Estonian Journal of Archaeology, 2016, **20**, 1, 3–32 doi: 10.3176/arch.2016.1.01

Ester Oras, Valter Lang, Eve Rannamäe, Liivi Varul, Marge Konsa, Jana Limbo-Simovart, Gurly Vedru, Margot Laneman, Martin Malve and T. Douglas Price

TRACING PREHISTORIC MIGRATION: ISOTOPE ANALYSIS OF BRONZE AND PRE-ROMAN IRON AGE COASTAL BURIALS IN ESTONIA

There have been various explanations in archaeological literature about whether the earliest Bronze Age stone-cist graves and the first Pre-Roman Iron Age *tarand* graves in Estonia were built by locals or non-locals. As to possible immigrations, the stone-cist graves have been often related to Scandinavian populations, whilst early *tarand* graves allegedly had roots in eastern directions. The oldest known examples of these cemetery types are at Jõelähtme and Muuksi for stone-cist graves, and at Ilmandu and Kunda for early *tarand* graves, in the coastal zone of northern Estonia. In order to test the migration hypothesis we carried out a bioarchaeological study, measuring and mapping local biologically available Sr and O isotope ratios and analysing stable isotope signals of altogether eight individuals from these early stone-cist and *tarand* graves. The study material was chosen on the basis of the oldest AMS dates of skeletons available so far, or according to the earliest burial constructions in the cemeteries. Based on the comparison of local biologically available Sr and O isotopic baseline results and the results obtained from the individuals, we can talk about migrants in the case of two persons from Kunda and perhaps one from Muuksi, whilst most of the individuals analysed are of local origin. Thus, the idea of Early Metal Period migrations to Estonia from the surrounding regions is supported to some extent. However, the discussion of these migrations might turn out to be surprisingly different from what is expected on the basis of material culture. We also emphasise the importance of further analysis, especially mapping isotopic baseline data in the eastern Baltics, in order to draw further conclusions about the directions and extent of prehistoric migration in this region.

Ester Oras, Institute of History and Archaeology and Institute of Chemistry at the University of Tartu, 18 Ülikooli St., 50090 Tartu, Estonia; ester.oras@ut.ee
Valter Lang, Institute of History and Archaeology at the University of Tartu, 18 Ülikooli St., 50090 Tartu, Estonia; valter.lang@ut.ee
Eve Rannamäe, Institute of History and Archaeology at the University of Tartu, 18 Ülikooli St., 50090 Tartu, Estonia; eve.rannamae@ut.ee
Liivi Varul, Institute of History and Archaeology at the University of Tartu, 18 Ülikooli St., 50090 Tartu, Estonia; liivivarul@gmail.com
Marge Konsa, Institute of History and Archaeology at the University of Tartu, 18 Ülikooli St., 50090 Tartu, Estonia; marge.konsa@ut.ee

Jana Limbo-Simovart, Independent Scholar; jana.limbo@gmail.com
Gurly Vedru, Archaeological Centre NGO, 6 Rüütli St., 10130 Tallinn, Estonia; gurli11@mail.ee
Margot Laneman, Institute of History and Archaeology at the University of Tartu, 18 Ülikooli St., 50090 Tartu, Estonia; margot.laneman@ut.ee
Martin Malve, Institute of History and Archaeology at the University of Tartu, 18 Ülikooli St., 50090 Tartu, Estonia; martin.malve@ut.ee
T. Douglas Price, Laboratory for Archaeological Chemistry, University of Wisconsin-Madison, Madison WI 53706, USA; tdprice@wisc.edu

Introduction

The past human migration has been one of the most intriguing and fascinating subjects in archaeological research for decades. Discussions of prehistoric migrations in Baltic archaeology have traditionally relied on material culture, physical anthropology and linguistic evidence. Different 'anthropological types', burial practices, burial goods and burial structures have been used to prove or disprove the movement of people within, but also to and from the eastern regions of the Baltic Sea and very often these have ended up in interpretations with strong ethnic connotations (see e.g. EREA 1956; Schmiedehelm & Laul 1970; Jaanits et al. 1982; Denisova et al. 1985; Michelbertas 1986; Lietuvių etnogenezė 1987; Tvauri 2003; 2007). In those discussions there still remains a question whether one can talk about a movement of people or perhaps an exchange of ideas/objects instead.

Recent decades have provided us with several scientific methods that help to create better-argued statements about past migrations, their scale, motives and directions. The studies of ancient DNA (aDNA) are no doubt prolific enquiries in this field, especially when it comes to large-scale and long-term human evolution, demographics and movements (Richards et al. 2000; Hofreiter et al. 2001; Richards 2003; Haak et al. 2008; Chatters et al. 2014). The second largest field of analysis evolves around stable isotope studies. This includes tracing migration via in-depth dietary studies (mainly the analysis of $\delta^{13}C$ and $\delta^{15}N$) of different bone tissues that on the basis of their different formation processes in time allow adding temporal scale to the analysis (e.g. Eriksson 2007; Fischer et al. 2007; Eriksson & Lidén 2013). The most widely used method, however, remains strontium and oxygen isotope analysis ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$, see below for details and references) which has been little employed in the eastern Baltic region (see Price et al. forthcoming). This method forms the basis for this article in which we discuss its application on the earliest stone graves in Estonia.

Stone-cist graves of the Late Bronze and early Pre-Roman Iron Age (ca 1200–400 BC) are the first above-ground stone burial structures that appeared in the area of Estonia. Early *tarand* graves emerged in the last centuries of the Bronze Age and persisted through the Pre-Roman Iron Age (ca 800 BC – AD 100). Both grave types turn up mostly in the coastal regions of Estonia, being almost absent in inland areas. Their origin and distribution has been discussed on the basis of both structural peculiarities and artefactual material and explained either via migrations, cultural influences or local developments without remarkable movement of people (see below). We set out a pilot project to contribute to this discussion with rather different archaeological evidence, i.e. the biological remains of the deceased themselves by analysing strontium and oxygen isotopes in their tooth enamel. Four analysed persons out of eight had no grave goods; the items of the other four are briefly discussed below in terms of their origin. However, we stress herewith that the origin of grave goods cannot be taken as an evidence of the origin of buried people. The main aim of this paper is to add new material, independent of cultural belongings, concerning the origin of the past people.

Pairs of the earliest cemeteries of their kind were chosen for the analysis: Jõelähtme and Muuksi for stone-cist graves, Ilmandu and Kunda for early *tarand* graves (Fig. 1; Table 1). We chose our material according to the earliest AMS dates of the deceased. We also took into account relative chronology of the cemetery aiming for the earliest burial structures. Where possible, imported goods were also considered, though radiocarbon dates and building chronology was prioritised when choosing the material for the analysis. It needs to be emphasised that due to the small number and intrinsic inexactness of radiocarbon dates and the circumstance that the cemeteries are not entirely excavated, we cannot be certain that the selected individuals belonged to the first generation of grave-builders. Therefore, our results cannot provide an all-conclusive answer whether the discussed grave types

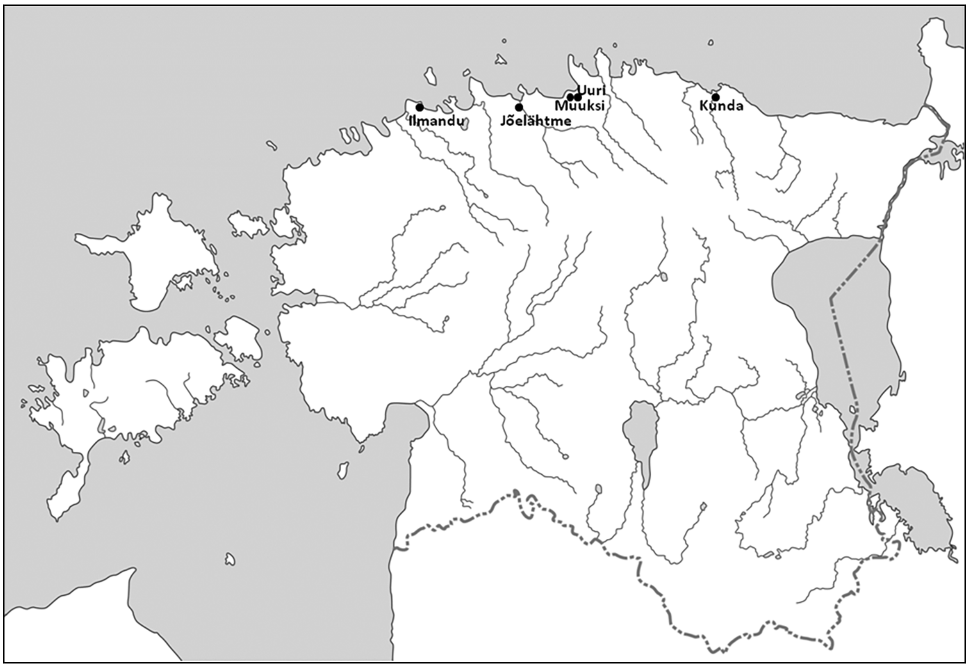

Fig. 1. Map of sites discussed in the article.

Table 1. Overview of analysed human samples and their radiocarbon dates

Grave	Context	Collection No.	Sex	Age (years)	Dated material	^{14}C lab. No.	Date: Conventional BP	Date: Calibrated BC (95.4%)[1]	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	References
Ilmandu III	*tarand* IV, burial 1	AI 6009: 166	M	35–45	Tooth	UBA-26113	2484 ± 41	790–430	–20.7	9.4	This project
Ilmandu III	cist 1	AI 6009: 180	F	19–25	Fibula	SUERC-44060	2361 ± 29	540–380	–21.2	9.4	Laneman & Lang 2013b, 112
Jõelähtme 7	cist	AI 5306	M	30+	Left humerus	Hela-2365	2924 ± 32	1220–1010	–21.3	9.7	Laneman & Lang 2013b, 102
Jõelähtme 34	cist / outside cist	AI 5306	M	30–50	Right femur	Hela-2361	2815 ± 33	1060–850	–21.2	10.2	This project
Kunda	*tarand* III, burial 9	TÜ 1325: 777	M	17–25	Tooth	UBA-26114	2530 ± 41	800–530	–20.5	10.9	This project
Kunda	*tarand* XI, burial 24	TÜ 1325: 1925	M	25–35	Tooth	UBA-26115	2484 ± 40	790–430	–20.2	10.9	This project
Muuksi 5	cist 1	AM 365: T4	M	50–60	Left radius	SUERC-44064	2966 ± 29	1280–1050	–21.2	10.3	Laneman & Lang 2013b
Muuksi 5	cist 1	AM 365: T5	F	20–25	Left humerus	SUERC-44065	2943 ± 29	1260–1040	–21.1	10.2	Laneman & Lang 2013b

[1] Calibration according to OxCal v4.2.4 (Bronk Ramsey 2009; Bronk Ramsey & Lee 2013) and InCal13 atmospheric curve (Reimer et al. 2013).

arrived to Estonia with migrants. Nevertheless, they shed new light upon the origin of the people according to the currently available oldest AMS dates in those cemeteries and, hopefully, encourage further research on the subject.

Our further aim is to draw attention to the importance of incorporating archaeological material and scientific techniques to tackle grand-scale archaeological narratives. We exemplify the importance of interdisciplinary approach to archaeological material and show how questioning bold archaeological problems can trigger a need for further enquiries, which make an important contribution to the overall development of local archaeological research.

Estonian coastal burials and the question of migrations in Bronze and Pre-Roman Iron Age

Stone-cist graves are above-ground structures that have a stone-cist (or several cists) in the middle and one or several circular stone walls around it (them), all covered with stones (see more in Lang 2007, 147 ff.). Although these structures were seemingly built for individual burials, the actual number of burials can vary from two-three to twenty or even more but usually they scatter over long periods in chronological terms. Inhumation is the most common form of burial but cremations also occur, particularly outside the cists. Grave goods are rather rare, consisting mostly of ornaments and small tools/everyday items. By their structure and burial practices, the Estonian stone-cist graves very much resemble stone barrows in central Sweden and on Gotland in the earlier part of the Bronze Age, though they are smaller in size and later in date.

For early archaeologists, such as Artur Spreckelsen (1927), Adolf Friedenthal (1931) and Birger Nerman (1933), the distribution of stone-cist graves was a clear sign of direct migration of the Scandinavians from Gotland or eastern central Sweden towards the eastern shore of the Baltic Sea. This explanation was then accepted by Harri Moora as well, although he also considered cultural influences from East Prussia quite likely (Moora 1932). In the 1950s, the Finnish archaeologist Carl F. Meinander (1954) explained this phenomenon as a result of long-lasting cultural influence, which first and together with some people distributed from Scandinavia to coastal Finland and next from coastal Finland to northern Estonia. Reaching Estonia, this cultural impact did no longer contain so much direct Scandinavian elements, but indeed was more or less a Finnic occurrence. This explanation also achieved much support in Estonia since the 1950s, the more so because similar ideas had already been presented earlier by Artur Vassar (1943). At those times, within the Marxist paradigm in Soviet Estonian archaeology, migratory explanations – particularly when concerning probable immigrations from the west – were not favoured (with a few exceptions) and local socio-economic developments were preferred instead (e.g. Jaanits et al. 1982, 161). Today, a few direct migrations from Scandinavia as initiative events for the distribution of stone-cist graves in coastal Estonia are considered plausible again (Lang 2011; 2015).

The *tarand* graves can be divided into two large groups, the so-called typical (dated from the Roman Iron Age) and early *tarand* graves. *Tarands* are quadrangular stone enclosures for burials built on the ground, while the number of *tarands* in one grave can vary from one to a few dozen (see e.g. Lang 2007, 170 ff.). The earliest *tarands* were usually built for only a few inhumations; the *tarands* of the later Pre-Roman Iron Age contain mostly cremations. The main distribution area of early *tarand* graves covers coastal Estonia, south-western Finland and eastern central Sweden but a few are also to be found in what are today Courland in Latvia and Ingermanland in north-western Russia.

After the discovery and excavations of the first early *tarand* graves they were dated by Vello Lõugas to the early Roman Iron Age, i.e. to the 1st–2nd centuries AD (Lõugas 1972). Later research into typology of grave goods and grave structures together with radiocarbon dating of human skeletons has clearly shown that these graves must belong to much earlier times, some already to the final Bronze Age (Lang 2007, 188 ff.).

As there are several sites where early *tarands* occur together with round-shaped stone-cist graves, they were initially considered as bounded 'genetically' – i.e. the *tarands* were taken as a further development of stone-cist graves belonging to the same local population (Lõugas 1977; Laul 1985). Later they were considered as a separate type of graves, not as a new evolutionary stage of stone-cist graves, which was born and developed contemporarily in coastal Estonia, Finland and eastern Sweden as a result of dense contacts between coastal people (Lang 2007). Some scholars have also found similarities between the typical *tarand* graves and the so-called mortuary houses known in the Volga–Oka region (Vassar 1943; Mägi 2005); yet, similar comparisons can also be made between the early *tarand* graves and some burial structures at e.g. Elder Akhmylovo cemetery in the Volga region (Patrushev 2000, 139, fig. 47). This has led to preliminary suggestions of possible immigrations from the east (Lang 2015).

Stone-cist graves at Muuksi

More than 60 stone-cist graves are preserved in Muuksi village, northern Estonia. The largest group of them is called Hundikangrud and it consists of more than 30 graves located close together. The Hundikangrud group is situated on the north-western shore of Lake Kahala not far from the northern-Estonian limestone cliff escarpment in the area of thin rendzina soils on limestone bedrock. Seventeen graves have been excavated either partially or completely during the 20th century (see Laneman & Lang 2013b, 93 and the literature cited). All of these graves were built mainly of limestones, but also granite stones were used. The graves mostly contain inhumation burials, but with some cremated bones buried as well. Most of the excavated graves lacked finds or were poor of them. The majority of finds are pieces of ceramics, but also some bone, stone, and metal objects have been found. Based on the finds, these graves have been dated to the Bronze and Pre-Roman Iron Ages.

Grave No. 5 is located in the central part of the Hundikangrud group. The central cist of the grave was excavated in 1925 and its peripheral parts in 1995 and 1996 (Vedru 1997; 1998). It is the only grave in Muuksi that has been AMS dated. There were altogether four NNE–SSW oriented stone cists, surrounded by an exterior stone circle, in the grave (Fig. 2). The central cist was 4.4 m long

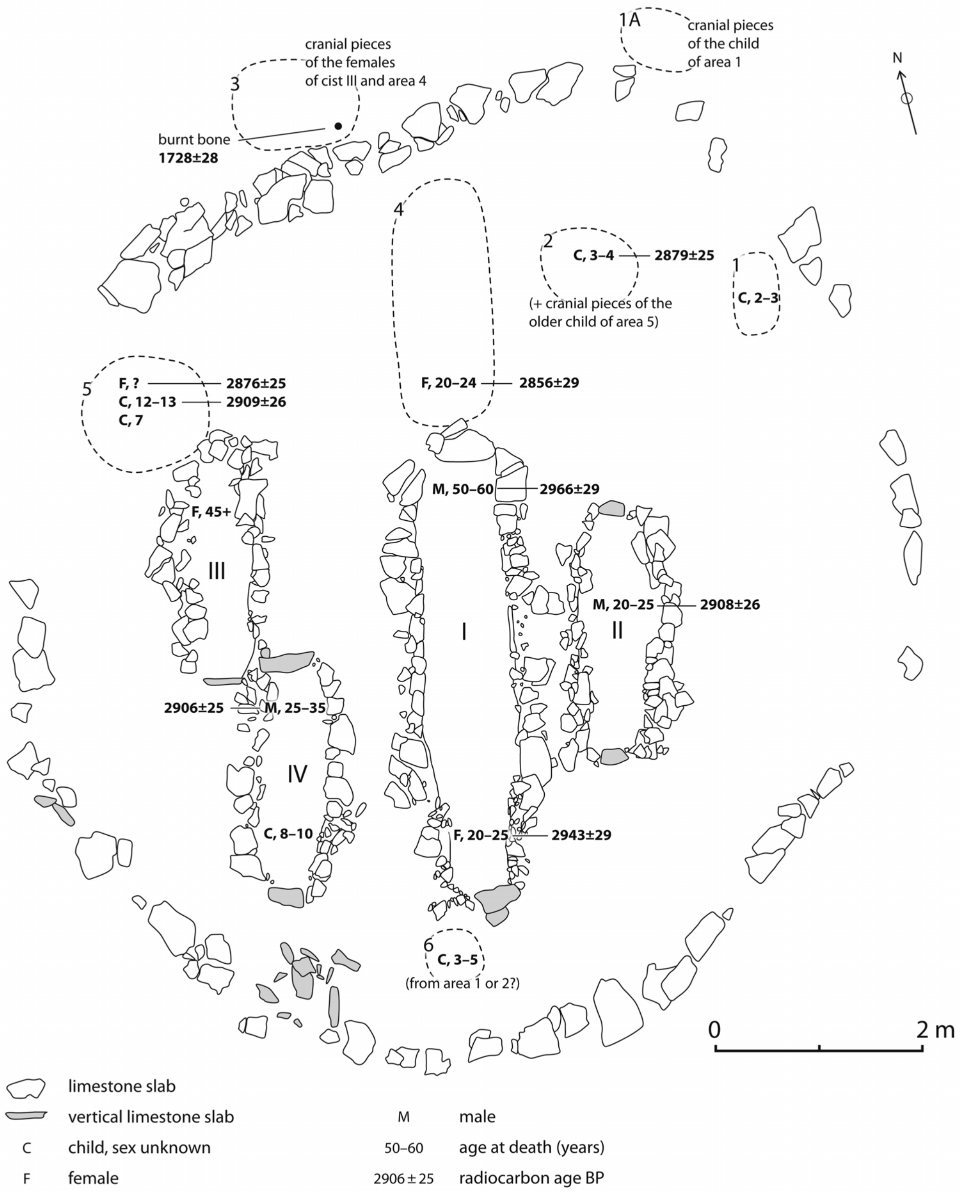

Fig. 2. Plan of grave 5 at Muuksi with available AMS dates and age-sex determinations of the buried individuals (adapted from Vedru 1998, fig. 2) (Laneman & Lang 2013b, fig. 3).

instead of the usual 2 metres. Whether there were originally two separate cists remained unknown because of the poor preservation of the grave. Mostly inhumation burials were found, but also some cremated bones were unearthed. Anthropological determination showed that there was a minimum of 11 persons buried (Friedenthal 1931; Kalman 1997). Bones of eight individuals have been radiocarbon-dated recently (Laneman & Lang 2013b), and these formed the basis for the selection of material for this study. In the central cist (cist I), a man about 50–60 years and a woman of 20–25 years old were buried. The male burial in the central cist was dated to 1280–1050 cal BC, and the female to 1260–1040 cal BC. They both were analysed in the current study. The other dated inhumation burials of that grave belonged to the time period between 1210–930 cal BC, and the cremated burial to 240–390 cal AD (Laneman & Lang 2013b). No grave goods were discovered in grave 5.

Stone-cist graves at Jõelähtme

Stone-cist graves at Jõelähtme next to a karst on limestone bedrock in northern Estonia were rescue excavated in 1982–1984 (Kraut 1985). Altogether 36 graves built of limestone and granite were found on a burial ground of 60 × 50 metres, although originally the number of graves was probably higher and the cemetery even more extensive (Fig. 3). Osteological analysis (Kalman s.a.; Varul in prep.) showed that the preserved graves (predominantly cists) contained altogether around 100 inhumed individuals from infants to elderly people, both male and female. The number of people per grave varies from one to at least six, and some individuals were represented by only a few bones while others had almost complete skeletons. Grave goods were generally few and comprised bone pins of local origin (e.g. Luik 2013, 25) and bronze items of mainly Scandinavian origin (see Kraut 1985, pls V–VI). The mentioned bronze items allow dating the graves to periods IV and V of the Nordic Bronze Age (Kraut 1985; Lang 1996, 295, 311). It is not possible to tell which graves or burials were among the earliest and which among the latest.

The isotope samples were taken from two adults from graves Nos 7 and 34. They were selected from among the few skeletons that have been subjected to radiocarbon dating so far (Laneman, unpublished data) and had also suitable teeth for isotope analysis (due to heavy fragmentation, skeletons at Jõelähtme are usually very incomplete). In the case of grave 7 the presence of potentially foreign grave inclusions was also taken into account.

The male in grave No. 7, whose remains were mostly inside the cist along with a bronze razor and tweezers of Scandinavian origin (Kraut 1985, pls III: 1, V: 3, 5), was radiocarbon-dated to 1220–1010 cal BC. According to Kalman (s.a.), he had died at the age of 30–35, but according to Varul (Varul in prep.) he was over 40 years old at death. The grave also included a few metatarsal bones of a child, found outside the cist.

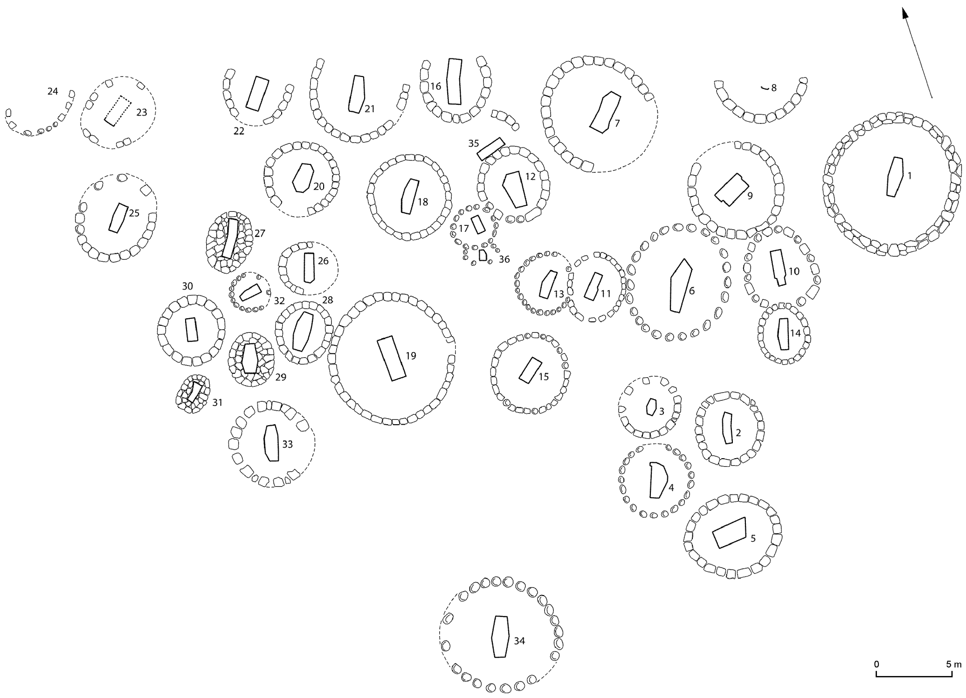

Fig. 3. Plan of stone-cist graves at Jõelähtme (adapted from the archives of the Estonian National Heritage Board, site No. 17543, file No. TMN 1-14/3 VIII).

Commingled remains of at least two adults, one male and another possibly female, in grave No. 34 were found inside the cist as well as between the cist and the circular wall. Osteologists disagree about the details of their sex and age (cf. Kalman s.a.; Varul in prep.; Malve & Laneman 2015). The sample was taken from the male who had died at the age of approximately 30–50 years around 1060–850 cal BC. The cist contained fragments of two bone pins of most likely local origin (Kraut 1985, pl. V: 6; Malve & Laneman 2015). Numerous sherds of at least two clay vessels of Iron Age date were collected from other parts of the grave (Laneman & Lang 2013a).

Early tarand *grave at Ilmandu*

Early *tarand* grave III at Ilmandu was located close to northern Estonian limestone cliff, in the area of rendzina soils above limestone bedrock (Fig. 4). It was partly destroyed by building a house and rescue excavated in 1994 (Lang 1995). Three stages or layers of burials separated both stratigraphically and chronologically were discovered.

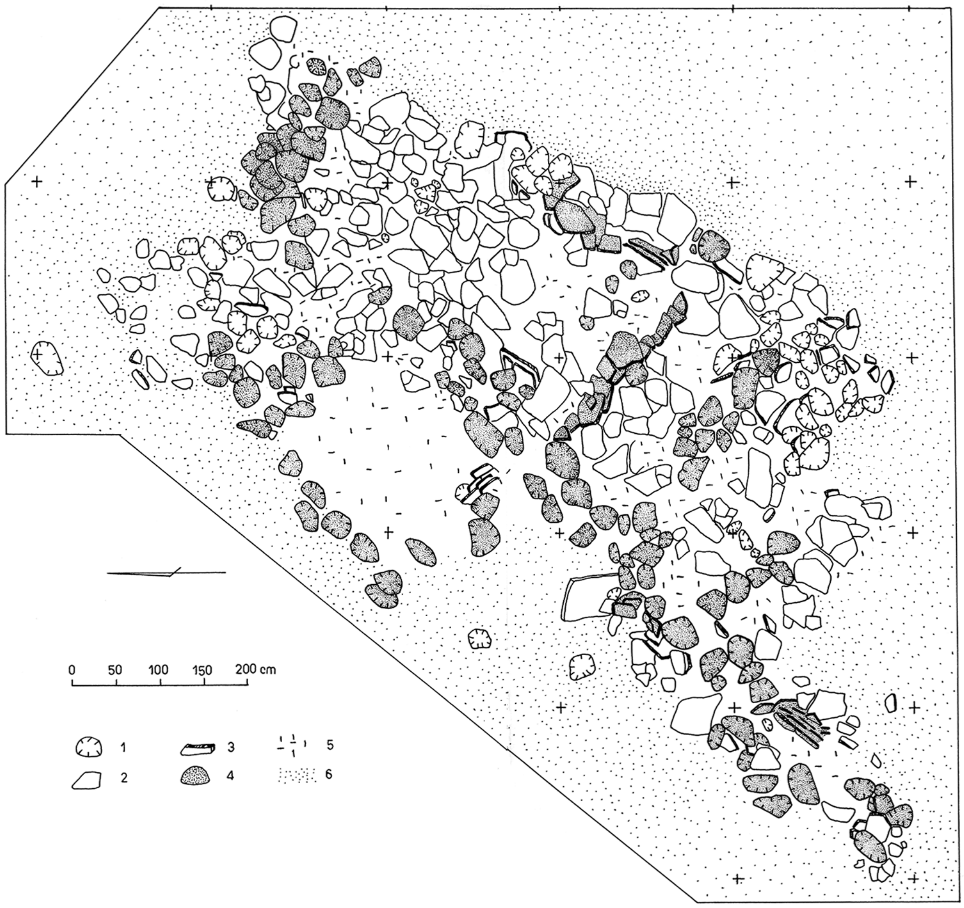

Fig. 4. Early tarand grave at Ilmandu. 1 granite stone, 2 limestone slabs, 3 limestone slabs standing upright, 4 wall stone, 5 shingle, 6 destroyed area (Lang 1995, fig. 2).

In the uppermost layer of stone structures both burnt and unburnt human bones were found in the northernmost section of the grave. These burials were associated with some grave goods of late Roman – early Migration period date, confirmed by one radiocarbon date of burnt human bone from cal AD 440–620.

The main stage of burials had left at least six *tarands* and two cist-like constructions in the preserved part of the grave. All the grave constructions were erected with great carelessness or inexperience and it was not possible to fix the building order of separate enclosures. This burial stage contained only inhumations. During the excavation the location of at least 17–18 adult persons was recognised but the number of original burials, incl. children, was certainly much higher. Complete osteological analysis of the site is absent. The preliminary osteological analysis of the individuals discussed in the current article was conducted for this project, during which only the key bones to assess sex and age of the relevant individuals were studied. One of the persons isotope-analysed for this study was burial No. 1 in *tarand* No. IV. The remains belonged to a male who had died around 35–45 years of age. He was radiocarbon-dated to 790–430 cal BC. He lay by the south-western wall of the *tarand* (head towards the south-east) and, like other burials, was covered with large limestone plates. There was a clay vessel close to upper part of the skeleton as the only grave good, classified as pottery of Ilmandu type. The latter is considered as a new style in Estonian final Bronze Age pottery, which was formed under the influences from the Oka and Moscow rivers' region (Lang 2015). The second analysed person was a young female aged 19–25 years, who was discovered in cist No. 1. She was oriented towards the north-east and was also furnished with a clay pot of Ilmandu type (Lang 1995, fig. 3: 1; 2007, fig. 61: 1). This burial was radiocarbon-dated to 540–380 cal BC. Two other burials from this use-phase analysed in relation to the study of Ilmandu-style pottery chronology had previously given the results of 750–400 and 520–370 cal BC[2] (Laneman & Lang 2013b, 112).

The earliest stage in the use of this burial place was discovered beneath the stone structures. Scattered over the whole area of the grave, fragments of burnt bones and small pieces of charcoal occurred below the bottom pavement of *tarands*, at a depth of 5–10 cm. This charcoal was radiocarbon-dated to the 12th–9th centuries cal BC (Lang 1996, 299).

Early tarand grave at Kunda

The early *tarand* grave on the hill of Hiiemägi ('sacred grove hill') is located on a magnificent ridge in the outskirts of the town of Kunda in north-eastern Estonia, some two kilometres off the present-day coastline.[3] Half of the 50 m long *tarand* grave was destroyed by quarrying activities. From the preserved part an area of 80 m^2 was excavated in 2004–2006. In the excavated area altogether 11 cist-like *tarands*, built of limestone slabs, were distinguished (Fig. 5). The small *tarands* or cists were constructed in clusters parallel to and transversely across each other, forming a honeycomb pattern. Each *tarand* contained one or more inhumation burials. During the excavation altogether 32 burials were recorded. The majority of the few grave goods consisted of potsherds and animal bones. Exceptional finds were a knife with a curved back and three decorative iron pins. Such pins with disc-shaped heads are unique in Estonia so far. They originate either from central Europe or Scandinavia and date from the beginning of the Pre-Roman Iron Age (Lang 2007, 184). Unfortunately the context of the iron pins did not allow us to relate them to any particular burial and thus we could not select a skeleton relating to those finds for the isotopic analysis.

2 Calibration according to OxCal v4.2.4 (Bronk Ramsey 2009; Bronk Ramsey & Lee 2013) and InCal13 atmospheric curve (Reimer et al. 2013).

3 Since the material from the Kunda early *tarand* grave is published for the first time in this article the overview of the cemetery and skeletons analysed is provided in further details.

Fig. 5. Early *tarand* grave at Kunda. Photo by Tõnno Jonuks.

One of the persons analysed was burial No. 9 in *tarand* No. III. The analysed bones were fragmented. It was possible to reconstruct most of the skull bones but no postcranial bones. The masculine skull belonged to a man. Teeth were well preserved and his dental age (Mays 2002) was 17–25 years. Reconstructed left parietal bone had a *peri mortem* injury. The head of the man pointed towards the north-west. He had a fragment of a left maxilla of a yearling sheep/goat (*Ovis aries*/*Capra hircus*) and ceramics as grave goods. This burial had been earlier radiocarbon dated to 730–410 cal BC[4] (Lang 2007, 174), but we also ran an additional AMS of the same tooth analysed in this study, which gave the result of 800–530 cal BC.

The second person analysed in this study was burial No. 24 in *tarand* No. XI. According to the building sequence, this was the first *tarand* built in the excavated area. Analysed bones were also fragmented and the only reconstructed bone was the left radius. The dental age (Mays 2002) of this individual was 25–35 years. Sexually discriminating features of the frontal and occipital bone (Bass 2005) were typical of a man. Only the upper part of the man's skeleton was preserved, which, like the former, was turned towards the north-west. Some potsherds were found near the skull. This person was AMS dated to 790–430 cal BC as part of this project.

[4] Poz-10801; 2430 ± 35 BP.

Isotopic analysis

Isotopic analysis in provenience studies

One of the most elaborately used methods in mobility and provenience studies is strontium (Sr) isotope analysis which has been practised for several decades (Ericson 1985; Price et al. 1994; 2000; 2012; Budd et al. 2000; 2004; Bentley et al. 2004; Bentley 2006; Montgomery et al. 2007). The basics of this analysis is fairly simple. Each geological formation has its own characteristic isotopic signals. Every living organism picks up local isotopic signals by feeding on the plants, animals and water in the region. These signals are stored in the organism's tissues, including bones and teeth. By analysing isotopic signals in these tissues and comparing them with local geological isotopic signals, one can estimate whether or not the person has been feeding on local resources.

The element Sr (with the standard atomic mass 87.62) has four naturally occurring stable isotopes: ^{84}Sr, ^{86}Sr, ^{87}Sr, ^{88}Sr. The ^{87}Sr is radiogenic in origin, formed as a result of the decay of radioactive ^{87}Rb (rubidium) with a half-life of 4.88×10^{10} years. Both ^{87}Rb and ^{87}Sr are incorporated into geological formations (rocks and sediments), but relating to different quantity of original Rb in local geology and different ages of geological formations – the older the formation the less ^{87}Rb and more ^{87}Sr there is – the amount of ^{87}Rb and ^{87}Sr varies. In tracing human migration, we are interested in the ratio of ^{87}Sr/^{86}Sr. Knowing that the natural occurrence of ^{87}Sr is ca 7% and ^{86}Sr is 9.86% of total Sr, theoretically their ratio should be ca 0.7000. In actual fact, geological formations usually fall in the range of 0.7030 to 0.74 and higher (Price et al. 2012).

As explained, this local isotopic ratio is picked up by different organisms through food chain. An important additional aspect, however, is that the isotopic signal of the geological formation cannot be directly applied to the one deposited in living organisms. Dietary sources of ^{87}Sr/^{86}Sr ratio may vary and it is necessary to measure local biologically available ratios. In order to ascertain that indeed the local biologically available Sr is measured, the organic samples analysed must come from the same local habitat in question. In principle both flora and fauna with limited habitation region and movability are suitable, although fauna is preferred (Price et al. 2002, 124 f.). And of course, species with the high likelihood of having moved from one place to another in the past are not suitable for determining local baselines.

Although Sr isotope analysis is most commonly applied and simplest for tracing past migrations, important additional information can be gained from other stable isotopes like O and C. There are several studies that have combined those isotopic analyses for achieving a better resolution in tracing people's movements (Bentley & Knipper 2005; Chenery et al. 2011; Price et al. 2012; forthcoming; Hughes et al. 2014).

All oxygen isotopes are stable, and their concentration in the environment derives from local climate conditions and geographical location. The ratio of heavy ^{18}O (with two additional neutrons) against ^{16}O in water (expressed as δ^{18}O) depends on precipitation, condensation and evaporation that derive from the altitude above sea level and the N/S latitude which together affect the temperature and local humidity conditions. These processes influence the fraction of oxygen isotopes, with the $\delta^{18}O$ value being more depleted higher, further from the sea and in colder conditions (Bentley & Knipper 2005, 630 ff.; Chenery et al. 2014). Local isotopic fraction is bound into dental enamel in early childhood, thus reflecting the provenience of the individual. As with Sr isotopes it is necessary to compare analysed human ratios with a local baseline. We analysed the oxygen in the carbonate $(CO_3)^{-2}$ ions of bioapatite in tooth enamel.

In archaeology usually the $\delta^{18}O$ in local rainfall is taken as a proxy to which results from human tissues are compared. This is based on an assumption that much of the drinking water came from the precipitation. However, it does not take into account the consumption of groundwater. Additionally, when using this data, it has to be kept in mind that this isotopic fraction is heavily dependent on specific climate conditions, which can vary seasonally and in time. Therefore, O isotopes are less direct and slightly more problematic, but certainly useful additions when tracing migrations in archaeology (see e.g. Chenery et al. 2012).

The stable C isotopes (^{13}C and ^{12}C, their ratio expressed as $\delta^{13}C$) are widely used in dietary studies, although there, C isotope fraction is analysed in bone collagen. In the case of bone carbonate, they might include some hints on provenience deriving from $\delta^{13}C$ in local plants. Namely, there is slight enrichment in plant ^{13}C in higher altitudes (over 1000 m), $\delta^{13}C$ is less negative in warmer climate, and depleted in more humid conditions (Bentley & Knipper 2005, 632 and the literature cited). However, these changes are rather modest and therefore less used in provenience studies. Additionally, in the eastern Baltic region the elevation conditions do not vary significantly and therefore the $\delta^{13}C$ results do not have much weight in further interpretation of our study.

Methods

The methods used in Sr isotope analysis are well developed and there is a widely followed sampling and analytical protocol (e.g. Frei & Price 2012, 106 ff.; Price et al. 2012, 313). The most commonly used high-resolution instrument for measuring $^{87}Sr/^{86}Sr$ ratios is TIMS (thermal ionisation mass spectrometer).

Several previous studies have addressed the questions of sampling techniques and choosing suitable material for the analysis tackling the issues of contamination and diagenesis (Budd et al. 2000; Price et al. 2002, 127 ff.; Bentley 2006). It is important to be aware of the temporal scale of the processes of incorporation of isotopic signals in human tissues. Bone tissues are in constant formation and therefore reflect the isotopic signal incorporated up to a decade before the death of the individual. Additionally, due to its physical properties (soft, porous) bone tissue is very susceptible to post-mortem contamination and incorporating local soil isotopic signals into its structure. Therefore, when measuring bone material, it might easily reflect the isotopic signal of the surroundings in which the individual has been buried.

Teeth form during early childhood, though at different times depending on a tooth. After the formation enamel is not remodelled and it incorporates the isotopic signal of the environment where the teeth were formed for a lifetime. In Sr isotope analysis premolars and first molars are usually analysed, because these start to develop in foetal status and in very early childhood, reflecting the isotopic signal from this period and region accordingly. The dentine part of the teeth has basically the same characteristics as bone and has been proved to include more of the surrounding environmental signals and go through very variable diagenesis making it less reliable for provenience studies (Budd et al. 2000). Tooth enamel, however, as a considerably denser, less porous, and stronger tissue is far more resistant to these contaminants. Therefore, in current analytical procedure enamel is preferred.

Preparing the samples for the current project, teeth were first cleaned in deionized water in ultrasonic bath until the water was completely transparent. Human teeth surfaces were cleaned with a Dremel burr to remove any contamination and soil particles on the surface. A piece of enamel was removed with a small saw-drill and dentine part drilled off so that only the strong enamel would be used for the analysis. The enamel was crushed into powder with an agate pestle and mortar. For animal samples whole teeth were used. The samples were around 7–10 mg of which 1–2 mg was sent for C and O isotope analysis at the University of Arizona Department of Geosciences and the rest for Sr isotope analysis with the TIMS at the University of North-Carolina at Chapel Hill, Department of Geological Sciences.

Samples and results

Faunal samples

Faunal samples were taken from local small vertebrates with limited home range. Measuring their isotopic content provides a baseline for local biologically available isotopic signal against which human results can be plotted. In most sites we were able to analyse fauna discovered during the excavations of the cemeteries, although it is likely that the bone material of small mammals is of later date than the burials. In order to cross-check the baseline results two samples from each site were analysed. Seven samples were taken from small rodents (F. *Cricetidae*/*Muridae*) incisors, one from a hedgehog (*Erinaceus* sp.) (Table 2).

The geological base for all the samples is Ordovician limestone. Local biologically available strontium signal in the area ranges between 0.7106 and 0.7159. The difference between the $^{87}Sr/^{86}Sr$ ratios within a site is the maximum of 0.0008 making the baseline results reliable source material. The results for $\delta^{18}O$ vary from 5.05 to 6.98 providing a range of local oxygen isotopic baseline in the region.

Table 2. Isotopic results from fauna

Sample No.	Collection No.	Site	Species	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	$^{87}Sr/^{86}Sr$
F9411	AI 6009: 103	Ilmandu III	Small rodent	–7.26	–6.59	0.710560
F9410	AI 6009: 105	Ilmandu III	Small rodent	N/A	N/A	0.711366
F9413	AI 5306	Jõelähtme 21	Small rodent	–7.43	–5.05	0.711442
F9412	AI 5306	Jõelähtme 22	Small rodent	–7.34	–6.5	0.711872
F9414	TÜ 1325: 458	Kunda	Hedgehog	–8.06	–6.98	0.710933
F9415	TÜ 1325: 504	Kunda	Small rodent	–7.42	–6.95	0.711555
F9416	AI 4980	Muuksi 71	Small rodent	–8.82	–5.99	0.713724
F9417	AI 4887	Uuri	Small rodent	–5.08	–6.25	0.715943

The only significant difference is in the case where we had to combine faunal remains from two different nearby sites. In the Muuksi cemetery we only found one suitable vole/mouse mandible. In order to obtain comparative material a vole/mouse tooth from the Uuri cemetery (Moora 1977) was analysed. These two cemeteries are only a couple of kilometres apart and situated on the same geological bedrock. However, the isotopic difference in the case of this pair is significant, i.e. 0.0022. The differences in Sr isotopic signal in close regions could be the result of many factors: variations in environmental conditions, including differences in glacial till formations, modern fertilisers, and possibly also sea spray (Bentley 2006, 152 ff.; Frei & Price 2012, 105 f.). The bedrock and top soil formations of these two sites are very similar and thus glacial till is probably not the reason. Sea spray is probably not an issue either, because being of lower isotopic value ($^{87}Sr/^{86}Sr$ of seawater is 0.7092, see Frei & Price 2012, 106) it should rather deplete the results than raise them. Previous studies have shown that fertilisers with relatively high values can raise local groundwater values (Price et al. 2002, 126 and the literature cited) and thus effect recent faunal samples. In our case fertilisers might be one of the reasons for this fluctuation, but further investigation is necessary to determine the exact cause. Thus, these higher Sr signals from Muuksi and Uuri fauna samples are problematic, especially in comparison with otherwise very closely clustering Ordovician limestone bedrock values in the range of 0.7106 and 0.7119. Despite these deviations discussed we were able to create the first isotopic baseline results for mainland Estonia.

Human samples

From each cemetery two human samples were selected for isotopic analysis. The samples were chosen on the basis of previously collected archaeological information. As our main interest was in the early burials of the cemeteries and the homelands of the first generations buried, we used different data to select the samples. When possible we relied on previous AMS dates of the individuals preferring the oldest material[5]. The latter was combined with the analysis of specific burial features and relative spatial and chronological structure of the cemetery. Any foreign burial goods clearly related to the deceased in the earliest graves were taken into account as additional hints at possible non-local origin of the person. Extra AMS-dates were provided as part of this project for attaining a direct date of the individuals whose burial context seemed to belong to the earliest phase of the cemetery but who had not been dated so far. In these cases we used the same remaining teeth analysed for isotopic signals for the AMS. If not provided by previous scholars, the individuals went through the basic anthropological analysis of age and sex determination (see Table 1). As explained above, we analysed teeth enamel preferring premolars to first molars with the aim of identifying where the person was born.

It needs to be emphasised that although we were aiming for the oldest burials and first generations of the deceased, this endeavour remains biased due to limited availability and precision of AMS dates, not to mention the question of preservation and integrity of the skeletons (incl. the presence of suitable premolars or molars), as well as the level of documentation for the older excavation material. Only a few burials from the cemeteries under discussion have been dated thus far, whilst the total number of individuals reaches up to a hundred. Additionally, current calibration curves allow setting the results into rather wide timespans. Finally, all these cemeteries are only partly excavated by the archaeologists. Thus the level of precision and representation of the material is far from ideal and our selection of data is limited by the data available in the current state of research.

$^{87}Sr/^{86}Sr$ ratio results for the whole sample set vary from 0.7110 to 0.7196 (Table 3). This is quite a remarkable variation considering that the geological basis of all four cemeteries is the same Ordovician limestone. The highest $^{87}Sr/^{86}Sr$ is evident in the case of the two Kunda samples (0.7189 and 0.7196), which exceed all the other samples considerably. The lowest and very close to faunal baseline data are the results from the Ilmandu early *tarand* grave (0.7110 and 0.7121). Both Jõelähtme and one of the Muuksi samples are slightly over local baseline values (0.7126, 0.7139 and 0.7120 respectively), whilst the second Muuksi sample (0.7160) is higher than the expected local value. On a site basis, it is evident that Ilmandu isotopic signals are extremely close. The same applies to Jõelähtme and Kunda although in those two the $\delta^{18}O$ value is slightly more variable exceeding 0.5‰. The two individuals from the Muuksi cemetery are set more apart in the scale of Sr ratios, while their oxygen signal is very close. The oxygen values are rather homogeneous ranging between 6.51 and 7.35‰.

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[5] Unfortunately, in the current state of research we are lacking local faunal isotopic reference material for estimating possible reservoir effect in samples dated. The $\delta^{13}C$ values fall in the range of –21.3 to –20.2‰ and $\delta^{15}N$ values in the range of 9.4–10.9‰ (see Table 1). Based on previous research in the field (Eriksson et al. 2003; Olsen et al. 2010) these values do not show a large proportion of marine diet intake, and rather seem to fall in the range of terrestrial food, although a proportion of freshwater intake cannot be entirely excluded. We acknowledge this problem and a need for further research and additional dates to make any substantial conclusions about the possible reservoir effect in our dated material.

Table 3. Isotopic results from humans. Abbreviations: t – *tarand*, b – burial, c – cist, T – individual number

Sample No.	Collection No.	Site, context	Tooth analysed	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	$^{87}Sr/^{86}Sr$
F9402	AI 6009: 166	Ilmandu III, t IV, b 1	M_1	–14.94	–6.78	0.712061
F9403	AI 6009: 180	Ilmandu III, c 1	P_1	–14.44	–6.51	0.711003
F9404	AI 5306	Jõelähtme 7	P_1	–14.81	–6.83	0.712553
F9405	AI 5306	Jõelähtme 34	P^2	–15.07	–7.35	0.713892
F9406	TÜ 1325: 777	Kunda, t III, b 9	P_2	–14.69	–6.26	0.719555
F9407	TÜ 1325: 1925	Kunda, t XI, b 24	P^2	–14.28	–7.08	0.718898
F9408	AM 365: T4	Muuksi 5, c 1, T4	P_1	–14.78	–7.27	0.711964
F9409	AM 365: T5	Muuksi 5, c 1, T5	P_1	–14.97	–6.98	0.716028

Discussion

For the interpretation of the results one has to start from grouping animal samples as local baseline data and compare those with the human samples. The values for the majority of our fauna samples indicating biologically available $^{87}Sr/^{86}Sr$ ratio in coastal Estonia are in the range of 0.7106–0.7119. The only problematic faunal samples falling out of this range are the samples from the Muuksi and Uuri cemeteries with their $^{87}Sr/^{86}Sr$ ratio reaching 0.7137 and 0.7159, despite the fact that the bedrock for all fauna samples is the same Ordovician limestone and the top soil is described as thin top surface deposits. Thus, this pair remains a slight outlier and further enquiry is needed to solve this discrepancy. However, on the basis of material in hand we can estimate that the $^{87}Sr/^{86}Sr$ ratio for local samples should be in the range of 0.7106–0.7137 (or max. 0.7159 if the extreme Uuri sample is taken into account).

Plotting the human sample results against faunal baseline data (Fig. 6) shows that at least half of the human samples fall into the range of local Sr isotope ratio. Both individuals from Ilmandu as well as the male burial T4 from Muuksi follow local isotopic signal. The deceased from Jõelähtme also seem to be of local origin: the individual from grave 34 does have slightly higher isotopic signal compared to local fauna samples, but it still falls into the range of local bedrock and thus is probably not a foreigner. Therefore, we can conclude that these five individuals are most likely of local origin or at least from the same geological formations that spread in northern coast of Estonia.

The samples from Kunda with their isotopic values 0.7189 and 0.7196 clearly exceed the local faunal isotopic baseline within the rounded range of 0.711–0.712. However, before drawing further conclusions about the migratory nature of the Kunda individuals, a couple of region-specific geological circumstances which could affect the biologically available Sr isotopic results have to be considered. First, the Kunda cemetery is situated in the area where variable geological formations, namely Ordovician and Cambrian limestone masses, meet. The

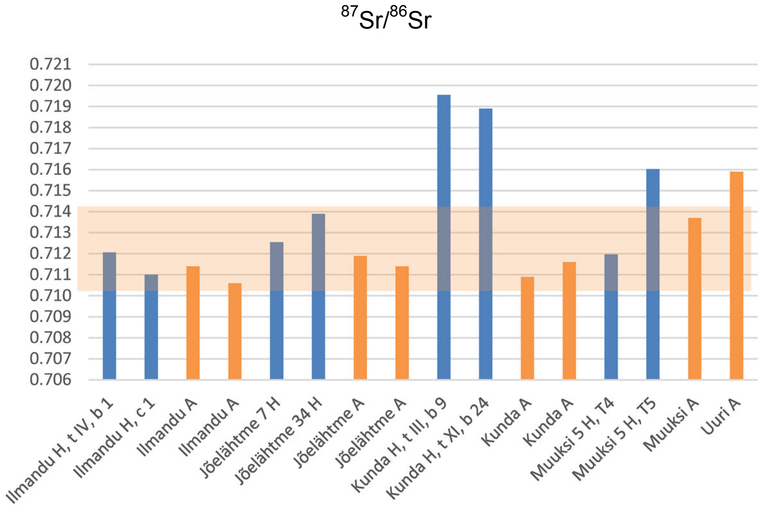

Fig. 6. $^{87}Sr/^{86}Sr$ ratios of animal (A) and human (H) samples. The shaded area expresses the local baseline in the northern coast of Estonia. Human samples considerably exceeding this value are of non-local origin. Abbreviations: t – *tarand*, b – burial, c – cist, T – individual number.

$^{87}Sr/^{86}Sr$ signal for these two marine origin limestones should fall in the range of 0.7078–0.7091 (Veizer 1989, figs 8–9). The latter is still considerably lower than the Kunda human results indicating that the higher isotopic results attained from the Kunda individuals cannot be the result of these varying limestone bedrock formations. Second, although the Kunda cemetery is located on a hill with thick moraine glacial till (Lake Võrtsjärv Subformation ice lake deposits) which could raise the isotopic value to some extent, its surroundings are mainly characterised by Ordovician limestone bedrock. The diet of the local people must have relied on much wider regions than the moraine hill where the cemetery was located. Thus the local biologically available isotopic signal in human remains should correlate with the lower isotopic signals of Ordovician bedrock (i.e. within the range of 0.711–0.712) as seen in the case of other local fauna and human remains. Thus, the higher isotopic data for these two Kunda individuals do not seem to be the result of different geological formation in the region, and we are very likely dealing with migrants in the case of these two individuals.

Besides the Kunda examples, the third possible migrant with higher Sr isotopic signal is the female burial T5 at Muuksi. However, it has to be emphasised that in this case the Sr signal is in good correlation with the deviating local faunal ratio (0.7137 and 0.7159). The latter is unexpectedly high for the geological formation in this area and especially in comparison with other sites located on the same limestone bedrock. It might be affected by factors currently unknown to us, e.g. a variation in glacial till or later contaminations. Thus in one case scenario it cannot be entirely excluded that the overall Sr signal in this area is indeed higher and that the female could be of local origin after all. But if we are dealing with later contaminations which would affect only faunal results, she must be non-local.

Since the oxygen isotope signals are species-specific, the $\delta^{18}O$ of local faunal and human samples are not comparable and these results cannot be used to identify non-locals. One can compare different human results to trace their similar or different origin. Plotting $^{87}Sr/^{86}Sr$ values against $\delta^{18}O$ highlights outliers (though mostly based on Sr ranges) compared to local individuals (Fig. 7), and supports the idea that the Kunda individuals and possibly also Muuksi T5 are non-locals. However, it has to be kept in mind that although providing some additional information about the provenience, in the current state of research the $\delta^{18}O$ values cannot be taken for self-sufficient arguments for tracing migration.

On the basis of isotopic data we can conclude that at least the individuals at Kunda and possibly a female burial T5 at Muuksi are non-locals. Trying to trace their origin is, however, not an easy task. First, there are several regions with close and comparable isotopic ratios making the determination of the individual origin very complicated, allowing us often to propose several potential homelands. Second, comparative analysis hinges on the availability of local baseline data from Estonia as well as from neighbouring regions. Scandinavia, especially Denmark and southern and central Sweden and its islands are well covered thanks to numerous previous studies (e.g. Price et al. 2011; Frei & Price 2012; Dobat et al. 2014; see also Table 4). The majority of the eastern Baltics, however, lacks Sr isotopic baseline data almost completely, with the exception of some material from Poland (Price et al. 2013; Gregoricka et al. 2014). There is no comparison from north-western Russia either. In the case of Finland there is a publication

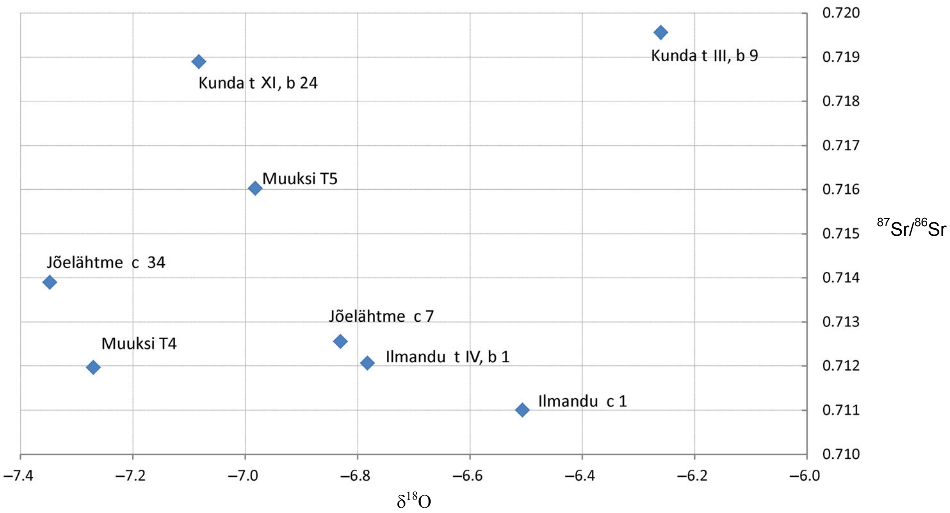

Fig. 7. Scatterplot of $^{87}Sr/^{86}Sr$ values against $\delta^{18}O$ of analysed individuals.

Table 4. Average $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ratios in the Baltic Sea region (Bläuer et al. 2013; Price et al. 2013; forthcoming; Dobat et al. 2014; Gregoricka et al. 2014)

Region	$^{87}Sr/^{86}Sr$	$\delta^{18}O$ (‰)
Denmark	0.7072–0.7119	–5.0 to –4.0
S-Sweden	0.7105–0.7122	–5.0 to –4.0
C-Sweden	0.720–0.726 (average rounded)	
	0.7206 (Stockholm)	–6.4 (Stockholm)
	0.7256 (Birka)	–4.9 (Birka)
	0.7260 (Uppsala)	–7.3 to –4.6 (Uppsala)
Öland	0.7144	N/A
Gotland	0.7112	–4.7
N- and C-Poland	0.7100–0.7148	N/A
W-Finland	0.7301–0.7304	–10.1 and –8.1
Saaremaa	0.7094–0.7199	–8 to –6.3
N-Estonia	0.7106–0.7119	–7 to –5.0

with two measurements from the same cattle (*Bos taurus)* tooth from the western coast of the country yielding $^{87}Sr/^{86}Sr$ values of 0.7301 and 0.7304 and $\delta^{18}O$ as –10.1 and –8.1‰ (Bläuer et al. 2013). There is also some comparative material from Finnish geological measurements (Kaislaniemi 2011).

The only baseline data from Estonia so far is from Saaremaa Island (Price et al. forthcoming). Here the Sr-signals vary from 0.7094–0.7199. However, all the higher values above 0.714 are from the Asva archaeological samples whereas other local samples stay within 0.7094–0.7139 (Price et al. forthcoming). This is quite a remarkable deviation and might hint at possible unreliability of the Asva results. The $\delta^{18}O$ for Saaremaa are from Asva archaeological samples only and range between –8 and –6.3‰.

The two Kunda samples gave $^{87}Sr/^{86}Sr$ values of 0.7189 and 0.7196 which are considerably higher than the local rounded baseline 0.711–0.712. Their rounded $\delta^{18}O$ value is –6.3 and –7.1‰. Looking at comparative data from around the Baltic Sea (Table 4) one can exclude southern Scandinavia as well as Gotland and northern and western Poland with their relatively low $^{87}Sr/^{86}Sr$ and high $\delta^{18}O$ values. Central Sweden and western Finland display generally higher Sr and lower O ratios than the Kunda samples. It is therefore more likely that these individuals did not come from the western part of the Baltics. Unfortunately, we do not have any comparative Sr data from the majority of Estonian mainland or Latvian and Lithuanian archaeological material. Considering the known geological formations, most of Estonia and Latvia are covered by younger Silurian and Devonian formations yielding probably lower $^{87}Sr/^{86}Sr$ ratios than we see in Kunda. Unfortunately, there is no reference material known to the authors from north-western Russia.

On the basis of material in hand it is reasonable to look further to the north, namely towards Finland, when tracing the origin of the Kunda people. It has been reported that some central Finland and central Karelian regions tend to have lower Sr values compared to the rest of the country (Kaislaniemi 2011) which would potentially fit with our measurements. This interpretation is still very tentative, because more research, especially baseline data for bioavailable Sr and O in the area and for north-western Russia is needed to confirm this hypothesis. However, from the archaeological point of view no similar *tarand* graves have been discovered in central Finland and Karelia so far, which of course does not necessarily disprove the possibility of migrations from these areas. Interestingly, the Kunda samples are strikingly similar with the archaeological samples from Asva, so that if we were to trust Asva baseline data the isotopic signals would be spot-on and in principle south-east of Saaremaa could be their homeland. However, the Asva archaeological baseline results remain slightly questionable, because all the other faunal isotopic signals from Saaremaa have considerably lower Sr values.

As for the T5 female burial from Muuksi, her Sr signal (0.7160) is slightly higher than expected according to local baseline data, whilst her $\delta^{18}O$ value (–6.98‰) fits well into the local oxygen signal. Thus her migrant status remains with a question mark. Her slightly higher Sr isotope result does not seem to fit with any of the Baltic Sea regions where we have some baseline data. As with the Kunda discussed above, we can exclude coastal old rock formation areas in Finland and central Sweden. Neither Sr nor O data would fit with the western Baltic islands of Gotland and Öland directly. Thus her origin remains an open question. Indeed, based on the available data we cannot exclude local Estonian islands as her possible place of birth, since the results from Saaremaa, especially when taking the Asva samples into account, fit rather well with the individual in question. However, the lack of sufficient baseline data from other eastern Baltic regions remains a major issue that does not allow us to draw any firm conclusions.

In this context it is also necessary to emphasise that we can only recognise migration if it has resulted in difference in Sr isotopic signals of local fauna and humans. It means that if people have moved within the same geological formation with the same or similar isotopic signals recorded in biological tissues, these migrations remain undiscovered. This might be a serious issue when large areas with similar geology are under discussion. In our case, for instance, the geological formations in Saaremaa Island and mainland northern coast are rather close. Based on local geology, it is likely that other local islands and areas of western Estonia could be added to these regions as well. Additionally, one cannot exclude the islands of Gotland and Öland either: they have very similar geological formations and Sr signals are basically the same. Although O isotopes are higher there compared to Estonian data, the $\delta^{18}O$ are variable and highly dependent on time of the year and environmental conditions. Thus the oxygen isotope data cannot be used directly to trace homelands and separate locals from foreigners. What it means is that the individuals we regard as local northern coast inhabitants might in fact have been born in other areas of Estonia or even in other Baltic islands with similar geology, but we just cannot differentiate them based on Sr and O isotopes. Incorporating different scientific analysis, including diet-based and possibly aDNA studies, might help to provide a more fine-scaled data to tackle these problems.

Our results and discussion clearly demonstrate how important it is to have a fine-scale and detailed baseline information from different regions in order to draw any further conclusions about past migration routes. This applies especially to the three Baltic countries, Finland and north-western Russia, which currently are clearly unrepresented in the isotopic baseline maps and relevant archaeological discussions. More substantial and large-scale analysis of archaeological material which would help to determine outliers and reliable results is needed in the future in order to make more substantiated conclusions of the prehistoric migrations in the Baltic Sea region.

Conclusions

Our pilot study of Sr and O isotopes has provided new insights into migration-related questions in the Bronze and Pre-Roman Iron Age Estonian material. In the case of early stone-cist graves at Jõelähtme and Muuksi isotopic signals indicate mostly local origin of the individuals analysed. We were able to show that only one individual from Muuksi was possibly of non-local origin. However, the Muuksi migrant female (if migrant at all) does not seem to have roots in coastal Sweden and Finland; she might belong somewhere in western Estonia or even Baltic islands. However, without data from other eastern Baltic regions one cannot exclude those areas either.

As to early *tarand* graves both local and foreign connections are seen. In the case of the Kunda burials we can potentially talk about migrators. Their origin could be in the north-eastern or eastern directions, which would partially correlate with some of the archaeological theories discussed above. However, the exact location of their birth place is not certain and more isotopic baseline mapping is needed to identify it. The migratory nature does not seem to be the case in the similar cemetery of Ilmandu, which belongs to the same time period. There, at least in the case of individuals we analysed, the deceased were local people.

On a larger scale, our pilot study concludes that the Early Metal Period communities in the Baltic Sea region were partly mobile, and at least some people died outside their place of birth. As to stone-cist graves, this study did not solve the question whether or not this grave type was introduced in coastal Estonia by immigrants because one cannot be sure that the analysed persons belonged to the very first generation of grave builders. What we know, at least, is that these persons were not immigrants from central Sweden or south-western Finland. This makes the theory of Vassar and Meinander weaker but does not disprove it because, as yet, it holds true only about four persons. Gotland, however, as one of the possible source areas of Estonian stone-cist graves, as suggested by many authors, is still quite conceivable. The earliest *tarand* grave at Kunda so far yielded at least two immigrants, which is a rather strong argument in favour of the migration hypothesis. Although we do not know where they came from, they certainly did not arrive from central Sweden and south-western Finland either, which is also a step forward in our knowledge about the early *tarand* graves. The analysed persons from Ilmandu were locally born, but again – there is no certainty that they belonged to the first generation of grave builders. Thus our study has provided at least some new pieces of evidence on the communities and people building our earliest stone graves.

With this project, being an early bird in eastern Baltic archaeological scholarship, the first step was taken to create preliminary baseline data for analysing past migrations through Sr isotope analysis. The material collected is a crucial input for starting mapping bioavailable Sr signals in the eastern regions of the Baltic Sea area which can be used in the future as a reference material for the analysis of material from any time period in northern and eastern Europe. As our results and discussion prove, more analysis and reference material is needed in order to make more substantiated interpretations of the origin of individuals analysed. There is a very good comparison material from Scandinavia, whilst eastern Baltics, especially the Baltic countries, are currently in the status of *terra incognita*. We would like to encourage Baltic archaeologists to look into the opportunities that Sr isotope analysis might provide for their archaeological interpretations and carry out further analysis. This would not only help to make better interpretations of the specific regional archaeological questions, but also contributes to the overall research into human and animal migrations in the Baltic Sea region.

Acknowledgements

We are very grateful to James H. Burton at the Laboratory for Archaeological Chemistry, University of Wisconsin-Madison, and Drew S. Coleman at the Department of Geological Sciences, University of North Carolina, Chapel Hill for the warm welcome at their facilities and all the help with laboratory analyses. We also thank Maria Smirnova for her help with the plan of Jõelähtme stone-cist graves. The laboratory visit was financed by the Foundation Archimedes, Estonia. This research was supported by the Estonian Ministry of Education and Research institutional research funding IUT20-7 “Estonia in Circum-Baltic space: archaeology of economic, social, and cultural processes”.

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Ester Oras, Valter Lang, Eve Rannamäe, Liivi Varul, Marge Konsa, Jana Limbo-Simovart, Gurly Vedru, Margot Laneman, Martin Malve ja T. Douglas Price

MUINASAJA MIGRATSIOONI UURINGUD: EESTI RANNIKUALA PRONKSI- JA EELROOMA RAUAAJA KALMETE ISOTOOPANALÜÜS

Resümee

Artiklis on arutletud Eesti põhjaranniku pronksi- ja varase rauaaja kivikalmetesse (joon 1) maetute päritolu ning võimalike toonaste migratsiooniküsimuste üle. Kivikirstkalmed kuuluvad hilispronksi- ja varasesse eelrooma rauaaega (dateering 1200–400 eKr). Eesti kivikirstkalmed meenutavad nii matmiskommetelt kui ka konstruktsioonidelt Kesk-Rootsi ja Gotlandi varasema pronksiaja kivikalmeid. Varased tarandkalmed ulatuvad hilispronksiaja lõpust rooma rauaajani (800 eKr – 100 pKr). Selliseid kalmetüüpe on teada ka Edela-Soomest, Kesk-Rootsi idaaladelt, vähemal määral Kuramaalt ja Ingerimaalt.

Eestis on mõlemad kalmetüübid levinud rannikualadel. Nende päritolu ja levikut on kivikonstruktsioonide ilme ning neis esinevate hauapanuste põhjal seostatud võimalike migratsioonide, kultuurimõjutuste, aga ka kohapealsete arengutega. Maetute päritoluküsimuste lahkamiseks toimusid luustike strontsiumi (Sr) ja hapniku (O) isotoopuuringud, mille eesmärgiks oli tuvastada maetute esialgne sünnikodu ning nende võimalik kohaliku elaniku või migrandi staatus. Uurimismaterjal valiti varaseimate omataoliste kalmetüüpide hulgast: Muuksi (joon 2) ja Jõelähtme (joon 3) kivikirstkalmetest ning Ilmandu (joon 4) ja Kunda (joon 5) varastest tarandkalmetest. Valiku aluseks olid seni vanimad olemasolevad radiosüsinikudateeringud või kalme konstruktsiooni ülesehituse põhjal eeldatavalt varasematesse tarinditesse maetud luustikud (tabel 1).

Sr- ja O-põhiseid migratsiooniuuringuid on Eesti arheoloogias seni vähe kasutatud. Analüüsi põhimõte seisneb asjaolus, et igal geoloogilisel formatsioonil on tulenevalt selle vanusest kindel stabiilse ^{86}Sr isotoobi ja radioaktiivse rubiidiumi lagunemisel tekkiva ^{87}Sr suhe. Viimane kajastub ehk ladestub toiduahela kaudu inimese erinevates kudedes. Kuna hambad hakkavad moodustuma juba looteeas, kajastab nende kudedesse ladestunud isotoopsignaal inimese sünnikodu Sr isotoopfraktsiooni. Teades erinevate geoloogiliste alade toidu ja joogiga omistatavat Sr isotoopide suhet, mida saab kindlaks teha väikese levikuareaaliga fauna analüüsil, võib võrrelda, kas analüüsitava isiku hammastesse ladestunud isotoopsignaal on kohaliku Sr isotoopsuhtega sarnane või sellest erinev. Nõnda on võimalik tuvastada, kas analüüsitud isik on kohalik või sündinud mõnes kaugemas piirkonnas. Analüüsiks eelistatakse hambaemaili (tavaliselt 1. molaar või premolaarid), sest see on kõige vastupidavam luustiku osa, mis kujuneb varakult välja ning jääb oma ülitugeva ülesehituse ja tihkuse tõttu aja jooksul kumuleeruvatest deponeerimiskeskkonna mõjutustest puutumata. O isotoobi signaalid iseloomustavad teatud piirkonna sademete hulka ja aurustumise taset ning sõltuvad paiga kõrgusest üle merepinna ning põhja- ja lõunalaiusest. O isotoobid annavad Sr analüüsi kõrval küll olulist lisainfot, kuid nende tulemuste tõlgendamine on keerukam ja mõnevõrra problemaatilisem.

Kohaliku isotoopsignaali kaardistamiseks koguti analüüsitavatest kalmetest või nende lähedusest väikese levikuareaaliga loomade hambaproovid (tabel 2). Need näitavad, et Põhja-Eesti ordoviitsiumi paekivi pinnaselt bioloogiliselt omistatav Sr isotoopsignaal peaks jääma vahemikku 0,7106–0,7119. Paar proovi andsid ka veidi kõrgemaid tulemusi (0,7137 ja 0,7159), kuid need teiste sama piirkonna tulemustega võrreldes oluliselt kõrgemad suhtarvud võivad mõjutatud olla hilisemast reostusest või jääaja setete anomaaliatest konkreetses piirkonnas.

Võrreldes loomaluudest saadud Põhja-Eesti ordoviitsiumi paepealset kohalikku Sr isotoopsignaali inimeste hammaste isotoopmäärangutega (tabel 3), ilmneb, et analüüsitud luustike hulgas võime eristada nii kohalikke kui ka mittekohalikke isikuid (joon 6–7). Mõlemad Ilmandu varasest tarandkalmest ja Jõelähtme kivikirstkalmetest analüüsitud indiviidid ning Muuksi mehematus (T4) on kohalikku päritolu. Kunda puhul võime suure tõenäosusega eeldada mõlema analüüsitud maetu võõrapärast päritolu. Võimalik, et ka Muuksi naisematuse (T5) puhul on tegemist migrandiga, kuigi tuleb märkida, et selle indiviidi isotoopmäärangud korreleeruvad erandlike Muuksi ja Uuri loomaluude kõrgemate proovitulemustega.

Mittekohalike indiviidide päritolupiirkonna tuvastamine on keerukam ülesanne, sest see sõltub olemasolevast bioloogiliselt omastatava Sr isotoopide kaardistamisest, aga ka sama signaaliga geoloogiliste formatsioonide levikuareaali ulatusest. Olemasoleva Läänemere piirkonna kohaliku isotoopkaardistuse põhjal (tabel 4) saame Kunda indiviidide puhul nende võimaliku päritolupiirkonnana välistada Taani, Kesk-Rootsi, Läänemere saared, Lääne-Soome ja ilmselt ka Poola alad. Ühe hüpoteesina pakume Kundasse maetute võimaliku sünnipaigana Kesk-Soome, Karjala või Eestist idakaartesse jäävaid piirkondi, kuid kindlamate järelduste tegemiseks on vajalikud täiendavad ja suurema valimiga edasised analüüsid. Lisaks tuleb n-ö kohalikena tõlgendatud tulemuste puhul silmas pidada, et Põhja-Eestiga sarnast isotoopsignaali hõlmav ala ulatub ka näiteks Eesti saartele ja Ojamaale. Seetõttu ei saa välistada, et isotoopide põhjal kohalikeks peetavad indiviidid võisid sündida siiski mõnes teises analoogilise isotoopsuhtega geoloogilises regioonis.

Artiklis on näidatud, et Eesti rannikuala varastesse kivikalmetesse maeti nii kohalikke kui ka mujal sündinud indiviide. See iseloomustab teataval määral tollaste inimeste liikumist ja olukorda, kus sugugi mitte kõik ei lahkunud elust seal, kus oli nende sünnikodu. Laiemas plaanis, kuigi väikesemahulise pilootuuringuna, pakuvad meie tulemused lisateavet hilispronksiaja ja eelrooma rauaaja kontaktidest ning kultuuriilmingutest ja nende levikuprotsessidest. Põhjapanevamateks järeldusteks selles teemavaldkonnas on kahtlemata vajalik täiendavate analüüsidega jätkamine nii ajalises kui ka geograafilises mõõtmes.