Strontium isotopes and human mobility in Ceramic Neolithic-Middle Chalcolithic Cyprus (ca. 5200/5000–3000/2800 B.C.): a pilot study

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ABSTRACT

The present study discusses aspects of human mobility in Ceramic Neolithic (ca. 5200/5000–4000 B.C.) and Middle Chalcolithic Cyprus (ca. 3500–2800 B.C.) through the application of strontium isotope analysis. Small-scale intra-island movement in prehistoric Cypriot contexts is usually inferred by the circulation of finished artifacts and raw materials, while several researchers in the past supported large-scale migrations based exclusively on the ostensibly abrupt changes in the material culture. Focusing on the strontium isotopic values of sampled human teeth from sites of the Limassol district, this pilot study attempts to demonstrate the potential of this methodology for the identification of non-local individuals and/or groups. The results provide fresh insights on prehistoric mobility patterns in Cyprus, while also discussing some of the methodological limitations in archaeological contexts.

1. INTRODUCTION

Recent advances in osteoarchaeology and relevant analytical techniques, such as the application of stable isotope analysis, strontium (Sr) isotope analysis, and the growing interest on ancient DNA studies provide valuable information on individuals, their daily activities and the human past in general. Strontium isotopes, in particular, are used with increasing frequency in order to investigate questions of population mobility, and several researchers have applied this methodology in archaeological contexts, demonstrating its potential concerning the identification of non-local individuals in given geographic regions.[1] The increasing interest

1 E.g. Nafplioti 2011; Bentley 2013; Borić and Price 2013; Whelton et al. 2018.

on isotopes, along with the growing number of analytical applications involved, is also evident in Cyprus.[2] Nevertheless, osteological materials of the Ceramic Neolithic (ca. 5200/5000–4000 B.C.) and Chalcolithic (ca. 4000/3900–2500/2400 B.C.) periods remain extremely underrepresented, while the use of strontium isotope ratios to determine mobility patterns, in particular, is even rarer.[3]

In this paper, we discuss the results of strontium isotope analysis conducted in human specimens from prehistoric sites of the Limassol district. This study forms part of the Neolithic and Chalcolithic Cyprus Project (NCCP)[4] and complements recent research on palaeopathology and palaeodiet through stable isotope analysis of skeletal remains from the same area of the island.[5] To our knowledge, studies on strontium isotopes from human remains are totally absent in the case of prehistoric Cyprus. Thus, this pilot attempt aims to explore their potential and to provide an initial assessment of their importance in identifying ancient mobility patterns.

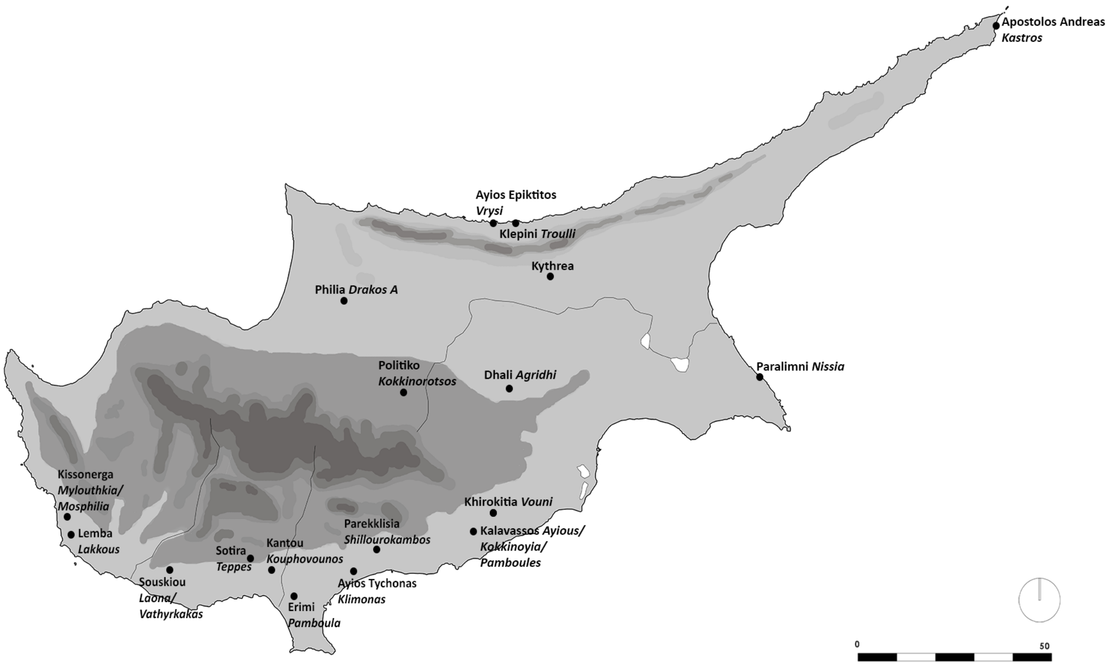

Fig. 1. Map of Cyprus with the main excavated Neolithic and Chalcolithic sites (prepared by A. Marda-Stypsianou and E. Tzanni).

2 E.g. Lange-Badré and Le Mort 1998; Sciré-Calabrisotto 2017; Goude et al. 2018.

3 E.g. Ladegaard-Pedersen et al. 2020; for another relevant study on strontium isotopes see Rich et al. 2012.

4 https://nccp.arch.uoa.gr/

5 Voskos and Vika 2020.

2.1. ARCHAEOLOGICAL BACKGROUND, AIMS AND OBJECTIVES

The NCCP aims to contribute in a series of long debated subjects concerning socio-economic evolution and cultural change in Cyprus during the 5th–4th millennia B.C. For this purpose, an area with abundant traces of diachronic habitation[6] was selected and is being analysed in depth. The Kouris valley lies in south-central Cyprus (Fig. 1) and includes a number of important excavated settlements, such as the "key-sites" of Sotira *Teppes*[7] and Erimi *Pamboula*,[8] along with another recently published Ceramic Neolithic settlement at Kantou *Kouphovounos* (Fig. 2).[9] The three sites are located within the narrow coastal strip between the sea and the foothills of mountain Troodos. Sotira *Teppes* and Kantou *Kouphovounos* developed in prominent hills and their main phases are dated between ca. 4400–4100/4000 B.C. Erimi *Pamboula*, on the other hand, lies near the mouth of river Kouris and the life span of the settlement covers the second half of the 4th millennium (ca. 3500–3000 B.C.). All three settlements exhibit signs of permanent habitation in curvilinear or sub-rectangular structures, while the evidence from various categories of material culture and bioarchaeological data implies a mixed agropastoral economy largely complemented by deer hunting.[10]

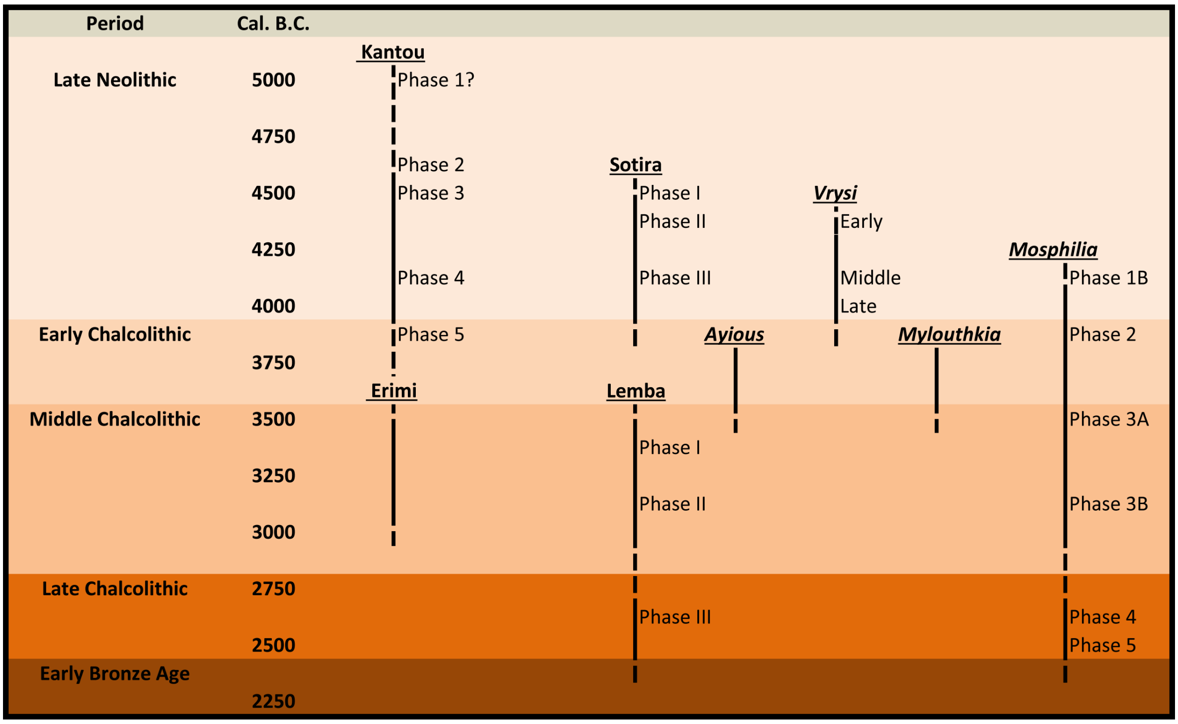

Fig. 2. Chronological chart with the main excavated Ceramic Neolithic and Chalcolithic settlement sites and their individual phases (after Voskos 2021).

6 I.e. the Kouris valley and its periphery in Limassol district.
7 Dikaios 1961.
8 Dikaios 1936; see also Dikaios 1962, 113–32; Bolger 1988.
9 Mantzourani 2009; Mantzourani and Voskos 2019a.
10 See also Voskos 2018; Voskos and Vika 2020.

Although the geology of this region does not provide favourable conditions for the preservation of human/animal bones in general, a number of burials were uncovered in the rich archaeological deposits of the excavated parts of the selected settlements. More specifically, 12 pit burials were excavated at the site of Sotira *Teppes*, two more burials along with some scattered osteological material were located at Kantou *Kouphovounos* and 4–5 more individuals were identified at Erimi *Pamboula*.[11] The inhumated individuals of the former two sites represent nearly the 100% of the existing skeletal remains of the Ceramic Neolithic period on the island. In addition, the identified individuals at Erimi account for the only excavated osteological material of the Chalcolithic period in Limassol district.

Given the fact that most of the human remains from Sotira *Teppes* and Erimi *Pamboula* were either lost or published several decades ago, it was imperative for us to revisit them from a different perspective. Thus, an integral part of this project was the reexamination of the available skeletal remains using a series of innovative analytical techniques, such as stable isotope analysis on bones and strontium isotope analysis on teeth. The application of these techniques along with the macroscopic revisiting of the osteoarchaeological material aimed at enriching our knowledge on several aspects of prehistoric life, such as dietary customs, pathologies, economic strategies, mobility and exchange, habitation patterns and, in general, the socio-economic behaviour of Neolithic and Chalcolithic Cypriot communities.

Another main objective of the project is to elaborate the existing knowledge concerning mobility patterns on the island. Seasonal or regular intra-island movement of groups or individuals is thought to have been practiced since the earliest phases of Cypriot prehistory, based on material evidence. Beyond the traditional deer exploitation that characterizes the economic strategies of all Cypriot communities in the Stone and even the Bronze Age,[12] there is some evidence that points to the existence of small-scale exchange networks promoting contact between early prehistoric groups within the island, as well as between Cypriot and other communities in the broader eastern Mediterranean area. For example, small quantities of picrolite –an ideologically charged material with several sources in south and southwest Cyprus including the Kouris area[13]– were located in eastern and northern sites,[14] while the existence of finished artifacts from raw materials that originate in the neighbouring continental regions[15] point to continuous contact with SW Asian communities at least since the initial phases of the local Aceramic Neolithic period (ca. 9000–5500 B.C.), if not earlier.[16]

2.2. ASPECTS OF MOBILITY IN PREHISTORIC CYPRUS

Recent research has enriched the relevant evidence on regular intra-island movement and/or contact stemming from the circulation or at least direct procurement of specific raw materials such as jasper,[17] various types of

11 For a recent comprehensive description of this osteological material including relevant bibliography see Voskos and Vika 2020, Tables 1–3.

12 Several researchers, such as Croft (1988, 1991), have referred in the past to this unusual dependence. See also Wasse 2007, 61; Webb et al. 2009; Croft 2010; Voskos 2018, 469.

13 Xenophontos 1991.

14 E.g. the picrolite objects (485, 655, 777) from Ayios Epiktitos *Vrysi*; Peltenburg 1982, 316. For relevant objects at Paralimni *Nissia* see Flourentzos 2008, 87–8. For the distribution of picrolite objects in Neolithic/Chalcolithic Cypriot sites see also Peltenburg 1991, 110–13, figs 1–3 and the Appendix in pages 123–26.

15 E.g. carnelian and "butterfly" beads, small amounts of Cappadocian obsidian etc.; see for example Clarke 2010, 199; Kloukinas and Voskos 2013; Moutsiou 2018, 2019; Moutsiou and Kassianidou 2019. For more evidence on relevant contact through exotic materials and artifacts see McCartney 2010, 190, Table 22.2.

16 For a diachronic view of maritime interaction and connectivity between Cyprus and neighbouring areas see also Knapp 2020.

17 Mantzourani et al. 2019, 159.

flints/cherts[18] and clays for the production of pottery.[19] Hunting or seasonal pastoralist activities might have also promoted contact between groups from different parts of the island.[20] Indeed, the existence of mobile components within prehistoric Cypriot society is inferred by the various, mainly upland and mainland, seasonal encampments and settlements with ample evidence for hunting-gathering, pastoral, timbering and several other activities such as resource procurement and intensive wild plant exploitation.[21] The latter seem to coexist with numerous Neolithic and Chalcolithic coastal or near-coastal villages exhibiting more permanent characteristics, such as the three settlements under investigation.

The main questions that arise here then concern the degree of mobility among the prehistoric Cypriot population, the relationship between seemingly settled agropastoral and more mobile groups, and also the nature of social contact between communities from different parts of the island. From this point of view, identification of non-local individuals within the sampled osteoarchaeological material of this study would provide some hints about existing economic strategies, the dynamics of social interaction and also the patterns of local or interregional contacts, such as active exchange networks or perhaps intermarriage relationships in order to ensure demographic viability.[22] Concerning the latter, for instance, it has been argued that decorative traditions and stylistic variability on clay vessels formed effective ways to negotiate regional identities and the economic and social space on the island.[23] Assuming that the selected stylistic elements and decorative techniques reflect symbolic expressions of identity,[24] then identification of small quantities of Combed Ware (Cb)[25] in Ceramic Neolithic sites of the central and northern part of Cyprus[26] might echo the presence of non-local individuals, and hence the conscious manifestations of their identities. Equally, small quantities of the dominant in the eastern, central and northern part of the island Red-on-White Ware (RW) are identified in southern Cypriot sites, including the area of the Kouris valley.[27] Thus, the presence of imported vessels within an otherwise homogeneous Cypriot tradition might reflect the forging of supra-regional social alliances between distant households or broader communities, a process perhaps also involving the exchange of brides, who carried their familiar vessels as dowries. Alternatively, the existence of these imports along with some attempts to imitate decorative traditions of other parts of the island suggest that the earliest decorated clay vessels in Cyprus[28] might have also functioned as prized items, whose acquisition from distant sources added to their symbolic value and to the prestige of their owners.[29]

Another important issue related to population movement, concerns past and more recent interpretations of the large chronological gap between the Khirokitian or Late Aceramic Neolithic (ca. 7000–5500 B.C.) and the

18 Papagianni 2019, 298–300; see also McCartney 2002.

19 See for example the discussion on the collection of clay from specific sources for the production of Coarse Ware trays; Boness et al. 2015.

20 See for example Clarke 2001, 77.

21 E.g. Simmons 2012; Simmons et al. 2018 (Kritou-Marottou *Ais Giorkis*); Ammerman et al. 2018 (Agia Napa *Nissi Beach*); Efstratiou et al. 2018 (Vretsia *Roudias*); McCartney et al. 2018 (Agia Varvara *Asprokremmos*) and several more.

22 For the importance of marriage alliances and networks in small egalitarian communities see for example Peltenburg 1991, 107–8 with relevant bibliography.

23 Clarke 2001, 65, 71.

24 On the "symbolic style" and individual identities see for example Clarke 2001, 72.

25 Combing was the dominant decorative technique of southern-central Cypriot sites, including Sotira *Teppes* and Kantou *Kouphovounos*.

26 E.g. Clarke 2007, 101.

27 For example, the percentage of Red-on-White (RW) and the hybrid ware of Red-on-White and Combed (RW-Cb) or Painted and Combed (PCb) was estimated between 6.5–11.5% at the site of Kantou *Kouphovounos* (Mantzourani and Voskos 2019b, 29–30). Most of the relevant vessels, however, seem to form attempts to imitate other decorative traditions and were not direct imports from central or northern sites.

28 I.e. pottery of the Ceramic Neolithic period (5th millennium B.C.).

29 See for example Knappett et al. 2010, 602, 604.

Sotiran or Ceramic Neolithic cultures (mainly 4600–4000 B.C.).[30] Most of the traditional explanations revolved around the decisive involvement of natural disasters and abrupt climatic change, leading to island-wide abandonment and subsequent recolonisation of Cyprus.[31] Nevertheless, several recent studies have highlighted the considerable continuities in the material culture, tool production sequences and embedded socio-economic behaviours between the Aceramic and Ceramic Neolithic phases.[32] Thus, even if we accept the existence of intrusive groups, which, among others, might have transferred crucial new technologies[33] or new crops,[34] the inhabitants of Cyprus during the Ceramic Neolithic and Chalcolithic periods seem to have largely retained the traditional "anachronistic" lifeway of the previous millennia. The potential identification of people originating from an area beyond Cyprus or the exclusion of migrationist episodes during the Late Neolithic and Chalcolithic periods would, therefore, contribute to the ongoing discussions on the exact conditions of appearance of new cultural traits and generally the active processes of long-term socio-cultural change on the island.

3. STRONTIUM ANALYSES IN ARCHAEOLOGY

Strontium is an element that forms part of the natural environment and is found in the rocks and the soil, but also in water and atmospheric deposition. The strontium isotope ratios in bedrock are a result primarily of geological age and composition of the rock, and can vary distinctly.[35] In general, older rocks (like granites) will have a higher $^{87}Sr/^{86}Sr$ compared to younger formations, like limestones.[36] Through weathering of the rocks, strontium is transported into the overlying soils and surface waters, from where it is uptaken by plants and enters the food cycle. This principle formed the basis of measuring strontium from skeletons to directly investigate mobility in archaeology.[37] The methodology relies in comparison: soil will contain strontium from its underlying rock and so will the plants that grow on the soil, and the animals that feed on the plants. Therefore, animals and rocks will be linked through their strontium values. Archaeologists saw a powerful tool to directly investigate mobility, and since 1985 a multitude of studies[38] have applied the method to archaeological populations, describing both the potential and the numerous problems of it.[39]

During life, strontium is deposited in the skeleton through a rather complicated metabolic process that involves strontium and calcium.[40] In the dentition, strontium is incorporated in the enamel and the dentine. A large number of studies have shown that enamel can be considered a stable tissue, resistant to chemical changes even in long, geological timescales.[41] This means that tooth enamel will retain the strontium values that were acquired during the time of tooth mineralisation, and will not be affected by time or the burial environment. With the exception of the third molar, strontium measured from the enamel of the adult dentition will

30 For the relevant hiatus estimated between 500–1000 years (i.e. ca. 5500–4600 B.C.) see for example Mantzourani 2001, 26; Peltenburg et al. 2003, xxxiii; Steel 2004, 63; McCartney 2007, 77; Clarke 2007, 10–11, 17 and fig. 2.1; 2010, 199.

31 E.g. Catling 1966, 11; Stanley-Price 1977a, 1977b; Held 1992. For a brief review of these perspectives see Kloukinas and Voskos 2013, 313; Voskos 2018, 468–69.

32 McCartney 2007; Legrand-Pineau 2009; Kloukinas and Voskos 2013.

33 Such as pottery production. For a full discussion see Clarke 2007, 97–9.

34 See for example Kloukinas and Voskos 2013, 315 with relevant bibliography; also Voskos 2018, 469–70 and Table 48.1.

35 Rogers and Hawkesworth 1989; Bataille and Bowen 2012; Bataille et al. 2020.

36 Ezzo et al. 1997; Bentley 2006.

37 Ericson 1985.

38 From Sealy et al. 1991 to Vytlačil et al. 2021.

39 See Montgomery 2010 for a thorough review.

40 Burton and Wright 1995.

41 Vernois et al. 1988; Glimcher et al. 1990; Lee-Thorp and van der Merwe 1991; Price et al. 1994, 2002; Wang and Cerling 1994; Michel et al. 1996; Rink and Schwarcz 1995; Koch et al. 1997; Budd et al. 2000; Nielsen-Marsh and Hedges 2000; Montgomery et al. 2000; Trickett et al. 2003.

correspond to the individual's childhood.[42] In contrast, dentine strontium is affected by the burial environment and cannot be linked to the individual's diet. However, it can be used to provide information about the burial soil or local biosphere strontium ratios.[43] Research has also shown that for humans with a balanced diet, the primary contributor to strontium is likely to be the plant part of the diet, with animal sources making a negligible input.[44]

Even though the basic principle of mobility studies in archaeology is based on the observation that strontium isotopes are transported from local rocks and soils into animal and human tissues, several recent studies have demonstrated that certain factors influence this correspondence between geology and tissues.[45] This means that soil $^{87}Sr/^{86}Sr$ will differ from bioavailable $^{87}Sr/^{86}Sr$. The parameters that can contribute to the alteration of strontium values from the geology to mammalian tissue are mainly atmospheric dust, sea spray, and rainwater. Atmospheric dust can transport sediments over extensive distances. Studies have shown that up to 75% of strontium in vegetation can be attributed to atmospheric deposition and not local geology.[46] The effects of atmospheric dust transportation and deposition will differ from one region to another as a result of topography, wind direction, and forestation. Similarly, local isotopic signatures may change due to sea spray. Sea spray carries strontium with an isotopic composition close to the modern, global seawater $^{87}Sr/^{86}Sr$ ratio. Plants and animals that receive large amounts of sea salt particles through the sea spray effect will show strontium values that are closer to seawater, erroneously suggesting location by the sea. Sea spray can travel quite far from the shore, although the exact extent of the phenomenon is not known.[47] Rainfall is another parameter that can change local geology strontium values to resemble those of rainwater.[48] What this implies is that if a certain region undergoes a phase of climatic change, characterized by extreme rainfall, the strontium values of the vegetation will change. Recent studies demonstrate how these parameters could have affected Cyprus in antiquity and discuss the variability within and between regions.[49]

From the above, it is apparent that for archaeological reconstructions of mobility, it is not enough to know the geological composition of the substrate, but the local bioavailable ratios also need to be investigated. For this, archaeologists rely on measuring the isotopic ratios from local animals, especially the species that are presumed not to have been highly mobile,[50] together with local plants and water samples.[51] The use of modern local plants as reference is usually avoided, for fear of contamination by modern fertilizers, although the extent of such contamination is not accurately demonstrated.[52] Similarly, water sources must be carefully selected to represent natural sources.[53] For the faunal material to work as an accurate reference, it is necessary to assume that grazing took place in the same area as crop cultivation. If animals were grazing in a different location to the one where crops for human consumption were grown, the values will not be comparable. Arguably, there are many problems in the reconstruction of isoscapes, and more research is needed before it is shown which reference materials can work best to describe the bioavailable range of values.[54] In addition to the above, it is critical to understand that strontium measurement is an analysis that works by elimination, as it can only exclude places of origin. For this, a measurable strontium isotope difference needs to exist between the place the person grew up in and the place they ended their life in.

42 Hillson 1996.
43 Montgomery et al. 2007; Evans et al. 2010.
44 Elias 1980; Burton and Price 1999.
45 E.g. Price et al. 2002.
46 Graustein 1989; Miller et al. 1993.
47 Gustafsson and Franzén 2000; Price and Gestsdóttir 2006.
48 Capo et al. 1998; Raiber et al. 2009.
49 Ladegaard-Pedersen et al. 2020.
50 Price et al. 2002; Bentley et al. 2004; Wright 2005.
51 Price et al. 2002; Frei and Frei 2011; Maurer et al. 2012; Ryan et al. 2018.
52 Horn 2005.
53 Frei and Frei 2011.
54 Bataille et al. 2020.

4. MATERIALS AND METHODS

Cyprus has a complicated geological substrate, framed between two mountain ranges, Pentadaktylos on the north and Troodos on the south. The three sites of this study are located in Neogene and Quaternary sediments on the southern-central part of the island.[55] Kantou *Kouphovounos*[56] is situated on an elevation near the west bank of river Kouris, while Erimi *Pamboula*[57] lies on the alluvial soils of the eastern bank, only a few kilometres from the coast. Sotira *Teppes*,[58] also on a small hill, lies further inland. Kantou and Sotira fall into the geological formation of Pachna, which is dominated by sedimentary rocks, mainly marls, chalks and sandstones.[59]

Sample no.	Site	Element	Museum-storeroom/shelf
ERI – 5	Erimi *Pamboula*	Left upper molar	Archaeological Museum of Limassol district (Bones 8)
ERI – 7	Erimi *Pamboula*	Left lower molar. Deciduous	Archaeological Museum of Limassol district (Bones 8)
ERI – 9	Erimi *Pamboula*	Right lower second molar (M2)	Archaeological Museum of Limassol district (Skeleton 2, Bones 8)
ERI – 13	Erimi *Pamboula*	Left lower second molar (M2)	Archaeological Museum of Limassol district (Skeleton 3, Bones 4, Box 2)
SOT – 15	Sotira *Teppes*	Right upper third molar (M3)	Archaeological Museum of Limassol district (Skull 3, tray 3)
SOT – 17	Sotira *Teppes*	Left lower second molar (M2)	Archaeological Museum of Limassol district (Skull 4, tray 4)
SOT – 20	Sotira *Teppes*	Left lower third molar (M3)	Archaeological Museum of Limassol district (Skull 11, tray 2)
SOT – 24	Sotira *Teppes*	Lower molar. Deciduous	Archaeological Museum of Limassol district (Skull 9, tray 1)
SOT – 26	Sotira *Teppes*	Right lower first molar (M1)	Archaeological Museum of Limassol district (Skull 8, tray 1)
KAN – 30	Kantou *Kouphovounos*	Right upper third molar (M3)	Local Archaeological Kourion Museum at Episkopi (Burial 2, Building 15, Section IB 28, Phase III or Rectangular phase tray labelled: box with skeleton of burial 2)
KAN – 35	Kantou *Kouphovounos*	Upper third molar (M3)	Local Archaeological Kourion Museum at Episkopi (tray labelled: fill of grave 2)
KAN – 36	Kantou *Kouphovounos*	Right upper first molar (M1)	Local Archaeological Kourion Museum at Episkopi (area north of Building 1, Section B25, Phase II or Expansion phase, tray labelled: Section B. North of N part of T1)

55 Cohen et al. 2011, 2012.
56 Mantzourani 2009; Mantzourani and Voskos 2019a.
57 Dikaios 1936, 1962; Bolger 1988.
58 Dikaios 1961.
59 See Panagides and Mantzourani 2009.

Sample no.	Site	Element	Museum-storeroom/shelf
Water – 1	–	Modern surface water	–
Water – 2	Kantou village	Groundwater	–
Water – 3	Sotira village	Groundwater	–

Table 1. Samples analysed by the NCCP and relevant contextual information.

In a precedent paper we described the general dearth of Ceramic Neolithic human remains and also the scarcity of Chalcolithic skeletons in the Limassol district.[60] For this reason, even small-scale studies on Cypriot material make a significant contribution, although a lot more work is needed to understand past mobility on the island. Thus, in an effort to investigate the potential of this method and to further explore the archaeological questions of mobility in Cyprus, strontium isotopes from 24 samples of human enamel and dentine were measured, together with surface water and groundwater samples as proxies (see Tables 1–2). Dentine measurements were used as an indication of diagenetic strontium, in absence of other faunal or environmental background, as discussed in section 3.

All the sampled individuals come from inhumations in shallow pits within the domestic contexts of the sites under investigation or at least within the limits of the settlements.[61] The dead were normally buried in a contracted position and, in most cases, there are no burial goods. As is shown in Table 1, there are four samples from Erimi *Pamboula*, five from Sotira *Teppes* and three from Kantou *Kouphovounos*. The human samples from Kantou *Kouphovounos* come from the single adult male of burial 2, while another sample was extracted from the scattered material in the vicinity of Building 1.[62] Another adult male (skeleton 2) along with a child (skeleton 3) were sampled at Erimi *Pamboula*, while there are two more samples coming from scattered material. Lastly, at Sotira *Teppes*, we sampled five out of the 11–12 available individuals.[63] The selection of samples was dictated by preservation and availability of molars. Only teeth with intact enamel were included. Preference was given to teeth that did not exhibit taphonomic depositions. Only teeth that could be confidently assigned to discreet individuals were sampled.

Samples were prepared at the Vrije Universiteit Amsterdam. To remove potential contaminations, the outer surface of the dental enamel samples (n=12) was scoured, and 2±1 mg of dental enamel powder was sampled. The dentine samples underwent the same pre-treatment, and approximately 1 mg of dentine powder was collected. The samples were stored in hydrochloric acid pre-cleaned 2 ml polyethylene Eppendorf® centrifuge tubes. The Eppendorf® tubes were transferred to the US Federal Standard Class 100 clean laboratory facility at the Vrije Universiteit Amsterdam for strontium purification. The enamel samples were leached in 0.1M acetic acid, to remove possibly added diagenetic strontium. Strontium column extraction and sample loading were performed, following the protocols published in Kootker et al. 2016. The isotope compositions were measured using a Thermo ScientificTM Triton PlusTM instrument. The strontium ratios were determined using a static routine and were corrected for mass fractionation to 86Sr/88Sr ratio of 0.1194. The NBS987 standard gave a mean $^{87}Sr/^{86}Sr$ ratio of 0.71025 ± 0.00009 (n=14). In this study, the measurements were all normalized to an accepted NBS987 ratio of 0.710240. The total procedural blanks (n = 4) contained an average of 30 pg strontium. This is negligible compared to the average amount of strontium present.

60 Voskos and Vika 2020, Tables 1–3.

61 In the case of Sotira *Teppes* the burial area is situated at the foothills of the mound; Dikaios 1961, 142–47.

62 The latter seemingly belongs to another adult.

63 The sampled material originates from skulls 3, 4, 8, 9 and 11 (three adult males, one adult female and one sub-adult). For more information on Ceramic Neolithic and Chalcolithic burials and the existing osteological material (including age, sex etc.) in the three settlements under examination see Voskos and Vika 2020 with relevant bibliography.

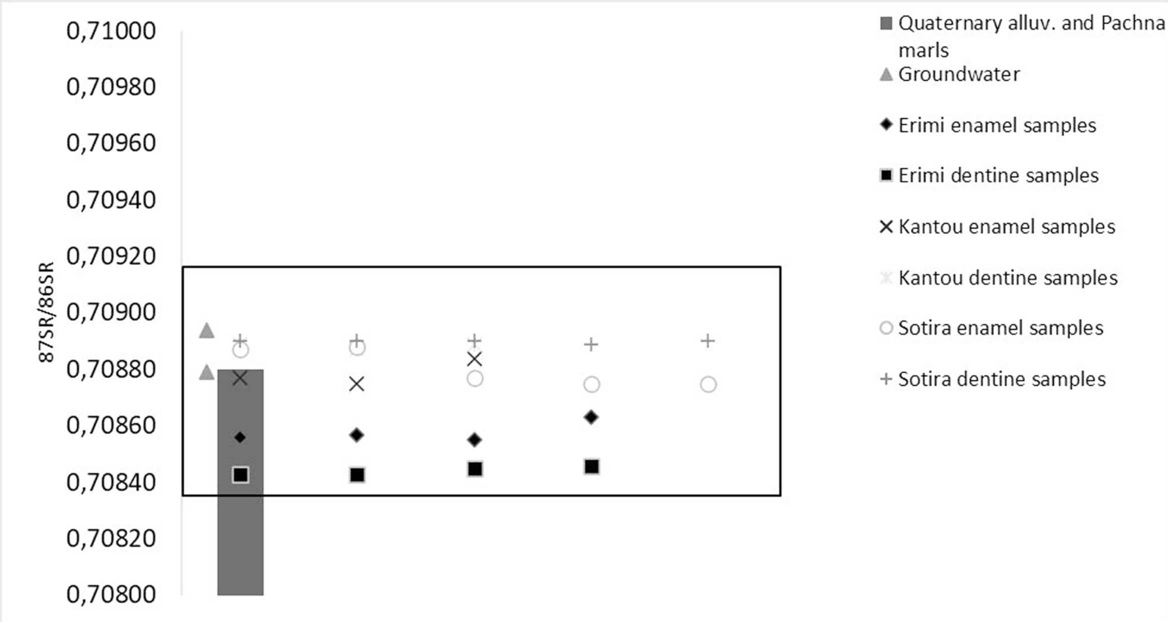

Fig. 3. $^{87}Sr/^{86}Sr$ values discussed in the text. The area in the box corresponds to "local" range, calculated by the mean dentine and groundwater values ±2SD. The grey bar corresponds to the range of environmental samples from Pachna and alluvial soils from Ladegaard-Pedersen et al. 2020 (prepared by E. Vika).

5. RESULTS AND DISCUSSION

Results are shown in detail in Table 2 and Fig. 3. Applying a simple comparison, we see that in most cases the difference between the average enamel strontium isotope composition and that of the dentine is less than 0.0003. The samples are within the local Sr range calculated from the mean dentine and water values ±2SD, and also correspond to the published environmental values for Neogene and Quaternary sediments and alluvium for Cyprus.[64] The most straightforward interpretation of this data is that the geology of the region where the individuals grew up and procured their diet from is the same as that of the region where they were buried.

Sample no.	Material	$^{87}Sr/^{86}Sr$	2SE2
ERI – 5	Dentine	0,70842	0,000008
	Enamel	0,70858	0,000007
ERI – 7	Dentine	0,70844	0,000007
	Enamel	0,70856	0,000001
ERI – 9	Dentine	0,70844	0,000008
	Enamel	0,70868	0,000008
ERI – 13	Dentine	0,70842	0,000007
	Enamel	0,70857	0,000007
SOT – 15	Dentine	0,70890	0,000009
	Enamel	0,70888	0,000009
SOT – 17	Dentine	0,70890	0,000008
	Enamel	0,70890	0,000008

64 Ladegaard-Pedersen et al. 2020.

Sample no.	Material	$^{87}Sr/^{86}Sr$	2SE2
SOT – 20	Dentine	0,70892	0,000007
	Enamel	0,70868	0,000007
SOT – 24	Dentine	0,70889	0,000001
	Enamel	0,70875	0,000008
SOT – 26	Dentine	0,70890	0,000009
	Enamel	0,70868	0,000009
KAN – 30	Dentine	0,70889	0,000006
	Enamel	0,70877	0,000007
KAN – 35	Dentine	0,70889	0,000008
	Enamel	0,70874	0,000007
KAN – 36	Dentine	0,70889	0,000001
	Enamel	0,70884	0,000001
Water – 1	Modern surface water	0,70565	0,000008
Water – 2	Kantou groundwater	0,70892	0,00001
Water – 3	Sotira groundwater	0,7088	0,000001

Table 2. $^{87}Sr/^{86}Sr$ results from enamel, dentine, and water samples of the NCCP.

If no other indication of mobility exists for the individuals under study, such as archaeological evidence, the most direct way to interpret the results is to assume that all of the individuals in this case were "locals". However, for the entirety of reasons discussed in section 3, this is not a solid assumption. Firstly, large geographic areas can be lain on the same geological formations. This means that, under certain circumstances, strontium isotopes can be the same throughout these entire regions, which could have hosted multiple settlements. Thus, people who lived in different settlements on the same area have a high chance of presenting isotopically local, and this is an example of why all the archaeological parameters need to be considered in the discussion of mobility and locality. The latter also exemplifies accurately the limitations of using strontium isotopes alone to answer complex archaeological questions: locality and mobility are concepts far more complicated than a mere isotopic number.[65]

Individual mobility is also much more difficult to understand in archaeological terms. The metabolism of strontium in humans is a complicated process[66] and many physiological parameters can remain elusive in archaeological studies. Then the presence of a single outlier, a single non-local, poses more questions than perhaps the presence of an entire group of non-locals.[67] Seasonal mobility, a type of movement frequently discussed in prehistory and arguably practiced widely in Neolithic-Chalcolithic Cyprus as discussed in section 2.2, is also very difficult to identify, and would require the combined measurements of several elements.[68] And, as hinted above, movement between areas with a similar geological substrate would not be easily identifiable, unless the entire range of bioavailable strontium is known for each area.[69] For the same reason, provenancing an individual based on strontium isotopes alone,[70] especially with the lack of extensive local background data, may prove to be misleading.

65 For a recent discussion on the issues pertaining to the interpretation of strontium values, see Szostek et al. 2015.
66 Parker and Toots 1980.
67 See for example the case of the Egtved girl; Frei et al. 2015.
68 See for example Nafplioti et al. 2021.
69 Ladegaard-Pedersen et al. 2020.
70 I.e. directly linking an individual to a potential place of origin.

In addition to the theoretical problems on defining mobility, it appears in recent studies that determining a "local" strontium value is much more complicated than previously thought. As science progresses and scholars gain a better understanding of methodologies, it is becoming evident that selecting the right proxies to determine the locally bioavailable strontium values is of critical importance.[71] In our study, one of the three sites is set on a different substrate to the other two (Fig. 4). Erimi *Pamboula* is located on sandy clays of Quaternary alluvial formations, whereas Sotira *Teppes* and Kantou *Kouphovounos* are located on marls of the Neogene Pachna formation. The difference is reflected in the slight δ^{87}Sr differentiation between the sites. Our measurements also demonstrate that groundwater can be a good indicator of soil strontium, whereas modern surface water cannot be used here as an indication of locality.[72]

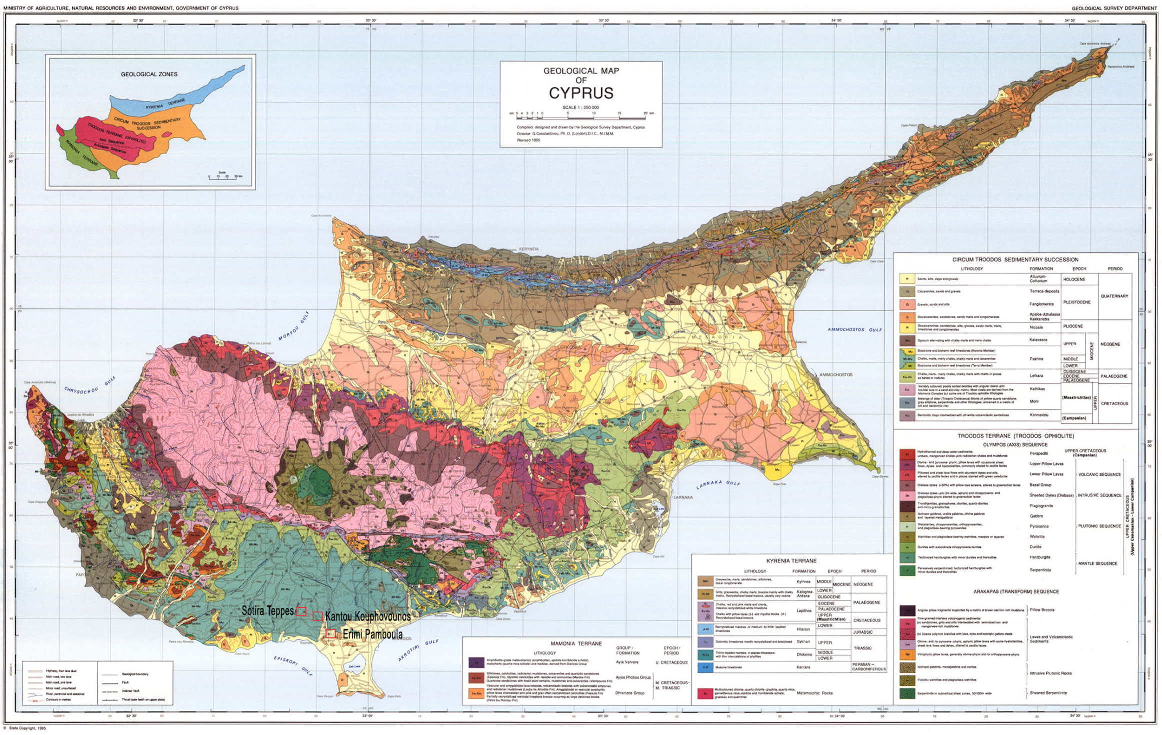

Fig. 4. Geological map of Cyprus. Source: Geological Survey Department, Government of Cyprus (modified by A. Marda-Stypsianou).

The present analysis shows no significant movement of the individuals under investigation between different landscapes, for none of the sites studied. At present, and taking into consideration all the factors that have been discussed here and that influence the local bioavailabilty of strontium, we can interpret this result as an indication of "locality" for the individuals studied. On the other hand, small scale mobility through the region of the same geological substrate cannot be excluded, as it is not something that can be detected with this methodology at present. Similarly, mobility between regions of the same geological substrate regardless of distance is also not excluded, as for the moment there is no comprehensive isoscape study for the eastern Mediterranean to help researchers differentiate between areas with similar geology, but different bioavailability.

71 Evans et al. 2010; Frei and Frei 2011; Maurer et al. 2012.

72 Wadleigh et al. 1985; Mazor 2004.

6. CONCLUSION

Strontium isotope analysis supplements the existing data from material culture studies concerning human movement and patterned contact between Cypriot communities. For the three sites investigated, it is shown that large scale mobility cannot be supported with current evidence. Although the sampled individuals account for a very large percentage of the available human remains from Limassol district, they are still negligible comparing to the total population of the three settlements. Nevertheless, the fact that none of the individuals represented seems to originate from an area with different geological background, on current evidence, points to sporadic interregional contact[73] and perhaps the existence of exogamic networks functioning only at a localized level.[74] On the other hand, as was expected, small-scale intra-island mobility or movement within regions of similar geological substrate cannot be excluded. Most importantly, the latter does not preclude a socio-economic model based on seasonal movement of specific individuals or groups and the utilisation both of "permanent" settlements and open-air encampments by the same population. This study also demonstrates that provenancing individuals based on strontium isotopes alone can lead to erroneous conclusions, while selection of the right proxies is decisive in order to successfully estimate the locally bioavailable strontium values. Ultimately, our preliminary results show a promising beginning for the application of the method for the identification of mobility patterns and a better understanding of existing lifeways in early prehistoric Cyprus. Nevertheless, much more information is necessary, both in terms of methodological advances as well as corroborative archaeological information, to more confidently identify locals and non-locals in archaeological assemblages.

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73 E.g. for the exchange of prized raw materials or finished artifacts for the reasons described in section 2.2.

74 For example, this might have been the case for Sotira *Teppes* and Kantou *Kouphovounos* which exhibit remarkable stylistic similarities on pottery and also architecture, tool/ornament production and other categories of the material culture.

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