The Enigma of the Hyksos
Volume I

Contributions to the Archaeology of Egypt, Nubia and the Levant

CAENL

Edited by Manfred Bietak

Volume 9

2019
Harrassowitz Verlag · Wiesbaden

The Enigma of the Hyksos
Volume I

ASOR Conference Boston 2017 –
ICAANE Conference Munich 2018 – Collected Papers

Edited by
Manfred Bietak and Silvia Prell

2019
Harrassowitz Verlag · Wiesbaden

Cover illustration: redrawn by S. Prell after J. de Morgan, Fouilles à Dahchour: mars - juin 1894, Vienna 1895, figs. 137-140

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 668640).

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This publication has undergone the process of international peer review.

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

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

Printed on permanent/durable paper.
Typesetting and layout: u.ni medienservice, Hönze
Printing and binding: Hubert & Co., Göttingen
Printed in Germany
ISSN 2627-8022
ISBN 978-3-447-11332-8

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Stable Isotope Analyses to Investigate Hyksos Identity and Origins

by Chris Stantis [1] and Holger Schutkowski [1]

Abstract

With collaboration from universities and museums worldwide, we seek to integrate multiple lines of isotopic evidence using the human remains from Tell el-Dabʿa and comparative sites to pinpoint similarities (and differences) across the region. Strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) analyses will elucidate childhood residence of individuals and therefore identify local versus non-local provenance at any given site, while carbon, nitrogen and sulphur ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, respectively) will provide clues about cultural groupings related to diet and socially and ecologically mediated food access.

Though isotope analyses on this scale will take time to provide statistically meaningful insights, we discuss our experiences of baseline collection, initial collection endeavours and research expectations to set the stage for what evidence we might contribute towards 'the Hyksos Enigma'. We provide a 'case study' of a selection of previous isotopic studies of mobility in the Nile Valley in order to highlight the utility of larger-scale metadata analyses and bring attention to the potential difficulties of palaeo-mobility assessment using isotope analysis with the current corpus of knowledge.

Introduction

The investigation of human remains from archaeological contexts in the Near East have incorporated theoretical and methodological refinement in the last few decades to produce research capable of addressing complex questions.[2] Within our research group, we aim to integrate palaeopathology, ancient DNA, stable isotopes, and morphological studies in order to address questions of population affinity, social identity and demographic changes through time using an integrated biocultural approach.

This paper focuses on the application of stable isotope analysis of human tissues. Isotopic analysis is a potentially powerful toolset to investigate mobility and diet, and the data can be integrated with existing archaeological knowledge in order to elaborate on complex topics such as economic exchange networks and culturally mediated access to foodways. We have experience with carbon and nitrogen stable isotope analysis of bone samples in the Levant and Near East spanning a time period from the Early Bronze Age to the modern era,[3] along with experience in the application of isotope systems for the reconstruction of provenance and palaeo-diet and their interpretation in a wider biocutural context[4] and will follow established protocols for extracting high-quality, publishable stable isotopes data.[5]

As sample collection, processing and analysis is underway for the collections at the time of writing this proceeding, we will instead use this opportunity to bring attention to the growing corpus of stable isotopes research in Egypt and the Near East that will be strong comparative data when engaging with the 'Hyksos Enigma'.

Stable Isotopes in Archaeology

Like all subfields of archaeology, archaeological chemistry is best outside the vacuum of its specialization, integrated in a multidisciplinary approach with other lines of data to tackle the pressing questions in the wider field. Thus, it is in the best interest of archaeologists integrating stable isotopes research into their interpretations to understand some of the basic principles of this toolset, just as it is imperative that destructive analyses such as stable isotopes begin from a solid foundation of site- and region-specific research questions. More detailed treatises on the principles of stable isotopes in biological systems are available,[6] but we provide a brief overview of the isotopic analyses we plan to utilize.

Isotopes are variants/forms of a chemical element that have the same number of protons and electrons but different numbers of neutrons. The difference in the number of neutrons creates variation in atomic mass between isotopes. Isotopes of the same element, due to their difference in atomic mass, will behave differently during physical reactions, while the chemical properties of these isotopes remain largely the same, as chemical reactions generally involve electron activity rather than neutrons.

Heavier isotopes have a lower vibrational frequency relative to lighter isotopes; this results in a proportional decrease of energy and velocity in the heavier isotopes. The lower energy results in stronger covalent bonding when the heavier isotope forms a molecule, but increases the amount of energy

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[1] Bournemouth University, cstantis@bournemouth.ac.uk.

[2] Rose 2017; Sheridan 2017.

[3] Schutkowski and Ogden 2011/2012; Sołtysiak and Schutkowski 2015; 2018.

[4] Stantis et al. 2015; Stantis et al. 2016.

[5] Brown et al. 1988; Evans, Chenery and Fitzpatrick 2006.

[6] For recent reviews, see Hoefs 2009; Sharp 2017.

necessary for the molecule with the heavier isotope to react. As such, lighter isotopes preferentially diffuse out of a system, leaving the heavier isotope forms in the reservoir. These differences in reaction rates between isotope forms, also known as kinetic isotope effects or fractionation, dictate the ratio of isotopes in a sample. These differences in isotope ratios can be observed and measured using a mass spectrometer.

Some isotopes are deemed stable as they are not known to undergo radioactive decay, a stochastic process resulting in an atomic loss of energy that can transform an atom into a different element. A classic example of radioactive isotopes is radiocarbon (^{14}C), which is constantly formed in the Earth's atmosphere by cosmic radiation and decays into stable ^{14}N. Most stable isotopes are primordial: they were created by cosmic forces and have existed in their current state since before the Earth was formed. Other stable isotopes are radiogenic (like ^{14}N) and were created by the radioactive decay of another nuclide but are not themselves radioactive. While understanding radiocarbon's rate of decay permits accurate dating of archaeological material,[7] as stable isotopes do not decay over time, the stable isotope ratio in an organism will remain constant after death (barring diagenetic effects).

Presenting isotope data as absolute isotope abundances tends to provide long, unwieldy ratios with no guarantee to the reader that the sample has been compared to international reference standards. In most studies, the absolute isotopic ratio is of less interest than knowing the differences between samples. To compare these differences easily, an equation is used and the result is designated by delta notation (δ):

$$\delta = (R_{sample}/R_{standard} - 1)$$

Carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), sulphur ($\delta^{34}S$) and oxygen ($\delta^{18}O$) isotopes are presented in this fashion. Since the fractionation processes typically cause very small changes in ratios, these isotope ratio values are reported as per mil, or parts per thousand (‰). A sample with a more positive δ value contains more heavy isotopes relative to the international reference standard and a more negative δ value indicates the sample has more of the lighter isotopes relative to the international reference standard.[8] The exception is strontium isotope values, which are presented as a ratio, $^{87}Sr/^{86}Sr$.

International standards are samples used to calibrate isotopic compositions in laboratories to ensure reliable and accurate measurements for all researchers in the world. If isotope studies do not report calibrating to an international reference standard, then the data are essentially useless. These agreed-upon international standards are very scarce (and very expensive), and not used in everyday laboratory procedures. The international standards are given a δ value of 0‰, and all other materials are measured against this value.[9]

The first international reference standard for $\delta^{13}C$, Pee Dee Belemnite (PDB), was a Cretaceous-era fossil (Belemnitella americana) from the Pee Dee region of South Carolina, USA. Cañon Diablo troilite (CDT) was the iron sulphide portion of a meteorite from the Barringer Crater of Arizona, USA. CDT was used as an international standard for sulphur. Both international standards have been depleted for four decades (and the CDT had problems with isotopic homogeneity), so new standards have been created that are identical for practical purposes, named VPDB (Vienna PDB) and VCDT (Vienna CDT).[10] AIR (Ambient Inhalable Reservoir) is the Earth's air, which has a constant $^{15}N/^{14}N$ ratio[11] and, at the time of writing this, has not been depleted.

Isotope analysis could potentially be conducted using any body tissue, as all tissues reflect the diet and movement of the individual. However, due to the rarity of soft tissue survival in many archaeological settings, bone and teeth are most often sampled, even though the dry conditions in Egypt have provided opportunities for skin, organ tissue, hair and fingernails to be analysed in mummified human and animal remains,[12] and even preserved bread and egg yolk.[13] Soft tissues are also more susceptible to diagenetic effects, the chemical and physical changes that occur after deposition,[14] though there are means of assessing the degree to which tissues have been altered (discussed later).

Isotopes for Interpreting Diet

The analysis of the carbon, nitrogen and sulphur stable isotopes is based on the principle that we build our body out of the food we eat and the water we drink, and that our tissues reflect these dietary inputs: that "we are what we eat", to paraphrase Feuerbach.[15] Using this principle, bioarchaeological studies aim to place humans within the food web of the local ecological community, to understand the relative proportions of consumption of certain types of foods. A common context for dietary isotope research is investigating culturally mediated food access within stratified societies and how

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[7] Libby 1946.

[8] Hoefs 2009.

[9] Sharp 2017.

[10] Gröning 2004.

[11] Junk and Svec 1958.

[12] Touzeau et al. 2013; Williams 2008.

[13] Iacumin et al. 1996.

[14] Hedges 2002.

[15] Ambrose and Krigbaum 2003; Hedges et al. 2007; Katzenberg 2007; Schoeninger 2010.

this differential access creates differences in these relative proportions between social groups;[16] but dietary isotope research can also address more complex diachronic changes, such as shifting subsistence strategies in the face of environment change and/or urban development over time.[17]

Carbon primarily enters the food web through primary producers (plants), and, thus, most of the differences in carbon isotopic values ($\delta^{13}C$) between food webs arises from the varying $\delta^{13}C$ values of autotrophs.[18] Carbon stable isotope ratios of bone and dentin collagen are used to differentiate between the consumption of terrestrial C_3 plants, i.e., most cultivars and domesticates of temperate climates, and marine foods in past populations.[19] Marine food webs display higher $\delta^{13}C$ values due to differences in the oceanic carbon reservoirs.[20] C_4 plants, such as maize, millet and sorghum, display higher $\delta^{13}C$ values compared with terrestrial C_3 plants such as wheat and barley, and their values tend to overlap with marine foods.[21]

Examining nitrogen stable isotope values ($\delta^{15}N$) in bone collagen allows researchers to understand an organism's trophic level, or where they are on the food web and largely reflects intake of animal protein.[22] In a closed model system, a herbivore would display $\delta^{15}N$ values ~3–5‰ higher than the plants it consumes, and a carnivore would display $\delta^{15}N$ values ~3–5‰ still higher, with omnivores somewhere in between. Marine food webs tend to be more complex with higher trophic levels. Used in conjunction with $\delta^{13}C$ values, $\delta^{15}N$ values of human and animal bone collagen can be used to assess on organism's reliance on marine and terrestrial resources.

Sulphur stable isotope ($\delta^{34}S$) analysis for dietary reconstruction is not as well established as carbon and nitrogen isotope analyses but is emerging as a method for differentiating between terrestrial and marine food sources.[23] Marine seaweeds and plankton have extremely uniform $\delta^{34}S$ values consistent with the $\delta^{34}S$ range of sea-salt sulphates. Terrestrial and freshwater plants draw upon sulphur from a variety of sources and will show more variation than marine plants.[24] Additionally, the sulphur composition of the underlying geological substrate and microbial processes in the soil are often the main contributors in terrestrial ecosystems, inspiring some researchers to use $\delta^{34}S$ analysis as a tool for the geographic origin of human remains.[25]

Isotopes for Interpreting Mobility

Two isotopes of strontium, ^{87}Sr and ^{86}Sr, are of interest for reconstructing the residential mobility of humans and animals in the past. The interpretation of movement using strontium isotope analysis rests upon the assumption that the $^{87}Sr/^{86}Sr$ ratios of an individual's tooth enamel will generally reflect the $^{87}Sr/^{86}Sr$ ratios of the underlying geology in which they lived during childhood.[26] Strontium has an atomic radius similar to the atomic radius of calcium (215 pm and 197 pm, respectively) and belongs to the same periodic group of alkaline earth elements in the periodic table. As a result, strontium readily replaces calcium in minerals, including calcium carbonate in chalk, limestone and marble, and calcium in the bones and teeth.[27] Erosion of the underlying geological formations is the major contributor to the $^{87}Sr/^{86}Sr$ ratios of the soil, and plants display $^{87}Sr/^{86}Sr$ values nearly identical to the soil in which they grow.[28] Plants and animals will not perfectly reflect the strontium ratios of the underlying geology due to mixing effects and differential erosion of different geological formations, and, so, bioavailable $^{87}Sr/^{86}Sr$ ratios as observed in plants and animals provide better ideas of local ratios than geological baselines.

Oxygen stable isotope ($\delta^{18}O$) analysis is another common method of examining movement in individuals. The main input of oxygen atoms in the body is drinking-water,[29] and the difference in proportions between ^{18}O and ^{16}O is dependent largely on the location's climate (e.g., mean temperature, altitude) from which the drinking-water is sourced.[30] Because of this, $\delta^{18}O$ analysis has been used successfully to track the movement of humans in past populations.[31] Though $\delta^{18}O$ can also provide information about breastfeeding and weaning strategies in the past due to differences in $\delta^{18}O$ values between drinking-water and breast milk, it is placed under the grouping of 'mobility isotopes' for this paper alongside $^{87}Sr/^{86}Sr$, while $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ are grouped as 'dietary isotopes'.

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[16] Al-Bashaireh et al. 2010; Gregoricka and Sheridan 2013.

[17] Fetner 2015; Sołtysiak and Schutkowski 2018; Styring et al. 2017.

[18] Lee-Thorp, Sealy and van der Merwe 1989; Sharp 2017.

[19] DeNiro and Epstein 1978; Hoefs 2009; Lee-Thorp, Sealy and van der Merwe 1989.

[20] Fry et al. 1982; Keegan and DeNiro 1988; Schoeninger, DeNiro and Tauber 1983.

[21] Sharp 2017.

[22] Bocherens and Drucker 2003; Minagawa and Wada 1984; O'Connell et al. 2012; Perkins et al. 2014.

[23] Nehlich 2015; Richards, Fuller and Hedges 2001; Richards et al. 2003.

[24] Peterson, Howarth and Garritt 1985; Richards, Fuller and Hedges 2001.

[25] Vika 2009.

[26] Bentley 2006; Montgomery et al. 2005.

[27] Burton 2008.

[28] Evans et al. 2010.

[29] Bryant and Froelich 1995; Longinelli 1984; Luz and Kolodny 1989.

[30] Daux et al. 2008.

[31] Chenery et al. 2010; Muldner, Chenery and Eckardt 2011; Prowse et al. 2007.

'Standing on the Shoulders of Giants'

There are certain challenges to sample collection and analysis this research project must face. As the project is still underway, there is currently no single geographic region that stands as a testable hypothesis for determining the origin of the Hyksos. As such, there are limitations in terms of project resource costs for collecting samples from all possible regions of the Near East from which the Hyksos might have originated. A similar set of challenges arises with the dietary data; when interpreting palaeo-diet, it is important to establish a dietary baseline specific to the region of interest. There are slight but significant variations around the globe for $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ values of plant and animal life due to variable rainfall, soil conditions, climate and other factors.[32] The difference in $\delta^{13}C$ and $\delta^{15}N$ values has even been used to consider childhood place of origin in past populations,[33] and the highly varied $\delta^{34}S$ values in environments have been utilized in ecological and archaeological studies to track human and animal migrations and diet.[34]

The collection and analysis of past isotopic research data ameliorate these challenges. The increasing availability of quantitative information within bioarchaeological research has given more impact to metadata analysis, the statistical technique of combining data from multiple studies.[35] The data produced by stable isotopes analysis is ideal for metadata analysis: it is nominal data that, thanks to standard practise of (a) calibrating to international and in-house reference material and (b) publishing the raw data with quality indicators in order to confirm the reproducibility, is comparable between quality laboratories. Already metadata analyses of stable isotope data have been conducted in Britain,[36] Mesoamerica[37] and Germany.[38] The vast quantity of previous stable isotope research within the Near East provides opportunity to compile a large dataset to address questions not addressed in the individual studies, with a greater ability to conduct powerful statistical analyses.

Building a Database

Thus far, datasets from 38 studies have been incorporated to create a relational database of isotopic data from archaeological human, plant and animal samples across Egypt and the Near East. The database has been built using IsoMemo's (isomemo.com) best practice guidelines for curating stable isotopes data, similar to IsoArch, the open access database that curates stable isotopes data from the Greco-Roman world.[39]

A relational database is critical to complex archaeologically derived data. The core of the database is the sample description (e.g., sex, age, contextual information and dating), while one-to-many relationships tie together key site information (e.g., latitude, longitude) and the literature cited (Fig. 1). This relational database structure allows the isotope data to tie to the primary key of each sample, while also allowing room for the database to grow into other tables in future research (i.e., DNA information, detailed osteological data). The isotopes table catalogues the isotopic ratios ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$, $\delta^{34}S$ and $^{87}Sr/^{86}Sr$) along with relevant quality assessors and laboratory information, as well as the tissue analysed, and whether the isotopes are analysed from organic or mineral fractions in the cases of oxygen and carbon stable isotopes (which can be analysed from either). The one-to-many relationship between the individual ID key in the Sample Description table and the Isotopes table lets us include multiple samples from the same individual, as in cases where a tooth and a bone have been sampled[40] or where serial sectioning of tooth dentine was collected in order to study changes in diet and mobility over time.[41]

Selection Criteria

Data from grey literature and other non-peer-reviewed sources (e.g., master's theses and doctoral dissertations) were included; though it was preferred that peer-reviewed publications were also available from those projects.

Deciding on what date range to include for comparative purposes is difficult. For mobility isotopes, geological and hydrological isotopes should not change demonstrably over the Holocene period[42] so long as we remain aware that $\delta^{18}O$ values might reflect seasonal shifts and/or small-scale climate variability,[43] and, so, all available archaeological data within the Mediterranean/Near Eastern region is included.

For dietary isotopes, the acceptable date range for human comparative samples is narrower. Currently, information as late as Byzantine is included, though the increasingly global trade could create dietary profiles significantly different from the New Kingdom onwards, at least for the upper classes.[44] Conversely, we cannot assume that pre-Ptolemaic Egypt was as

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[32] Casey and Post 2011.
[33] Schroeder et al. 2009.
[34] Hesslein et al. 1991; Peterson, Howarth and Garritt 1985; Richards, Fuller and Hedges 2001; Thomas and Cahoon 1993.
[35] Cooper 2016; Haidich 2010; Schmidt and Hunter 2014.
[36] Evans, Chenery and Montgomery 2012.
[37] Price et al. 2008.
[38] Münster et al. 2018.
[39] Salesse et al. 2018.
[40] Hornig 2010.
[41] Eerkens et al. 2018.
[42] Bentley 2006.
[43] Cook et al. 2015.
[44] Alcock 2006.

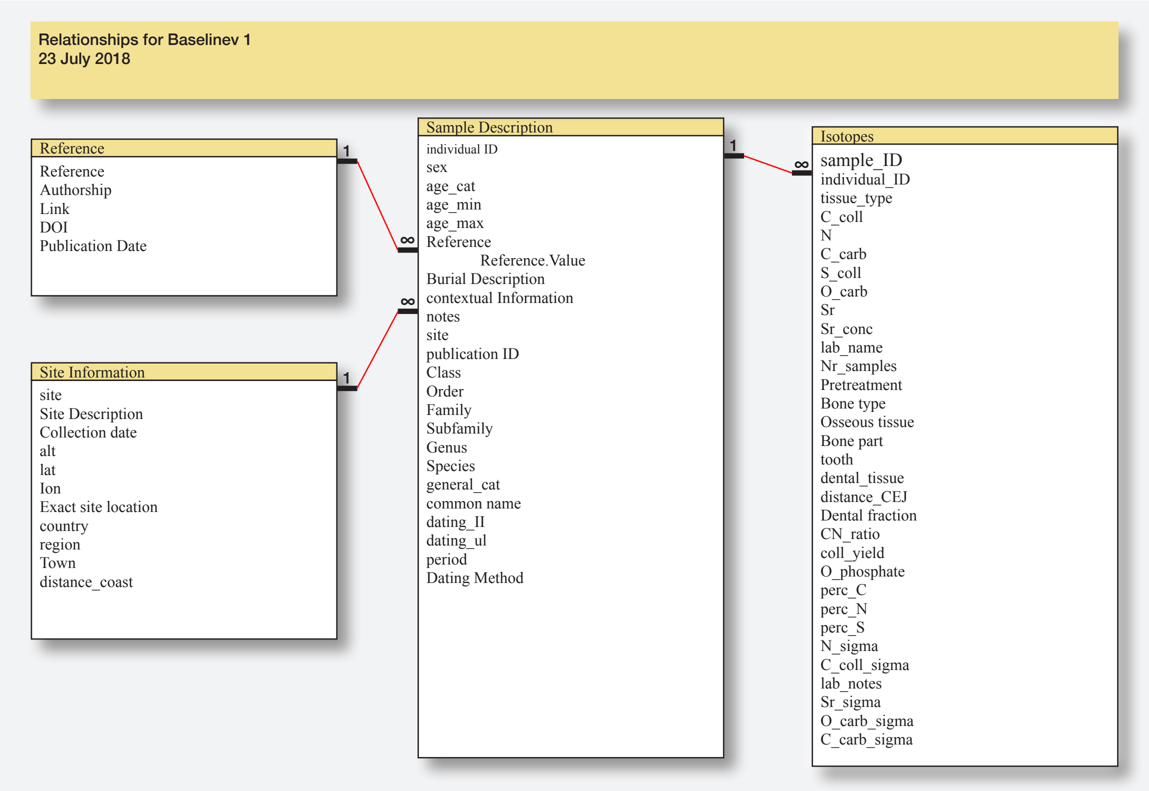

Fig. 1 Database structure

isolated as previously assumed.[45] Modern floral and faunal samples from the studied regions were also included as dietary baselines.

Contaminated samples of poor quality need to be eliminated before statistical analysis. For stable isotope analyses of collagen, collagen integrity assessments are important for identifying poorly preserved and/or contaminated tissue samples.[46] Collagen-derived samples were not included in the database if no collagen integrity assessments were provided. As a minimum, a reported C/N ratio was required for collagen integrity assessment. DeNiro (1985) observed that modern bone displayed a C/N ratio within 2.9–3.6, though van Klinken et al. (1999) suggest the upper bounds can be higher than 3.6; any C/N ratio 2.9–4.0 was considered acceptable for this baseline. If %C, and %N were provided, %C values between 15 and 47% and %N values between 5 and 17% were required.[47] Exceptions were made for the data provided by Copley et al. 2004 and Basha et al. 2016; both studies assured the reader that all samples were within 2.9–3.6 C/N ratios, but did not provide the individual quality data.

For modern plant and animal tissue used as reference material, samples for dietary isotopes were excluded from the database if no defatting protocol was clearly stated in the methods; lipids are depleted in ^{13}C relative to carbohydrates and proteins due to differential metabolic processes,[48] and, thus, it is best to reduce variation in lipid levels between tissues and species for ancient food pathway studies. Due to the long-term combustion of fossil fuels in the industrial age, shifts in the global carbon reservoirs (the ‘Suess effect’) require a correction to make modern samples comparable regarding δ^{13}C values: +1.5‰ for terrestrial samples and +0.86‰ for marine samples.

There are fewer, less universally accepted methods of assessing mineral quality of archaeological bone and teeth compared to the collagen quality indices. As such, most studies analysing isotopes from the mineral portion of teeth (^{87}Sr/^{86}Sr, δ^{18}O and $\delta^{13}C_{carbonate}$) do not report any quality assessments. Shewan (2004) rejects some modern plant samples as potentially contaminated due to modern car exhaust fumes, but all other modern samples analysed for ^{87}Sr/^{86}Sr are included in this database. Though new techniques for assessing mineral quality are being presented as de rigueur for stable isotopes studies,[49] no samples were excluded for lacking these assessments, as the quality of data is deemed to be sufficiently robust.

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[45] Schneider 2003; Zakrzewski 2007.

[46] Dobberstein et al. 2009.

[47] Ambrose 1990; Ambrose and Norr 1992.

[48] DeNiro and Epstein 1978; Hobson and Clark 1992; Sotiropoulos, Tonn and Wassenaar 2004.

[49] Garvie-Lok, Varney and Katzenberg 2004; Metcalfe, Longstaffe and White 2009.

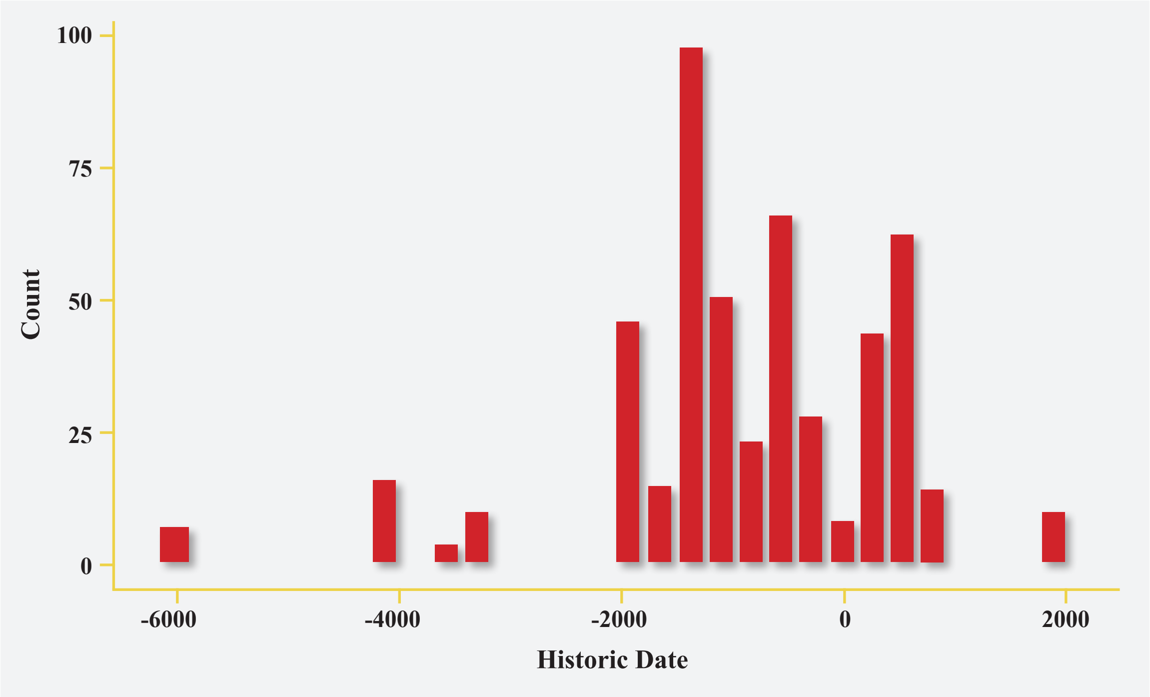

Fig. 2 Year distribution of human and animal samples with mobility isotope data ($\delta^{18}O$ or $^{87}Sr/^{86}Sr$) from the Nile Valley and Dakhla Oasis. Historic dates are mean year of site use range

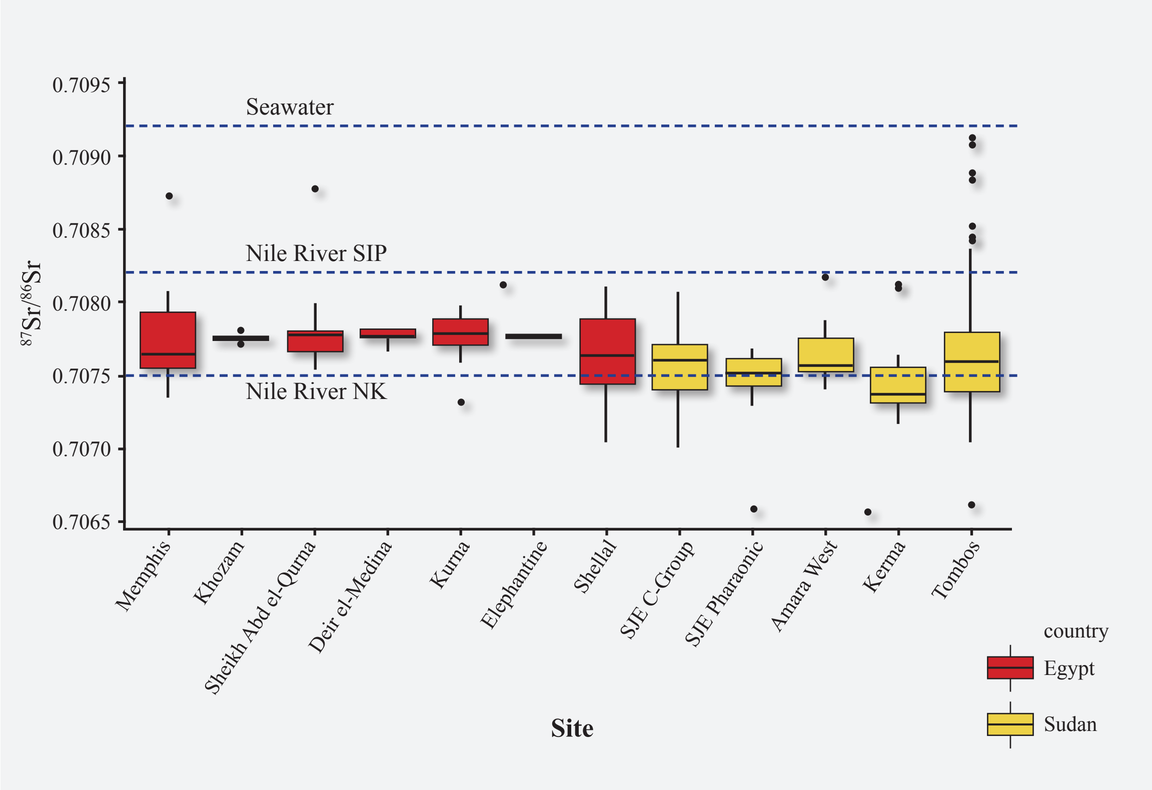

Fig. 3 Box plot of $^{87}Sr/^{86}Sr$ data for humans, by site. Sites ordered by latitude. Value of modern sea-water (0.7092), Nile River c. 3500 BP (SIP, 0.7082), and Nile River c. 2900 BP (NK, 0.7075) as dashed lines

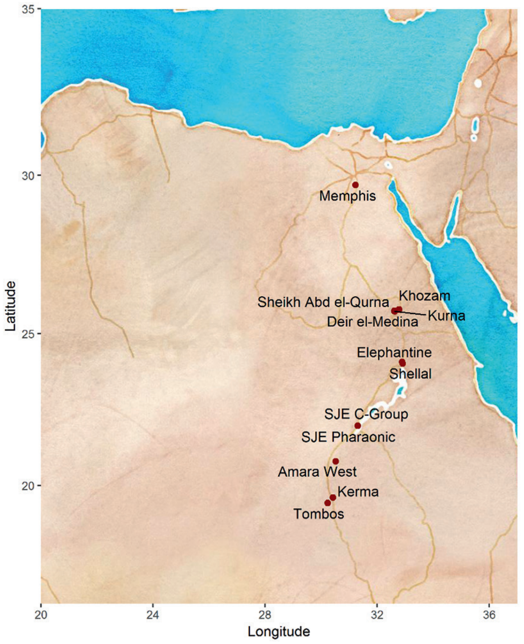

Fig. 4 Sites with human $^{87}Sr/^{86}Sr$ data

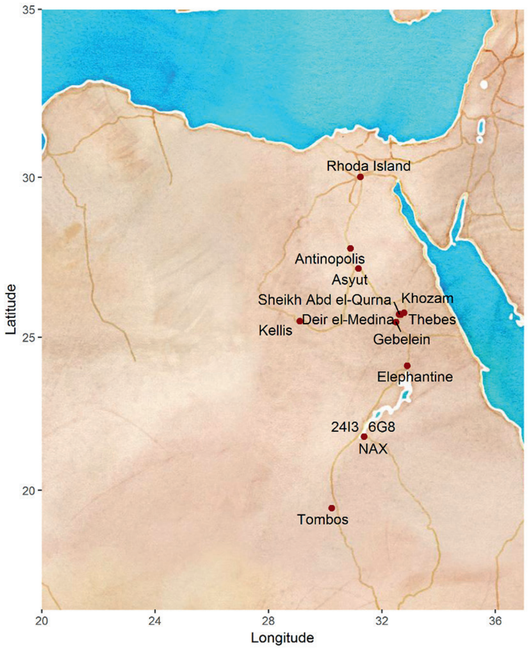

Fig. 5 Sites with human $\delta^{18}O$ data

$^{87}Sr/^{86}Sr$ values from enamel and modern faunal bone or dentine samples were included in the database, but $^{87}Sr/^{86}Sr$ from bone or dentine samples were excluded; these tissues are more prone to leaching from the local groundwater and the exchange of Sr between the groundwater and in the mineral portion.[50] There is no means of determining whether bone and dentine have been altered in this fashion, and it is wiser simply to exclude all $^{87}Sr/^{86}Sr$ values from archaeologically derived samples such as these. $\delta^{18}O$ and $\delta^{13}C_{carbonate}$ are not considered to be as prone to changes due to leaching effects from groundwater as $^{87}Sr/^{86}Sr$ values and, so, could be included in the database, even if no quality assessments were presented.

Case Study: Using Metadata to Identify Residential Mobility in Egypt and Sudan

As a pilot investigation of the value of the database, we incorporate eight previous studies of Egypt and Sudan to investigate the utility of strontium and oxygen isotope analyses in identifying migrants.[51] These studies included sites in the Nile Valley and in the Dakhla Oasis in the Western Desert, spanning 6950 BCE to 700 CE, as well as modern faunal samples (Fig. 2). No $^{87}Sr/^{86}Sr$ values from floral samples could be found in the literature. In total, 442 individuals and 63 faunal samples from these studies have $\delta^{18}O$ and/or $^{87}Sr/^{86}Sr$ data.

Human Data

Strontium Isotopes

In total, 227 individual from sixteen sites throughout the Nile Valley in Egypt and Sudan have $^{87}Sr/^{86}Sr$ values. Figure 4 highlights an important research gap for strontium data, as there are no sites from the Western Desert, Eastern Desert or Sinai Peninsula, and, so, the potential utility for $^{87}Sr/^{86}Sr$ palaeo-mobility analysis when the drinking-water source is *not* the Nile River cannot be assessed.

The collated data of human $^{87}Sr/^{86}Sr$ values is summarized on Tab. 1. The median and interquartile range (IQR) are presented rather than mean and standard deviation as the data are not normally distributed and possibly skewed by immigrants with 'deviant' values. Some likely immigrants are observable as outliers in the box plot of values by site (Fig. 3), especially from the Nubian site of Tombos,[52] where New Kingdom Egyptian imperial expansion caused the import of workers from other regions of the empire.[53] However, most individuals fall within the Nile River $^{87}Sr/^{86}Sr$ values between the Second Intermediate Period and the New Kingdom as estimated by Krom et al. 2002, though of course those outliers present in each site cannot be dismissed.There are statistically significant differences in $^{87}Sr/^{86}Sr$ values between

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[50] Bentley 2006.

[51] Buzon and Bowen 2010; Buzon and Simonetti 2013; Buzon, Simonetti and Creaser 2007; Dupras and Tocheri 2007; Iacumin et al. 1996; Metcalfe, Longstaffe and White 2009; Touzeau et al. 2013; White, Longstaffe and Law 1999; White, Longstaffe and Law 2004.

[52] Buzon, Simonetti and Creaser 2007.

[53] Smith 2007.

Site	Median	IQR	n
Amara West	0.70756 0.70775	0.0002125	24
Deir el-Medina	3 0.70776	0.000078	5
Elephantine	9	0.0000175	3
Kerma	0.70736	0.00024 0.0000202	15
Khozam	0.70777	5	6
Kurna	0.70778	0.000175	15
Memphis	0.70764 0.70778	0.000375 0.0001374	15
Sheikh Abd el-Qurna	5	8	14
Shellal	0.70764	0.000445	15
SJE C-Group	0.7076	0.00031	15
SJE Pharaonic	0.70751	0.000185	15
Tombos	0.70759	0.00042	85
All sites combined	**0.70762**	**0.000344**	**227**

Tab. 1 Summary of human $^{87}Sr/^{86}Sr$ values, tabulated by site

Site	Median	IQR	n
24I3	2.5	2.46	7
6G8	4.2	1.43	10
Antinopolis	1.9	0.54	2
Asyut	-1.4	0.46	9
Deir el-Medina	0.8	1.69	5
Elephantine	-1.2	0.92	3
Gebelein	-0.8	0.85	15
Hambukol	15.3	1.23	14
Kellis	-3.9	3.36	59
Khozam	-1.7	2.46	7
NAX	2.6	2.23	46
Rhoda Island	-1.2	0.85	3
Sheikh Abd el-Qurna	1.1	2.16	45
Thebes	0.8	1.77	3
Tombos	0.9	3.30	30
Total	**0.6**	**4.47**	**244**

Tab. 2 Summary of human $\delta^{18}O_{drinking\text{-}water}$ values, tabulated by site. Hambukol excluded from total median and IQR

the sites ($H(11) = 33.907$, $p < 0.0001$). In addition, the IQRs are remarkably small for all sites, ranging from 0.0000175 to 0.000445. These IQRs would suggest that we could assert the *provenience postulate*: that between-sources differences must exceed within-source differences in order for provenience estimation to be possible.[54] Unfortunately, the differences between sources are also very small, with an overall IQR for the Nile Valley of ±0.000344. Put simply, the geographic origins of individuals from these sites cannot be confirmed without further, extensive baseline collection of samples and/or the combination of other palaeo-mobility evidence. To put these numbers into some perspective, a pan-Mesoamerican study[55] found that Central America's $^{87}Sr/^{86}Sr$ variation between sites was generally ~±0.001, fivefold the average variation between these Nile Valley sites; the researchers commented that ±0.001 was exceptionally low from their experience.

This lack of variation offers no surprise to geologists, as $^{87}Sr/^{86}Sr$ variation is largely dependent on the underlying geology of an area. With the Nile serving as the main source of drinking-water through the valley, erosion of the heterogenous and complex geological formations in Egypt, Sudan and Ethiopia[56] combine to create a tight range of biogenically available strontium. Strontium isotope data may have utility for differentiating between Nile Valley and non-Nile Valley individuals (i.e., identifying Asiatic immigrants in Avaris for the Hyksos Project or looking beyond the Nile Valley to the desert regions in Egypt); those potential difficulties remain to be explored in a later publication.

Oxygen Stable Isotopes

Six studies present $\delta^{18}O$ data from 244 individuals.[57] All sites with $\delta^{18}O$ data are within the Nile Valley with the exception of Kellis, a Roman-era site in the Dakhla Oasis (Fig. 5). One additional study analysed 297 teeth from 102 individuals associated with Kellis, but the publication (Dupras and Tocheri, 2007) only provided averaged values and not raw data for comparison and it is also unknown how many individuals were originally published in Dupras and Schwarcz 2001.

Oxygen stable isotopes are a reflection of the local climatic factors such as altitude, mean temperature

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[54] Weigand, Harbottle and Sayre 1977.

[55] Price et al. 2008.

[56] For a review, see Said 2017.

[57] Dupras and Schwarcz 2001; Iacumin et al. 1996; Metcalfe, Longstaffe and White 2009; Touzeau et al. 2013; Touzeau et al. 2014; White, Longstaffe and Law 2004.

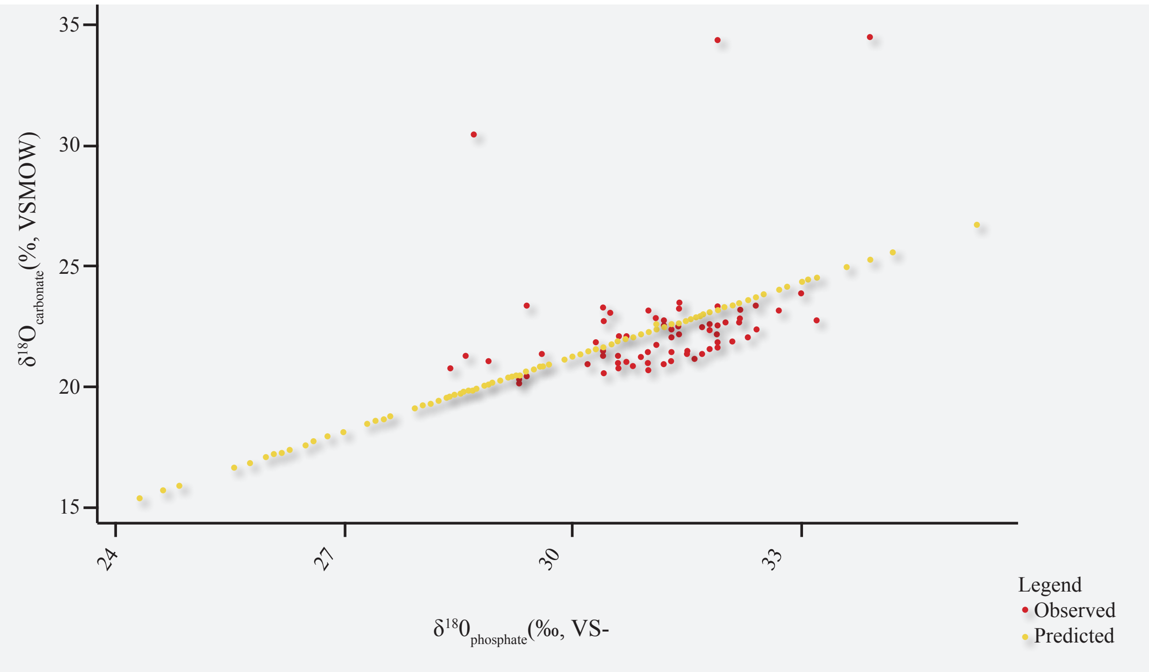

Fig. 6 Observed and predicted $\delta^{18}O_{phosphate}$ values plotted against observed $\delta^{18}O_{carbonate}$ values from the human δ18O values given within the data collected for this metadata analysis

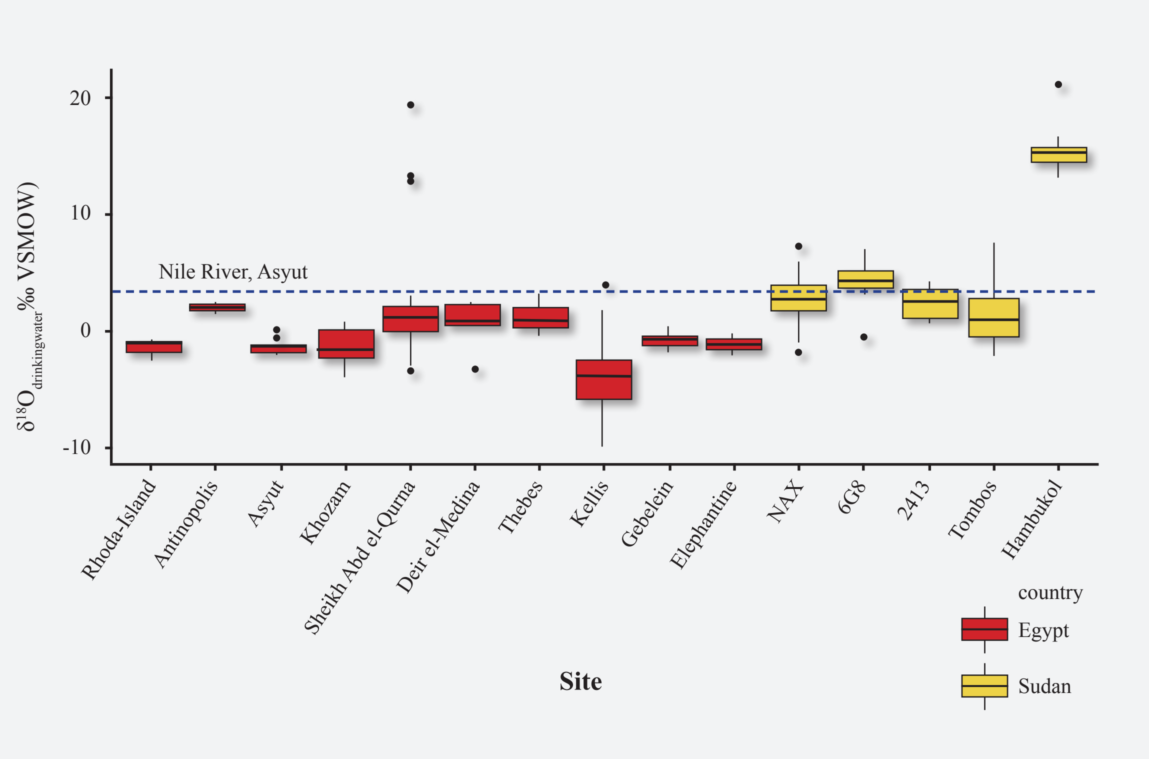

Fig. 7 Box plot of $\delta^{18}O_{drinking\text{-}water}$ data for humans, by site. Sited ordered by latitude. Value of river water from Asyut

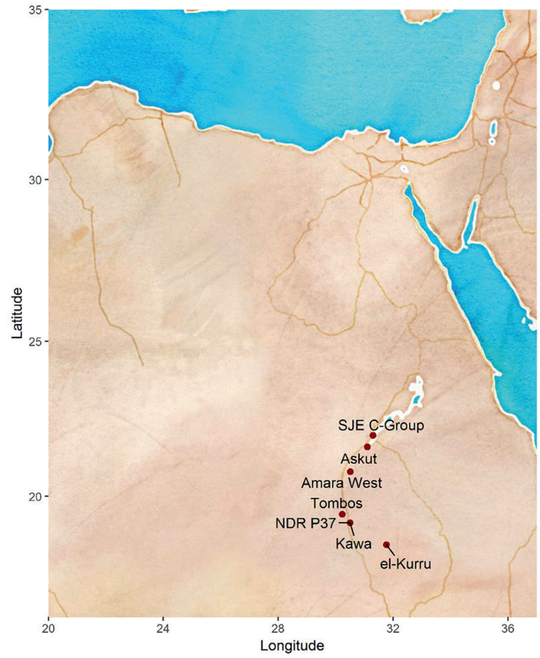

Fig. 8 Sites with faunal 87Sr/86Sr data

Site	Median	IQR	n
Amara West	0.707145	0.000205	10
Askut	0.70724	0.0011775	14
el-Kurru	0.70869	0.00194	3
Kawa	0.7091	0.001495	11
NDR P37	0.70692	0.000385	3
SJE C-Group	0.707615	0.000725	10
Tombos	0.70743	0.000282	12
Total	**0.70748**	**0.00098**	**63**

Tab. 3 Summary of animal 87Sr/86Sr values, tabulated by site

and latitude.[58] It is important to note that oxygen stable isotopes are presented in δ-value relative to international standards, and can be standardized to two different scales: VPDB and VSMOW.[59] All data published relative to VPDB were converted to VSMOW for comparison using the standard conversion equation.[60]

Oxygen stable isotopes can be analysed from two forms of oxygen within the mineral portion of tissue: structural carbonate (CO_3^{2-}) and phosphate (PO_4^{3-}).[61] There are risks and benefits related to potential preservation, financial cost and laboratory procedures when analysing these two sources of oxygen, but they can be compared when $\delta^{18}O_{carbonate}$ values are converted to $\delta^{18}O_{phosphate}$ values using a linear equation fit from experimental data.[62] In the instances where the original researchers processed both carbonate and phosphate and, so, the observed values can be compared,[63] differences between the observed values were 0.4‰ on average; this is minimal and within analytical error for many laboratories. The observed $\delta^{18}O_{carbonate}$ and $\delta^{18}O_{phosphate}$ values are plotted along with the converted $\delta^{18}O_{carbonate}$ in Figure 6; the three obvious outliers with $\delta^{18}O_{carbonate}$ values above 30‰ are from Metcalfe, Longstaffe, and White 2009 using the results from their "weak pretreatment method 'GB50' method" and no hypothesis for these diverging values is provided by the original researchers.

The oxygen data can be converted one final time from $\delta^{18}O_{phosphate}$ to $\delta^{18}O_{drinking-water}$ using Equation 6 from Daux et al. 2008. In this form, the individual data as plotted by site can be compared to a mean of modern $\delta^{18}O$ values collected from Asyut and curated by IAEA/WMO 2011. As with the $^{87}Sr/^{86}Sr$ data, there is little variation between sites in Egypt and Sudan. There appears to be a slight relationship between site latitude and $\delta^{18}O_{drinking-water}$ values as there is an increase in $\delta^{18}O_{drinking-water}$ values observable with the sites ordered along the x-axis by latitude, but the gradation appears too fine to use for mobility investigation. The exceptions are the extremely high values from Hambukol, which are not contextualised by the original authors.[64]

We can also assess $\delta^{18}O$ values as tools for provenancing the same way we evaluated $^{87}Sr/^{86}Sr$ variation, by examining the median and IQRs between and within sites. In Table 2 we provide median and IQRs of converted $\delta^{18}O_{drinking-water}$ by site, along with a total median and IQR, with Hambukol excluded due to its much higher $\delta^{18}O_{drinking-water}$ values. Despite the general median overlap easily observable in Figure 7, the low within-site IQRs and larger between-sites IQR suggest some potential utility for the use of $\delta^{18}O$ values to discern mobility along the Nile Valley.

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[58] Balasse et al. 2003; Zazzo, Balasse and Patterson 2006.
[59] Sharp 2017.
[60] Coplen 1988.
[61] Chenery et al. 2012.
[62] Chenery et al. 2012.
[63] Iacumin et al. 1996; Metcalfe, Longstaffe and White 2009; Touzeau et al. 2013.
[64] Metcalfe, Longstaffe and White 2009.

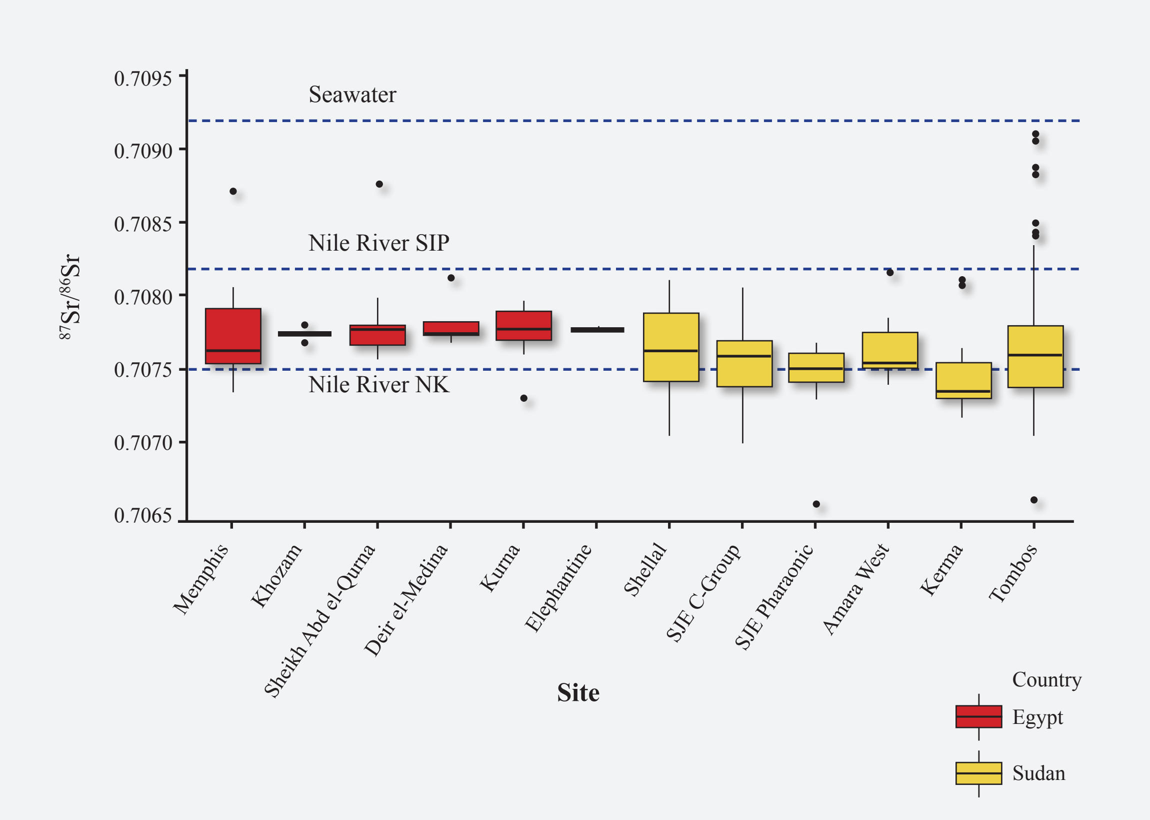

Fig. 9 Box plot of ^{87}Sr/^{86}Sr data for animals, by site. Sited ordered by latitude. Value of modern sea-water (0.7092), Nile River c. 3500 BP (SIP, 0.7082), and Nile River c. 2900 BP (NK, 0.7075) as dashed lines

Faunal Data

The only oxygen stable isotope values for animals were presented by Touzeau et al. 2013, who analysed eight Egyptian animal mummies (hyena, crocodile, fish and cat). However, lacking oxygen stable isotope data for local fauna is not an issue for palaeo-mobility studies, as differences in metabolic processing of drinking-water and drinking-water strategies (e.g., gazelles licking morning dew) create non-comparable δ^{18}O values. Touzeau and colleagues advise that the data could stand as independent palaeoclimatic information if the sample size were expanded in the future, but for now these samples are not included in this case study. The only faunal samples with strontium data for the region are from Sudan (Fig. 8), highlighting a major research gap.

All faunal samples (*n* = 63) are from Buzon and Simonetti 2013, who included modern and ancient animal enamel samples as a means of understanding the local baseline of their Sudanese archaeological sites (Fig. 9). There is a wide range in animal ^{87}Sr/^{86}Sr ratios compared to the human ratios observed in Figure 3. The wide range in animal ratios could be a result of long-distance trade, with cattle displaying the widest ranges in values across sites. Another potential contributor for the wider range in ^{87}Sr/^{86}Sr ratios compared to human values observed in Figure 3 could be because humans, as omnivorous top-level consumers eating foods from a variety of sources, can represent an averaged value of such foods compared to herbivorous domesticates, where herds are kept in controlled feeding ranges. Transhumance across biospheres of varying strontium ratios may cause significantly different isotope values to be captured in single samples of tooth enamel between animals of different ages; incremental sampling along animal teeth in future research could address these possibilities. With 63 samples across seven sites, the group size is too small to assess suitability of ^{87}Sr/^{86}Sr effectively using the provenience postulate like with the human data (Tab. 3), and seems to be inappropriate anyway as there is clearly large between-species variation.

Discussion and Conclusions

Overall, strontium and oxygen stable isotopes appear to be poor tools for determining origins along the Nile River Valley when either is used singly, with δ^{18}O values showing slightly more promise when tested using the provenience postulate. Mobility isotopes would likely show greater value for discerning places of origin in tandem using principle components analysis, but for this metadata case study that possibility cannot be assessed, as only 43 individuals from all previous studies were analysed for both isotope values.

The metadata case study presented here demonstrates the value of collating previous studies to answer larger-scale questions about methodology and identify gaps in current research knowledge. Comparative floral and faunal data is an important tool for placing human provenience, and this study highlights the lack of mobility isotopic data for floral and faunal samples. Any archaeologists interested in questions of human mobility surrounding their research should be encouraged to collect modern floral and faunal samples from their site, as time and export permits allow. As research gaps in isotopic information available for the Near East are identified, we aim to work with other researchers to amend them, or at the very least bring attention to these areas.

Regarding the database, it will continue to expand as new research is found and added. Within our research group, this baseline database has already served as a framework for a relational database to tie together all of our research group's future data (DNA, biodistance, palaeopathology) to allow fast, efficient information sharing between the researchers involved in the holistic synergizing of data planned for the end of this project.

"This project has received funding from the
European Research Council (ERC)
under the European Union's Horizon 2020 research and
innovation programme
(grant agreement no. 668640)"

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