Strontium isotopes as a method of obtaining knowledge of mobility and trade in prehistory and historical times

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Abstract

Migration and trade are important themes, as they contribute to our general understanding of the dynamics behind socio-economic networks through time. In order to study migration and trade, the provenance of either the individuals or the artefacts being investigated must be known. As the archaeological material record is restricted and incomplete, the question of origin is not always easy resolvable. This article offers an overview of one of the scientific methods – the so-called strontium isotope tracing system – which keeps providing new ways in which provenance and origin can be investigated.

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Introduction

There are various methods of investigating past population mobility, identifying foreign presence in a given region and tracing trade of goods. In archaeology, the provenance of human remains can be investigated for example by looking at types of burial and grave goods. Similarly, ceramics and metals are often assigned a certain provenance on the basis of typological analysis. However, in the past decade, there has been a great increase in research projects that combine and integrate methods from the natural sciences with archaeological investigations in order to explore mobility and trade in prehistory in a whole new way. Hence we see that, more and more often, archaeological projects attempt to incorporate approaches like ancient DNA analysis, isotopic tracing analysis, trace element and main element analysis, with the aim of adding an extra dimension of information. Furthermore, there seems to be a clear pattern where archaeological research projects aim at performing multi-analytical investigations – that is, they wish to include several types of natural-science methods. Such interest is leading to a growth in the present, already broad palette of scientific methodologies. Additionally, some of the already well-established techniques are still being refined and improved. This article will concentrate on one of these methodologies, which continues to grow and develop further in providing information on provenance: the strontium (Sr) isotope system (Fig. 1).

Here, I wish to offer a general overview of the various ways in which this tracing system has been applied within archaeology, as well as a single modern example. The case studies come from a variety of regions as well as from different population groups and archaeological materials. The intention is therefore not to provide insight into the technique itself, but rather to inspire and to give an impression of what just one of these scientific methodologies can contribute to the field of archaeology. For insight information on the technique, several review articles can be recommended (Bentley, 2006; Frei, 2014; Montgomery, 2010).

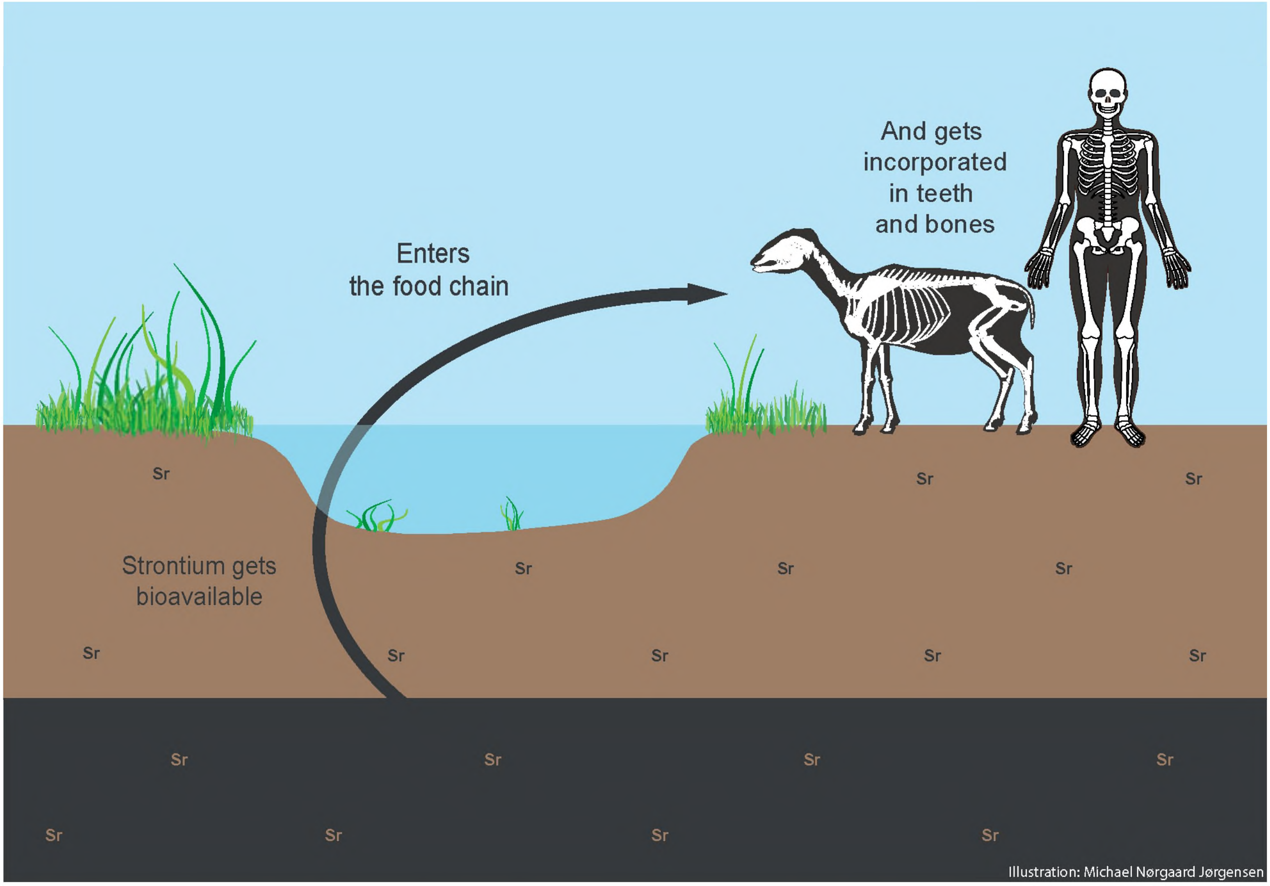

Figure 1. Simplified drawing depicting the strontium cycle. Strontium in the biosphere derives from the soil and underlying bedrock, i.e. the local geology. Strontium is very similar to calcium; hence it can substitute for calcium entering the food chain via plants, animals and drinking water. Consequently, strontium is naturally incorporated into the human and animal plant tissues. Because different lithologies show systematic isotopic variations which are traceable, the strontium isotope compositions of different human, animal and plant tissues can be tracked to a certain type of geology which can in turn be restricted to certain areas of origin. (Graphic by Michael N. Jørgensen, design by Karin M. Frei)

Mobility traced by the strontium isotope system

Mobility of humans in prehistory

In the field of archaeology, strontium isotope analyses are mainly known to have contributed to studies of migration in prehistoric periods. Probably one of the best known studies in which strontium isotopes were used is the investigation of the provenance of the Alpine Iceman "Ötzi" (Muller et al., 2003). Ötzi is a well-preserved human mummy that was discovered at the edge of a glacier in the Alpine region between Italy and Austria in 1991. He lived c. 5200 years ago during the European Neolithic-Copper Age and was approximately in his 40s when he died. Because of the uniqueness of this find, Ötzi has been studied with a huge variety of scientific methods in order to gain as much information as possible about him as well as the environment in which he lived. In order to establish his provenance, strontium isotope analyses, combined with lead (Pb) and oxygen (O) isotope analyses of tooth enamel from Ötzi, provided the necessary information for the authors to establish that the Alpine Iceman spent his entire life in an area south of the discovery site, most plausibly Feldthurns in Bolzano, Italy (Muller et al., 2003).

Figure 2. Sampling tooth enamel from the first molar of an individual dating back to the Bronze Age at the Danish Centre for Isotope Geology (DCIG) at the University of Copenhagen. (Photo: Karin Margarita Frei)

Figures 2 and 3 depict how tooth enamel samples are taken after previously being deeply rinsed; only a few milligrams of tooth enamel are necessary to conduct a reliable strontium isotope analysis.

Since strontium isotope analyses relate to the individual's geographic provenance, there is great potential for combining ancient DNA analyses -which provide information on the genetic provenance of the individual -, with strontium isotope analyses - which provide information on the geographical origin of the individual. One outstanding example of such a combination of methods is the investigation of four Stone Age multiple burials discovered in Eulau, Germany in 2005. The individuals buried at this site were men, women and children who lived c. 4,600 year ago. As their preservation was quite good scientists were able to extract ancient DNA, and at the same time they conducted strontium isotope analyses (Haak et al., 2008). Ancient DNA analyses revealed a direct child-parent relationship in one of the burials, which provided the oldest genetic evidence of a nuclear family. On the other hand, the strontium isotope analyses provided evidence of places of origin differing between men and children in relation to the women. The men and children seem to originate from the Eulau region, indicating that they were of local origin. In contrast, the women's strontium isotope signatures showed that they were of non-local provenance. The authors therefore argue that this could be interpreted as evidence of exogamy and patrilocality.

These types of provenance analysis have also proved useful for proto-historical and historical periods where written sources help to pinpoint the research questions to be put to the archaeological material. For example, we know from written sources that the Inca Empire performed human sacrifices called *capacocha*. Furthermore, these colonial documents indicate that this sacrificial rite involved the most beautiful children in the Empire and that these children were carefully selected from diverse regions within the Empire. Recently, excavations at Choquepukio, Peru, uncovered the human remains of seven children (aged 3-12 years, dating to c. AD 1410-1520), thus providing archaeological material for the investigation of this issue. The children were buried together, accompanied by highly elaborate, high-status artifacts. The strontium isotope analyses of the children revealed that at least two of them were of non-local origin, which seems to verify the statements of the colonial documents (Andrushko et al., 2011).

In Denmark such investigations have only recently been conducted. However, they have already uncovered new aspects of Danish prehistory. For example, the Viking Age site of Trelleborg (dating back to c. AD 980) - one of the large monumental circular fortresses erected by King Harald Bluetooth, located in the western part of the island of Zealand - proved particular interesting. These fortresses, which are unique to southern Scandinavia, are believed to have had a military character. During early excavations at the Trelleborg fortress between 1934 and 1942 by Nørlund from the National Museum of Denmark, human remains of 157 individuals, including men, women and children, were uncovered. Recent strontium isotope analyses of 48 of these individuals (Fig. 3) showed that nearly 50% of them were of non-local provenance (Frei et al., 2014; Price et al., 2011). This study has revealed the largest assemblage (to date) of non-locals in one single burial site in Denmark. Furthermore, the non-locals seem to originate from a variety of places, which might indicate that King Harald Bluetooth had a kind of mercenary military.

Mobility of animals

Animal migration is a phenomenon of great importance, as it provides insight into the biological mechanisms behind these movements. In archaeology, animal migration studies can also provide valuable information on trade networks and routes.

One example in which animals and trade in goods are closely connected is the case of elephant ivory. Elephant ivory is considered a very precious material, and consequently its value endangers the life of elephants. Efforts have therefore been made with the aim to find scientific methods that will enable us to identify origin of ivory (i.e. the elephants' area of origin) in order to combat potential illegal trade. Strontium and nitrogen (N) isotope analyses are among the methods that have been developed to trace the illegal trading routes. These investigations have shown that there are clear isotopic distinctions among different African elephant populations (Vogel et al., 1990). As a result these studies provide a good background for tracing ivory in prehistory and protohistory.

Another case study that illustrates how strontium isotope analyses can be used to trace animal mobility comes from the USA, where a group of scientists used strontium isotopes to reconstruct the migratory behaviour of mammoths and mastodons - members of the megafauna during the Pleistocene (c. 11.000 BP) - found in Florida. Their study revealed that the late glacial mastodons undertook migrations of at least 120 to 300 km. In contrast, the mammoths, which had previously been believed to have undertaken transcontinental migrations, had strontium isotope ratios that pointed to local feeding ranges (Hoppe et al., 1999). The authors therefore concluded that these mammoths did not migrate outside Florida.

In Denmark, a recent archaeological investigation from the Viking Age and Early Medieval site of Sebbersund (AD 700-1100) has uncovered that one of the animals found at the site has strontium isotope compositions that point to a non-local origin (Price et al., 2012). A total of six sets of archaeological animal remains from domestic pig, cow, sheep and horse as well as a mole were analysed for their strontium isotopic composition. Interestingly, most of the animals seem to be of local provenance; only the horse had a strontium isotopic signature that was too radiogenic to be of local origin. This indicates that this horse was probably traded from elsewhere, outside the region

Figure 3. Tooth enamel sample from one of the individuals buried at the largest of the three mass graves at the Trelleborg fortress, at the Danish Centre for Isotope Geology (DCIG) at the University of Copenhagen. (Photo: Karin Margarita Frei)

that is outlined by Denmark today (excluding the island of Bornholm).

Trade in materials traced by the strontium isotope system

There also are several examples where strontium isotopes have been used as provenance indicators for archaeological artifacts with the main aim of tracing trade.

A recent investigation of this kind used a combination of major element analyses with strontium and neodymium (Nd) isotope analyses on 33 colourless glass fragments retrieved from two Roman shipwrecks discovered in the northern Mediterranean (Ganio et al., 2012). Their aim was to identify potential glass trading routes across the Mediterranean. On the basis of the results of these multi-analyses, the authors could distinguish two compositional groups, suggesting the use of different raw materials. The authors concluded that the glass samples might have been produced in two separate workshops/factories.

Although hard, inert materials such as glass and metal constitute the majority of archaeological cultural remains thanks to their preservation characteristics, organic materials such as food and textiles have in some cases also been preserved as a result of specific climatic and soil conditions. For example, maize cobs were recovered from the pre-Columbian site of Pueblo Bonito (AD 850-1150) in Chaco Canyon, USA, because the very dry conditions there enabled their preservation (Fig. 4).

The find of these cobs is very important because maize was a dietary staple of most pre-Columbian so-

Figure 4. Image of the pre-Columbian site of Pueblo Bonito (AD 850-1150) in Chaco Canyon, USA. The very dry conditions at the site have enabled the preservation of maize cobs as well as wood beams, both of which have been investigated with the strontium isotope system to determine their provenance. (Photo: Karin Margarita Frei)

cieties. The Chaco people of Pueblo Bonito are known to have constructed monumental 'great houses' with roof beams as well as water-controlled systems for agricultural purposes and an impressive network of roads. Since the main function of the Chaco cultural system of 'great houses' and roads is not yet understood – there may have been economic, political or ritual reasons – a provenance study of the Chacoans' main food source could provide important information that would help to resolve this issue. A group of scientists therefore conducted strontium isotope analyses and elemental analyses of some of the cobs from the Pueblo Bonito site (Benson et al., 2003). The strontium isotope analyses revealed that the maize cobs were of non-local origin and that they came from a place at least 80 km from the Pueblo Bonito site. Moreover, the cobs were grown in several different areas. Benson et al. (2003) concluded that this was a finding fundamental "to understanding the organization of pre-Columbian southwestern societies" and that it "supports the hypothesis that major construction events in Chaco Canyon were made possible because maize was brought in to support extra-local labor forces".

Strontium isotope analyses specifically developed for ancient textiles have also recently shown that textiles made of plant and wool fibres were imported/traded (Frei, 2014; Frei et al., 2009a; Frei et al., 2010). A large one-piece tubular woollen garment from the pre-Roman Iron Age (500 BC – AD 0) recovered from the Huldremose bog site (Fig. 5) in Denmark was one of the first textiles investigated by this new method (Frei et al., 2009b).

Figure 5. Image of the Huldremose bog site, northeastern Denmark. At this site pre-Roman Iron Age (500 BC – AD 0) textiles have been recovered twice. One of the cases was the single deposition of a large tubular textile which proved to be made of a mixture of local and non-local wool. (Photo: Karin Margarita Frei)

This large textile garment (Fig. 6), was made of a very homogenously spun wool, and was woven in a technique indicating that the garment was of local origin. However, the 11 random wool samples showed that the wool of which this garment was made originated from sheep that grazed in several different regions, including regions outside mainland Denmark (defined as Denmark excluding the island of Bornholm). Hence, the authors argue that even though the textile might have been woven locally, the wool was gathered from several places, some of which were outside Denmark.

Figure 6. Sampling the Huldremose tubular garment at the Conservation and Natural Science Department of the National Museum of Denmark (on the right conservator Irene Skals and on the left Karin Margarita Frei). A total of 11 thread samples taken from both thread directions were analysed with the strontium isotope tracing system. (Photo: Karin Margarita Frei)

The last example also comes from the world of ancient textiles. Nettle, which we mostly know as a weed plant that stings when we come in contact with it, has been used in prehistory as a textile plant. The first strontium isotope provenance investigation of a nettle textile comes from the Voldtofte site in Denmark,

Figure 7. Image of the Lusehøj bronze urn which contained cremated human remains wrapped in a nettle textile from c. 2800 BC. The Lusehøj burial mound is one of the richest Bronze Age burials from Denmark. (Photo: Karin Margarita Frei)

Figure 8. A close-up image of the Bronze Age nettle textile found inside a bronze urn at the Danish site of Lusehøj, whose strontium isotope composition revealed a potential Austrian origin. (Photo: Karin Margarita Frei)

one of the most impressive centres of power during the Scandinavian Bronze Age. Voldtofte has several impressive burial mounds and the largest amount of gold from that period within Scandinavia has been unearthed there. One of the burial mounds, Lusehøj, which has been interpreted as a princely burial, contained a bronze urn (Fig. 7) with cremated human remains which were wrapped in a nettle textile from c. 2800 BC (Bergfjord et al., 2012; Frei et al., 2015).

The nettle textile was investigated using the new strontium isotope method for textiles (Frei, 2014), and surprisingly revealed that the textile was of non-local provenance (Fig. 8). Furthermore, the authors point to an area in Austria as the possible place of origin for the nettle, and this is in accordance with the archaeological/typological interpretation of the bronze urn (Frei et al., 2015). Both the bronze urn and the textile thus appear to have been imported goods of non-local origin. Currently, we are conducting further analyses to investigate whether the individual buried in the bronze urn (probably a prince or a person of very high status) was cremated locally or might have died and been cremated elsewhere.

General remarks

In order to investigate food resources and population dynamics in past societies, it is important to know the origin/provenance of the individuals and their foodstuffs as well as their goods. The strontium isotope tracing system has shown that it is an important scientific tool that can provide new information on archaeological research questions. The strontium isotope system adds an extra dimension to our understanding of the dynamics behind ancient human and animal mobility, as well as trade in food and a variety of other goods. Moreover, there is much potential in combining several scientific tracing systems, such as ancient DNA with strontium isotopes, as we have seen in the case of the Stone Age Eulau family. Finally, the development of new chemical protocols enables us to apply the strontium isotope system to new materials, as we have seen in the case of ancient textiles. With all scientific methodologies there are some limitations and the strontium isotope system is no exception. However, the combination of archaeological evidence with natural-science methods seems to continue to provide new platforms with which we can investigate the past.

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