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Migration in the Nile Valley during the New Kingdom period: a preliminary strontium isotope study

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Abstract

The value of strontium isotope analysis in identifying immigrants at numerous archaeological sites and regional areas has been demonstrated by several researchers, usually by comparing $^{87}Sr/^{86}Sr$ values of human tooth enamel and/or bone with the local strontium isotope signature determined by faunal and environmental samples. This paper examines the feasibility of using $^{87}Sr/^{86}Sr$ ratios to investigate residential mobility in the Nile Valley region, specifically at the New Kingdom period (~1050–1400 BC) archaeological site of Tombos (ancient Nubia). Archaeological and textual information regarding this period indicates that immigrant Egyptians and local native Nubians were likely interacting at this site during a period of Egyptian colonial occupation. The results of this study suggest that non-local individuals may be distinguished from locals using $^{87}Sr/^{86}Sr$ values and that colonial agents in the Tombos population were probably both local native Nubians and immigrants.

Keywords: Residential mobility; Nubia; Egypt; Tombos; Tooth enamel; MC-ICP-MS; Colonialism

1. Introduction

Researchers have established strontium isotope analysis as an exceptionally useful tool for examining human migration in the past. Archaeological questions regarding human residential mobility have been addressed in various areas of the world where strontium ratios are sufficiently varied to show differences between potential places of origin. Strontium isotope ratios have been used to identify immigrants in locations such as ancient Maya communities (Hodell et al., 2004; Wright, 2005a,b), the North American Southwest and Mexico (Ezzo et al., 1997; Ezzo and Price, 2002; Price et al., 1994, 2000, 2006), Central Europe (Bentley et al., 2003, 2004; Grupe et al., 1997; Price et al., 1998, 2001, 2004; Schweissing and Grupe, 2003), Bolivia and Peru (Knudson et al., 2004, 2005), South Africa (Cox and Sealy, 1997; Sillen et al., 1995, 1998), and Britain (Budd et al., 2004; Evans et al., 2006; Montgomery et al., 2000, 2003, 2005). The success of these studies in revealing local and immigrant individuals demonstrates the value of this technique and the potential for identifying residential mobility patterns in other areas that have been previously unexplored using strontium isotope analysis.

In this paper, we examine the feasibility of using strontium isotope analysis to identify first generation immigrants at the New Kingdom period Egyptian colonial site of Tombos, located in ancient Nubia (modern-day Sudan). We also investigate if the most likely place of origin for immigrants at Tombos, Thebes, Egypt (based on textual sources), is reflected in the $^{87}Sr/^{86}Sr$ ratio data and provide preliminary conclusions regarding evidence of residential mobility at this site.

2. Tombos and New Kingdom period residential mobility in the Nile Valley

Historically, the populations of Nubia and Egypt had a long, dynamic history of interaction, ranging from diplomatic

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coexistence to total invasion. The Egyptian New Kingdom colonial occupation of Nubia is a particularly momentous episode in this history. It is during this time that the foundations of the Nubian Napatan Kingdom, which later ruled Egypt as the 25th Dynasty, were first established. Scholars disagree about who controlled Nubia during this important time: Egyptian colonists or native leaders.

2.1. Military and colonial activities

Based on textual evidence, it appears that changes were made in New Kingdom Egyptian colonial policy subsequent to particularly violent military activities, which included the construction of fortresses in Nubia (Morkot, 2000). Researchers suggest that there was an increased use of diplomacy over war. Local Nubian polities linked to former chiefdoms may have wielded considerable autonomy, forming a 'decentralized state.' Egyptians may have simply eliminated the superstructure and replaced the dominant centre with their own colonial apparatus. It is suggested that Nubians were incorporated into the administration, rather than excluded as during previous eras (Adams, 1984; Kemp, 1978; Morkot, 1987, 1991, 2001; O'Connor, 1993; Smith, 2003; Torok, 1995).

The new strategies used by Egyptians during New Kingdom imperialism may have been advantageous to the local Nubians. In contrast to imposition of formal rule, Egypt's new, more indirect approach presumably garnered more support from the native Nubians. Part of this method may have included rewards and incentives for the elite (Smith, 1998). Due to this incorporation of Nubians into upper levels of Egyptian provincial government and society, the cultural differences between resident Egyptians in Nubia and native Nubians became increasingly blurred (Trigger et al., 1983). In fact, Nubian princes were likely responsible for the control of Nile trade. The New Kingdom in Nubia was probably peaceful and prosperous (Morkot, 2000).

2.2. Tombos

The human skeletal remains examined in this study come from the cemetery site of Tombos, which is located in northern Sudan at the Third Cataract of the Nile (Fig. 1). Tombos was part of Ancient Nubia, which encompassed modern-day northern Sudan and southern Egypt. Excavations conducted in 2000 and 2002 by the University of California, Santa Barbara team (led by director Stuart Tyson Smith) exposed the remains of an Egyptian style pyramid with intact burials in the surrounding alleyway. Pyramid style and the funerary cones found in the fill (cones of clay stamped on the flat end) are similar to those found at Thebes in Egypt. These funerary cones detail who was buried in the pyramid – a man named Siamun, the Overseer of Foreign Lands, a third level administrator, and his wife, Weren. Also found was a cemetery consisting of several Egyptian-style mudbrick chambers and shaft tombs (the burials used in this study come from this area). These burial areas date from the mid-18th Dynasty in the New Kingdom most likely until the 3rd Intermediate Period, ~1400–1050 BC (Smith, 2003).

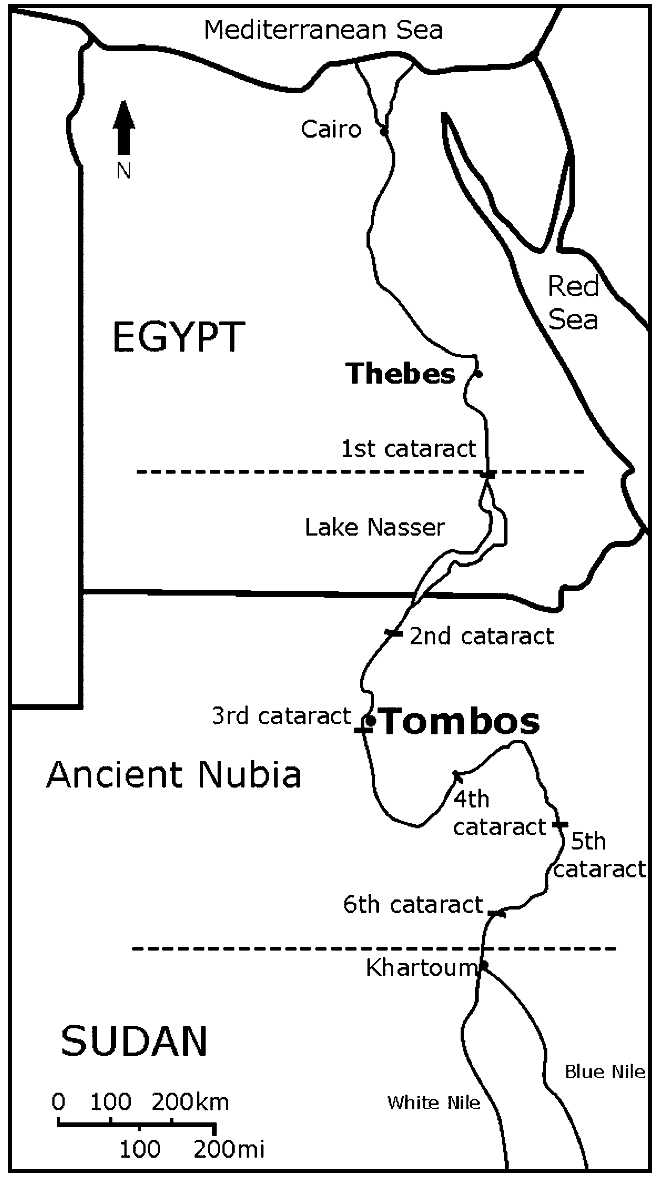

Fig. 1. Map of Tombos location and region. Dotted lines delimit the boundaries of Ancient Nubia.

2.3. Archaeological indications of ethnic identity

Despite speculation concerning how Nubia was governed, there is a nearly complete lack of archaeological evidence to support these claims about the relationship between Egypt and Nubia during this colonial period. One difficulty is the inability to differentiate Nubians and Egyptians in their burials due to the high degree of Egyptianization of Nubians during this time. Archaeologically, individuals from the two cultural groups are virtually indistinguishable. Documentary evidence indicates that foreigners who followed Egyptian standards were afforded more opportunities and, to a considerable extent, were accepted within society, while those who adhered to their foreign customs tended to belong to the lower levels of society (Ward, 1994). Thus, portraying oneself as an Egyptian may have had its advantages (Buzon, 2006).

Egyptian and Nubian burial styles during the New Kingdom period have been shown to be quite distinct (Edwards, 2004; Geus, 1991; Smith, 2003; Williams, 1991). Egyptian burials were generally placed in an extended position in coffins that were in either rectilinear tomb chambers or small pyramids. Conversely, Nubians tended to bury their dead in a flexed position, on a bed or cow's skin, and covered by a tumulus, or heap of earth. Archaeological evidence at Tombos suggests that people were portraying themselves as Egyptians in their burials. Artefacts recovered are mostly Egyptian in style, such as amulets of Egyptian gods, scarabs, and figurines. Burial position and the coffin use indicate a mostly Egyptian cultural group with only four individuals (all female) buried Nubian-style (3 of these 4 individuals are included in this study). All 4 of these Nubian-style burials were found in the earliest layers of the tomb chambers (Smith, 2003). However, the projected Egyptian ethnic identity portrayed by the majority of people buried at Tombos may reveal little about their origins due to Egyptianization of Nubians. It should be noted that looting caused disturbance in the tombs and not all individuals could be assessed for original burial position.

2.4. Cranial morphology and biological identity

Another means of assessing the composition of a population is to examine biological identity through the study of cranial morphology. Artistic representations by Egyptians of themselves and foreigners display distinct physical features of different types of people (Yurco, 1996). Buzon (2006) analyzed the cranial measurements of the people buried at Tombos as well as other Egyptian and Nubian populations for comparative purposes. Logistic regression equations based on principal components analysis of cranial measurements suggested that the group of individuals buried in Egypt using Egyptian burial styles had a more distinct comparatively homogenous cranial morphology than the group of individuals buried in Nubia using Nubian rituals. Using these logistic regression equations, approximately 60% of the Tombos population was categorized as having Egyptian cranial morphology. Although a mostly Egyptian ethnic identity is portrayed at Tombos, it is probable, based on these morphological data, that the population was composed of both Egyptians and Nubians (Buzon, 2006).

2.5. Potential use of strontium isotope analysis for identifying immigrants in New Kingdom Nubia

Because of unclear archaeological indications of ethnic identity and the complicated relationship between cranial morphology and cultural groups in the Nile Valley, the analysis of strontium isotopes may provide an additional means of investigating the identity of individuals at Tombos and the origin of the colonial administrators. If the variability in isotopic compositions for biologically available strontium for this region is sufficient (Fig. 1) to distinguish people from Tombos and people from the most likely place of immigrant origin, Thebes, then strontium isotope analysis may offer an important opportunity to elucidate details of the New Kingdom Egyptian occupation of Nubia.

2.6. The intersection of ethnic identity, cranial morphology, and strontium isotope analyses

It is important not to conflate the ideas discussed here – ethnic identity, cranial morphology, and strontium isotope ratios. These avenues of investigating the composition of the Tombos population reflect very different aspects of a person's biohistory. Ethnic identity portrayed through burial ritual reflects that individual's and/or family's ideas about their cultural affiliation (though not necessarily a reflection of ethnic identity during life). Cranial morphology only indicates the physical similarities between individuals and groups and may not correspond to an individual's portrayed ethnic identity. Finally, strontium isotope ratios in enamel reveal yet another aspect – a marker of where an individual lived as a child if locally-grown and raised food provided the sources of strontium consumed. While these isotope data may help to identify who is local, neither ethnic nor biological identity of a particular individual can be assumed based on this information.

3. Principles of strontium isotope analysis

Strontium, found in rock, groundwater, soil, plants, and animals is composed of four isotopes: ^{84}Sr, ^{86}Sr, ^{87}Sr, and ^{88}Sr. ^{87}Sr is the only radiogenic isotope, produced by the slow radioactive decay of ^{87}Rb (Faure, 1986). Because the relative mass difference between strontium isotopes is small, no isotopic fractionation through biological processes occurs (Faure and Powell, 1972). Strontium concentrations and ratios differ according to variations in local geology. ^{87}Sr/^{86}Sr ratios reflect the average ^{87}Rb/^{87}Sr ratios of the parent rocks in a particular area, which is mainly the function of the composition of the rocks and the time elapsed since the formation or deposition of that rock. Older rocks with very high ^{87}Rb/^{87}Sr ratios have the highest ^{87}Sr/^{86}Sr ratios today. Thus, areas with older rocks having high Rb/Sr, such as granite, are expected to have higher ^{87}Sr/^{86}Sr ratios than areas with geologically younger rocks with low Rb/Sr, such as basalt (Faure, 1986).

The strontium present in soil and groundwater is incorporated into local plants and animals. Thus, the strontium isotopic composition of an individual's diet will be reflected in his or her hard tissues (Ericson, 1985). Strontium commonly substitutes for calcium in the hydroxyapatite of teeth and bone (Nelson et al., 1986). Tooth enamel of permanent adult teeth forms during early childhood (various teeth form at different times in the first 12 years of life) and is considered a dead tissue because it is not penetrated by any organic structures (Steele and Bramblett, 1988). Therefore, tooth enamel will reflect the strontium isotope composition of the environment in which a person lived while the tooth was forming. Minerals may be taken up by the surface of the tooth during life or after burial, though these materials seldom penetrate deep into the enamel (Budd et al., 2000; Price et al., 2004; Wright, 2005a).

4. Geology and strontium sources of the Nile Valley, Tombos, and Thebes

The region considered in this study is the Nile Valley of ancient Nubia and Egypt. This area includes all of modern Egypt and northern Sudan (Fig. 1). Ancient Nubia extended from the First cataract of the Nile in Egypt south approximately to the modern city of Khartoum (Edwards, 2004; Morkot 2000). In particular, two areas in this Nile Valley region are of interest for this study: the Third cataract area where Tombos is located and Middle Egypt, near Thebes. Based on information from Egyptian texts (O'Connor, 1993) and burial style at Tombos (Buzon, 2006) it is proposed that immigrants to Nubia during the New Kingdom would have come from the area of Thebes, in Egypt, the capital of pharaonic government.

The archaeological populations relevant to this study inhabited land in the Nile Valley floodplain (arable land directly next to the river). The Nile flow is obstructed by cataracts (six classical and several smaller), outcrops of igneous rock (granite), which form natural boundaries and create navigation obstacles (Said, 1962, 1993; Whiteman, 1971). Few previous studies have explored the isotopic compositions of biologically available strontium within the Nile Valley and how these relate to the local geology, though Dupras and Schwarcz (2001) and White et al. (2004) discuss migration between the Nile Valley and desert oases using oxygen isotopes during later time periods. One important goal of this study is to begin to establish the baseline 'local' ratios for the Tombos region, and to determine if there is sufficient $^{87}Sr/^{86}Sr$ variability within other locations of the Nile Valley for the possible identification of immigrants.

The regional geology encompassing the Tombos area (northeastern Sudan) is complex (Fig. 2) given that the Nile River approximates the boundary between two major metamorphic/tectonic provinces. The East Saharan (or Nile) craton lies on the west side of the Nile River, and consists predominantly of rock units that are Archean (>2700 million years [Ma] old) to Paleoproterozoic ($\sim$1000 Ma old) in age; whereas the eastern side of the Nile River valley is made up of Neoproterozoic rocks ($\sim$800 to 600 Ma old) belonging to the Arabian-Nubian shield (Küster and Liégois, 2001). Within the vicinity of Tombos/Third cataract area, the rocks belonging to the East Saharan craton consist predominantly of complexly deformed gneisses that yield T_{DM} (relative to Depleted Mantle) Nd model ages between 2200 and 1200 Ma (Stern et al., 1994). A Nd T_{DM} model age is calculated using the rock sample's Sm/Nd value and its measured $^{143}Nd/^{144}Nd$. The latter is then 'back-corrected' so that it equates to a value along the depleted mantle temporal evolution curve (*i.e.* plot of $^{143}Nd/^{144}Nd$ versus age). The solution (or intersection) yields the Nd T_{DM} model date and this is usually regarded as the minimum age of rock formation. To the east (where the archaeological site of Tombos is located), the Arabia-Nubian province is characterized predominantly by metamorphosed juvenile (*i.e.* volcanic) island arc/back arc basin assemblages formed approximately 750 to 580 Ma ago (Küster and Liégois, 2001). In an isotopic study of analogous geologic units (gneisses, volcanic rocks and metasediments) at Wadi Halfa, located approximately 200 km north of Tombos along the Nile River, Stern et al. (1994) report highly variable measured (present-day) $^{87}Sr/^{86}Sr$ values that range from 0.70530 to 0.72405. In particular, five samples of older metamorphosed basement gneiss at Wadi Halfa (ages $\sim$2400 and $\sim$700 Ma) yield present-day strontium isotope ratios that range from 0.7083 to 0.7194 (Stern et al., 1994).

In contrast, the regional geology surrounding the Thebes area (Egypt), the proposed source region of immigrants to Tombos, is dominated by three distinct sedimentary rock formations (Dakhla chalk, Esna shale, and Theban limestone) deposited between 35 and 56 Ma. At Luxor (ancient Thebes), the Theban limestone formation is $\sim$300 metres thick, and underlain by the Esna shale (60 metres thick) (Said, 1962). Based on the well-established strontium isotope evolution of marine carbonates ($n = 786$) throughout the Phanerozoic time (*i.e.* last 600 million years) (Burke et al., 1982), the limestone formation at ancient Thebes should be characterized by an $^{87}Sr/^{86}Sr$ similar to the mean value of 0.70907 ± 0.00026 (standard deviation) based on 42 modern samples of marine carbonates world-wide (Burke et al., 1982). For example, this notion is confirmed by the strontium isotope values between 0.7090 and 0.7092 recorded by modern marine taxa (*e.g.* mollusks, foraminifera, ostracods) present within the high salinity areas of the Nile's River delta (Reinhardt et al., 1998).

Previous investigations have revealed that the modern-day $^{87}Sr/^{86}Sr$ isotope value of Nile river water and sediments are remarkably similar, starting from the confluence of the Blue and White Nile Rivers, to north of Cairo. Today, the source of water in the Nile that flows north from Khartoum is derived primarily (95%) from the Blue Nile (the Ethiopian Highlands). Thus, the majority of the Nile water sediment is from this source as well. Sediments from three areas (Blue Nile, Atbara confluence, and Wadi Halfa) all yield strontium isotope ratios of $\sim$0.7060, which is consistent with a dominant contribution from volcanic rocks of the Ethiopian Highlands (Krom et al., 2002). There is only an insignificant change in $^{87}Sr/^{86}Sr$ values of Nile water from Aswan to north of Cairo, with values also $\sim$0.706 (Gerstenberger et al., 1999). In contrast, the strontium isotope composition of floodplain sediment from the White Nile River upstream from Khartoum is more radiogenic at 0.7150 (Krom et al., 2002) and similar to the value for the White Nile waters (0.7095 to 0.71900) (Talbot et al., 2000). The higher $^{87}Sr/^{86}Sr$ values for sediments and waters along the White River reflect the drainage over a region dominated by crystalline basement rocks characterized by more radiogenic strontium isotope values, such as the gneisses within the East Saharan craton.

Research on Nile river sediments at the Delta from the time of 950 to 2200 B.P., which encompasses the New Kingdom Period, record $^{87}Sr/^{86}Sr$ values of $\sim$0.7075 (Krom et al., 2002). This slightly more radiogenic strontium isotope value compared to the modern-day $^{87}Sr/^{86}Sr$ ratio of $\sim$0.7060

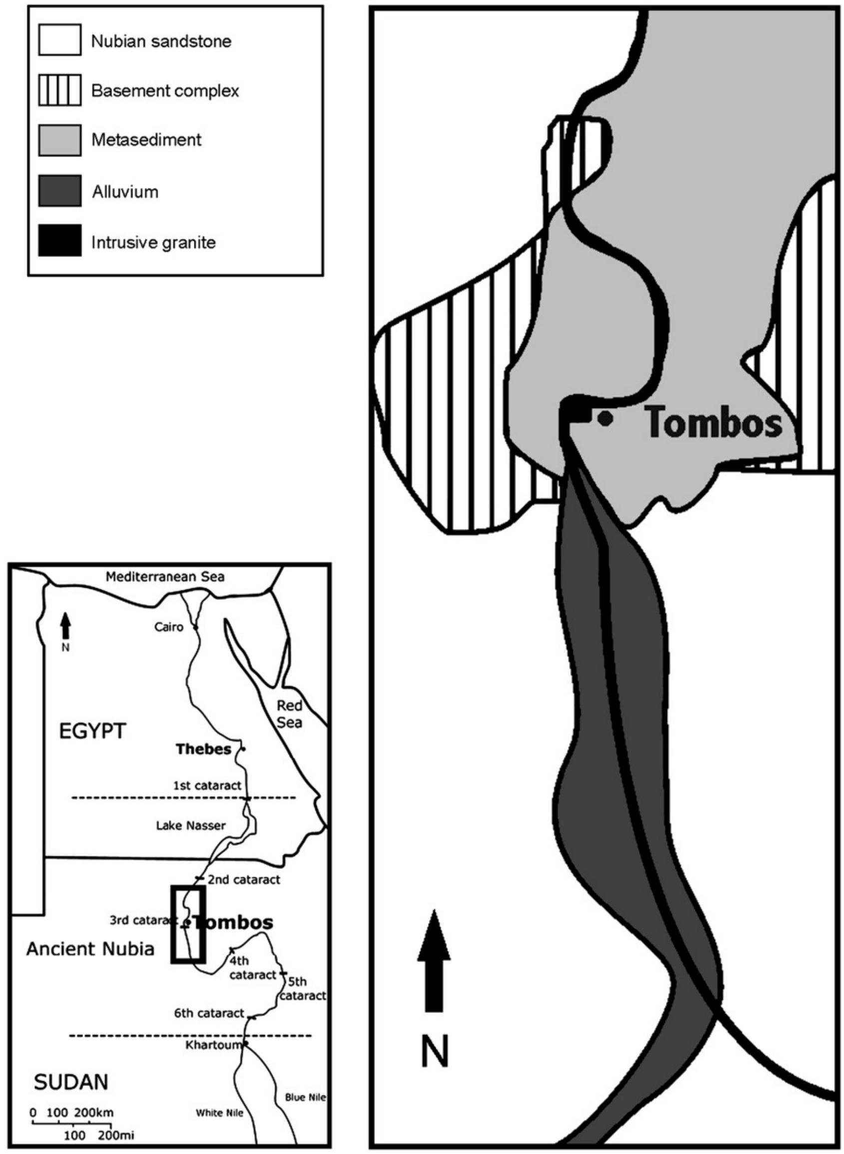

Fig. 2. Geological map of Tombos region.

would seem to indicate a larger contribution of sediments and water from the White Nile River system (relative to the Blue Nile) during early times, possibly the result of a higher river outflow water regime (Krom et al., 2002). Despite the present-day similar $^{87}Sr/^{86}Sr$ values in Nile water and sediment downstream from Khartoum, it is hypothesized (based on the highly contrasting regional geology between the Thebes and Tombos areas) that immigrants at Tombos during the New Kingdom Period may have had a different isotopic signature than local individuals.

Although the people buried at Tombos likely settled at this site due to its strategic location at the Third cataract for the control of Nile trade, it is most probable that the vast majority of food consumed was local to the area. The remains of cereals and the presence of ovens and bread moulds in the region suggest a well-developed agricultural system in the region; animal remains attest to the availability of cattle, sheep, and goat (Iacumin et al., 1998). In contrast, trade on the Nile concentrated on luxury goods such as ivory, incense, resin, animal skins, and wood (Trigger et al., 1983). Thus, it is unlikely that non-local food was consumed on any regular basis. However, because the geology of the Tombos area is complex (as discussed earlier), "local" foods could have different $^{87}Sr/^{86}Sr$ values. Accounting for the high-strontium, high-calcium foods that would have impacted human enamel $^{87}Sr/^{86}Sr$ values is important in interpreting the results of the analyses (Bentley, 2006). Grains, leafy greens, and dairy products comprise the foods with high strontium content in the Nile Valley. Although little information regarding where foods were grown and animals were raised is available for the region of Tombos, we can infer likely agricultural strategies based on practices used further north in Egypt (Brewer et al., 1994; Thompson et al., 2005).

Egyptians practiced a mixed system of plant cultivation, penned animal raising, and range herding (sheep, goat, cattle). The arable land along the Nile where irrigation was possible was reserved for food crop cultivation, though the amount of land varied from year to year due to the variable rainfall. When rainfall was low, land normally reserved for cultivation was often used as pasture; when the pastureland was unavailable, animals were often kept in pens or corals with food brought to them. There is also evidence of long range herding as well. As technology increased, more and more land came under cultivation (Brewer et al., 1994). Isotopic analyses of human and faunal samples by Thompson and colleagues (2005) from a variety of sites in the Nile Valley of Egypt reveal that humans were primarily consuming protein sources from C_3 plants (likely wheat and barley) and fauna that consumed C_3 plants. Although preliminary, their data suggest that humans did not consume significant amounts of beef and/or cattle milk derived products (Thompson et al., 2005: 461). However, their study also confirms the complex nature of the Nile Valley lands, indicating that there were multiple ecological niches and ecosystems (Nile, floodplain, and the desert).

Thus, it is difficult to determine the effects of animals raised outside of the arable land surrounding the Nile. Although consumption of these possible strontium sources appears to have been low, it is a factor that should be kept in mind during interpretation. Crops were likely grown in the land along the Nile, though as irrigation systems advanced, more land outside of the alluvial floodplain was utilized. Consequently, plant and animal sources of strontium may have been raised in Nile soil, which may have had very similar $^{87}Sr/^{86}Sr$ signatures throughout the valley. Yet, it is also likely that these food sources were raised in areas outside of the floodplain with $^{87}Sr/^{86}Sr$ signatures varying with local bedrock.

5. Materials and methods

This study included tooth enamel samples from 49 individuals buried in the Tombos chamber pits and the alleyway surrounding the pyramid in order to determine if individuals lived in the Tombos local area as children (during tooth development). The minimum number of individuals excavated at Tombos is 100; with the exception of two individuals excavated after analyses were complete, it appears that all of the burials in the non-elite portion of site have been excavated. The 49 individuals sampled represent nearly all of the burials for which dental enamel was available and provenience could be determined (looting resulted in many disarticulated and disturbed burials). Where possible, premolars, which have enamel that forms between the ages of 2 and 6, were used; if missing, another tooth type was substituted. In order to establish the local $^{87}Sr/^{86}Sr$ signature of Tombos, four samples of burial soil from the Tombos chamber tombs were analyzed. However, because water and soil sample $^{87}Sr/^{86}Sr$ ratios do not always have a direct 1:1 relationship with animal tissue (Price et al., 2002; Sillen et al., 1998), faunal samples were also analyzed in order to establish the local range. None of the burials contained faunal remains; however, one available sample of archaeological bone (sheep or goat) from a New Kingdom trash pit nearby the Tombos cemetery site was used. In addition, one enamel sample cut from a modern cow tooth local to Tombos was included in this study.

Although, as mentioned earlier, tooth enamel is much less susceptible to contamination than bone or dentine, we ensured that the tooth enamel samples were not changed by post-depositional contamination by mechanically cleaning and abrading the surface of the tooth as well as chemically cleaning. These techniques that have been shown to reduce some diagenetic contamination (Nielsen-March and Hedges, 2000). Contamination of enamel samples by post-depositional strontium was evaluated by examining the correlation between $^{87}Sr/^{86}Sr$ values and strontium concentration. The assessment of contamination was also made by measuring the concentration of uranium in the sample. Uranium, which can reflect the uptake of groundwater (Hedges and Millard, 1995), is not normally found in skeletal tissues and should be below the equipment detection limit (*i.e.*, 0.003 ppm – ICP-MS).

Using a diamond disk saw (Thin flex X929.7, 22.2 mm diameter, .022 mm thickness) fitted to a dental drill (Dremel Multipro Model 395), an enamel sample was cut from the crown and the pulp and dentine were removed leaving the intact enamel (10–20 mg). The samples were prepared for analysis in the Class 100 cleanroom facility in the Radiogenic Isotope Facility, Department of Earth and Atmospheric Sciences, University of Alberta. Samples were sonicated for 15 min in Millipore water (MQ) and then in 5% acetic acid for 15 min. After an overnight leaching in 5% acetic acid, the acid was removed and samples were rinsed with MQ prior to transfer to vials. After adding a Rb-Sr spike, the samples were digested in a microwave oven in 4 ml 16 N HNO_3 and 1 ml ~10 N HCl. Digested samples were dried overnight on a hot plate (80 °C). For the soil, MQ was added to cover the sample entirely (~10 ml). The sample was capped and heated on a hotplate overnight (80 °C). Samples were then transferred to a centrifuge tube and centrifuged to separate the water and soil particles. The water was transferred to a clean Teflon vial. The spike was weighed and added to the sample, and then dried down on the hotplate (80 °C) overnight. All dried samples (enamel, bone, soil) were dissolved in 3 ml of 0.75 N HCl and then loaded onto 10 cm ion exchange columns containing 1.42 ml of 200–400 mesh AG50W-X8 resin. Samples of 5 ml of 2.5 N HCl each were collected into Teflon vials with an added drop of H_3PO_4 and then left to dry overnight on a hot plate (80 °C).

Subsequent to ion chromatographic treatment of the samples, the Sr-bearing aliquots were diluted in a 2% HNO_3 solution and aspirated into the ICP torch using a desolvating nebulizing system (DSN-100 from Nu Instruments Inc.). Strontium isotope values were determined using a NuPlasma MC-ICP-MS instrument. This technology has led to innovative research studies involving radiogenic isotope systems due primarily to the overall high ionization efficiency of the ICP source coupled with the simultaneous acquisition of ion beams with flat-topped peak shapes (Simonetti et al., 2005).

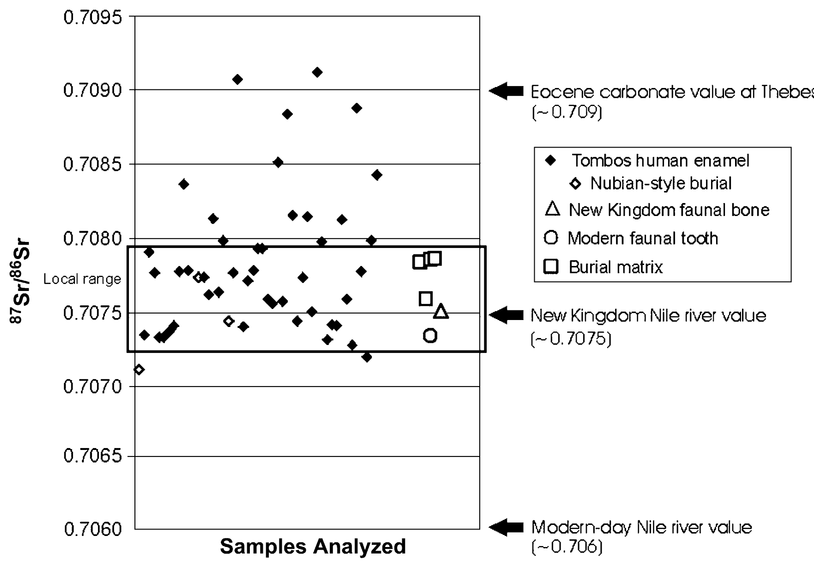

Fig. 3. Distribution of $^{87}Sr/^{86}Sr$ values for human enamel, faunal, and burial matrix samples.

Strontium isotope data were acquired in static, multicollection mode using five Faraday collectors for a total of 400 s, consisting of 40 scans of 10 s integrations. The 'wash-out' period following the analysis of a sample was approximately 5 min. Prior to the aspiration of a sample, a 30 s measurement of the gas (+acid) blank was conducted, which is critical for the correction of the ^{86}Kr and ^{84}Kr isobaric (plasma-based) interferences. The isobaric interference of ^{87}Rb was also monitored and corrected for using the ^{85}Rb ion signal; however, the latter was negligible for all of the results reported here. Accuracy and reproducibility of the analytical protocol were verified by the repeated analysis of a 100 ppb solution of the NIST SRM 987 strontium isotope standard during the course of this study; this yielded an average value of 0.710242 ± 0.000041 (2σ standard deviation; $n = 13$ analyses) and is indistinguishable compared to the accepted value of 0.710245. The typical internal precision ('error') associated with an individual strontium isotopic analysis varies from 0.00001 to 0.00003 (2σ level).

6. Results

6.1. Isotopic results for human enamel samples

Fig. 3 illustrates the $^{87}Sr/^{86}Sr$ ratios of the 49 human enamel samples from Tombos. The values for the individuals buried at Tombos range from 0.70712 to 0.70911 (Table 1). Of interest, some values for the enamel samples (Table 1) are similar and corroborate the $^{87}Sr/^{86}Sr$ value of $\sim$0.7075 recorded by Nile River delta sediments during the New Kingdom period (Krom et al., 2002). The $^{87}Sr/^{86}Sr$ ratios do not show a correlation with the strontium concentration (ppm) for each sample (Table 1), suggesting the enamel is not diagenetically altered. In addition, the concentration of uranium in these enamel samples is all near or below the detection level, another check against post-depositional contamination.

6.2. Local range

Fig. 3 also displays the results of the burial matrix and faunal sample analyses. Using only the faunal samples (archaeological bone and modern tooth), the local range determined by the mean of ratios $\pm 2\ \sigma$ error is 0.70732–0.70754. However, because only two samples were used to calculate the local range, which may not reflect the full local variability, it is prudent to widen the definition of the local range by including the burial matrix samples. With the inclusion of these samples the local range is extended to 0.70789. These isotopic values are consistent with the Tombos site overlaying the younger volcanic bedrock (Küster and Liégois, 2001). Using this larger local range, as depicted by the box in Fig. 3, several individuals have $^{87}Sr/^{86}Sr$ ratios above this upper limit. These preliminary data suggest that several individuals appear to have had a different, non-local source of strontium during childhood tooth development and may not have lived in the Tombos area while the enamel of their teeth was forming.

6.3. Isotopic results by ethnic identity based on burial features

In Fig. 3, individuals who identified themselves as Nubian in their burial style at Tombos are represented by an open diamond (listed in Table 1). Two have ratios within the suggested local range, while one has a slightly lower value.

6.4. Isotopic results by biological groups based on craniometric data

Seventeen individuals included in this study had cranial remains intact enough to be included in the previous craniometric analysis (Buzon, 2006). Using logistic regression equations, these individuals were categorized as either Egyptian or Nubian based on their cranial morphology (Table 1). Fig. 4 displays the distribution of these samples. Although only 17 of the 49 (35%)

Table 1
Results of strontium isotope analysis of archaeological human tooth enamel, burial matrix, archaeological faunal bone, and modern faunal enamel samples from Tombos

Specimen	$^{87}Sr/^{86}Sr$	2 σ error	Sr ppm	Burial Ritual	Predicted Group (cranial morphology)
Human TOM-1	0.70712	4.6E-05	273	Nubian	Egyptian
Human TOM-2	0.70735	1.6E-05	199	Egyptian	
Human TOM-3	0.70791	2.2E-05	150	Egyptian	
Human TOM-4	0.70777	2.0E-05	169	Egyptian	
Human TOM-5	0.70734	2.2E-05	181	Egyptian	
Human TOM-8	0.70733	1.7E-05	150	Egyptian	
Human TOM-9	0.70738	1.7E-05	290	Egyptian	
Human TOM-10	0.70741	2.9E-05	154	Egyptian	
Human TOM-11	0.70777	1.7E-05	104	Egyptian	
Human TOM-12	0.70837	2.8E-05	205	Egyptian	
Human TOM-13	0.70779	6.3E-05	184	Nubian	Nubian
Human TOM-15	0.70774	7.7E-05	114	Egyptian	Nubian
Human TOM-17	0.70774	1.2E-05	172	Egyptian	
Human TOM-19	0.70762	2.4E-05	131	Nubian	
Human TOM-20	0.70813	2.4E-05	120	Egyptian	Nubian
Human TOM-21	0.70763	2.9E-05	133	Egyptian	
Human TOM-22	0.70798	6.5E-05	115	Egyptian	
Human TOM-23	0.70744	3.0E-05	166	Egyptian	
Human TOM-24	0.70777	1.8E-05	87	Egyptian	
Human TOM-27	0.70907	3.1E-05	128	Egyptian	
Human TOM-29	0.70741	2.1E-05	118	Egyptian	
Human TOM-30	0.70771	2.2E-05	103	Egyptian	
Human TOM-31	0.70778	1.7E-05	140	Egyptian	Egyptian
Human TOM-32	0.70793	2.0E-05	152	Egyptian	Nubian
Human TOM-33	0.70793	1.8E-05	122	Egyptian	Egyptian
Human TOM-34	0.70759	2.1E-05	144	Egyptian	Nubian
Human TOM-36	0.70756	3.9E-05	137	Egyptian	
Human TOM-37	0.70851	2.2E-05	162	Egyptian	Egyptian
Human TOM-38	0.70757	1.9E-05	120	Egyptian	
Human TOM-39	0.70884	3.2E-05	143	Egyptian	
Human TOM-40	0.70815	2.9E-05	124	Egyptian	
Human TOM-41	0.70744	1.2E-05	123	Egyptian	
Human TOM-42	0.70774	6.0E-05	190	Egyptian	
Human TOM-43	0.70815	3.2E-05	130	Egyptian	Nubian
Human TOM-44	0.70751	2.5E-05	41	Egyptian	
Human TOM-45	0.70912	1.4E-05	153	Egyptian	
Human TOM-46	0.70798	2.6E-05	182	Egyptian	Egyptian
Human TOM-47	0.70732	2.6E-05	138	Egyptian	Egyptian
Human TOM-48	0.70742	1.5E-05	152	Egyptian	Egyptian
Human TOM-49	0.70741	1.5E-05	158	Egyptian	
Human TOM-50	0.70812	2.2E-05	118	Egyptian	
Human TOM-51	0.70759	2.0E-05	149	Egyptian	Egyptian
Human TOM-52	0.70728	2.1E-05	178	Egyptian	Egyptian
Human TOM-53	0.70888	4.8E-05	64	Egyptian	
Human TOM-54	0.70778	2.8E-05	155	Egyptian	
Human TOM-55	0.70720	1.3E-05	196	Egyptian	
Human TOM-56	0.70799	1.9E-05	139	Egyptian	
Human TOM-57	0.70843	2.6E-05	210	Egyptian	Nubian
Human TOM-58	0.70844	2.6E-05	171	Egyptian	Nubian
Burial Matrix 1	0.70784	7.8E-05	274[a]	–	–
Burial Matrix 2	0.70759	3.6E-05	186[a]	–	–
Burial Matrix 3	0.70786	2.2E-05	181[a]	–	–
Burial Matrix 4	0.70786	2.8E-05	232[a]	–	–
NK Faunal bone	0.70752	2.0E-05	750	–	–
Modern faunal enamel	0.70734	2.3E-05	324	–	–

Predicted groups based on cranial morphology (Buzon, 2006). Individuals without a predicted group designation had cranial remains too fragmentary or damaged to be included in the cranial morphology study.

[a] The Sr concentrations for the four burial matrix samples were determined by total sample digestion (∼50 mg) using a concentrated $HF:HNO_3$ acid mixture in pre-cleaned savillex© Teflon beakers placed at 130 °C on a hot plate for 24 h. The sample was diluted to a final volume of 90 ml (2% HNO_3) and subsequently analyzed using a Perkin Elmer Elan 6000 ICP-MS instrument. Operating conditions were: RF forward power – 1200 W; plasma, auxiliary, and nebulizer gas flow rates of 15, 1.0, and 0.95 Litre/minute Ar, respectively; dwell time of 10 ms in dual detector mode (pulse and analog); Sc, In and Bi were used as internal standards, and measurements were conducted in peak hopping mode using 35 sweeps/reading, 1 reading/replicate with 3 replicates in total.

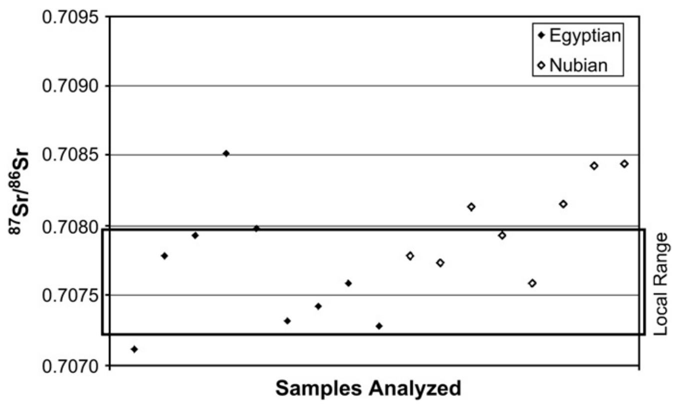

Fig. 4. Distribution of $^{87}Sr/^{86}Sr$ values by predicted group (based on cranial morphology, Buzon, 2006).

individuals used in the present study can be included here, the data suggest that individuals with both Egyptian and Nubian cranial morphology are local based on their $^{87}Sr/^{86}Sr$ ratios.

7. Discussion

7.1. Feasibility of strontium isotope analysis of residential mobility in the Nile Valley

The variable strontium isotope values recorded for human tooth enamel, faunal remains, and burial matrix samples from the Tombos area display a range that exceeds those obtained from Nile water during the New Kingdom Period (Krom et al., 2002), suggesting that the biologically available strontium within the Tombos region comes from the soil (which is then incorporated into plants, etc.) rather than the water. Given the somewhat complex local geological situation at Tombos, the strontium isotope signatures for enamel samples reported here (Table 1) are likely influenced by the variable local geology (in addition to input from the Nile river). However, the strontium isotope composition for the ‘local’ signature (as defined by faunal and burial matrix samples) is fairly restricted, indicating that the biologically available strontium within the Tombos area was characterized by a strontium isotope signature of ~0.7073 to 0.7079 (Table 1). Coincidentally, this range in isotopic compositions overlaps the $^{87}Sr/^{86}Sr$ values (~0.7075) of the Nile River deltaic sediments at Manzala Lagoon recorded during the New Kingdom Period (950 to 2200 B.P.; Krom et al., 2002). Individuals with enamel samples that record $^{87}Sr/^{86}Sr$ values $> \sim 0.7079$ may have incorporated a ‘non-local’ source of strontium during their childhood development.

7.2. Immigrants at Tombos

The higher strontium isotope compositions for some individuals (as high as ~0.7091; Table 1) approximate the $^{87}Sr/^{86}Sr$ value for marine carbonates of Lower to Middle Eocene age (35 to 56 Ma old) (Burke et al., 1982), such as those present at Thebes (Egypt). Thus, the preliminary strontium isotope data reported here do not invalidate the possibility that the immigrants at Tombos did originate from Thebes, Egypt. However, at present, it is not possible to determine with certainty whether these individuals are indeed from Egypt (Thebes) until additional research explores the strontium variability in the Nile Valley region. It is possible, for instance, that these non-local individuals came from another area of Nubia with a different strontium isotope signature. However, textual and archaeological evidence strongly suggests that immigrants at Tombos would be from Egypt (Buzon, 2006).

7.3. Variation by ethnic identity

The strontium isotope data of the individuals in Nubian-style burials (all with values below 0.7078) provide an additional indication that individuals with ratios above 0.7078 may be non-local. Other individuals not buried Nubian-style whose ratios fall within the local range could be Egyptianized native Nubian locals or the children of Egyptian immigrants born locally. It is not surprising that individuals who likely spent their childhood elsewhere are included in the group of people buried at Tombos — the archaeological indications of ethnic identity as seen through architecture (pyramid structure), artefacts (funerary cones), and burial ritual suggest a strong Egyptian presence in addition to the widespread Egyptianization of Nubians during this time. Smith (2003) has suggested that this pyramid tomb was built as a reflection of Siamun’s power and authority in the Egyptian hierarchy. It may have been a way to promote in-group solidarity with other Egyptians in the face of real or perceived Nubian threat.

7.4. Variation by biological affinity

These data on the strontium isotope ratios of predicted groups are difficult to interpret, as the differences between Egyptian and Nubian cranial morphology are far from straightforward. Although Egyptian samples examined by Buzon (2006) appeared to form a more morphologically homogenous group than the Nubians, it is clear that these ancient Egyptians and Nubians share many similar features. Several individuals with Egyptian cranial morphology are within the local range. This finding that some individuals who appear local in their strontium isotope ratios would have Egyptian cranial morphology is expected. Considering the time span of the cemetery (1400–1050 AD), it is probable that Egyptian immigrants would have had children at Tombos, who would then have the local strontium isotopic signature in their dental enamel as well as Egyptian cranial morphology. This corresponds well with the presence of individuals who were buried in Egyptian style and have $^{87}Sr/^{86}Sr$ values in the local range. Individuals with Nubian morphology outside the local range may be natives from another region of Nubia.

It is also possible that cranial morphology cannot accurately predict to which ethnic group an individual belongs. A previous examination of Egyptian and Nubian cranial features suggests that Nubians are a morphologically more variable group than Egyptians (some individuals buried as ethnic

Nubians with more Egyptian cranial features) (Buzon, 2006). This obscures the connection between cranial morphology and ethnic indicators, highlighting the disparity between different types of identity. This study calls attention to an additional kind of identity, geographic origin, which also may not correspond with ideas of ethnic and biological affinities. The combination of these multiple lines of evidence certainly complicates the reconstruction of the past, but it also serves to provide a more rich and meaningful picture of people we are investigating.

8. Conclusions and future research

The preliminary data in this exploratory study confirm the feasibility of using strontium isotope analysis to examine migration at Tombos. This analysis has revealed that the biologically available strontium within the Tombos region likely comes from the soil, rather than only Nile water and is thus influenced by the variable local geology. The group from Tombos analyzed in this study appears to contain some individuals of non-local origin (possibly from Thebes), based on the local strontium range as determined by faunal samples and burial matrix. The three ethnic Nubian burials fall within or close to the local range. Individuals displaying Egyptian and Nubian cranial features appear based on their $^{87}Sr/^{86}Sr$ values to be both local and non-local. This presence of non-local individuals is expected based on the textual information concerning Egyptian colonial activities during this time.

The preliminary data produced in this study suggest that distinguishing local individuals from immigrants at Tombos may be possible. Undoubtedly, more research is needed in order to fully interpret these data. Future research avenues include the analysis of additional faunal samples to more clearly establish the local range at Tombos, individuals from other areas in Nubia to determine the range of variability within the region, and individuals from Egypt, preferably Thebes, in order to establish the local signature of people who may have moved to Tombos from that area.

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