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

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ABSTRACT As a successful technique for identifying residential mobility in other areas, this study investigates the feasibility of using ^{87}Sr/^{86}Sr analysis to track the movements of the ancient peoples of Egypt and Nubia in the Nile Valley, who interacted via trade, warfare, and political occupations over millennia. Dental enamel from faunal remains is used to examine variability in strontium sources in seven regional sites; human enamel samples are analyzed from eight Nile Valley sites in order to trace human movements. The faunal samples show a wide range of ^{87}Sr/^{86}Sr values demonstrating that some animals were raised in a variety of locales. The results of the human samples reveal overlap in ^{87}Sr/^{86}Sr values between Egyptian and Nubian sites; however, Egyptian ^{87}Sr/^{86}Sr values (mean/median [0.70777], sd [0.00027]) are statistically higher than the Nubian ^{87}Sr/^{86}Sr values (mean [0.70762], median [0.70757], sd [0.00036], suggesting that it is possible to identify if immigrant Egyptians were present at Nubian sites. Samples examined from the site of Tombos provide important information regarding the sociopolitical activities during the New Kingdom and Napatan periods. Based on a newly established local ^{87}Sr/^{86}Sr range, human values, and bioarchaeological evidence, this study confirms the preliminary idea that immigrants, likely from Egypt, were present during the Egyptian New Kingdom occupation of Nubia. In the subsequent Napatan period when Nubia ruled Egypt as the 25th Dynasty, ^{87}Sr/^{86}Sr values are statistically different from the New Kingdom component and indicate that only locals were present at Tombos during this developmental time. Am J Phys Anthropol 151:1–9, 2013.

The development and activities of ancient polities are the subjects of much anthropological inquiry. Exploring population dynamics during significant sociopolitical changes allows for a more thorough understanding of those involved in the power relationships of these ancient interactions. In areas where the geological variability is sufficient, strontium isotope (^{87}Sr/^{86}Sr) analysis has proven to be a successful technique to address questions of archaeological significance regarding the interactions of societies such as Roman period mobility in Britain and Europe (e.g., Schweissing and Grupe, 2003; Evans et al., 2006; Chenery et al., 2010) and the movements of the Wari, Inca, and Tiwanaku in South America (e.g., Knudson, 2008; Andrushko et al., 2009; Slovak et al., 2009; Turner et al., 2009; Buzon et al., 2012), in addition to numerous other past cultures.

In the Nile Valley region of northeast Africa, the identification of immigrant individuals can be used to address questions regarding the interactions of the ancient Egyptian empire and Nubian state over the millennia. In this article, we present new faunal enamel sample ^{87}Sr/^{86}Sr data from various sites in the Nile Valley to explore the variability in strontium sources across the landscape. New human enamel sample ^{87}Sr/^{86}Sr data from Nubian and Egyptian sites are presented and assessed in terms of the usefulness of the technique for identifying immigrants in the region. Additionally, using samples from the site of Tombos, we explore the role of immigrants in Egyptian New Kingdom imperial activities in Nubia and the later development of the Nubian Napatan state that ruled Egypt as the 25th Dynasty.

Ancient Nubia during the New Kingdom, Third Intermediate, and Napatan Periods

From about 3000 BC, the Egyptian polity interacted heavily with the cultures of Nubia (O'Connor, 1993; Smith, 1998; Edwards, 2004), often with the goal of obtaining many important resources that it desired. Just before the beginning of the New Kingdom Period

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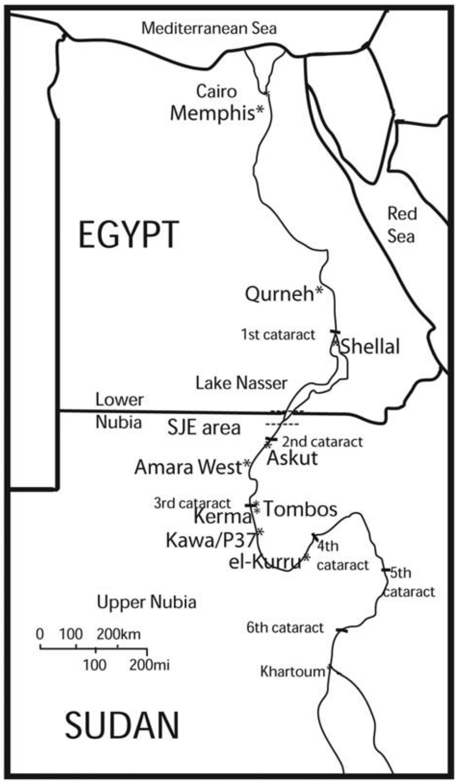

Fig. 1. Map of samples examined in this study.

(Pharaoh Kamose, c 1570 BC), Egypt began its capture of Upper Nubia (Fig. 1). The Nubian polity at Kerma (in third Cataract area) resisted aggression but eventually fell within 50 years of the initial attack and the Egyptian frontier was extended to the fourth Cataract by 1460 BC. Egyptian temple towns were built in Upper Nubia, which served as centers of government, redistribution, and presumably the propagation of Egyptian ideology (Kemp, 1978; Török, 1995; Smith, 2003). The New Kingdom ended with the decline of Egyptian power, although there is little information about the nature of the withdrawal from Nubia. It is unclear whether Egyptian colonists stayed in Nubia, though by ~1100 BC nearly all traces of the Egyptian domination are gone (O'Connor, 1993; Edwards, 2004).

By 850 BC strong rulers emerged at Napata in the fourth Cataract region (Fig. 1). Within a hundred years, the Napatans conquered Egypt, becoming the 25th Dynasty of Egypt and active participants in Near Eastern politics (Morkot, 1995). The Napatans legitimized their taking of the Egyptian throne by portraying themselves as "saviors" of the Egyptian civilization. As pharaohs, these rulers showed strong, though not wholesale, cultural emulation of Egyptian kingship dogma (O'Connor, 1993; Morkot, 1995). The rulers represented themselves with Nubian features, including some native costume and jewelry along with the Egyptian traditions. Nubian-style burials and rituals continued to be used, as did native domestic architecture and crafts (Dunham, 1950; Smith, 1998). The first burials of the indigenous ruling family appear at the site of el-Kurru, located about 20km downstream of the town of Napata. Although originally thought to be foreigners (Reisner, 1920), it is now clear these burials are native Nubians, possibly the direct ancestors of the Kerma royal line, though there is little direct evidence linking the Kurru and Kerma graves (Shinnie, 1996). Except for the royal burials, the archaeological record between the end of the New Kingdom and the rise of the Napatan rulers is scant (Edwards, 2004).

The dearth of archaeological evidence leaves unanswered questions: Who participated in the establishment of the Napatan state? Were local social processes or influences via outside migration responsible for these political changes? The Nubian elite may have survived the collapse of the Egyptian colonial system and maintained some authority with the Napatan state emerging in this local context aided by the survival of the colonial infrastructure. Alternatively, an influx of people from the south may have led to a Nubian revival that completely replaced the old Egyptian colonial system, or an influx of Egyptians from the north may have led a new wave of Egyptianization and alliances with emerging leaders that helped forge a new Egyptianized state (Kendall, 1999). By examining remains dating to these periods, the goal of this project is to explore the population composition via strontium isotope analysis to provide data to assist in answering these questions. With its rare evidence for continuity from the Egyptian New Kingdom Empire to the Napatan dynasty, the cemetery at Tombos represents one of the few sites in Nubia that can provide direct evidence to test these hypotheses.

Tombos

The site of Tombos is located in what was ancient Nubia in modern-day Sudan on the east bank of the Nile River at the third Cataract (Fig. 1). Excavations have documented an Egyptian colonial cemetery dating to the New Kingdom (~1050–1400 BC). The excavated skeletal remains primarily come from a middle-class cemetery consisting of several Egyptian-style mud brick chamber and shaft tombs with multiple interments. Additionally, several pyramids were uncovered, including one that belonged to a third level Egyptian administrator, Overseer of Foreign Lands, and his family (Smith, 2003). Bioarchaeological analyses suggest that these middle-class individuals showed biological affinities with both Egyptians and Nubians and were geographically local and non-local based on preliminary strontium isotope data (Buzon, 2006a; Buzon et al., 2007). In addition, paleopathological evidence implies peace and cooperation between Egyptians and Nubians buried at the site as well as signs of ill health associated with environmental stressors (Buzon, 2006b; Buzon and Richman, 2007).

While originally identified as a New Kingdom colonial site, the site of Tombos also contains features from the subsequent Third Intermediate Period and Napatan times (1070–747 BC; this component is referred to as 'Napatan' thus forward for brevity). The structure of the cemetery changed from its use in the New Kingdom. The area of middle-class mud brick structures was abandoned and a new cluster of Nubian-style tumuli were added. Concomitantly, the building of pyramids continued and older tombs within the cemetery were reused. Burial practice during these times included multiple interments in underground chambers and single inhumations in simpler pit and vaulted chamber tombs (Smith and Buzon, in press). Located in an important boundary area between colonial Egypt and developing Nubian polities, Tombos is one of the few sites that spans the transition between the New Kingdom Egyptian colonialism in Nubia and the critical Third Intermediate Period formation of the Nubian Napatan state, providing an opportunity to examine population composition and identity during this critical period of development.

Strontium isotope analysis and variability in the Nile Valley

Principles of strontium isotope analysis. The goal of $^{87}Sr/^{86}Sr$ analysis of skeletal and dental remains from archaeological sites is the identification of first generation immigrants in the burial sample. The resulting data can be used to address a variety of anthropological questions about the movements of individuals living in the past. This method is based on the idea the strontium present in food and water ingested by people reflects the geological age and bedrock composition of the region from which they originate. Strontium found in these sources is composed of four isotopes: ^{84}Sr, ^{86}Sr, ^{87}Sr, ^{88}Sr; only ^{87}Sr is a radiogenic isotope produced by the decay of ^{87}Rb; $^{87}Sr/^{86}Sr$ reflect the $^{87}Rb/^{87}Sr$ ratios and age of the parent rocks. Geological bedrock consisting predominately of old (>1 billion years old) granites are characterized by high $^{87}Sr/^{86}Sr$ ratios (>0.7200) while young rocks with low Rb/Sr, such as basalt, yield lower $^{87}Sr/^{86}Sr$ values (<0.7050; Faure, 1986).

When ingested, no isotopic fractionation through biological processes occurs, because the relative mass difference between strontium isotopes is small (Faure and Powell, 1972). In the hydroxyapatite of teeth and bone, strontium substitutes for calcium. Mature dental enamel is substantially denser and less porous than other skeletal tissues; thus, it is considered to be stable and more resistant to structural and chemical change (Horn et al., 1994; Montgomery, 2010). Strontium isotope ratios measured in dental enamel reflect various periods of life dependent on the tooth type sampled, ranging from the time in utero to approximately sixteen years of age (Hillson, 1996). Although previously thought to represent a discrete time-slice during mineralization of the enamel, the strontium incorporated is more likely an average of several months or years of strontium ingestion due to the long residence time in the body (Montgomery, 2010).

Geology and strontium isotope variability of the Nile Valley

One of the goals of this project is to explore the strontium isotope variability of the Nile Valley and to assess its usefulness as a method for investigating the movement of individuals in the region. In order for this technique to be successful, people must have been ingesting local strontium through locally raised foods and there must be a measureable difference in the strontium isotope values between the region of a person's origin and the place to which he/she migrated. Although some areas of the Nile Valley region are geologically similar, there are factors that create a more complex geological picture. The Nile River is obstructed by cataracts, outcrops of granite (Whiteman, 1971). In Egypt, the Nile Valley is primarily dominated by three distinct sedimentary rock formations: Dahkla chalk, Esna shale and Theban limestone, deposited between 35 and 65 Ma (Said, 1962). The limestone that dominates in the area of Thebes, Egypt should have an $^{87}Sr/^{86}Sr$ value similar to what has been measured in present-day marine carbonates with an average value of $^{87}Sr/^{86}Sr = 0.70907$ (Burke et al., 1982). In Nubia, the Nile Valley region consists of a largely pre-Cambrian Basement Complex characterized by a variety of igneous, metamorphic and sedimentary rocks overlain with the Nubian Sandstone Complex; the latter consist of a variety of conglomerates, grits, sandstones and mudstones. The major cataracts are the boundaries between the Nubian sandstone and basement complex (Whiteman, 1971; Edwards, 1989).

The source of the water that flows in the Nile north from Khartoum, Sudan is primarily derived (95%) from the Blue Nile originating in the Ethiopian Highlands. Modern sediments from three areas in Sudan at the Blue Nile, the Atbara confluence, and Wadi Halfa all yield $^{87}Sr/^{86}Sr$ ratios of ~0.706 (Gerstenberger et al., 1999). Krom and colleagues (2002) measured $^{87}Sr/^{86}Sr$ ratios in Nile Delta river sediment dating to 950–2200 BP to be ~0.7075, which may indicate a larger contribution of water from the While Nile during earlier times in comparison to the modern values.

Previous work at Tombos established a local $^{87}Sr/^{86}Sr$ range of 0.70732–0.70789 based on one archaeological faunal sample, one modern faunal sample, and four burial matrix samples (Buzon et al. 2007). Forty-nine human dental enamel samples from the New Kingdom component at Tombos were analyzed, and the $^{87}Sr/^{86}Sr$ values ranged from 0.70712 to 0.70911. The $^{87}Sr/^{86}Sr$ values for 18 of the 49 individuals were higher than the established local range (Buzon et al., 2007). The preliminary analysis of strontium isotope ratios from the Ginefab School site located in the Fourth Cataract region of Nubia by Masoner and colleagues (2011) yielded an average human value of $^{87}Sr/^{86}Sr = 0.70708$ and a local range of 0.70650–0.70740 based on faunal samples. Sandberg and colleagues (2008) analyzed human samples from the Medieval site of Kulubnarti located south of Wadi Halfa in the Batn el Hajar region and found the mean human value to be $^{87}Sr/^{86}Sr = 0.70758$, with values ranging ~0.70710–0.70850. An analysis of oxygen isotope compositions ($\delta^{18}O$) from Tombos human samples as well as published data from regional sites calls into question the usefulness of oxygen isotope analysis to identify immigrants in the Nile Valley due to the effects of environmental and cultural factors (Buzon and Bowen, 2010).

MATERIALS AND METHODS

Faunal samples

It has been suggested that, when possible, it is best to use archaeological samples from tooth enamel of small animals with limited home ranges in order to establish the local strontium isotope signature for a particular locale (Price et al., 2002). When such samples are not available, modern species can be substituted (Price et al., 2002). This study uses both archaeological and modern faunal samples as a means of establishing local signatures of various sites (Fig. 1) as well as a way to explore the strontium variability in possible food sources. Due to the lack of archaeological faunal remains at Tombos, modern rodent (*Rattus*/*Mus*) samples were collected from the modern Tombos town ($N = 10$) and used to establish the local range. In addition, faunal remains from various sites in the Nile Valley were analyzed to explore the variability in the region (Fig. 1). Archaeological faunal remains from the Amara West New Kingdom town site ($N = 10$) included sheep/goat (*Ovis*/*Capra*, difficult to distinguish from each other in archaeological remains), pig (*Sus*) and dog (*Canis*). Archaeological faunal remains from Askut ($N = 14$), a Middle Kingdom Egyptian fortress at the border of Nubia, which are housed at the Fowler Museum at the University of California, Los Angeles, included rodent (*Rattus/Mus*), sheep/goat (*Ovis/Capra*), and cattle (*Bos*). Cattle (*Bos*) samples from royal Napatan el-Kurru site ($N = 3$) located near the fourth Cataract housed at the Boston Museum of Fine Arts and Napatan Kawa ($N = 11$) located south of the third Cataract, which are housed at The British Museum were also included. Additionally, the analysis of faunal materials included sheep/goat (*Ovis/Capra*) samples from the Kerma period (Middle Kingdom) Northern Dongola Reach (NDR) Survey site P37 ($N = 3$) located south of the third Cataract housed at The British Museum and Scandinavian Joint Expedition (SJE) C-Group sites ($N = 10$) housed at the University of Copenhagen Zoological Museum.

Human samples

Human samples were analyzed from two Egyptian and five Nubian collections in order to investigate the variability in strontium isotope values in the Nile Valley region (Fig. 1). The number of samples taken was limited by collection size and cost of analyses. Individuals were selected for sampling based on preserved dental enamel and availability of contextual information. All samples collected were analyzed. Egyptian samples include material from Qurneh ($N = 15$), located near the Egyptian capital of Thebes in Middle Egypt, and Memphis ($N = 15$), located close to Cairo. Both samples date to the New Kingdom period and are curated in the Duckworth Collection at the University of Cambridge. Nubian materials include New Kingdom Shellal Cemetery 7 ($N = 15$, Egyptian-style burials), located near the second Cataract, Second Intermediate Period Kerma ($N = 15$, ca. 1680–1550 BC), the type-site for the Kerman culture located just south of Tombos at the third Cataract (both curated in the Duckworth Collection), human remains excavated by the Scandinavian Joint Expedition to Sudanese Nubia from New Kingdom C-Group ($N = 15$, 2000–1600 BC) and Pharaonic ($N = 15$, Egyptian-style burials, 1650–1350 BC) sites (excavated in the area stretching from the modern Egyptian border to ~60 km south) curated at the University of Copenhagen Panum Institute (Vagn Nielsen, 1970), and samples from Amara West ($N = 24$) located north of the third Cataract dating from the New Kingdom through Napatan periods excavated by The British Museum team led by Dr. Neal Spencer.

The human skeletal remains from Tombos (Fig. 1) examined in this study were excavated between 2000 and 2011 by researchers from the Universities of California-Santa Barbara and Purdue. The sample is derived from two components of the site: New Kingdom mud brick chamber and pyramid tombs and Napatan period tumulus and pyramid tombs. Dental enamel samples were analyzed from 53 New Kingdom individuals and 32 Napatan individuals, which comprised all available individuals with preserved dental enamel. The majority of the New Kingdom data was previously published by Buzon and colleagues (2007).

Laboratory methodology

Faunal and human tooth enamel samples were mechanically cleaned and abraded as well as chemically purified in order to reduce post-depositional contamination (Nielsen-Marsh and Hedges, 2000). Contamination was also assessed by measuring the concentration of uranium, which can reflect the update of groundwater (Hedges and Millard, 1995; Kohn et al., 1999) in a subset of the samples. U/Ca ratios were determined in order to examine the level of contamination (Price et al., 2002). Enamel samples were mechanically cleaned and cut at Purdue University and subsequently prepared at the University of Notre Dame Midwest Isotope and Trace Element Research Analytical Center (MITERAC) using published methodologies (Buzon et al., 2007). Radiogenic strontium isotope ratios were acquired using a NuPlasma MC-ICP-MS instrument at Nu Instruments (Wrexham, UK) and at the University of Notre Dame MITERAC facility. The NIST SRM 987 strontium isotope standard yielded an average value of 0.710238 ± 0.000007 (2σ standard error of the mean; $N = 13$ analyses). The latter is identical (given the associated uncertainty) to the accepted $^{87}Sr/^{86}Sr$ value of 0.710245 (Faure and Mensing, 2005) for this standard.

Statistical analysis of $^{87}Sr/^{86}Sr$ data

The mean $^{87}Sr/^{86}Sr$ values from both individual and grouped sites based on geography (Egypt versus Nubia) and cultural affiliation (Egyptian-style burials in Egypt and Nubian-style burials in Nubia) were initially evaluated using the *t*-test. However, because not all sample group data were normally distributed, the non-parametric Mann-Whitney test was also used for pairwise comparisons of median values. In order to avoid Type 1 errors (incorrect rejection of the true null hypothesis), the results of the statistical analyses are also interpreted using the Bonferroni adjustment procedure for the α level (new α level = desired α level/number of tests of significance). Finally, the multivariate non-parametric Kruskal-Wallis test was used to compare the median score across groups (Acock, 2008). Stata 12 was used for all statistical tests.

RESULTS

Of the 250 archaeological samples included in this study, 176 were assessed for diagenesis. The measured uranium concentrations suggest that the degree of contamination is very low in the samples examined in this study. Nearly half of the 176 archaeological human and faunal samples had uranium concentrations below the detection level of 0.003 ppm. The remaining samples yielded U/Ca values below levels considered contaminated (Price et al., 2002).

The $^{87}Sr/^{86}Sr$ data from the faunal samples is presented in Table 1 (Supporting Information Table S1) and Figure 2. With the exception of the modern rodent samples from Tombos, the faunal samples show a wide range of values. The $^{87}Sr/^{86}Sr$ data from the comparative Nile Valley human samples is presented in Table 2 (Supporting Information Table S2) and Figure 3 and show considerable overlap between the sites.

The results of the statistical tests are presented in Table 3. The Kruskal-Wallis test of all faunal samples revealed highly significant differences between the sites for $^{87}Sr/^{86}Sr$ values. The Kruskal-Wallis test of all human samples also indicated highly significant differences between the sites for $^{87}Sr/^{86}Sr$ values.

Pairwise comparisons were made using *t*-tests and Mann-Whitney tests. In terms of geography, the means/medians for Egyptian sites (Memphis, Qurneh: mean/

TABLE 1. Summary $^{87}Sr/^{86}Sr$ statistics for faunal samples

Site	Mean	Median	Standard deviation	Range
Askut	0.70900	0.70724	0.00153	0.70679–0.71248
C-Group	0.70790	0.70761	0.00114	0.70666–0.71086
Amara West	0.70723	0.70715	0.00030	0.70699–0.70802
Tombos (modern)	0.70746	0.70745	0.00018	0.70724–0.70773
NDR P37	0.70708	0.70692	0.00041	0.70678–0.70755
Kawa	0.70881	0.70910	0.00097	0.70740–0.71006
el-Kurru	0.70852	0.70869	0.00195	0.70649–0.71037

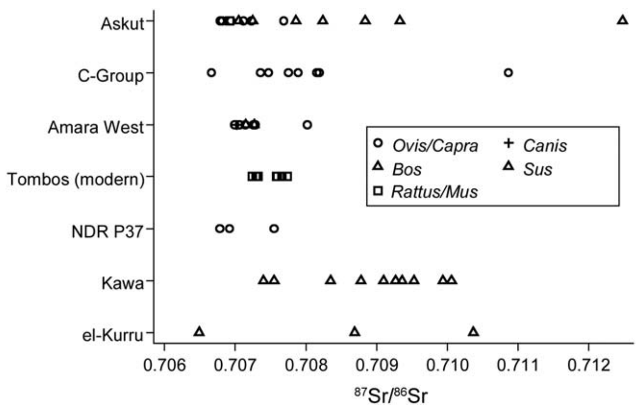

Fig. 2. Distribution of $^{87}Sr/^{86}Sr$ values from faunal samples. Sites are arranged from north to south (Askut to el-Kurru).

median [0.70777], sd [0.00027]) were significantly higher than for sites located in Nubia (Shellal, C-Group, Pharaonic, Amara West, Tombos, Kerma: mean [0.70762], median [0 .70757], sd [0.00036]). Sites grouped by cultural affiliation were also compared because some of the sites in Nubia had burial rituals that indicated the site may have had a population of mixed origin. With regard to cultural affiliation as represented by burial ritual, mean/median $^{87}Sr/^{86}Sr$ values sites with Egyptian-style burials in Egypt (Memphis, Qurneh: mean/median [0.70777], sd [0.00027]) were significantly higher than the Nubian $^{87}Sr/^{86}Sr$ values (C-Group, Kerma: mean [0.70753], median [0.70751], sd [.00028]). Within the site of Tombos (Table 2), the two components, New Kingdom and Napatan periods, are statistically different (Table 3). The Tombos Napatan sample is also significantly different from the Egypt group sample. All α levels for the Mann-Whitney pairwise comparisons continue to have $p<0.05$ when the Bonferroni adjustment is used.

DISCUSSION

Exploring the variability of strontium in food sources in the Nile Valley

Archaeological samples from various sites in Nubia were included in the study as a means of exploring the origin of strontium in possible food sources. Because the available faunal samples come from animals with large home ranges such as sheep/goat, pig, dog, and cattle, the distribution of $^{87}Sr/^{86}Sr$ values is expectedly wide. Generally, the results show that most of the faunal remains have wider distributions than the human samples and that cattle have the highest strontium isotope variability, indicating grazing in areas with variable geological composition (Table 1, Fig. 2).

What do the $^{87}Sr/^{86}Sr$ values of faunal remains indicate about the sources of strontium in the Nile Valley diet? Grains, leafy greens, and dairy products comprise the foods with strontium content in the Nile Valley. The Egyptians raised penned and grazed animals in addition to plant cultivation. The rich soil adjacent to the Nile was reserved for crops. The relative amounts of planting and herding depended on the subsistence risk based on the probability of receiving sufficient water. During years with sufficient moisture for cultivation, herded animals were likely driven far, perhaps hundreds of kilometers for pasture (Brewer et al., 1994). Cattle were the most important animal and used as a measure of wealth (Ikram, 1995). Meat and dairy products from cattle were eaten, but generally not by the majority of the population (Thompson et al., 2005). Sheep and goats were second in importance only to cattle. They provided meat and dairy to the general population. These smaller livestock could be grazed along the outskirts of the villages. Herds of cattle and sometimes sheep/goats were kept in the countryside, near oases, or in greener areas of the desert where pasturage could be found (Ikram, 1995, 2010). Egyptian tomb scenes also suggest that livestock were driven north to the Delta marshes for grazing and then returned south at a later date (Brewer et al., 1994). Attested in texts, Egypt also took cattle from Nubia – Pharaoh Snefru brought back more than 20,000 cattle from a raid in Nubia (Chaix and Grant, 1992).

Studies of faunal remains in Nubia suggest the importance of cattle and higher rate of consumption in comparison to Egypt. Sheep/goat and cattle were the most common domestic species at Kerma in Upper Nubia with both playing significant ritual roles in burials. Bucrania, the horns, frontal bones and sometimes nasal bones of cattle skulls, were found on the edges of burial pits at Kerma in very high numbers (129 animals surround Tomb 115; Chaix and Grant, 1992). These animals would have required such a large amount of land for grazing that it seems likely that not all were locally raised. The cattle may have been sent to Kerma from many places as tribute on the death of important leaders. These funeral rituals may have included feasting with the animals slaughtered and eaten in the town while the skulls were placed around the tomb. Sheep were important for both food and ritual at Kerma; however, in contrast to the bucrania placed around tombs, sheep found in burials were complete bodies (Chaix and Grant, 1992). The $\delta^{13}C$ and $\delta^{15}N$ analyses of sheep and cattle from Kerma also indicate that not all animals came from a local herd and span a large range, which may reflect access to different grazing resources within the area as well as more marginal grazing near the arid desert edge (Thompson et al., 2008). In Lower Nubia, C-Group sites also provide evidence for the importance of cattle as well as sheep/goat economically and ritually (Shinnie, 1996). While the

TABLE 2. Summary $^{87}Sr/^{86}Sr$ statistics for human samples

Site	Mean	Median	Standard deviation	Range
Memphis	0.70777	0.70764	0.00034	0.70735–0.70872
Qurneh	0.70777	0.70778	0.00017	0.70731–0.70798
Shellal	0.70765	0.70764	0.00031	0.70705–0.70811
C-Group	0.70758	0.70760	0.00026	0.70701–0.70807
Pharaonic	0.70746	0.70751	0.00027	0.70658–0.70769
Amara West	0.70763	0.70756	0.00018	0.70733–0.70817
Tombos Napatan	0.70747	0.70751	0.00026	0.70661–0.70789
Tombos New Kingdom	0.70779	0.70772	0.00047	0.70712–0.70912
Kerma	0.70748	0.70736	0.00029	0.70718–0.70812

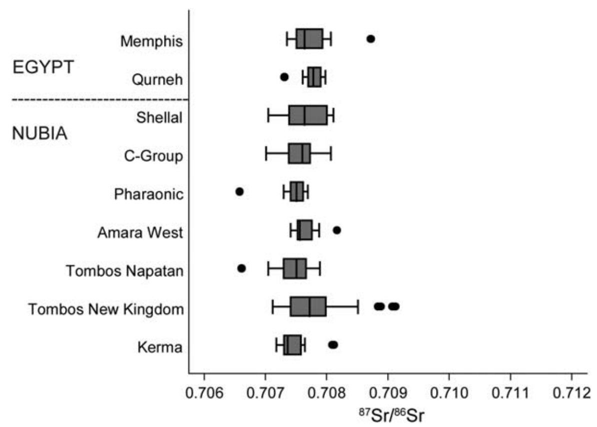

Fig. 3. Distribution of $^{87}Sr/^{86}Sr$ values of human samples. Sites are arranged from north to south (Memphis to Kerma).

land of Lower Nubia seems rather barren, a 1963 livestock census in the region demonstrated a relatively high carrying capacity (Connah, 2001). Cattle may have been obtained by Nile farmers from desert nomadic herders (Welsby, 1998).

However, when considering these possible food sources it is important to note that as calcium is biopurified through the foodweb levels, decreased concentrations of strontium are present from bedrock to soil to plants to herbivores to carnivores in the same environment because the amount of calcium absorbed is proportionally greater than the non-nutrient alkaline elements, such as strontium (Elias et al. 1982; Ezzo, 1994). Strontium uptake is lower in diets with high-calcium and/or protein-rich foods. Additionally, strontium is discriminated against in the mammary gland such that strontium levels are very low in dairy products (Ezzo, 1994; Burton and Wright, 1995). As a result, some dietary components (i.e., plants) contribute disproportionately more to the strontium levels than others (animal sources). For humans, the animal portion of the diet contributes little to skeletal strontium signatures while plants remain the dominant contributor (Burton and Price, 2000). Thus, while meat and dairy products, especially from cattle, may have come from areas with different geological compositions, the variable $^{87}Sr/^{86}Sr$ likely had only a negligible effect on human values (Montgomery, 2010). Additionally, the amount of cattle products in the diet was likely the highest for the elite (though proportionally higher for Nubia than Egypt) with the general populations subsisting on sheep/goat when meat was eaten and vegetable products that were very likely grown locally in Nile soils.

The distribution of human samples in the Nile Valley

The $^{87}Sr/^{86}Sr$ values in the human samples clearly overlap in all of the sites studied (Fig. 3). However, when examining the median $^{87}Sr/^{86}Sr$ values for all of the human samples, the Egyptian sites have higher $^{87}Sr/^{86}Sr$ values than the Nubian sites (Fig. 3, Table 2), many of which are statistically significantly different (Table 3). Additionally, median $^{87}Sr/^{86}Sr$ values appear to decrease from north to south in the Nile Valley for the sites studied (Fig. 3). There are two exceptions to this trend: Amara West and Tombos New Kingdom samples (Table 2). What is notable about these two sites is that they are both New Kingdom Egyptian towns with ample archaeological evidence of a strong Egyptian presence (Smith, 2003; Spencer, 2009), which may explain the higher $^{87}Sr/^{86}Sr$ values. While it is clear that $^{87}Sr/^{86}Sr$ values of Egyptians and Nubians overlap and concretely identifying Egyptians and Nubians in a sample is far from straightforward, the distributions and median values indicate that $^{87}Sr/^{86}Sr$ analyses can provide some information about possible immigrant individuals within the context of specific research questions.

Human residential mobility at Tombos

Using the accepted method of the mean of the faunal samples ± 2 standard deviations (Price et al., 2002), the Tombos local signature is $^{87}Sr/^{86}Sr = 0.70710–0.70783$. This range is very similar to the range established in the preliminary study at Tombos (Buzon et al., 2007). Eighteen individuals have $^{87}Sr/^{86}Sr$ values above this range; two individuals have values below this range.

The 18 individuals above the range (as identified in Buzon et al., 2007) all come from the New Kingdom component of the cemetery. As mentioned above, the higher $^{87}Sr/^{86}Sr$ values could indicate immigrants from Egypt and the New Kingdom component has strong indications of an Egyptian presence. Additionally, all of these individuals were buried using Egyptian rituals (such as coffins, specialized grave goods, pottery, and tomb structures, see Smith, 2003; Buzon, 2006a). Of the 35 remaining individuals from the New Kingdom component whose $^{87}Sr/^{86}Sr$ values are within the local range, four were buried in a Nubian-style (the only four individuals buried this way in the New Kingdom component of the site) and 31 were buried using Egyptian traditions. With this newly confirmed local range, these data lend support to the idea based on archaeological indications and cranial morphology that immigrant Egyptians lived and were buried at Tombos and that some local Nubians were buried using local traditions while others adopted Egyptianized rituals (Smith, 2003; Buzon, 2006a).

TABLE 3. $^{87}Sr/^{86}Sr$ statistical comparisons

Groups compared	Kruskal-Wallis	*t*-test	Mann-Whitney
All faunal sites	X^2w/ties=18.90, $P = 0.0042$		
All human sites	X^2w/ties=29.96, $P = 0.0002$		
Egypt-Nubia (geographic)		$t = -2.16$, $P = 0.0321$	$z = -3.14$, $P = 0.0017$
Egyptian-Nubian (cultural)		$t = -3.46$, $P = 0.0010$	$z = -3.30$, $P = 0.0010$
Tombos Napatan-New Kingdom		$t = -3.50$, $P = 0.0007$	$z = -3.10$, $P = 0.0019$
Tombos Napatan-Egypt		$t = -4.49$, $P = 0.0000$	$z = -4.08$, $P = 0.0000$

The two individuals with values below the local range are both from the Napatan component of Tombos. The remaining 30 individuals fall within the established local range. Identifying the portrayed ethnicity of these burials is more complex than with the New Kingdom burials. While half were recovered from Nubian-style tumulus graves and the other half were buried below Egyptian-style pyramid structures, detailed analysis of the burial practices during this time period reveals the emergence of a new and hybrid identity in burial ritual that incorporated both Egyptian and Nubian practices. The pyramid tombs appeared to commemorate the community's Egyptian ties with the use of mummification, specialized grave goods (such as a heart scarab), and jewelry within these communal, presumably family crypts (Smith and Buzon, in press). In contrast, the area of the cemetery devoted entirely to tumuli often had single or double burials, usually on beds, a remembrance of Nubian traditions. However, within these tumuli, the use of Egyptian-style coffins, mummification, burial position, and grave goods was evident. These combined practices suggest that the Napatan community at Tombos, likely descended from the New Kingdom population, embraced a strong sense of multivocality in their burial traditions (Smith and Buzon, in press).

With regard to the questions surrounding the rise to power for Nubians during Napatan times, these data suggest that individuals buried at Tombos primarily came from the local area. With the statistical difference the New Kingdom and Napatan samples (Table 3), this later Napatan component does not appear to include a large proportion of individuals with high $^{87}Sr/^{86}Sr$ values that could be attributed to an Egyptian site (Fig. 3). There are two individuals whose $^{87}Sr/^{86}Sr$ values are below the local Tombos range. Very few of the human samples used in the study have low values such as these at $^{87}Sr/^{86}Sr=0.70661$ and $^{87}Sr/^{86}Sr=0.70705$ (Fig. 3). The $^{87}Sr/^{86}Sr$ values of the faunal samples also tend to be more radiogenic (Fig. 2). These values are within the preliminary local range determined for the Ginefab School Site (Masoner et al., 2011), located in the fourth Cataract region near the main sites used by the Napatan state (Fig. 1, el-Kurru, Napata, Gebel Barkel).

The hypothesis that those involved in the rise and support of the Napatan state were local Nubians who may have used the earlier Egyptian colonial infrastructure to their advantage to organize, gain power, and establish dominance in Nubia and Egypt is supported by these data. Without additional isotopic data from further south in the region, the influence of southern foreign individuals is difficult to determine. However, given the range of values for the Napatan component at Tombos, it seems unlikely that Egyptian immigrants played a role during this time period. It should be noted, though, that Tombos is only one site that dates to this Napatan period. Additional excavations and human samples from this period in the Napata capital region would strengthen our understanding of human movements during this critical time of state development.

CONCLUSIONS

The $^{87}Sr/^{86}Sr$ data presented in this study indicate the utility of this technique for identifying the presence of immigrant Egyptians in Nubia. The faunal remains included in this study reveal that animals used for meat and dairy were likely pastured in locations with varying geological composition. The examination of samples from the site of Tombos suggest that while Egyptians were present during the New Kingdom occupation of Nubia at this site, there is no evidence that Egyptians continued to migrate to Nubia during the subsequent development of the Napatan state. The majority of individuals buried at Tombos during the Third Intermediate and Napatan periods fall within the local signature. Two individuals fall below the local range with values that could be representative of a southern Nubian locale. While the specific movement from one site to another within the Nile Valley cannot likely be determined using $^{87}Sr/^{86}Sr$ analysis, this study has demonstrated that technique is useful in addressing specific research questions, such as the contribution of immigrant Egyptians to the population composition of ancient Nubian sites.

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