

Assignment 1: With reference to a specific archaeological project, critically assess the methods of archaeological investigation employed, and the nature of the archaeological materials/data recovered

Introduction

Although a relatively new technique within the ever-evolving roster of archaeological investigation methods, isotope analysis has made an undoubtable impact on the amount and variety of data able to be extracted from archaeological remains (Somerville and Beasley 2023; Makarewicz and Sealy 2015). Multi-isotope studies combining different isotope systems have been particularly beneficial to this data generation, and are increasingly employed in research projects to answer diverse research questions (see for example: Muldner *et al.* 2011; Moore *et al.* 2020). This approach was used to investigate the remains of three individuals (SK1, SK2, and SK3) recovered from Großmugl, a Hallstatt period site in Austria. Here, analysis of carbon, nitrogen, strontium, and oxygen isotope ratios was employed in an attempt to answer focussed research questions set out by the client:

- What can the analysis of carbon and nitrogen isotope ratios reveal about the diets and dietary behaviours of the Großmugl individuals?
- Is this inferred dietary behaviour typical for the Hallstatt period and/or the geographical region?
- What can the analysis of strontium and oxygen isotope ratios reveal about the residential origins and mobility of the Großmugl individuals?
- Were these individuals local to Großmugl and the surrounding area?

A commercial report was compiled to interpret and contextualise the data generated by these chosen methods, and a redacted version is available in the associated supporting documentation. This essay aims to critically assess the suitability of using isotope analysis to answer these proposed research questions and to determine the impact of the generated data and inferences. To do this, the main themes of the project's objectives (understanding diet, mobility, and lifestyle) will be considered in the context of the methods used to investigate them and the significance of the interpretations produced.

Reconstructing Diet Using Carbon and Nitrogen Isotope Analysis

To infer the potential composition of the Großmugl individuals' diets, carbon and nitrogen isotope analysis was carried out on collagen extracted from rib and dentine samples. The combination of these two isotope systems is now a standard destructive scientific method to

investigate dietary behaviours in past populations (Mays *et al.* 2023), and is based on the principle that carbon and nitrogen isotope ratios measured in skeletal tissues such as teeth and bones reflect the isotopic composition of the plants and/or animal products consumed during the formation of these tissues (Kohn 1999). Within this project, the use of this analytical method to measure carbon and nitrogen isotopes ratios in different skeletal tissues allowed three different aspects of diet to be explored: contributions to the protein portion of the diet during childhood and later life; composition of the whole diet during childhood; and indications of dietary change and stress during tooth development. Carbon and nitrogen isotope values from rib samples suggested that during the last five years before death (Cox and Sealy 1997; Fahy *et al.* 2017), all three individuals consumed a predominantly terrestrial diet with protein sourced from the consumption of C₃ plants and products from C₃-plant-fed animals, which may have included both herbivorous and omnivorous mammals, as implied by the high nitrogen isotope values indicative of more than a single trophic level shift when compared to contemporaneous terrestrial faunal data (Bocherens and Drucker 2003; Murray and Schoeninger 1998). This C₃ terrestrial diet was also inferred for all individuals earlier in life during childhood using the carbon isotope values measured in the crown dentine and non-remodelling enamel apatite samples, with the latter representing whole diet during enamel development (Ambrose and Norr 1993; Jim *et al.* 2004; Froehle *et al.* 2010). Using these sets of data together consequently indicated no significant dietary changes for the Großmugl individuals between childhood and later life, and was beneficial to rule out other potential dietary contributions such as C₄ and marine resources (Froehle *et al.* 2010). Therefore, although isotopic analysis is destructive and sampling parts of bone and bisected halves of teeth was required here (Mays *et al.* 2023), the combination of isotope data from these tissues which form at different ages was a highly advantageous method to increase the amount and temporal resolution of generated data, thereby enabling the interpretation of dietary behaviour throughout the individuals' lives. This multi-tissue analysis and comparison was crucial to provide as much information as possible to the client using all available data, and thus helped answer the first research question by providing evidence of diet directly from the individuals' remains (Makarewicz and Sealy 2015).

However, interpreting isotopic data is not always straightforward even when analysing multiple tissue types, and is especially difficult to understand without accurate contextual information. For instance, within this project the sampling and data analysis were undertaken by different people, and unfortunately during initial analysis, the fact that the root apex of SK2's permanent incisor was incomplete had not been included within the provided data file. This meant that SK2's higher rib and dentine nitrogen isotope values were initially interpreted as this individual having access to different food sources than SK1 and SK2,

such as freshwater fish or omnivorous (e.g. suckling) pigs (Minigawa and Wada 1984; Schoeninger and DeNiro 1984; Dufour *et al.* 1999; Jay and Richards 2006), and their incremental dentine profile was constructed using the wrong approximate developmental age ranges for each increment. The unsampled half of SK2's incisor was eventually re-examined because of the unusual results, and the detection of the incomplete root apex signified that this individual in fact died during childhood (AlQahtani 2009; Beaumont and Montgomery 2015). This allowed an accurate incremental dentine profile to be created (figure 1) which acknowledged that incisor development was arrested at the time of death, and completely changed the interpretation of this individual's dietary behaviour. From this, it was suggested that whilst access to additional food sources could not be ruled out, the high nitrogen isotope values observed in SK2's tissues were more likely related to this individual experiencing continuous periods of stress throughout their short life, causing the breakdown of stored protein and hence increased nitrogen isotope values (Fuller *et al.* 2005; Mekota *et al.* 2006). Therefore, although the use of incremental dentine profiles allowed analysis of the Großmugl individuals' childhood diets with high temporal resolution (Beaumont *et al.* 2013), this method is reliant on accurate age-at-death information and significant inferences were almost missed here without it.

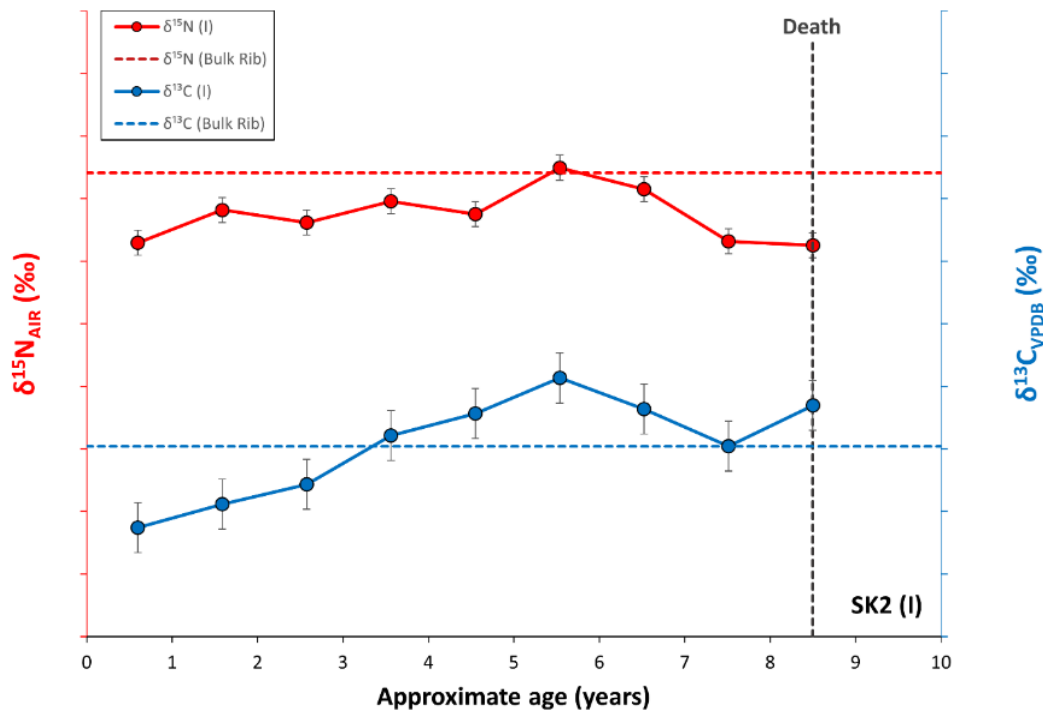


Figure 1: The incremental dentine profile for SK2, with redacted carbon and nitrogen isotope data. Once it was realised that this individual did not survive past childhood, the incremental profile was amended to show SK2's approximate age of death when the tooth development would have been arrested. This provided vital contextual information which ultimately facilitated the interpretation of the data (Chart produced by author 2023).

Once this initial constraint was rectified however, combining incremental data with bulk rib and dentine data and contextualising it with published literature allowed even more information to be revealed about this skeletal population's diet. Despite the general scarcity of literature related to this period and region, relevant contemporaneous and geographically related carbon and nitrogen isotope data was collated from studies of other Austrian Hallstatt period sites (Le Huray and Schutkowski 2005) and was used to scrutinise the Großmugl data. This comparative method was especially beneficial, as it highlighted that all of the Großmugl individuals' nitrogen isotope values were atypically high compared to these other sampled populations (figure 2), thereby answering the second research question and allowing potential explanations for this difference to be proposed. Suggested interpretations included the use of crop manuring, the consumption of omnivorous mammals such as suckling pigs, and/or the inclusion of freshwater fish in the diet, which have all previously been shown to increase nitrogen isotope values in humans (Minigawa and Wada 1984; Schoeninger and DeNiro 1984; Dufour *et al.* 1999; Jay and Richards 2006; Bogaard *et al.* 2007; Fraser *et al.* 2011). Although providing the client with multiple contrasting interpretations may seem like a disadvantage of using isotope analysis, it instead ensured the client was not led down a single (potentially incorrect) line of enquiry, and gave them as much information as possible from which to formulate further research objectives, whilst also emphasising that interpretations made using isotopic data are not conclusive (Madgwick *et al.* 2021). Rather, isotope analysis is employed most effectively within multidisciplinary methodologies. Thus, attempts were made to promote this to the client, for example through supporting the inference of a terrestrial C₃ diet concluded from the isotopic data with the factual knowledge that remains of terrestrial mammals such as sheep (*Ovis aries*) and pigs (*Sus scrofa*) were recovered during excavations at Großmugl. Ultimately, by not only analysing the isotopic data yielded from the remains themselves but also placing this data within the wider context, this project's methodology generated an increased understanding of the understudied Hallstatt period, revealed new unusual dietary findings from this period, and encouraged further research to uncover more evidence about these individuals' livelihoods.

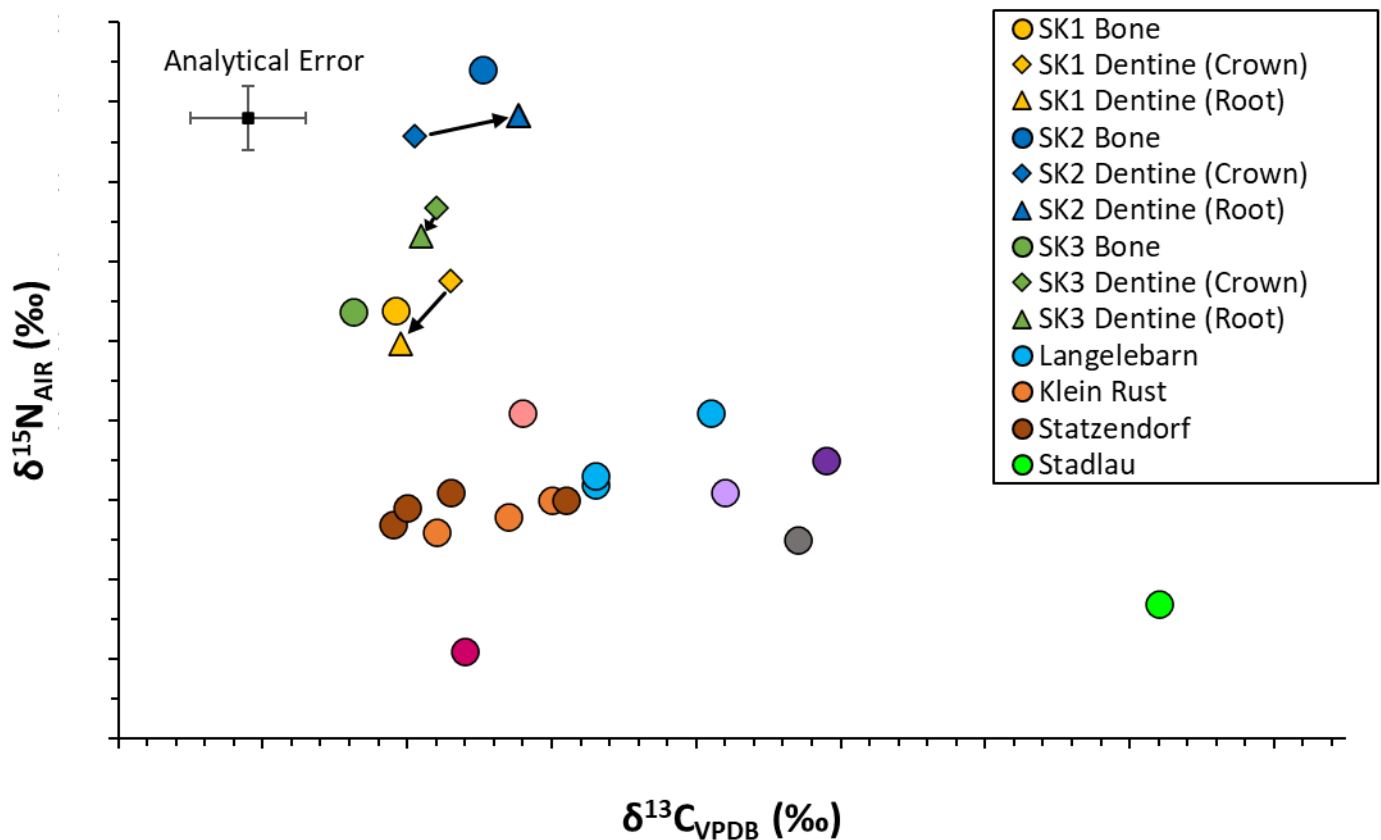


Figure 2: This graph compares the (redacted) carbon and nitrogen data of the Großmugl individuals' dentine and rib samples to contemporaneous data from other Hallstatt period burials from Northern Austria (Le Huray and Schutkowski 2005). The graph highlights that the Großmugl nitrogen isotope values are considerably higher than those from the comparative sites, suggesting that they are unusually high for the period (graph produced by author 2023).

Assessing Geographical Origins Using Strontium and Oxygen Isotope Analysis

Similarly, using strontium and oxygen isotope analysis to explore residential origin and mobility not only benefitted from the inclusion of analysing comparative data as part of the methodology, but was inherently reliant on this to form reliable interpretations. As the composition of strontium and oxygen isotope ratios measured in human tissues are directly related to the underlying geology on which food sources are grown (Bentley 2006; Montgomery 2010) and the water sources exploited for drinking (Kohn 1999; Darling and Talbot 2003), respectively, without researching the expected isotope values for Großmugl's local lithology and precipitation, it would not be possible to infer whether the three individuals originated from this area. A regional dataset was used to estimate the local oxygen isotope value range for Großmugl and the surrounding area (Lightfoot and O'Connell 2016). All of the individuals' enamel oxygen isotope ratios sat within this range and were therefore

consistent with a local childhood residential origin, although the range produced from this dataset was large and other regions with similar oxygen isotope compositions cannot be ruled out (figure 3). This serves to highlight the biggest caveat of using isotope analysis in mobility studies, in that it is an exclusionary method that cannot confirm a single location but only rule out potential origins, and often leaves a large amount of remaining possibilities (Montgomery and Jay 2013).

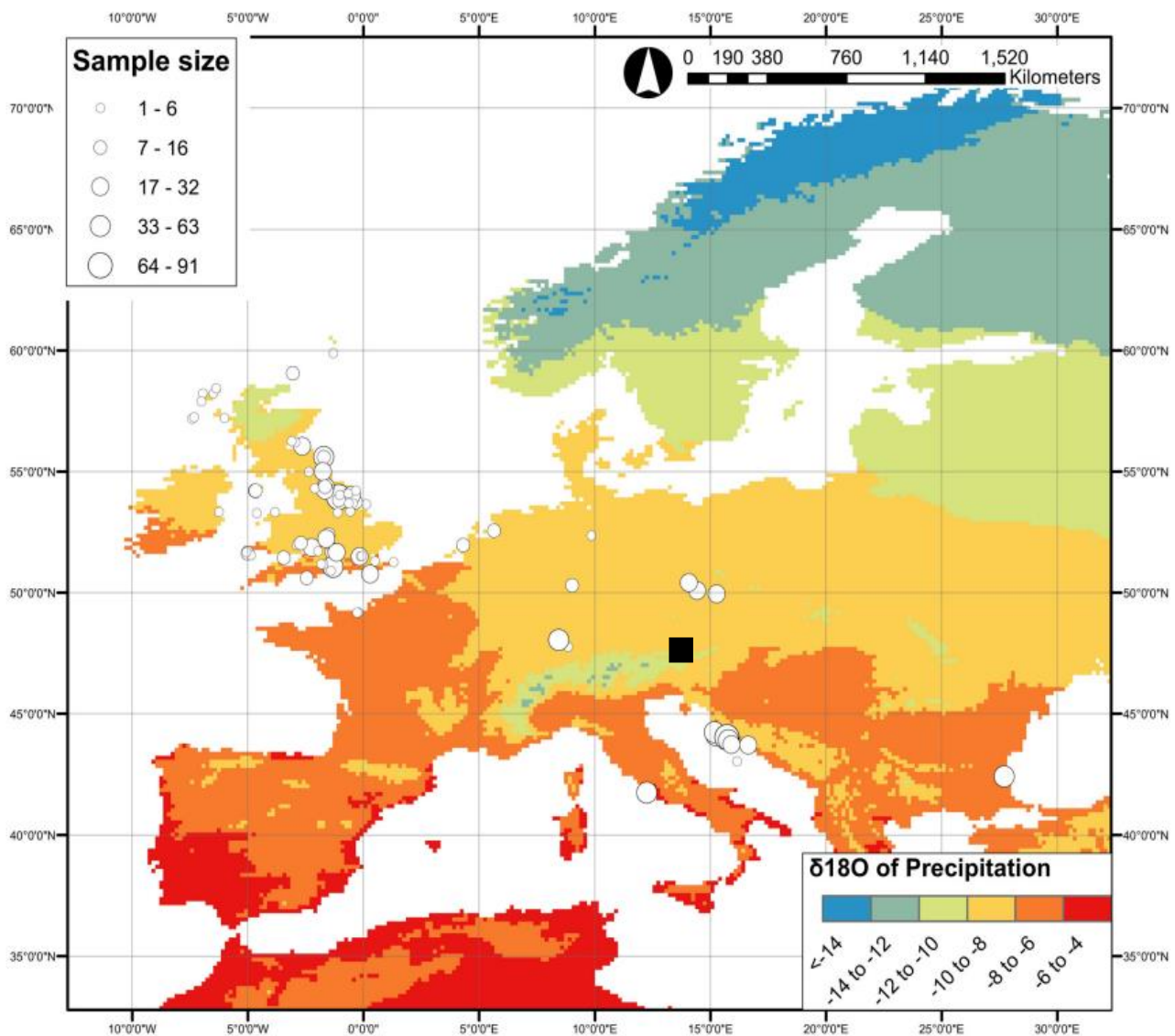


Figure 2: This regional dataset was used to estimate the local oxygen isotope range for Großmugl, in lieu of water samples directly taken from the site. This produced a large value range due to the site's location on the boundary of two zones with different expected oxygen isotope values (see the black square). As evident from the map, these value ranges are not unique to Großmugl and are common across much of Europe (Lightfoot and O'Connell 2016: Figure 6).

Though this limitation was unavoidable, the use of more directly related strontium data helped to make the inference that the individuals were likely local to Großmugl more credible. Strontium isotope data from a nearby Bronze Age hillfort (Retzmann *et al.* 2020) with similar underlying geology was used as a proxy to estimate Großmugl's local bioavailable strontium isotope range, and faunal dentine samples from Großmugl were analysed to provide a proxy for the variable strontium isotope range of the site's soil (Budd *et al.* 2000; Kendall *et al.* 2018). The strontium isotope ratios measured in the Großmugl individuals' enamel sat within both of these proxy data ranges, consequently implying that their values are not only consistent with consumption of food sourced from the same geology underlying the site, but also match Großmugl's burial environment. Of course, this still does not conclude Großmugl as the only possible place of origin, especially as SK1 and SK2's strontium isotope values fall within a range of undiagnostic values common across Europe (Montgomery *et al.* 2014). However, when used together, the strontium and oxygen isotope data excluded areas with expected higher oxygen isotope values such as south-east Europe and most of western Europe, and more locally to Großmugl ruled out lithologies of the Alps and the Bohemian Massif (figure 4) as potential residential origins. Hence, the use of strontium and oxygen isotope analysis within this methodology provided answers for the research questions relating to the residential origins of these individuals and their locality to Großmugl, yet also prefaced these conclusions with the necessary acknowledgement that other childhood residential origins are possible and should not be discounted.

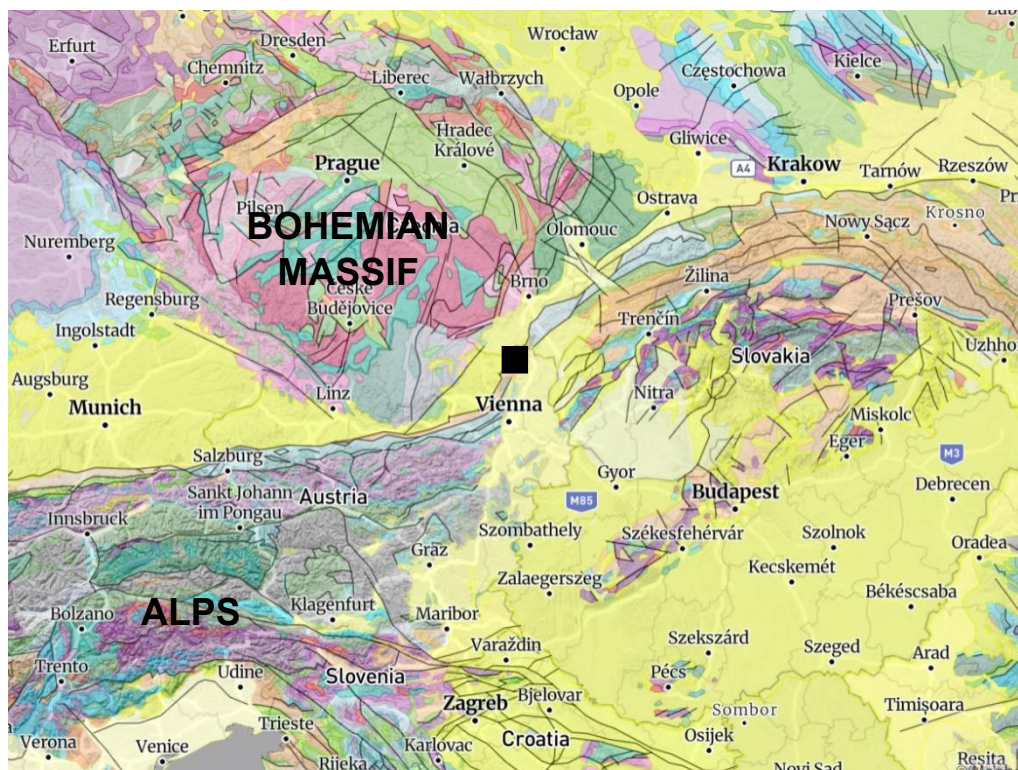


Figure 4: This map highlights that the geology underlying Großmugl (see black square) differs from that of the Bohemian Massif to the north and the Alps to the south-west, which would produce higher strontium isotope values than those observed in the Großmugl individuals (Macrostrat 2024).

Conclusion

In summary, whilst the scope of this essay does not permit a thorough investigation of every positive and negative aspect of the methods employed within this project, by focussing on what the data generated from the isotopic analysis itself has uncovered about the three individuals found at Großmugl, and how the use of comparative data has furthered these interpretations, the impact and efficacy of the chosen methods has been critically analysed here. The inference that the Großmugl individuals likely all consumed a typical terrestrial C₃ diet throughout their life, but still had higher nitrogen isotope values than those observed at multiple contemporaneous sites, serves to emphasise how carbon and nitrogen isotope analysis was used to analyse different skeletal tissues and draw out varied and useful findings. Additionally, the ability to infer periods of stress from incremental dentine profiles highlighted the unique information that can be gleaned from studying these isotopes, and how apt the method was for understanding past dietary behaviours and factors impacting the individuals' lifestyles. Finally, the information gained about mobility through the combination of strontium and oxygen isotope data with relevant comparative data underscored the cruciality of this method for exploring the Großmugl individuals' residential origins. However, it would be imprudent to consider these advantages of isotope analysis in isolation without acknowledging the innate constraints of the method. As a destructive and exclusive technique that is dependent on access to reliable contextual information, isotope analysis and any resulting data should be utilised in a conscientious manner, with the client being made aware of any ambiguity and restrictions, as they have been in this report. Ultimately, in spite of the various limitations associated with analysing isotopic data, the application of carbon, nitrogen, oxygen, and strontium isotope analysis within this project has not only allowed diverse interpretations to be made about the lifestyles of the Großmugl individuals, but has also provided the client with multiple possible explanations consistent with the produced results which could be used to develop future research objectives.

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