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RESEARCH ARTICLE

Galgedil: isotopic studies of a Viking cemetery on the Danish island of Funen, AD 800–1050

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Galgedil is a Viking Age cemetery located in the northern part of the Danish island of Funen. Excavations at the site revealed 54 graves containing 59 inhumations and 2 cremation burials. Previous study of the remains to date has included light isotopes of carbon and nitrogen in collagen (10 samples) and the radiocarbon determination of the age of 8 samples. In addition, aDNA was investigated in 10 samples from the cemetery. Here we report the analysis of strontium isotopes in human tooth enamel as a signal of place of birth. Some 36 samples have been measured and non-local outliers identified. Baseline levels of strontium isotope ratios in Denmark are discussed and documented. Our study also includes an in-depth consideration of the bioarcheology of the skeletal remains in terms of demography, paleopathology, and taphonomy. The burials are evaluated in light of the available archeological, chronological, anthropological, and isotope information available.

Keywords: bioarcheology; Denmark; strontium isotopes; mobility; archeology; prehistory; Vikings

Introduction

In the last 25 years, the chemistry of human bone, both at the molecular and atomic level, has become an important means for studying past human behavior and activity. Studies of ancient DNA, for example, provide important information on the genetic ancestry and kin relationships of past humans. The isotopic chemistry of skeletal remains is employed for the study of past diet and mobility. The use of light isotopes of carbon and nitrogen provides information on paleodiet, while isotopes of strontium, oxygen, and sometimes lead are used to study residence changes in the past. These methods provide a means to examine both the individual and the group in terms of prehistoric behavior and kinship and have the potential to open new windows into the study of the human past.

The study reported here will focus on the investigation of human movement in the past at the molecular and atomic level. We examine a skeletal population from the Viking Age cemetery of Galgedil in Denmark using various indicators. A thorough description of the cemetery and the graves is provided for the context of the skeletal remains and the cultural materials associated with them. The biological anthropology of the skeletons is presented with details of age, sex, stature, and pathology to define the biological characteristics of these individuals. A previously published aDNA study of the same skeletal material is briefly summarized to include those results (Melchior *et al*. 2008a, 2008b).

Strontium isotopes are used to examine the place of origin of the burials from Galgedil. Discussion of the characterization of the strontium isotope baseline in the local area is an important component in order to be able to distinguish local and non-local individuals. A study of carbon and nitrogen isotopic of the bone and dentin collagen was conducted some years ago (Kanstrup 2006). These data are briefly summarized and offer some information on the diet of the cemetery inhabitants. Carbon and oxygen isotopes in dental enamel provide dietary and locational information, respectively, from the early childhood of these individuals. Our summary integrates the results from the various molecular and chemical investigations in the context of the Viking cemetery. In the end, we learn more about the lives of these individuals who lived a millennium ago in northern Europe.

The Viking cemetery at Galgedil

A cemetery with 54 graves from the Viking age was excavated in 1999–2005 near Galgedil (Figure 1) in the northern part of the Danish island of Funen.[1] The total number of interred individuals was 61 as some of the graves contained more than one burial. Fifty-four of the graves had inhumations and there were two cremations. Originally more graves had been present, but sand quarrying in the 18th and 19th centuries destroyed an unknown number. Five of the excavated graves had

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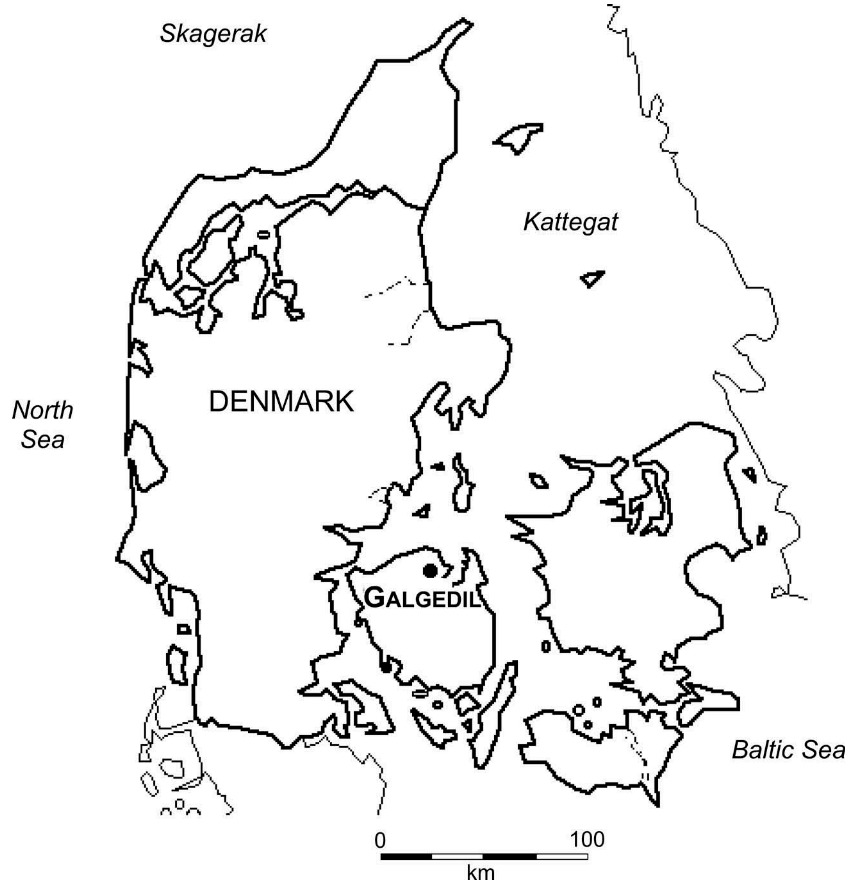

Figure 1. The location of the Galgedil cemetery on the island of Funen, Denmark.

been badly disturbed by the earlier sand quarrying. Preservation of the skeletal material in the intact graves was generally very good. As part of the excavation recording procedures, the graves and other features at the site were registered and numbered sequentially from A to BGE (Table 1).

The interments are generally described as pagan, or pre-Christian, because of the irregular orientation and the contents of the graves. The cemetery can be divided into two main phases, groups can be observed in the distribution of the graves, and a change in burial rites occurs during the lifespan of the cemetery. Artifacts document contact to a wider world, but the archeological finds give few clues regarding the mobility of the inhabitants of the burial ground.

The cemetery is situated on the top and down the southern and western slope of a small hill in a rolling, moraine landscape 5 km from the former seacoast (Crumlin-Pedersen *et al*. 1996). The distribution of the graves is, unlike a Christian cemetery, more or less random, although some groups and individual burials apart from the main group(s) can be observed (Figure 2). The graves have an irregular alignment. Some are orientated east-west, some north-south, and yet others in various directions. It is likely that the location of the grave was originally marked on the ground surface. Only in one case was a grave dug into an older one. In two cases, large stones were found on top of graves. Wooden grave markers may have been used as well, but they have long since disappeared.

Dating

There are eight ^{14}C dates available from Galgedil (Table 1), seven on human bone and one was made on charcoal from a cremation, with four dates from each of the two phases.[2] The range in the eight dates is between AD 770 and 1210. The majority of the dates fall between approximately AD 880 and 1060, with three slightly later measurements.

Fifteen of the 54 graves have been dated by association with the grave goods.[3] Five of the graves dated by association belong generally to the period from AD 800 to 1050, and 10 of these graves could be dated more specifically to shorter intervals within that time frame. Nineteen of the graves contained no grave goods and 16 held only an iron knife or a knife and one other artifact and could not be dated more specifically than Iron Age/Viking Age.

Table 1. Radiocarbon dates from the Galgedil cemetery.

Grave - sample	AAR-number	^{14}C Age (BP)	Reservoir corrected ^{14}C age (BP)	Calibrated age (1 and 2 sigma ranges)	$\delta^{13}C$ (°/$_{00}$)
KO - bone	AAR-11099	1214 ± 37	1110 ± 37 (Res. age: 0.26 x 400 years)	68.2% probability 890AD (68.2%) 980AD 95.4% probability 820AD (1.6%) 850AD 860AD (93.8%) 1020AD (intCal04)	−18.38
SB - bone	AAR-11100	1170 ± 34	1092 ± 34 (Res. age: 0.20 x 400 years)	68.2% probability 895AD (24.2%) 925AD 9400AD (44.0%) 990AD 95.4% probability 880AD (93.8%) 1020AD (intCal04)	−19.34
UD - bone	AAR-11101	1207 ± 37	1135 ± 37 (Res. age: 0.18 x 400 years)	68.2% probability 875AD (68.2%) 980AD 95.4% probability 770AD (93.8%) 990AD (intCal04)	−19.35
AKJ - bone	AAR-10569	1061 ± 35	988 ± 35 (Res. age: 0.18 x 400 years)	68.2% probability 990AD (38.0%) 1050AD 1080AD (30.2%) 1150AD 95.4% probability 980AD (95.4%) 1160AD (intCal04)	−19.44
AXE - bone	AAR-10568	995 ± 36	909 ± 36 (Res. age: 0.22 x 400 years)	68.2% probability 1040AD (68.2%) 1170AD 95.4% probability 1030AD (95.4%) 1210AD (intCal04)	−19.17
AYR - charcoal (Fagus)	AAR-10760	1101 ± 33		68.2% probability 895AD (25.9%) 925AD 935AD (42.3%) 985AD 95.4% probability 880AD (95.4%) 1020 AD (intCal04)	−24.26
BEW - bone	AAR-10570	993 ± 33	967 ± 33 (Res. age: 0.08 x 400 years)	68.2% probability 1020AD (25.8%) 1050AD 1080AD (42.4%) 1160AD 95.4% probability 1010AD (95.4%) 1160AD (intCal04)	−20.33
BFQ - bone	AAR-10571	1057 ± 30	985 ± 30 (Res. age: 0.18 x 400 years)	68.2% probability 1010AD (38.5%) 1050AD 1090AD (29.7%) 1150AD 95.4% probability 980AD (51.0%) 1060AD 1070AD (44.4%) 1160AD (intCal04)	−19.48

Notes: Bone samples are human. The wood comes from a cremation grave.

There are settlements from the Neolithic through the Older Iron Age in the same location at Galgedil, and this settlement waste in the graves in some cases confuses the dating of the contents. The overall characteristics of the graves and the cemetery and the grave goods, along with the radiocarbon dates, however, confirm the general Viking Age attribution, probably in use from around AD 800 to 1050.

Distribution and contents of the graves

Two phases can be observed in the horizontal stratigraphy of the graveyard (Figure 2); Phase 1 with 39 graves and Phase 2 with 15 graves. The dates from both artifact association in the graves and from radiocarbon provide chronological information on 22 of the 54 graves. Eighteen of the 39 graves were dated from Phase 1 and four of the 15 graves from Phase 2.

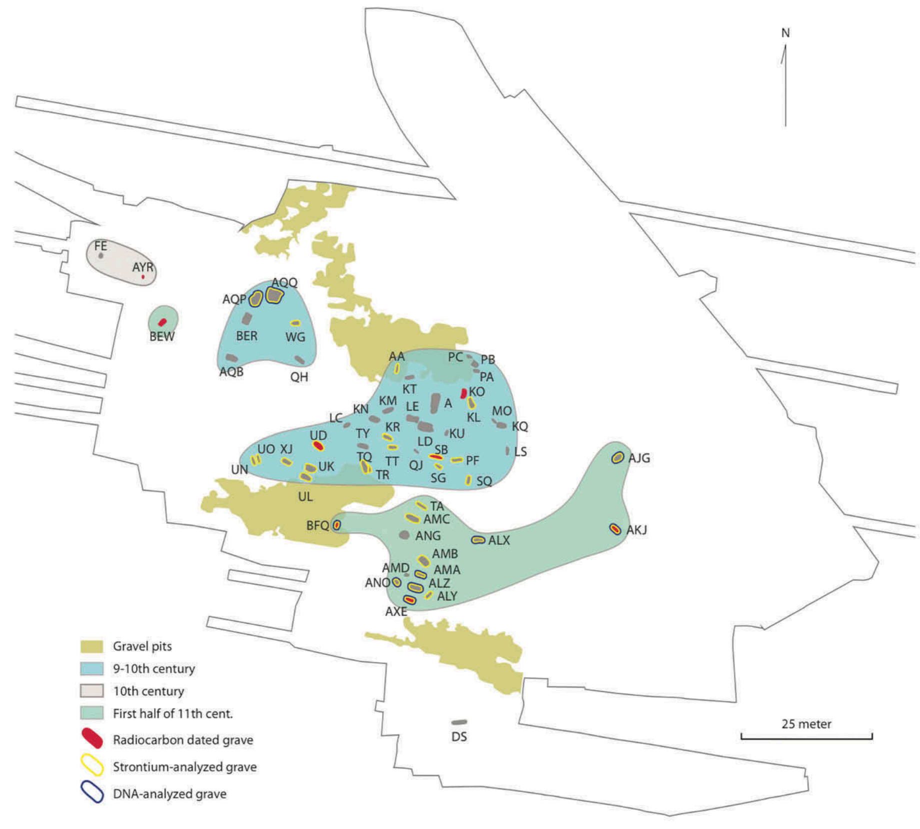

Figure 2. The cemetery at Galgedil with graves, various samples, and periods of use. Structures from Neolithic to the Older Iron Age settlements are not shown.

During Phase 1, in the 9th and 10th century, the first burials took place on the top of the hill and slightly down the southern slope. Thirty of the 39 graves are placed more or less together in one group with no clear subdivision. Very early in Phase 1, a single grave (DS) was placed in isolation at the bottom of the slope as the southernmost burial in the cemetery. Slightly later, but still in the first phase of the cemetery, a minor group of six graves were placed on top of the western part of the hill. Four of these graves (AQB, AQP, AQQ, BER) appear unusual, with wooden coffins, extraordinary artifacts, and deeper graves then other burials in the cemetery. On basis of the artifacts, for example, a trefoil brooch and belt garnish ornamented in Borre style probably inspired by the acanthus plant, these graves are dated between AD 850 and 950. Further west of this group, away from the inhumation graves, the two cremations (designated as FE and AYR) were found, the northwestern-most graves in the cemetery. On the basis of a single ^{14}C measurement, at least one of them (AYR) is from the 10th century.

The graves of Phase 2 were placed south of the main group of Phase 1 graves (Figure 2). This second phase of the cemetery presumably begins some time near the end of the 10th century. The youngest graves in the cemetery are from the first half of the 11th century. Most of the graves in Phase 2 cannot be accurately dated. Only one grave is dated by artifact association to the late Viking Age. However, ^{14}C dates place four of these graves (AKJ, AXE, BEW, BFQ) in the early 11th or early 12th century. According to the archeological context, a dating to the early 11th century seems most probable. Statistical probabilities for the dates indicate a tendency for the older date as well. Two graves (AJG, AKJ) from Phase 2, to the east, were placed separately from the other graves. An unusual isolated grave (BEW) to the northwest belongs to Phase 2 as well, based on a ^{14}C date, but close to the previously mentioned six graves and the two cremation graves from Phase 1. BEW contained only the lower half of an individual, from the hips to the feet with a knife and a whetstone. Two huge stones were placed on top of the grave as if to insure that the person would not rise up.

In general, the cemetery seems to have expanded from north to south in both Phase 1 and 2, with a few isolated graves placed away from the main group. Specifically, the area to the northwest was occasionally used throughout the life of the cemetery. For the most part, the graves were simple pits with no indications of a coffin (Figure 3). Some of the graves were so narrow that there would

Figure 3. Grave UO at Galgedil.

seem to have been no room. Only the four graves from Phase 1 (AQB, AQP, AQQ, BER) had coffins, as evidenced by the iron nails, rivets, and brackets that survived. In the main group of Phase 1 burials, one undated grave (LD) containing two individuals was of a size that might indicate a chamber grave.

The bodies were placed either on their back or side with flexed legs (a sleeping position) with their heads oriented in various directions. This lack of patterning reflects the general randomness of grave placement noted earlier. Of the 52 graves where the position of the dead could be determined, 40 individuals were placed on their back and twelve individuals in sleeping position. The latter position was apparently reserved for women and children. Out of these twelve graves, six, or perhaps seven, contained women and two out of three children were buried in sleeping position. Gender could not be determined for the three remaining individuals in sleeping position. It is tempting to suggest that they were women as well, give the ubiquity of this practice. Excavated Viking Age cemeteries on the island of Langeland, southeast of Funen, show a similar pattern (Skaarup 1976, Grøn *et al*. 1994).

While majority of the graves contain simple inhumations, there are two cremations and seven double graves. The double graves contain a mix of individuals. There are two double graves with an adult and an infant. There are five double graves with a male, two with a female, one with a male, and two indeterminate. There are also two pairs of closely adjacent graves with a male and a female that may represent the burials of couples. The double graves with two males may well represent a situation of master and slave, evidenced by the wealth differences, the location in the graves, and a contrast in the diets of the individuals. The diet information is discussed in more detail in the section on carbon isotope ratios at Galgedil.

The double graves all belong to Phase 1. Two examples (WG, XJ) involved adults with infants. The two adults were a 25-year-old woman and a 50 year-old whose gender could not be determined. The young woman may have died in childbirth, as the baby was a newborn. There was at least one man in each of the five remaining double graves (KL, LD, TR, UD, AQQ). In two cases, a man was buried together with a woman, in another case with a man, and in two cases it was not possible to determine the gender. Two bodies were placed next to each other at different levels in one grave, while the individuals in the other graves were buried one on top of the other.

Three of the double graves are located on a northwest-southeast line roughly in the middle of the main group (KL, LD, TR). The last two double graves (UD, XJ) are located in a group of six easternmost graves within this main group. The other four graves in this group are in two pairs placed exactly side-by-side only 40 cm apart and are thought to be contemporary (UK-UL, UN-UO). In both cases, the buried individuals are male and female. They might be interpreted as couples. Thus, these graves might be seen as a variation of double graves. From this perspective, the eastern group of graves consists entirely of double graves.

Double graves have often been interpreted as master and slave (e.g. Grøn *et al*. 1994). It seems reasonable to assume that this was sometimes the case at Galgedil. In one of the double graves (AQQ), a man more than 45 years of age was buried in a wooden coffin, maybe an old wagon bed. Most of the graves were shallow, but in this case, the coffin was placed about 1.2 m beneath the surface. A 25–30-year-old man was buried 25 cm above this level, parallel to the coffin, possibly on a wooden stretcher. The older man – presumably the master – had two knives, a whetstone and a belt with buckle and bracket with ornamentation inspired by Carolingian *archenthus*. The younger male – the slave – had only a knife. In this case, there appears to be a marked social difference between the two individuals. In the other examples, the difference between the two buried individuals is not so obvious and grave goods are not always present. Master and slave are difficult to identify. None of the potential slaves show evidence of cause of death. Analysis of carbon and nitrogen isotopes may provide a clue as there are striking differences in the diets of the two individuals in the same grave in several cases (discussed later).

As noted, the cemetery reveals a society with social classes. This is most obvious in Phase 1. Over time there was an overall reduction in the number of artifacts in the graves, and as the graves became more uniform with fewer artifacts, social differences are harder to see in the archeological record. If one disregards graves with only knives, 20 graves contain other artifacts. Several are related to dress and clothing, including belt buckles (six graves), belt brackets (two graves), oval brooches (two graves), trefoil brooches (two graves), and a ringed-pin. Other kinds of personal items are beads of glass, amber, and an unusual kind of rock crystal (seven graves), one Thor's hammer, and one comb. The rest of artifacts include one axe, seven whetstones, two keys, and one awl. A few iron artifacts could not be identified.

It is difficult to know what artifacts reflected social prestige, but some of the graves with several artifacts are clearly distinct. Coffins, which are rare, might also indicate a certain social status. There is an even distribution of males and females among the wealthier burials; with one or two possible exceptions all are adults.

Sacrificed animals are another category of grave offering. As the cemetery is located in an older settlement area, it was difficult to distinguish between grave deposits and settlement waste in the grave fills. In nine, perhaps twelve, of the inhumation graves (AA, KO, KR, LS, SB, TA?, TT, UD2, UL, UO, XJ?, AQP?), animals were intentionally included. It is always only a part of the animal, which was found in the grave lying next to the feet (4 graves), the thighs (2 graves), the torso (3 graves), at the stomach (1 grave) or by the face (1 grave). The identified animals are ox, sheep/goat, pig, horse and red deer.

With one possible exception (TA), all of these graves belong to Phase 1. Where gender is known, it is predominately male. In two cases with females (XJ, AQP), the interpretation of animal offerings is uncertain. Only in one case (UD) was an animal sacrifice definitely placed with a woman. She was in a double grave with a male. Perhaps both she and the animal should be seen as a sacrifice.

None of the artifacts help identify migrants to the area. The artifacts are of general well-known types in the Viking Age of South Scandinavia. The ornamentation on oval brooches, trefoil brooches, belt buckles and brackets are presumably all of local or regional origin. A generic connection to the southwest from Western Europe into Scandinavia can be seen in the two trefoil brooches. These Carolingian sword strap-tags were transformed in Scandinavia into female jewellery (Skibsted Klæsøe 1999). In a couple of cases, inspiration from Carolingian *archenthus* ornamentation can also be seen. The only artifacts definitely traded into the area were seven whetstones of slate from Norway and one bead of rock crystal, possibly from the Orient or Byzantium. Only one of the whetstones is from a grave (TA) with an individual with a high strontium isotope value, identified as non-local in the strontium isotope analysis described later. The whetstones are a common item of trade and do not provide indications of human movement. The burial with the crystal bead (XJ) was one of the richest in the cemetery, and this individual was also identified as non-local in the strontium isotope study.

All the graves in the cemetery are likely pagan. The graves and the individuals within them have random orientations, and one of the youngest graves (BFQ) from the first half of the 11th century contains a Thor's hammer, recognized as a pagan symbol. Although there are fewer artifacts and perhaps only one animal sacrifice in Phase 2, there are no definite indications of the arrival of Christianity.

From a general Danish and regional perspective, Galgedil seems to be a rather late pagan cemetery. A letter from the German emperor in AD 988 describes a bishop in Odense, 15 km south of Galgedil (Madsen 1988). In 2006, another Viking Age cemetery with 50 graves from the 10th century was excavated at Kildehuse south of Odense, 19 km from Galgedil (Runge *et al*. 2010). The orientation of the graves and the limited grave goods in this cemetery argue that it was early Christian. It appears that the conversion to Christianity in Denmark was locally variable.

No nearby Viking Age settlement is known at Galgedil. With a uselife for the cemetery of 250 years and more than 60 burials, approximately one individual was interred every four years on average. This number suggests either a sizable, nearby settlement or the use of the cemetery by several smaller settlements. If the latter we might expect family groupings of graves at the cemetery. This is not clearly visible in Phase 1, although there are the northwestern group of graves and the eastern group in the main series. In Phase 2, it seems more likely as the graves are lying in two groups of seven graves and three graves, each placed more or less separately. In both phases, but especially in Phase 2, a smaller number of graves are in an isolated location.

Contemporary with Phase 2 at Galgedil, there was another small cemetery of six graves in use only 850 m to the south.[4] It may be that the changes from Phase 1 to 2 at Galgedil and the use of the small cemetery contemporary to Phase 2 to the south indicate a change in the organization of the local settlement from larger to smaller units at the end of the 10th century.

Although no settlements are known, there is other evidence for the presence of the Vikings in the area. Contemporary with Phase 1 at Galgedil, a runic stone, with the longest inscription in Denmark, was raised between AD 900–950 some 6 km to the southwest at the present place of Glavendrup. About the same time, a wealthy and mighty chieftain was buried in a ship at Ladby, 17 km southeast of Galgedil (Sørensen 2001). In both cases, we are dealing with the traditions of a pagan society and an upper level in that society that had contacts with the larger world. The individuals buried at Galgedil were, to a greater or lesser extent, part of this way of life. Even though they must have lived primarily as local farmers, they would have been aware of and actively participated in that larger world. The presence of non-local individuals in their midst is witness to this larger realm of interaction.

Physical anthropology

The investigated skeletal material from Galgedil consisted of the human remains from 57 inhumations with varying degrees of preservation. The number of male and female skeletons was almost the same. There were 24 males (48%) and 19 females (38%). Sex could not be determined in six of the adult skeletons (14%) or for the eight subadult individuals of various ages.

Preservation and demography

The number (8) of subadults – only 16% of all preserved skeletons – cannot be considered as an accurate reflection of the mortality of infants, children and juveniles in the local population. The number is far too small. Children may have been buried elsewhere or perhaps the graves were not recognized during excavation. However, the number is similar to what has been found in other cemeteries of the same time period, between 0 and 23%, with an average of approx. 10% (Bennike 1993). Even though other factors should not be ignored, the main reason for this may be the taphonomy of small and fragile bones that have completely disappeared.

Preservation conditions may also be the reason why the males outnumber the female skeletons. In contrast to the male skeleton, the bones of the female skeleton are in general smaller and more fragile with less bone mass. It therefore seems reasonable to suggest that the six unsexed skeletons that could not be determined because of bad preservation may be female. Even though the difference in the number of male and female skeletons is seldom very high, it is not unusual to find more male than female skeletons in a Viking skeletal population (Bennike 1993). Only in places like Trelleborg (Price *et al*. 2011) were many more males than females found, probably because the site was related to some kind of military organization.

Stature

Comparative studies of Danish skeletal material reveal some periods with a decrease in stature and others with an increase. The changes seem to occur simultaneously in males and females, and the average height of women is usually about 93% that of men (Bennike 1985). It has been of special interest to examine whether the tall stature of the Vikings usually described in popular literature can be confirmed. Some studies have shown that the stature was reduced during the Viking period in Denmark compared to the previous Iron Age and the later Middle Ages (Sellevold *et al*. 1984, Bennike 1985). Variation is naturally seen in skeletal material from different sites. The average stature of 20 male skeletons and 13 female skeletons from Galgedil is 172.6 cm and 161.4 cm, respectively, not very different from the calculated average stature of the Viking Age period which for males is 172.5 cm and for females is 159.0 cm. While the male stature was almost the same, it seems that the women from Galgedil were slightly, but not significantly, taller than their peers at other Danish Viking sites.

Dentition

The status of the dentition was complete or partial depending on preservation. Almost all of the sexed skeletons had preserved teeth (23 males and 18 females). A significant finding was that a much more pronounced frequency of caries was present in the female dentition (67%) than in the males (17%). Caries may be related to various factors, but the most important seems to be nutritional – the amount and type of carbohydrates – and hygiene. Nutritional differences between males and females were not revealed in the carbon and nitrogen isotope analysis (see below). The higher frequency of caries might be explained by more carbohydrates in women's diets or a possible difference in the level of hygiene.

Three burials in simple graves (AA, PF, ALX) had modified incisors with horizontal furrows, a characteristic known as filed teeth, a possible marker of social group membership (Arcini 2005). There were no goods in one of these graves, in another one iron knife, and in the last an iron knife and a sacrificed animal. Two of the graves belong to Phase 1 and the third to Phase 2. In two out of the three graves, the individual was determined to be an adult male. The third individual was an adult of unknown sex. All three persons were identified as local from the strontium isotope analysis.

aDNA investigations

Melchior *et al*. (2008a, 2008b) conducted an aDNA study of tooth dentin from ten individuals in the Galgedil cemetery. The results of their published investigations are briefly summarized here. Measures to avoid contamination included field excavation of the human remains by laboratory staff in full decontamination body suits. Teeth were removed from each mandible and taken immediately to the lab for analysis. Widely accepted guidelines for the aDNA analysis were followed in the lab (Gilbert *et al*. 2005, Melchior *et al*. 2008b). mtDNA extracted from the dentin samples was amplified, cloned, and sequenced. Haplogroup affiliations were assigned following established rules and definitions (e.g. Richards *et al*. 1998), and population affinities by haplotype/group frequencies were determined by comparison with published data for extant populations of Europe and Near East.

The results of the study indicate that the Viking burials from Galgedil are similar to other Viking and Iron Age samples from Denmark in their haplogroup frequency distribution (Table 2). However, five of the ten haplotypes in the Galgedil samples either have not been observed before or are infrequent in modern Scandinavians. In particular, haplotype X2c in Burial AJG is interesting. Haplogroup X is rare (0.9% in Scandinavians), but has a very wide geographic range, and X2c is a rare subgroup of X accounting for only 5% of 175 Hg X samples surveyed in 2003 (Reidla *et al*. 2003). Hg I occurs at less than 2% among modern Scandinavians, but markedly higher (10–20%) in Danish Iron Age and Viking population samples (Rudbeck *et al*. 2005, Melchior *et al*. 2008b). In sum, the mtDNA evidence from Galgedil points only to Burial AJG as potentially unusual.

Strontium isotope analysis

Strontium isotope analysis provides a robust means for examining questions regarding human mobility in the past. The method is straightforward and described in detail in a number of publications (e.g. Price *et al*. 1998, 2001, 2011, Montgomery et al. 2003, Price and Gestsdóttir 2006). The strontium isotope ratio of $^{87}Sr/^{86}Sr$ varies among different kinds of rocks. Because the ^{87}Sr is produced by the decay of an isotope of rubidium (^{87}Rb) in a radiogenic process over time, 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 lower ratios. Sediments reflect the ratio of their parent material. Strontium moves into humans from rocks and sediment containing nutrition for vegetation through the food chain. 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. The incidence of diagenesis in tooth enamel is low because of the hardness and density of this material (Hoppe *et al*. 2003, Lee-Thorp and Sponheimer 2003, Sponheimer and Lee-Thorp 2006). Values of $^{87}Sr/^{86}Sr$ in human tooth enamel that differ from those of the place of burial indicate that the individual was not buried where he/she was born.

A total of 36 individuals were sampled for strontium isotope analysis from the Galgedil cemetery. We selected a premolar from the majority of individuals; other teeth were used if a premolar was not available, and this information is provided in the table. Preparation followed conventional methods described in detail in Frei and Price

Table 2. Results of mtDNA analysis of 10 individuals from the Galgedil cemetery (Melchior *et al*. 2008a, 2008b).

Grave	Age	Sex	Haplogroup	Comment
AMA	50+	F	K	No exact match in European or in haplogroup K database
ALZ	45+	M	H	Common haplotype throughout Europe
AKJ	40–50	F?	H	No exact match in the database.
ANO	35–40	M?	H	Rare but widely spread haplotype throughout Europe
ALX	30–40	M?	U5a1a	Common haplotype throughout Europe
AXE	50+	M	I	Common haplotype throughout Europe
AJG	20–30	F	X2 c	Rare but widely spread haplotype throughout Europe
BFQ	50+	F	H	Rare type observed in Eastern Europe
AQQ	25–35	M	T2	Common haplotype throughout Europe
AQP	45+	F	H	Rare but widely spread haplotype throughout Europe

(2012), Price *et al.* (2001), and Sjögren *et al.* (2009). Small pieces of clean tooth enamel were dissolved in weak acid. Elemental strontium was isolated using an ion-specific resin, and the resulting pure strontium was placed on a filament for instrumental measurement. Strontium isotope ratios in the samples were measured on a VG Sector 54 Thermal Ionization Mass Spectrometer at the Institute of Geography and Geology, University of Copenhagen.

Results of the isotopic analyses are presented in Table 3, a large data set listing strontium, carbon, and oxygen isotopes from tooth enamel and carbon and nitrogen isotopes from bone collagen and tooth dentin for many of the same individuals. The $^{87}Sr/^{86}Sr$ values range from 0.7092–0.7155. The mean value is 0.7105 ± 0.0012. The enamel values from Galgedil are presented in graphic form in Figure 4. In this graph, the $^{87}Sr/^{86}Sr$ values are ordered from lowest to highest, left to right.

In order to determine if individuals analyzed in this study were non-local, it is essential to know the local baseline strontium isotope values at Galgedil and the surrounding area (Price *et al.* 2002). Two of us (Frei and

Table 3. Isotopic data for Galgedil enamel samples.

Grave	Sex	Age	Bone	C_{col}	N_{col}	C:N	Dentin	C_{col}	N_{col}	Tooth	87Sr/86Sr	C_{ap}	O_{ap}
SQ	M?	>45	Femur							4+	0.7092	−15.0	−2.5
SG	F	>40	Femur	−19.7	10.3	3.24				5-/ 4-	0.7093	−11.9	−4.8
WG	F	50	Femur	−20.4	11.0	3.33	−5	−20.1	11.4	−5	0.7093	−12.5	−4.3
UK	F	35–45	Femur			3.45				5+	0.7094	−11.9	−4.2
AKJ	F?	40–50	Femur	−19.9	10.8	3.36				3-	0.7094	−13.1	−5.8
AQP	F	>45	Femur	−19.4	11.3	3.19				2	0.7094		
AJG	F	20–30	Femur	−19.9	11.2	3.30	−4	−19.9	10.7	−4	0.7095	−12.7	−3.7
UN	F	30	Femur	−20.0	11.5	3.27	5	−19.5	13.2	5	0.7097	−13.5	−2.9
AMA	F	>50	Femur	−19.7	11.2	3.26				5	0.7098		
ALZ	M	>45	Femur	−19.7	12.0	3.49				5	0.7099	−14.5	−4.1
AMC	F?	>45	Femur	−19.2	11.3	3.19	4	−20.0	11.9	4-	0.7099	−15.1	−4.5
AA	M	25–35	Femur	−19.5	11.6	3.27	5-	−19.7	11.7	5-	0.7100	−13.4	−4.3
KQ	?	late 50s	Femur	−19.6	11.7	3.47				−5	0.7101	−12.9	−4.1
ALY	F	30–40	Femur	−20.2	10.7		4	−19.4	12.1	4	0.7101	−14.2	−3.3
PB	M	25–35	Femur	−20.1	11.6	3.31	5+	−20.0	10.5	5+	0.7101	−15.2	−3.3
TT	M	30–40	Femur	−19.8	11.9	3.27	5-	−19.8	12.5	5-	0.7102	−13.3	−4.6
KM	F	>50	Femur							−5	0.7102	−13.8	−4.2
TR 1	F	>30	Femur	−20.0	9.2	3.33				5+	0.7103	−12.4	−4.3
UL	M	30	Femur	−19.7	11.6	3.38	−5	−19.7	11.0	−4	0.7103	−14.5	−4.1
AXE	M	>50	Femur	−19.7	11.5	3.31				−3	0.7104	−14.3	−4.3
KR	M	late 40s	Femur	−19.5	12.3					−5	0.7105	−13.9	−4.5
BFQ	F	>50	Femur	−20.0	11.4	3.33	−5	−19.5	12.2	−5	0.7105	−14.5	−4.3
ALX	M?	30–40	Femur	−20.4	10.4	3.24	−4	−19.6	10.9	−4	0.7105	−14.4	−4.3
AQQ	M	25–30	Femur	−19.3	10.9	3.19	4-	−19.9	11.4	−5	0.7106	−15.8	−4.3
ANO	M?	35–45	Femur	−19.2	12.2	3.18	−5	−19.8	12.0	−5	0.7107	−14.4	−4.0
KL 2	M	50	Femur	−19.5	9.1	3.19				3-	0.7108	−13.5	−5.1
KL1	F?	25–35	Femur	−19.3	12.1	3.13	−4	−19.6	9.2	−4	0.7109	−11.4	−6.0
SB	M?	35–45	Femur	−19.3	12.2					−7	0.7109	−13.5	−3.7
AQQ	M	>45	Femur	−19.4	11.7	3.17				5	0.7109	−12.9	−3.9
TQ	F	35–45	Humerus	−20.4	11.6	3.28	4+	−20.1	12.3	−4	0.7109	−14.5	−4.2
UD 2	F?	>45	Femur	−19.9	10.6	3.41	−4	−19.7	11.6	−4	0.7111	−11.8	−4.4
UD 1	M	30–35	Femur							5-	0.7114	−13.9	−5.4
XJ	F	25	Femur	−19.8	10.5	3.25	4-	−19.2	10.8	4-	0.7115	−13.7	−4.4
TA	M	40–45	Femur	−19.2	10.8	3.31	4-	−18.4	11.7	4-	0.7119	−10.8	−3.2
UO	M	30	Femur	−20.5	11.8	3.40	max.	−20.4	11.7	max.	0.7130	−14.0	−3.9
AMB	F	35–45	Femur	−20.0	10.6	3.29				5	0.7155	−13.4	−4.2
LS	M	35–45	Femur	−19.4	12.4	3.27							
LD 1	?	Adult	Femur	−19.8	10.7	3.20							
LD 2	M	30–35	Femur	−18.9	11.5	3.24							
BEW	M	Adult	Fibula	−20.0	11.3	3.26							
BER	M	>40	Femur	−19.3	11.6	3.17							
ANG	M	35–45	Femur	−19.2	10.6	3.17							
KU	?	9	Femur	−19.7	10.8	3.20							
TR 2	M	25–35	Femur	−20.0	9.2	3.30							

Notes: C_{ap} = apatite carbon, O_{ap} = apatite oxygen, C_{col} = collagen carbon, and N_{col} = collagen nitrogen. Samples are ordered by the strontium isotope ratio.

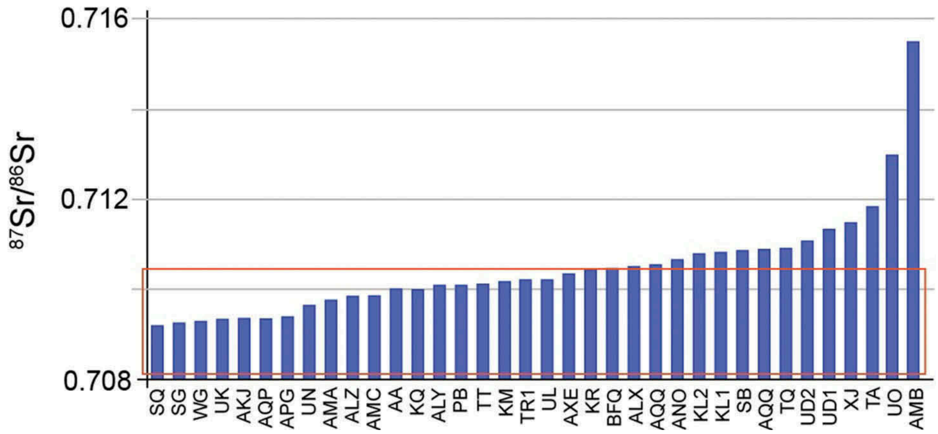

Figure 4. Bar graph of the ranked strontium isotope ratios from 37 graves at Galgedil. The red box defines the local ranges for this part of Denmark, 0.7081 to 0.7103. Grave numbers are listed. (This figure is presented in colour online.)

Price 2012) have been involved in a long-term project to develop a baseline map of strontium isotopes across Denmark. This project is summarized briefly here, and the results are presented to place Galgedil in the larger context of Danish strontium isotope sources.

The sea and the land are two major sources of food and isotopes for human consumption. Marine foods everywhere share the same isotopic value of 0.7092, which is also the value of seawater (e.g. Veizer 1989). Terrestrial sources vary according to bedrock and surface sediments. In actual fact, however, levels of strontium isotopes in human tissue may vary somewhat from local geology for various reasons (Sillen *et al*. 1998, Price *et al*. 2002). It is necessary to measure *bioavailable* levels of ^{87}Sr/^{86}Sr in a region to determine local strontium isotope ratios. Bioavailable strontium isotope ratios are those ratios actually available in the food chain.

We have measured a variety of materials to determine bioavailable levels of ^{87}Sr/^{86}Sr from throughout Denmark, including small rodents in modern owl pellets, modern snails, modern wool, and archeological fauna. The results of our study indicate that there are two major terrestrial sources in Denmark from two different lobes of ice that covered most of Denmark in the last glaciation. The island of Sjælland and the eastern quarter of the island of Funen were covered by a lobe from the east that brought rock and sediment from Sweden and the Baltic Basin into Denmark. Western Funen and Jutland were covered by another lobe coming from the north, bringing sediments from Norway and the North Sea Basin.

Our baseline measurements show slightly higher ^{87}Sr/^{86}Sr values on Sjælland and eastern Funen. We have suggested that a range from 0.7072 to 0.7119 likely defines the local bioavailable values for this area (Frei and Price 2012). For the rest of Funen and Jutland, values were slightly lower and a range of 0.7081 to 0.7103 should define the bioavailable ^{87}Sr/^{86}Sr in this western part of Denmark. Although these sources differ somewhat, they also overlap significantly and cannot be used to ascertain mobility between the two regions of the country, except perhaps in the most extreme cases. For Denmark as a whole, except for the island of Bornholm, any human ^{87}Sr/^{86}Sr values above 0.7119 are considered non-local. Galgedil lies in western Funen and should fall in the 0.7081 to 0.7103 baseline range of values.

We can use this baseline range (i.e. 0.7081 to 0.7103) to distinguish local and non-local individuals at the site. This range is plotted on the graph in Figure 4. This less cautious baseline range would suggest that between 12 and 16 of the individuals at Galgedil with ^{87}Sr/^{86}Sr values outside the range were probably non-local to the area. There are four values just at the cutoff line that may or may not belong in the non-local group. The proportion of non-local individuals is quite high, 12/36, or 33%. Individual AGJ, with the unusual haplotype in the aDNA analyses, is identified as a local individual in the strontium isotope analyses.

The samples measured for baseline values were completely terrestrial, without marine input. Human diets in Viking Denmark, on the other hand, often included a marine component. Kanstrup's study of carbon and nitrogen isotopes in bone collagen, dentin, and enamel (2006), summarized in a subsequent section of this article, documents the diet of the individuals buried at Galgedil. Tηε δ^{13}C values ranged from −20.5‰ to −18.9‰. In prehistoric Danish human remains, this value ranges from approximately −21‰ for a completely terrestrial diet to −12‰ for a fully marine diet. The values for the individuals at Galgedil suggest the consumption of some marine foods in the diet of these individuals, up to as much as 30%, assuming a linear relationship between δ^{13}C and the proportion of marine food in the diet.

Consumption of marine foods will pull higher or lower terrestrial ^{87}Sr/^{86}Sr values toward the marine value

Table 4. Individuals with highest strontium isotope values, context data.

Grave	Orientation	Grave size	Position	Sex	Age	Grave goods
TA	ESE-WNW	240 x 75 x 15 cm	On back	M	40–45	X933 mica whetstone
UD 2 (Double Grave. Upper)	NW-SE	233 x 123 x 8 cm	Hocker on left side Hocker is in the text called sleeping position	F?	Over 45	X781 iron rod X782 iron masses X784 iron masses
UD 1 (Double Grave. Lower)	NW-SE	233 x 123 x 10–18 cm	On back, lightly flexed legs	M	30–35	X794 iron knife
UO	NW-SE	180 x 63 x 45 cm	On back, legs spread	M	ca. 30	X714 iron masses X715 iron belt buckle X716 iron knife X717 food offering. sheep
XJ	ESE-WNW	200 x 100 x 5 cm	On back	F	ca. 25 with newborn infant	X826 glass bead X827 crystal bead X828 silver bead with filigree X829 glass bead X836 iron knife with possible silver wire
AMB	NW-SE	260 x 150 x 38 cm	On back, legs spread	F	35–45	X1361 iron knife

(0.7092) in tooth enamel, in proportion to the amount of seafood in the diet. For this reason, we would suggest that the terrestrial baseline values for Galgedil are generous in defining local individuals and cautious in distinguishing non-local persons.

Because there is a possibility that the higher $^{87}Sr/^{86}Sr$ values of eastern Funen extend into the area of Galgedil, we will take a more cautious approach to identifying non-local individuals. We will focus on the six individuals with the highest $^{87}Sr/^{86}Sr$ values, above 0.711, as definitely non-local and likely not from Denmark. A summary of these burials and grave contents appears in Table 4. Of these six non-local individuals, four are female and two are male. Females appear to be slightly more mobile than males in the Galgedil population. There are $^{87}Sr/^{86}Sr$ values for 18 females and 17 males from the cemetery. The mean and s.d. for females is 0.7104 ± 0.0015 and for males is 0.7107 ± 0.0009. While the average value for males is slightly higher yet still local, the s.d. is much higher for females suggesting more variability in places of origin.

There is no observed difference in the proportion of non-local graves between Phase 1 and 2 at the Galgedil cemetery. Spatially, the non-local graves appear scattered among the others with the exception of the western corner of the larger Phase 1 burial area (Figure 2). Here there are several adjacent graves (UD, UO, XJ) with non-locals present. Grave UD is a double grave with a male and female, both of whom are non-local and have very similar $^{87}Sr/^{86}Sr$ values.

It is important to remember that the non-local designation does not imply a specific distance or place of origin. Determining the place of origin for non-local individuals is difficult and often not possible. The key utility of strontium isotope analysis is identifying non-locals, not place of origin. Often several different regions may share the same $^{87}Sr/^{86}Sr$ values, and distinguishing a homeland among these is not feasible with strontium isotopes alone. Examination of the non-local values at Galgedil suggests that there are several different non-local strontium isotope ratios, indicating several different places of origin for these individuals. The place of origin of some of the non-locals may not have been so distant. Eastern Funen has a somewhat higher strontium isotope source and values up to 0.711 could come from that region.

Values higher than 0.711 are very rare in Denmark. Values of 0.712, 0.713 and 0.715 are unknown in Denmark (outside of Bornholm) and must come from older terrains, such as the rocky areas of western Sweden or southern and western Norway. To the south, there are few high $^{87}Sr/^{86}Sr$ sources across the North European Plain from the Netherlands across northern Poland. Some older rock outcrops with higher values are known to the south from Central Europe such as the Mittelgebirge in central Germany, the Black Forest region of southern Germany, and in the Carpathian Mountains. Given the location of Galgedil, close to the Kattegat, it seems most likely that the three high ratio non-local individuals may have come from Norway or western Sweden.

Light isotopes: carbon, nitrogen, and oxygen

Analysis of the stable isotopes of carbon and nitrogen in human bone collagen is standard practice in the study of past diet. This analysis provides an index ($\delta^{13}C$) of long-term average diet and of certain dietary patterns. For northern Europe, carbon isotope ratios are used largely to distinguish between marine and terrestrial foods. Collagen carbon is largely produced from ingested protein (Ambrose and Norr 1993). Carbohydrates are not well represented in the collagen, so that a somewhat biased view of diet is provided. Nitrogen isotopes provide information on the trophic level of the individual and reflect the importance of meat in the diet.

In this study, three separate tissues have been used for isotope analysis: bone collagen, dentin collagen, and tooth enamel. Each tissue provides somewhat different information. 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. Dentin collagen is similar to bone collagen, but turns over more slowly and may provide a measure of diet from the younger years of life. Carbon 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, Sealy 2001). Although there are potential problems with contamination in apatite, this carbon isotope ratio can provide substantial insight. Apatite carbon is discussed more thoroughly in a subsequent section.

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. Different standards are also used in oxygen isotope studies, usually either 'Standard Mean Ocean Water' (SMOW) or PDB belemnite (a fossil from the Cretaceous Pee Dee Formation in South Carolina). PDB was the standard for this study.

Oxygen isotope ratios in the skeleton come from body water (Luz *et al*. 1984, Luz and Kolodny 1985), which in turn predominantly reflects local rainfall. Isotopes in rainfall are greatly affected by the enrichment or depletion of the heavy ^{18}O isotope relative to ^{16}O 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 through adulthood. 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.

Carbon and nitrogen isotopes in collagen

This study was undertaken several years ago by Marie Kanstrup (2008) and is briefly summarized here. Isotopic analysis of bone and dentin collagen from the Galgedil skeletal material provides direct evidence for diet and permits an assessment of the homogeneity of Viking diet. Dietary variability at Galgedil is examined at three different levels: (1) intra-individual (life history), (2) inter-individual (in relation to sex, height and status), and (3) the population.

Standard procedures were followed in the preparation of collagen (Ambose 1990, van Klinken 1999, Jørkov *et al*. 2007). The isotope analysis was performed at the radiocarbon facility at Aarhus University using a GV instruments IsoPrime mass spectrometer in combination with a Euro Vector 3024 continuous flow Elemental Analyzer.[5] The results are presented in Table 3.

A total of 40 individuals were analyzed for bone collagen carbon and nitrogen isotopes. The ratio of carbon to nitrogen abundance was measured as an index of preservation and the quality of the sample (DeNiro and Weiner 1988, Ambrose 1990, van Klinken 1999). The percentage of collagen recovered from a sample and its C:N ratio are common measures of sample integrity. Collagen percentages were routinely high in these samples. Collagen samples from preserved bone or dentin are considered largely unaltered if their C:N ratios fall in the range of living bone, i.e., 3.22 to 3.45 (Schoeninger *et al*. 1989). The average C:N ratio in the Galgedil samples was 3.3 ± 0.1. There were 2 samples with values greater than 3.45 (3.47 and 3.49) and several lower than 3.22 but above 3.10. The mean $\delta^{13}C$ for bone collagen was −19.7 ± 0.4 with a narrow range from −20.1 to −18.9. The mean $\delta^{15}N$ for bone collagen was 11.3 ± 0.8, with a range from 9.1 to 12.4. The samples generally exhibited good integrity and all were used in the analysis discussed below.

Nineteen of the same individuals were sampled for tooth dentin. The mean $\delta^{13}C$ for dentin collagen was also −19.7 ± 0.4, with a range from −20.4 to −18.4. The mean $\delta^{15}N$ for dentin was 11.6 ± 1.0, with a range from 9.2 to 13.2. The bone and dentin collagen were generally highly correlated. For this reason, most of the discussion below focuses on the bone collagen results.

Although there was relatively little variation in the carbon and nitrogen isotope ratios, there are clear differences between male and female diets. Carbon vs. nitrogen isotope ratios for bone collagen in males and females are plotted in Figure 5. The differences in isotopic signatures and hence diet between adult men and women are statistically significant when $\delta^{13}C$ and $\delta^{15}N$ are combined in a paired student's *t*-test (p = 0.0023). Comparison of the means and s.d. of $\delta^{13}C$ and $\delta^{15}N$ for men and women, respectively, suggests that women had a more

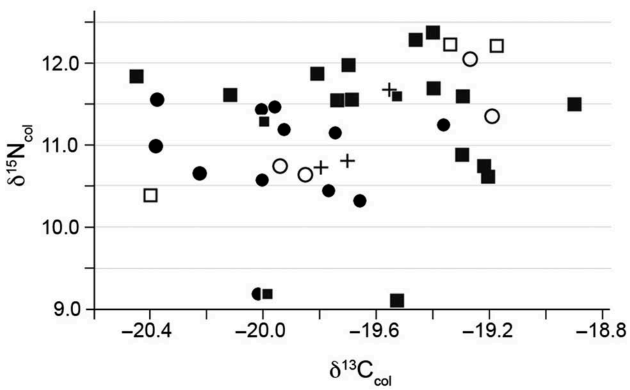

Figure 5. Carbon and nitrogen isotope ratios plotted for men, women, and children at Galgedil. Square = male, circle = female, hollow = sex uncertain, triangle = child.

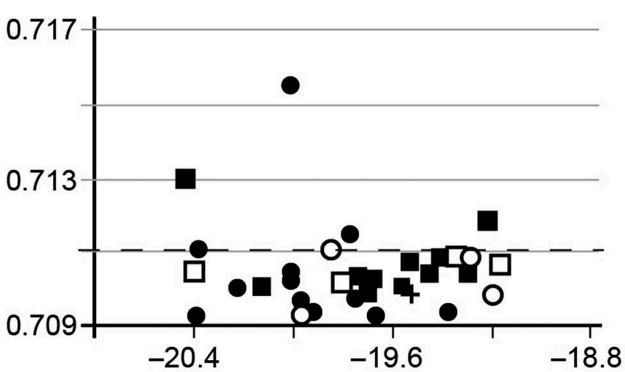

Figure 6. Carbon and strontium isotope ratios plotted for burials at Galgedil.

homogenous diet than men. Three individuals have markedly low δ^{15}N values. Burials TR1, TR2, KL2 were all from the double graves. The low δ^{15}N values suggest less carnivorous diets, perhaps a reflection of status.

Comparison of bone $\delta^{13}C_{col}$ and ^{87}Sr/^{86}Sr values is of interest (Figure 6). The individual (UO) with the most negative $\delta^{13}C_{col}$ value has the second highest ^{87}Sr/^{86}Sr and is very clearly non-local. This individual likely came from an inland region where marine foods were rare or absent in the diet. The remainder of the non-locals fall within the same δ^{13}C range as the local individuals. The difference in male and female diets appears again in the carbon isotope data.

The tooth dentin from the individual in grave UN has a very high δ^{15}N value. The bone value falls within the normal range of the Galgedil population. This difference appears to reflect a change of diet from childhood, due perhaps to preferences, illness, or a change in residence. However, the strontium isotope ratio does not suggest mobility for this individual. A similar difference is evident in δ^{13}C in the bone and tooth sample from the individual buried in grave TA. In the dentin that may represent diet at a younger age, this individual consumed a good bit of marine food, whereas the adult diet represented in the femur collagen resembles the low marine input more typical of the general population. The ^{87}Sr/^{86}Sr value (0.7119) indicates mobility.

The relatively high values for δ^{15}N in the Galgedil population should represent a diet that is largely carnivorous (e.g. Ambrose 1993, Bocherens and Drucker 2003). The variation observed in these values reflects the normal dietary differences that existed among Viking individuals. The combination of carbon and nitrogen isotopes in bone collagen suggests a diet that is largely carnivorous. Comparative data from other periods in Denmark can be found in Jørkov *et al*. (2010) and Yoder (2010).

The isotopic data and archeological findings do not indicate any clear relationship between stature and diet or status and diet. A few individuals are, as noted earlier, clearly outliers. These individuals have often been interpreted as slaves, based on their presence in double graves and general lack of grave goods. A δ^{15}N offset of 2.5–3‰ between the presumed master and slave and is seen between the two individuals in grave KL and in a comparison of the individual buried in grave TQ just next to a double grave (TR) with two possible slaves. These individuals were eating less meat and may represent a segment of the population otherwise often anonymous in the archeological record.

Oxygen isotopes in enamel

Oxygen isotopes in dental enamel reflect water sources in early childhood. Apatite enamel δ^{18}O values from Galgedil have a mean of −4.2 ± 0.7, with a range from −2.3 to −6.0. Fricke *et al.* (1995) reported a δ^{18}O phosphate value of 18.1 for tooth enamel from medieval Risby, Denmark. This value, converted to a carbonate scale, is very similar to the average measured at Galgedil.[6] A scatter plot of δ^{18}O vs. ^{87}Sr/^{86}Sr (Figure 7) shows very little pattern, suggesting that oxygen values are not varying geographically among the non-local individuals. Two of the lowest δ^{18}O values, and one of the highest, occur with local individuals. Only three of the non-local individuals exhibit higher oxygen isotope ratios. The fact that a local individual has a similar value suggests that variation in δ^{18}O‰ values is high and that little geographic variation is being recorded. Oxygen isotopes are often problematic as a marker of geographic variation.

Conclusions

Excavations of a Viking Age cemetery near the town of Galgedil in Denmark uncovered some 54 graves containing 61 buried individuals. These burials have been the focus of anthropological, aDNA, and isotopic

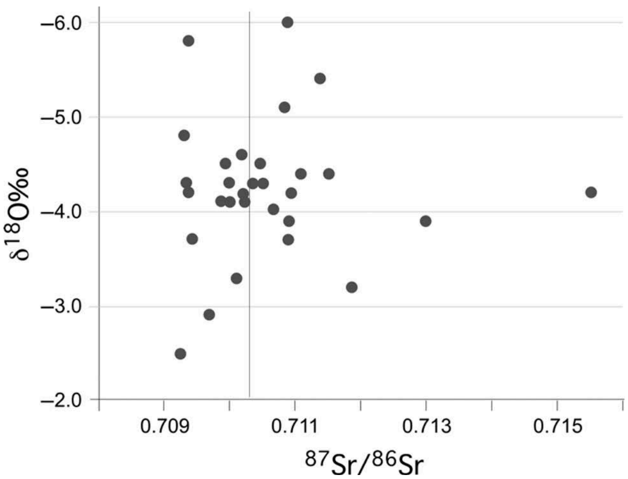

Figure 7. Scatterplot of δ^{18}O vs. ^{87}Sr/^{86}Sr for enamel samples from Galgedil. The vertical line marks the upper limit of the local baseline in this part of Denmark (0.7103).

investigation to learn about the life histories of the deceased individuals. Based on the typology of the grave goods and radiocarbon dates, this pre-Christian cemetery was in use from approximately AD 800 to 1050. Of the 57 skeletons analyzed for age and sex, there were 24 males, 19 females, and six indeterminate individuals. Only eight subadults were found among the largely adult population of the cemetery.

Several lines of inquiry have been pursued in the investigation of the human remains from Galgedil. An aDNA study (Melchior *et al.* 2008a, 2008b) involved a sample of 10 individuals. Only burial, AJG, was recognized as genetically unusual and perhaps exotic to the population at Galgedil. The isotopes did not distinguish this individual.

A multi-isotope approach was employed in the investigation of these burials. Strontium isotope ratios were used to identify non-local individuals in the burial population. Light isotopes of carbon and nitrogen in bone collagen provided information on diet (Kanstrup 2006). Dentine collagen isotopes were generally similar to the bone collagen results. Oxygen isotopes in tooth enamel were also measured as a potential index of mobility, but there was no patterned variation in these data and no clear relationship with the ^{87}Sr/^{86}Sr values.

Carbon isotope ratios in samples of bone collagen averaged −19.7‰ ± 0.4, documenting a largely terrestrial diet with marine foods comprising approx. 10%–30%. Nitrogen isotope ratios show a pronounced difference between male and female diets. Males were significantly more carnivorous. Nitrogen isotopes also revealed three individuals with markedly low δ^{15}N values, all from the double graves and all non-local individuals. These individuals were local based on ^{87}Sr/^{86}Sr, but their diets were much less carnivorous than the rest of the population.

Comparison of the carbon isotope data with the local/non-local information from the strontium isotope analysis provided some insight. The individual (UO) with the most negative $\delta^{13}C_{collagen}$ (least marine) had the second highest ^{87}Sr/^{86}Sr value, clearly non-local and likely from an inland region of older rocks in central or northern Scandinavia. In general, however, there was little difference in the diets of local and non-local individuals.

Strontium isotopes identified a number of non-local individuals. The proportion is quite high, 6/37, or approximately 16% of the burials. Several patterns were observed. Four of the individuals buried during Phase 1 have high strontium isotope values (UD1, UD2, UO, XJ). They are located more or less together at the edge of the cemetery in the southwestern part (Figure 2). Here there were several adjacent graves (UD, UO, XJ) with non-locals present. In Phase 2, the two non-locals from 15 burials in this group were placed in separate groups. This might indicate a change over time in the status of and/or the integration of newcomers. In Phase 1, the individuals in double graves are often of non-local origin. For example, grave UD is a double grave with a male and female, both of whom are non-local and have very similar ^{87}Sr/^{86}Sr values. There are no double graves in the Phase 2 cemetery. As the practice of double graves ends, they are buried in ordinary single graves in Phase 2.

The graves with more contents were more likely to contain non-local individuals. The grave with one of the highest strontium isotope value (XJ) was one of the richest with four valuable beads, two of glass, one of rock crystal and one of silver with filigree ornamentation, and an iron knife possibly with silver wire. A few beads of rock crystal are known from Denmark, but they are more common in Sweden (Jansson 1988), a potential place of origin for the woman buried in grave XJ.

Animal sacrifices may have been more common with non-locals, but this association is uncertain. Three of the graves with sacrificed animals (UD2, UO, XJ) from Phase 1 have high strontium isotope values indicating non-local origin. The only grave from Phase 2 with a possible animal sacrifice (TA) also has a high strontium isotope ratio, indicating the male burial as non-local. He is lying on his back with a whetstone and a bird next to his face. The bird bone may have been accidentally or intentionally included in the grave.

In sum, the investigation of Galgedil has revealed a number of new aspects in the lives of its Viking inhabitants. Information on place of origin, diet, and social organization are apparent in the context and contents of the graves, in the physical skeletal remains of these individuals, and in the molecular and isotopic chemistry of their bones and teeth.

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Notes

1. The excavation was conducted for Odense Bys Museer by Susanne Clemmensen and Mogens Bo Henriksen in 1999-2001 and by Lisbeth Christensen and Kirsten Prangsgaard in 2005 under the file number OBM 4520.
2. Five of the ^{14}C AMS measurements were made at the Department of Physics and Astronomy, University of Aarhus, AMS ^{14}C Dating Laboratory, by Jan Heinemeier in connection with the excavations in 2005: AAR10568, AAR10569, AAR10570, AAR10571, AAR10760; and three of the ^{14}C AMS dates in conjunction with Marie Kanstrup's work on diet: AAR11099, AAR11100, AAR11101.
3. The dating of the artifacts is generally based on Calmer (1977), Arwidson (1984, 1986, 1989), Skibsted Klæsøe (1999), Eisenschmidt (2004), and Maixner (2005).
4. This excavation was conducted in 1998 by Susanne Clemmensen under the file number OBM 8532.
5. Precision for this system is ±0.2‰ and ±0.3‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively. The samples are at a minimum measured in duplicate with the exception of GAL 46 where there was insufficient material. All of the collagen samples extracted using the Longin method with ultra-filtration (30 kDa) fulfilled conventional quality criteria (Ambrose 1990, p. 438, Brown et al. 1988, Longin 1971, p. 241, van Klinken 1999, p. 689).
6. Conversion of $\delta^{18}O$ phosphate to $\delta^{18}O$ carbonate is fairly straightforward. The formula $\delta^{18}O_c = 1.2* \delta^{18}O_p + 8.3$ can be used (Coplen *et al.* 1983, Bryant *et al.* 1996, Hoefs 2004), where Op and Oc are phosphate oxygen and carbonate oxygen, respectively. Calculating $\delta^{18}O_c = 1.2*18.1\ \delta^{18}O_c+8.3$.

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