The Provenance of Ancient Cotton and Wool Textiles from Nubia: Insights from Technical Textile Analysis and Strontium Isotopes

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Abstract

Late antique and medieval cotton and wool textiles found in the middle Nile Valley (Nubia, northern Sudan) were analysed for their technical characteristics and strontium (Sr) isotope composition. All wool textiles exhibit Sr isotope signatures consistent with the isotopic background of the region studied and are considered to be of local origin. However, a medieval wool kilim from Meinarti shows technical and aesthetic features suggesting its foreign Maghreb provenance. As this fabric dates back to the occupation of Meinarti by the Beni Ikrima tribe, it is suggested that the kilim was woven by the Beni Ikrima people from local Nubian raw material. The cotton samples tested come from abroad and document trade with the oases of the Egyptian Western Desert, the west coast of India, and perhaps also with the Arabian Peninsula or Pakistan.

Keywords

wool textiles – cotton textiles – provenance – strontium isotopes – late Antique period – medieval period – Sudan

1 Introduction

In preindustrial times, textile production was a long and demanding process that combined environmental resources, technical knowledge, and social organisation (Good 2001; Strand et al. 2010). Archaeological textiles are thus informative on multiple levels: they reflect the technical skills of the weaver and the material at his or her disposal but can also provide insights on clothing traditions and give direct information on the wearer of the finished cloth, including his or her status, gender, and age (e.g. Barber 1991; Costin 1993; Brumfiel 1996). Finds of ancient textiles can also provide evidence of the development of technologies and exchange economics (e.g. Crawford 1973; McCroriston 1997; Ryan et al. 2021).

Studies of archaeological textiles in Sudan were initiated in the first half of the 20th century (Crowfoot 1921). Since then, several studies have been conducted describing textiles found during numerous excavations in the middle Nile Valley (Crowfoot 1931; Griffith & Crowfoot 1934; Bergman 1975; Mayer-Thurman 1979; Adams 1996). The main fibres attested in archaeological evidence were wool and cotton; linen also appeared quite often in textile assemblages but in smaller quantities. Silk was never produced in Sudan; it appeared only among imported textiles. The threads were traditionally spun in S-direction (created by an anti-clockwise rotation of the spindle) and woven into tabbies and weft-faced tabbies (e.g. Bouchaud et al. 2018; Yvanez & Woźniak 2019), sometimes decorated with bands or stripes (usually in two different shades).

The distinction between locally produced textiles and imported ones is sometimes delicate to assess, as tabbies and weft-faced tabbies are among the most common weaves in textile production, and in the vast majority, the textiles are preserved as small, undecorated fragments. The spinning direction remains an uncertain criterion (Bouchaud et al. 2019), as the presence of spinners with different spinning traditions among, for example, pastoral communities cannot be excluded. Therefore, additional analyses are necessary, and in particular strontium isotope measurements, as Sr isotopes constitute the most accurate tool for confirming the local vs non-local origin of textiles (Benson et al. 2006; Frei et al. 2009; Frei 2014; Kiseleva et al. 2021). Our study focuses on selected...
archaeological cotton and wool textiles found in the middle Nile Valley (Fig. 1). The novelty of the study is its interdisciplinary approach taking into account both Sr isotope data and information resulting from technical analysis of finished handicraft products.

2 Strontium Isotopes in Archaeological Research

Strontium isotopes are widely used in archaeological studies as an effective method for investigating the mobility of past human populations (e.g. Grue et al. 1997; Bentley et al. 2003; Price et al. 2004; Montgomery 2010; Szczepanek et al. 2018), tracking the migration of archaeofauna (e.g. Hoppe et al. 1999; Britton et al. 2009; Evans et al. 2019), and identification of the origin of food and various archaeological materials, including stone tools, glass, and textiles (e.g. Freestone et al. 2003; Benson et al. 2006; Frei et al. 2009; Degryse et al. 2010). The usage of Sr isotopes as a provenance tracer requires knowledge of spatial variations in the Sr isotope composition ($^{87}\text{Sr}/^{86}\text{Sr}$) within the geological substrate and environment at a local and regional scale (e.g. Evans et al. 2010; Bataille & Bowen 2012; Zieliński et al. 2021). The key issue in interpreting the Sr isotope data of ancient textiles is their provenance, i.e. whether they are of local or imported origin. Wool and cotton represent fibres of animal and plant origin, respectively, hence the analysis of isotopic data requires a separate approach and taking into account the isotopic composition of various elements of the natural environment. During the Sr uptake and metabolic processes in plant and animal tissues, there is no Sr fractionation (Poszwa et al. 2004; Montgomery et al. 2007; Flockhart et al. 2015), hence the isotopic compositions of both animal tissues and plant material are the results of mixing of strontium derived from two basic reservoirs: the geological substrate (together with the soil) and water (surface water, groundwater, atmospheric water) (e.g. Lengfelder et al. 2019; Toncala et al. 2020). However, the contribution of these reservoirs towards the Sr isotope composition of tissues is naturally different in plants and animals. As a consequence, in a given area plant and animal tissues usually

**Figure 1** Simplified geological map of northern Sudan (after Merla et al. 1979, modified). Red asterisks indicate places where the investigated wool and cotton textiles were found. Numbers refer to the samples listed in Table 1. Inset shows the location of the study area.
differ slightly in their isotopic composition (Blum et al. 2000; Poszwa et al. 2004; Maurer et al. 2012). Even at the same location, there is variability in \(^{87}\text{Sr}/^{86}\text{Sr}\) ratios within various types and species of plants (Poszwa et al. 2009; Britton et al. 2020; Zieliński et al. 2021). Unfortunately, so far no Sr isotope studies have been performed on raw materials of wool and/or cotton textiles coming from controlled environmental experiments.

3 Materials

The cotton and wool samples investigated in the present study are listed and summarized in Table 1. From an archaeological point of view, the destructive nature of the isotopic measurements is an important criterion to take into account when sampling. Even if the required amount of fibre is minimal (typically between 100 and 150 mg), the dry and desiccated state of preservation of the textiles requires the selection of at least one to two square centimetres of the fabric (depending on the fibre) to make the analysis feasible. Four samples (NT1–NT4) were collected from textiles retrieved in recent excavations in the 4th cataract area (Zurawski 2010) and made available to the authors by the Polish Academy of Sciences. The three other samples (NT5–NT7) have been obtained from collections of the Sudan National Museum and the National Corporation for Antiquities and Museums, Khartoum. Except for sample NT7, all samples were taken from textiles found in a funerary context. Despite their limited number, the selected textiles are representative of the two most common fibres used in Antique and Medieval Sudan, namely wool and cotton (Adams 2007; Yvanez & Wozniak 2019). For each type of fibre, samples were selected which were presumed to be local as well as imported products. All textile fragments selected for isotopic analysis were well preserved showing no signs of degradation or fibre decomposition. Therefore, a possible secondary replacement of endogenous Sr in wool and cotton fibres by exogenous Sr from the soil is very unlikely and may be neglected. Textile preservation is generally not a straightforward process but is subject to various components and environments (e.g. Lipkin et al. 2021). In Nubia, the arid environmental conditions of the past two millennia have certainly favoured the general good preservation of ancient textiles at archaeological sites.

3.1 Wool Samples

Sample NT1 was taken from a warp-faced tabby, woven with S-spun threads, with a density of 14–16 warps for 8 wefts/cm (Fig. 2A). The warp alternates cream and brown threads which create cream stripes of various widths on a brown ground. The textile fragment was retrieved at the bottom of the funerary chamber found in the cemetery (El-Ar 1, tumulus 24) located near the El-Ar village in the Shamkiya district (Fig. 1). It is one of the very few decorated fragments found in the cemeteries at El-Ar. The El-Ar necropolis was dated to the 2nd–3rd centuries CE (Zurawski 2010).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>Coordinates</th>
<th>Context number</th>
<th>Date</th>
<th>Fibre</th>
<th>Spinning direction</th>
<th>Weave</th>
<th>Decor</th>
<th>(^{87}\text{Sr}/^{86}\text{Sr})</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT1</td>
<td>El Ar 1 cemetery, tumulus 24</td>
<td>19°27′30.2″ N, 32°54′42.4″ E</td>
<td>PAS, inv. 27/2008–09</td>
<td>2nd–3rd c. CE</td>
<td>wool</td>
<td>S</td>
<td>Warp-faced tabby</td>
<td>Stripes</td>
<td>0.707781 ± 45</td>
</tr>
<tr>
<td>NT2</td>
<td>El Ar 4 cemetery, grave 1</td>
<td>19°27′46.9″ N, 32°56′07.1″ E</td>
<td>PAS, inv. 2/2007</td>
<td>6th–15th c. CE</td>
<td>wool</td>
<td>S</td>
<td>Tabby</td>
<td>None</td>
<td>0.708389 ± 27</td>
</tr>
<tr>
<td>NT3</td>
<td>El Ar 4 cemetery, grave 9</td>
<td>19°27′46.9″ N, 32°56′07.1″ E</td>
<td>PAS, inv. 27/2007</td>
<td>6th–15th c. CE</td>
<td>cotton</td>
<td>S</td>
<td>Weft-faced tabby</td>
<td>None</td>
<td>0.708427 ± 15</td>
</tr>
<tr>
<td>NT4</td>
<td>KK1 cemetery, tumulus 2</td>
<td>19°27′12.1″ N, 32°55′08.5″ E</td>
<td>PAS, inv. 92/2008–09</td>
<td>2nd–5th c. CE</td>
<td>cotton</td>
<td>Z</td>
<td>Resist-dyed</td>
<td>Tabby</td>
<td>0.708624 ± 74</td>
</tr>
<tr>
<td>NT5</td>
<td>4th cataract?, mummy 0005</td>
<td>?</td>
<td>NCAM</td>
<td>6th–15th c. CE</td>
<td>cotton</td>
<td>Z</td>
<td>Tabby</td>
<td>None</td>
<td>0.708645 ± 87</td>
</tr>
<tr>
<td>NT6</td>
<td>4th cataract?, mummy 0004</td>
<td>?</td>
<td>NCAM</td>
<td>6th–15th c. CE</td>
<td>wool</td>
<td>S</td>
<td>Tabby</td>
<td>None</td>
<td>0.707853 ± 29</td>
</tr>
<tr>
<td>NT7</td>
<td>Meinarti, building VII</td>
<td>21°43′34.7″ N, 31°11′22.8″ E</td>
<td>SNM, inv. 18135</td>
<td>14th c. CE</td>
<td>wool</td>
<td>Z</td>
<td>Slit-tapestry (kilim)</td>
<td>Ornamented bands</td>
<td>0.707505 ± 48</td>
</tr>
</tbody>
</table>
Sample NT2 was collected from a shroud fragment recovered in the Christian cemetery at El-Ar (El-Ar 4, grave 1). The wrapping consisted of a dark brown tabby (Fig. 2C), evenly woven with S-spun threads, with a density of 8–9 warp threads and 7 weft threads/cm. Such woollens were most probably used as mantles, blankets, and often reused as shrouds.

Sample NT6 was collected from a partially preserved shroud, wrapping a naturally mummified body. The fabric, very desiccated, is a coarse wool tabby, woven with S-spun brown wool threads (density is 8 threads/cm both in warp and weft) (Fig. 2B). The extended body of the mummy was in a supine position, with hands placed on the pelvis, indicative of a Christian burial (6th–15th century CE).

Sample NT7 was collected from an extraordinary textile – a 14th century CE wool kilim (Wozniak & Czaja 2020), woven in slit-tapestry technique, which creates the same decor on both sides. The fabric has a ‘tight’ close weave. Its density is 7 warp threads/cm and 32 weft threads/cm. The cream-coloured warp is Zs-plied; the weft is Z-spun. The investigated piece displays a bright banded decoration on a red ground, with various geometrical and floral patterns in green, blue, orange, yellow and pink (Fig. 3). The textile was found in 1963 in Meinarti (Adams 2002), a town located near the 2nd cataract (Fig. 1). Its numerous
fragments (over 50) were stored in the Sudan National Museum (No. SNM-18335) until 2017 when it was submitted to conservation.

3.2 Cotton Samples

Sample NT3 was collected from a fragment of a weft-faced tabby with a density of 11 warps for 19 wefts/cm. All the threads of golden shade are S-spun and the fabric is evenly woven (Fig. 4A). The warps are thinner than the wefts. The fabric represents a medium-quality cloth, rather common in archaeological assemblages in the middle Nile Valley. The textile was retrieved from the Christian cemetery in El-Ar (El-Ar 4, burial 9).

Sample NT4 was collected from small textile rags retrieved from a Late Antique burial at El-Ar (site KK1, tumulus 2). The fragments were originally part of a fine-quality cotton tabby (22–24 threads/cm). The threads, shiny white, are Z-spun and there are fragments with traces of blue, green, and red decor. The presence of bi-coloured portions of threads along with undyed ones points to the application of a resist-dyed decoration (Fig. 4B).

Sample NT5 was provided by the National Corporation for Antiquities and Museums (NCAM), Khartoum. It was collected from the burial of a naturally mummified body of uncertain provenance. The textile, much desiccated, was a cotton tabby of low density (8 warps × 8–9 wefts/cm), woven from Z-spun threads of golden shade (Fig. 4C). The supine position of the mummy, with hands on the pelvis, points to a Christian burial (6th–15th century CE).

4 Methods

The analytical part of this work, including chemical pre-treatment, separation of Sr and measurements of Sr isotope ratios was performed in the Isotope Laboratory of the Adam Mickiewicz University at Poznan, Poland. Sample preparation and Sr separation were done in a Class 100 cleanroom; all acids were ultrapure. Before dissolution, the textile samples (90–140 mg) were cleaned following the procedure described by Frei et al. (2009). The cleaned wool material was dissolved in a 1:1 mixture of 30% HNO3 and 30% H2O2. The cleaned cotton textiles were placed in porcelain crucibles and burned at 500°C. The ash was digested in 65% HNO3 before preparation for isotope measurements. The miniaturized chromatographic technique described by Pin et al. (1994) was applied for Sr separation. Some modifications in the column size and concentration of reagents were introduced by Dopieralska (2003). Strontium was loaded with TaCl5 activator on a single Re filament and analysed in dynamic collection mode using a Finnigan MAT 261 mass spectrometer. During this study, the NIST SRM 987 Sr standard yielded 87Sr/86Sr = 0.710232 ± 11 (2σ mean on ten
analyses). The total blanks of the procedure were less than 80 pg. The $^{87}\text{Sr}/^{86}\text{Sr}$ values were corrected to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$. The Sr results for samples were normalized to the certified value of NIST SRM 987 = 0.710240.

5 Geological and Strontium Isotope Background

In its course between the 2nd and 5th cataracts, the Nile River flows across an area where Precambrian rocks are widely exposed (Fig. 1). They represent a fragment of the Arabian-Nubian Shield which is composed of a large variety of magmatic and metamorphic rocks, separated by suture zones with small occurrences of ophiolites and deep-water sedimentary rocks (Shackleton 1994; Stern et al. 1994; Stern & Abdelsalam 1998). West of the Nile Valley, the Precambrian igneous rocks are bordered by a belt of sedimentary rocks, predominantly Silurian sandstones. In the entire region, the Precambrian and Palaeozoic rocks are unconformably overlain by horizontal strata of the Nubian sandstone, a lithological unit widespread across North Africa, which includes continental, estuarine, and marine, mainly sandy sediments (Medani 1975). In Sudan, these rocks are considered predominantly Cretaceous in age. Nubian sandstones have been mostly removed by erosion in northeastern Sudan. They form extensive exposures in the Bayuda Desert and the area west of the Nile (Fig. 1). In the area south of Abu Hamad, where the Nile forms a great bend, first flowing northward, then southwest for over 200 km, there are several

**Figure 4**

(A) Fragment of cotton tabby, sample NT3 (photograph by M. Wozniak, courtesy of the Institute of Mediterranean and Oriental Cultures of the Polish Academy of Sciences); (B) Bi-coloured threads from the cotton tabby, sample NT4 (photograph by M. Wozniak, courtesy of the Institute of Mediterranean and Oriental Cultures of the Polish Academy of Sciences); (C) Fragment of cotton tabby woven from Z-spun threads, sample NT5 (photograph by M. Wozniak, courtesy of the National Corporation for Antiquities and Museums)
occurrences of Tertiary basaltic rocks that intruded into the Precambrian and Cretaceous substrate. The youngest sediments of northern Sudan are represented by alluvial Holocene muds, silts, and sands forming the floodplains in the Desert Nile Valley, as well as infilling of tributary wadis and dune sands distributed on the surface in the entire region.

The geochemistry of the Precambrian basement rocks of northern Sudan has been extensively studied in the past. However, Sr isotope data are mostly available from volcanic rocks (basalts, andesites) which occur as subordinate elements within the basement. Their Sr isotope signatures are unradiogenic and range from 0.7024 to 0.7071 (Stern et al. 1991; Abdelsalam & Stern 1993; Reischmann & Kröner 1994). In contrast, the predominating acid metamorphic and plutonic rocks are characterized by radiogenic ratios from 0.7158 to 1.0039 (Harms et al. 1990; Stern et al. 1994). In contrast, the predominating acid metamorphic and plutonic rocks are characterized by radiogenic ratios from 0.7158 to 1.0039 (Harms et al. 1990; Stern et al. 1994). The clastic material of the Nubian sandstone, which is recycled from the basement rocks, yields a pattern of Sr isotope signatures that corresponds to that of the Precambrian basement, with two group values around 0.7070 and 0.7160, respectively (Padoan et al. 2011). Consequently, these two groups of Sr isotope ratios were also recognized in detrital material eroded during the Pleistocene and Holocene and accumulated in the wadis.

In contrast to the geological substrate of northern Sudan, which is composed of rocks and sediments having both unradiogenic and radiogenic Sr isotope signatures, the alluvial sediments of the Desert Nile and its water are characterized by exclusively low, unradiogenic ratios (Fig. 6). This is because, after the end of the African Humid Period (ca. 4.5 ka B.P.), when the modern hyper-arid climatic regime began, the sediment load of the Nile became dominated by material delivered by the Blue Nile and Atbara rivers which drain Cenozoic volcanic rocks in the Ethiopian Highlands (Padoan et al. 2011; Woodward et al. 2015). As a consequence, alluvial sands and floodplain muds in the Desert Nile Valley have an unradiogenic composition with signatures around the Sr isotope ratio of the modern Nile water (0.7062), measured downstream of the 3rd cataract by Gerstenberger et al. (1997). However, it should be noted that the relatively wide range of isotopic signatures of floodplain deposits, from 0.7047 to 0.7076, results from temporal changes in the composition of the Nile mud. While the Nile mud exhibited lower Sr isotope ratios (0.7052–0.7057) just after the African Humid Period, it yielded much higher signatures (0.7058–0.7076) between ~1000 BCE and ~500 CE (Woodward et al. 2015).

### 6. Provenance of Wool Textiles

#### 6.1 Evidence from Technical Textile Analysis

From a technical point of view, samples NT1, NT2 and NT6 exhibit features considered to be characteristic of locally produced textiles. All of them are simple wool tabbies made of single S-spun threads with a rather low density. The undyed wool fibres of samples NT2 and NT6 are coarse and dark, whereas cream and brown threads alternate in the warp of sample NT1. Interestingly, cream-coloured wool appeared in a rather limited quantity in the textile assemblages found at El-Ar. The low presence of this type of wool may be related to the genetic characteristics of the local flock (more brown sheep, less cream sheep), or cream wool may have been imported from other areas.

In contrast, sample NT7 differs significantly from the other wool samples by the use of Z-spun threads, the application of the split-tapestry technique developing a rich decorative repertoire, and the variety of the colour palette. All these elements point to foreign production. The use of lac dye is also unusual for local textiles since the Nubian dyers worked typically with madder (Wozniak et al. 2021). Recently, Wozniak & Czaja (2020) linked this kilim to a nomadic culture of the Maghreb. A few written sources and archaeological evidence confirm the occupation of Meinarti by a foreign pastoral community, the Beni Ikrima tribe, in the 14th century CE, corresponding to the cultural layer in which the kilim was found.

#### 6.2 Isotopic Evidence

The Sr isotope composition of the investigated ancient wool textiles from Sudan is presented in Table 1 and Fig. 5. The four samples yield unradiogenic Sr isotope signatures, grouped within a relatively wide range between 0.7075 and 0.7084.

The simplest and, at the same time, direct way to recognize the provenance of wool is to compare its Sr isotope composition with isotopic signatures of sheep or goats. Numerous Sr isotope data of Ovis/Capra remains (difficult to distinguish from each other in archaeological bone material) are known from several historical sites located along the Nile Valley in northern Sudan, between the 2nd and 4th cataracts (Fig. 5). However, this fauna has been recovered from historical sites older than the wool textiles tested during the present study. Buzon & Simonetti (2013) and Schrader et al. (2019) provided more than two dozen \(^{87}Sr/^{86}Sr\) ratios for Ovis/Capra remains from the Kerma to Napatan (~2500 BCE to ~500 BCE) periods. In northern Sudan, downstream of the 3rd cataract, where the Nile
drains a radiogenic Precambrian bedrock, the Sr isotope signatures of the Ovis/Capra remains vary within a relatively wide range between 0.7068 and 0.7082. It should be noted, however, that among the ten investigated samples there was also a single sheep with a significantly more radiogenic ratio of 0.7109. This signature deviates so much from the isotopic composition of the entire archaeofauna known from northern Sudan that it seems justified to speculate a non-local origin of this sheep. More to the south in the Nile Valley, upstream of the 3rd cataract, where the river crosses the Nubian sandstone formations, the sheep remains appear to have slightly less radiogenic compositions but are still within the range characteristic for northernmost Sudan (Fig. 5). Very recently, Osypinska et al. (2021) reported a single Early Holocene (~4000 BCE) sheep with a \(^{87}\text{Sr}/^{86}\text{Sr}\) value of 0.7075 from Affat (a prehistoric site located 100 km downstream of the 4th cataract).

Strontium isotope signatures of the three investigated wool textiles (NT1, NT6, and NT7) are consistent with the Sr isotope composition of ancient Ovis/Capra tissues from the Desert Nile Valley (Fig. 5). So it seems very likely that wool fibres of these textiles may come from northern Sudan. It is also possible that the sample NT2 with a \(^{87}\text{Sr}/^{86}\text{Sr}\) ratio of 0.7084 is also of similar origin. Admittedly, this signature is slightly more radiogenic than those of prehistoric sheep from northernmost Sudan, north of the 2nd cataract, but it still falls within the range of Sr isotope composition of cattle and humans from the Desert Nile Valley (Buzon & Simonetti 2013; Osypinska et al. 2021).

7 Provenance of Cotton Textiles

7.1 Evidence from Technical Textile Analysis

Although the spinning direction is not a completely unequivocal criterion (Bouchaud et al. 2019), it is often characteristic of a specific textile tradition in a given part of the ancient Old World. Hence, it does not seem coincidental that the spinning direction of the fibres is one of the features that differentiates the cotton samples studied. The sample NT3 is characterized by the use of threads spun in an anti-clockwise direction, suggesting a local production. In contrast, the spinning of the fibres in samples NT4 and NT5 was clockwise to produce Z-spun yarns — a spinning direction that is not characteristic of textile production in Nubia and Egypt. The foreign origin of the NT4 sample is also indicated by its resist-dyed decoration. For the period under consideration (2nd–5th century CE), such a technique has not been documented in Nubia so far. At first glance, the general features of this textile point towards textile production in India (Barnes 1993, 1997).

7.2 Isotopic Evidence

The Sr isotope composition of the investigated ancient cotton textiles from Sudan is presented in Table 1 and Fig. 6. The three samples of cotton textiles exhibit a very narrow range of \(^{87}\text{Sr}/^{86}\text{Sr}\) values from 0.7084 to 0.7086, strongly suggesting an origin from the same crop area.

Cotton cultivation requires the presence of hot and dry climate conditions and the availability of relatively large amounts of water (at least for a few months of the year). In Sudan, those conditions can be met in the valleys of the Nile and its tributaries. In the upper Nile valley, from its beginning (i.e. at the confluence of the White and Blue Nile near Khartoum) to the 2nd cataract, alluvial sediments (mud and sand), river waters, and plants exhibit Sr isotope signatures below 0.7075 (Fig. 6). This practically excludes the origin of the studied textiles from this part of the Nile valley. Likewise, the area of the Nile delta is also out of question, although the \(^{87}\text{Sr}/^{86}\text{Sr}\) values of water and mud are on average slightly higher there. Numerous finds of ancient cotton fibres and seeds have been reported at several archaeological sites located along the Nile Valley,
downstream of the 2nd cataract (e.g. Chowdhury & Buth 1971; Wild et al. 2008; Bouchaud et al. 2011; Bouchaud et al. 2018; Yvanez & Wozniak 2019). Although there are no data on the composition of sediments filling this section of the Nile valley, the unradiogenic signature of the Nile water around 0.7069 (Gerstenberger et al. 1997) suggests that here the floodplain sediments must have an isotopic composition with $^{87}\text{Sr}/^{86}\text{Sr}$ values below 0.7075. Consequently, this excludes that the cotton used for the production of the investigated textiles was grown in any part of the Nile Valley. Likewise, the valleys of the Atbara and Blue Nile rivers, where river waters and sediments are highly unradiogenic, with $^{87}\text{Sr}/^{86}\text{Sr}$ between 0.7041 and 0.7060 (Padoan et al. 2011), are also not an option.

However, an origin of the studied cotton from lower Nubia (the Egyptian Western Desert) is not excluded. Its isotopic composition, with $^{87}\text{Sr}/^{86}\text{Sr}$ values around 0.7085, indicates that the place of cotton cultivation must have been an area with a geological substrate dominated by sedimentary carbonate rocks. In the Egyptian Western Desert, such conditions prevail on the western side of the Nile, where there is a vast plateau made of the Eocene limestones, characterized by $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.7077–0.7078. In several oases (Kharga, Dakhla, Kellis) situated at the foot of this plateau, cotton was clearly an established crop already by the 2nd–3rd century CE (Bowen 2001; Coombs et al. 2002; Wild et al. 2008; Bouchaud et al. 2018). Moreover, there is also detailed documentation of irrigation systems and their careful supervision (Cuigny et al. 1993; Wuttmann 2001). The irrigation water available in these places had to come from shallow-seated groundwater reservoirs supplied with atmospheric-originating water (with $^{87}\text{Sr}/^{86}\text{Sr}$ value of about 0.7092). Therefore, it can be assumed with a high probability that, as a result of the interaction of rainwater with Eocene carbonates, groundwater must have had isotopic signatures slightly lower than 0.7092. Under such conditions, due to the mixing of strontium derived from groundwater and bedrock, cotton would have an isotopic composition with values of about 0.7085.

Another potential cotton growing area in Sudan may have been along the lower course of the White Nile. Such a scenario is indirectly suggested by finds of ancient cotton fabrics at Meroe (south of Khartoum), dating to the Roman period (Griffith & Crowfoot 1934; Yvanez 2016; Yvanez & Wozniak 2019). Here, in contrast to the Nile, river waters and alluvial sediments are characterized by radiogenic Sr isotope signatures higher than those of the cotton textiles under study and rainwater (Fig. 6). Therefore, it is completely excluded that the investigated
cotton comes from the White Nile basin but also from any area in Sudan where the bedrock is composed of radiogenic Precambrian granites and/or gneisses.

While the evidence now strongly supports the indigenous origin of cotton used in Egypt and Sudan in Roman and later times (Wild et al. 2008; Clapham & Rowley-Conwy 2009; Fuller 2014; Bouchaud et al. 2018), the possibility of importing cotton and textiles via trade across the Red Sea must also be taken into account (Griffith & Crowfoot 1934), as the Arabian Peninsula and India were the centres of cotton cultivation and textile production during antiquity (Bouchaud et al. 2011) and there are written sources, for example the Periplus Maris Erythraei, indicating the import of Indian cotton to Arabia and Africa during the 1st century CE (Wild & Wild 2014). Very recently, Ryan et al. (2021) provided isotopic data on ancient cotton seeds and fabrics excavated at Mleiha, an archaeological site (2nd–3rd century CE) situated in the Arabian Peninsula (United Arab Emirates). By analysing variations in $^{87}$Sr/$^{86}$Sr values across south-eastern Arabia and the Indo-Pakistani region, they showed the non-local origin of cotton seeds and textiles found at Mleiha, suggesting their potential origin from regions of modern western India. Unfortunately, there are only a few isotopic signatures of botanical material from south-eastern Arabia and the Indo-Pakistani region that can be directly compared with the $^{87}$Sr/$^{86}$Sr values of the ancient cotton of Sudan. Available $^{87}$Sr/$^{86}$Sr values of domestic animals and/or humans give, in fact, only a certain approximation of local plant $^{87}$Sr/$^{86}$Sr signatures in a given area. Taking all the data together (see for review Ryan et al. 2021), it appears that the Sr isotope signatures of the Sudan cotton textiles under study are consistent with those of the bedrock and fauna in very few areas of Arabia, Pakistan, and India. Among the potential source areas from which cotton found in Sudan could be imported are the lower part of the Indus River basin in Pakistan, the Kathijawar Peninsula on the west coast of India, Kuwait, and the Oman Peninsula.

8 Discussion and Conclusions

As already mentioned above, the Sr isotope composition of the investigated wool samples from the ancient Nile Valley of Nubia points to their local origin. This interpretation is consistent with the technical features of the samples NT1, NT2, and NT6. However, this compatibility does not apply to the origin of the NT7 sample. The general technical and aesthetic features of this wool kilim found at Meinarti suggest namely its foreign provenance from outside of Nubia. Remarkably, the layer (14th century CE) in which the kilim was found coincides with the time of the occupation of Meinarti by the Beni Ikrima tribe. Therefore, it cannot be ruled out that the kilim was imported by this nomadic pastoral community from the Maghreb, an area where the geological substrate has a Sr isotope composition similar to that of northern Sudan. The more likely scenario, however, is that the kilim was produced from local raw wool by the Beni Ikrima people during their stay in Meinarti. If the wool was cut from the Beni Ikrima sheep flock, it would be indicative of a longer stay of the nomads in the region, at least for one pasturing season. Another possibility is that the Beni Ikrima people obtained raw wool from the Nubian inhabitants of Meinarti or its vicinity and spun the thread and wove the kilim according to their tradition, as attested by the Z-spinning direction. The combination of different approaches and study analyses allows us to better understand the context and conditions in which the kilim was presumably produced. Contrary to previous expectations, it was most likely made in Nubia.

The Sr isotope composition of the cotton samples is not consistent with the isotopic background of the Nile Valley and strongly suggests the non-local origin of the textiles tested. Although their isotopic signatures are very similar, they were not produced in the same site as shown by the different spinning directions applied during the transformation of raw fibre to thread. The isotopic signature of sample NT3 points to oases (Dakhla/Kharga) located in the Egyptian Western Desert as potential areas of cotton cultivation. The oases provenance provides a remarkably interesting context for the place of production of this textile, considered as a local product. Indeed, the S-spinning direction is strongly representative of the textile production of the Nile Valley, including oases, where cotton production is also attested in archaeological evidence (Letellier-Willemin 2020). The necessity of importing standard cotton textiles from the Egyptian oases makes only sense if the local production in the Nile Valley would struggle to supply the market. Such a period, with a drop of cotton fibre frequency, is documented in Nubian textile assemblages in the Late Antique and Early Medieval periods (Adams 1996; Vranckx & Woźniak 2019). Another possibility is that the fabric was not traded but ‘travelled’ with the deceased during his lifetime.

The Indian provenance of sample NT4, attributed on the basis of technical characteristics, especially traces of resist-dyed decoration (block-printing technique), is in line with the Sr isotope composition of the geological substrate of the Kathijawar Peninsula on the west coast of India. Therefore, there is no question that the fine-quality cotton tabby found at El-Ar was imported from India, where this textile was produced from local raw material. This textile fragment is unique additional evidence for the
connection of the 4th cataract area with long-distance trade with India during antiquity, attested so far only by the presence of numerous glass beads in burials of this region (Then-Obluska & Wagner 2019; Then-Obluska 2021).

The non-local origin of cotton sample NT5 is now indicated independently by both the spinning technique (Z-spun) and the isotopic signature of the raw material. However, these features do not allow for a precise indication of where the cotton was grown and where the textile was produced. Sr isotope data indicate the origin of the raw material from one of several regions, including the Indus River basin in Pakistan, the west coast of India, Kuwait, and the Oman Peninsula.

Although it was not possible to determine the origin of the tested cotton and wool fabrics in all cases, this research shows the great potential of the applied methods. A comprehensive approach to the study of ancient textiles is needed. The origin of raw materials and the places of textile production can be determined when, in the analysis, the technical descriptive features of textiles (fibre, yarn structure, weave, decoration) are combined with the Sr isotope composition of fibres. Such an integrated approach can provide new knowledge about agriculture, textile production, and exchange networks and thus about people and societies in historical times.

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