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Strontium isoscapes in The Netherlands. Spatial variations in $^{87}Sr/^{86}Sr$ as a proxy for palaeomobility

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ABSTRACT

Strontium isotope analysis has been successfully applied to archaeological questions of residential mobility and animal husbandry for over three decades. To obtain a full understanding of variations in archaeological samples, spatial variations in bioavailable strontium should be accurately mapped or inferred. This paper presents the first archaeological bioavailable strontium map of The Netherlands. The map is compiled solely from archaeological enamel samples of rodents and selected mammals as they are considered to provide the best proxy of bioavailable Sr. The diversity of the Dutch geological subsurface is directly reflected in the spatial distribution of $^{87}Sr/^{86}Sr$ ratios. Six isoscapes are defined: A) Lower terrace of the river Meuse (0.7074–0.7091, $n = 2$); B) Marine and river Rhine sediments (0.7088–0.7092; $n = 85$); C) Holland peat area, Kempen and northern sand areas (0.7091–0.7095, $n = 14$); D) Rur Graben (0.7095–0.7105, $n = 11$); E) Push moraines (0.7095–0.7110, $n = 7$) and F) Northern and southern loess areas (0.7104–0.7113, $n = 15$). Although individual isoscapes may show some overlap, the mean of each isoscape is statistically significant different, except for zones D and E. Five other geological environments yielded no archaeological data, mainly due to poor preservation in acidic soils. To fill this data gap, additional biosphere samples will be collected and analysed. This approach, however, will require validation of the extent to which specific floral are offset compared to the average archaeological bioavailable strontium. The base map presented here now allows such a detailed assessment of potential offsets in the $^{87}Sr/^{86}Sr$ recorded by different proxies at the regional scale.

1. Introduction

Archaeological migration models used to be based on the spatial dispersal of cultural artefacts. This approach, however, has led to a lively debate about whether the archaeological cultural record represents the actual movement of people or the broader diffusion of cultural heritage in the form of ideas, materials and objects (Childe, 1925; Burmeister, 2000; Hakenbeck, 2008). Over the last three decades, advances in several bioarchaeological disciplines, such as DNA and isotope research, have offered new perspectives on this debate. Stable isotopes, such as carbon (C) and nitrogen (N), are used to address very diverse archaeological questions. Originally introduced by Van der Merwe and Vogel (1977), both isotopes are now established as invaluable tools for the reconstruction of palaeodiet, the determination of patterns of breastfeeding and weaning age, and the investigation of animal husbandry (e.g. Richards et al., 2002; Mays and Beavan, 2012; Hammond and O'Connor, 2013). Moreover, the use of the radiogenic strontium isotope system ($^{87}Sr/^{86}Sr$) in bioarchaeological research has matured into an established tool for providing information about human and animal residential mobility and husbandry practices in prehistory (see Bentley, 2006; Schwarcz et al., 2010; Slovak and Paytan, 2011 for review).

Strontium isotope ratios serve as a proxy of palaeomobility due to the geographical variation in ^{87}Sr produced by the β-decay of ^{87}Rb as a result of the spatial variations in the initial amount of ^{87}Rb in the geological bedrock and the age of the lithology. Strontium isotope ratios ($^{87}Sr/^{86}Sr$) are released to the environment through the weathering of rocks (Capo et al., 1998). Strontium isotope ratios in soil substrates, however, can deviate significantly from the biologically-available Sr that is taken up by vegetation and introduced into our food chain due to inputs from the atmosphere, such as precipitation and sea-spray, and outputs through stream- and groundwater (Fig. 1; Price et al., 2002; Hedman et al., 2009). Ultimately, the bioavailable strontium is conveyed into the skeletal tissues of human and animals through their diet where it substitutes for calcium in the structure of hydroxyapatite in bone, dentine, enamel, keratin, ivory and shell. Tooth enamel is formed during childhood and barely undergoes any change after mineralisation and during burial (Nelson et al., 1986; Budd et al.,

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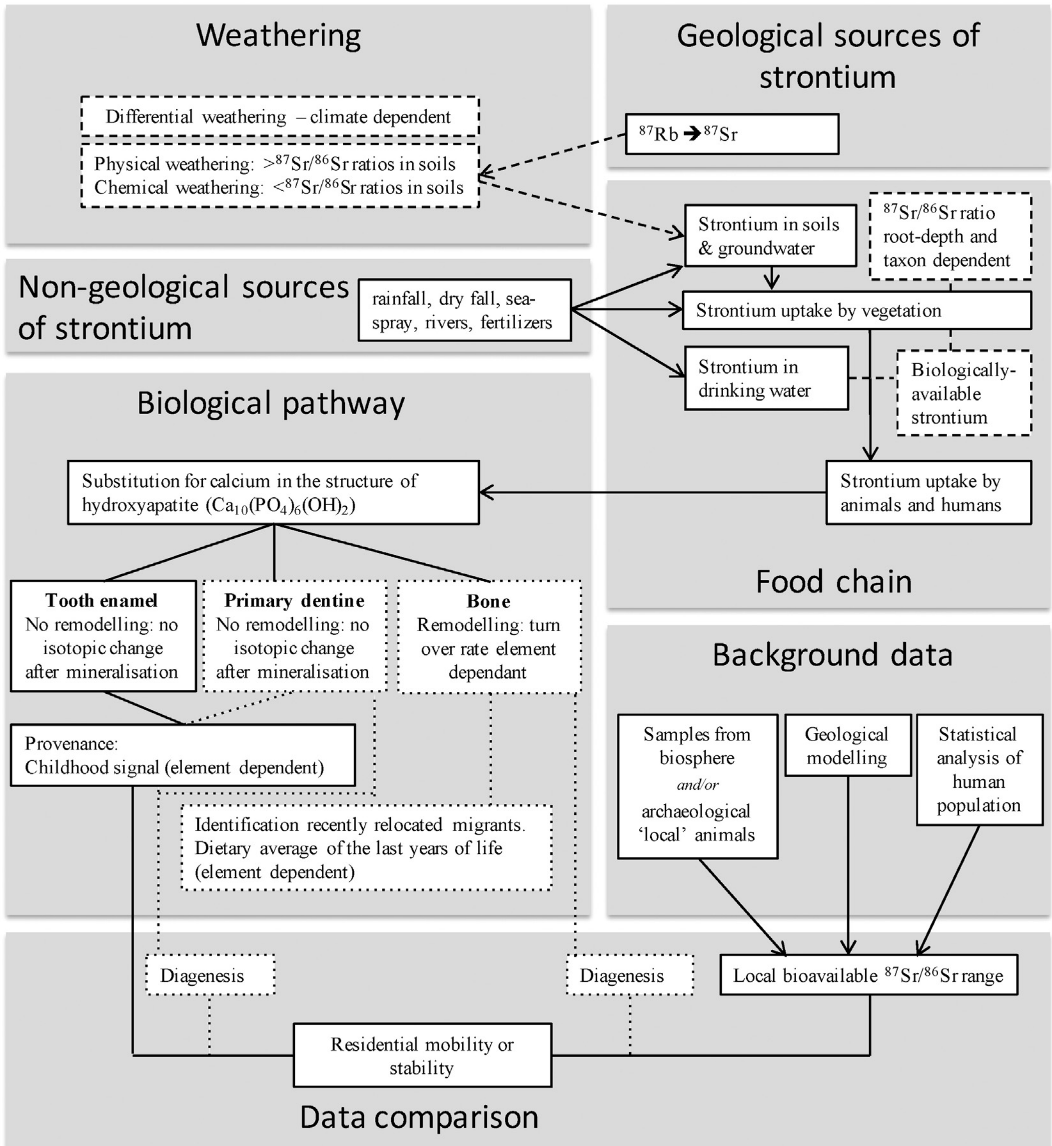

Fig. 1. Schematic diagram showing the basic principle of strontium isotope analysis of archaeological skeletal material. Key: - - - - $^{87}Sr/^{86}Sr$ dependent on differential weathering or differential uptake; ····· biomaterials susceptible to diagenetic alterations.
Modified from Tütken et al. (2008).

2000; Hoppe et al., 2003). Hence, the $^{87}Sr/^{86}Sr$ ratio in tooth enamel reflects the strontium intake during childhood, and thus can serve as a tracer of the geological area where the individual grew up, assuming that his or her diet was dominated by locally grown foods (Hillson, 1986; Price et al., 2002; Pye, 2004).

The main principle of this provenance technique is to compare the isotopic signatures from an individual to the local bioavailable strontium. Differences between the $^{87}Sr/^{86}Sr$ of an individual's dental enamel and the local bioavailable strontium range indicate the individual did not live in the region during their youth and has migrated from an isotopically different geographical location (Fig. 1). In contrast, similarities between the local biosphere strontium signal and the individual's biogenic signal indicate residential stability or residential mobility between two geographic locations with similar isotopic signatures.

A prerequisite for the interpretation of strontium isotope signatures in archaeological organic materials is the accurate mapping of the spatial variations in bioavailable $^{87}Sr/^{86}Sr$ ratios within the study area, or the development of accurate so-called isoscapes (Bowen, 2010). In Europe, $^{87}Sr/^{86}Sr$ reference maps have been published for the United Kingdom (Evans et al., 2009, 2010), Denmark (Frei and Frei, 2011; Frei and Price, 2012), Sweden (Sjögren et al., 2009), France (Willmes et al., 2014), Greece (Nafplioti, 2011) and southwest Germany (Bentley et al., 2004; Bentley and Knipper, 2005). To date, however, there is no baseline information for bioavailable $^{87}Sr/^{86}Sr$ in The Netherlands. The aim of this paper is to present a first archaeological $^{87}Sr/^{86}Sr$ spatial distribution map. This study approach allows us to evaluate the spatial variation in bioavailable $^{87}Sr/^{86}Sr$ in The Netherlands and to assess migration in an archaeological context. Moreover, the data presented here contributes significantly to our understanding of the European strontium isoscapes, and ultimately allows a more accurate investigation of ancient intra-European mobility.

2. Building Sr isotope reference datasets

A large variety of methods are used to investigate regional variability in $^{87}Sr/^{86}Sr$ ratios (Hodell et al., 2004; Evans et al., 2010; Viner et al., 2010; Maurer et al., 2012). Since the $^{87}Sr/^{86}Sr$ ratio is directly related to the initial amount of ^{87}Rb in rocks and the age of the lithology, direct