Survey of Strontium Isotope Analysis in Archeolgical Research of Ancient Egypt

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Abstract

This paper explores the pivotal role of strontium isotope analysis in reshaping our understanding of Ancient Egyptian history and migration. It delves into the methodology, challenges, and advancements in this analytical approach, emphasizing its ability to discern geographic origins and trace human movements.

1 Introduction

The exploration of Ancient Egyptian civilization has been significantly enhanced by advancements in analytical techniques, particularly the application of strontium isotope analysis. This paper navigates the transformative role of strontium isotope studies in augmenting our comprehension of Ancient Egyptian history and migration.

Archaeologists routinely unearth human skeletal remains, and one valuable tool for elucidating more about them is isotope analysis. This involves investigating the levels of various elements such as oxygen, carbon, or strontium using chemistry. Strontium isotope analysis, in particular, proves indispensable for archaeologists as it facilitates an understanding of the geographic movement of humans and animals.

Over the last decade, strontium isotope analysis has gained substantial momentum, propelled by advancements in measuring technology (Holt et al., 2021). While a comprehensive study of strontium analysis and its broad application to archaeology exceeds the scope of this paper, our focus centers on its relevance to archaeological research in Ancient Egypt. This choice is driven by the intriguing application of strontium analysis to Egyptian mummies.

Within the confines of Ancient Egypt, a rich array of questions has emerged, leading to insightful revelations through strontium isotope analysis. This paper aims to elucidate how strontium isotope analysis functions, its primary use cases, and several compelling case studies that leverage its potential. As I delve into the intricacies of this analytical approach, I will explore its application in unraveling migration patterns, shedding light on cultural dynamics and historical nuances within Ancient Egypt.

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

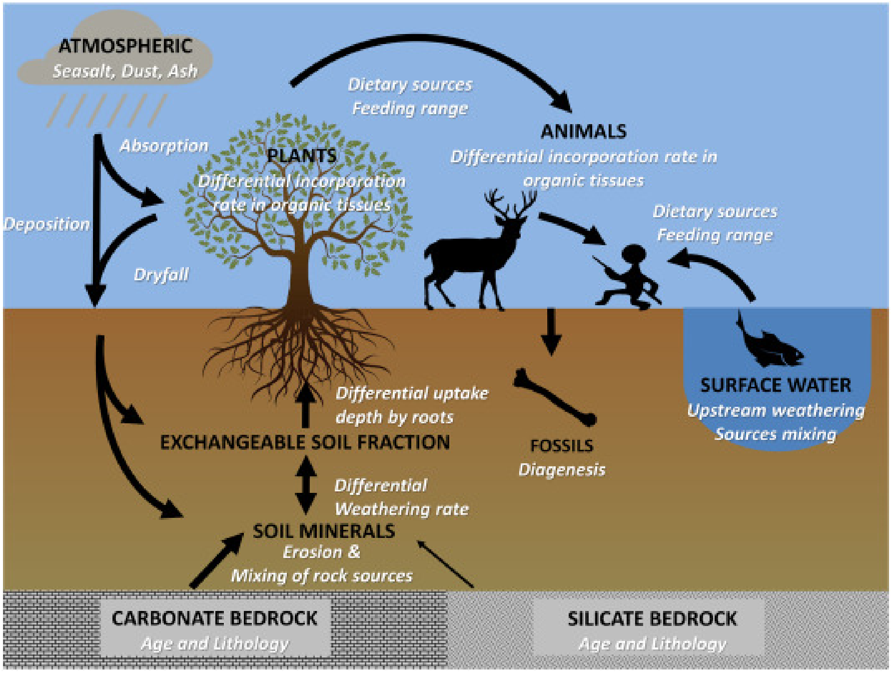

Figure 1: A depiction of how strontium from bedrock gets into the ecosystem (Bataille et al., 2020).

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 together into "domains." This is the simplest approach to creating an isoscape. An example of a domain map can be seen in Figure 2.

2.4.2 Contour Mapping

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).

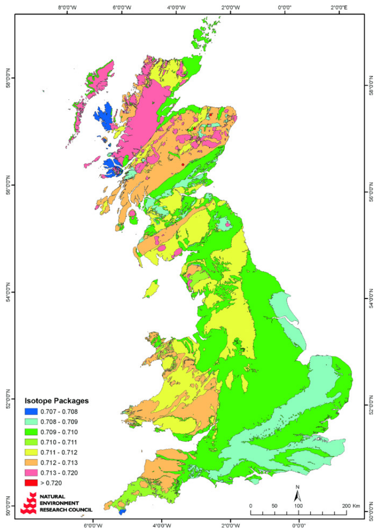

Figure 2: A domain map of Great Britain (Evans et al., 2010).

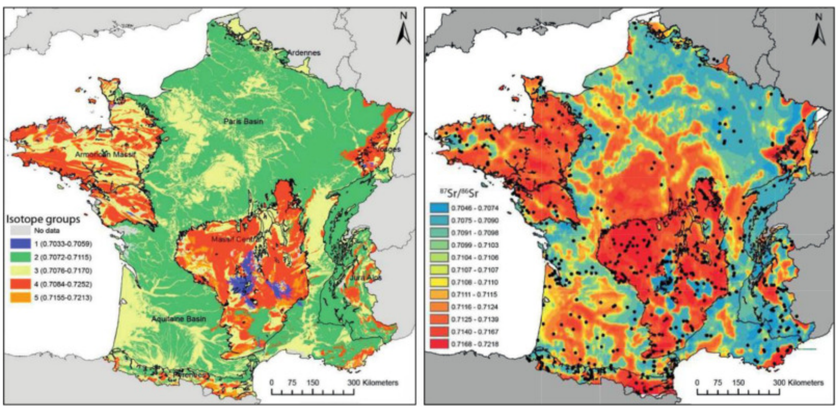

Figure 3: A contour map of France (Willmes et al., 2018)

2.5 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 Holt et al. (2021), the main focus of strontium research now is creating new isoscapes and refining existing ones.

2.6 Limitations

The main weaknesses of strontium isotope analysis are accuracy, precision, and cost.

2.6.1 Accuracy

Strontium isotope analysis can sometimes be inaccurate. It assumes that ancient humans under study sourced their food and water from around where they lived. Further, plant consumption disproportionately affect strontium ratios (Price et al., 2006). So, even if most of a persons diet consisted of local food and water, a relatively small amoun of non-local farm products could give a false-negative on a locality test. But, if one understands what historical people ate and where they got their food, one can account for it in one's strontium analysis and thus resolve the issue of accuracy.

2.6.2 Precision

Strontium analysis can give results that are too broad. In many parts of the world, isoscapes are not refined. So, strontium measurements often only give a general region that a skeleton came from, which is sometimes insufficient to answer a research question. However, this can be alleviated by combining strontium isotope analysis with other tools, such as analyzing isotopes of ^{13}C, ^{18}O, and ^{34}S to understand diet, climate, and likely distance to a water source respectively (Madgwick et al., 2019).

2.6.3 Price

Strontium isotope analysis is expensive (Holt et al., 2021). It involves highly specialized tools along with expertise in chemistry to operate them. There is no simple solution to this. The best approach is to apply strontium analysis only where needed and make the most out of any results generated from it. However, as technology improves, strontium isotope analysis will inevitably get cheaper and more effective, so the outlook for strontium isotope analysis is good.

3 Main Areas

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

3.1 Archeological Use Cases

3.1.1 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.

3.1.2 Animal Origins

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

3.1.3 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).

3.1.4 Crops

Just as human and animals intake the strontium ratios of their environment, crops have the same effect. Larsson et al. (2020) used strontium isotope analysis to determine the origins of historic farm produce of Uppåkra in Sweden. They found non-local crops, which gave insight into trade and movement for the culture under study.

3.1.5 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).

3.2 Other Use Cases

3.2.1 Forensics

Strontium isotope analysis can be used to learn more about the body of a recently deceased victim.

3.2.2 Illegally Poached Animals

Researchers can get an idea of where a poached animal product came from after it gets to market. This can be useful for finding and shutting down illegal poaching operations.

3.2.3 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).

4 Case Studies

4.1 The Hyksos' Rise to Power

Figure 4: Egyptian painting of Abisha the Hyksos (Commons, 2022)

During the period of 1638 BCE to 1530 BCE, the foreign Hyksos people rose to power and ruled over Egypt. Unfortunately, little is known about it. What little we do know comes from a single Egyptian priest named Manetho hundreds of years after the Hyksos were gone, who claimed that the Hyksos were oppressive rulers who seized power through invasion (Stantis et al., 2020a). An ancient picture of a Hyksos ruler is in Figure 4. There are a wealth of resources on applying strontium isotope analysis to the origins of the Hyksos (Stantis et al., 2020a, 2021; Weinstein, 2021; Maaranen et al., 2019) I have selected the one I found the most interesting. In a research article from 2020, Stantis et al. (2020a) challenges this narrative with evidence gathered with strontium isotope analysis.

The researchers first sought after graves of people who lived during and immediately before the Hyksos period. They decided to excavate a cemetary in Tell el-Dab'a, was the capital of the Hyksos kingdom. The cemetary had generations of Egyptians spanning 500 years before and during the Hyksos rule.

Then, the researchers sampled tooth enamel from these skeletons to see if they fell in the "local" range of strontium ratios. Specifically, they analyzed second permanent molars, first permanent premolars, and second permanent premolars. 75

skeletons were analyzed, with half being before the Hyksos rose to power and half being during the Hyksos rule. The range of strontium ratios that the researchers considered local were between 0.70761-0.70780, which was based on an isoscape genearted from local animal bones (Stantis et al., 2020b).

The researchers found that there were numerous non-local people from a wide range of places across all time periods. About half of all skeletons studied were non-local according to their strontium isotope ratios, and mot of the non-local people died during the pre-Hyksos period. Further, there were disproportionately more non-local women in the researchers' study.

Thus, the researchers concluded that the Hyksos were likely not an invading source as Manetho asserted. The researchers argue that a more likely explanation was that the Hyksos arrived centuries before and gradually rose to power. This is supported by the fact that there were increasing amounts of non-local people before the Hyksos rose to power. If the Hyksos seized power through invasion, one would expect few non-local people before Hyksos rule and a large amount of non-local people immediately after they conquered Egypt, which is not the case. The disproportionate number of non-local women also supports this conclusion as an invading force would consist of non-local men (Stantis et al., 2020a).

4.2 Mummified Birds

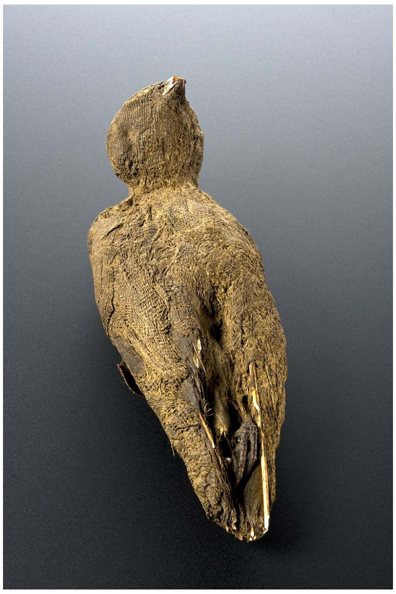

Figure 5: An ancient Egyptian mummified bird (Commons, 2020)

In addition to famous human mummies, ancient Egyptians sometimes mummified birds like ibises or birds of prey. One reason they did this was to honor gods who took the forms of birds, such as Horus and Thoth. One example of a mummified bird is in Figure 5. Linglin et al. (2020) asked whether these mummified birds were farmed or hunted in the hopes of understanding more about ancient Egyptian capabilities, their economy, and potential effects on the environment.

First, the researchers took bone samples from mummified birds. Samples from major bones were used; as birds do not have teeth, the researchers could not analyze tooth enamel as they would with humans or other animals.

Then, the researchers combined a few isotopic analyses, including one of strontium ratios.

They found that most of the ibises were local, but the birds of prey were nonlocal.

The researchers thus concluded that the ibises and birds of prey were wild.

4.3 Migrational Origins in Ancient Egypt

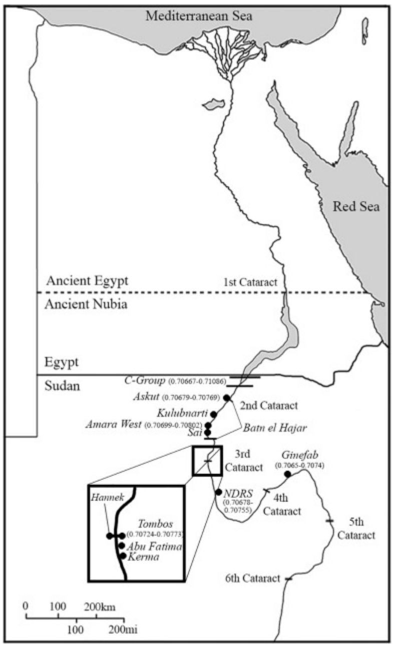

Figure 6: A map of Egypt, with the regions under study highlighted (Schrader et al., 2019).

Egypt rose to dominance in ancient times. Schrader et al. (2019) asked why; to do so, they investigated the movement of rural and urban settlements in Egypt from 2500 BCE to 656 BCE.

First, the researchers measured strontium isotope ratios of tooth enamel samples to identify local and non-local skeletons in three Egyptian graveyards, which range across time and urbanness.

The researchers concluded that, across the board, there were numerous non-local people. They reason that this indicates migraiton between the Second and Third Nile Cataract was normal in ancient times. This is enforced by the fact that even skeletons in ostensibly poorer graveyards showed non-local people, which likely means that people across financial brackets migrated consistently.

5 Conclusion

In conclusion, strontium isotope analysis emerges as a potent and illuminating tool for delving into the mysteries of Ancient Egypt. The method, which discerns the geographic origins of humans and animals through the examination of strontium isotope ratios in their remains, provides a unique lens into the past.

Through this paper, I've explored the foundations and applications of strontium isotope analysis, particularly in the context of Ancient Egypt. Strontium isotope analysis reveals the historical mobility and migration patterns of ancient populations, challenging conventional narratives and shedding light on the dynamic nature of human societies.

Case studies, such as the investigation into the origins of the Hyksos and the migrational patterns in ancient Egypt, exemplify the method's capacity to rewrite historical interpretations. The ability to discern the provenance of individuals, animals, and even crops enhances our understanding of trade, societal structures, and environmental interactions.

Beyond the realm of archaeology, strontium isotope analysis extends its utility to diverse fields. From forensics, where it aids in post-mortem investigations, to conservation efforts by tracking the illegal trade of animal products, this analytical method demonstrates its versatility and relevance.

The study of mummified birds and the assessment of migrational origins in Ancient Egypt showcase the breadth of insights that strontium isotope analysis can provide. Despite its strengths, strontium isotope analysis is not without limitations. Challenges related to precision, accuracy, and cost underscore the need for a nuanced approach and complementary methods.

However, ongoing advancements in technology and analytical techniques hold the promise of overcoming these challenges, making strontium isotope analysis an increasingly indispensable tool in the archaeologist's toolkit. As our understanding of strontium isotope analysis continues to evolve, it opens avenues for interdisciplinary research, encouraging collaboration between archaeologists, chemists, and environmental scientists.

By unraveling the secrets embedded in skeletal remains and ancient artifacts, strontium isotope analysis contributes significantly to reconstructing the intricate tapestry of human history. In conclusion, the journey through the survey of strontium isotope analysis in archaeological research of Ancient Egypt underscores its significance in unraveling the complexities of the past, paving the way for a more nuanced and enriched narrative of human civilization.

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