFAR, T. and DAVIES, G.R.
2020 Strontium, oxygen, and carbon isotope variation in modern human dental enamel, *American Journal of Physical Anthropology* 172 (4), 586–604.

PRICE, T.D., BURTON, J.H. and BENTLEY, R.A.
2002 The characterization of biologically available strontium isotope ratios for the study of prehistoric migration, *Archaeometry* 44, 117–135.

R CORE TEAM
2020 *R: A Language and Environment for Statistical Computing*, Vienna.

RETZMANN, A., BUDKA, J., SATTMANN, H., IRRGEHER, J. and PROHASKA, T.
2019 The New Kingdom population on Sai Island: Application of Sr isotopes to investigate cultural entanglement in Ancient Nubia, *Ägypten & Levante* 29, 355–380.

SCHOENINGER, M.J. and DENIRO, M.J.
1984 Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals, *Geochimica et Cosmochimica Acta* 48 (4), 625–639.

SCHWARCZ, H.P. and SCHOENINGER, M.J.
1991 Stable isotope analyses in human nutritional ecology, *American Journal of Physical Anthropology* 34 (S13), 283–321.

SCHRADER, S.
2019 *Activity, Diet and Social Practice: Addressing Everyday Life in Human Skeletal Remains*, Cham.

SCHRADER, S.A., BUZON, M.R., CORCORAN, L. and SIMONETTI, A.
2019 Intraregional $^{87}Sr/^{86}Sr$ variation in Nubia: New insights from the Third Cataract, *Journal of Archaeological Science: Reports* 24, 373–379.

SCHRADER, S. and SMITH, S.T.
2022 *Status and diet in Ancient Nubia: New insights from Abu Fatima*. Presented at the 15th International Conference for Nubian Studies, Warsaw.

SIMONETTI, A., BUZON, M.R., CORCORAN, L., BREIDENSTEIN, A.M. and EMBERLING, G.
2021 Trace element and Pb and Sr isotope investigation of tooth enamel from archaeological remains at El-Kurru, Sudan: Evaluating the role of groundwater-related diagenetic alteration, *Applied Geochemistry* 132, 105068.

SIMONETTI, A., BUZON, M.R., SIMONETTI, S.S., GUILBAULT, K.A., KORDOFANI, M.A. and MILLER, N.F.
2023 Assessing the impact of Holocene climate change on bioavailable Sr within the Nile River Valley: Geochemical and radiogenic isotope perspectives, *Bioarchaeology International* Vol. 7, No. 3, 211–233, https://doi.org/10.5744/bi.2022.0024.

SMITH, B.N. and EPSTEIN, S.
1971 Two categories of $^{13}C/^{12}C$ ratios for higher plants, *Plant Physiology* 47 (3), 380–384.

SMITH, S.T.
1998 Nubia and Egypt: Interaction, acculturation, and secondary state formation from the Third to First Millennium B.C., in: J.G. CUSICK (ed.), *Studies in Culture Contact: Interaction, Culture Change and Archaeology*, Carbondale, 256–287.
2003 *Wretched Kush: Ethnic Identities and Boundaries in Egypt's Nubian Empire*, London.

SMITH, S.T. and BUZON, M.R.
2014 Identity, commemoration, and remembrance in colonial encounters: burials at Tombos during the Egyptian New Kingdom Nubian empire and its aftermath, in: B.W. PORTER and A.T. BOUTIN (eds.), *Remembering the Dead in the Ancient Near East: Recent Contributions from Bioarchaeology and Mortuary Archaeology*, Boulder, 185–216.
2018 The fortified settlement at Tombos and Egyptian colonial strategy in New Kingdom Nubia, in: J. BUDKA and J. AUENMÜLLER (eds.), *From Microcosm to Macrocosm: Individual Households and Cities in Ancient Egypt and Nubia*, Leiden, 205–225.

SPENCER, N., BINDER, M., BUZON, M.R., WOODWARD, J., MACKLIN, M. and SIMONETTI, A.
In rev Maintaining empire: Isotopic evidence for elite mobility in Nubia under pharaonic rule, *Journal of African Archaeology*.

STANTIS, C., NOWELL, G.M., PRELL, S. and SCHUTKOWSKI, H.
2019 Animal proxies to characterize the strontium biosphere in the northeastern Nile Delta, *Bioarchaeology of the Near East* 13, 1–13.

STANTIS, C., KHAROBI, A., MAARANEN, N., NOWELL, G.M., BIETAK, M., PRELL, S. and SCHUTKOWSKI, H.
2020 Who were the Hyksos? Challenging traditional narratives using strontium isotope ($^{87}Sr/^{86}Sr$) analysis of human remains from ancient Egypt, *PLOS ONE* 15 (7), e0235414.

STANTIS, C., KHAROBI, A., MAARANEN, N., MACPHERSON, C., BIETAK, M., PRELL, S. and SCHUTKOWSKI, H.
2021 Multi-isotopic study of diet and mobility in the Northeastern Nile Delta, *Archaeological and Anthropological Sciences* 13 (6), 105.

THOMPSON, A.H., RICHARDS, M.P., SHORTLAND, A. and ZAKRZEWSKI, S.R.
2005 Isotopic palaeodiet studies of ancient Egyptian fauna and humans, *Journal of Archaeological Science* 32 (3), 451–463.

THOMPSON, A.H., CHAIX, L. and RICHARDS, M.P.
2008 Stable isotopes and diet at Ancient Kerma, Upper Nubia (Sudan), *Journal of Archaeological Science* 35 (2), 376–387.

TIESZEN, L.L. and FAGRE, T.
1993 Effect of diet quality and composition on the isotopic composition of respiratory CO_2, bone collagen, bioapatite, and soft tissues, in: J.B. LAMBERT and G. GRUPE (eds.), *Prehistoric Human Bone: Archaeology at the Molecular Level*, Berlin, 121–155.

TOUZEAU, A., AMIOT, R., BLICHERT-TOFT, J., FLANDROIS, J.-P., FOUREL, F., GROSSI, V., MARTINEAU, F., RICHARDIN, P. and LÉCUYER, C.
2014 Diet of ancient Egyptians inferred from stable isotope systematics, *Journal of Archaeological Science* 46, 114–124.

TOUZEAU, A., BLICHERT-TOFT, J., AMIOT, R., FOUREL, F., MARTINEAU, F., COCKITT, J., HALL, K., FLANDROIS, J.-P. and LÉCUYER, C.
2013 Egyptian Mummies Record Increasing Aridity in the Nile Valley from 5500 to 1500yr before Present, *Earth and Planetary Science Letters* 375, 92–100.

TURNER, B.L., KAMENOV, G.D., KINGSTON, J.D. and ARMELAGOS, G.J.
2009 Insights into immigration and social class at Machu Picchu, Peru based on oxygen, strontium, and lead isotopic analysis, *Journal of Archaeological Science* 36 (2), 317–332.

VAIGLOVA, P., LAZAR, N.A., STROUD, E.A., LOFTUS, E. and MAKAREWICZ, C.A.
2023 Best practices for selecting samples, analyzing data, and publishing results in isotope archaeology, *Quaternary International* 650, 86–100.

WHITE, C.D.
1993 Isotopic determination of seasonality in diet and death from Nubian mummy hair, *Journal of Archaeological Science* 20 (6), 657–666.

WHITE, C.D., LONGSTAFFE, F.J. and LAW, K.R.
2004 Exploring the effects of environment, physiology and diet on oxygen isotope ratios in ancient Nubi-

an bones and teeth, *Journal of Archaeological Science* 31 (2), 233–250.

WHITEMAN, A.J.
1971 *The Geology of the Sudan Republic*, Oxford.

WICKHAM, H.
2016 *Ggplot2: Elegant Graphics for Data Analysis*, New York.

WRIGHT, L.E. and SCHWARCZ, H.P.
1998 Stable carbon and oxygen isotopes in human tooth enamel: Identifying breastfeeding and weaning in prehistory, *American Journal of Physical Anthropology* 106 (1), 1–18.

XIA, Y., ZHANG, J., YU, F., ZHANG, H., WANG, T., HU, Y. and FULLER, B.J.
2018 Breastfeeding, weaning, and dietary practices during the western Zhou Dynasty (1122–771 BC) at Boyangcheng, Anhui Province, China, *American Journal of Physical Anthropology* 165 (2), 343–352.