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ORIGINAL ARTICLE

Isotopic Evidence for Socio-economic Dynamics Within the Capital of the Kingdom of Alwa, Sudan

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Abstract Between the sixth and fifteenth c. CE, a vast expanse of central and southern Sudan belonged to the kingdom of Alwa, ruled from the urban metropolis of Soba. Renewed investigation of the city unearthed a small cemetery in the northern part of the site. The heterogeneity of burial practices raised some questions as to the cultural and religious affinities of the deceased and suggested potential multiculturalism of the local urban population. We applied isotopic analyses to investigate the origins of the people buried at Cemetery OS and their concomitant ways of life. Non-concordance of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values with local hydro-geological background speaks to the mixing of water sources as a result of residential mobility. The concordance of human and faunal strontium and oxygen results, combined with elevated $\delta^{13}C$ values corresponding to almost exclusive reliance on C_4 produce, points to the possibility of seasonal movement of people with their herds between the Nile valley and the adjacent grasslands. Despite the turn of the medieval Nubian economy towards settled agriculture, by revealing the granular specificities of human adaptation in challenging ecosystems, our results produce the first insight into the enduring diversification of economic production, even in urbanized settings, and persisting participation of local peoples in agro-pastoral symbiosis.

Résumé Entre le VIe et le XVe s. CE, une vaste étendue du centre et du sud du Soudan appartenait au royaume d'Alwa, gouverné depuis la métropole urbaine de Soba. Une nouvelle enquête sur la ville a mis au jour un petit cimetière dans la partie nord du site. L'hétérogénéité des pratiques funéraires a soulevé certaines questions quant aux affinités culturelles et religieuses des défunts et a suggéré un potentiel multiculturalisme de la population urbaine locale. Nous avons appliqué des analyses isotopiques pour étudier les origines des personnes enterrées au cimetière OS et leurs modes de vie concomitants. La non-concordance des valeurs de 87Sr/86Sr et δ18O avec le contexte hydrogéologique local témoigne d'un mélange de sources d'eau résultant de la mobilité résidentielle. La concordance des résultats humains et fauniques en strontium et en oxygène, combinée aux valeurs élevées de δ13C correspondant à une dépendance

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presque exclusive aux produits C4, indique la possibilité de mouvements saisonniers de personnes et de leurs troupeaux entre la vallée du Nil et les prairies adjacentes. Malgré le tournant de l'économie nubienne médiévale vers une agriculture sédentaire, en révélant les spécificités granulaires de l'adaptation humaine dans des écosystèmes difficiles, nos résultats donnent le premier aperçu de la diversification durable de la production économique, même dans les contextes urbanisés, et de la participation persistante des populations locales à l'agriculture. symbiose agro-pastorale.

Keywords Medieval archaeology · Isotopes · Nubia · Christianity · Mobility · Diet

Introduction

In the tenth century record of his travels to Nubia (modern Sudan), Arab traveller Ibn Selim Al-Aswani describes Soba, the capital of the mighty kingdom of Alwa, as a magnificent metropolis with extensive palaces, gilded churches, and lush gardens, hosting a cosmopolitan population originating from farthest reaches of the medieval world (Vantini, 1975: 613). The realm of the Alwan kings has been argued to have extended from somewhere between the Fourth and Fifth Nile Cataracts in the north of Sudan to beyond Sennar in the south, covering not only the alluvial plains along the Nile valley, but also vast stretches of adjacent grasslands and deserts (Welsby, 2002: 84). While the first mention of the city of Soba comes from the ninth c. Arab writer Al-Yaqubi (Shinnie, 1955: 12), the archaeological evidence attests to the existence of an extensive urban center as early as the sixth c. AD (Drzewiecki & Michalik, 2021; Welsby, 1998: 272).

While often listed alongside Nobadia and Makuria as being among three medieval Nubian kingdoms (Welsby, 2002) (Fig. 1), Alwa extends far beyond historical Nubia, the southern border of which is now placed somewhere around the modern town of Debba in Sudan's northern province. Located at the confluence of the Blue and White Niles, Soba was much closer to the Sahel's savannah belt. Covered in grassland peppered with shrubs and occasional acacia trees, regional subsistence strategies have relied on a completely different economic basis. Outside of the alluvial plain flanking the Nile valley, people supported themselves through small-scale seasonal rain-fed agriculture and, mostly, transhumant pastoralism (Brass, 2015). Due to its location, Soba was also situated at the crossroads of medieval trade routes connecting the Nile valley with Kordofan and Darfur on one side, with Red Sea shores and Ethiopian realm on the other. Throughout its entire history, we know next to nothing about the society of medieval Alwa and its ethno-cultural makeup. Sparse historical sources and relatively impersonal material culture say little of the identity of the city's inhabitants. In this study, we aim to address this question by capturing behaviorally meaningful patterns of differentiation reflecting individuals' origins and concomitant ways of life through the application of isotopic analysis of paleomobility and diet.

Historical Background

Soba appeared on the eastern side of the Blue Nile seemingly out of nowhere in the sixth c. AD and rapidly rose to the rank of an international power. Although displaying many of the cultural traits common for the Nubian cultural sphere, such as Christian faith or Greek literacy (Welsby, 2014), its material culture also possessed also its own idiosyncrasies, not seen anywhere else in Nubia. Pottery specialists highlight the disparities between Makurian and Alwan ceramic traditions, especially in the earliest periods of their development (Danys & Zielińska, 2017; Czyżewska-Zalewska, forthcoming). Pottery styles such as the characteristic Soba Ware (wheel-made fine ware with painted decoration on black/brown or cream background in geometric patterns and/or human and faunal representations) and Red Ware (wheel-made, red-slipped bowls) appear to be descendant from the preceding Meroitic and Post-Meroitic traditions, showing also some affinity with the Ethiopian Aksumite styles (possibly a testament of a closer kinship with the southern reaches of the modern Sudanese domain than Alwa's northern neighbors). After the dissolution of the Meroe state in the fourth century AD, various regions appear to have followed somewhat diverging paths and in effect certain cultural differentiation ensued (Danys & Zielińska, 2017). Probably due to its relative proximity to the Meroitic center, Soba inhabitants retained their artistic affiliation with this past state for much

Fig. 1 Map of Sudan with the location of three Nubian kingdoms of Makuria, Nobadia, and Alwa with its capital Soba (J. Ciesielska)

longer than the Makurian and Nobadian centers which drew their inspiration from neighboring Egypt.

Archaeological Context

Soba is situated on the outskirts of Khartoum, the capital of the modern Sudan state, ca. 20 km to the southeast of the city center, on the eastern bank of the Blue Nile River. Originally approximately 275 ha in size, the city's remains have shrunk to no more than 52 ha of land not yet covered by modern occupation. Peppered with numerous, but severely flattened mounds housing what remains of the original occupation at the site, until recently the city's spatial organization was still poorly understood and continues to be researched (*see* Drzewiecki et al., 2021, 2022).

Renewed investigation of the site of Soba by the University of Warsaw team under the direction of Dr. Mariusz Drzewiecki, which began in 2019 in so-called Area OS, uncovered a small cemetery dating to the eleventh c. CE onwards (Drzewiecki et al., 2021, 2022; Ciesielska, forthcoming). Mound OS, housing

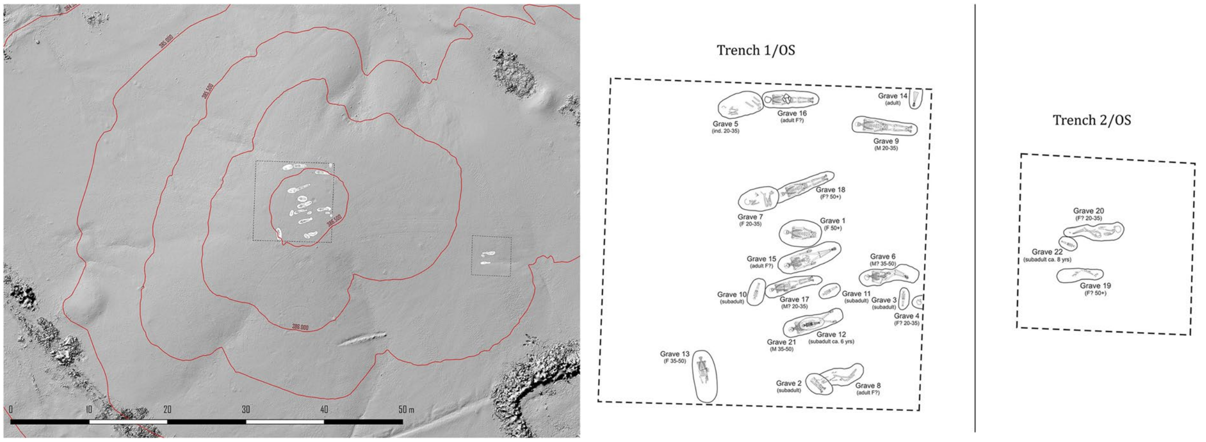

Fig. 2 Positioning of the cemetery on Mound OS and a plan of uncovered burials (M. Drzewiecki and J. Ciesielska)

the remains of seventh to tenth c. CE occupation, is located in the northern part of the site (Michalik, forthcoming). The last phase of human activity at the site comprises a necropolis extending over the top of the mound towards its foot to the north-east (Ciesielska, forthcoming) (Fig. 2). Human remains were found in Trench no. 1 (1/OS) and Trench no. 2 (2/OS). The cemetery contains no less than two dozen burials of adults of both sexes and children. Altogether, 22 graves were uncovered, containing the remains of at least 23 individuals (MNI = 23). All burials were interred in shallow oval pits, with no accompanying funerary structures. According to common Christian practice, most of the deceased were aligned along an E-W axis with their heads pointing west. While some remains at the cemetery on Mound OS were clearly placed in an extended supine position, others rest on either their right or left side, or even facing down (Fig. 3). At least two burials follow a N-S orientation instead of E-W. Some of the deceased must have originally been wrapped in shrouds or buried in clothing, but no other installations were identified within, or in association with, the burial pits. Only a single metal ring was clearly associated with one of the burials (SOBA_2019/OS1/B006). Some beads were also recovered from the fill of graves nos. 8, 10, and 15 (*see* Then-Obłuska & Dussubieux, 2023). However, as the burial units were not provided with any lining, and no clear boundaries of the pits could be identified, the association between the beads and the burials could not be established beyond reasonable doubt. Despite the fact that radiocarbon dating of two graves (nos. 15 and 16) at the cemetery on Mound OS yielded dates from the ninth and tenth centuries AD,[1] well within the period of the domination of Christian faith in the region, the heterogeneity of burial practices raised some questions regarding the cultural and religious affinity of the deceased and suggested potential multiculturalism of the local population.

Over the last few decades, isotopic research has made impressive contributions to our understanding of past populations in a much more direct way than traditional archaeological approaches (Britton, 2017), proving its applicability to the investigation of socioeconomic processes (*see, for example,* Alexander et al., 2015; Brusgaard et al., 2019), intra-communal diversity (Buzon et al., 2023; Ciesielska et al., 2021, 2023; Guede et al., 2017; Knudson & Stojanowski, 2008, 2020; Perez-Ramallo et al., 2022), and the interconnectedness of historical societies (Perry et al., 2017; Turner et al., 2009; Wang et al., 2023). Since the early 2000s, a number of bioarchaeological studies applying isotopic techniques to the investigation of subsistence strategies and mobility have been conducted within the Nile valley (Buzon & Bowen, 2010; Buzon & Simonetti, 2013; Buzon et al., 2023; Kozieradzka-Ogunmakin, 2020; Kozieradzka-Ogunmakin & Sołtysiak,

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[1] Grave 15 was dated to 1055.30 BP, ca. 944AD (83.9%) 1025AD, and grave 16 to 1200.30 BP, ca. 765AD (87.8%) 895AD; for details, see Drzewiecki et al. (2021).

Fig. 3 Selected burials from the cemetery on Mound OS with an overview of recorded burial manners (T. Michalik and J. Ciesielska)

2023; Retzmann et al., 2019; Schrader et al., 2019; Simonetti et al., 2021). Singular studies present data from Christian period sites, such as Kulubnarti (Sandberg et al., 2008), Ghazali (Ciesielska et al., 2023; Stark et al., 2022), or Ginefab school (Masoner et al., 2011), but none further south than the bend of the Nile at Abu Hamed. In fact, only a few samples from two sites in the southern part of modern Sudan, Al-Khiday on the White Nile (7000 BC–ca. sixth c. CE; *see* Iacumin et al., 2016) and Jebel Moya in southern Gezira (most burials dating to the Late Meroitic period; *see* Brass et al., 2019), have ever been analyzed. The population of medieval Alwa has, notably, been un-explored using such an approach, leaving a significant gap in our understanding of this period, early state formation in northeastern Africa, as well as isotopic research in the region. Nevertheless, based on existing research in the region, it is clear that such an approach promises to yield novel insights into the social life of the city of Soba, a key urban node in an increasingly cosmopolitan eastern African region.

Biogeochemistry of the Isotopic Studies of Migration

The principles of applying isotopic analysis of migration to archaeological remains have been explained in detail elsewhere (Bentley, 2006; Chenery et al., 2010; Lee-Thorp & Sponheimer, 2003; Montgomery, 2010; Price, 2023). The technique relies on comparing isotopic signatures retrieved from analyzed individuals to baseline values considered "local" for a particular region. Both oxygen and strontium are incorporated into dental enamel bioapatite, which forms during a single period in an individual's lifetime and is not subject to remodelling. Oxygen is incorporated into the skeleton predominantly through imbibed drinking water (Longinelli, 1984; Luz & Kolodny, 1989; Luz et al., 1984), with dietary water and atmospheric oxygen playing secondary roles (Sponheimer & Lee-Thorp, 1999; White et al., 2004). Oxygen isotope values can be reported relative to either Vienna Pee Dee Belemnite (VPDB) or Vienna Standard Mean Ocean Water (VSMOW) standards. The $\delta^{18}O$ local water range is often established based on 2σ variation from the sample mean; however, more robust measures of scale, such as the median absolute deviation (MAD), have been argued to be more reliable (Lightfoot & O'Connell, 2016).

Strontium isotope analysis ($^{87}Sr/^{86}Sr$) is routinely used to track human and animal movements (Evans et al., 2006; Ezzo et al., 1997), as $^{87}Sr/^{86}Sr$ varies geologically across space according to bedrock mineral composition and mineral age (Ericson, 1985; Faure, 1986). Strontium is found in bedrock but is released into local ecosystems through weathering processes and is passed from groundwater into the plants and animals consumed by humans (Bentley, 2006; Nelson et al., 1986). The assessment of migration and non-locality based on both $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values usually relies on the comparison of obtained values with a bioavailable $^{87}Sr/^{86}Sr$ baseline, preferably from local faunal samples, which may differ in composition from bulk rock and bulk soil values (Price et al., 2002; Sillen et al., 1998).

Regional Hydro-geological Background

The city of Soba sits on the eastern bank of the Blue Nile, ca. 25 km before the river's junction with its western counterpart. River waters typically possess strontium contents that are a weighted average of the composition of rocks across the drainage basin (Palmer & Edmond, 1992). The Blue Nile waters drain Cenozoic volcanic rocks with characteristically low average $^{86}Sr/^{87}Sr$ values at ca. 0.7060 (Krom et al., 2002; Palmer & Edmond, 1989; Talbot et al., 2000), which correspond to the low $^{87}Sr/^{86}Sr$ of the volcanic rocks of the Ethiopian Highlands, ca. 0.7030–0.7043 (Pik et al., 1999). Apart from the Nile itself, a number of hydrogeological entities that may be of interest to the present study can be distinguished around Soba as, even close to the river, water can also be acquired from groundwater wells and springs supplied by underground aquifers (Whiteman, 1971: 181–204; Vail, 1978: 53–56; Thorweihe, 1990). While $^{87}Sr/^{86}Sr$ values of ground waters away from the river are closely related to the geological composition of the immediate area, Nile water infiltrates neighbouring groundwaters up to ca. 20–25 km from the river, impacting their isotopic signatures and bringing them close to the weighted average of the Nile waters (Vrbka et al., 2008: 346).

The area around Khartoum is covered with Phanerozoic clastic sediments and evaporites of the Littoral Group, Umm Rawamba, and Giff Kebir Formation (Schlüter, 2008: Fig. 342) (Fig. 4). In general, Northern Gezira (the patch of very fertile land between the two Niles, as the Blue Nile terminates here in the form of an inland alluvial fan and floodplain deposits of the Mansur Formation; *see* Wycisk et al., 1990) is composed of Pre-Cambrian Basement Complex covered with Cretaceous sedimentary rocks (Wycisk et al., 1990) and Quaternary Gezira formations (Magboul, 1992; Williams and Adamson, 1980; Salama, 1987). The water table is located at a depth of only a few meters in the Upper Gezira Formation and up to 150 m in Cretaceous levels of the Lower Gezira Formation (Awad & Bireir, 1993; Awad et al., 1997; El Boushi & Abdel Salam, 1982; Magboul, 1992). The Nubian aquifer is capped here with overlying mudstone layer, much thicker in the central parts of the Gezira and thinning towards the rivers (Kudoda, 2011), where strong admixture of Blue Nile and White Nile waters to Gezira groundwaters can be observed (Vrbka et al., 2008: 345). However, due to higher transmissivity and partial confinement, water is relatively fresher and shows growing mineral dissolution along its flow paths away from the Blue and White Nile towards the central Gezira (Elkrai et al. 2004; Kudoda & Abdalla, 2015), with strontium values ~ 0.705–0.706 in its central part.

Local Oxygen Isotope Variability

Stable oxygen isotope values reflect the complexity of hydrological systems in each region. After the rainy season in the Ethiopian mountains, as much as 68–75% of Nile discharge comes from the Blue Nile and Atbara (Farah et al., 2000; Kebede et al., 2005) due to the White Nile undergoing a 40–50% evaporation. In the vicinity of Khartoum, the confluence point of the Blue and White Niles, modern Nile $\delta^{18}O_{dw}$ values average between 0.91 and 2.76‰ (Iacumin et al., 2016), while the weighted mean for the Nile waters is 2.51‰ (Farah et al., 2000). Rainy season flows in the Blue Nile have values as low as − 5.7‰.

Ground waters often show a large variation in $\delta^{18}O$ values. Iacumin and colleagues (2016), while conducting an isotopic study of human and faunal remains from the site of Al-Khiday in the area of Khartoum, investigated water from a number of wells, from Selima in the north to Khartoum in the south, obtaining $\delta^{18}O_w$ values with a range of − 10.29 to − 0.47‰.

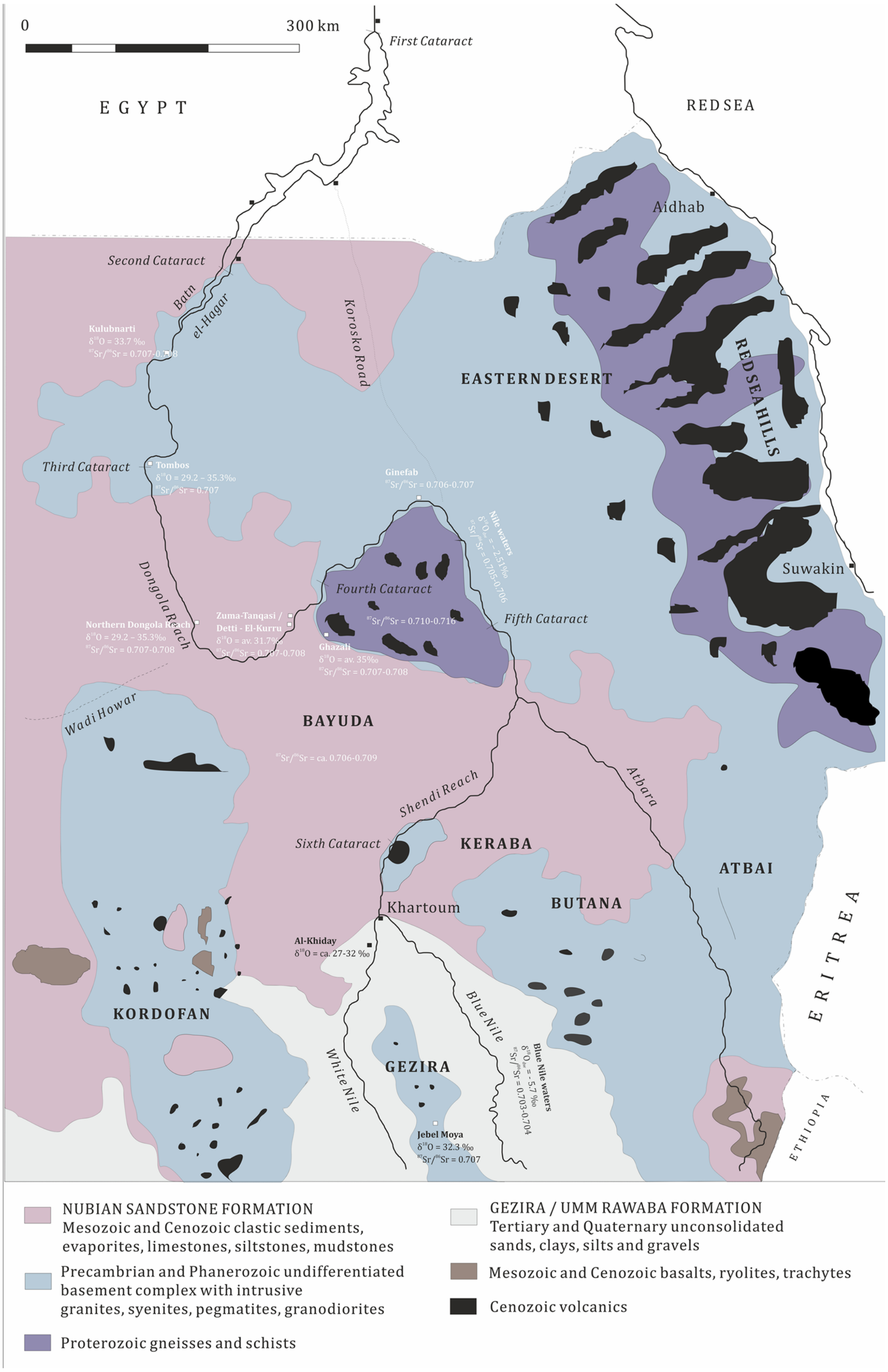

Fig. 4 Simplified geological map of Sudan with the distribution of most important geological units and known ^{87}Sr/^{86}Sr and δ.^{18}O values from previous archaeological studies in the region (J. Ciesielska, *after* Buzon et al., 2023; Sandberg et al., 2008; Masoner et al., 2011; Kozieradzka-Ogunmakin, 2020; Simonetti et al., 2021; Iacumin et al., 2016; Buzon & Simonetti, 2013; Iacumin et al., 1998) (J. Ciesielska, after Schlüter, 2008)

Precipitation generally occurs as summer monsoon rain, with a maximum in August. Seasonal rains between July and October in the Welega Province, where the sources of Blue Nile are located, were documented by Cosmas Indicopleustes as early as the sixth c. CE (Vantini, 1975: 2). Although recently trending towards lower values, long-term rain patterns for Khartoum average at 153 mm/a (Vrbka et al., 2008: 339). Mean $\delta^{18}O$ of rain water in Sudan is − 0.93‰. According to IAEA records, rainwater $\delta^{18}O_{dw}$ values measured in the area of Khartoum average at ca. − 1.6‰, though in parts of the year, values drop to − 4.06‰ (IAEA/WMO, 2021).

Isotopic Reconstruction of Paleodiet

The analysis of stable carbon ($\delta^{13}C$) isotope ratios from human skeletal remains is the most commonly applied technique for the investigation of palaeodiet (Ambrose, 1986; Bird et al., 2021; Katzenberg, 2018). Variation in $\delta^{13}C$ among terrestrial plants is primarily influenced by the photosynthetic pathway followed. C_3 plants, such as barley, rice, wheat, legumes most fruits and vegetables, as well as temperate wild grasses, shrubs, and trees, have $\delta^{13}C$ values ranging from − 35 to − 20‰, while C_4 plants, such as millet, sorghum, maize, sugarcane, and most tropical grasses, have values in the range of − 16 to − 9‰. Plant $\delta^{13}C$ values are also influenced by factors beyond dietary consumption, such as issues of animal foddering, climate, and physiological stress (Ambrose, 1991; Sealy et al., 1987; van Klinken et al., 2001). $\delta^{13}C$ in dental enamel bioapatite reflects dietary intake during the period of enamel formation (Hillson, 2003).

While the climate between the sixth and fourteenth c. CE was likely similar to that of today, reconstructed higher flood levels in the Nile between 600 and 1000 CE (Butzer, 1980), along with occasional reports from early travellers to the region, attest to more extensive vegetation (Wickens, 1975). Since the adoption of the *saqia* waterwheel in the Post-Meroitic period (fourth to sixth c. AD), C_4 crops such as domesticated sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), proso millet (*Panicum miliaceum*), and wild grasses, such as wild sorghum (*Sorghum arundinaceum*) and wild millet (*Setaria cf. sphacelata*), were widely consumed in Nubia, mostly in the form of *kisra*, a flat sorghum bread, attested by archaeobotanical evidence and an abundance of *dokat*, dedicated kitchenware (Cartwright, 1998; Ciesielska et al., 2021). Nubian diets, as inferred from isotopic studies, tend to exhibit clear C_4 contributions (Iacumin et al., 1998; Thompson et al., 2008), though it has been suggested that in the later periods more C_3 foodstuffs were incorporated into local menus through contacts with Egypt. The main cereal cultigens observed archaeobotanically in Soba were indeed sorghum and millet, considered staples for rainfed agriculture in the semi-arid tropics (van der Veen & Lawrence, 1991: 271; Cartwright, 1998: 260, 265).

In terms of animal exploitation, the prominence of domestic cattle and ovicaprines in archaeological contexts in Sudan can be attested from the Middle Holocene onwards (Chaix, 2019). Present in the Egyptian and Nubian Western Desert since ca. 7000 BC, both cattle and ovicaprines have long been a basis for human subsistence strategies in the region (Linseele, 2010). The importance of cattle dramatically increased during the Kerma period, when the animals took on a significant ritual role (Chaix, 1993). Cattle were still predominant in Napatan and Meroitic assemblages and domestic mammals are ubiquitous at Christian-period sites (Chaix, 1998; Osypińska, 2013). As inferred from previous research, domestic contexts in Soba are dominated by cattle and caprines (Chaix, 1998), however animal remains collected during the latest archaeological fieldwork at Soba attest to the presence of cattle, sheep, and goat, as well as a wide variety of wild game (Osypińska, forthcoming). Domesticated animals formed 98% of the skeletal assemblage, though the frequency of wild animals remains higher than in the northern kingdom of Makuria during the same period (Osypińska, forthcoming). Throughout the medieval period, a clear predominance of cattle herding over ovicaprines could be observed. Pig farming did not play a significant role in Soba. Meat consumption clearly focused on beef, which would have likely required large herds of cattle to maintain an adequate meat supply.

Materials and methods

Faunal Samples

A number of faunal samples were incorporated into the study for the construction of a local isotopic baseline. Altogether, 14 animal samples were analyzed, among them were bovids, caprines (goat/sheep species), and a single pig (*Sus scrofa*). Analyzed remains derived from various areas and contexts within the site excavated by the University of Warsaw team in 2019/2020 fieldwork season. Large ruminants, especially cattle, are not considered ideal for such studies due to their relative mobility and potential for long-distance trade. However, as inferred from detailed morphological analysis of Soba cattle performed by Marta Osypińska, (forthcoming), populations of domesticated cattle were markedly stable and homogeneous, suggestive of sustained breeding of local herds. Bovids and ovicaprids were previously used in isotopic investigations of mobility in the Nile valley and beyond (Kozieradzka-Ogunmakin & Sołtysiak, 2023). In addition to these samples, we also integrate our results for strontium and oxygen isotopes with a wider database published for Sudan and the Nile valley in general, as well as an extensive inquiry into the local hydrogeological background. In the future, we will aim to refine the local baseline by including smaller species in our analyses.

Human Samples

The assemblage of human samples analyzed within the current study comes from the 2019 excavations in Area OS in the northern part of the city of Soba. Two trenches were excavated within the so-called cemetery on Mound OS, Trench 1/OS located on top of a small mound and Trench 2/OS at its foot on the eastern side. Altogether, 22 graves were uncovered, containing the remains of at least 23 individuals (MNI = 23). The majority of burials (19 out of 22) was located in Trench 1/OS. Fourteen individuals from among this group were subjected to isotopic analysis of diet and mobility. Due to post-depositional factors (poor preservation of bone tissue), only dental enamel could be used for analysis. Standard osteological techniques were applied for the estimation of sex and age of the sampled human remains (Buikstra & Ubelaker, 1994). To address the provenience of analyzed individuals, whenever possible, second molars (M2s) were sampled, as their mineralization reflects the period after weaning, but before the age of nine (Hillson, 2003). The isotopic values of first molars may be impacted by the weaning effect (Wright & Schwarcz, 1998). The first permanent teeth begin mineralization during the pre-weaning period when diet reflects the $\delta^{18}O$ values of the mother's milk, which is higher in comparison to drinking water (Prowse et al., 2004; Roberts et al., 1998). However, the exact correction factor for this offset is still disputed in the Nile valley contexts. Considering the difficulty of establishing a dependable correction factor, transformed values accounting for nursing enrichment by + 0.6‰ (after Wright & Schwarcz, 1999) are provided in brackets (Table 1).

No clear change from pre- to postnatal enamel in terms of $^{88}Sr/^{86}Sr$ was clearly confirmed in recent research (Szostek et al. 2015). However, $^{88}Sr/^{86}Sr$ ratios may be reflective of weaning behaviors and include the signal of the mother, especially if she mobilized skeletal Ca (thus skewing Sr ratios in the bone) during fetal skeleton formation and lactation. Studies in pregnant women suggest that fetal Ca demand is mostly met by intestinal absorption, but in times of inadequate calcium dietary supply, the maternal skeleton becomes a resource to the developing fetus (Kovacs, 2005).

Strontium Isotope Analysis of Tooth Enamel Bioapatite

Tooth surfaces were mechanically cleaned using a Renfert dental sandblaster. Using a diamond-coated drill bit mounted onto a Dremel drill, approx. 10 mg of enamel powder was collected from either the lingual/palatal or buccal sides of the dental crown (depending on preservation). Samples of powdered enamel were immersed in 2 ml 65% HNO_3 in a covered Teflon beaker, resulting in their complete dissolution (after one hour) on a hotplate at 140 °C. After drying down, the samples were re-dissolved in 1.5 ml 2 M HNO_3 and the strontium elemental fraction was isolated following standard chemical procedures (*see* Pin et al., 2014). Each sample of isolated Sr solution was dried, dissolved in 2 ml 0.2% HNO_3 and diluted to 200 ppb Sr concentrations for further analysis. $^{87}Sr/^{86}Sr$ ratios were measured using a Nu Instruments NuPlasma HR MC-ICP-MS in the Department of Geological Sciences at the University of Cape Town using previously described procedures (*see* Scott et al., 2020).

International isotope standard NIST SRM987 with a reference value of 0.710255 was used here as bracketing reference to sample analyses (Waight et al., 2002). Results for four analyses of an in-house carbonate reference material (NM95), processed and measured with the batches of unknown samples in this study, yielded an average $^{87}Sr/^{86}Sr$ value of 0.708912 ± 0.000049 2σ (0.708922 ± 0.000013; 0.708935 ± 0.000013; 0.708878 ± 0.000013; and 0.708914 ± 0.000025, respectively), in good agreement with long-term results from

Table 1 Isotopic $\delta^{18}O$, $\delta^{13}C$, and $^{87}Sr/^{86}Sr$ data for the set of human samples from Soba cemetery on Mound OS and faunal samples from archaeological contexts in Soba; raw carbonate and drinking water values from the first molars (M1) or unidentified molars (M) were additionally corrected to account for nursing enrichment (indicated in brackets)

Sample ID	Context	Arrangement and orientation	Sex	Age	Tooth	C	$\delta^{18}O_{ca}$ VPDB (‰)	$\delta^{18}O_{ca}$ VSMOW (‰)	$\delta^{18}O_{ph}$ VSMOW (‰)	$\delta^{18}O_{dw}$ (‰)	$^{87}Sr/^{86}Sr$
SOBA_2019/OS1/B001	1/OS, grave 1	E-W, hW EXT/SUP	Female	50+	M	−1.24	0.77	31.71	22.58	1.79	0.708385
SOBA_2019/OS1/B004	1/OS, grave 3	E-W, hW EXT/SUP	Subadult	ca. 5 yrs	M1	0.73	0.85	31.80 [31.20]	22.66	1.92	0.708199
SOBA_2019/OS1/B006	1/OS, grave 5	E-W, hW CTR/ORS	(?)	20–35	M	−0.52	0.70	31.64	22.51	1.68	0.708979
SOBA_2019/OS1/B007	1/OS, grave 6	E-W, hW, fN FLX/OLS	Male (?)	35–50	M2	−1.04	7.40	38.55	29.28	12.66	0.707932
SOBA_2019/OS1/B008	1/OS, grave 7	E-W, hW, fS CTR/ORS	Female	20–35	M2	−1.24	−1.21	29.67	20.58	−1.46	0.708737
SOBA_2019/OS1/B009	1/OS, grave 8	ESE-WNW, hW, fS FLX/ORS	Female (?)	Adult	M2	−0.07	−0.02	30.90	21.78	0.49	0.707913
SOBA_2019/OS1/B010	1/OS, grave 9	E-W, hW, fN EXT/SUP	Male	20–35	M2	−0.14	1.88	32.86	23.70	3.61	0.707153
SOBA_2019/OS1/B013	1/OS, grave 12	?	Subadult	ca. 6 yrs	M1 (?)	0.93	1.52	32.49 [31.89]	23.34	3.03	0.707151
SOBA_2019/OS1/B016	1/OS, grave 15	E-W, hW VTR	Female (?)	Adult	M	−3.29	4.73	35.80	26.58	8.29	0.707610
SOBA_2019/OS1/B017	1/OS, grave 16	E-W, hW, fN SUP/EXT	Female (?)	Adult	M1	−0.34	5.85	36.96 [36.36]	27.72	10.13	0.708910
SOBA_2019/OS1/B018	1/OS, grave 17	ESE-WNW, hW	Male (?)	20–35	M2	0.35	−0.69	30.21	21.11	−0.60	0.707714
SOBA_2019/OS1/B019	1/OS, grave 18	ESE-WNW	Female (?)	50+	M3	−3.08	0.80	31.74	22.61	1.84	0.708338
SOBA_2019/OS2/B020	2/OS, grave 19	E-W, hW, fN OLS	Female (?)	50+	M	−1.78	2.93	33.94 [33.34]	24.76	5.69	0.706927
SOBA_2019/OS2/B021	2/OS, grave 20	E-W, hE, fN ORS	Female (?)	20–35	M2	−0.67	−1.40	29.47	20.38	−1.77	0.711521
Faunal (bovine)	1/OS					4.00	5.94	37.05	27.81	4.21	0.707435
Faunal (bovine)	1/OS					3.64	5.38	36.47	27.24	3.57	0.707493
Faunal (caprine)	1/OS					−5.87	5.28	36.36	27.14	3.45	0.706940
Faunal (caprine)	1/OS					0.46	5.21	36.29	27.06	3.37	0.707627
Faunal (bovine)	1/SH					2.53	4.76	35.82	26.61	2.85	0.707766
Faunal (caprine)	1/CW					−11.03	5.46	36.55	27.31	3.65	0.706796
Faunal (bovine)	1/CW					−0.70	4.43	35.48	26.27	2.47	0.706787
Faunal (bovine)	1/CS					1.75	1.53	32.50	23.35	−0.85	0.706961
Faunal (bovine)	1/CW					2.89	3.68	34.71	25.52	1.61	0.708141
Faunal (bovine)	1/CS					3.37	8.37	39.55	30.26	7.00	0.707364
Faunal (bovine)	1/CS					0.78	2.87	33.87	24.70	0.68	0.707353
Faunal (bovine)	1/SH					2.99	5.39	36.48	27.25	3.58	0.707277
Faunal (bovine)	1/CW					1.80	3.23	34.25	25.07	1.10	0.708098
Faunal (suidae)	1/CS					−1.11	0.46	31.40	22.27	−2.08	0.706919

this facility (0.708911 ± 0.000040 2σ; $n = 414$). All procedural blanks measured during this study are typical for this facility (elemental Sr < 250 pg) and negligible, indicating the validity of the analytical methodology.

Stable Carbon ($\delta^{13}C$) and Oxygen ($\delta^{18}O$) Isotope Analysis of Tooth Enamel Bioapatite

Teeth surfaces were cleaned in a similar manner as described above, using a Renfert dental sandblaster. Approx. 8 mg of enamel powder was collected for analysis. After washing with 1% bleach solution (NaClO) for 60 min and three cycles of rinsing with Milli-Q water followed by micro-centrifuging, a modified dilute acetic acid protocol was used (Ventresca et al., 2018). The samples, first treated with 1 ml of 0.1 M acetic acid for 10 min, were then rinsed again. Frozen for 24 h before being freeze-dried for another 4 h, resulting 2.5–3.0 mg of powder was weighed into borosilicate vials.

Gases produced as a result of a reaction with 100% phosphoric acid were analyzed using a Gas Bench II Interface coupled to a Thermo Delta V Advantage IRMS. Results were then normalized to international scales using standard reference materials (IAEA-603, $\delta^{18}O = -2.37‰$, $\delta^{13}C = 2.46‰$; IAEA-CO-8, $\delta^{18}O = -22.7‰$, $\delta^{13}C = -5.76‰$; USGS44 calcium carbonate, $\delta^{18}O = -13.8‰$, $\delta^{13}C = -42.1‰$; NBS18, $\delta^{18}O = -23.2‰$, $\delta^{13}C = -5.04‰$). Replicate analyses of standards indicate machine measurement error to be ca. ± 0.1‰.

Both stable carbon and oxygen values are reported relative to the V-PDB standard. $\delta^{18}O$ values were converted to the V-SMOW standard according to the formula provided by Sharp (2007). Drinking water ($\delta^{18}O_{dw}$) values were calculated directly from the $\delta^{18}O_{caVSMOW}$ values using the equation presented by Chenery and colleagues (2012). Calculation of $\delta^{18}O_{dw}$ for the faunal samples followed the conversion of $\delta^{18}O_{ca}$ to $\delta^{18}O_{ph}$ (carbonate- to phosphate-derived $\delta^{18}O$ values) according to the formula proposed by Delgado and colleagues (1995) for C*apra ibex* (as the best available approximation for the mathematical rendering of metabolic pathways in bovids), with uncertainty between 0.5 and 1.0‰.

Statistical analysis of collected results was performed in the R environment for statistical computing (R Development Core Team, 2021). The normality of sample distribution was assessed using Shapiro–Wilk test, while Pearson's correlation coefficient and Kendall's Tau were used to investigate the association between isotopic variables. Kruskal–Wallis *H* test was applied to determine if there were statistically significant differences between groups.

Results

Recorded $^{87/86}Sr$ ratios for the set of analyzed faunal samples range from 0.706787 to 0.708141 (Table 1). Human samples exhibit a wider spectrum of strontium signatures from 0.706927 to 0.711521. Five individuals appear outside the local range of 2 s.d. from the mean (0.706379–0.708355) (Fig. 5), their $^{87/86}Sr$ ratios exceeding 0.708355. Some of those individuals with seemingly "non-local" strontium ratios using this approach also yielded oxygen $\delta^{18}O_{ca}$ values which do not apparently align with the local oxygen isotope range. The most divergent non-local individual based on $^{87/86}Sr$ measurements (SOBA_2019/OS2/B021) is also an outlier when it comes to oxygen values (at. 29.5‰).

The mean $\delta^{18}O_{caVSMOW}$ value for human tooth enamel of the sampled individuals was 32.6‰, with values ranging from 29.5 to 37.0‰. Meanwhile, sampled fauna display values in the range of 31.4–39.6‰, with the highest value identified as an outlier using Tukey's 1.5IQR method (Lightfoot & O'Connell, 2016). Based on the conventional measure of 2σ from the average (35.7‰) to establish local range (32.7–38.0‰), at least six human individuals with low values appear to be non-local. With a median established at 35.9, the cut-off defined at ± 3MAD (33.1–38.7‰) excludes the six and another two samples, with all of the values being below the reference spectrum. The distribution of values from Soba shows high degree of negative skewness at − 0.89, despite a number of very high $\delta^{18}O$ values.

Human individuals possess values both higher and lower than the faunal average. The inclusion of both pre-weaning and post-weaning teeth may contribute to the variability seen in the sample, but the lack of any systematic difference in $\delta^{18}O$ values suggests that this factor cannot completely explain the large $\delta^{18}O$ range observed. Statistical analysis shows no correlation between oxygen isotope values and biological

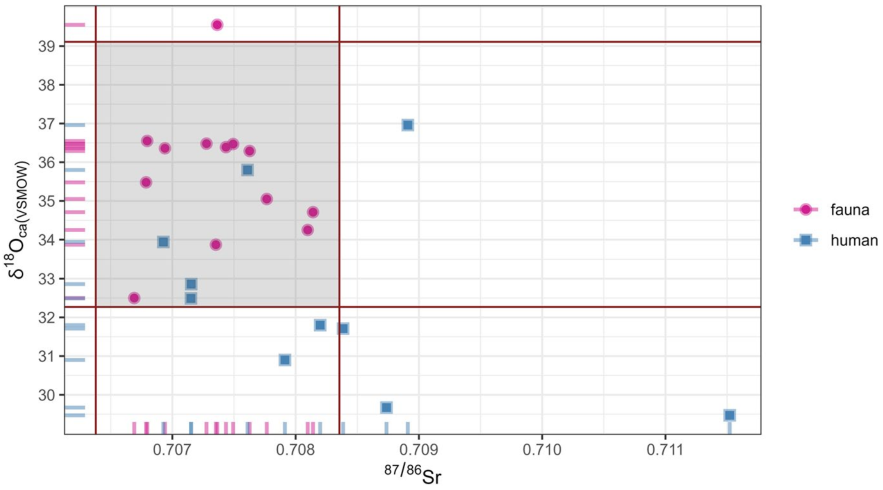

Fig. 5 Scatter plot of ^{87}Sr/^{86}Sr and δ.^{18}O$_{ca}$ values for human individuals disinterred from cemetery on Mound OS and faunal samples (by J. Ciesielska)

sex, age of the deceased, nor the period of their lives addressed by stable oxygen isotope values (as reflected in the difference in mineralization between first vs. second molars). Statistical comparison of the human and faunal groups showed significant differences in δ^{18}O. Shapiro–Wilk testing showed that neither human nor faunal δ^{18}O values are normally distributed. The non-parametric alternative for comparing means between group, Kruskal–Wallis test, showed that there was a statistically significant difference in oxygen values between human and faunal samples ($H(1)=8.5603$, $p=0.003436$). Reconstructed drinking water δ^{18}O values for the faunal assemblage yielded a range of − 0.9 to 7.0‰, averaging at 2.70‰. Human δ^{18}O$_{dw}$ values are far more diverse, covering the span of − 1.8 to 10.1‰ (ave. 3.00‰).

Both human and faunal samples are characterized by relatively high δ^{13}C$_{ap}$ values. Animals exhibit a wide range of values from − 11.0 to 3.6‰. Quite predictably, samples of ovicaprines yielded the lowest values with one specimen seemingly feeding almost only on C$_3$ plants. Three other ruminants enjoyed a mixed C$_3$-C$_4$ diet, while the diet of the other nine appears to have been completely dominated by C$_4$ plants. Humans exhibit even greater reliance on C$_4$ plants and/or produce derived from animals sustained on plants from the same group, their δ^{13}C$_{ap}$ values ranging from − 3.3 to 0.9‰. The statistical comparison of humans and fauna via Kruskal–Wallis test showed a significant difference in subsistence, with humans showing even higher δ^{13}C$_{ap}$ than bovids (at $p=0.02208$).

Discussion

An overview of published human and faunal strontium records paints a clear picture of the Nile valley isoscape, consistently associating known strontium signatures from archaeological contexts with river signatures along its course (Buzon & Simonetti, 2013; Buzon et al., 2023; Kozieradzka-Ogunmakin, 2020; Masoner et al., 2011; Retzmann et al., 2019; Sandberg et al., 2008; Simonetti et al., 2021). At 0.706–0.708, these values appear to be an explicit consequence of Blue Nile low values (between 0.703 and 0.706) mixing with White Nile high values (0.710–0.715) at their confluence in Khartoum. Despite the fact that bioavailable strontium ratios are the result of isotope mixing from various reservoirs, if the rule holds for the Main Nile tributaries, one would expect a similar association along the banks of the Blue Nile where Soba is located. Both human and faunal values (0.706787–0.708141 and 0.706927 to 0.711521, accordingly) are clearly elevated in relation to the known Blue Nile water values (at ca. 0.705–0.706; *see* Talbot et al., 2000) (Fig. 6). When considered alongside the backdrop of animal baseline, most of our human data fall in line with the established local range (0.706379–0.708355), suggesting that the disparity between Blue Nile water and our results do not necessarily indicate non-locality (the investigation of which is usually pursued through the application of isotopic oxygen and strontium analyses to archaeological populations). Instead, the obtained values may reflect the population's internal diversity and regional

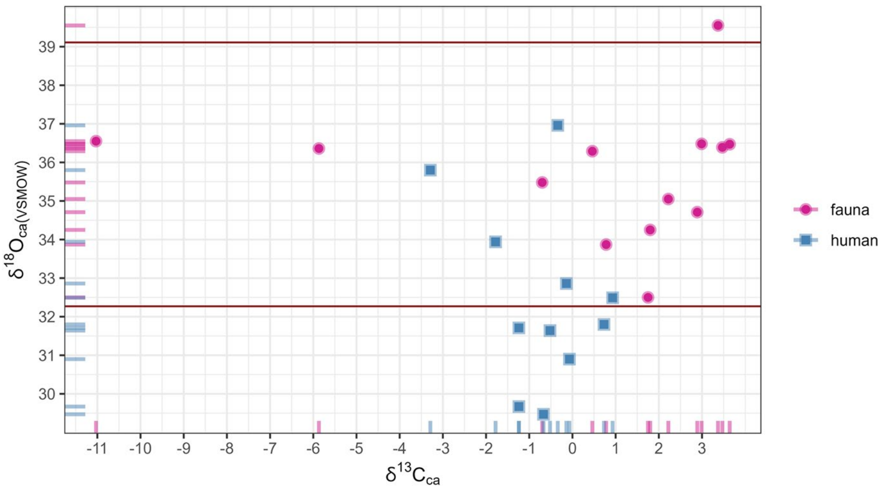

Fig. 6 Scatter plot of δ^{18}O and $\delta.^{13}$C values for human individuals disinterred from cemetery on Mound OS and faunal samples (by J. Ciesielska)

mobility, possibly associated with local subsistence strategies and economic models. That being said, only one individual (SOBA_2019/OS2/021) whose strontium signature of 0.711521 clearly points to non-local origins, probably came to Soba from outside the Nile valley. However, the exact provenience of this person cannot be established at present, as no reference studies have been conducted on either side of the river as of yet.

The congruence of human and faunal values suggests close co-existence of humans with cattle (constituting the core of our reference assemblage). According to Marta Osypińska, who analyzed faunal remains from the site, the morphology of bovine remains from Soba (small-sized, short-horned specimens) appears to suggest a very stable breeding of an homogeneous, crossbred population (Osypińska, forthcoming). The model of animal exploitation at Soba is very similar to ancient Kushite states (from Kerma to Napata and Meroe, *see* Chaix, 2011, Osypińska, 2018) with an economy based on cattle and, to a lesser extent, on smaller ruminants, which require extensive, good quality pasture with fixed water access (Osypińsk, forthcoming). In relatively humid conditions, cattle herders would have been preferably residential, moving seasonally to meet the annual needs of the animals (Tafuri et al. 2006: 399).

In addition to the elevated strontium ratios, all of the animals and a significant portion of the human individuals exhibit stable oxygen isotope signatures that are clearly higher compared to available reference data from the region. In the case of humans, oxygen isotope values may be affected by evaporation during water storage (e.g., in *zirs*, large ceramic vessels with thick, porous walls to keep the water cool) and handling (including brewing of *mizr* beer) (Butzer, 1976; Brettell et al., 2012), where evaporative loss increases δ^{18}O values, which would be reflected in the consumption of such products (Turner et al., 2009; White et al., 2004). However, the same cannot be said about the local fauna, possibly indicative instead of mixed water sourcing. It is thus suggested that markedly high oxygen isotope values observed among some of the inhabitants of Soba may relate to at least partial water intake from open reservoirs away from the river Nile and/or rain water consumption (at ^{87}Sr/^{86}Sr = 0.7092).

Seasonal transhumance is well-attested in Sudan, where specialized pastoral economies took on their shape no later than the first millennium BC (Linseele, 2010). During the period of the Meroitic states' dominance in the region (ca. 300 BC–350 AD), local people seem to have relied equally on animal husbandry (Bradley, 1992; Brass, 2015) and seasonal rain agriculture (Fuller, 2014). Movements of animal herders with their flock, exploiting the resources of the vast grasslands of Butana and Keraba to the east of the Blue Nile, depended largely on seasonal lakes forming in the savannah away from the alluvial plain, or so-called *hafirs*. A *hafir* is an artificially constructed water reservoir located in the bed of a *wadi,* a temporary water course, or on its banks, open in the direction of water runoff to collect water for later use after the rainy season is over (Negood Hassan

Bashir, 2018: 544). Deliberate entrapment of water permits the drainage of excess water during the wet season and its judicious distribution during the dry. The largest *hafir* at Abu Hereig holds water for up to 5 months (Nuha, 2019). Widespread use of *hafirs* was documented during the Meroitic period (ca. fourth c. BC to fourth c. AD) (Hinkel, 1991; Karberg, 2014; Scheibner, 2014; Varadzin et al., 2019), but similar water harvesting systems dating to the Christian and Islamic periods were recorded at Jebel Sabaloka in the Sixth Cataract region (Sukova & Cilek, 2012: figs. 17–18).

Modern Shaigiya tribes of the Western Butana Naqa region practice seasonal *wadi* cultivation in addition to rearing sheep, goats, cattle, and camels (Nuha, 2019). Sorghum constitutes the dietary staple, while its canes are often used for fodder. Both wells and *hafirs* are used as water sources. In the Naqa region, pastoralism is considered the main economic activity for accumulation of capital, while crop cultivation is a subsistence activity. Dairy products are used for domestic purposes only. During the rainy season, both animals and shepherds drink from *wadis*. Once they dry up, they drink from *hafirs* and finally from wells. Some *hafirs* are restricted for human drinking only and they are surrounded by fences to protect them from contamination by animals.[2]

Ephemeral lakes formed during the rainy season usually show higher $\delta^{18}O$ values when compared to the average values of rain in Khartoum and the associated groundwaters (Vrbka et al., 2008: 344). Standing water in open deliberate ponding areas is not only characterized by higher evaporation rates, but could have easily been influenced by aeolian sediment and precipitation, skewing the strontium values upwards as well (Woodward et al., 2015).

Subsistence Economy

Dominant exploitation of savannah grasslands instead of the agricultural resources of the alluvial plain should and does find reflection in both human and animal diets. Almost exclusive consumption of C_4 plants among Soba cattle, along with slightly more varied feed of the caprines, is not unusual and remains in agreement with previously conducted isotopic research on the main domestic species in eastern Africa, especially Nubia (Ciesielska et al., 2021; Copley et al., 2004; Iacumin et al., 1998; Thompson et al., 2008). Mostly subsisting on wild C_4 graminoids, during the dry season, cattle herds could have easily been fed leftover straw as fodder if and when needed. Sorghum, a Nubian cultivable staple whose straw constitutes a great feed, and most savannah graminoids both belong to the C_4 family, contributing to the high $\delta^{13}C$ signatures.

Noteworthy however is the almost complete human reliance on C_4 resources (likely in the form of a combination of plants and C_4-sustained animal produce) in their dietary regimes. Generally, high C_4 intake in Nubia (in relation to the Egyptian portion of the Nile valley) has previously been observed (Buzon & Bowen, 2010; Buzon et al., 2019; Thompson et al., 2008), but none as high as is indicated by the values exhibited by the deceased buried at Soba Cemetery OS. As previously mentioned, the results obtained within the current study attest to individuals' dietary intakes during the period of mineralization of their first and second molars, so between 2.5 and 3 years (for M1s) and around 9 years of age (for M2s), respectively. In pre-industrial societies of northeastern Africa, the period between 6 months and the third birthday is the time of weaning, when other foodstuffs are being introduced into the infants' diets (Dupras & Tocheri, 2007; Dupras et al., 2001). Cereal gruel is usually the staple during this period, alternating with milk produced by domesticated animals (Bourbou et al., 2013; Dunne et al., 2017, 2021; Garvie-Lok, 2001; Prowse et al., 2008). The consumption of a sorghum/millet gruel in tandem with C_4-fed animal derivatives could account for the signatures of human samples from Soba. Since herbivores incorporate most of their carbon from plants, the consumption of milk from C_4-sustained animals would result in higher $\delta^{13}C_{ap}$ in infants, as $\delta^{13}C_{milk}$ shows strong linear relationship with the percentage of consumed C_4 plants (Dupras et al., 2001; Richards et al., 2002). In the case of individuals whose M2s were tested, sorghum mash could have been replaced with *kisra* or a similar C_4 cereal staple along with varying consumptions of animal produce from C_4-consumming ruminants.

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[2] Interestingly, the oldest *hafirs* in the area of Western Butana are known as *Anaj Hafirs*, indicating their ancient origins (Nuha, 2019). *Anaj* is a term used to describe the descendants of the people who fled Soba upon its conquest by the Funj in the sixteenth c. AD.

Among the aforementioned Shaigiya tribes in the nearby Butana region, shepherds' main sustenance is *'asiida* (sorghum porridge) with milk and *gasheit* (a mixture of sorghum flour and water cooked over fire). High contributions of milk into the diet could also account for the observed δ^{18}O values. Higher δ^{18}O values of raw cow milk reaches up to 6.6–8‰ over drinking water, depending on the season (Ehtesham et al., 2015; Garbaras et al., 2019; Hamzić et al., 2019). Regular consumption of isotopically enriched animal milk could be responsible for increasing δ^{18}O values in humans during infancy when dental crowns mineralize.

Social Implications

By the end of the tenth c. when the Cemetery in Area OS was founded, the city of Soba was a regional power lauded by external visitors. The life of Soba denizens revolved around a religious center located on Mound B where the remnants of a cathedral and at least one other church structure were found by the British expedition in the 1980s (Welsby, 1998; Welsby & Daniels, 1991). While the city has long left behind its "wooden shack" phase and moved onto much sturdier brick architecture, some regions of the city, such as Area OS, were not used for residential purposes anymore and might have been taken over by squatters (indicated by the haphazard nature of the burial ground). The results of isotopic analyses indicate a very close relationship between individuals buried at Cemetery OS and domesticated animals, suggestive of an economy based on herding.

Nomads and pastoralists often develop symbiotic relations with settled communities (Brass, 2015; Sadr, 1991). As rightly pointed out by Alfredo González-Ruibal, mobile communities tend to resist complete integration with state structures and governance associated with sedentariness that is largely incompatible with the way they relate to the landscape and resource management (González-Ruibal, 2022; González-Ruibal & de Torres, 2018). Instead, they choose to occupy so-called liminal ecologies, participating in more than one environment at the same time. Yearly movement could have involved a section of the residential group (not necessarily age- or gender specific) resulting in strontium variation between individuals as the consequence of a continual relation with the landscape. In this model, mobility is not only adopted by male herders. In contrast, they appear to be accompanied by their families, including children, subsisting on the resources available at any given time (Hemer et al., 2013; Evans et al., 2006; Prowse et al., 2008), something perhaps also seen in our data as no patterning in isotopic values according to either sex or age of the deceased could be traced.

As previously mentioned, the interments at Cemetery OS exhibit relatively large diversity in terms of burial manner. However, observed patterning does not correspond in any way to the internal diversity of our sample in terms of either strontium, oxygen, or carbon values. This in turn may indicate that the burial ground was not used exclusively by any particular group of people, such as the local pastoral groups engaging in the semi-sedentary way of life. Instead, by the break of the tenth and eleventh centuries this area, previously in the middle of the medieval metropolis, was clearly left derelict and re-purposed for a cemetery, possibly used by very different people who happened to inhabit the district. Previous investigations indicate that at least in the Early Christian period (between the sixth and ninth c. AD) the eastern suburbs of the city (especially so-called Area Z and Area UA) were allocated for mortuary purposes (Welsby, 1998; Welsby & Daniels, 1991). Whether the establishment of Cemetery OS in the middle of the capital was a purposeful act associated with spatial re-arrangement of the city by its rulers or a completely unauthorized construction on the part of its inhabitants remains currently unanswered and requires further research into the process of urban and social transformations over the period of the city's existence.

Conclusions

Against all expectations for the medieval Nubian states and its urban centers, whose economies were thought to be largely reliant on the potential of the river Nile and its agricultural resources, our data attest to enduring agro-pastoral symbiosis and synchronic interaction of various economic activities in the urbanized context of medieval metropolis.

After the ninth c. CE the structure of the Soba metropolis changed towards the concentration of authority into one seat of power, probably revolving around the main ecclesiastical complex (*see*

Welsby & Daniels, 1991). However, in contrast to other contemporary metropoles, such as Faras and Old Dongola in the north, Soba was never provided with any fortifications and enjoyed an open plan, facilitating its continuous connections with the surrounding hinterland and promoting its status as an economic hub, attracting goods from rural areas and facilitating regional and international trade. While the fertile Nile soil supported a prosperous agricultural sector, contributing to the overall economic stability of the region, the city appears to be largely reliant on its livestock as a source of subsistence, wealth, and trade commodities. Pastoralists often moved their herds to find fresh grazing grounds, while sedentary communities engaged in settled agriculture. These diverse communities interacted with each other, exchanging goods, services, and cultural influences. The diversification of economic activities provided a level of sustainability and resilience to the local economy. By relying on a combination of agricultural and pastoral practices, the Alwans were better equipped to adapt to changes in climate, resource availability, and trade patterns.

Variability in economic activity in north-eastern Africa is clearly linked to the site's location and to the seasonality of the available food resources (Salvatori and Usai 2019: 269). However, the predominant reliance on C_4 foods combined with seasonal mobility of at least a portion of local population in order to provide sustained supply of basic commodities speaks to the complexity of local urban economy and the entanglement of the Nile valley and its hinterland. Further contextualization of isotopic data is hoped to shed light on environmental and social forces that ensure and/or facilitate such adaptations.

Author Contribution Joanna Ciesielska was responsible for the study conception and design. Data collection and analysis were performed by Joanna Ciesielska. Material preparation was performed by Petrus Le Roux, as well as Mary Lucas and Erin Scott, supervised by Patrick Roberts. Funding was acquired by Joanna Ciesielska and Patrick Roberts. The first draft of the manuscript was written by Joanna Ciesielska and reviewed and edited by Patrick Roberts. All authors read and approved the final manuscript.

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Code Availability Not applicable.

Declarations

Competing Interests The authors declare no competing interests.

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