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Isotopic Proveniencing of the Salme Ship Burials in Pre-Viking Age Estonia

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Abstract

Two buried Pre-Viking Age ships were uncovered in archaeological excavations at Salme, Estonia, between 2008 and 2012. These are the earliest known such ships to have crossed the Baltic. Buried with the two ships were the skeletal remains of 41 individuals, a variety of weapons and tools, and the bones of a number of animals. The remains, dated to ca. AD 750 appear to represent the hasty burial of two ships and the deceased members of their crews who died violently. These finds represent the first discovery of mass burials in ships in Estonia as well as in the rest of Europe. Their grave-goods – weapons and other objects – were of Scandinavian design, largely unknown in Estonia. One of the intriguing questions concerns the origins of the dead. In this investigation we have used isotopic ratios of strontium and oxygen to examine this question. We document significant differences in strontium isotope ratios among the Salme locality and other possible homelands around the Baltic. The artifactual evidence suggests that the Stockholm-Mälaren region may have been the likely homeland for these items. The isotopic data fit well with this region as the probable place of origin for the dead.

Keywords

strontium, oxygen, isotopes, bioarchaeology, Baltic, Vikings, Salme, Estonia, mobility, archaeology, Scandinavia

Salme is a small coastal village on the island of Saaremaa in western Estonia, on the east side of the Baltic Sea (Fig. 1). In the summer of 2008, workmen building a new cycle path exposed extraordinary archaeological finds, including human skeletal remains, iron swords and rivets, and bone gaming pieces. The objects were dated to around AD 750, the end of what is known as the Pre-Viking Age in Estonia and as the Vendel Age and the beginning of the Viking Age in Sweden. None of the artifacts were of local origin and a number exhibited a style associated archaeological materials from Scandinavia, across the Baltic Sea (Konsa *et al*. 2010, Peets and Maldre 2010, Peets *et al.* 2011, 2013). During the course of subsequent excavations the remains of two ships were uncovered buried beneath the ground. The ships had been dragged approximately 100 m inland and partly covered with stone and soil. These ships were then completely buried rather quickly by marine sediments washed ashore by storm and perhaps carried by ice.

Fig. 1. The Baltic Sea and some of the locations mentioned in the text.

In the following pages we discuss these finds with more details on the ship burials, the physical anthropology of the human remains that were found, and isotopic measurements on tooth enamel from some of the burials. The goal of our study is to examine the question of the place of origin of these individuals who apparently came to the island of Salme from elsewhere, met their death, and were buried in these two ships along the coast.

The Salme Ship Burials

The Salme I ship was heavily damaged by the modern construction activities. It was probably a rowing ship, approximately 11.5 m long, with six pairs of oars. Both ships were clinker built with rows of iron rivets joining the overlapping horizontal planks of the hull. Seven human skeletons of tall young males were found with this ship. At least two of these individuals had been placed in a sitting position, perhaps all of them. Most of the archaeological materials were recorded outside the ship where they had been moved by the construction workers who first encountered the site in 2008. The finds included fragments of two swords, spear- and arrowheads, knives, a small socketed axe, fragments of ornamented combs of deer antler and 75 gaming pieces of whale and cattle bone, belonging to at least two separate sets, together with three dice made of antler. Animal bones (a few pig bones and lots of sheep, goat, and cattle bones) at the site may have resulted from a funeral feast or were left as food for the afterlife. There were also the remains of two decapitated hawks (Konsa *et al.* 2009, Peets and Maldre 2010, Allmäe *et al.* 2011). In Sweden, the bones of birds of prey frequently occur in wealthy burials in the 6th–10th centuries. Raptor bones in graves have mainly been found in eastern Sweden, Uppland and Södermanland (Sten and Vretemark 1988, 153; Tyrberg 2002, 228–230). The most common species is the goshawk, found in 27 of 34 graves containing raptor's bones (Tyrberg 2002, 228, fig. 11).

The Salme II ship was found largely preserved in 2010 by archaeologists, approximately 30 to 50 m southwest of Salme I (Fig. 2). The first finds included lots of rivets, sword fragments, two shield bosses, and two human skeletons. The humerus of one of the skeletons had been chopped through in three places and the skull of the second individual had distinct traces of axe or swords cuts. In addition, a dog skeleton was found cut in half. Continuing excavations in 2010 - 2011 exposed the entire length of the ship along with the skeletal remains of a total of 34 individuals. Five or six rows of rivets used in clinker construction were preserved from the ship, which was approximately 17–17.5 m long and about 3 m wide with a keel for sailing (Peets *et al.* 2013). Such a boat would likely have held a crew of around 30 individuals (HCL VII: 2).

Fig. 2. The Salme II ship in different stages of excavation. The yellow line is a cable. 1. Outline of ship rivets and humus stains together with skeletons. Skeleton layers I – III are visible. 2. Skeleton layer IV, located perpendicular to the ship's long axis. 3. Excavated boat contour without skeletons (black objects are plastic sand bags). (Photos by Jüri Peets and Reet Maldre).

The 34 skeletons were stacked like firewood in four layers an area of 3 x 4 m on the ship. The bodies had been buried with 40 swords (both single and double-edged types, including examples with gilded and jeweled bronze hilts), covered by large, round wooden shields with bosses of iron, and by cloth, probably from the sail. Other grave goods included some 15 ornamented antler combs, broken shears, beads, pendants of bear canines, bronze and iron plaques, and small padlocks. Gaming pieces made from whalebone and walrus ivory had been scattered among the bodies. A large number of arrowheads were found, but only a few spears and no axes. Many of the arrowheads were stuck in the wood of the ship and in the shields and, along with the many injuries observed in the skeletal remains, document the conflict that must have resulted in the deaths of these individuals.

One of the important questions surrounding these remarkable finds concerns the origin of the individuals on the ships. The archaeological finds were non-local and pointed west across the Baltic to Sweden — places such as the Mälaren region west of Stockholm, the Swedish island of Gotland, Denmark with the island of Bornholm, or south to Swedish colony of Seeburg (a.k.a. Grobina), near Liepaja in Courland, in present day Latvia (Nerman 1958, 198).

The human skeletons were silent and, until recently, provided no information on their place of origin. New isotopic methods employed in archaeology for proveniencing human remains were applied to these skeletons from Salme. Isotopic ratios of strontium, carbon, and oxygen were measured in the dental enamel of a number of these individuals. This information was compared with local conditions as well as with data from Sweden and Denmark. We first present a brief summary of the findings from the anthropological analysis of the skeletal remains, followed by a brief introduction to isotopic proveniencing, a discussion of the isotopic parameters of the larger Baltic region, the results of our isotopic analysis of the dental enamel, and an interpretation of these results.

Anthropological Analysis of the Skeletal Remains

The human skeletal remains from the Salme I ship grave came to the laboratory largely as mixed osteological material. All together the remains of seven male skeletons were recorded; the cause of their death was not obvious. The likely burial positions of the bodies were estimated from the photos taken on site; the exact positioning of corpses is only speculative (Allmäe et al. 2011).

The positions of the human skeletons in the Salme II ship grave were recorded during the excavations in 2010-2011. The exact positions of skeletons were measured with GPS equipment to facilitate 3D drawings; the drawings demonstrate the burial arrangement and technique used in this mass burial (Fig. 3). The bodies were buried in four layers, the bottom layer perpendicular to the long axis of the ship and three other layer parallel to the sides of the ship (Peets et al. 2011, 2013). At Salme II edged-weapon perimortem injuries were observed on the first skeletons exposed. The individuals were treated with respect during burial as dismembered body parts were placed in anatomically correct positions. All together 34 complete or partial skeletons were recorded from the grave, plus a single skull. Biological age and sex determinations of the skeletons were made according to standard criteria (Buikstra and Ubelaker 1994, White and Folkens 2000, WEA 1980).

Fig. 3. Schematic 3D plan of the position and distribution of burials on the Salme II ship. Numbered skeletons were included in the isotopic analysis discussed below. (Drawing by Reet Maldre).

For stature calculations the maximum length of femoral bone was used. If the femur was absent, the maximum length of humerus or tibia was used. The long bones of upper and lower extremities were measured according to Martin and Saller (1957), the right side was used if applicable. The stature and body weight were calculated according to formulas proposed by Ruff and co-workers (2012). The Northern formula was used for tibia stature estimations; additionally the formulas of Trotter and Gleser (1952, 1958) were used for stature estimations (in parentheses in the following text). The completeness of the skeletons, trauma, including blade wounds, and/or other special features of skeletons were also recorded.

Salme I Ship Grave

From Salme I the three best-preserved skeletons *in situ* were SaI/1, SaI/2 and SaI/3 (Fig. 4). The skeletal remains of these three men were found in the stern of ship and were buried in rather relaxed positions (Allmäe 2011). The upper skeletons were articulated, but earlier construction works had destroyed the lower parts of the axial skeletons. SaI/1 was lying shoulders up with its chin on the chest. This individual was a male, aged 25–35 years of age, with an estimated height of 181.2 cm (182.9 cm). SaI/2 was lying on his right side with his head resting on the left shoulder of SaI/1. SaI/2 was a male, aged 18–25 years ,with an approximate height of 174.7 cm (176.7 cm). SaI/3 was lying prone with his head turned left and his upper extremities stretched out behind him. SaI/3 was a young male, aged 25–30 years, with a height of 179.3 cm (181.3 cm). One premolar was collected from each individual for isotopic analyses.

Fig. 4. Upper parts of skeletons SaI/1, SAI/2, and SaI/3 preserved in situ in the Salme I ship. (Photo by Külli Rikas).

Salme II Ship Grave

The burials in the second Salme ship were quite different, distinguished by the regular placement of the corpses in a common extended supine position, the respectful attitude towards the buried individuals, and the presence of injuries from sharp edged weapons. The analyses of the human remains from Salme II is underway and to date ten skeletons present injuries from sharp-edged weapons. Six of the individuals have multiple injuries and some skeletons exhibit trauma characteristic of decapitation. Based on the skeletons investigated so far, the average body height estimated from the femur is 174.3 cm (177.6 cm) and body weight is 76.6 kg.

The five skeletons from which a premolar was removed for isotopic analysis are described below. The position of these skeletons in the mass grave is shown in Fig. 3.

Skeleton I (SaII/4) is a male, aged 40-60 years, estimated height 170.6 cm (174.6 cm) and weight 82 kg. The skeletal remains of this man were lying on the west side of the ship, first in the upper burial row, in an extended supine position. His head was turned left (all the other man in upper row were buried with their heads turned to the right). A broken sword had been placed on his right forearm (palm upwards) and on top of it a damaged shield boss was found. The skeleton exhibited several perimortem injuries: stab wounds (probably from a sword) on the posterior side of thoracic vertebrae, five blade strokes to the right humerus that cut through the bone in 3 places, a heavy slash with a blade that caused a 10 cm penetrating injury to the left side of his skull (involving both the frontal bone and the left parietal). Evidence of decapitation was observed on 1st and 2nd vertebrae.

Skeleton XII (SaII/2) belongs to a male, aged 25–35 years, height 169.1 cm (173.2 cm), weight 73 kg. A specific feature – atlanto-occipital fusion – was observed on the vertebra of this individual. The occipitalization of the atlas is one of the most common abnormalities of the upper cervical spine (Lang 1995, 54) and may cause orthopedic problems and occasionally induce neurological effects (Skrzat et al. 2010). The skeleton exhibited blade wounds, one in the proximal end of left ulna and another on the medial lower edge of the femoral head. The man was buried in the second layer (Fig. 3). A gaming piece with an iron tack was found near his mouth.

Skeleton XIV (SaII/3) was the poorly preserved skeleton of a 25-35 year-old male. His estimated height is 170.4 cm (174.6 cm). The man was buried first in second row on the west side of the ship. The skeleton had been placed in an extended supine position, head turned left, left hand probably under the head. The right arm was stretched away from the body. A sword hilt of gilded bronze with a pommel with precious stones was found under his right upper arm along with the head of sacrificed dog.

Skeleton XXXII (SaII/5) belonged to a male, aged 25-30 years. His estimated height is 179.7 cm (182.2 cm) and body weight is 87 kg. The man was buried in the transverse bottom layer in extended supine position, head pointed towards the east with his head resting on his left shoulder. A full set of gaming pieces and three die, made of whalebone and walrus ivory, were placed in his lap (probably originally in a cloth bag); a damaged sword had been placed above his left hip.

Skeleton XXIII (SaII/1) is a male aged 30-40 years; his estimated height was 176.9 cm (179.9 cm) and weight 79 kg. A blade injury (caused most likely by a single slashing blow) was found on proximal end of right ulna and distal lateral end of left humerus. The man was buried in the transverse bottom layer, separately from others, in the northeast part of the ship. His body was placed in an extended supine position, with the head resting on his left shoulder. A single-edged sword had been placed between his body and left arm, parallel to the body.

In sum, the individuals buried with the two ships at Salme were young, tall males with substantial evidence for trauma and violent death. Less is known about the context of the Salme I burials because of the nature of their initial discovery. The Salme II burials were placed carefully in the ship in laid out positions in a stack of bodies four deep. They were buried with weapons and other grave goods. In addition to questions about who buried them and how they died, we would like to know from where they came.

Isotopic Proveniencing

To pursue this question, light and heavy isotope ratios have been measured in samples of tooth enamel from the Salme ship burials. Three individuals from Salme I (SaI/1, SaI/2, SaI/3) and five individuals from Salme II (Skeleton I = SaII/4, Skeleton XII = SaII/2, Skeleton XIV = SaII/3, Skeleton XXXII = SaII/5, and Skeleton XXIII = SaII/1) were obtained for this project. Premolars were the tooth of choice for our study as they are easier to extract and exhibit less diagnostic information that other teeth for various kinds of research. These are permanent teeth and the enamel on the premolar forms between 1.5 and 7 years of age (Woelfel and Scheid 2002). The isotopic composition of this enamel can provide information on diet and place of origin. Isotopic ratios of carbon, oxygen, and strontium were deposited in the enamel apatite during the period of formation and have remained largely unaltered after death. Light isotopes of carbon in enamel provide information on childhood diet, e.g., marine vs. terrestrial resources or certain species of plants. The isotopic ratio of carbon was measured in these teeth, but the results are not discussed further. Oxygen and strontium isotopes are used for proveniencing and are discussed in more detail below and in the supplementary materials. Procedures for sample preparation and measurement are described In the supplementary materials.

Oxygen Isotopes

Oxygen has three major isotopes, ^{16}O (99.762%), ^{17}O (0.038%), and ^{18}O

(0.2%), all of which are stable and non-radiogenic. Oxygen isotopes are much lighter and highly sensitive to environmental and biological processes. Oxygen isotopes, which are commonly reported as the per mil difference (‰, or parts per thousand) in ^{18}O /^{16}O between a sample and a standard, can be measured in either the carbonate $(CO_3)^{-2}$ or phosphate $(PO_4)^{-3}$ ions of bioapatite. This value is designated as $\delta^{18}O$. In this study we have measured carbonate as a component of tooth enamel using the reference standard PDB (PeeDeeBee Carbonate). VSMOW (Vienna Standard Mean Ocean Water) is another standard based on ocean water often used in environmental oxygen isotope studies.

Oxygen isotope ratios in the skeleton reflect those of body water (Luz et al. 1984, Luz and Kolodny 1985), which in turn comes predominantly from local rainfall. Isotopes in rainfall are greatly affected by enrichment or depletion of the heavy ^{18}O isotope relative to ^{16}O in water due to evaporation and precipitation. Major factors affecting rainfall isotope ratios are latitude, elevation, and distance from the evaporation source (e.g., an ocean) - i.e., geographic factors. Oxygen, primarily from drinking water, is also incorporated in dental enamel - into both carbonate and phosphate ions - during the early life of an individual where it remains unchanged through life. Oxygen isotopes are also present in bone apatite, and are exchanged through the life of the individual by bone turnover, thus reflecting place of residence in the later years of life. Thus, oxygen isotopes, although non-radiogenic, have the potential to be used like strontium to investigate human mobility and provenience. At the same time, there is significant variation in oxygen isotope ratios that makes their application less straightforward.

Strontium Isotopes

Strontium isotope analysis is used to "provenience" prehistoric human skeletons and determine non-local individuals within a burial population. The ratio of strontium 87 to strontium 86 is used in such studies ($^{87}Sr/^{86}Sr$). The amount of ^{87}S in nature varies but is around 7% of total strontium and ^{86}Sr is 10%. Strontium in both elemental concentrations and isotopic ratios varies with the age and type of rock (Faure and Mensing 2004). This ratio normally varies from about 0.700 in young rocks with low amounts of Rubidium (Rb) to >0.720 in high Rb rocks that are billions of years ago (bya). Geologic units that are very old (> 100 mya) will usually have high $^{87}Sr/^{86}Sr$ ratios, above 0.7010 and as high as 0.740. In contrast, rocks that are geologically young (< 1- 10 mya) generally $^{87}Sr/^{86}Sr$ is less than 0.706. Enamel has been shown to be generally resistant to contamination and a reliable indicator of biogenic levels of strontium isotopes (e.g., Budd et al. 2000, 2004, Hoppe et al. 2003, Schoeninger et al. 2003). $^{87}Sr/^{86}Sr$ values in human tooth enamel generally range between 0.704 and 0.735.

Strontium moves from bedrock into the food chain and is deposited in human bones and teeth. The enamel in teeth forms during infancy and early childhood and undergoes relatively little change during ones lifetime. Strontium isotopes in prehistoric human teeth contain a geochemical signature of the place of birth. Strontium Isotope ratios in teeth that do not match those of the local value of the burial location indicate movement. The technique has been in use for more than 20 years in bioarchaeological research and described in detail in a number of articles (e.g., Bentley 2006, Price et al. 1994, 2002, 2011, Montgomery 2010, Montgomery et al. 2000).

Isotopic Baselines

Isotopic baseline information from the Baltic region is not widely available, but there are several useful sources. A more detailed discussion of isotope ratios for oxygen and strontium from Denmark and Sweden in the western Baltic has been placed in the Supplementary Online Material and is summarized in the following paragraphs. There is less information on the eastern Baltic and Estonia. We have collected some data from Estonia and especially the island of Saaremaa where Salme is located. This information is summarized below.

In general terms there are significant differences among several areas of relevance for the Salme burials. The baseline range of values in Denmark and southwestern-most Sweden falls between 0.708 and 0.711 in the glacial moraine landscape that covers that region. It is clear that the older rocks of the Fennoscandian Shield across most of Sweden result in higher $^{87}Sr/^{86}Sr$ values. The Stockholm region, reflecting the very old Fennoscandian Shield on which it sits, exhibits $^{87}Sr/^{86}Sr$ values generally above 0.715 and often greater than 0.720. The Swedish island of Gotland has a different geology with late Pleistocene glacial deposits on top of Silurian bedrock and equally distinctive $^{87}Sr/^{86}Sr$ values around 0.711 to 0.713. A list of mean $^{87}Sr/^{86}Sr$ values at several Iron and Viking Age sites in Denmark and Sweden (Table 1) provides some indication of local ratios although these human values may of course incude non-local individuals. Grødbygård is a an Early Medieval cemetery on the Danish island of Bornholm in the southern Baltic. The highest values are seen at Birka and Stockholm in central eastern Sweden. Birka is on an island in Lake Mälar. Koppersvik is a major Viking settlement on the Swedish island of Gotland. Uppåkra is an important Iron Age center near Lund in southwestern Scania, Sweden.

Table 1. Average strontium isotope ratios in prehistoric human tooth enamel from selected localities in Denmark (DK) and Sweden (S).

	□	$^{87}Sr/^{86}Sr$	±1 sd
Trelleborg (DK)	49	0.7116	0.0020
Sebbersund (DK)	19	0.7104	0.0010
Galgedil (DK)	38	0.7105	0.0012
Grødbygård (DK)	38	0.7140	0.0018
Kopparsvik (S)	131	0.7135	0.0057
Birka (S)	10	0.7174	0.0070
Stockholm (S)	3	0.7175	0.0054
Uppäkra (S)	10	0.7132	0.0024

Oxygen isotope ratios in modern rainfall across the Baltic region are variable, but $\delta^{18}O$ in human enamel are rather homogeneous, generally between -4.0‰ and -6.5‰ (Table 2). Three samples from Stockholm average -6.4‰. Three Uppsala samples are highly variable ranging from -4.6‰ to -7.3‰. At Birka the average was -4.9‰. Oxygen isotope ratios in the human enamel samples from Gotland average -4.7‰. Across Denmark and southernmost Sweden the value for $\delta^{18}O$ generally falls between -4.0‰ and -5.0‰.

Table 2. Average oxygen isotope ratios in prehistoric human tooth enamel carbonate from selected localities in Denmark (DK) and Sweden (S).

	□	$\delta^{18}O_{en}$	±1 sd
Trelleborg (DK)	41	-4.4	0.7
Sebbersund (DK)	7	-4.0	0.5
Galgedil (DK)	34	-4.2	0.7
Grødbygård (DK)	36	-4.9	0.6

Kopparsvik (S)	44	-4.7	1.1
Birka (S)	29	-4.9	1.1
Stockholm (S)	3	-6.4	0.3

Estonia, Saaremaa, and Salme

Estonia sits at the edge of the Fennoscandian Shield on the northwestern East European Shield (Raukas and Teedumäe 1997). The Proterozoic igneous and metamorphic rocks of this shield form the bedrock of the country and lie at depths greater than 100 m increasing to the south. The sedimentary cover is composed of Cambrian, Ordovician, Siluarian and Devonian materials and consists largely of limestone and sandstone. Quaternary deposits largely of glacial origin normally cover these sedimentary layers at depths of 5 to more than 100 m across the rather level landscape. Alvar formations are visible in areas where the cover materials are particularly thin or absent. Although there is very little strontium isotope data from mainland Estonia, we do have a few samples from northern part of the country. Values range from 0.7106 to 0.7159 (Oras et al., in prep).

The island of Saaremaa lies on the western edge of the East European Shield. The crystalline rock basement underlying Saaremaa is composed primarily of metamorphic rocks (various forms of gneiss) in eastern Saaremaa, while acid igneous rocks (mostly types of granite) dominate in the western part of the island (Raukas et al. 2009). The sedimentary platform on top of this basement is meters in thickness and composed entirely of Silurian carbonate rocks, primarily limestones. This limestone is exposed as alvar in areas of thin or absent surface materials.

The surface materials and topography of the island of Saaremaa are the result of the last glaciation and changes in sea level at the close of the Pleistocene. Glacial lobes moved across the island in several directions, depositing sediments from different sources primarily to the east and west of the island. The weight of glacial ice depressed the earth's surface in the Baltic substantially and the rise of sea level following the disappearance of this ice flooded this area during the Late Glacial. The island gradually emerged from the sea after 10,000 years ago and large parts of the surface are covered with marine sediments from that period. The map in Fig. 8 provides information on the location and extent of quaternary deposits on Saaremaa. The archaeological site at Salme lies at the head of the narrow peninsula of Sörve Spit, a remnant of a large esker from the late Pleistocene. The immediate area around the site is low-lying and covered with marine sediments — clays, sands, and gravels.

Fig. 8. Quaternary deposits on the island of Saaremaa (Raukas et al. 2009) and the location of Salme and baseline samples from the island.

We have obtained a number of modern and archaeological faunal samples from Saaremaa to determine the local bioavailable strontium isotope ratios on the island. These data are presented in Table 3. There are 6 samples of snail shells from around the island along with 7 samples of small fauna and snails from the site of Asva, dating from the Bronze Age or pre-Viking Age, located 44 km northeast of the ship burial (Fig. 8). In addition there are 8 samples of human tooth enamel from Salme, discussed in the next section.

The strontium isotope ratios for these snails are provided in Table 3 and graphed in Fig. 9. The locations where the snail samples were collected on the island are shown in Fig. 8. The snail values from around the island show a wide range of variation from 0.7104 to 0.7139.

Measurement of fauna and snails from the Asva site exhibits a wide range of values with a bimodal distribution. The two snails and the rodent have $^{87}Sr/^{86}Sr$ values in line with the other snails from the island. The voles have higher ratios approaching 0.720. These values between 0.709 and 0.720 define the maximum range for baseline values for the island.

Isotopic Analysis of the Salme Human Remains

The results of the isotopic analysis of the Salme human enamel samples are provided in Table 3. Three isotope ratios — strontium, carbon, and oxygen — are listed. The $\delta^{13}C$ carbon isotope data from the enamel is a reflection of early childhood diet, is very homogeneous in the Salme sample, and is not discussed further in this presentation. The $^{87}Sr/^{86}Sr$ for the eight Salme human samples averaged 0.7291 ± 0.27 (1 s.d.) with a range from 0.7237 to 0.7324.

The strontium isotope ratios for the Salme humans along with faunal samples from the site and from the island of Saaremaa are shown in the bar graph in Fig. 9. It is very clear that the human remains from the Salme ship burials are isotopically distinct from the snails and other fauna from the larger area of the island as well as from the baseline samples from the Asva site. This is definitive evidence that the buried individuals at Salme are not local to the island. Moreover it is very probable that these individuals were not from the eastern Baltic region given the geological homogeneity of this larger region and $^{87}Sr/^{86}Sr$ values generally below .720.

Fig. 9. Bar graph of faunal and human $^{87}Sr/^{86}Sr$ values from Saaremaa Island and Salme.

The oxygen isotope data are less informative. Oxygen isotope ratios in the Salme human samples averaged -5.6‰ ± 0.5 (1 s.d.), ranging between -4.6‰ and -6.2‰. A plot of $^{87}Sr/^{86}Sr$ vs. $\delta^{18}O$ for the human samples from Salme is shown in Fig. 10. The $\delta^{18}O$ values are randomly scattered across the range of values and no clear pattern in their distribution can be observed. The range of $\delta^{18}O$ values is not inconsistent with values from the Stockholm region in Central Sweden (mean =-6.4‰) and slightly higher than ratios found to the south and on Gotland.

Fig. 10. Scatterplot of $^{87}Sr/^{86}Sr$ vs. $\delta^{18}O$ for the 8 human samples from Salme.

Interpretation And Conclusion

It is important to reiterate several points here. Isotopic proveniencing is useful for identifying non-local individuals in a burial population. There are often a number of places with similar isotopic ratios that make the distinction of a single place of origin very difficult. In some cases, the combination of isotopic ratios (strontium, oxygen, and/or lead) can help to delimit the original home of the buried individuals. Oxygen however is not a powerful discriminator in the Baltic region because similar values are found over a very large area. In order to constrain the possible homeland for the Salme burials, it is essential to combine isotopic and archaeological evidence to more accurately identify their place of origin.

The artifacts found with the burials are of particular interest. Find material from Salme ship-graves was generally quite rich and included gaming pieces (326), swords (about 40), arrowheads (91), antler combs (15), and shield bosses (15). Certain artifact types were present in very limited quantity, including ornaments — two brooches, a handful of beads made of different materials, two bear canine tooth pendants, and file and shear fragments. Such limited find material, however, has a positive use. Because all the materials were found together associated with a single, short-lived event and because the finds include items with considerably different dates, there is an opportunity to obtain a highly detailed chronology for the find complex.

With regard to the origins of the Salme warriors, the sword hilts of gilded bronze, decorated with Scandinavian designs, and scabbard remnants with ornaments of gilded bronze or gilded bronze wire, preserved on some sword blades provide some useful information. A gilded bronze decoration on the upper edge of a scabbard from Salme (Fig. 11) has an exact analog found with the Ultuna ship burial near Uppsala, Sweden (Nerman 1958, Fig. 241; Nograd Jørgensen 1999, Fig. 49: 2). A repetitious, frieze-like ornamental band of gold foil and wire decorating the wooden section of another scabbard, bears the same motif (Fig. 12). The sword hilts of gilded bronze from the Salme ships have close parallels with the Vendel and Valsgärde ship burials near Uppsala, Sweden, and richly furnished warrior graves in other parts of Scandinavia and Finland (Nørgård Jørgensen 1999, fig. 49: 1, 3). These ornament types from the Swedish inland date from the middle of the Vendel Period – ca. AD 700–750 (Salmo 1938, Plate XLII; Kivikoski 1973, Plate 55: 507, 508; Lamm & Rundkvist 2005, 108 and others).

Fig. 11 Fragment of the upper edge of a sword scabbard. Gilded bronze. (Photo by Reet Maldre).

Fig. 12. A frieze-like decorative band of gold foil and wire on a wooden part of a scabbard. (X-ray photo by Reet Maldre).

The pommel of gilded bronze decorated with the image of a human-faced beast and 25 almandines (Fig. 13) also has close parallels, e.g. with the pommel depicting a beast with almandine eyes from the warrior grave with cremation burial at Ägget in the Mälaren district in Sweden, and several burials from southwest Finland (e.g., Kivikoski 1973). The find from Ägget has been dated to the earlier phase of the Vendel Period – approximately AD 520–600 (Lamm & Rundkvist 2005: 102–107).

Fig. 13. Four views of a sword pommel of gilded bronze decorated with an image of a human-faced beast and 25 almandines. (Photo by Reet Maldre).

During the Vendel Period there were still relatively few large urban centers for craft production and trade in Scandinavia. Most important among them were Helgö on an island on the Mälar Lake in Uppland, and Uppåkra in southwest Sweden (Hårdh 2001). The production of the jewelers at these centers was highly esteemed by local as well as foreign elite.

Undoubtedly weapons decorated with precious metals, garnets, and other luxury items were important gifts at negotiations of trade contracts and political alliances among aristocratic families. This practice contributed to the spread of high status items to places quite distant from the production centers. One possible explanation for the presence of the Salme individuals in Estonia is as members of a diplomatic mission bearing gifts to promote trade and alliiance. This interpretaton is also supported by the fact that dogs and hawks had been placed among with the Salme warriors as grave goods in addition to luxury weapons and the abundant (326) gaming pieces. These items would not have been particularly suitable for a military campaign, but may be more related to the equipment of an entourage of envoys. Diplomatic deputations from that time always travelled with a numerous and well-armed cohort of elite warriors – *hird* (*hirdman* – attendant).

The luxurious sword hilts with Scandinavian decoration found at Salme II have similar features with analogous finds from rich noblemen´s graves near Uppsala and other places in the Mälar region of Sweden (e.g. graves at Vendel, Valsgärde, Ultuna, and others). The production center at Helgö was their likely place of origin.

Several other issues are important in understanding the Salme ship burials — political relationships in Scandinavia and the Baltic, trade routes, and the introduction of sailing vessels. There were two powerful groups in Sweden known as the Svears and the Gotars. The Svears lived in Central Sweden, concentrated around Uppsala area and in the Mälar region. The Götars (a.k.a. Geats, Goths) were another North Germanic tribe who lived south of Svears, inhabiting what is now much of Götaland ("land of the Geats") in present-day Sweden.

A Central Swedish provenience for the warriors killed at Salme is also supported by the location of trade routes, most likely established in the Bronze Age. It is possible that there was a settlement and cemetery with a Scandinavian population on the Sõrve peninsula, which was an island separated from Saaremaa by water through the Middle Ages. A group of stone graves in the middle of the present Sõrve peninsula includes two ship-like stone contours and stone cists with finds of Scandinavian design.

There were two major trade routes across the Baltic Sea. The northern route was controlled by the *Svears* tribal elite. The ancient seaway from Mälaren to the eastern part of the Baltic likely ran first across the archipelago of the Åland islands between Sweden and Finland, and either entered the Gulf of Finland heading east to the Great Eastern Way (*Austrvegr*), or south through the straits at Salme along the island of Saaremaa to the amber-rich Courland region of Latvia. The Great Eastern Way was the major route from Scandinavia to Constantinople via the Gulf of Finland, Neva River, Dnjepr River to the Black Sea, or down the Neva and Volga rivers to the Caspian Sea and east.

The southern coast of the Baltic and the estuaries of the great rivers there — the southern passage to the Great Eastern Way — were under the control of nobility from the northern part of the present-day Poland, northern Germany and Denmark. There was a long-lived enmity between the courts of the *Götars* and the *Svears* over control of the Scandinavian Peninsula and the Great Eastern Way, which occasionally also led to violent encounters. At times, the Norwegians also interfered in this so-called “frozen conflict“.

The shortest route from Courland to the mother country in the Mälar district ran through the Salme straits. Noblemen from Denmark, the southern coast of the Baltic, and the *Götars* wanted control of that route. It is entirely possible that the dead at Salme were the victims of an armed conflict between these foreign groups that left the Svear seafarers buried near the shoreline. Local Estonians need not have been involved in this conflict in any way.

The research reported in this study was driven by a question about the origins of the individuals buried on the two ships at Salme. The combination of isotopic and archaeological evidence clearly points to the Mälaren region in Central Sweden as the most likely homeland of those men who travelled to Salme, died violently, and were hastily buried in two ships around 750 AD.

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Tables

Table 1. Average strontium isotope ratios in prehistoric human tooth enamel from selected localities in Denmark (DK) and Sweden (S).

Table 2. Average oxygen isotope ratios in prehistoric human tooth enamel carbonate from selected localities in Denmark (DK) and Sweden (S).

Table 3. Strontium, carbon, and oxygen isotope ratios from baseline fauna and human remains from Salme and the island of Saaremaa.

Table 3. Strontium, carbon, and oxygen isotope ratios from baseline fauna and human remains from Salme and the island of Saaremaa.

Lab No.	**Location**		**Material**		**$^{87}Sr/^{86}Sr$**	**$\delta^{13}C$**	**$\delta^{18}O$**
Baseline Fauna		**Species**		**Catalog No.**			
F9105	Asva	Arvicola t.	Enamel	AI 3658:729	0.7188	-7.9	-7.5
F9106	Asva	Arvicola t.	Bone	AI 3799:467 (624)	0.7189	-11.2	-7.8
F9107	Asva	Arvicola t.	Enamel	AI 3799:467 (625)	0.7199	-9.6	-6.8
F9108	Asva	Arvicola t.	Bone	AI 3799:467 (491)	0.7190	-9.3	-8.0
F9109	Asva	Rodentia	Enamel	AI 3799:467 (492)	0.7130	-10.8	-6.3
F9115	Asva	Snail	Shell		0.7097		
F9170	Asva	Snail	Shell		0.7094		
F9113	Maasilinn	Snail	Shell		0.7139		
F9114	Kaali crater	Snail	Shell		0.7124		
F9116	Sääre (Sörve)	Snail	Shell		0.7128		
F9171	Sääre (Sörve)	Snail	Shell		0.7104		
F9118	Kuressaare	Snail	Shell		0.7114		
F9172	Kuressaare	Snail	Shell		0.7109		
Human		**Skeleton**		**Tooth**			
F9097	Salme	Sa I /1	Enamel	LRP2	0.7275	-14.8	-5.9
F9098	Salme	Sa I /2	Enamel	LRP2	0.7299	-15.3	-6.2
F9099	Salme	Sa I/ 3	Enamel	URP2	0.7237	-15.3	-5.9
F9100	Salme	Sa II/ 1	Enamel	LRP2	0.7324	-13.7	-5.9
F9101	Salme	Sa II/ 2	Enamel	LLP2	0.7282	-14.6	-4.6
F9102	Salme	Sa II/ 3	Enamel	LRP2	0.7303	-14.4	-5.4
F9103	Salme	Sa II/ 4	Enamel	LLP2	0.7311	-13.6	-5.1
F9104	Salme	Sa II/ 5	Enamel	LRP2	0.7294	-14.3	-5.6

Figures

Fig. 1. The Baltic Sea and some of the locations mentioned in the text.

Fig. 2. Salme II ship in different stages of excavation. 1. Outline of ship rivets and humus stains together with skeletons. Skeleton layers I – III are visible. 2. Skeleton layer IV, located transverse to the ship. 3. Excavated boat contour without skeletons. (Photos by Jüri Peets and Reet Maldre).

Fig. 3. Schematic 3D plan of the position and distribution of burials on Salme II (Drawing by Reet Maldre).

Fig. 4. Upper portions of skeletons SaI/1, SAI/2, and SaI/3 preserved in situ in the Salme I ship. (Photo by Külli Rikas).

Fig. 5. Distribution of runestones in Sweden. The darker areas have more runestones, the gray areas have none (Sveriges Nationalatlas). *In Supplementary Online Material.*

Fig. 6. Oxygen isotope ratios in rainfall in Sweden (Burgman et al. 1987). *In Supplementary Online Material.*

Fig. 7. Averaged strontium isotope ratios from human and archaeological fauna samples from southern and central Sweden. *In Supplementary Online Material.*

Fig. 8. Quaternary deposits on the island of Saaremaa (Raukas et al. 2009) and the location of Salme and baseline samples from the island.

Fig. 9. Bar graph of faunal and human $^{87}Sr/^{86}Sr$ values from Saaremaa Island and Salme.

Fig. 10. Scatterplot of $^{87}Sr/^{86}Sr$ vs. $\delta^{18}0$ for the 8 human samples from Salme.

Fig. 11. Fragment of the upper edge of a sword scabbard. Gilded bronze. (Photo by Reet Maldre)

Fig. 12. A frieze-like decorative band of gold foil and wire on a wooden part of a scabbard. (X-ray photo by Reet Maldre).

Fig. 13. Four views of a sword pommel of gilded bronze decorated with an image of a human-faced beast and 25 almandines. (Photo by Reet Maldre).

Isotopic Proveniencing: Principles and Procedures

Enamel powder for isotopic analysis was collected from the teeth by first burring the area to be sampled to remove possible surface contamination and then extracting a cusp or fragment in the case of friable enamel. Any remaining dentine was carefully removed and the sample ground to powder. The powder is weighed and submitted for measurement.

Measurement of $^{87}Sr/^{86}Sr$ in the enamel powder was done in the Geochronology and Isotope Geochemistry Laboratory (Dept. of Geological Sciences, University of North Carolina-Chapel Hill). Samples were dissolved in nitric acid and the strontium fraction purified by ion selective chromatography (Eichrom Sr resin) prior to analysis by TIMS on a VG Sector 54 mass spectrometer run in dynamic mode. Internal precision in the laboratory is consistently around 0.0007% standard error (or $1\sigma=0.00006$ in the ratio of a particular sample). Long-term, repeated measurements of SRM-987 are around 0.710260—an acceptable difference from the recognized value of 0.710250—and raw sample values from individual runs are standardized to the recognized value of SRM-987. Light isotopes of carbon and oxygen in enamel powder were measured simultaneously in the Environmental Isotope Laboratory (Department of Geosciences, University of Arizona) using a Kiel device attached to a Finnigan MAT252 ratio mass spectrometer. Samples are converted to CO_2 with dehydrated 70°C phosphoric acid. External precision, as measured by repeated measurements of standard reference materials (NBS-18 & NBS-19) is ±0.08‰ for $\delta^{13}C$ and ±0.1‰ for $\delta^{18}O$.

Strontium isotopes

Strontium isotope analysis provides a robust means for examining past mobility. The strontium isotope ratio of $^{87}Sr/^{86}Sr$ varies among different kinds of rocks, based on their age and composition. The heavier isotope (^{87}Sr) is formed by the radioactive decay of rubidium-87. Thus, older rocks and sediments with more rubidium have higher $^{87}Sr/^{86}Sr$ values, while younger materials with less rubidium are at the opposite end of the range with lower ratios (e..g., Faure and Mensing

2004). The proportion of ^{87}S varies in the terrestrial ecosystem, but averages around 7% of total strontium; ^{86}Sr is about 10%. Their ratio normally varies from about 0.700 in rocks with low Rb to 0.730 and much higher in high-Rb rocks that are billions of years old.

Strontium moves into humans from rocks and sediment through the food chain (Price 1985, 2000, Sillen and Kavanagh 1982) and deposited in the skeleton. The enamel in teeth forms in early childhood and contains the strontium isotope ratio of the food consumed and the local geology from the first years of life. The ratio in the enamel remains largely unchanged during life and after death. In archaeology, enamel is used as a signal of place of birth. If an individual moves to a new location in a different geologic context, or is buried in a new place, the enamel isotope ratio will differ from the new location, allowing the designation of that individual as non-locally born. Most measurements of human enamel fall in the range of 0.705 to 0.725.

Carbon Isotopes in Apatite

The primary factors affecting carbon isotope ratios in skeletal tissues are those associated with dietary input of plants (C_3 vs C_4) with different patterns of photosynthesis (Farquhar, Ehleringer, and Hubick 1989) and the consumption of marine foods (Tauber 1981). Most paleodiet work involving carbon isotopes has focused on the organic collagen in bone. Carbon is also present in the mineral portion of bone and tooth enamel as carbonate and records the aggregate (protein and carbohydrate) value of individual diet (Ambrose and Norr 1993, Lee-Thorp et al. 1989, Lee-Thorp 2002, Sullivan and Krueger 1981). Although there are potential problems with contamination in apatite (e.g., Hedges 2002, Schoeninger and DeNiro 1982), it can nonetheless provide substantial insight into the composition of individual diet.

Oxygen Isotopes in Apatite

Oxygen isotopes have been widely used as a proxy for temperature in many climate and environmental studies and vary geographically in surface water and rainfall (Dansgaard 1964). The oxygen isotope ratio in the skeleton reflects that of body water, and ultimately of drinking water (Kohn 1996, Luz et al. 1984, Luz and Kolodny 1985), which in turn predominantly reflects local rainfall. Water from food and atmospheric oxygen are minor, secondary sources. Measured oxygen isotope ratios of body water are enriched relative to those of meteoric water in mammalian species due to the combined fractionation effects of the physiological processes involved in regulating daily water flux (e.g., Nagy 1989).

Oxygen has three isotopes, ^{16}O (99.762%), ^{17}O (0.038%), and ^{18}O (0.2%), all of which are stable and non-radiogenic. Isotope ratios in rainfall are greatly affected by enrichment or depletion of the heavy ^{18}O isotope relative to ^{16}O in water due to evaporation and precipitation (e.g. Dansgaard 1964). Major factors affecting rainfall $\delta^{18}O$ values are primarily geographical: latitude, elevation, amount of precipitation, and distance from the evaporation source (e.g., an ocean).

Isotope measurements are reported as a ratio of one isotope to another, lighter and more common cousin. Like carbon, oxygen isotopes are commonly reported as the per mil difference (‰ or parts per thousand) in the ratio of ^{18}O to ^{16}O between a sample and a standard. This value is designated as $\delta^{18}O$. This value can be measured in either carbonate $(CO_3)^{-2}$ or phosphate $(PO_4)^{-3}$ ions of apatite in tooth and bone. Phosphate and carbonate produce comparable results. Traditionally, two standard scales have been used to report oxygen isotope ratios by researchers investigating either carbonate (PDB, PeeDee Belemnite) or hydrological systems (VSMOW, Vienna Standard Mean Ocean Water) (Hoefs 2009).

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Isotopic Baselines in Sweden

A distribution map of runestones provides an approximation for the location of human population in Sweden during the Viking Age (Fig. 5). Stockholm and Gotland are two areas with substantial Viking settlements closest to Estonia. The island of Gotland is approximately 200 km to the southwest of Saaremaa, while the Stockholm region is roughly 250 km to the northwest. There were several large settlements on Gotland during the Vendel and Viking periods. The region around Stockholm and the Mälar Valley directly to the west were also important centers of Viking population. The agricultural lands on the shores and islands of Lake Mälar are some of the richest in Sweden. One estimate suggests there were 4000 farms in *Mälardalen* (the Mälar Valley) during the Viking period and perhaps 40,000 people (Hyenstrand 1982). Another major Viking center in this part of Middle Sweden was located around Uppsala, 70 km northwest of Stockholm.

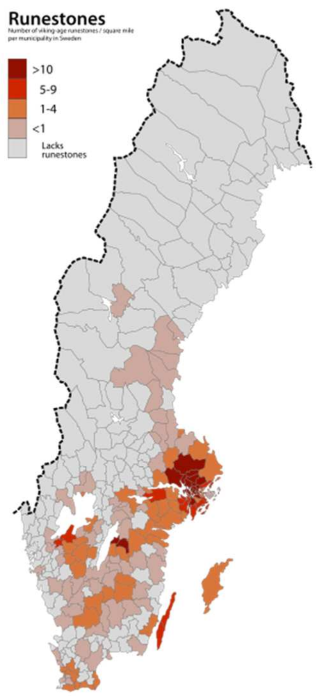

Fig. 5. Distribution of runestones in Sweden. The darker areas have more runestones, the gray areas have none (Sveriges Nationalatlas).

Oxygen Isotope Baselines

Oxygen isotope ratios vary largely with latitude, temperature, and elevation. For that reason there is pronounced variation in $\delta^{18}O$ from south to north in Sweden. Burgman et al. (1987) measured δ^{18}_{VSMOW} in annual precipitation and run-off from a number of sites in Sweden and published a map of estimated ratios for the entire country (Fig. 6) using the seawater standard reference (VSMOW). Values range from -14‰ in the north to -8‰ in the southwest. Slightly more negative

$\delta^{18}0$ values should be expected to the east in Estonia. Values for $\delta^{18}O$ in ground waters in Estonia vary from -10.8‰ to -12.8‰ (Punning et al. 1987). An annual average for rainwater is assumed to be ca. -10.4‰ by local scientists (Liina Laumets, pers. comm.). Although little data exists for Estonia, there is information from Riga in Latvia where average monthly values for modern rainfall range between ca. -12.0‰ and -7.0‰ over 12 months of the year. These $\delta^{18}O_{VSMOW}$ values correspond to a range in $\delta^{18}O_{PDB}$ in enamel between approximately -9‰ and -5‰ (Chenery et al. 2012).

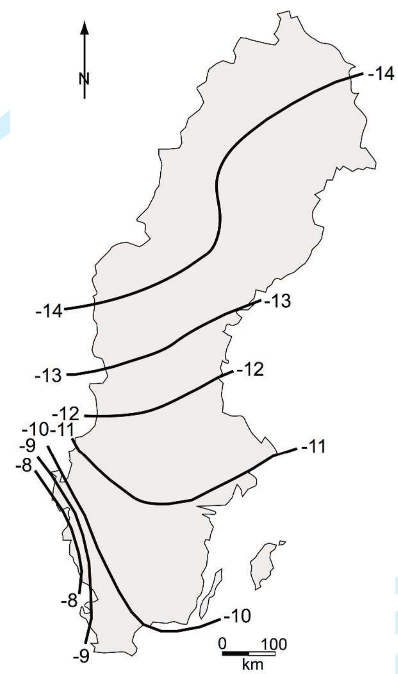

Fig. 6. Oxygen isotope ratios in rainfall in Sweden (Burgman et al. 1987).

We have also measured $\delta^{18}O$ in human enamel from Viking Age sites elsewhere in Scandinavia, including the Stockholm area, Birka, and Gotland. Some of these data are presented in Table 1. What are particularly notable in this table are the very similar values between -4.0‰ and -5.0‰ for all of the locales except Stockholm with a value of -6.4‰. Nearby Birka has an average oxygen isotope ratio of -4.9‰.

Strontium Isotope Baselines

An essential aspect of strontium isotope analysis involves the determination of the local strontium isotope signal (Price et al. 2002). The actual level of strontium isotopes in human tissue may vary from local geology for various reasons. It is necessary to measure *bioavailable* levels of $^{87}Sr/^{86}Sr$ to determine regional and local strontium isotope ratios for comparison with the human remains.

Because the archaeological materials found with the Salme ship burials have a distinct Viking affiliation we have focused on eastern Sweden and Denmark as potential homelands for these individuals. Denmark, Sweden and Norway were the primary homeland of Viking culture. It seems unlikely that Norway might have been place of origin for the individuals buried on the ships at Salme because of the travel distance involved and known connections between the Swedish Vikings and the east during the Viking period. In the following pages we present a very brief summary of the geology and strontium isotope sources in the larger region of the Baltic and specifically eastern Sweden and Denmark. The discussion of baseline values concentrates on the island of Gotland and the region around Stockholm as possible homelands of the Salme burials. We then look in more detail at Estonia and the island of Saaremaa.

The Baltic

The Baltic Sea, 1600 km long and averaging 190 km in width, is one of the major bodies of water on earth. The Baltic fills a relatively shallow depression in the earth's surface in northern Europe, bordered by the countries of Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland, and Germany. A major geological division in the region runs along the south Swedish coast, crosses the Baltic toward Finland and continues through the Gulf of Finland, separating the Fennoscandian (or Baltic) Shield from the East European Platform to the east.

The Fennoscandian Shield in the Scandinavian Peninsula is a region of ancient craton exposed on the surface. Such ancient cratons with a Precambrian basement (>543 mya) were part of the cores of the earliest continental blocks of Archaean Age (>2.4 bya) and contain some of the oldest rocks on earth. These

Precambrian crystalline rocks often crop out along the Swedish and Finnish coasts. The Eastern European Platform is characterized by a younger basement of crystalline rocks of Proterozoic age beneath a thick Palaeozoic sedimentary cover (younger than 543 my) that is sometimes found on the surface in the eastern Baltic area, particularly along the coast (Tuuling et al 2011).

There have been several studies of environmental $^{87}Sr/^{86}Sr$ in the Baltic region. There is also some published information on the brackish waters of the Baltic Sea. The waters of the Baltic come from two major drainage regions to the north and to the south (Åberg and Wickman 1987). To the north, most of the waters that flow into the Baltic come off the Precambrian rocks of the Fenno-Scandinavian Shield and have generally high strontium isotope ratios (>0.720). To the south, a large sedimentary basin from northern Germany to the Neva River near St. Petersburg provides approximately 55% of the waters to the Baltic and a much lower $^{87}Sr/^{86}Sr$ signature. Values reported from the Vistula and Oder average 0.710 (Åberg and Wickman 1987). Andersson et al. (1992) measured Sr and Nd isotope ratios in the Baltic to study mixing of waters from river input and the sea. Strontium isotope ratios are generally correlated with salinity in the Baltic waters. Modern $^{87}Sr/^{86}Sr$ values for the southern Baltic Sea waters are slightly variable and somewhat higher depending on salinity, but usually fall within the range of 0.7092 and 0.7097.

Denmark

Denmark is characterized by a relatively young and rather homogenous “basement” geology. About 50% of the country is constructed of Late Cretaceous-Early Tertiary carbonate platforms, the other 50% by marine clastic sediments, all covered by more or less thick sequences of diverse glaciogenic sediments deposited during the two last Ice Ages. The Quaternary glaciogenic sediments are composed, among other things, of various weathered Precambrian granitoids (gneiss and granite). Almost everywhere in Denmark, glacial deposits are the source of strontium isotopes for plants, animals, and people. There is very little bedrock exposure anywhere in the country. Baseline strontium isotope data from Denmark has been published (Frei and Frei 2011, Frei and Price 2012). Frei and Price (2012) present strontium isotope ratios from samples of modern mice, snails, and archaeological fauna. The $^{87}Sr/^{86}Sr$ values for faunal samples range from 0.70717 to 0.71185, with an average of 0.70919 (s.d. = 0.0011). These values increase slightly from west to east, but in general terms the geology and the strontium isotope ratios in this heavily glaciated region are largely homogeneous.

Sweden

Sweden's geology is rather complex but generally can be divided into three main components: Precambrian crystalline rocks (which are part of the Baltic or Fennoscandian Shield and include the oldest rocks found on the European continent), the remains of a younger sedimentary rock cover, and the formation of the Caledonides during an ancient mountain building episode in the Mesozoic, ca. 400 mya.

The oldest rocks in Sweden are Archaean (> 2,500 million years old), but these only occur in the northernmost part of the country. Most of the northern and central parts of Sweden are composed of Precambrian rocks belonging to the Fennoscandian Shield, an ancient craton of mantle rock with generally high strontium isotope ratios. This rock is covered in places by glacial moraine, but is exposed intermittently to frequently on the surface. Further to the south, Phanerozoic sedimentary rocks rest upon the Precambrian shield. They are less than 545 million years old and cover large parts of Skåne, the islands of Öland and Gotland, the Östgöta and Närke plains, the Västgöta mountains, the area around Lake Siljan in Dalarna and areas along the Caledonian front in northern Sweden.

The youngest rocks in Sweden are from the Tertiary, formed about 55 million years ago. They occur in the most southerly and southwestern parts of Skåne. Quaternary deposits formed during and after the latest glaciation (when Sweden was completely covered by an ice sheet) partially cover this bedrock.

Southernmost Sweden is a glaciated landscape much like the neighboring areas of Denmark and strontium isotope ratios should be similar as well.

There is a growing body of baseline $^{87}Sr/^{86}Sr$ values from central and southern Sweden (Fig. 7). The Swedish Geological Service has measured $^{87}Sr/^{86}Sr$ across the country and reports very high rock values from most of the area, generally greater than 0.722. There is some information from environmental studies. For example, Åberg et al. 1990 sampled soil and water from five different locations (none in the southwest) and reported values higher than 0.715 at all five sites, often above 0.725. Most of the Fennoscandian Shield across Sweden exhibits similar high values for $^{87}Sr/^{86}Sr$. We have some baseline data from the greater Stockholm region. The site of Birka in the Mälar Valley west of modern Stockholm was a major Viking center and gateway to the east. Samples of five archaeological rodents from Birka averaged 0.7256, while 29 human enamel samples provided a mean of 0.7207 ± 0.0073 with a range from 0.7103 to 0.7343, values that include a number of non-local individuals. We also have several other human samples of Viking Age from central Sweden including three from Uppsala with a mean of 0.7260 and three from the medieval cemetery of Helgeandsholmen in Stockholm. One of the three from Stockholm appears to be non-local with a value of 0.711, while the other two are similar with an average of 0.7206. In general human and faunal values from much of Central Sweden appear to have $^{87}Sr/^{86}Sr$ values between 0.720 and 0.726.

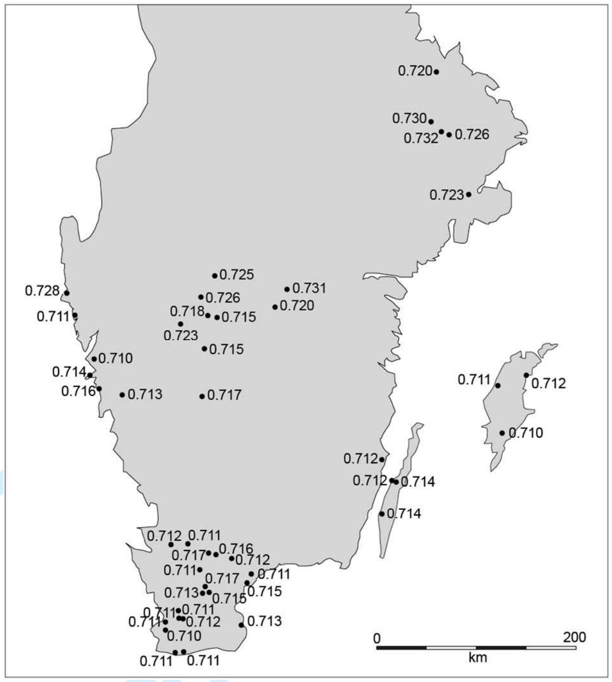

Fig. 7. Averaged strontium isotope ratios from human and archaeological fauna samples from southern and central Sweden.

There are a few exceptions to the generally high values found across much of Sweden. The southwest corner of the southwestern province of Scania has a geology and strontium isotope ratios similar to Denmark, around 0.708 - 0.711. The southeastern island of Öland has a distinctive geology and faunal samples from archaeological sites on the island had an average $^{87}Sr/^{86}Sr$ value of 0.7144. 106 samples of human enamel from the island averaged 0.7160 ± -0.008, including a number of non-local individuals. Gotland, an important center of trade in the middle of the Baltic during the Viking period, is another important exception. Most of the island is composed of Silurian limestone, covered by glacial deposits of till and outwash. $^{87}Sr/^{86}Sr$ values in Silurian limestones on Gotland have been measured and show a very narrow range from 0.7084 - 0.7085 (Azmy et al. 1999). Archaeological materials have also been analyzed. From Gotland we have ca. 140 samples, of which 11 are archaeological faunal. These 11 baseline samples of hare, fox, dog, hedgehog, and beaver from several sites around the island have an average $^{87}Sr/^{86}Sr$ value of 0.7112. Human samples from Gotland, which include a high proportion of non-local individuals, average 0.7135 ± 0.0057 with a range from 0.7083 to 0.7389.

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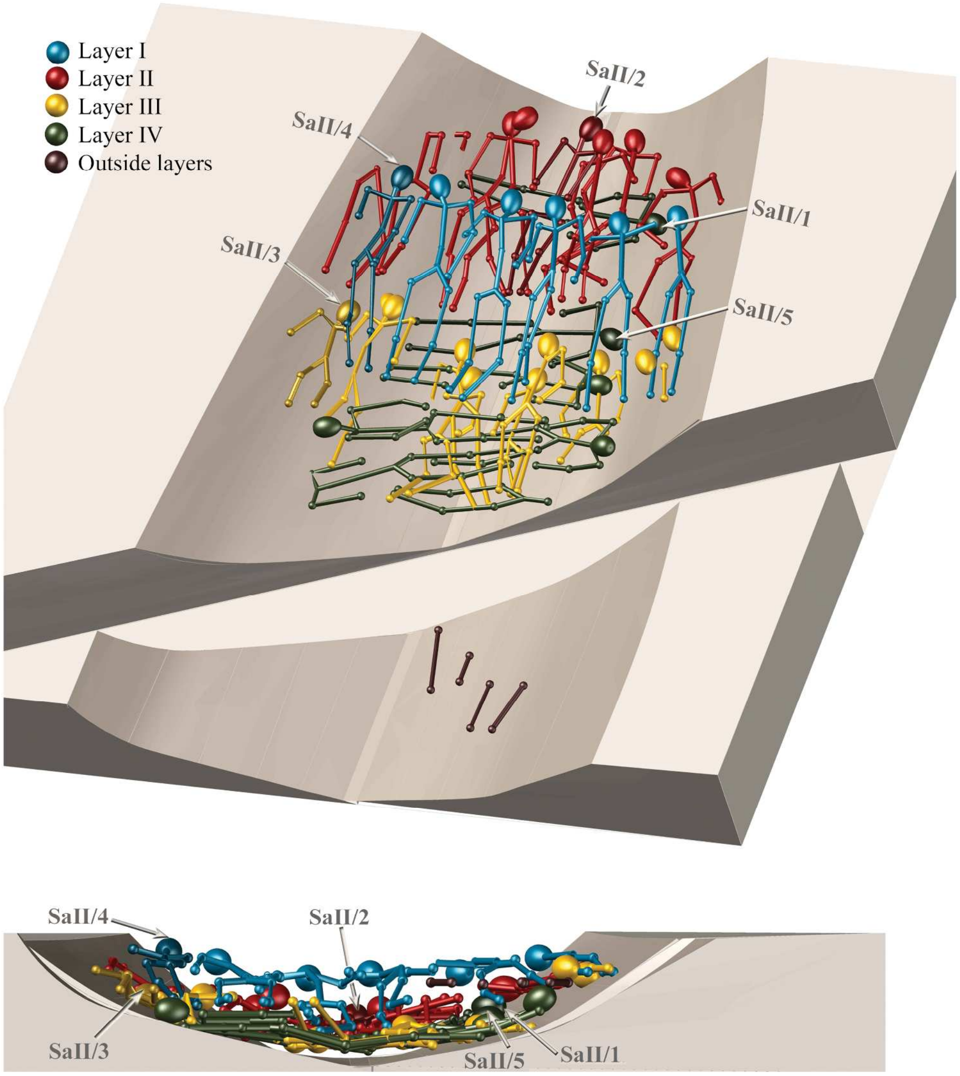

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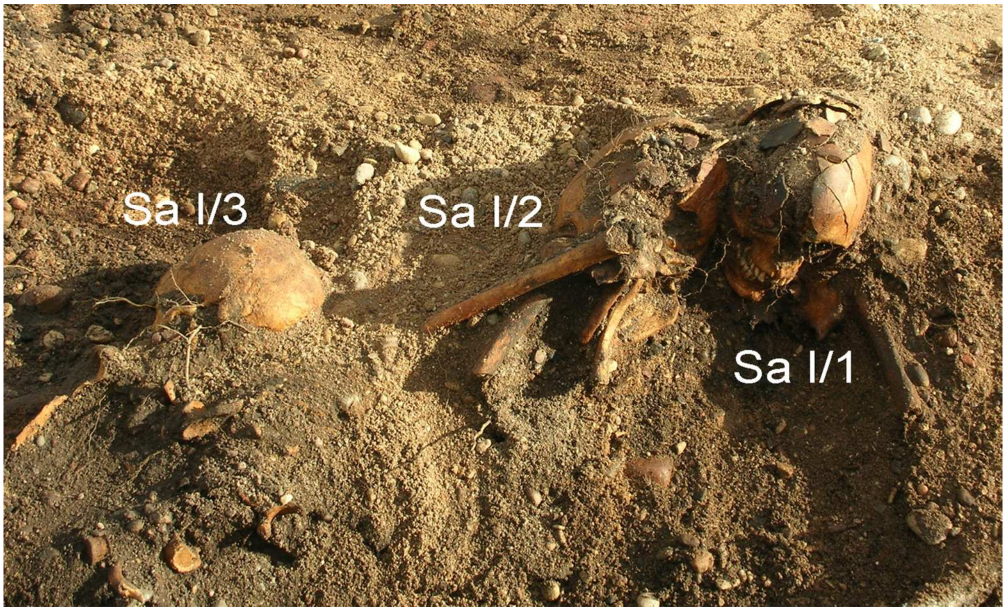

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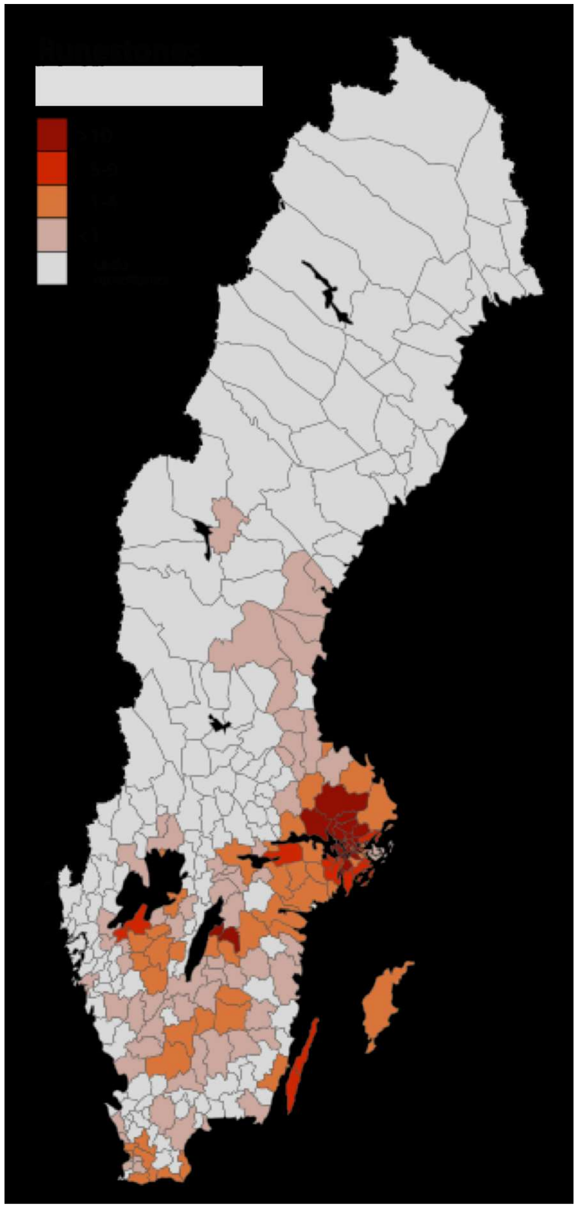

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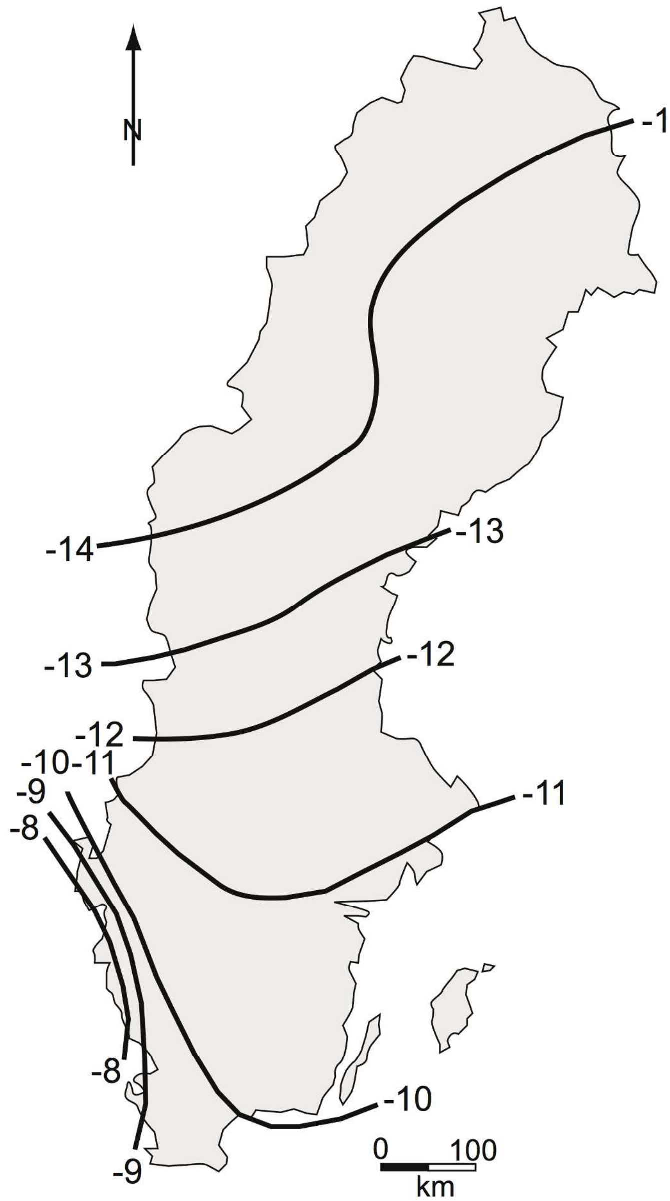

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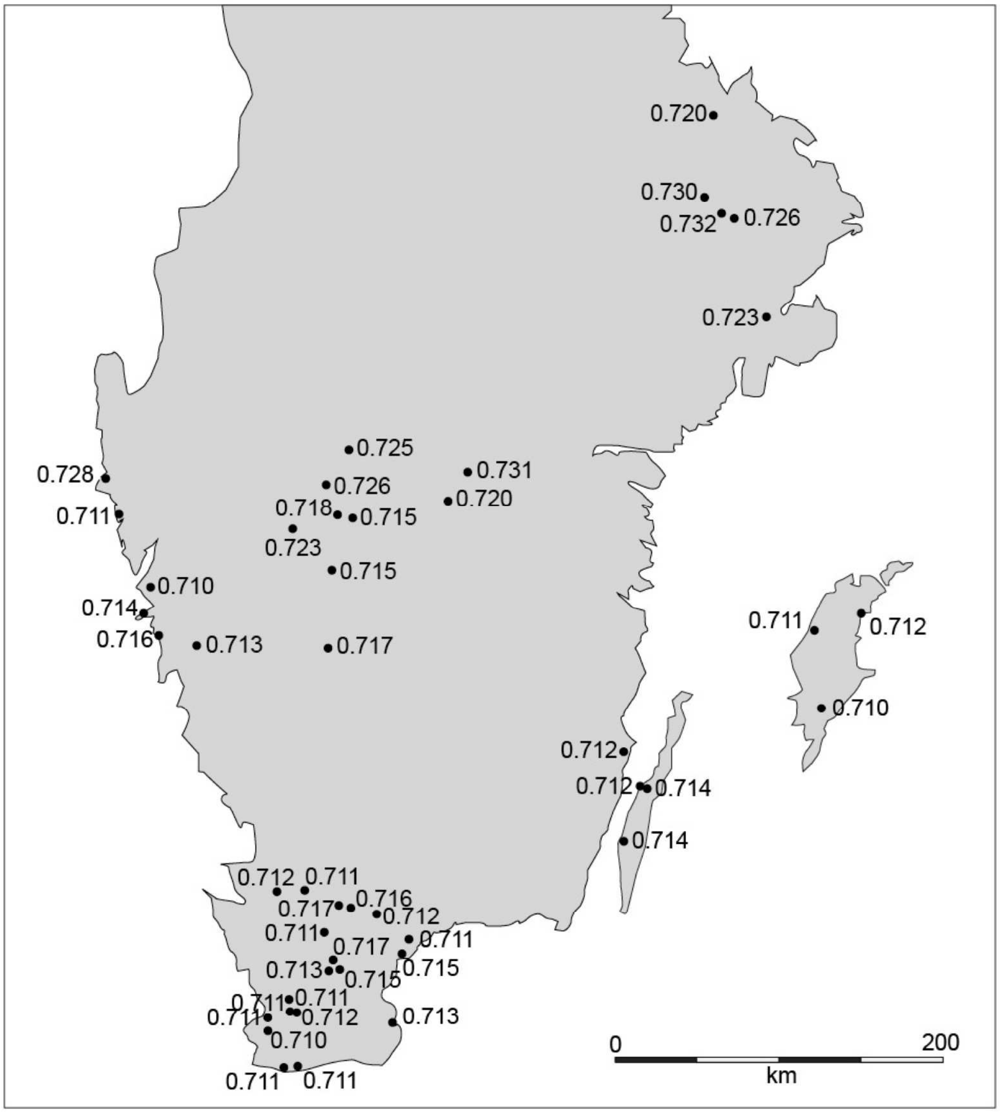

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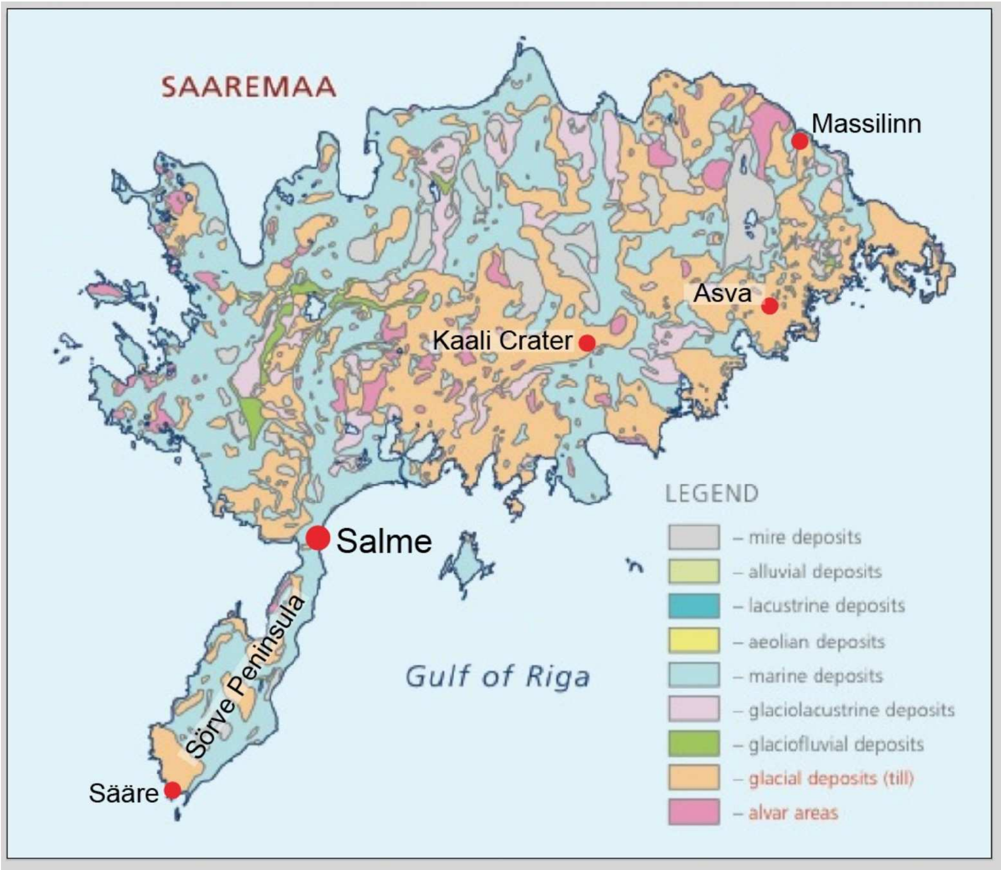

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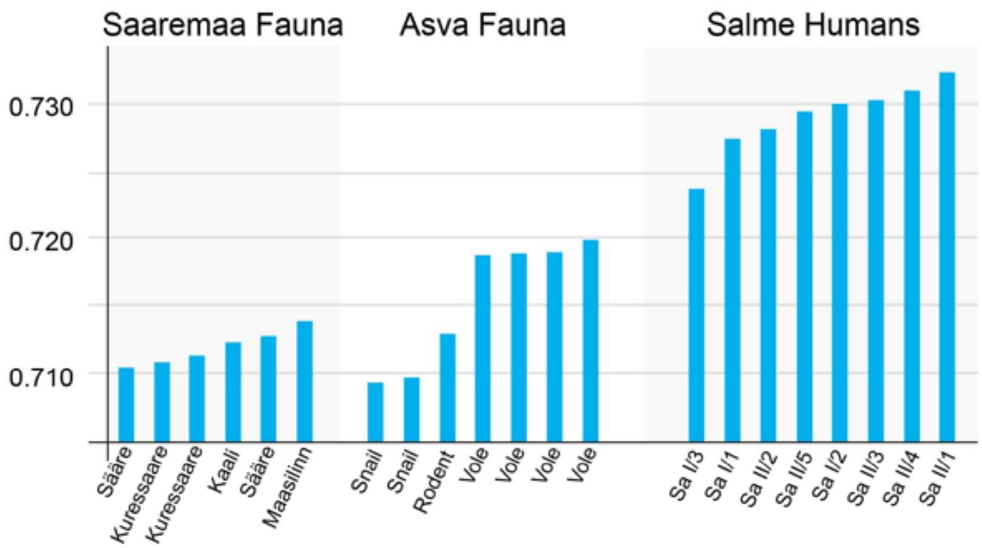

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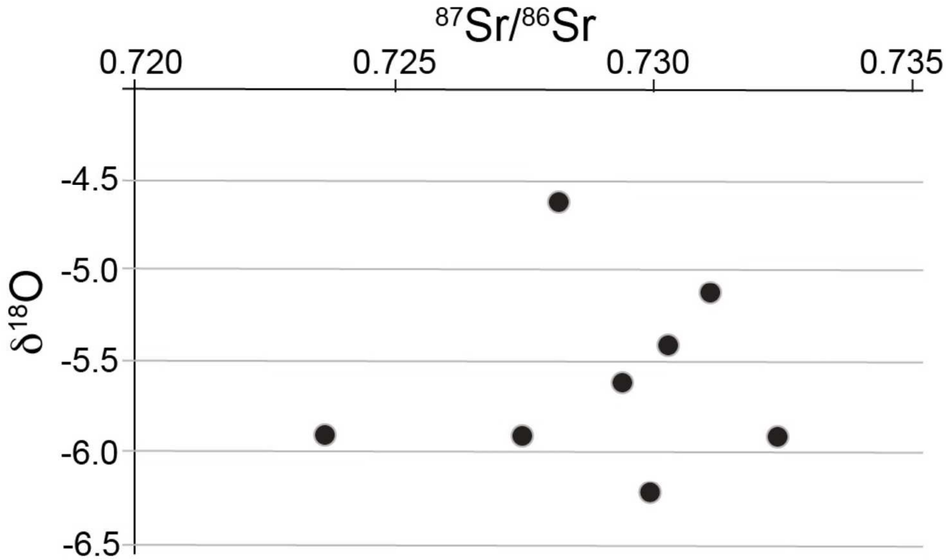

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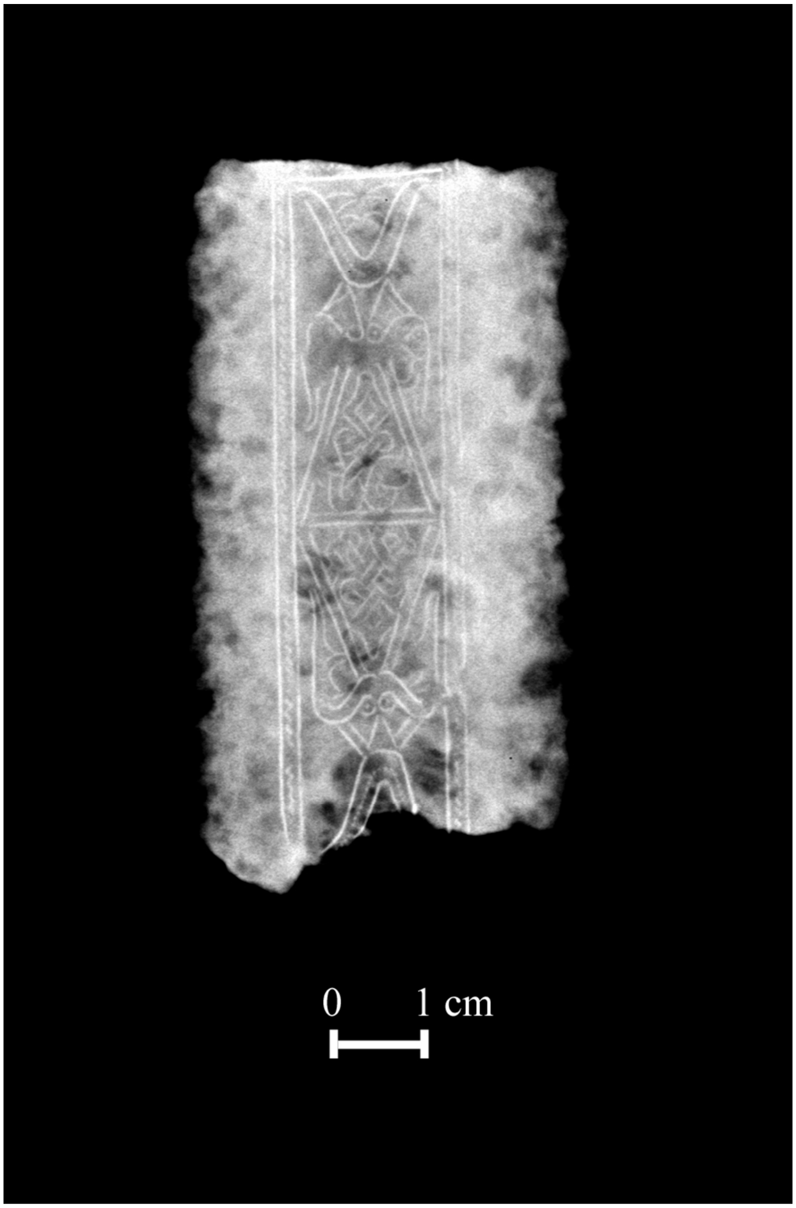

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