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Intraregional $^{87}Sr/^{86}Sr$ variation in Nubia: New insights from the Third Cataract

Sarah A. Schrader[a,*], Michele R. Buzon[b], Loretta Corcoran[c], Antonio Simonetti[c]

[a] Faculty of Archaeology, University of Leiden, Einsteinweg 2, Leiden 2333 CC, the Netherlands
[b] Department of Anthropology, Purdue University, 700 West State Street, West Lafayette, IN 47907, USA
[c] Department of Civil and Environmental Engineering and Earth Sciences, University of Notre Dame, 156 Fitzpatrick Hall, Notre Dame, IN 46556, USA

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ABSTRACT

Previous research of $^{87}Sr/^{86}Sr$ variability in human dental tissue from the Nile Valley has shown diversity in bioavailable strontium across the landscape. Local ranges, determined from faunal sampling, have been suggested for several sites in Nubia, including Tombos (Third Cataract, Sudan). This study builds on previous research by testing human and faunal dental enamel samples from three sites in the Third Cataract region: Tombos, Hannek, and Abu Fatima. The addition of Abu Fatima and Hannek into the assessment of the Third Cataract region brings new temporal and socioeconomic juxtapositions that can shed light on migration and locality in Bronze Age Nubia.

Two faunal samples, a sheep from Abu Fatima and a horse from Tombos, had $^{87}Sr/^{86}Sr$ values that were consistent with the previously established local Third Cataract strontium range. Seven of the 29 human samples tested for Abu Fatima are suggestive of non-local origin and consistent with the Second Cataract region. One of the four individuals tested from Hannek may have migrated to the region from Egypt or the Second Cataract region. Lastly, four of the 30 samples from Tombos indicate possible non-local origin; the $^{87}Sr/^{86}Sr$ values may suggest Egypt, the Second Cataract, or the Fourth Cataract as places of origin. These findings suggest complex human migration networks were present in the Nile Valley during the Bronze Age. We support the continued examination of migration using strontium while acknowledging that further research needs to be done.

1. Introduction

Strontium (Sr) isotope geochemistry has become an increasingly popular and informative method for assessing migration and locality in the ancient world. Based on the premise that $^{87}Sr/^{86}Sr$ ratios vary across landscapes, we can establish regionally specific $^{87}Sr/^{86}Sr$ ranges and, because human tissues absorb Sr *via* groundwater and food consumption, test whether individuals fall within this range (*i.e.*, locals) or not (*i.e.*, non-locals; Bentley et al., 2004). Using this method, researchers have investigated how migration, or in some cases, locality, contextually align with group identity, warfare, interaction, religious practices, and social inequality (*e.g.*, Grupe and McGlynn, 2016; Knudson and Torres-Rouff, 2009; Marsteller et al., 2017; Montgomery, 2010; Perry et al., 2017; Pestle et al., 2013; Sheridan and Gregoricka, 2015; Torres-Rouff et al., 2015).

Like other world regions, Sr isotope studies in Nubia (southern Egypt, northern Sudan) have proven both successful and interesting. In 2007 Buzon and colleagues assessed the local $^{87}Sr/^{86}Sr$ range for the Third Cataract region, focusing on the archaeological site Tombos (Buzon et al., 2007; Fig. 1). Buzon et al. questioned whether or not Egyptians occupied this Nubian town during the New Kingdom Period of colonization (1550–1070 BCE). They established a local $^{87}Sr/^{86}Sr$ range using burial matrix ($n = 4$) as well as ancient ($n = 1$) and modern ($n = 1$) faunal samples (0.7073–0.7079). Some of the human remains ($n = 49$) fell within the local $^{87}Sr/^{86}Sr$ range, while others, who had $^{87}Sr/^{86}Sr$ values outside of this range, were deemed of non-local origin ($^{87}Sr/^{86}Sr$ values as high as 0.7091). In this case, Buzon et al. make a strong argument that the non-local individuals may have in fact been Egyptian colonizers sent to Nubia.

Buzon and Simonetti built upon this original research in 2013, by testing Sr variability across several sites in the Nile Valley (Buzon and Simonetti, 2013). Faunal remains from other archaeological sites in Nubia ($n = 51$) allowed for a broader $^{87}Sr/^{86}Sr$ characterization of Nubia than was previously possible. Human $^{87}Sr/^{86}Sr$ values from Egypt and Nubia also illustrated $^{87}Sr/^{86}Sr$ variability in the Nile Valley ($n = 114$). An increased faunal sample ($n = 10$) allowed for the local

* Corresponding author.
E-mail address: s.a.schrader@arch.leidenuniv.nl (S.A. Schrader).

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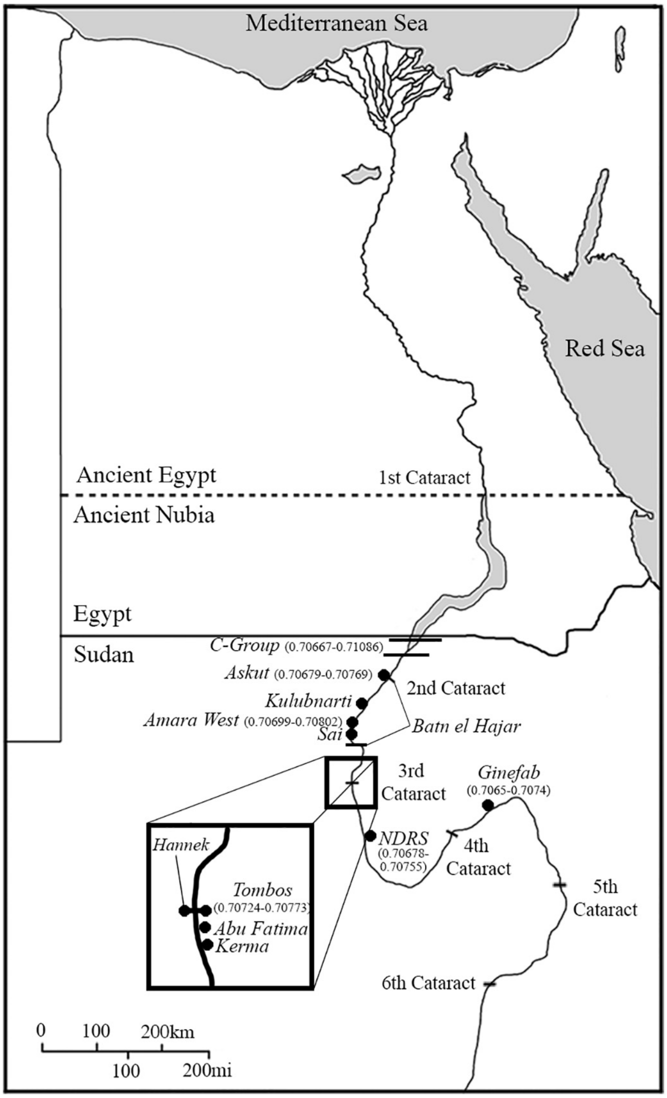

Fig. 1. Nubian archaeological sites with strontium data.
Available local $^{87}Sr/^{86}Sr$ ranges ascertained from faunal specimens in parentheses (Buzon and Simonetti, 2013 and Masoner et al., 2011).

Third Cataract $^{87}Sr/^{86}Sr$ signature to be further refined (0.70710–0.70783). Additional immigrants, possibly of Egyptian origin, were identified from New Kingdom Tombos ($n = 53$). Third Intermediate/Napatan Period (1070–747 BCE) human samples were also tested ($n = 32$); while many were likely local, two individuals stood out with $^{87}Sr/^{86}Sr$ values below the local Third Cataract rage (0.70705 and 0.70661). Buzon and colleagues suggest that, because $^{87}Sr/^{86}Sr$ values decrease from north to south, their findings may reflect migration from south of the Third Cataract to Tombos.

As the New Kingdom slowly deteriorated a new polity began to emerge in Nubia—Napata (Kendall, 1999; Török, 1995). In 2016, Buzon and colleagues provide Sr isotopic evidence that, while many early New Kingdom individuals from Tombos were non-local ($n = 19/55$), later New Kingdom and Third Intermediate/Napatan Period individuals were mostly local ($n = 28/30$; Buzon et al., 2016). This suggests that rather than a group of foreigners establishing what would become the Napatan State, as had been previously assumed (see Kendall, 1999; Priese, 1973; Trigger, 1976), a local movement starting from entangled Nubian-Egyptian communities like Tombos may have been the roots of the Napatan State.

Here, we further explore the Third Cataract local $^{87}Sr/^{86}Sr$ range by including recently excavated skeletal samples from: Abu Fatima (2500–1550 BCE), Hannek (1550–656 BCE) and Tombos (1550–656; Fig. 1). Abu Fatima, a middle-class peri-urban cemetery, and Hannek, a rural village, provide interesting socioeconomic juxtapositions to Tombos. Were middle-class and rural communities as mobile as administrative Tombos? Did this pattern change through time? We analyze the $^{87}Sr/^{86}Sr$ isotopic ratios of human and animal dental enamel to (1) assess if individuals from Abu Fatima, Hannek, and Tombos fall within the established Third Cataract $^{87}Sr/^{86}Sr$ range, and (2) determine if any individuals of non-local origin are present in these samples. This study will not only build upon our existing knowledge of $^{87}Sr/^{86}Sr$ values from the Third Cataract, it will also examine the locality of individuals in different temporal and socioeconomic contexts than Tombos.

2. Materials

Abu Fatima is located ~5 km south of Tombos and pre-dates New Kingdom Tombos (Fig. 1). It is ~10 km north of the ancient Nubian capital city, Kerma. Kerma is also the type-site of the broader Kerma culture, which, at its height, extended from the First Cataract to south of the Fourth Cataract (Edwards, 2004). Recent ^{14}C dates as well as ceramic and mortuary typology indicate that Abu Fatima was in use during the Ancient Kerma (2500–2050 BCE), Middle Kerma (2050–1750 BCE), and Classic Kerma (1750–1500 BCE) Periods (Akmenkalns, 2018). During this time Kerma grew from an incipient town to an urban city, with breweries, bakeries, religious buildings, defensive enclosure walls, a port, and a massive necropolis (Bonnet, 1990, 1992; Bonnet and Valbelle, 2007). It is estimated that as many as 20,000 individuals, including the royal and elite of Kerma society, were buried at the Kerma necropolis (O'Connor, 1993).

Abu Fatima was situated in a peri-urban space, in between the urban city, Kerma, and the sparsely populated rural hinterland. It would take approximately 2–3 h to walk from Abu Fatima to Kerma (Schrader and Smith, 2017). The location and size of the cemetery as well as the amount and quality of grave goods all suggest this population was not high-status, but more likely reflects a non-urban group that may have engaged in manual labor, agropastoralism, craft production, baking, and brewing (Edwards, 2004). However, it should be noted that the habitation of Abu Fatima lies below the modern village and is therefore not available for excavation at this time. Burial practices, which typically include 1–2 inhumations in a circular subterranean pit (1–2 m in diameter, ~2 m deep), are consistent with Nubian burial traditions (Gratien, 1978, 1985). This peri-urban and non-royal context is particularly interesting because much of Kerma archaeology has focused on either larger cities or rural landscapes (Edwards, 2004; Gratien, 1998; Welsby, 2001). Furthermore, because Abu Fatima spans from the Ancient Kerma to Classic Kerma periods, we are able to access how lifeways changed diachronically as the Kerma State grew.

As discussed above, Tombos was built as an Egyptian imperial town and fortress in Upper Nubia during the New Kingdom ~1450 BCE (Smith and Buzon, 2018). During this time, the Egyptian Empire aimed to thoroughly incorporate local Nubian communities into the greater governmental structure *via* the construction of temple towns, the promotion of local administrators, and socioeconomic reorganization (Trigger et al., 1983). Tombos served as an administrative center within Nubia, controlling trade, population movement, and also instituting Egyptian-Nubian coexistence. As indicated by Buzon, Smith, and colleagues, there is archaeological, osteological, and isotopic evidence to suggest that Egyptians, likely administrators, migrated south to live at Tombos (Buzon, 2006; Buzon et al., 2016; Buzon and Simonetti, 2013; Smith, 2003). The Tombos population continued after the decline of the New Kingdom and through the rise of the Napatan Period. Tombos is one of few sites spanning the New Kingdom, Third Intermediate, and Napatan Periods that has been excavated.

Hannek is located on the west side of the Nile River, directly across from Tombos (Fig. 1). It spans the New Kingdom to Napatan Periods and was contemporary with Tombos. Tombos was an administrative town and was home to high-ranking Egyptian officials, such as Siamun, Scribe-Reckoner of the Gold of Kush (Buzon et al., 2016). Hannek, however, probably represents working agropastoralists, who were not of the same high-status. Like Abu Fatima, this interpretation is grounded in the location and size of the cemetery as well as associated grave goods. Excavation of the habitation at Hannek supports this interpretation (Akmenkalns, 2018). Graves at Hannek were rectilinear pits, oriented north/northwest. Interments were in an extended burial position, with hands placed at the hips or across the torso. Wind erosion at the Hannek cemetery was particularly severe, which contributed to poor preservation of the skeletal remains. However, several teeth associated with burials were found well preserved and deemed suitable for $^{87}Sr/^{86}Sr$ analysis.

The Third Cataract regional geology is notably uniform, consisting of a relatively thin strip of recently deposited alluvium, which is surrounded by Cretaceous-aged Nubian sandstone formations (continental crust-derived sandstones, siltstones, mudstones, and conglomerates; European Union Commission, European Soil Data Centre, Geological Map of the Sudan, 1981). With this geological composition, we can expect Abu Fatima (~5 km south of Tombos) and Hannek (~4 km west of Tombos) to have similar local Sr ranges to that of Tombos. However, faunal samples from Abu Fatima will be used to test this hypothesis (no faunal samples from the Hannek cemetery are available).

A total of 65 human and faunal dental enamel samples were analyzed (Abu Fatima = 30, Hannek = 4, Tombos = 31; see Tables 1 and 2). Tooth enamel is not as prone to contamination as bone or dentine and, thus, is less likely to be compromised by diagenesis (Budd et al., 2000; Price et al., 2004; Wright, 2005). Because dental enamel forms in children and young adults (depending on the tooth) and does not turnover, or remodel, during life, the $^{87}Sr/^{86}Sr$ values will reflect the geology of where the individual grew up (Steele and Bramblett, 1988). Thus, if we record a $^{87}Sr/^{86}Sr$ ratio that is outside of the accepted Third Cataract local range, we can infer that this individual may have migrated to the Third Cataract region. Estimated age of enamel formation is listed in Table 2; there were no differences in the age distribution of the samples between Tombos, Abu Fatima, and Hannek.

3. Methods

Sex was estimated in adults using accepted bioarchaeological analysis of the pelvis and skull (Buikstra and Ubelaker, 1994). For adults, age-at-death was estimated using pubic symphysis and auricular surface degeneration (Buikstra and Ubelaker, 1994). For subadults, age-at-death was estimated using epiphyseal fusion and dental eruption methods (Buikstra and Ubelaker, 1994).

All Sr isotope analyses were conducted in a class 1000 cleanroom facility at the University of Notre Dame Midwest Isotope and Trace Element Research Analytical Center (MITERAC). Samples were prepared according to previous published methods (see Buzon et al., 2007; Buzon and Simonetti, 2013). Strontium isotope ratios were analyzed using a NuPlasmaII MC-ICP-MS instrument. Repeated analyses ($n = 6$) of a 100 ppb solution of the NIST SRM 987 strontium isotope standard during the course of this study yielded an average $^{87}Sr/^{86}Sr$ value of 0.710236 ± 0.000057 (2σ), which is within uncertainty of the accepted value (0.710245; Faure and Mensing, 2005). U/Ca ratios, determined *via* Nu Instruments Attom HR-ICP-MS and ICP-OES units, were tested to assess contamination. The presence of uranium, which occurs naturally in ground water but not in human remains, can indicate post-mortem contamination (Hedges and Millard, 1995). All samples tested were found to be below the equipment detection limit (0.003 ppm ICP-MS) and therefore included in further interpretation (see Tables 1-2). To statistically test whether two populations had different mean $^{87}Sr/^{86}Sr$ values, the non-parametric Mann-Whitney *U* test was employed due to non-normally distributed data.

Table 1
Results of strontium analysis of archaeological faunal teeth.

Site	Burial #	Species	Period	$^{87}Sr/^{86}Sr$
Abu Fatima	5B1A	*Ovis aries*	Kerma	0.70734
Tombos	23.C	*Equus caballus*	3IP	0.70764

4. Results

Sr isotope results suggest that both locals and migrants were present in these Third Cataract populations. $^{87}Sr/^{86}Sr$ values from the two faunal samples tested, a sheep from Abu Fatima and a horse from Tombos, suggest that these animals were reared locally (Table 1). This is the only ancient faunal dental specimen recovered form Abu Fatima at this time; no *in situ* ancient faunal samples were found at Hannek. At Abu Fatima, of the 29 human individuals tested, seven have $^{87}Sr/^{86}Sr$ values that are indicative of non-local origin (human Sr at Abu Fatima: range = 0.70715–0.71473, $\bar{x}$ = 0.70783 ± 0.00137 1σ; Table 2). $^{87}Sr/^{86}Sr$ values for the seven non-local individuals are all higher than the local range (i.e., > 0.70783). Of the four samples tested from Hannek, one individual had a non-local $^{87}Sr/^{86}Sr$ value (human Sr at Hannek: range = 0.70713–0.70966, $\bar{x}$ = 0.70808 ± 0.00110 1σ). Like Abu Fatima, this value was higher than the local Third Cataract range. For Tombos, four individuals have $^{87}Sr/^{86}Sr$ values that suggest they were of non-local origin (human Sr at Tombos: range = 0.70696–0.70825, $\bar{x}$ = 0.70757 ± 0.00027 1σ). Three of these non-local individuals had $^{87}Sr/^{86}Sr$ values higher than the local range and one individual had an $^{87}Sr/^{86}Sr$ value that was lower than the local range. These results suggest that the Third Cataract was home to a combination of local and non-local individuals throughout the 3rd–1st millennia BCE.

5. Discussion

The data presented here suggest there were both locals and non-locals living together at Abu Fatima, Hannek, and Tombos. The two faunal samples, a sheep from Abu Fatima and a horse from Tombos, further support the established local strontium range (5B1A (sheep): $^{87}Sr/^{86}Sr$ = 0.70734 and 23.C (horse): $^{87}Sr/^{86}Sr$ = 0.70764; local range per Buzon and Simonetti, 2013 = 0.70710–0.70783). The Abu Fatima sheep was likely reared locally and then sacrificed as part of a grave offering, something that is relatively common in Kerma burials (Chaix, 1993; Gratien, 1978). These data suggest that the horse buried at Tombos was also local (see Schrader et al., 2018 for further discussion). Horse and sheep transhumance is, of course, dependent upon culture-specific herding practices.

Whether or not faunal migration can be assessed *via* strontium depends on (1) the distance the animal traveled, and (2) local strontium variation (*i.e.*, if the bioavailable strontium varies enough to detect said travels). Other studies have used sheep to infer local isotope ranges (Frei and Price, 2012; Valenzuela-Lamas et al., 2016). Previous strontium analysis from various Nubian sites suggest that *Ovis/Capra* have a more limited strontium value range, likely reflecting the local geology (Amara West mean sheep $^{87}Sr/^{86}Sr$: 0.70726 ± 0.000352; Askut mean sheep $^{87}Sr/^{86}Sr$: 0.70710 ± 0.000336; NDRS P37 mean sheep $^{87}Sr/^{86}Sr$ 0.70708 ± 0.00041; C-Group mean sheep $^{87}Sr/^{86}Sr$ 0.70790 ± 0.001135), as opposed to cattle, which illustrate dramatic variation in strontium values (Askut mean cattle $^{87}Sr/^{86}Sr$ 0.70872 ± 0.001846; el-Kurru mean cattle $^{87}Sr/^{86}Sr$ 0.70852 ± 0.001946; Kawa mean cattle$^{87}Sr/^{86}Sr$ 0.70874 ± 0.000993; Buzon and Simonetti, 2013). These cattle data are particularly interesting and suggest that long-distance trading networks and/or pastoralism may have been active throughout the Third-First centuries BCE. Additional *Bos taurus* samples from various sites are needed to investigate this hypothesis further. However, given the high

Table 2
Results of strontium analysis of archaeological human teeth.

Site	Burial #	Period[a]	Sex[b]	Age[c]	Tooth sampled[d]	Estimated Age (yrs) of enamel formation[e]	$^{87}Sr/^{86}Sr$
Abu Fatima	1A1	Kerma	M	MA	M^1	2.5–3.8	0.70769
	1B1	Kerma	F	OA	RP_2	5.4–9.1	0.70759
	1E1	Kerma	F	YA	LI^1	3.3–5.0	0.70715
	1F1	Kerma	PM	MA	LP_1	4.4–7.2	0.70741
	1F2	Kerma	M	MA	LM^3	12.0–16.0	0.70739
	2A1	**Kerma**	**F**	**MA**	$\mathbf{LP^2}$	**5.9–7.1**	**0.70810**
	2A2	Kerma	M	MA	LP^1	5.0–6.8	0.70748
	2B1	Kerma	M	MA	RP_2	5.4–9.1	0.70720
	2C1	**Kerma**	**M**	**YA**	$\mathbf{LP^1}$	**5.0–6.8**	**0.71473**
	2D1	Kerma	F	OA	RI^2	3.8–5.0	0.70748
	2D2	Kerma	I	2.5–3	Lm	*in utero*–0.5	0.70718
	2F1	Kerma	F	MA	RP^1	5.0–6.8	0.70752
	2J1	Kerma	M	MA	LM_3	10.4–16.0	0.70751
	3A1	Kerma	M	MA	LI_1	3.6–5.0	0.70719
	4A1	Kerma	M	YA	LI^2	3.8–5.0	0.70746
	4B1	Kerma	I	0.5–1	RI^1	3.3–5.0	0.70764
	4C1	Kerma	F	OA	RI_2	3.3–5.0	0.70742
	4D1	**Kerma**	**F**	**MA**	$\mathbf{RM_3}$	**10.4–16.0**	**0.70876**
	4E1	Kerma	PM	MA	LC^1	4.1–7.0	0.70761
	4F1	Kerma	PM	MA	LI^2	3.8–5.0	0.70741
	5A1	**Kerma**	**I**	**MA**	$\mathbf{LP^1}$	**5.0–6.8**	**0.70787**
	5B1	Kerma	F	YA	LP^2	**5.9–7.1**	0.70758
	6B1	Kerma	PM	MA	LP_1	4.4–7.2	0.70737
	7B1	Kerma	I	IA	LP_1	4.4–7.2	0.70748
	7C1	**Kerma**	**I**	**IA**	$\mathbf{RP_2}$	**5.4–9.1**	**0.70804**
	7E1	Kerma	M	MA	RI^2	3.8–5.0	0.70732
	8A2	**Kerma**	**F**	**OA**	$\mathbf{LP^1}$	**5.0–6.8**	**0.70786**
	8B1	Kerma	F	MA	LI^2	3.8–5.0	0.70749
	9A1	**Kerma**	**M**	**MA**	$\mathbf{LI_1}$	**3.6–5.0**	**0.70801**
Hannek	1.2	NK-Nap	PF	IA	I_2	3.3–5.0	0.70778
	1.3	**NK-Nap**	**I**	**IA**	$\mathbf{RM^2}$	**6.3-8.0**	**0.70966**
	1.4	NK-Nap	PF	YA	LC_1	3.5–7.0	0.70774
	2.1	NK-Nap	PF	IA	RI^1	3.3–5.0	0.70713
Tombos	4-L13	NK	I	IA	LM^1	2.5–3.8	0.70773
	18-T2-B2	NK	M	MA	LM^1	2.5–3.8	0.70741
	18-T2-B4	NK	M	IA	LM_1	2.0–3.5	0.70747
	18-T2-B5	NK	F	YA	M^1	2.5–3.8	0.70779
	18-T2-B6	**NK**	**M**	**IA**	$\mathbf{RM^1}$	**2.5–3.8**	**0.70810**
	18-T2-L5-B3046	NK	I	I	Rc_1	*in utero*–0.75	0.70718
	18-T2-L5-B3064	NK	I	3–5	Rm^1	*in utero*–0.5	0.70743
	35-S2-L7-B3	NK	F	OA	LP^2	5.9–7.1	0.70759
	36-L25-B10	NK	F	OA	LI^1	3.3–5.0	0.70778
	36-L27[f]	NK	I	IA	LM^2	6.3–8.0	0.70751
	36-L27[f]	NK	I	IA	RP^1	5.0–6.8	0.70771
	36-S2-L5-B2	NK	I	0–1	Lm^1	*in utero*–0.5	0.70746
	36-S2-L2-B3	NK	F	YA	LP_1	4.4–7.2	0.70743
	36-S2-L9-B4	NK	M	OA	RP_2	5.4–9.1	0.70751
	36-S2-L11-B5	NK	I	4–5	Li^1	*in utero*–0.1	0.70746
	36-S2-L13-B6	**NK**	**F**	**YA**	**LP1**	**4.4–7.0**	**0.70819**
	36-S2-L14-B7	NK	I	0	m1	*in utero*–0.5	0.70754
	36-S2-L15-B8	NK	I	0–1	Rm^2	*in utero*–0.9	0.70744
	36-S2-L19-B11	NK	I	0–2	Lm_2	*in utero*–0.8	0.70766
	36-S5-B1	**NK**	**M**	**MA**	$\mathbf{LM_1}$	**2.0–3.5**	**0.70825**
	36-S7-L3-B1	NK	I	12–14	LP_1	4.4–7.2	0.70737
	36-S8-L3-B1	**NK**	**I**	**6–8**	$\mathbf{RI^2}$	**3.8–5.0**	**0.70696**
	37-B4	NK	F	IA	LM^2	6.3–8.0	0.70747
	37-L7	NK	I	I	LC^1	4.1–7.0	0.70760
	38-S2-L3-B1	NK	M	MA	LP_2	5.4–9.1	0.70766
	38-S2-L4-B2	NK	I	12–14	RI^1	3.3–5.0	0.70724
	45-B1	NK	F	YA	RM_1	2.0–3.5	0.70758
	46-L4-B1	NK/3IP	F	MA	RM_1	2.0–3.5	0.70760
	48-S3-B2	NK	I	9–12	Li_1	*in utero*–0.2	0.70752
	49-B1	NK	I	3–4	Li_2	*in utero*–0.3	0.70751

Bold = Outside of the previously established Third Cataract local range (0.70710–0.70783).

[a] Period: K = Kerma (2500–1550 BCE); NK = New Kingdom (1550–1050 BCE), 3IP = Third Intermediate Period (1069–750 BCE); Nap = Napatan Period (750–656 BCE).

[b] Sex: F = Female, PF = Probable Female, I = Indeterminate, PM = Probable Male, M = Male.

[c] Age: YA = Young Adult, MA = Middle Adult, OA = Old Adult, A = Adult, IA = Indeterminate Adult; for subadults, estimated age-at-death is provided in years.

[d] Tooth Sampled: L = left, R = right, I = incisor, C = canine, P = premolar, M = molar, i = deciduous incisor, c = deciduous canine, m = deciduous molar, ^{1} = maxillary first, ^{2} = maxillary second, ^{3} = maxillary third, $_1$ = mandibular first, $_2$ = mandibular second, $_3$ = mandibular third; if no super/sub-script is indicated, then we were unable to determine if the tooth was maxillary or mandibular.

[e] According to Hillson, 2002.

[f] While these two teeth are from the same tomb shaft, they were sampled from two different maxillae, thus assuring that they reflect two separate individuals.

degree of $^{87}Sr/^{86}Sr$ variability in the cattle samples, we have chosen to exclude these cattle data from the local faunal ranges originally reported by Buzon and Simonetti (2013). The local $^{87}Sr/^{86}Sr$ ranges based on faunal data (excluding cattle) are as follows: Askut = 0.70679–0.70769, C-Group = 0.70667–0.71086, Amara West = 0.70699–0.70802, Tombos (modern) = 0.70724–0.70773, and NDRS P37 = 0.70678–0.70755.

Human samples from Abu Fatima indicate the presence of both locals and migrants at this Kerma-period cemetery. Of the 29 individuals tested, seven had $^{86}Sr/^{87}Sr$ values that suggest they were of non-local origin. As discussed above, Abu Fatima was in a peri-urban space, ~10 km from the capital city Kerma, and thus, may have attracted migrants throughout the state-formation process. As with modern migrants, people may have come to Abu Fatima in search of job opportunities, trade, marriage, and the potential for higher socioeconomic status (DuToit and Safa, 1975). Buzon and colleagues have suggested that values that are higher than the Tombos local range (> 0.70783) might indicate an individual who originated north of Tombos (Buzon and Simonetti, 2013; Buzon et al., 2016); conversely, $^{86}Sr/^{87}Sr$ values that are lower than the Tombos local range (< 0.70710) may suggest an individual who was originally from a region south of Tombos. If this holds, all of the non-local individuals from Abu Fatima originated from an area north of the Third Cataract. It is possible that some of the individuals originated from northern cities or rural communities. Sai Island was a Kerma community, concurrent with Kerma and Abu Fatima (Fig. 1). It is thought that it served as a satellite city to the capital city, Kerma, as the Kerma state expanded (Edwards, 2004). Sai Island is ~20 km south of Amara West, the latter of which Buzon and Simonetti (2013) present a $^{87}Sr/^{86}Sr$ range for (0.70699–0.70802). Assuming the geology is similar between Sai and Amara West, it is possible that one of the seven non-local individuals from Abu-Fatima originated from this area (Burial 5A1). Amara West does have a Kerma component, however, the population would have been much smaller than at Sai (Vila, 1977).

Six of the other individuals with non-local $^{87}Sr/^{86}Sr$ ratios, may have originated from farther north (Burials 2A1, 4D1, 7C1, 8A2, 9A1). Buzon and Simonetti report the following $^{87}Sr/^{86}Sr$ local ranges for two Second Cataract Populations: C-Group ($^{87}Sr/^{86}Sr$ = 0.70667–0.71086) and Askut ($^{87}Sr/^{86}Sr$ 0.70679–0.70769). Sandberg and colleagues also have assessed $^{87}Sr/^{86}Sr$ at Kulubnarti, which is in between Amara West and the Second Cataract ($^{87}Sr/^{86}Sr$ 0.70760 ± 0.0029 and 0.70756 ± 0.00023; Fig. 1; Sandberg et al., 2008). There remains one individual from Abu Fatima whose $^{87}Sr/^{86}Sr$ value (Burial 2C1, 0.71473) is somewhat of an outlier. Stern et al. (1994) have published $^{87}Sr/^{86}Sr$ values (0.71338 ± 0.00373) from Batn el Hajar, a particularly rocky region at the Second Cataract (Fig. 1). The outlier from Abu Fatima does match the gneiss analyzed by Stern et al. (1994) and might suggest individual 2C1 was from the Batn el Hajar and migrated to the Third Cataract region at some point during his life. However, the publications that present local ranges for the Second Cataract region indicate a markedly wide local Sr range (0.70470–0.71711). These data suggest that the Second Cataract is particularly geologically complex and needs further investigation before individuals are identified as having originated from this region (see also European Union Commission, European Soil Data Centre, Geological Map of the Sudan, 1981). For now, we can only hypothesize that the Second Cataract region could be a place of origin of some samples examined here. As discussed below, there remains a gap in our Sr knowledge of Egypt; individuals with non-local Sr values from Abu Fatima may have originated from Egypt, however without local Egyptian Sr ranges, we cannot assume that this is the case. Other comparative publications do not provide any viable alternatives for a region of origin for this individual (Janzen, 2015; Masoner et al., 2011; Sandberg et al., 2008; Stojanowski and Knudson, 2011; Stojanowski and Knudson, 2014; Tafuri et al., 2006).

When we compare the results of $^{87}Sr/^{86}Sr$ from Abu Fatima to Kerma, the capital city of the ancient Kerma State, there does appear to be a difference in proportion of non-local to local inhabitants. Of the 15 human samples from Kerma, originally tested by Buzon and Simonetti (2013), two have $^{87}Sr/^{86}Sr$ values that are non-local to the Third-Cataract region (13%). Both of these individual $^{87}Sr/^{86}Sr$ values fall within the faunal range of the C-Group sample (0.70667–0.71086; also presented by Buzon and Simonetti, 2013). While further testing is necessary, this initial examination may indicate a higher proportion of immigrants in the peri-urban space of Abu Fatima (24%) *versus* the urban capital city Kerma (13%). According to original excavations, the individuals buried at the Kerma necropolis likely represent the rulers, the bureaucrats, and the laborers of Kerma (Reisner, 1923). However, the burial traditions varied markedly depending on socioeconomic status, with the largest and most lavish tombs being reserved for the elite and the smaller, subsidiary tombs designed for those of lower socioeconomic status. Additionally, Reisner, who excavated the Kerma necropolis between 1913 and 1916, suggested that the individuals buried in the central corridors of the largest graves were human sacrifices and likely reflect laborers and servants of Kerma royalty (see Schrader, 2015 for further discussion). The two Kerma samples reported by Buzon and Simonetti (2013) include a human sacrificial burial and a small subsidiary tomb, suggesting that these two non-local individuals were not of elite status. Locality may have been preferred, if not required, for elevated socioeconomic status and positions of power in Ancient Kerma. Migrants may have been limited to occupations associated with lower socioeconomic status and more likely to inhabit peri-urban communities, such as Abu Fatima. Additional data from Kerma and other peri-urban spaces similar to Abu Fatima, as well as a chronological assessment of migration, are necessary to fully support this argument, however.

One of the four individuals from Hannek was non-local (Burial 1.3). With a $^{87}Sr/^{86}Sr$ value of 0.70966, this individual may have originated from the Second Cataract region. This value falls within the variation presented for the C-Group sample published by Buzon and Simonetti (2013). It is also possible that this individual originated from Egypt, as might be expected given the documented colonial context of the New Kingdom. However, local $^{87}Sr/^{86}Sr$ ranges, based on faunal material, in Egypt are lacking. Additional research of Egyptian material needs to be done before this hypothesis can be substantiated. Hannek, located across the river from Tombos, is thought to be a relatively small settlement. Tombos would have served as an administrator center with Egyptians and Nubians living side by side. It is thus not surprising—in fact it is expected—that we find non-local individuals at Tombos. However, as described above, the people of Hannek were more likely working agropastoralists. These findings suggest that not only were people migrating from the Second Cataract to the Third Cataract during the Second Millennium BCE, but that this movement was accessible to people of various socioeconomic groups.

At Tombos four of the 30 individuals tested have $^{87}Sr/^{86}Sr$ values that are non-local (13%). Three individuals (18-T2-B6, 36-S2-L13-B6, 36-S5-B1) have $^{87}Sr/^{86}Sr$ values that suggest they may have originated from the C-Group Region (Buzon and Simonetti, 2013). Strontium data from burial 36-S5-B1 ($^{87}Sr/^{86}Sr$ = 0.70696) corresponds to Second Cataract sites, including Askut and the C-Group, as well as the Fourth Cataract site of Ginefab (Fig. 1; faunal Sr at Ginefab: 0.70688 ± 0.00036; Masoner et al., 2011). It is equally possible that these individuals originated from Egypt, as has been previously posited by Buzon and colleagues (Buzon et al., 2007; Buzon and Simonetti, 2013; Buzon et al., 2016). However, as discussed above, further research into the local $^{87}Sr/^{86}Sr$ ranges for Egypt needs to be undertaken. The data presented here do concur with Buzon's hypothesis that there was a strong foreign component to this New Kingdom administrative town. When these new Tombos data are compared with previously published data (Buzon and Simonetti, 2013), there is no significant difference between the samples (entire sample: $U = 614.500$, $p = 0.087$; local sample, excluding non-local individuals: $U = 426.500$,

p = 0.5677). This provides additional support for the argument that the Tombos population consisted of both locals and migrants during the New Kingdom.

Woodward et al. (2015) recently published data on the long-term shifts in sediment sources of the Nile. They argue that global climate changes throughout the Holocene have impacted Nile Valley drainage and strontium variation and, thus, critique bioarchaeological approaches that assess mobility *via* strontium. Woodward and colleagues posit that aeolian wind-borne dust may have been consumed, thereby enriching strontium in Egyptians and Nubians. Furthermore, Woodward et al. suggest that the extensive dental wear present in Nile Valley populations, citing Buzon and Bombak (2010), is further evidence of the consumption of windborne dust. We disagree with the aeolian dust line of reasoning for several reasons. First, if we assume that the dust was ingested, as one might suspect from Woodward et al.'s dental wear argument, there are several issues that arise. From a geological perspective, aeolian dust is composed of sand (quartz) and clay (silicate)—quartz does not contain strontium and the strontium composition of clay has yet to be determined. To our knowledge, no studies have tested how, if ingested, clay will be metabolized and incorporated into tooth enamel. Furthermore, toothwear, otherwise known as attrition, could equally be the product of grit from using grinding stones; "if we assume a staple Egyptian diet of wheat and barley, usually consumed in the form of bread and beer (Samuel, 1993), and that much of the grain processing was undertaken using stone quern and mortar implements (Ruffer, 1920; Samuel, 1993) … this could have led to contamination of grain with grit, thus accelerating dental attrition" (Zakrzewski et al., 2016:176–177). The grinding vessels used were made of quartz and, as stated above, because quartz does not contain strontium, would not have impacted an individual's strontium ratio.

Alternatively, if Woodward et al. are suggesting that enriched strontium was gradually incorporated into plant resources, which then transfer bioavailable strontium to the consumer, again, we find the argument lacking. First, it takes tens-of-thousands of years for trees and plants to acquire the Sr isotope signature of aeolian dust (Coble et al., 2015). Second, the Sr imprint of aeolian dust becomes a significant factor only when carbonate sources are being weathered (Van der Hoven and Quade, 2002). If, for example, silicate is being weathered by wind and creating dust, the calcium and strontium component is minimal (Van der Hoven and Quade, 2002). Thus, if the aeolian dust within the Nile Valley consists predominantly of weathered silicate material, then the amount of bioavailable Sr for humans and plants is limited. Even if there was a climatic shift to more arid conditions over the past ~1500 years, the change in bioavailable Ca (and Sr) for humans and plants, if available, would not be instantaneous. Moreover, as discussed in Van der Hoven and Quade (2002), the resultant Sr isotope composition of bioavailable Sr in the Nile Valley will come down to a mixing of two components and mass balance calculation, it would not consist of one source (aeolian) completely swamping the pedogenic Sr that is from local sources.

The primary thrust of Woodward et al.'s thesis concerns long-term climate change in the Nile Valley and how this may result in changing strontium values through time. Even if this were the case, the vast majority of Buzon and colleagues' data originates from archaeological specimens (the exception is New Kingdom Tombos, where no archaeological fauna were found; however, this is slowly being rectified, as illustrated by this paper, as new archaeological finds allow for additional strontium sampling of ancient faunal specimens). Thus, if the archaeological human material is being compared to contemporary archaeological faunal material—both animals and humans having been exposed to similar environmental conditions—the critique that strontium values have changed through time would not apply to specimens from the same period. It would, however, apply to diachronic comparisons. The data presented here, comparing Kerma-period Abu Fatima to New Kingdom Hannek and Tombos, does not suggest chronological strontium variability at the Third Cataract. While additional faunal samples from Abu Fatima are needed to further establish a local range, we can tentatively say that the Abu Fatima and Tombos signals overlap. Lastly, if Woodward et al.'s model, centered upon increasing contribution of aeolian sediments with time were correct, we would expect to find higher Sr ratios in more recent skeletal material. Rather, Buzon et al. (2016) found quite the opposite; skeletal material dating to the New Kingdom Period (1500–1070 BCE), including the multiple hypothesized migrants, was much higher (n = 55, range = 0.70712–0.70935, $\bar{x}$ = 0.70780 ± 0.0005 1σ) than the latter Napatan Period (1400–650 BCE; n = 30, range = 0.70661–0.70789, $\bar{x}$ = 0.70749 ± 0.0003 1σ).

While we do not agree with Woodward et al.'s interpretation, we do contend that additional strontium studies, both geological as well as bioarchaeological, need to be conducted in the Nile Valley. There are gaps in our knowledge of the strontium landscape, most notably Egypt. While Buzon and Simonetti (2013) were able to test human samples from Egypt, but given the likelihood of human migration, faunal samples with small home ranges are needed to establish strontium ratios that are representative of the local geology. Furthermore, Sr human and faunal samples are needed from farther south. With the exception of the Ginefab publication (Masoner et al., 2011), there is a dearth of data from the Fourth Cataract and beyond. We also know that trade networks through the desert as well as the Horn of Africa were active areas of human migration, but as of yet, are not incorporated into our interpretations (Phillips, 1997; Edwards, 2004). Lastly, the strontium complexity of the Second Cataract should be further investigated with additional faunal and soil samples from multiple sites.

6. Conclusion

Faunal data from Abu Fatima and Tombos fall within the previously established local range put forward by Buzon and Simonetti (2013). The majority of human individuals from Abu Fatima, Hannek, and Tombos have $^{87}Sr/^{86}Sr$ values that are congruent with previously published Sr data from the Third Cataract region. There were several individuals from all three sites that fell outside of this local $^{87}Sr/^{86}Sr$ range and, therefore, may have been of non-local origin. This suggests that complex migration networks may have existed during the Nile Valley Bronze Age, with people traveling from Egypt and Second Cataract to the Third Cataract and possibly *vice versa*. These new data from Tombos support previous publications, which conclude there was a mixture of migrants and locals cohabiting this colonial space. Despite the Hannek sample being small, one non-local individual was also detected. This is interesting because it suggests migration during the New Kingdom was not necessarily limited to the elite administrators, but was something people of lower socioeconomic status could do as well. Looking forward, additional $^{87}Sr/^{86}Sr$ testing of archaeological specimens, both faunal and human, in Nubia and Egypt is necessary to gain a better understanding of mobility in the ancient past. The Second Cataract region, in particular, appears to be markedly geologically complex and needs further investigation. While much more research needs to be done, we have presented more data that supports strontium analysis in Nile Valley archaeological contexts.

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