Survey of Strontium Isotope Analysis in Archeolgical Research of Ancient Egypt

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Abstract

Archeologists often dig up human skeletal remains. One common tool for learning more about these is isotope analysis, which involves investigating the levels of various elements such as oxygen, carbon, or strontoum using chemistry. Strontium isotope analysis in particular is useful for archeologists since it helps them understand the geographic movement of humans and animals.

1 Introduction

Archeologists often dig up human skeletal remains. One common tool for learning more about these is isotope analysis, which involves investigating the levels of various elements such as oxygen, carbon, or strontoum using chemistry. Strontium isotope analysis in particular is useful for archeologists since it helps them understand the geographic movement of humans and animals.

Strontium isotope analysis has gained significant moementum in the last 10 years due to advancements in measuring technology (Holt et al., 2021). As a result, an study of strontium analysis and its application to archeology as a whole would be too large of a scope for this paper. As a result, I will focus on strontium isotope analysis as it pertains to archeological research in Ancient Egypt, which I chose because of strontrium analysis' interesting application to Egyptian mummies.

In this paper, I will detail how strontium isotope analysis works, its main use cases, and a few interesting case studies that utilize it.

2 Strontium Isotope Analysis

2.1 Overview

Strontium is an element, which occurs naturally at varying concentrations in rock formations. Strontium gets into the water stream through erosion and eventually is inadvetently consumed by plants and animals in trace amounts (Bartelink and Chesson, 2019). Eventually, when humans or animals inevitably consume plants, water, or other animals, a small amount of strontium gets into their bones and tissue. Notably, although the amount is trace, the ratio of strontium stays constant throughout all these processes since there is no "isotopic fractionation" (Bartelink and Chesson, 2019). Thus, measuring strontium in bones or tissue gives a picture of where humans or animals source their food and water. Measuring the strontium level of longer bones gives insight into the last 7-10 years of a person's life and measuring the strontium of hair can tell where someone took residence immediately prior to death (Kamenov et al., 2014)

2.2 Purpose

Although this is trivially already useful for fields such as forensics (Kamenov et al., 2014), archeologists usually have a good idea of where a person lived before they died since people are usually buried where they lived. However, since tooth enamel forms during childhood and does not change, measuring it can give the general location that the person lived in during their tooth formation, i.e., when they were a child (Holt et al., 2021; Kozieradzka-Ogunmakin, 2021; Lazzerini et al., 2021). Thus, archeologists can identify the "provenance," or place of origin, of skeletal remains they dig up (Holt et al., 2021).

2.3 How It Works

Now, I will describe in detail how archeologists do strontium isotope analysis. First, an "isotope" is a version of an element with a particular atomic weight, which is indicated by a superscripted number to the left of the elemental symbol (Meave60, 2015). For example, one isotope of Oxygen is ^{18}O, where 18 represents the atomic weight of the isotope. There are four possible isotopes of strontium in nature (Holt et al., 2021), but only two are relevant to strontium isotope analysis: ^{87}Sr and ^{86}Sr. Notably, these isotopes are extremely stable, so they do not react with other elements and their abundances in the environment will stay constant unless outside forces interfere (Long, 1998).

One such outside force is the radioactivity of ^{87}Rb, which forms ^{87}Sr when it decays. So, the ^{87}Sr concentration in a substance will increase over time depending on the initial concentration of ^{87}Rb. ^{87}Rb has a half-life of 48.8 billion years, so it takes billions of years for ^{87}Rb to fully decay into ^{87}Sr; as a result, ^{87}Rb will always have a small but measurable effect on the ^{87}Sr levels of the substance it is in. Thus, the relative concentraion of ^{87}Sr / ^{86}Sr is constantly increasing.

In contrast with the stable strontium, ^{87}Rb varies signifantly across the environment. This is because of how rocks form; in deep Earth layers, magma mixes and moves constantly, which spreads and changes ^{87}Rb concentrations. In addition, when the magma cools, ^{87}Rb will spread out such that even different parts of the same rock formation has different ^{87}Rb concentrations.

Throughout all of this, ^{87}Sr and ^{86}Sr concentrations remain generally constant due to the aformentioned stability and the fact that strontium isotopes do not fractionate, or separate, at magma tempeartures. Therefore, different rock formations will have different quantities of ^{87}Sr and ^{86}Sr depending on where the rock formed, when it formed, and the initial concentrations of ^{87}Rb, ^{87}Sr, and ^{86}Sr (Long, 1998).

For the purposes of archeology, we can assume that every rock has a random, unique concentration of ^{87}Sr and ^{86}Sr. As stated previosuly, the concentrations of these two values eventually travels through the ecosystem to all nearby plants and animals. Since the exact concentrations may get diluted, archeologists often measure the ratio of ^{87}Sr / ^{86}Sr since this remains constant through the strontium transfer process (SOURCE NEEDED). Archeologists can use a mass spectrometer to determine this ratio (Long, 1998).

In summary, ^{87}Sr / ^{86}Sr ratios vary greatly across the environment, but both isotopes are stable once formed. Therefore, measuring this strontium isotope ratio is desirable because there are essentially no unpredictable factors that can affect the measurement.

2.4 Isoscapes

In order for strontium measuremnts to be useful, archeologists need a baseline to compare to. So, much of the research into strontium isotope analysis in the last decade has gone into mapping "isoscapes," which are maps of the expected strontium isotope ratios of tissue in various geographic regions (CITATION NEEDED).

I will discuss the three main approaches for creating an isoscape: domain mapping, contour mapping, and machine learning (Holt et al., 2021). I will also go into their strengths and weaknesses.

2.4.1 Domain Mapping

To do domain mapping, researchers simply sample the strontium isotope ratios of various locations, plot their results on a map, and then group similar results

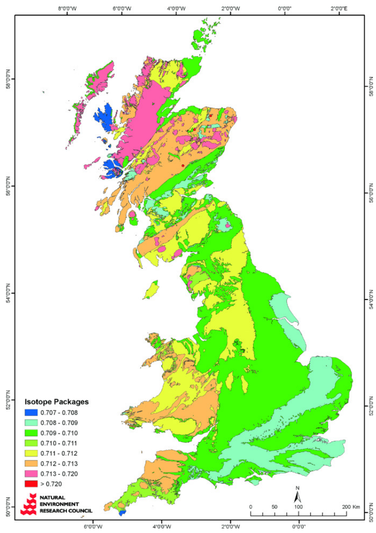

Figure 1: A domain map of Great Britain (Evans et al., 2010).

together into "domains." This is the simplest approach to creating an isoscape. An example of a domain map can be seen in Figure 1.

2.4.2 Contour Mapping

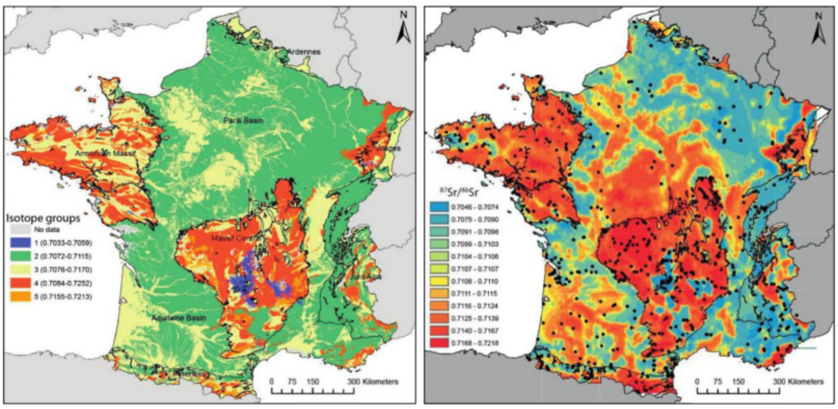

Figure 2: A contour map of France (Willmes et al., 2018)

This approach builds on domain mapping. Researchers apply statistical methods such as Inverse Distance Weighting, ordinary kiging, empirical Bayesian kirigin, and cokroing extrapolate strontium isotope ratios (Holt et al., 2021).

2.4.3 Machine Learning

This is the most recent approach to creating isoscapes. Researchers use machine learning methods such as random forest regression in order to combine domain and contour maps into one cohesive isoscape (Willmes et al., 2018).

2.5 Use Cases

As stated before, identifying "provenance," or place of origin, is the main use of strontium isotope analysis for archeologists. By studying tooth enamel of humans and animals, the place of origin for that human or animal can be determined (Holt et al., 2021). This assumes that the person or animal did not consistently travel long distances during the formation of their teeth during childhood. For archeologists, this is generally a reasonable assumption since humans were not highly mobile in history (SOURCE NEEDED). Understanding provenance gives insight into the movement of the subject, which can be used to answer questions about historical human migration patterns. In this section, I will briefly discuss other applications of the method for archeologists.

2.5.1 Local vs Non-Local

Archeologists often measure the ratio of skeletons in a graveyard that came from the area around the graveyard versus some far away area (Holt et al., 2021). This approach has the advantage of not requiring a perfect isoscape since any skeleton that does not fall in the range for the specific area under study may be classified as "non-local" without needing to know exactly where they came from.

2.5.2 Animal Origins

As another extension of provenance study, prehistoric animal fossils can be analyzed to uncover their place of origin.

2.5.3 Material Origins

More rarely, archeologists use strontium isotope analysis to determine the origin of physical artifacts. For example, Gry Brafod et al. concluded that celebrated clear glass in Roman cities came from Egypt (Barfod et al., 2020).

2.6 History

Originally, strontium analysis was used simply to study erosion of rocks and tracing how rock formations' strontium levels travelled around an environment through rivers (Crowley et al., 2017). Around the late 1980s and early 1990s, archeologists theorized that strontium could be used to learn where a human skeleton originated. This spawned a flood of studies to prove its viability and test its limitations (Crowley et al., 2017). Since then, archeologists have increasingly used strontium isotope analysis to answer questions of human provenance. Recently, there has been an explosion of strontium isotope analysis research (Crowley et al., 2017), which is likely due to scientific advnacnements such as high performance laser ablation and multicollector inductively coupled plasma mass sepctrometry, which both make strontium analysis more accurate and more accurate (Holt et al., 2021). According to Evans Holt et al., the main focus of strontium research now is creating new isoscapes and refining existing ones.

2.7 Limitations

3 Main Areas

In this section, I will discuss how strontium isotope analysis is used in archeology and beyond.

3.1 Ancient Habitat Use and Settlement Patterns

Strontium isotope analysis unveils insights into settlement patterns. It allows archaeologists to discern whether individuals were indigenous or from other regions, shedding light on migration, resource utilization, and societal dynamics (Crowley et al., 2017).

3.2 Tracing Animal Origins and Interactions

Strontium isotope analysis is instrumental in tracing the origins of diverse animals like anadromous fish and extinct hominins. This exploration offers valuable perspectives on ancient ecosystems, human-animal interactions, and resource exploitation by past societies (Crowley et al., 2017).

3.3 Unraveling Farm Product Sources

By utilizing strontium isotope analysis, researchers uncover the geographic origins of farm products like rice, corn, and medicinal plants. This knowledge contributes to understanding ancient agricultural practices, trade networks, and resource distribution (Crowley et al., 2017).

3.4 Mapping Migration Routes

The application of strontium isotope analysis in mapping migration routes provides critical insights into ancient human mobility, societal exchanges, and the patterns of population movement throughout history (Crowley et al., 2017).

3.5 Tracing the Origins of Illegally Poached Animals

Efforts to combat illegal wildlife trade can be supported through the identification of regions from which poached animals originate using strontium isotope analysis (Crowley et al., 2017).

3.6 Mapping the Range of Invasive Species

Understanding the spread and impact of invasive species in different regions is essential for assessing environmental changes and human influences. Strontium isotope analysis helps in mapping the distribution and movement patterns of invasive species in archaeological contexts (Crowley et al., 2017).

3.7 Comprehending Landscape Use

Strontium isotope analysis aids in understanding ancient populations' interactions and utilization of landscapes. This perspective enriches the reconstruction of ancient societies, offering insights into settlement patterns and land use practices (Crowley et al., 2017).

3.8 Application in Forensic Studies

Beyond archaeology, the use of strontium isotope analysis extends to forensic studies, aiding in determining the geographic origins of individuals and supporting forensic investigations (Kamenov et al., 2014).

4 Specific Case Studies

4.1 Hyksos

- 1638 BC - 1530 BC [5] - Foreign Hysos rise to power - Lots of non-local women before Hyksos rule - likely gradual power grab by Hyksos, which contradicts historical narrative [5]

- Original narrative: Egyptian priest Manetho– terrible invasion. But, this was a biased source, albeit the only available source. [5] - Methods: –> Excavating

Figure 3: Egyptian painting of Abisha the Hyksos (Commons, 2022)

various graves –> Check tooth enamel (which was formed during childhood) for falling in "local" range of Sr values - Conclusions: –> Non-local people came from all over –> Hyksos were not an invading source. They arrived centuries before and gradually rose to power.

4.2 Mummified Birds

- Where ancient Egyptian mummified birds came from - Farmed vs hunted – capabilities, economy, and effect on environment - Some bird gods like Horus and Thoth - Methods: –> Take bone samples from birds –> Combination of lots of isotope analyses, including Sr - Results: –> 8/11 ibises local, birds of prey were not local - Conclusions: –> ibises and birds of prey were wild– they all moved a good deal (ibises a little, birds of prey a lot)

4.3 Migrational Origins in Ancient Egypt

- 2500 BCE - 656 BCE - Figuring out mobility of rural and urban settlements in Egypt over time - Methods: –> Dental Sr to determine localness of Abu Fatima, Hannek, and Tombos graves - Conclusions: –> Across the board, there were some non-local people, which indicates that migration was normal b/w First and Second Nile Cataract –> Even poorer people migrated

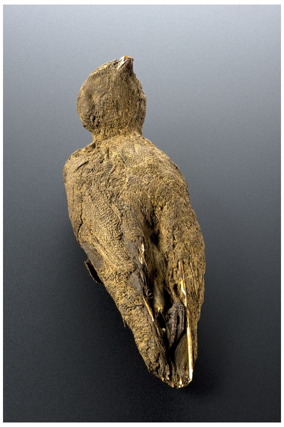

Figure 4: An ancient Egyptian mummified bird (Commons, 2020)

5 Conclusion

Strontium isotope analysis is a relevant and useful tool for archeologists studying Ancient Egypt. Recently, strontium isotope analysis has exploded in popularity for its utility in ascertaining provenance. Archeologists have increasingly taken advantage of this method to answer questions ranging from power rises to ancient economies to migrational patterns.

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