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Tracing population mobility in the Aegean using isotope geochemistry: a first map of local biologically available $^{87}Sr/^{86}Sr$ signatures

Argyro Nafplioti*

British School at Athens, Athens, GR-10676, Greece

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ABSTRACT

Strontium isotope ratio ($^{87}Sr/^{86}Sr$) analysis of archaeological human skeletal remains is an efficient method of investigating past population movement and residential mobility by determining probable geographical origins for the individuals examined. For this to be achieved, however, a map of biologically available $^{87}Sr/^{86}Sr$ signatures across the region investigated is needed. This paper presents a first such map for the Aegean, based on $^{87}Sr/^{86}Sr$ values recovered mainly from archaeological animal dental enamel and modern snail shells from sites largely distributed in the southern part of this region. Although not exhaustive, this comprehensive dataset of local biologically available $^{87}Sr/^{86}Sr$ signatures shows a marked difference between Mainland sites of the Pindos and Parnassos zones and the islands of south-eastern Aegean crossed by the Sub-Pelagonian zone (0.70808–0.70869), and sites in the central Cyclades and the north-eastern Aegean islands falling into the Attic-Cycladic metamorphic belt and the Vardar zone, respectively (0.70926–0.71187). Biologically available $^{87}Sr/^{86}Sr$ values from sites on central Euboea in the Pelagonian zone, south-eastern Attica and the western Cyclades in the Attic-Cycladic metamorphic belt, and on Crete in the Gavrovo zone are also relatively high (0.70853–0.70931), but lower than those recorded for the central Cyclades and the north-eastern Aegean.

1. Introduction

Although isotope geochemistry has successfully been employed in studies of past population movement and residential mobility principally in America and northern Europe over the past three decades (e.g. Price et al., 1994; Price et al., 2000, 2002; Bentley, 2006; Evans et al., 2006a, 2006b; Slovak et al., 2009), it is only recently that it began to be used in archaeological research in the Aegean (Nafplioti, 2007, 2008, 2009a, 2009b, 2010; Richards et al., 2008), pioneered by the author. However, the single biggest obstacle to the further development of this research field in the Aegean remains the lack of a map of biologically available isotope signatures in the region, such as those generated by Bentley and Knipper (2005) for southern Germany, Evans et al. (2009) for the Isle of Skye (Scotland), and Evans et al. (2010) for Britain.

This paper presents and discusses the first comprehensive set of high-quality data on biologically available $^{87}Sr/^{86}Sr$ signatures in the Aegean to make it readily accessible to the research community and facilitate further advancement of this research field. Owing to the paucity of background research and of $^{87}Sr/^{86}Sr$ published data for Aegean rocks, the dataset presented in this paper comprises necessary groundwork for research into population mobility in the Aegean using $^{87}Sr/^{86}Sr$ analysis. Further, this paper discusses the potential of $^{87}Sr/^{86}Sr$ analysis of archaeological skeletal material for investigating questions of geographical origin and population movement in the Aegean context, and sets the scene for further developments in research in this field by defining potential future research directions.

The data presented here are the result of various case studies carried out by the author as part of her doctoral and ongoing postdoctoral research over the past five years. They comprise $^{87}Sr/^{86}Sr$ values from samples of archaeological or modern animal skeletal tissue from twenty-one (21) sites in the Aegean, plus $^{87}Sr/^{86}Sr$ values from samples of archaeological human bone only, for an additional five (5) sites.

2. Materials and methods

2.1. Principles of analysis

Studies of human population movement and residential mobility use $^{87}Sr/^{86}Sr$ analysis of human skeletal tissues as a proxy of local geology to determine the geographical origin of the individuals examined and distinguish between locals and non-locals at

* Tel.: +30 6970219454.
E-mail address: argyro.nafplioti@googlemail.com.

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the sites investigated. In nature, strontium occurs in the form of four stable isotopes, ^{87}Sr (comprises c. 7.04% of total strontium), ^{88}Sr (c. 82.53%), ^{86}Sr (c. 9.87%) and ^{84}Sr (c. 0.56%). The strontium isotope ^{87}Sr is radiogenic and is the product of the radioactive decay of the rubidium isotope ^{87}Rb, which has a half-life of approximately 47 billion years. The other three strontium isotopes are all non-radiogenic (Faure, 1986). Therefore the strontium isotope ratio ($^{87}Sr/^{86}Sr$) in any local geology depends on the relative abundance of rubidium and strontium and on the age of the rocks (Rogers and Hawkesworth, 1989). Proximity to marine environments can also impact on local $^{87}Sr/^{86}Sr$ signatures as $^{87}Sr/^{86}Sr$ for modern ocean is measured as a constant of 0.7092 (Veizer, 1989). Finally, although other factors, such as atmospheric deposition (Miller et al., 1993) and in modern context fertilizers too, can contribute to the strontium composition of local soils, $^{87}Sr/^{86}Sr$ largely reflects mineral weathering (Bentley, 2006: 14). The strontium isotope ratio passes from the bedrock into the soil and groundwater and hence into the food chain, reaching human tissue from the food and water consumed with no fractionation related to biological processes (Graustein, 1989; Blum et al., 2000). Thus $^{87}Sr/^{86}Sr$ in human tissue largely reflects local geology.

The application of $^{87}Sr/^{86}Sr$ analysis to archaeological research, and to studies of residential change in particular, is based on the properties of strontium and the possibility of identifying migrants who moved between geologically different regions by comparing strontium isotope ratios measured in human skeletal tissues (bone and dental enamel) formed at different ontogenetic stages (Price et al., 1994, 2000). Bone undergoes continuous replacement of its inorganic phase, and $^{87}Sr/^{86}Sr$ measured in bone reflects the last seven to ten years of the life of the individual (Parfitt, 1983). Dental enamel on the other hand is a cell-free tissue that forms during early childhood and does not remodel thereafter (Hillson, 2002, 148). In principle, therefore, since $^{87}Sr/^{86}Sr$ in soil reflects local geology and passes to human skeletal tissues through the food and water consumed, analysis of dental and osseous tissue from an individual should show very similar $^{87}Sr/^{86}Sr$ values to that measured in the local geological material, if that individual was born, raised and spent at least the last 7–10 years of his/her life in the local area. Otherwise, if the $^{87}Sr/^{86}Sr$ value of the enamel is significantly different from bone samples from the same individual and the local biologically available $^{87}Sr/^{86}Sr$ values, it may be concluded that he/she spent his/her childhood at a location geologically and isotopically different from his/her residence prior to death (Sealy, 1989; Steele and Bramblett, 1988).

2.2. The geological context and $^{87}Sr/^{86}Sr$ data for Aegean geological materials

The geology of the Aegean region is complex as a result of high tectonic activity (Higgins and Higgins, 1996: 17), and is divided into isopic or tectonic (the two terms are interchangeable) zones that comprise groups of rocks sharing a common geological history. Fig. 1 reproduces the map of isopic zones and massifs of the Aegean after Higgins and Higgins (1996), and marked on it are the sites for which this paper presents biologically available $^{87}Sr/^{86}Sr$ data. These twenty-six sites sampled are distributed across a great portion of the South Aegean crossed by the Gavrovo, Ionian, Pindos, Parnassos, Sub-Pelagonian, Pelagonian, and the Vardar zones, and the Attic-Cycladic metamorphic belt. Brief background information on the local bedrock geology of these sites is given below, with reference to the isopic zone relevant to each site.

The island of Crete largely falls within the Gavrovo zone, which was a continental fragment for the early part of its history (Higgins and Higgins, 1996: 19). Knossos in the central part of the island (n.3, Fig. 1), which is the most extensively sampled site in this paper, is mainly underlain by Neogene sedimentary rocks. Cretaceous limestone crops out in less than 1 km distance to the north-east of the site, while the hill of Gypsades, at the same distance to its south, partly consists of gypsum formed about 6 million years ago. At the western part of the island, the site of Chania (n.7, Fig. 1) lies in a small graben of Miocene marls and limestone covered to their greatest extent with terra rossa soils, and is bordered by Triassic to Cretaceous limestone mountain and hill formations to its south and north-east (Higgins and Higgins, 1996: 202–203). Kastelos (n.6, Fig. 1) also in western Crete, and Maroulas (n.5, Fig. 1) and Margarites (n.4, Fig. 1) in the north-central part of the island are situated on Neogene sediments with crystalline limestone and marble, and areas of Permian limestone in proximity. Myrtos Pyrgos (n.1, Fig. 1) in south-eastern Crete is set on Neogene sediments (Fortuin, 1977, cited by Myers et al., 1992: 203), while flysch and Permian limestone appear to the north and north-west of the site (Higgins and Higgins, 1996: 198).

Mycenae (n.8, Fig. 1) and Tiryns (n.9, Fig. 1) in the Argolid are crossed by the Pindos Zone, which was an ocean basin for the early part of its history (Higgins and Higgins, 1996: 19). The site of Mycenae was built on a knoll of Late Triassic to Middle Jurassic limestone, which also underlies the hills and the mountain range to the north, south and east of the site. The valley to the west of the site was largely formed by marls and conglomerates deposited during the Late Pliocene to Pleistocene. Tiryns is set on Early Cretaceous limestone. The Argive plain nearby, is a Neogene graben dominated by geologically recent alluvial deposits (Higgins and Higgins, 1996: 45-48). Franchthi (n.10, Fig. 1) and Koilada (n.11, Fig. 1), also in the Argolid, appear to fall at the border between the Pindos and the Parnassos zones, and are situated on Cretaceous limestone (Susskoch, 1967, cited by Forney, 1972; Jameson, 1976).

Kranidi (n.12, Fig. 1) in the Argolid, and Perachora (n.13, Fig. 1) in Corinthia are crossed by the Parnassos zone. The Parnassos zone mainly comprises shallow-water Triassic to Palaeocene carbonates and locally developed bauxite deposits covered by flysch and late Eocene conglomerates (Ager, 1980: 509; Higgins and Higgins, 1996: 19). Kranidi is set on Triassic to Jurassic limestone with Neogene and Pleistocene sediments to its south (Jameson, 1976; Higgins and Higgins, 1996:41). Perachora is also situated on Triassic to Lower Jurasic limestone, which is overlain by Upper Jurassic volcano-sedimentary series and Lower Cretaceous Boeotian flysch (Maroukian et al., 2008).

The south-eastern Aegean, where the islands of Kos (nos.24 and 25, Fig. 1) and Rhodes (n.26, Fig. 1), comprises a variety of different geological environments. Kos and Rhodes largely fall in the Sub-Pelagonian zone, which is mainly characterised by ophiolite suite rocks and Triassic to Jurassic grey limestone (Higgins and Higgins, 1996: 40). Kardamena-Antimacheia and Chora on Kos are set on Neogene sediments exposed beneath recent volcanic rocks and alluvium, respectively (Higgins and Higgins, 1996: 159). The Koumelo Cave on Rhodes is formed in Cretaceous limestone, while Neogene sediments and alluvium are present in the vicinity of the site (Higgins and Higgins, 1996: 153).

The sites of Manika (n.14, Fig. 1) and Tharrounia (n.15, Fig. 1) on Euboea represent in this paper the Pelagonian zone; a continental fragment dominated by Triassic and Jurassic limestone (Higgins and Higgins, 1996: 18). Manika is mainly underlain by serpentinite and Triassic to Jurassic limestone. To the south-west of the site, the low hills are formed by late Cretaceous limestone, while the plain that extends to its east and south comprises alluvium and Pleistocene sediments. Tharrounia is situated on Late Triassic to Early Cretaceous limestone. Earlier schist rocks are exposed in short distance to the west and north of the site, while Neogene sediments occur to its east and south, respectively (Higgins and Higgins, 1996: 84–85).