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Isotopic investigation of human provenience at the eleventh century cemetery of Ndr. Grødbygård, Bornholm, Denmark

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Bornholm is a Danish island almost in the center of the southern Baltic Sea. The strategic location of the island, its rich archeology, and its complex geology make it an intriguing location for the isotopic study of past human mobility. The focus of this study is on the large cemetery of Ndr. Grødbygård in the southern part of the island, which dates to the eleventh century AD and contains 553 individuals in 516 graves. The majority of the burials were in a supine position oriented west–east, with the heads to the west, following the tradition of that time. In contrast to the Christian traditions, however, the graves at Grødbygård were richly equipped by Scandinavian standards and some of the burial practices more closely resembled those from the Western Slavic region of the south (present day northeastern Germany and Poland). We have used isotopic analyses to examine the external relations and potential places of origin of the inhabitants of the cemetery. Strontium and oxygen isotope ratios in human tooth enamel provide a signature of place of origin and can be compared to the ratios of the place of burial to determine local or non-local origins. In the case of Bornholm, the local geology is quite complex, with a variety of rocks of different age and composition, resulting in a wide range of strontium isotope sources on the island, complicating the issue of identifying migrants. At the same time, Grødbygård provides an important example of the application of such methods in less than ideal conditions.

Keywords: strontium isotopes; oxygen isotopes; carbon isotopes; migration; archeology; Baltic Sea; bioavailable; bioarcheology; human remains

Late Viking Age/Medieval Bornholm

Bornholm is a small island in the Baltic Sea (Figure 1). It is the easternmost island of Denmark, located to the south of Sweden and north of Poland. The island is roughly trapezoidal in shape with dimensions of approximately 25 km east–west, 30 km north–south. Bornholm is 587 km^2 in area and has a coastline of roughly 140 km in length. The population today is slightly more than 42,000 people. The closest landfall is the southern tip of Sweden, 38 km to the northwest. The capital of Denmark, Copenhagen, lies 150 km to the west. The coasts of Kaliningrad, Lithuania, and Latvia lie further to the east. The topography of the island consists of dramatic rock formations in the north, sloping down towards pine and deciduous forests and farmland in the center, and sandy beaches to the south. Most of the northern three-quarters of the island is a plateau, composed of Precambrian magmatic and metamorphic rocks, with elevations above 100 m. The castle ruins of Hammershus on the northwestern tip of the island are those of one of the largest medieval fortresses in northern Europe, testimony to the importance of the island's strategic location.

In the Viking Age and in the Middle Ages, Bornholm's position on the sea lanes connecting Scandinavia with the southern and eastern coasts of the Baltic made the island a well-known place to the merchants, sailors, and travelers. The eleventh-century German chronicler, Adam of Bremen, noted that the island was 'the most celebrated port of Denmark and a safe anchorage for the ships that are usually dispatched to the barbarians and to Greece' (Adam of Bremen, Book 4, p. 16).

In the light of archeological sources, Bornholm appears as not only a convenient stop on Baltic Sea routes, but also a place involved in the contemporary political and economic activities of the region. The overseas contacts of the Bornholmers, related to trade, warfare, or migration, seem to be extensive. The evidence from a large number of English coins issued at specific mints found in the silver hoards on the island points toward Bornholmers' participation in the Viking raids on England (Von Heijne 2004,

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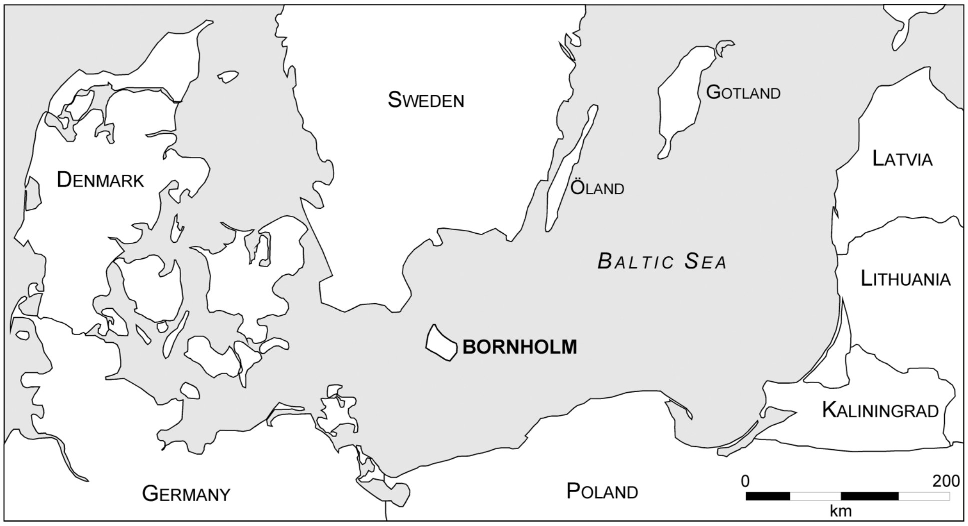

Figure 1. Bornholm and its neighbors in the southern Baltic Sea.

pp. 134–135, Ingvardson 2012). Numismatic sources (numerous hoards and single coins found in the context of settlement sites) also indicate close trade connections with the Saxons and Slavs along the southwestern coasts of the Baltic (Watt 1988, Von Hejine 2004, p.24).

The runic scribes working on the island in the eleventh century used styles characteristic of central–Swedish runic art, perhaps indicating direct personal contacts with provinces of Västmanland and Uppland. Other archeological sources from the island point to the eleventh century immigration of people from the Slavic-speaking areas south of the Baltic Sea (Naum 2008). To add to this picture of complex interactions to the north, west, and south, one also has to consider the eastern orientation of Bornholmers' travels and interests, although these are more difficult to document from the archeological and historical record.

Despite extensive travel to and from the island and its strategic position, contemporary writers had very little to say about Bornholm. One of the earliest pieces of information comes from Wulfstan, a traveler who was sent by king Alfred the Great around the year 880 to explore the Baltic Sea. Wulfstan describing his journey from Hedeby to Truso notes that Bornholm, or Burgenda-land, as he calls the island, had a king of its own. Wulfstan's remark about the island's self-rule, as well as the longevity of Bornholm's independence, continues to ignite debates among archaeologists and historians (e.g., Randsborg 1980, p.163, Nielsen 1998, Lihammer 2007, pp. 261–262).

Another interesting historical reference regarding Bornholm's position and political status comes from the pages of *Gesta Hammaburgensis Ecclesiae Pontificum,* written by Adam of Bremen. In his description of the island, he describes the official conversion of the island to Christianity, which, according to the author, happened in the 1060s. In Adam's words, Egino, the Archbishop of Lund, won the islanders to Christ, moving them to tears with his preaching and he made them destroy their idols and recognize their errors, which they did immediately and without hesitation (Adam of Bremen, Book 4, p. 8). Although this description might be rhetorical exaggeration, Adam's words nonetheless are an important indication that at least from the second half of the eleventh century the process of strengthening ties with the Danish kingdom and the institutionalization of the Church had begun on the island. Adam, who spent some time in Denmark as a guest of the king Sven Estridsen (ruling between 1047 and 1074) had first-hand knowledge of these events.

The cemetery of Ndr. Grødbygård

More helpful information for understanding Viking and medieval Bornholm comes from archeology. Some of the most exciting excavations in the years have involved three cemeteries dated to the end of the Viking Age and the early Middle Ages (AD 900–1100), in the southern part of Bornholm (Watt 1985, Wagnkilde and Pind 1996, Wagnkilde 1999, 2000, 2001, Naum 2008, pp.179–253, 2009). The discoveries made at Runegård, a small burial ground most likely used by a single extended family, and the excavations at the much bigger, communal cemeteries of Ndr. Grødbygård and Munkegård provide clues about the process of Christianization on the island, and the potential tensions that was created (Naum 2007). Moreover, the evidence reveals the particular character of eleventh century burial customs on the island, and invites interpretations about possible immigration to the island.

The cemetery at Ndr. Grødbygård warrants particular attention. It is the largest totally excavated early medieval

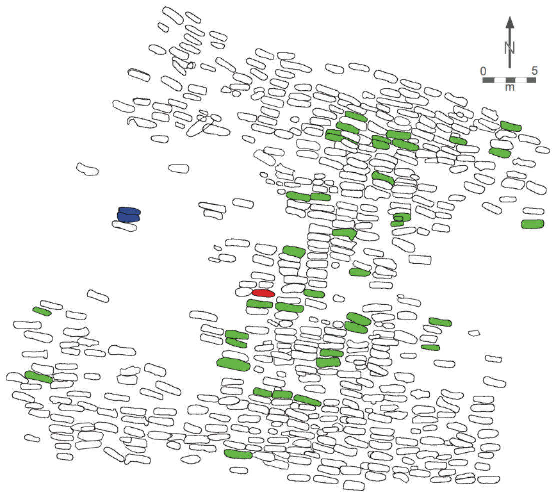

Figure 2. The cemetery at Ndr. Grødbygård The two large shaded areas represent structures at the site predating the cemetery. The graves with dark fill were sampled for strontium isotope analysis. The dark isolated grave in the left center of the plan has the highest strontium isotope ratio of the sampled individuals.

burial site on Bornholm. The cemetery is located in Aaker parish in the southern half of the island not far from the coast. Approximately, 553 individuals were buried there in 516 graves covering an area of 2275 m^2 (Figure 2). The cemetery was excavated between 1986 and 1993 (Wagnkilde and Pind 1996, Wagnkilde 1999, 2000, 2001) and has been dated to the eleventh century (ca. AD 991–1074?) AD by coins and other objects in the graves. A total of 123 coins were found in 61 graves with dates from AD 985–1074.

Although no archeological traces of a church were found, it is likely that such a structure was originally present at the site. Other features of the cemetery also point to a Christian tradition of burial. Similar to other medieval cemeteries in Scandinavia, Ndr. Grødbygård was a row-grave burial ground, divided into two zones – a northern female zone and a southern male one. Children's graves were found in both zones and a few were grouped in the central part of the cemetery in the liminal space between the female and the male graves.

In spite of the large number of burials in the cemetery, the preservation of human skeletal remains was very poor and relatively little anthropological information is available. In most cases only the teeth, some parts of the skulls and very few other bone fragments remained. Tooth enamel is largely composed of the mineral apatite, an inorganic material, and is the most durable tissue in the skeleton. Most information regarding the individuals in the cemetery is the result of the odontological study by Torben Pind (Wagnkilde and Pind 1996, Wagnkilde 2000).

Sex and age determinations for the population from Ndr. Grødbygård are based largely on the protuberant aspects of the badly damaged skulls such as occipital, frontal, temporal, and mastoid parts. In the material, sex could be determined for only 254 of the 553 skeletons, with 56% males and 44% females. It is rather usual to find more male than female skeletons in a medieval cemetery, and again poorer preservation at Ndr. Grødbygård of the more fragile female remains may be a factor.

It was possible to estimate the age of only 82% of the individuals recorded in the cemetery. Of those, 167 individuals (15%) were non-adults and 386 were adults. Some of the burials were without any physical remains, but the length of the grave could be used to suggest an adult or a non-adult context. As commonly seen in medieval cemeteries, only very few individuals belonged to the oldest group, senilis, more than 45 years of age. The small percentage of non-adults is certainly not representative of the actual number of children and young people in the population at Ndr. Grødbygård, and may be a function of the very poor conditions of preservation. In some other medieval burial populations, up to or more than 50% of the non-adults have been reported, a number which is actually recorded in some of the first church registries in the Aaker Parish at Bornholm during the seventeenth century (Vensild 1996). At other known medieval cemeteries, the average age of women was somewhat lower than the average age of men. The calculation of average age is usually rather inaccurate, but of those who reached adulthood, 18–20 years, most had less than 20 years left to live.

Based on the number of burials, the age distribution in the cemetery, and the length of cemetery use, this churchyard might have served a once-living population of some 300 individuals or 20–25 farms (Wagnkilde 1999). Most of them seem to be local, but some of the interred may also have come from other parts of Bornholm, or indeed abroad. The majority of the burials were oriented west–east, with the heads to the west and most were placed in a supine position, reflecting the Christian ideas of preparation for resurrection and a readiness to see Christ appearing in the east. The custom of placing the deceased in coffins was fairly common and appeared in more than half of the burials. In some cases arrangement of the bones could suggest that the dead person was wrapped in a shroud. The uniformity of the graves and the presence of iron pins and buckles in a number of the graves, likely used to hold the shroud together, suggest that wrapping of the body was a common feature of burial at Ndr. Grødbygård.

Ndr. Grødbygård is distinct from Danish or Scanian eleventh century cemeteries (although consistent with other contemporary burial grounds on Bornholm) in the custom of burying the deceased equipped with jewelry and common tools. More than half of the graves (about 63%) contained elements of dress such as jewelry, metal parts of garments, simple tools, and everyday objects (knives,

Figure 3. Grave 210 at Ndr. Grødbygård.

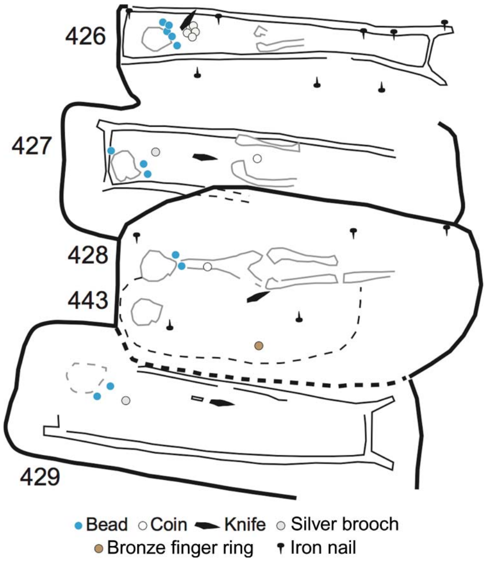

Figure 4. Grave Cluster 426–429, 443, at Ndr. Grødbygård.

whetstones, sewing needles, and less often spindle whorls and tweezers, pottery) and other grave gifts (Figure 3).

Other traces of rituals, like food preparation and consumption, associated with funerals and commemoration of the dead, were also observed. These took the form of burnt animal bones in the fill of the graves, in cooking, and other pits recognized in the cemetery area, that were filled with burnt organic material and with potsherds. While some of these are of earlier date, others were contemporary with the burials, as indicated by the finds of potsherds of Baltic ware produced on the island between the eleventh and the thirteenth century AD.

Another interesting feature at Ndr. Grødbygård is the stratigraphic superpositioning of the burials, and the occurrence of clusters of graves with the interred provided with similar sets of objects (Naum 2008, pp. 235–242). While the overlapping of graves is not unusual in the context of medieval cemeteries and is frequently observed at crowded town churchyards, it is less common at rural graveyards. In case of Ndr. Grødbygård, the fact that some of the individuals buried close to one other were given similar objects and buried in a similar manner may indicate that at least some of these clusters represent family groupings.

One such cluster was made up of five female graves located in the central part of the northern zone of the cemetery (graves 426–429, 443). In the three overlapping graves, the women were given almost the exact same grave goods, consisting of beaded necklaces including the same type of silver beads in two graves, knives (one in a mounted sheath), and coins (Figure 4). In another group of graves 613, 617, 618, 619, and 621, the adult women (613, 617, 618, and 619) were wearing beaded necklaces (beads were found underneath their chins). Three of them were buried with brooches for fastening clothing and three of them were given knives. Two of these women, buried last in this group, were also given iron needles, which in the case of the woman interred in grave 613 was placed inside her mouth.

Yet, another distinct cluster of four burials was observed in the western part of the cemetery, cutting through the remains of an older house, and spatially isolated from other interments. Burials in this grouping (77, 78a, 78b, 219) lay very close to one other. Two of them involved the stratigraphically older burial of an adult (78b) beneath the largely destroyed burial of a 11–12 year-old child (78a); the child had been put in a coffin and buried on top of the adult. The graves of these two individuals were lined up and covered with stone slabs, suggesting perhaps that the buried individuals might have been members of the founding family of the church (?) or cemetery or considered as different by the community using the cemetery due to some other factors. The only object found in these burials was an iron knife placed under the left arm of the person in grave 78b. Some contemporary potsherds were found in the soil covering graves 219 and 78a (Figure 5).

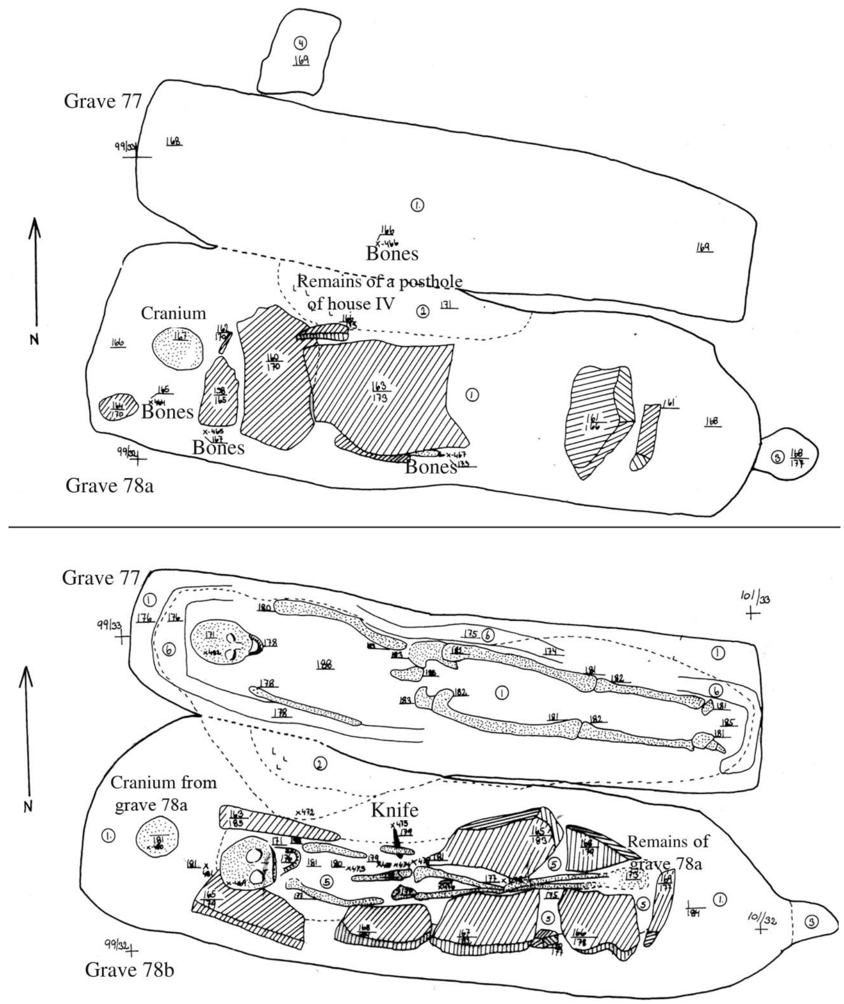

Figure 5. Upper and lower excavation levels of the graves 77, 78a, and 78b.

Ndr. Grødbygård and external connections

Towards the beginning of the twelfth century AD, most of the churchyards in southern Scandinavia, particularly those associated with urban centers, show a uniform pattern of burial in which the dead were swaddled and placed in wooden coffins without clothing, goods, or gifts (Kieffer-Olsen 1997). Against this background, Bornholm's early medieval cemeteries (ca 1000–1100 AD), including Ndr. Grødbygård, appear unusual. The material evidence of rituals and norms of practice required to complete a proper funeral might be a reflection of a lingering continuation of pre-Christian ideas about dying, death, and afterlife. Such a blend of Christian practices (the use of coffins, the orientation of the graves, the existence of separate female and male zones) with pre-Christian traditions (the deposition of tools, vessels with food, and perhaps commemorative feasts) may be due to the relatively recent arrival of Christianity on the island or a relatively weak impact of missionary efforts in this place (Naum 2007).

Material remains of ritualized practices at the Ndr. Grødbygård cemetery raise attention for yet another reason. Not only are the graves richly equipped by contemporary Scandinavian standards, but the sets of objects and the way they were treated and placed in some of the graves resemble the funerary customs in the eleventh century Western Slavic region in modern northeast Germany and Poland (Naum 2004, 2008, 2009). The most visible elements of foreign culture are the amulets and female jewelry. A number of burials located in the female zone had head ornaments of beads (made of silver and other materials). Their use as head ornaments is supported by the fact that they were found by the ears and temples of the interred or collected during the excavation of the crania. Similar beads in the form of a necklace were also found under the mandible in other graves.

The custom of wearing head decoration in the form of a headband or a scarf with attached rings or sewn-on beads is regarded as Slavic, and does not seem to have been practiced in the Viking Age/Medieval Scandinavia. Most of the silver beads found at Ndr. Grødbygård (interpreted as parts of the head ornaments or located in different parts of the body/grave) came from earrings or beaded necklaces produced by Slavic silversmiths.

Other pieces of jewelry that are connected with the Slavic practice of body decoration include temple rings (i.e., thin rings attached to a headband or scarf, found in two separate graves) and a tabular amulet, the so-called *kaptorga*. Besides female jewelry, knives in bronze-mounted sheaths and a particular way of depositing pottery, namely the custom of breaking a pot into sherds and placing a single sherd or a selection of pieces next to the body, seem closer to Slavic practices than Scandinavian ones (Naum 2008, pp. 190–196, 227–232). These objects and practices were observed in about 16% of Ndr. Grødbygård burials (Figure 6).

The possibility of Slavs buried at the Ndr. Grødbygård cemetery gains credence when considered in the context of other archeological sources from the island. In the eleventh century AD, there was a dramatic change in the technology and style of pottery production in Bornholm. The local hand-made, undecorated, and rather uniform pottery was replaced by ceramics made on a turning table, decorated with incised designs, and produced in a variety of new forms (Watt 1988, Nielsen 1998, Naum 2008, pp. 85–146, 2012). The new style of pottery, the so-called Baltic ware, was inspired by the late medieval Slavic ceramic production. Its swift adoption and similarities with Slavic pottery, as well as lack of evidence for experimentation with the new technology and style prior to its widespread production, suggests that it was made by the Slavic potters.

Migration is also possible in the light of contemporary political events around the Baltic Sea. From the early tenth century AD until the end of the twelfth century AD, the Slavic groups occupying the coastal zone of the Baltic Sea (the Obodriti, Veleti/Liutizi and Pomeranian tribes) were drawn into a struggle for independence and survival against their ambitious and expansive neighbors in the German and Polish kingdoms. Harsh economic and political conditions forced many of them into exile. Considering the trading activities that connected Bornholm with the southern coast of the Baltic it is possible that these previously established contact networks and routes were utilized by the refugees in their flight.

Figure 6. Some of the finds associated with Slavic workshops and funerary practices found in Ndr. Grødbygård graves: (A) remains of a tabular amulet (kaptorga) and a silver bead from grave 28; (B) Baltic ware pot and bronze knife sheath mounting from grave 496; (C) potsherd and fragment of a bead from grave 542; (D) knife sheath mounting from grave 243; (E) clover-shaped silver bead from grave 426; and (F) silver bead pendant and bead from the so-called basket shaped earring from grave 627.

Even though Slavic settlement on the island can be traced through the archeological finds usually associated with Slavic culture, the straightforward interpretation of these artifacts as tokens of Slavic migration to the island can be problematic. Taking into consideration the mobility and trading activities of the Bornholmers, their orientation towards the sea, and their exposure to foreign customs and material culture, one has to consider that some of these objects functioned simultaneously in cultural worlds of both the Slavs and the islanders.

Strontium isotope analysis

Correlation of material culture with the identity of its makers and tracing human movements unrecorded in historical sources are difficult problems in archeology. In the recent years, the application of bone chemistry analyses, especially isotopic studies, has provided a means for directly assessing the place of origin of human skeletal remains, and can be used to answer certain questions concerning migration in the past (e.g., Montgomery *et al.* 2003, Price and Gestsdottir 2006, Price *et al.* 2011, Montgomery 2010) The application of strontium isotope analysis to the human skeletal material from the cemetery at Ndr. Grødbygård offers a means to evaluate such questions.

Strontium isotope analysis provides a robust method for examining human mobility in the past, and in tracing the first generations of immigrants. The principle is straightforward. The strontium isotope ratio of $^{87}Sr/^{86}Sr$ varies among different kinds of rocks. Because ^{87}Sr forms through a radiogenic process from rubidium-87 over time, in general, older rocks with more rubidium have a higher $^{87}Sr/^{86}Sr$ ratio, while younger rocks with less rubidium are at the opposite end of the range with low ratios. Sediments reflect the ratio of their parent material.

Strontium moves into humans from rocks and sediment through the food chain (Sillen and Kavanagh 1982, Price 1989). Strontium substitutes for calcium in the formation of the human skeleton and is deposited in bone and tooth enamel. Tooth enamel forms during early childhood and remains unchanged through life and commonly after death. A number of studies have demonstrated the general robustness of enamel in a variety of burial contexts and in the survival of biogenic ratios over time (Budd *et al.* 2000, Lee-Thorp and Sponheimer 2003, Schoeninger *et al.* 2003). Values in human tooth enamel that differ from the place of burial usually indicate that the individual moved from one geological terrain to another during their lifetime. Analytical methods are described in detail in several publications (e.g., Sjögren *et al.* 2009, Frei and Frei 2011).

An essential question regarding strontium isotope analysis concerns the local strontium isotope signal for the larger region in which the cemetery is located. This baseline information on isotope values across an area needs to be obtained in order to make useful and reliable statements about the origin of the human remains under study (Price *et al.* 2002, Frei and Price 2012). There are two major sources of isotopes for human consumption: marine and terrestrial. Marine foods everywhere share the same isotopic value of 0.7092, which is also the value of seawater (e.g., Vezier 1989).

Terrestrial sources vary according to bedrock and surface sediments. Strontium moves from rocks and sediments into plants, animals, and human tissue through the food chain. Although local levels of elemental strontium in plant and animal tissue vary due to many factors (e.g., Burton and Wright 1995, Burton *et al.* 1999), the $^{87}Sr/^{86}Sr$ value is not changed (fractionated) by biological processes because of the very small relative mass differences of the strontium isotopes (Blum *et al.* 2000, Faure and Mensing 2004). The strontium isotope compositions of plant tissues and the bones and teeth of animals and humans thus match to those of the nutritional intake of the individuals, which in turn is *assumed* to reflect the strontium isotope composition of the local geology.

In actual fact, levels of strontium isotopes in human tissue may vary in local geology for various reasons (Price *et al.* 2002). It is necessary to measure *bioavailable* levels of $^{87}Sr/^{86}Sr$ to determine local strontium isotope ratios. In the following pages we first present a very brief summary of the geology and strontium isotope sources of the countries surrounding the western Baltic. We then turn to the geology of Bornholm as an introduction to sources of strontium isotopes on the island, followed by a report of baseline bioavailable ratios. We then report the isotopic results from Ndr. Grødbygård and their implications for assessing immigration in the early medieval period on the island.

Bioavailable strontium isotopic ratios

As part of this study, we have measured various materials from Bornholm and around the Baltic in order to establish the range of strontium isotope ratios on the island and in the possible homeland areas for migrants to Bornholm. Materials we have analyzed include surface water, modern owl pellets, modern snails, archeological fauna, and prehistoric human remains. This research is summarized briefly here and the results to date are presented to place Bornholm in the larger context of Baltic strontium isotope sources.

The baseline strontium mapping of the larger Baltic area is a long-term project that is still underway. Denmark is largely completed (Frei and Frei 2011, Frei and Price 2012); there is a good bit of unpublished data from northern Germany, there is a growing body of data from central and southern Sweden, and we have some samples measured from Poland and a few from Kaliningrad. The available information from these countries and the baseline data from Bornholm are discussed below.

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 isotopic 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 are 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 (geologically) 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, the glacial deposits are the source of strontium isotopes for plants, animals, and people. There is very little bedrock exposure anywhere in the country. Frei and Price (2012) present strontium isotope ratios from samples of modern mice, snails, and archeological 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 a 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 era, ca. 400 mya.

The oldest rocks in Sweden are Archean (> 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. The Swedish Geological Service has measured $^{87}Sr/^{86}Sr$ across the country and reports very high rock values for most of this region, generally greater than 0.722. 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 the 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.

The west coast of Sweden was an area of known medieval settlement. Isotopic studies there provide some information on the levels of $^{87}Sr/^{86}Sr$ in this region (Figure 7). As part of a study of inland Neolithic sites in this area, Sjögren *et al.* (2009) measured a few samples of human enamel from the sites in the coastal region. These samples exhibit substantial variation, although the sample numbers per site are too small to provide much information. Specifically, values generally range from 0.711 to 0.714 and probably reflect the local range in Bohuslän.

We also have some additional data from the southern and eastern parts of Sweden. From the east coast and Gotland we have ca. 140 samples, of which 8 are faunal. We have 10 or more samples from several sites in eastern Sweden, and the pattern of $^{87}Sr/^{86}Sr$ is similar at each site. There is a high proportion of what appear to be local values showing a continuous range and then a few significantly higher values that very likely represent individuals from inland areas or much older terrains. The site of Birka near modern Stockholm was an important Viking center and the gateway to the east. We have sampled 10 individuals from the cemetery at Birka. These values range from 0.7103 to 0.7335, with a mean of 0.7174 ± 0.0078. These ratios clearly represent a range of origins but may provide at least a rough estimate of values in this area. It is clear that the older rocks of the $^{87}Sr/^{86}Sr$ Fennoscandian Shield dominate most of Sweden and play a large role in higher values. Lower values

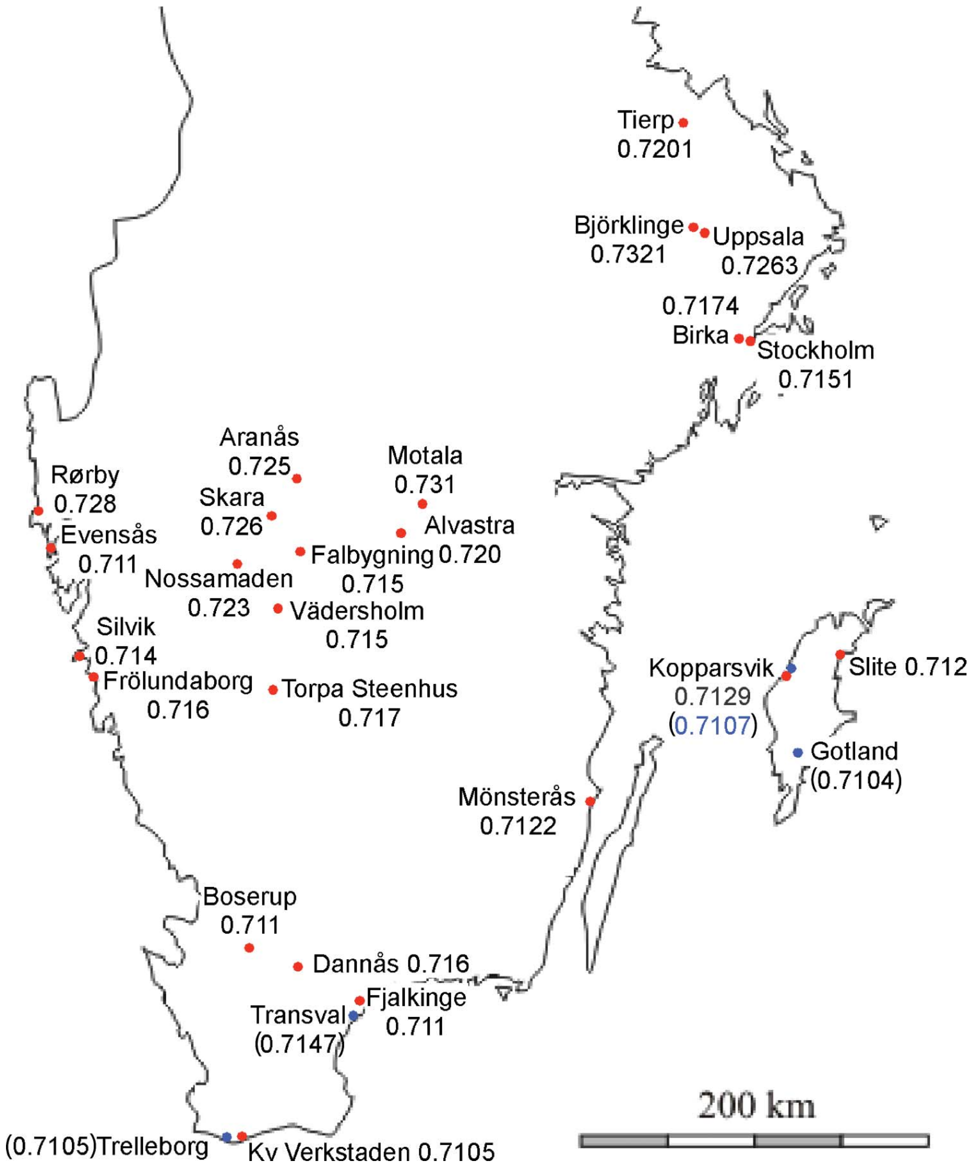

Figure 7. Averaged strontium isotope ratios from human and archeological faunal (in parentheses) samples from southern and central Sweden. Values are averaged.

around 0.710–0.711 are found largely in the southernmost part of the country in the province of Scania and on the island of Gotland in the Baltic. These data are summarized in Figure 7.

Northern Germany

There have been a significant number of strontium isotopic studies done in Germany to date, albeit the majority in the south of the country. There are some data, however, from the north. There are two major surface deposits in Northern Europe. The ground moraine and glacial deposits of the last glaciation covers the northernmost parts of Germany and almost all of southern Scandinavia. The coversand deposits of the North German Plain run east-west from the Netherlands across northern Germany and into Poland. The morainic landscape of southern Scandinavia is a mixture of rocks and sediments carried south by glacial advance and ground is into the surface of the region. The coversand region, stretching from the Netherlands across northern Germany to Poland, is dominated by aeolian sands consisting largely of reworked fluvial and glaciofluvial sediments. These coversands rest on the glaciogenic materials deposited in this region during the Late Glacial.

Gillmaier *et al.* (2009) report a series of strontium isotope samples from the North German Plain, primarily in the state of Schleswig-Holstein. The six samples are largely from archeological bone and antler and the $^{87}Sr/^{86}Sr$ values range between 0.7090 and 07096, similar to the values reported from the southern part of nearby Denmark. Strontium isotope studies of the Iron Age war sacrifices from the northern German bog of Thorsberg in the same region (Carnap-Bornheim *et al.* 2007) report similar values around 0.7090 for peat samples from the bog and the local archeological materials. De Jong *et al.* (2010) in a study of five human teeth from the Neolithic site of Eulau in the southern part of Saxony-Anhalt reported two sets of values, three teeth averaged around 0.7015 and two teeth averaged ca. 0.7133. These two distinct sets of values are likely to reflect the local landscape which is composed of glacial moraine lowlands and Paleozoic uplands in the south of northeastern Germany.

Our own studies have added more data to the strontium isotope information from Northern Europe. A number of reindeers from the site of Stellmoor near Hamburg had values ranging from 0.7092 to 0.7105. The site is located in a classic tunnel valley in the glacial landscape of northern Germany. We have also measured a number of samples of archeological fauna from the coastal site of Neustadt in Schleswig-Holstein, with results from 0.7090 to 0.7100. Data also come from the Bronze Age war sacrifices locale at Weltzin in the easternmost part of northern Germany, not far from the Polish border. At Weltzin, we see a wide range of values from 0.7080 to 0.7150 in archeological fauna and human teeth. Many of the individuals found here may well be non-locals given the context of the finds, but the three samples of local fauna (a roe deer, a black rat, and a snail) show a wide range of values, 0.7075, 0.7013, and 0.7110, respectively. The higher values seen in the rat and snail suggest that the glacial and coversand landscape in this region may have a significantly higher strontium isotope ratio than the North German Plain to the west.

In sum, much of the North German Plain, in the areas of coversand and glacial moraine has $^{87}Sr/^{86}Sr$ ratios very similar to Denmark, with values around 0.7090–0.7100. At the same time, as one moves south and east, the emerging uplands generally contain older rocks and higher strontium isotope ratios. It may also be the case that the glacial moraine and coversand in parts of the North German Plain across Poland are composed of source materials from older rocks exposed on the floor of the Baltic and transported by a glacial lobe to this region of Northern Europe.

Poland

The focus here is on northern Poland and those areas closest to Bornholm. The geology of Poland was shaped primarily by tectonic forces from the continental collision of Europe and Africa during the Cenozoic era, and by the Pleistocene glacial activity in northern Europe. Continental ice sheets moved across the northern half of the Polish landscape, leveling the terrain and leaving deep glacial deposits. The moraine landscape of northern Poland contains sediments largely of sand or loam, while the river valleys toward the south also contain loess.

There is some information available regarding strontium isotope ratios in Poland from other studies. Voerkelius *et al.* (2010) report $^{87}Sr/^{86}Sr$ for natural mineral waters, surface water, soil extracts, and wheat from various countries in Europe. Original data values and sample locations are not provided, but approximate ranges of strontium isotope ratios can be estimated from Figure 2. Soil extracts range from 0.7069 to 0.7123 with a mean value of 0.709. Surface water ratios exhibit a narrower range from 0.7078 to 0.7096, with a mean ca. 0.7085. Wheat ratios range from 0.7090 to 0.7106, with a mean of approximately 0.7100. Rossmann *et al.* (2000) report a ratio in Polish butter of 0.7088. Löfvendahl *et al.* (1990) report a value of 0.7095 for the waters of the Vistula and estimate a mean of 0.710 for the sedimentary basin of the southern Baltic Basin which includes much of the area of Poland.

To date, we have recorded only a small number of locations, shown on the map in Figure 8. Two values for a site in Figure 8 indicate the range of values in the samples from there. There is a substantial variation in $^{87}Sr/^{86}Sr$ in these samples, and we are uncertain whether the higher values in Northern Poland reflect non-local origin of our samples, taken primarily from rural medieval settlement sites (fauna) and cemeteries, or if these higher values, above 0.711, come from local sources in the terrain. In general, it appears that lower isotope ratios are more common in the north of Poland, increasing in value to the center and south of the country, where older rocks dominate a higher terrain.

Bornholm

In contrast to most of the sand or moraine regions around the coasts of the southern Baltic Sea, the island of Bornholm is made up of a number of rock formations ranging from Precambrian bedrock to Mesozoic sediments (Figure 9). Technically, the island is known as the Bornholm Block, a composite fault block. Bornholm is located within the Fennoscandian Border Zone, and the bedrock on the island is composed of a Precambrian crystalline basement of gneisses and granites outcropping to the north. A complex mosaic of fault blocks outlined by Lower Paleozoic platform sediments are found to the south, while Mesozoic sediments, largely of marine origin, occur mainly to the southwest. Upper Cretaceous deposits here consist of greensand and limestone formations made up of marine glauconitic sands, marls, clays and limestones, and conglomerates with numerous fossils.

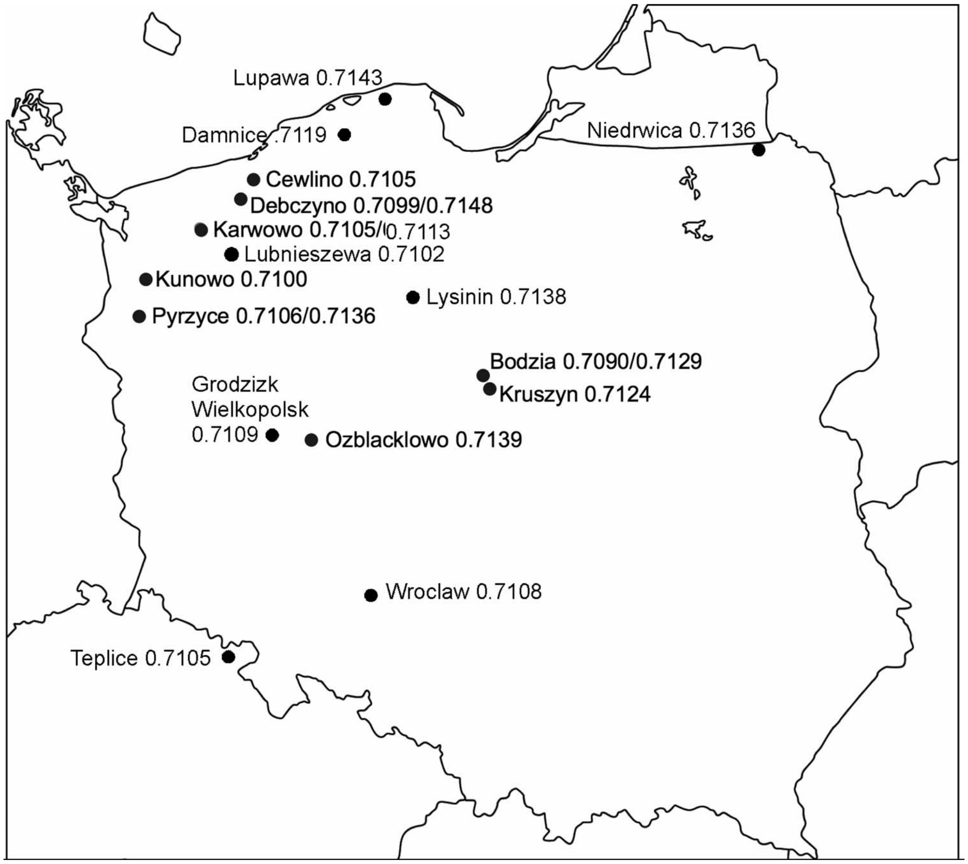

Figure 8. Baseline strontium isotope ratios from selected sites in northern and central Poland.

The bedrock geology of Bornholm is covered in many places with Quaternary deposits of till and meltwater sediments (Figure 10). The glaciers that covered Bornholm came from the northeast, and deposited till from the Baltic Sea floor on the western coast of the island (Lindstrom 1991). The till also forms moraine plains in the south as well as in some parts of the crystalline bedrock area in the north. Further inland and east of the island, the till is composed of older island sediments and bedrock (Møberg 1994). Late Glacial deposits on Bornholm include sands and gravels deposited by the Baltic Ice Lake. Littoral and eolian sediments, e.g., the dune sands in the southeast, are largely postglacial deposits (Fuchtbauer and Elrod 1971).

We have measured a number of samples of archeological fauna, modern snails, and surface water to record the bioavailable $^{87}Sr/^{86}Sr$ on Bornholm. The water data are taken from Frei and Frei (2011). We attempted to sample fauna from each of the major geological units on the island. The results appear in Table 1 and are shown graphically on the map of the island in Figure 8. The bedrock geology of the sample location, where known, is also included in the table. These values show a wide range, 0.7092–0.7231, reflecting the diverse geology of the island. Porcelænsgård is located in an area of kaolin which may explain the unusually high strontium isotope ratio for the Mesozoic deposits in that area of the island.

We have also measured a series of 15 snails from the site of Ndr. Grødbygård itself, and these values are shown in Figure 11. The mean value for these snails is 0.7133 ± 0.0020, with a range from 0.7093 to 0.7155. Ground moraine covers bedrock in the area immediately north of the site, but the transition to ^{87}Sr-rich Paleozoic bedrock lies only a few kilometers away. The bimodal distribution of $^{87}Sr/^{86}Sr$ for the snails appears to confirm this situation, with values ranging from 0.7095 to 0.7160, depending on the sources of the food that were consumed. Based on the bioavailable data from the snails at Ndr. Grødbygård, and with consideration of the baseline values from the rest of the island, we would suggest a range of 0.7095–0.7155 be used for the baseline values at the site. The upper value is a particularly cautious estimate for humans, as seafood consumption would increase the intake of the lower marine $^{87}Sr/^{86}Sr$ at 0.7092 and reduce the terrestrial strontium isotope ratios.

The diversity of strontium isotope ratios on Bornholm makes the definition of local and non-local individuals a difficult talk, and brings into question the meaning of

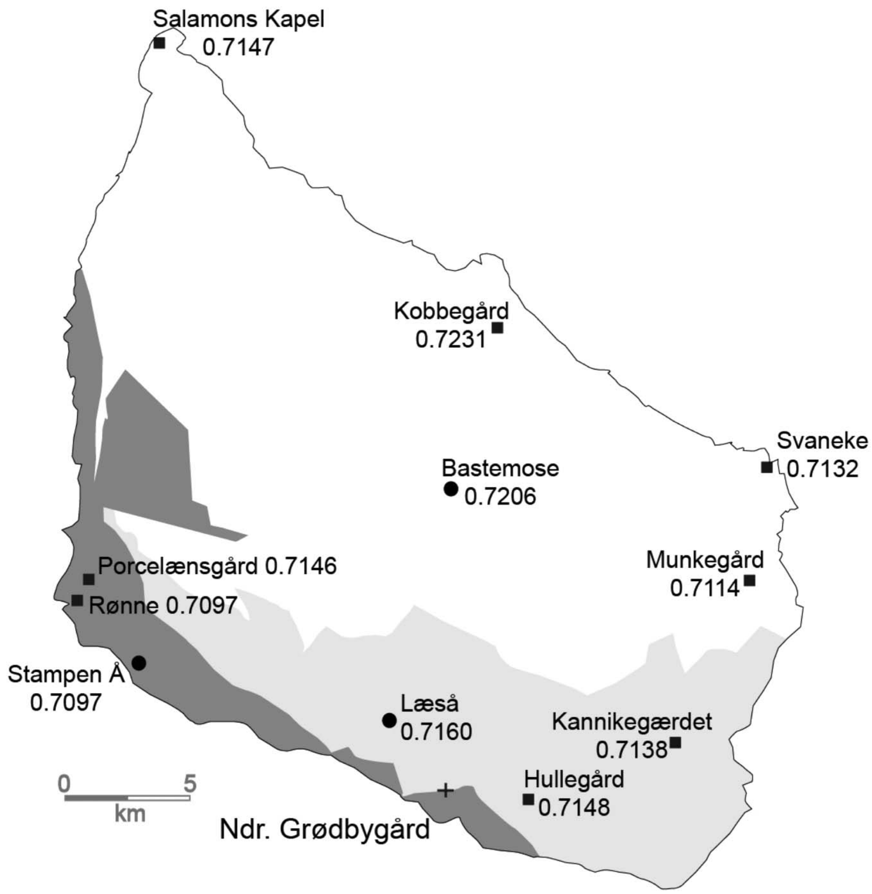

Figure 9. A simplified geological map of Bornholm, the location of Ndr. Grødbygård, and the sampling sites for bioavailable strontium isotope ratios. The white geological zone to the north is underlain by rocks of largely Precambrian age, the lighter grey area to the south consists of Paleozoic rock, heavily faulted, and the darker gray area along the west and south coast is composed of Mesozoic Age deposits, often of marine origin. Circles are water samples, squares are fauna.

local. In the case of the analysis of Ndr. Grødbygård local really has two meanings: 1. individuals from the area around the cemetery. This area could be defined by previous analysis of the cemetery (Nielsen 1998, pp. 12–17) that suggested that the cemetery may have been used by the inhabitants of 20–25 farms that could have been found within a ca. 5 km radius and individuals who are from the island of Bornholm. Non-locals could be from elsewhere on the island or from off the island. Because of the isotopic variation present in the samples from the cemetery itself, these distinctions are not immediately obvious and our discussion of the results must be taken as speculative rather than demonstrated.

Results

The skeletal remains in the Ndr. Grødbygård cemetery were for the most part very poorly preserved, in contrast to the teeth. Tooth enamel was, however, often preserved and was available for isotopic analysis. This in fact also allowed for an age evaluation of most of the individuals (by analyses of the dental development (subadults) and age-related abrasion (adults).

Some 41 samples were originally selected for this study based in part on the prior archeological analysis of burial practices at the cemetery, and constrained by the preservation of the dental material. Our sample included a substantial number of individuals that were buried with objects associated with the Slavic tradition, such as beads and fragments of earrings found in the cranial area, knives in mounted sheaths, and potsherds of Baltic ware (graves 272, 107, 428, 427, 518, 6, 294, 536, 459, 628, 281, 558, 382, 243, 496, 613, and 452).

Four additional samples for this study were selected based on possible unusual physical features observed during excavation. Burial 256 was reported to exhibit the only distinctively Slav morphology in the teeth. Burial 292 was an adult individual without tooth wear, in marked contrast to others in the cemetery. Burial 418 seemed to have rather massive muscle insertions at the base of the cranium, and

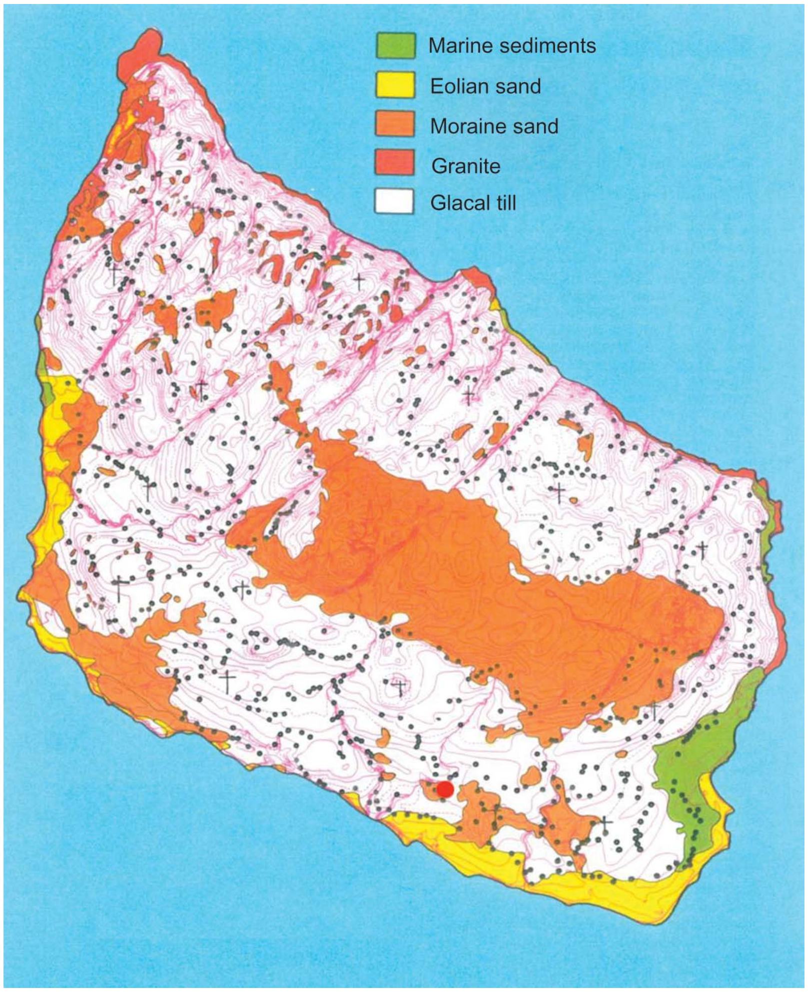

Figure 10. Soil map of Bornholm showing the distribution of more recent sediments on the island. The black dots mark the location of some of the 962 farms on Bornholm and the crosses indicate 15 rural churches (Messenburg 1972). The location of Ndr. Grødbygård is marked by a red dot.

Table 1. Samples of fauna and water for bioavailable strontium isotope ratios on the island of Bornholm.

Location	Material	Geology	$^{87}Sr/^{86}Sr$
Kobbegård	Arch. fauna	Granite/Gneiss	0.7231
Munkegård	Arch. fauna	Svaneke granite	0.7114
Kannikegærdet	Arch. fauna	Glauconitic sandstone	0.7139
Hullegård	Arch. fauna	Rastrirtes/Cryptograptus shale	0.7148
Porcelænsgård	Arch. fauna		0.7146
Svaneke	Modern snails	Svaneke granite	0.7131
Svaneke	Modern snails	Svaneke granite	0.7134
Rønne	Modern snails		0.7092
Rønne	Modern snails		0.7104
Stampen Å	Surface water		0.7097
Bastemose	Surface water		0.7206
Læså	Surface water		0.7160

such massive muscle attachments were also seen on Burial 438, along with apparently very broad cheekbones. Later physical anthropological examination of these individuals did not indicate that these features were significantly different. However, due to poor conservation, thus rendering more precise dental and physical anthropological analyses

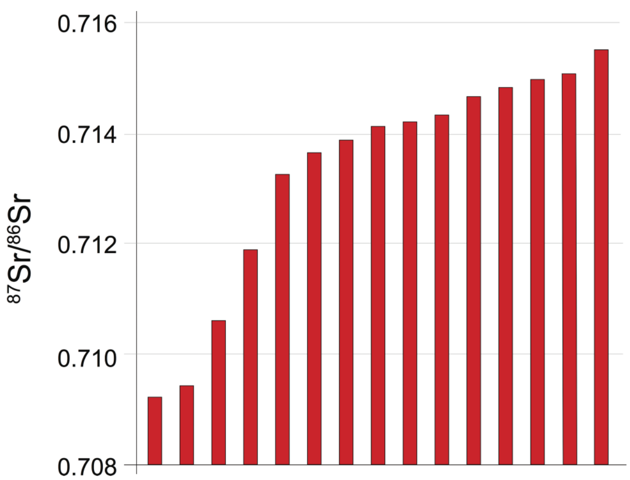

Figure 11. Histogram of $^{87}Sr/^{86}Sr$ values for 15 snail shells measured at Ndr. Grødbygård.

difficult, it was decided to sample these individuals anyway.

Furthermore, burial 250 was selected for sampling at a later point, because this individual displayed a probable sharp trauma to the occipital region, the only evidence of violence found in the cemetery. The blow could very well have been lethal, probably from a sword, but does not look like an attempt at decapitation.

The results of the analysis of 45 samples of enamel from the graves are provided in Table 2. The location of the graves that were sampled is shown in Fig. 2, and the graves with the highest and the lowest strontium isotope ratios are indicated on the plan. The $^{87}Sr/^{86}Sr$ values for both baseline and human enamel samples are shown in the graphic form in Figure 12. In this bar graph, values within the two groups of samples are rank ordered from lowest to highest. The baseline values include both fauna and surface water. The

Table 2. Burial and isotopic data from the Ndr. Grødbygård cemetery, Bornholm, Denmark.

Lab#	Burial#	BMR#	Sex	Age	$^{87}Sr/^{86}Sr$	$\delta^{13}C_{ap}$	$\delta^{18}O$
F5714	8	x264		A	0.71317	−13.71	−4.95
F6907	77			S	0.71024		
F5727	78A		M	sub	0.71077	−12.58	−6.31
F5713	107	x589	M	S	0.71268	−12.66	−4.66
F5717	196	x937		M	0.71716	−10.86	−5.16
F5720	199 o	x949		M	0.71510	−15.23	−5.39
F5721	199 y				0.71171	−11.81	−4.90
F5709	210	x951		A	0.71465	−14.31	−4.86
F5700	243	x1121	M	M	0.71780	−15.30	−5.58
F5710	249	x1138	M	M	0.71530	−12.81	−4.61
F5706	250		M	A	0.71421	−13.97	−4.36
F5705	251	x1147	M	M	0.71490	−14.41	−4.50
F5704	272	x1181	M	A	0.71260	−13.04	−3.64
F5730	280		M	A	0.71531	−13.19	−5.24
F5715	281	x1324	M	A	0.71524	−14.07	−4.80
F5731	294		M	A	0.71334	−9.38	−4.84
F5734	306		M	M	0.71644	−13.74	−5.30
F5728	307		M	A	0.71375	−14.00	−4.89
F5708	382	x1508	M	A	0.71599	−14.31	−4.63
F5733	427	X1687	F	A	0.71300	−13.44	−4.87
F5732	428	x1724	F	A	0.71298	−13.04	−4.96
F5725	429	x1749	F	A	0.71296	−14.64	−4.76
F5718	452	x1739		M	0.71484	−13.01	−4.60
F5707	459	x1780	F	A	0.71441	−14.42	−4.29
F5722	465	x1766	F	M	0.71166	−12.88	−6.41
F5723	496	x1898	F	A	0.71223	−14.79	−4.46
F5703	518	x1984		A	0.71315	−14.02	−5.29
F5711	527	x1983	F	M	0.71319	−14.65	−5.01
F5702	536	x2076	F	A	0.71383	−14.51	−5.53
F5738	554			sub	0.71680		
F5712	558	x2087	F	M	0.71547	−14.24	−5.04
F5735	559	x2088	F	A	0.71680	−13.86	−4.40
F5719	613	x2310	F	A	0.71483	−14.53	−4.07
F5724	617	x2334	F	A	0.71446	−12.57	−4.58
F5729	618	x2366	F	A	0.71394	−13.74	−4.38
F5726	619	x2346	F	A	0.71135	−13.54	−5.36
F5716	626	x2389	F	M	0.71146	−13.16	−5.62
F5701	628	x2407	F	M	0.71442	−14.22	−4.48

Note: M = male, F = female, A = adults, S = senilis, M = maturus. O = old, y = young.

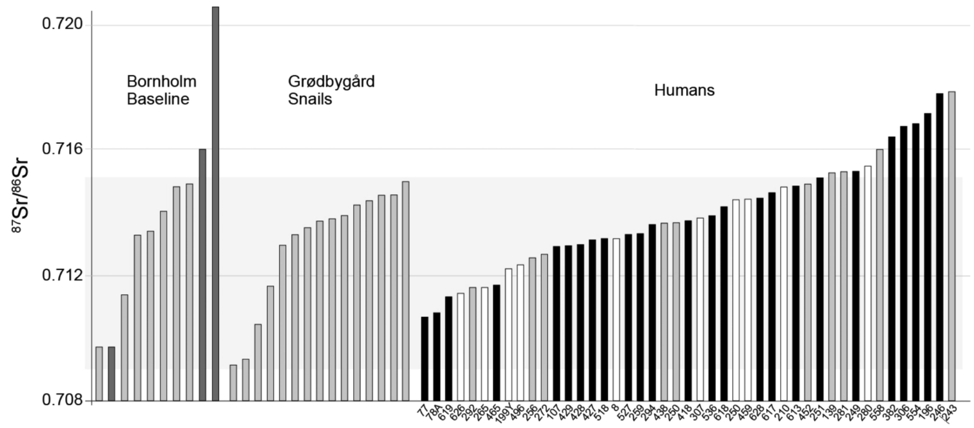

Figure 12. ^{87}Sr/^{86}Sr values for Bornholm baseline, fauna are light grey, water samples are dark grey. snails at Ndr. Grødbygård and Ndr. Grødbygård humans in rank order. White = female, grey = male, black = unknown. The large grey rectangle is an estimate of the local strontium isotope ratio available in the area around Ndr. Grødbygård.

range of values is very wide, 0.7092–0.7231, as noted above. The wide range of ^{87}Sr/^{86}Sr values on the island makes the identification of immigrants a difficult undertaking. The estimated local range for Ndr. Grødbygård suggested above, 0.7095–0.7155, is shown in the horizontal band on the graph.

There are several things to be noted from the graph. First, most of the human enamel values fall within the range of baseline bioavailable values from Ndr. Grødbygård. This means that many of the individuals in the cemetery may be local to the area of the cemetery, or from other parts of the island with similar isotopic values. Second, there is an interesting break in the curve of the human enamel values in the bar graph. The seven highest human values in the bar graph (Burials 382, 306, 554, 559, 196, 246, 243) show a slightly different angle of increase from the remainder. In addition, these individuals lie outside the baseline values for the site and outside all but the two highest water values from the island, suggesting that they are non-local and possibly not from Bornholm. These seven graves are found scattered through the cemetery, without obvious spatial relationships. If these individuals are non-local to Bornholm, the more likely homeland for these individuals would be to the north and west, where the ancient rocks of eastern Sweden have comparably high values. There is little evidence of values above 0.716 in northern Poland or northern Germany.

There are also five individuals very close to the upper boundary of the local ^{87}Sr/^{86}Sr range (Burials 199, 281, 249, 280, and 558) that may or may not belong to the local population. These are at the limits of 'locality' but lie on the same curve as the majority of the burials in our sample. For these burials, we hesitate to distinguish them and for the present will include them in the local group of burials.

It is also the case that there are no human values below 0.7108 in the cemetery, suggesting that few or none of the inhabitants are coming from the glacial and coversand areas of northern Germany, Denmark, or southwestern Sweden. The moraine/coversand area of northern Poland, on the other hand, does have some values in the range between 0.7095 and 0.7150, so that some of the individuals who appear to be local to Bornholm could also have originated in those parts of Poland.

It should be noted that two individuals (77 and 78a), an 11–12 year-old boy buried directly above an adult male, found in the isolated group with the stone-built grave to the west in the cemetery (Figures 2 and 5), had the two lowest ^{87}Sr/^{86}Sr values recorded in human enamel at Ndr. Grødbygård, although still within the local baseline. The isolated location of the burials, the construction of the graves, and the exceptionally low strontium isotope values suggest that these individuals were personages of some note. These stone-built chambers are unusual, as most of the other burials are in simple earthen flat graves. There is a possibility that these graves were associated with an original church at Ndr. Grødbygård, of which no trace remains today. Because these are the two lowest values we have recorded, there is also a possibility that these individuals may not originate from Bornholm.

There is one other intriguing pattern in the ^{87}Sr/^{86}Sr data from the cemetery. Three individuals buried very close to one another in a cluster of five graves (Burials 427, 428, 429—an adolescent ca. 14 years of age, and two women aged ca. 30–35 years, respectively) were sampled in our study and have remarkably similar isotope values (0.71300, 0.71298, and 0.71296 respectively). This similarity suggests a similar provenience and diet for these individuals, perhaps as members of the same household. Furthermore, the material culture recovered from these graves, suggests rather uniform ritual customs surrounding burial of these individuals. They were buried in coffins and given knives, strings of beads of silver, glass and sandstone, or amber. Two of them were clothed in a garment requiring a brooch and two of them were given a fragment of a coin. The spatial proximity of these internments, as well as the similarities in burial ritual and strontium values suggests close connections and the same origin for these individuals, perhaps as members of the same household.

None of the four individuals selected because of perceived unusual morphologic dental and skeletal traits (at excavation) showed non-local strontium levels, in line with later dental and physical anthropological analysis, which did not indicate anything unusual about these individuals. Burial 250, the one example with probable trauma to the head, showed a likewise local strontium level.

Oxygen isotopes in enamel apatite

The addition of oxygen isotopes in the provenience analysis of the inhabitants of the Grødbygård cemetery provides some further insight, but the absence of a narrow strontium isotope baseline on the island limits the resolution of our analysis.

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. 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 $(CO3)^{-2}$ or phosphate $(PO4)^{-3}$ ions of bioapatite. This value is designated as $\delta^{18}O$. In this study, we have measured carbonate as a component of tooth enamel.

Oxygen isotope ratios in the skeleton reflect those of body water (Luz *et al.* 1984, Luz and Kolodny 1985), which in turn predominantly reflects those in 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. Like strontium, oxygen is incorporated into dental enamel – both into carbonate and phosphate ions – during the early life of an individual where it remains unchanged throughout adulthood. Oxygen isotopes are also present in the bone apatite, and are exchanged throughout 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 isotopes that makes their application less straightforward.

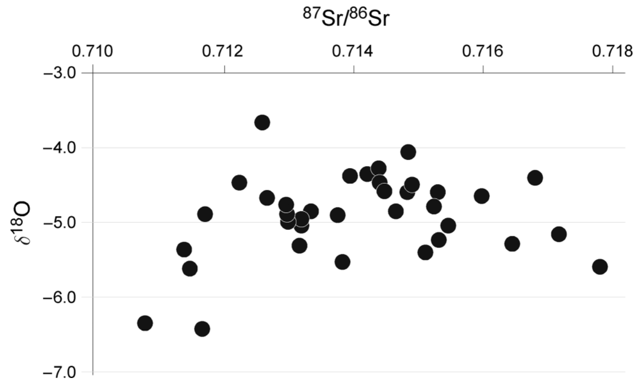

Figure 13. Strontium and oxygen isotope ratios in human tooth enamel from the cemetery at Ndr. Grødbygård.

Oxygen isotopes were measured in 36 samples of tooth enamel carbonate, and gave a mean of –4.9‰ and an SD of +0.56, and range from –3.6‰ to –6.4‰. These values are listed in Table 2 for the individual samples. These $\delta^{18}O$ values are plotted against $^{87}Sr/^{86}Sr$ in Figure 13. The spread of $\delta^{18}O$ values, with the exception of three individuals, varies between –4.0‰ and –6.0v in the data. $\delta^{18}O$ values in a population generally vary between ±1.0, so this range seems to be reasonable as a 'local' value for Bornholm.

The three exceptions are 1. The individual with the lowest $^{87}Sr/^{86}Sr$ value has a $\delta^{18}O$ of –6.3‰. The combination of the two end-range values likely points to this individual (burial 78a) as unusual and non-local to Bornholm. This is the same individual reported earlier in the strontium isotope analysis. 2. There is another individual (465, an approximately 50-year-old female), with a very negative $\delta^{18}O$ (–6.4) and $^{87}Sr/^{86}Sr$ value (0.7117) that stands out in the graph. 3. Finally, there is an individual (272; a young male) with the most positive $\delta^{18}O$ value (–3.6‰) and a $^{87}Sr/^{86}Sr$ value of 0.7126 who appears different from the majority of the sample. Again, it should be noted that oxygen provides a rather weak measure of geographic variation and these results must be viewed with caution.

From an archeological point of view, these last two graves (465 and 272) are not distinctive. Both were simple burials in coffins without any diagnostic grave goods. The only artifact associated with burial 465 was a potsherd of contemporary Baltic ware deposited in the fill of the grave. In grave 272, probably of an adult male, a single potsherd of Baltic ware was found under his knee. Between his knees a few animal teeth were found in a dark, fatty clump.

Carbon isotopes in bone collagen

Carbon isotope ratios were measured for five bone collagen samples from the cemetery at Grødbygaard. The results are presented in Table 3. These data provide an estimate of the contribution of marine foods to the diet, averaging 20% for the five samples with relatively little

Table 3. $\delta^{13}C$ values from five burials at Ndr. Grødbygård.

Lab#	Burial	Age	Sex	$\delta^{13}C$	% Marine food
K-6865	11	40	F?	−18.5	25
K-6866	379	40	M	−19.0	20
K-6867	438	40	F?	−19.0	20
K-6868	476	28	M	−19.3	17
K-6869	538	40	F?	−19.2	18

variation. The intake of seafood will affect the strontium isotopic composition of the individual, depending on the amount consumed. The marine foods will shift the strontium isotopic values in human enamel towards the $^{87}Sr/^{86}Sr$ value of seawater 0.7092. In the case of Bornholm, this will mean that the terrestrial bioavailable values in enamel are reduced toward the value of seawater, in proportion to the marine foods in the diet.

Carbon isotopes in enamel apatite

The measurement of carbon isotope ratios in bone collagen is well-known in the study of marine resources or C_4 plants in human diets. Carbon is also is present in the mineral or apatite portion of bone and tooth enamel and also contains information on diet (Ambrose and Norr 1993, Ambrose *et al.* 1997). $\delta^{13}C$ values in dental enamel reflect the diet of early childhood and may inform on movement if diets changed between place of origin and place of burial.

Carbon isotopes were measured in 36 samples of tooth enamel (Table 2) and yielded a mean value of –13.57‰ with an SD. of 1.18. All but three of the values range from –13.0‰ to 15.3‰. The three values of –11.8‰ (Burial 199, ca. 50 year-old), –10.9‰ (196, ca. 45 year-old individual), and –9.4‰ (294, ca. 40 year-old male) distinguish individuals with a significantly higher marine component in their diets. Burials 199 and 196 are adjacent and overlapping in the southern part of the cemetery, again suggesting potential kin relations among the inhabitants. The $^{87}Sr/^{86}Sr$ values are not distinct. None of these three individuals were measured for $\delta^{13}C$ in bone collagen.

Conclusions

Bornholm is an unusual place in the Baltic, significantly different from the countries that surround it in terms of its geology. Bornholm is a mosaic of rock types of different ages and composition. In terms of strontium isotope ratios, there is a wide range of values (ca. 0.7095–0.7160) present on this small island that contrasts greatly with the generally homogenous areas that surround the southern Baltic Sea. Most of the southwestern Sweden, Denmark, northern Germany, and parts of northern Poland are composed of relatively recent sediments from the last glacial and early Holocene. These moraine and coversand materials generally have $^{87}Sr/^{86}Sr$ values between 0.709 and 0.7105, values lower than most of those found on Bornholm. Higher $^{87}Sr/^{86}Sr$ values are found in many parts of Sweden in association with the Fennoscandian shield of very old rock. There, with exceptions, values generally range above 0.712. The easternmost part of northern Germany and northern Poland exhibit a range of values from ca. 0.709 to ca. 0.715 that may represent two distinct sources of strontium isotopes in the region, perhaps a result of deposits from different lobes of glacial ice.

Given this broad-ranging strontium isotope ratio context, the analysis of human burials from the eleventh century cemetery of Ndr. Grødbygård for information on place of origin becomes a difficult assignment. The majority of $^{87}Sr/^{86}Sr$ values from 45 samples of human dental enamel fall within the range of baseline bioavailable samples we have measured from the different geological provinces on the island.

The wide spectrum of isotope ratios recorded of those buried at Ndr. Grødbygård may be reflective of internal mobility among the islanders. The eleventh and twelfth centuries seem to be a transformative period involving the reorganization of existing settlement, the establishment of new farms (so-called Østersø-settlements), and the foundation of royal farms (Nielsen 1994, Naum 2008, pp. 55–56). These changes were likely responsible for some resettlement on the island. Other factors at play in the wide range of isotope values may also be the movement at marriage, and perhaps even the sharing or exchanging of food across the island.

At the same time, we can identify a number of individuals who do not appear to fit within the population at Ndr. Grødbygård. The seven highest $^{87}Sr/^{86}Sr$ values (Burials 382, 306, 554, 559, 196, 246, 243) may indicate a small group of burials that are different from the others in the cemetery. As noted, there is a reasonable probability that these individuals are not from Bornholm and, given the high isotope ratios exhibited, may be from the north and west of the island. Individuals from the Slavic region of eastern Germany and Poland could not be distinguished isotopically from persons born on Bornholm because of the overlap in isotope values between Bornholm and these two regions. There may well be individuals buried at Ndr.

Grødbygård from these areas that we simply cannot recognize.

The presence of Slavic objects in the burials of individuals whose isotope ratios indicate that they were born on the island merits attention. The inclusion of knives in characteristic knife sheaths (Burials 281, 243, 382, 452, and 613), potsherds (Burials 452 and 558), and beads from earrings found in the necks and head area of the deceased (Burials 459, 558, 559, and 628) might be a testimony of a persistence of cultural practices and ideas about proper burial among the second and following generations of Slavic immigrants. Being born on the island and consuming foods from the same sources as the rest of Bornholm's population would make their isotopic values indistinguishable from other individuals raised in the vicinity of Grødbygård or elsewhere on Bornholm. Such conservatism and preservation of traditions is a frequently noted aspect of pre-modern and modern diaspora (e.g., Cohen 1997, Safran 2005, Androshchuk 2008, Naum 2012).

However, one cannot exclude another scenario. Perhaps objects, such as mounted knife sheath, silver string, and earring beads lost their cultural associations becoming elements of material culture on Bornholm. Considering close contacts between southern Scandinavia and Slavic areas reflected in archeological material and historical sources, the possibility of including these artifacts into new fashions has to be taken into account.

Three individuals with very similar $^{87}Sr/^{86}Sr$ values (Burials 427, 428, 429) were buried in a rather special context of five isolated graves in the western part of the cemetery that may also reflect their distinctiveness. The oxygen isotopes were not particularly helpful in our study but do suggest three individuals that may also be of interest, one of whom is Burial 78a, a 11–12-year-old child, also identified in the strontium isotope analysis. This person may be of non-local origin and is buried with an adult male with a similarly low $^{87}Sr/^{86}Sr$ value. The fact that this individual is a child suggests movement with other family members, perhaps the other individuals buried in this isolated plot at the cemetery.

In sum, isotopic studies of human provenience depend on patterned variation in the sources of the isotopes in order to effectively discriminate between local and non-local individuals. On the Danish island of Bornholm, a mosaic of geological formations provides a range of isotopic values that can be matched in many of the neighboring areas of the island. We can identify a few probable migrants to the island, and we are able to suggest related individuals or family members on the basis of very similar isotope values. In order to proceed further, it will be necessary to use other methods such as ancient DNA and perhaps lead isotopes to better determine the place of origin of these early medieval inhabitants of the island.

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