'To the land or to the sea': diet and mobility in early medieval Frisia

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Abstract

This study investigated palaeodiet and population mobility in early medieval Frisia, through the stable isotope analysis of individuals buried in the 5th-8th century AD cemetery of Oosterbeintum, a *terp* site on the northern coast of the Netherlands. The results throw new light on the role of the northern Netherlands in trade and migration in the early medieval period and have significance for the study of interaction and movement throughout the wider North Sea region. Bone collagen and tooth enamel from humans and animals were analysed using carbon, nitrogen, oxygen and strontium isotopes. $\delta^{13}C$ and $\delta^{15}N$ results indicated that the population had a terrestrial, C_3-based diet. High $\delta^{15}N$ values were observed in humans and fauna, which are probably related to the *terp*'s salt-marsh location. The $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ data revealed a high proportion of non-locals buried at Oosterbeintum, some of whom had probably migrated from regions as distant and varied as Scandinavia and southern England. It is suggested that this immigration may be associated with Frisian maritime trading activities. New data are also presented from a small number of contemporaneous European sites.

Keywords

Frisia, stable isotopes, migration, palaeodiet, *terp*.

Introduction

"There, twice in every twenty-four hours, the ocean's vast tide sweeps in a flood over a large stretch of land and hides Nature's everlasting controversy about whether this region belongs to the land or to the sea" Pliny, Hist. Nat. Book XVI 2

The relationship between the land and the sea has been a central influence on the Frisian environment, landscape and way of life. In the early medieval period, Frisia comprised parts of northern Belgium, the Netherlands and Germany. Although documentary sources referring to the region and its inhabitants are scarce up until the seventh century AD (Heidinga 1990), there is evidence that Frisia was a more important region than its marginal location would suggest. Situated on the North Sea coast between Scandinavia and Britain, the Frisians would have been ideally positioned to take an important role in maritime trade, a fact supported by historical sources and archaeological evidence (Lebecq 1990). Most significantly, perhaps, sources such as Bede's *Historia Ecclesiastica* and Procopius' *Wars* name the Frisians among the Anglo-Saxon immigrants to England. Links between the two regions are evidenced by similarities in material culture (Hills 1996), genetics (Capelli et al. 2003; Weale et al. 2002) and linguistics (Markey 1981). In addition, archaeological evidence points to an occupation hiatus in Frisia from the mid-third century AD to the fifth century AD, and a subsequent repopulation which coincides with a period of depopulation in the Anglo-Saxon 'homelands' to the east. This has contributed to the theory that the region was repopulated, at least in part, by Germanic migrants on their way towards England (Meier 2003, Van Giffen 1936). The name 'Frisia', which has remained associated with the region from the Roman period to the present day, may therefore hide a substantial population change. Much of the human skeletal material recovered from Frisian sites was excavated in the early twentieth century or even earlier and lacks important information about its original context. In addition, there is a paucity of isotope

data from the region so isotopic evidence of migration to or from Frisia has not previously been investigated. This study aims to apply a range of isotope methods (δ^{13}C, δ^{15}N, ^{87}Sr/^{86}Sr and δ^{18}O) to skeletal material recovered from a Frisian *terp* cemetery at Oosterbeintum in order to investigate whether there is any evidence of immigration to the site, to provide an insight into how people were living in this liminal environment, and to contribute to the body of isotope data from Migration Period Europe.

The Oosterbeintum *terp* cemetery

The human and faunal remains analysed in this study were excavated from the cemetery of Oosterbeintum in the modern province of Friesland, the Netherlands (Figure 1). It is located in what would have been the Middelzee estuary, to the east of the *terp* of Hogebeintum. The cemetery was in use between AD 400 and AD 750 and, as is typical for Frisian cemeteries of this period, was used solely for cremations until around AD 450 from which point cremations and inhumations occurred concurrently (Knol et al. 1996). Forty-six inhumations (including one double burial) and possibly up to 116 cremation features were excavated by the Biological-Archaeological Institute of the University of Groningen in the late 1980s. There is a high degree of variability in the burial rite used at Oosterbeintum, with no apparent consistency or patterning in cemetery organisation, grave orientation or treatment of the body. As a result, it is impossible to identify a local burial tradition or exogenous burial practices.

The cemetery is situated on a *terp*, an artificially raised mound built up with sods and dung, which are commonly found in this region. Prior to the construction of dikes and coastal barriers from the tenth century AD, much of Frisia would have been low-lying salt-marsh, formed on marine clays deposited by frequent and repeated episodes of tidal inundation and sedimentation. From the sixth century BC onwards the inhabitants of Frisia began to construct *terpen* in order to protect settlements from the risk of flooding. These could range in size from a '*huisterp*' (house *terp)* about 10 to 20m across, to a large '*dorpsterp*' (village *terp*) which could be over 4 hectares in size

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(Miedema 1983:71). Due to the accumulation of sods and organic refuse many *terpen* were 'quarried' for their fertile soil during the twentieth century, resulting in the loss of significant amounts of archaeological information and material. An area of 220m^2 was excavated at Oosterbeintum, but due to soil quarrying the original extent of the *terp* and the cemetery is not known. *Terp* settlements were often arranged in a radial pattern around a pool or 'dobbe' which would have served as a fish pond and provided the settlement's human and animal occupants with a source of fresh water (Hoeksema 2006:26). The saline conditions of the salt-marsh would have made it unsuitable for the cultivation of certain crops, such as wheat (Pals 1999), although experimentation and archaeobotanical evidence have shown that arable agriculture would have been possible on elevated parts of the salt-marsh (Cappers and Raemaakers 2008; Van Zeist 1976). However, crop yields would have been limited and the risks of crop failure due to flooding were high. In contrast, salt-marsh provides particularly fertile pasture for livestock, and pastoralism rather than agriculturalism is likely to have been the favoured means of subsistence. Local products, such as wool, hides and salt could have been traded for resources like timber and wheat, which could not be produced on the salt-marsh (Te Brake 1978).

Stable isotope analysis in archaeology

Stable isotope analysis has become an increasingly important tool in the study of migration and palaeodiet in past populations. A range of stable isotope techniques were applied to the material sampled in this study: carbon and nitrogen isotope analysis to investigate palaeodiet, and strontium and oxygen isotope analysis to investigate the geographical origins of the individuals buried at Oosterbeintum.

Carbon and nitrogen isotopes

The carbon and nitrogen isotope ratios of bone collagen reflect the diet, or more specifically the dietary protein, consumed by an individual over the period of bone formation. Bone undergoes

constant remodelling during life, and isotope ratios measured in collagen therefore represent an average diet over a number of years. The rate of collagen turnover is not firmly established but has been demonstrated to be more than 10 years and possibly up to as much as 30 years (Hedges et al. 2007; Wild et al. 2000). Carbon isotope analysis can be used to distinguish between the consumption of different types of plants: C_3, comprising most plants in terrestrial, temperate environments, with $\delta^{13}C$ of around -25‰, and C_4, generally found in tropical regions with $\delta^{13}C$ around -10 to -14‰ (Schwarcz and Schoeninger 1991). In temperate regions, where C_4 plants are few, carbon isotope analysis is more useful in differentiating between terrestrial and marine/freshwater diets. Seawater carbonate is approximately 7‰ more positive than atmospheric CO_2 and this difference is passed up the food chain. A human diet consisting of 100% marine protein would therefore have $\delta^{13}C$ of approximately -13‰, compared with -20‰ for a purely terrestrial diet (Chisholm et al. 1982). Nitrogen isotope ratios are primarily used to investigate the amount of protein consumed by an individual and their resulting trophic level. There will generally be 3-5‰ increase in $\delta^{15}N$ between the body tissue of the consumer and their diet, so organisms which are higher up the food chain or consume more protein will have higher $\delta^{15}N$ (Bocherens and Drucker 2003). Nitrogen isotope ratios can also indicate the consumption of aquatic resources. The presence of ^{15}N-enriched nitrates in marine ecosystems and the greater complexity of the marine food chain results in higher $\delta^{15}N$ than would be seen from a purely terrestrial diet (Schwarcz and Schoeninger 1991). The nitrogen and carbon found in freshwater ecosystems can derive from a wider variety of sources, so organisms which inhabit freshwater environments display greater variability in isotope ratios than those found in terrestrial or marine habitats. Nitrogen isotope ratios are also used to investigate weaning and studies have shown that breast-feeding infants are effectively one trophic level higher than their mother and will therefore have higher $\delta^{15}N$ values than adults from the same population (e.g. Richards et al. 2002).

Strontium and oxygen isotopes

Strontium and oxygen isotope ratios are linked to geographical variables and are a key tool in the archaeological investigation of population mobility (e.g. Chenery et al. 2010; Knudson 2011; Smits et al. 2010). Enamel is currently the material of choice for strontium and oxygen isotope analysis, due to its greater resistance to diagenesis, relative to bone or dentine (Kohn and Cerling 2002). Tooth enamel is formed early in life and is not subsequently remodelled so the information derived from it will reflect the early years of an individual's life and the environment in which they grew up. Oxygen and strontium isotope ratios are influenced by different geographical factors so they are particularly useful in combination. Strontium isotope composition is conventionally measured as the ratio of two isotopes, ^{87}Sr and ^{86}Sr. The relative frequency of these isotopes in a particular ecosystem is influenced by the age and geological composition of the local underlying rock. As these rocks weather, strontium is released into the soil, contributing to the local pool of biologically available strontium, which can be taken up by plants and thereby enter the food chain. Within the body, strontium substitutes for calcium in hydroxyapatite, the mineral phase of bone and tooth enamel. There is negligible fractionation of strontium during this process so the ^{87}Sr/^{86}Sr value in an individual's tissue will reflect the isotopic composition of their sources of strontium and not be significantly affected by diet or trophic level (Price et al. 1994). In coastal regions, however, the incorporation of sea-spray and/or seawater-derived precipitation can shift soil ^{87}Sr/^{86}Sr towards that of seawater (Montgomery 2010; Raiber et al. 2009; Whipkey et al. 2000), which is homogenous worldwide, at approximately 0.7092 (Veizer 1989). The oxygen isotope composition of meteoric water in a given region is influenced by local climatic factors including temperature and latitude (Dansgaard 1964). The oxygen isotope ratio of water ingested by an individual via drinking water and food will affect the δ^{18}O of water within the body, which will in turn be incorporated into tissues, such as enamel, during their formation. As with strontium, the measurement of oxygen isotope ratios in human enamel can indicate the geographical region in which an individual grew up. Oxygen isotope ratios can be measured in either phosphate or carbonate and the relationship between the two has formed the basis of numerous studies (e.g. Bryant and Froelich 1995; Chenery et al. 2012;

Iacumin 1996; Martin et al. 2008). The δ^{18}O of ingested meteoric water (groundwater derived from precipitation) has been shown to have a direct, linear relationship with the δ^{18}O preserved in bone phosphate, which is the material analysed in this study. A number of different equations have been developed to allow conversion between these two values (Daux et al. 2008; Levinson et al. 1987; Longinelli 1984; Luz and Kolodny 1985), although the danger of introducing statistical errors through the use of these regression equations has recently been highlighted (Pollard et al. 2011). This study will therefore avoid the use of conversion equations and instead base its interpretation on the oxygen phosphate values.

Material and methods

Materials and sampling strategy

Thirty-four inhumations from Oosterbeintum were sufficiently well preserved to enable samples to be taken (see Table 1 for details). This included a fairly even distribution of males and females, with age groups ranging from young children to mature adults. In most cases the sample was taken from a rib, although in six instances the poor state of preservation resulted in long bones or cranial bones being sampled instead. This should not affect the comparability of the results as studies have shown negligible isotopic variations between different elements within the same skeleton (Sealy et al. 1995). The teeth sampled were predominantly second molars or second premolars, which commence mineralization after the age of two years when breast milk, if still consumed, is less likely to be the dominant source of nutrients or fluid. Young children were excluded from this subset as deciduous teeth form earlier in life and may retain isotope ratios from the period of breast-feeding (Wright and Schwarz 1998). Tooth and bone samples were also taken from the range of faunal species found at Oosterbeintum (Table 2). A sample was taken from soil associated with one of the human graves (405).

The plant samples were collected from the Eexterhalte Hunnerbed area of Drenthe in the Netherlands (53° 0' 6.51" N 6° 43' 50.49" E). The Hunnebeds are megalithic structures, built of large

granite boulders of Scandinavian origin and transported to the Netherlands though glacial activity. The radiogenic ratios of the plants are testament to the Scandinavian origin of the glacial sediments in this area. This pilot data suggests that radiogenic biospheres may well exist in the Netherlands, in areas where such megalithic structures are found as an indication of Scandinavian glacial deposits. The plants sampled were shallow-rooted wild plants, such as dandelion and cow parsley, and samples comprised a few leaves from each individual plant.

Carbon and nitrogen isotope analysis

All bone samples were prepared and analysed at the University of Bradford. Collagen extraction was carried out using a modified Longin (1971) method, as described by Müldner and Richards (2005). Samples were run in duplicate, and four standards were run alongside the collagen samples: two international standards (IAEAN1 and IAEA600) and two laboratory standards, BLS (Bovine Liver Standard) and fish gelatine. The analytical error for both carbon and nitrogen was ±0.2‰ (1σ). C:N ratios and collagen yields for all samples were within the acceptable parameters for well-preserved collagen (Ambrose 1990; Van Klinken 1999), with the exception of dog 340 which is therefore represented by only one measurement.

Strontium isotope analysis

Initial preparation of enamel and dentine samples was carried out at the University of Bradford, according to the method described by Montgomery (2002). Separate samples of dentine were taken from the crowns of three of the human teeth (OOS241, OOS410 and OOS486) and three faunal enamel samples were removed using the same method. All dentine and enamel samples were placed in sealed containers and transferred to the HEPA-filtered laboratory at the NERC Isotope Geosciences Laboratory (NIGL), Keyworth, where sample preparation continued according to the method described in Evans et al. (2006). About 1 gm of soil was place in a test tube with de-ionised water and left for 24 hours, agitating occasionally. The sample was centrifuged and an aliquot of the

supernatant fluid was removed. This was acidified using quartz distilled 6M HCl and dried down. The residue was taken up in 2.5HCl and the strontium separated by the same method as that used for the tooth enamel. Plant samples were dried and cryogenically powdered to homogenise the sample. The strontium samples were loaded on rhenium filaments using TaF emission enhancer (Birck 1986). Strontium ratios and concentrations of all the samples were measured using a Triton multi-collector mass spectrometer. The measurements were made using a 4V beam in dynamic mode. NBS 987 gave 0.710253 ± 0.000006 (2σ; n=15) during the analysis. As this is within error of the accepted value (0.701250) no normalising was necessary. Procedural blanks were generally <100pg.

Phosphate oxygen analysis

Small fragments of enamel (< 10 mg) were treated to extract PO_4 radicals and precipitated as silver phosphate, using a method adapted from O'Neil et al. (1994) and described in Lamb et al. (2012). Each sample was analysed in triplicate and the results were corrected against NBS120C (Florida phosphate rock) using a value of 21.7 ‰. The value of 21.7‰ was derived from a calibration using a fluorination method (30 second pre-treatment with BrF5 followed by 16 hour reaction with BrF5 at 500°C and analysed on a Finnegan Matt 253 mass spectrometer) corrected against the certified reference material NBS28. ACC-1, a commercially available hydroxyapatite (Aldrich) converted to Ag_3PO_4, was also used as a batch control and prepared as small size samples to replicate the sample preparation: the precision was ±0.36‰ (1σ; n=6). The mean error of replicate analysis of NBS120C during this set of analyses was ±0.23‰ (1σ; 3 batches of 22) and the sample reproducibility based on triplicate sample analyses was ± 0.10‰ (1σ). See Chenery et al. (2010) for more discussion. Oxygen isotope data are reported relative to VSMOW.

Results

Carbon and nitrogen isotope analysis

All isotope data are presented in Tables 1 and 2. Means are reported to one standard deviation. The variability among the δ^{15}N values of the faunal specimens generally follows predicted trophic levels with the highest terrestrial δ^{15}N values belong to the dog samples and the lower δ^{15}N values belonging to the herbivores (Figure 2). The only marine specimen sampled was a single whale rib, which could not be identified to species. Figure 2 shows the high δ^{15}N and δ^{13}C values of this animal, but as the dietary habits of different species of whale differ greatly and no other marine fauna were available to sample from the site, it is difficult to draw too much from this value.

Interestingly, although two of the pig samples have high δ^{15}N values, suggestive of an omnivorous diet, the other three are among the lowest faunal δ^{15}N values (Figure 3). Although inferences are limited by the small data set, this suggests that the pigs consumed at Oosterbeintum ate two distinct diets. It may indicate the presence of imported pigs, or the hunting of wild pigs which had eaten a more herbivorous diet. The 5.7‰ difference between the mean δ^{15}N of the high and low clusters is greater than would be expected between suckling and adult pigs. Unfortunately the ages of the pigs sampled are not known so it cannot be ruled out that the difference between the two groups has been increased by a suckling effect. The mean δ^{13}C of the high δ^{15}N group is slightly higher (-20.2±0.6‰) than the low δ^{15}N group (-21.4±0.2‰), which supports the dietary distinction between the two groups.

The humans from Oosterbeintum had a wide range of δ^{15}N values, from 7.8‰ to 16.1‰ (mean 12.4± 1.5‰). The two highest δ^{15}N values (15.9‰ and 16.1‰) belonged to children aged between 4 and 5 years (Figure 4), and are consistent with the expected δ^{15}N increase in breast-feeding children. The human δ^{13}C values were less variable, with a maximum of -19.5‰ and a minimum of -21.2‰ (mean -20.1± 0.4‰). A Mann-Whitney test showed no statistically significant difference between males and females at the 5% level of significance.

Strontium and oxygen isotope analysis

Given the marginal location of the site and the relative homogeneity of the local geology, the strontium isotope results from the human enamel samples display a high degree of heterogeneity, ranging from 0.7088 to 0.7164 (Figure 5). The median value was 0.7096 (n=23). The three human dentine samples all have $^{87}Sr/^{86}Sr$ different from that of enamel from the same tooth. The significance of this will be discussed below. Samples of modern plants from Drenthe (Table 2), a province to the south-east of Friesland, displayed $^{87}Sr/^{86}Sr$ values as high as 0.7156 (mean 0.713±0.002), which are likely to be related to the presence of glacial till of Scandinavian origin in that region (Hoek 2000). Radiogenic values could also be possible closer to Oosterbeintum, such as at the town of Rinsumageest, 6km southeast of Oosterbeintum. In this area glacial till is generally covered by less than a metre of coversands. Further north of Rinsumageest most glacial till lies under layers of Holocene peat and/or clay (Bodenkaart Van Nedeland 1:50,000). The $\delta^{18}O_p$ results for the human enamel (Figure 6) ranged from 16.4‰ to 18.4‰ (mean 17.5±0.4‰, 1σ).

Discussion

Palaeodiet

The Oosterbeintum human $\delta^{15}N$ values (Figure 7) are high compared to contemporary European populations (Hakenbeck et al. 2010; Lamb et al. 2012; Mays and Beavan 2012; Richards et al. 2006; Schutkowski et al. 1999). However, there is no corresponding elevation in $\delta^{13}C$ to suggest that this is due to the consumption of marine resources, as at Newark Bay (Richards et al. 2006). Similar data were obtained from humans at late Medieval sites in the north of England (Müldner and Richards 2005), and were interpreted as reflecting a mixed diet of terrestrial, freshwater and marine protein. High $\delta^{15}N$ with low $\delta^{13}C$ were also found at Auldhame on the east coast of Scotland and, in the absence of associated faunal data, were suggested as indicating the consumption of freshwater fish or the practice of manuring (Lamb et al. 2012). The terrestrial fauna analysed from Oosterbeintum, in contrast to those from Newark Bay (Richards et al. 2006), also display unusually high $\delta^{15}N$ (Figure 8). The mean human adult $\delta^{15}N$ is 2.8-4.5‰ higher than the mean $\delta^{15}N$ of the three species of food

animal, which corresponds to the expected trophic enrichment in ^{15}N (Bocherens and Drucker 2003). Taking into account the dietary base-line provided by the faunal data, it is probable that the unusually high human values are the result of an underlying ^{15}N enrichment affecting the isotope ratios of the animals they were eating. The three dogs sampled have similar δ^{15}N values to the human results, so it is likely that they were consuming a similar diet to their human keepers. One dog had a δ^{13}C value of -18.5‰, suggesting that it may have had a marine protein component in its diet, although as the duplicate run of this sample was unsuccessful it is not possible to verify this result. The lack of a marine component in the human diet is surprising, considering the maritime location of Oosterbeintum. The high δ^{15}N values could indicate the consumption of freshwater fish, which would produce high δ^{15}N values with more variable δ^{13}C values. It has been suggested that freshwater fish were unimportant at *terp* sites (Prummel and Heinrich 2005), although the lack of sieving at many excavations, including Oosterbeintum, means that fish bones are likely to be underrepresented in the zooarchaeological record. However, the 3.4‰ difference between the mean δ^{15}N of the humans and that of the terrestrial food animals (cattle, sheep/goat and pig) is no greater than the trophic shift expected between a consumer and their primary source of protein. Thus it seems reasonable to attribute the elevated δ^{15}N of the human population to the elevated δ^{15}N of the site's fauna.

The answer to the δ^{15}N increase in faunal collagen may lie in the peculiarities of the brackish *terp* environment. A positive relationship has been demonstrated between salinity and δ^{13}C (Van Groenigen and Van Kessel 2002), but the relationship between salinity and δ^{15}N is less clear (Cleom et al. 2002; Handley et al. 1997; Heaton 1987; Van Groenigen and Van Kessel 2002). Britton et al.'s (2008) study of fauna from the Severn Estuary suggested that grazing livestock on salt-marsh can result in elevated δ^{15}N values compared to fauna from inland sites (Figure 8). Although the number of specimens analysed from Oosterbeintum is relatively small, they are consistent with the conclusions of that study (Figure 8). The increased faunal δ^{15}N values could also be related to the composition of the *terp* itself. Huisman et al. (2008) found that soil from the *terp* at Dokkum

contained high concentrations of carbon, nitrogen and phosphorus, possibly due to the incorporation into the *terp* of marine sediments or dung and other settlement refuse. If the amount of usable land around Oosterbeintum was restricted by the risk of flooding this could have led to the grazing of livestock and growing of crops on land into which there had been a persistent and heavy deposition (intentional or unintentional) of refuse and dung. This would have resulted in the increased $\delta^{15}N$ values observed in studies of manuring (Bogaard et al. 2007, Choi et al. 2003), which would then have been passed up the food chain to the human population. As previously mentioned, *terps* could expand to a substantial size, and even the smaller village *terps* would still have been sufficiently large to potentially allow for some livestock to be grazed and crops to be grown on the *terp*.

The two youngest individuals in the data set (4-5 years old) have the highest $\delta^{15}N$ values and among the highest $\delta^{13}C$. Their average $\delta^{15}N$ is 16.0±0.1‰, 4.1‰ higher than the average adult female $\delta^{15}N$ (11.9± 1.5‰, n=14) and their average $\delta^{13}C$ is -19.5±0.1‰, compared with the average female $\delta^{13}C$ of -20.2±0.5‰. These differences are consistent with the trophic difference and 'carnivore effect' (Schoeninger and Deniro 1984) which have been observed in individuals of breast-feeding age , although the ^{15}N enrichment at Oosterbeintum is approximately 1‰ greater than that seen at other medieval sites (Privat et al. 2002; Richards et al. 2002). The two 6 year old individuals also show relatively high $\delta^{15}N$ values (13.0±0.6‰), although they are within the range of values for the adult population, as are the $\delta^{13}C$ values. These four juveniles therefore could be argued to demonstrate a 'weaning effect', as the dietary shift from breast milk to an 'adult' diet is reflected by a gradual decrease in $\delta^{15}N$. However, the size of the enrichment and the age of the children displaying it demand more discussion. The youngest children sampled from Oosterbeintum were 4 or 5 years old and it is unlikely that they were still being breast-fed at this age. It may be that the high $\delta^{15}N$ values represent an earlier period of breast-feeding, observed due to the slow turnover of bone. However, in Oosterbeintum juveniles with elevated $\delta^{15}N$ are older than those in Richards et al.'s (2002) and Privat et al.'s (2002) studies, where juvenile $\delta^{15}N$ values had decreased towards the adult range by 2

or 3 years of age. In fact, Richards et al. (2002) found that juveniles between the ages of 4 and 8 had slightly lower $\delta^{15}N$ values than the adult population. This suggests that children at Oosterbeintum may have had a distinct diet, enriched in ^{15}N, for a substantial period after weaning had ceased. Unfortunately no children under the age of 4 were found at Oosterbeintum. This may be related to the burial of juveniles in a particular area or areas of the cemetery, as six of the eight children excavated at the site were buried relatively close together in the western part of the cemetery. The excavated part of the cemetery may therefore be a biased representation of the original burial community. The small number of juveniles sampled here, and the lack of younger individuals, makes it difficult to draw too firm a conclusion as to the reason for this elevation in $\delta^{15}N$.

Establishing a 'local' strontium composition

In a coastal region, such as Frisia, the local strontium range will lie between the two predominant isotopic sources; the bedrock or drift $^{87}Sr/^{86}Sr$ and sea/rainwater at ~0.7092. It can be determined, therefore, using a mixing model in which the local $^{87}Sr/^{86}Sr$ would be expected to be distributed linearly between the two end points on a plot of strontium isotope ratio versus inverse of strontium concentration (Montgomery et al. 2007). The geology of the northern Netherlands is relatively homogenous, with an underlying substrate of quaternary drift overlain by glacial deposits and later marine clays (Zagwijn 1974). The Oosterbeintum soil leach and herbivore enamel samples (Table 2) support an estimation of the local bio-available $^{87}Sr/^{86}Sr$ composition around the sea water $^{87}Sr/^{86}Sr$ of 0.7092. The pig enamel had a higher $^{87}Sr/^{86}Sr$ (0.7100), but as the carbon and nitrogen isotope values have hinted at two distinct diets among the pigs sampled, it is possible that this animal was not originally from Oosterbeintum. Unfortunately the pig tooth analysed was not associated with any other skeletal elements so no bone $\delta^{13}C$ or $\delta^{15}N$ data are available from that animal to investigate this hypothesis further.

A comparison of the dentine and enamel samples further supports a local $^{87}Sr/^{86}Sr$ around 0.7092 (Figure 9). Several studies have demonstrated the tendency of bone and dentine to absorb labile

strontium from the burial soil through incorporation or replacement of biogenic strontium and their strontium isotope ratios can thus help to characterise local values (Budd et al. 2000; Tricket et al. 2003; Montgomery et al. 2007). The convergence of these shifts in the dentine samples measured in this study on a value close to the soil and herbivore $^{87}Sr/^{86}Sr$ values supports a conservative estimate of the lower boundary of the local $^{87}Sr/^{86}Sr$ range of 0.7090. The upper boundary is more difficult to define but consideration of the very narrow local range at the nearby Neolithic sites of Swifterbant and Schipluiden (Smits et al. 2010) (Figure 10) suggests that a conservative estimate of the local range at Oosterbeintum of 0.7090-0.7094 is not unreasonable (Figure 5). Defining the local range for Oosterbeintum as 0.7090-0.7094 will only be applicable if its inhabitants sourced all their food and drink from the site and its environs, as appears to have been the case at Swifterbant and Schipluiden. The Frisian reputation for trading and seafaring, combined with the agricultural limitations of the salt marsh, makes it quite likely that some food was imported. This could have introduced 'non-local' isotopic sources into the diet of the inhabitants, contributing in part to the degree of variability at the site.

Migration

Even considering the possible influence of imported food sources on the local isotopic ranges, the $^{87}Sr/^{86}Sr$ and $\delta^{18}O_p$ results observed at Oosterbeintum indicate that not all of those buried at the cemetery grew up in the *terp* region. In this brackish environment there would have been few alternative sources of fresh drinking water other than the settlement's wells or central pond. It is therefore to be expected that individuals who had grown up at Oosterbeintum would have a relatively limited range of $\delta^{18}O_p$, produced predominantly by individual biological variation rather than changes in water source. This appears to be supported by the $\delta^{18}O_p$ results, as the majority of the data cluster together in a narrow range between 17.2‰ and 17.8‰ (Figure 6). This 0.6% range is therefore proposed as an indicative $\delta^{18}O_p$ range for a single population drinking from a sole source of water. It is not suggested that this cluster includes only local individuals (some of the associated

strontium isotope ratios preclude origins in the *terp* region) but rather that those who are local plot in this range.

Of the four individuals identified as non-local by their oxygen isotope values, only OOS360 has a $\delta^{18}O_p$ value that is over two standard deviations lower than the mean. This individual's value is too low to support origins in the Netherlands and indicates that they spent the early years of their life further east, possibly, considering the associated $^{87}Sr/^{86}Sr$ value of 0.7100, in Germany or coastal Scandinavia. The $\delta^{18}O_p$ result obtained for OOS624 is over two standard deviations higher than the mean and suggests this individual may have originated to the west of the Netherlands, potentially in France or the southern or western coast of Britain. The possible British origin of OOS624 is interesting, due to the strong links between England and Frisia. More consideration is needed of migration from England to continental Europe during this period, as there is a tendency to neglect this possibility and focus only on migration in the opposite direction, as discussed in historical sources. The $\delta^{18}O_p$ values of OOS241 and OOS487 are approximately one standard deviation higher than the mean so are less distinct from the rest of the population, but their identification as non-local is supported by their high $^{87}Sr/^{86}Sr$ values.

As Figure 10 shows, the range of $^{87}Sr/^{86}Sr$ at the site is far greater than that found at contemporary sites. This includes Ringlemere, Kent, UK which has itself been suggested to represent a possible migrant population and into whose range OOS624 falls comfortably (Brettell et al. 2012). There is also a certain amount of overlap between the lower half of the Oosterbeintum $^{87}Sr/^{86}Sr$ range and the data from the Caen region with the differences in $\delta^{18}O_p$ reflecting the geographical distance between the sites. OOS460, a 20-30 year old male, has the highest $^{87}Sr/^{86}Sr$ value of the dataset (0.7164), and must have grown up in a region of ancient or granitic rocks. Unfortunately it was not possible to obtain $\delta^{18}O_p$ data from OOS460. The next highest $^{87}Sr/^{86}Sr$ values (0.7132 and 0.7125) belong to OOS486 and OOS487: the two individuals in the double burial. Both skeletons were aged over 45 years, but sex assessment was only possible for OOS486, a probable male. Both have $\delta^{18}O_p$ values within the expected local range. The similarity of their strontium isotope ratios combined

with their inhumation in the same grave suggests that they may have grown up in the same area, and it is intriguing to consider the possible relationship between them. These high $^{87}Sr/^{86}Sr$ values rule out origins in any area of calcareous geology, such as eastern England, or in northern Germany or Denmark (two of the areas from which Anglo-Saxon migrants would have originated). The closest source (approximately 500km from Oosterbeintum) of solid geology that records radiogenic $^{87}Sr/^{86}Sr$ values over 0.712 is the Ardennes massif in Belgium (Drouet et al. 2005) where beech wood gives values up to 0.716. Glacial deposits, derived from Scandinavia, also provide a source of such values. Modern plant samples from Drenthe give values between 0.711 and 0.716 (Table 2) and supply a source of such values about 80km distance from the coast.

There are several individuals with $^{87}Sr/^{86}Sr$ below 0.7092, all of whom have $\delta^{18}O$ values within the expected local range, but who must have been exposed to a source of strontium with $^{87}Sr/^{86}Sr$ less than 0.7092. Marine carbonates such as chalk and limestone or drift deposits containing significant amounts of those rocks would provide such values, but although the Chalk Group runs under the whole of the Netherlands it only crops out in the southern and eastern parts of the country (Duin et al. 2006). It is possible that there is greater variation in biosphere strontium isotope values than there might at first appear, especially considering the high ratios found in Drenthe and other studies indicating variation in surface water $^{86}Sr/^{86}Sr$ values throughout this area of Europe (Frei and Frei 2011; Voerkelius et al. 2010). Another possible explanation, particularly pertinent in this economic and environmental context, is the consumption of 'foreign' strontium from imported foodstuffs. If certain resources, such as cereals, were being imported from areas with a lower $^{87}Sr/^{86}Sr$ range this would introduce a strontium source into the Oosterbeintum diet which was different from the local strontium range. As cereals have a high Sr/Ca this will have a disproportionate impact on biogenic $^{87}Sr/^{86}Sr$ in the skeleton compared with the consumption of 'local' meat. The individual with the lowest $\delta^{15}N$ (7.8‰) also has the lowest $^{87}Sr/^{86}Sr$ (0.7088) which, if food were being imported, could be explained by a cereal-rich, meat-poor diet. However, this pattern is not consistent among the

other individuals with low ^{87}Sr/^{86}Sr, all of which have δ^{15}N values within the range of the rest of the cemetery.

If the high δ^{15}N seen in the Oosterbeintum population is related to the salt-marsh and *terp* environment then the relatively low δ^{15}N of OOS473, and also OOS435 (9.2‰), could be interpreted as an indication of migration. No oxygen isotope data was available from OOS435 but this individual had ^{87}Sr/^{86}Sr within the local range of the site and so could have grown up nearby but outside of the *terp* region. OOS473 has a δ^{18}O value within the expected range for the site but their low ^{87}Sr/^{86}Sr would be consistent with having origins in a region of marine carbonates such as eastern England or France. That these two potentially recent migrants were a 40-50 year old female and a 19 year old male may suggest that migration was not confined to a specific age group, although this is impossible to confirm on the basis of two individuals. All of the non-local δ^{18}O and ^{87}Sr/^{86}Sr values come from individuals with δ^{15}N close to the site average (Figure 11), which may indicate that they were resident at Oosterbeintum for a sufficient length of time before death for the elevated *terp* signal to be present in their bones. The nature of migration to Oosterbeintum may therefore have been, at least for some, a permanent or long-term settlement, rather than a temporary stopping-place on a longer migration route to England.

Conclusion

The results of this study have revealed new information about the environment and inhabitants of the *terp* region. It has been shown that the peculiarities of the *terp* environment, either the salinity or the high organic content of the soils, resulted in elevated δ^{15}N values in both animals and humans. In certain contexts and in combination with other data, it should therefore be possible to use high δ^{15}N values to support an individual's residence in the *terp* region. In individuals whose strontium and/or oxygen isotope ratios suggest non-local origins, this more recent, 'local' signal can be used to draw inferences about the length of time since migration to the area. The narrow range

of δ^{18}O among the population of Oosterbeintum reflects the limited range of drinking water sources available to those living on a *terp*. The presence of outliers among the oxygen isotope results, and the wide range of strontium isotope values indicate that a significant number of those buried at Oosterbeintum did not grow up there. It is possible that some of these non-locals originated in the Anglo-Saxon 'homelands' of southern Denmark and northern Germany, as proposed by Van Giffen (1936). However, the range of ^{87}Sr/^{86}Sr and δ^{18}O at Oosterbeintum cannot be explained solely by this particular migration event. Individuals must have also migrated from more distant regions, such as England and Scandinavia. These results therefore have implications beyond Frisia itself. The distance and diversity of the geographical origins of the non-locals buried at the cemetery suggests that Oosterbeintum, and by inference the wider *terp* region, was part of a wide network of contact and movement that spanned the North Sea region. This is likely to be related to the Frisian reputation for trading and seafaring. Maritime trade would have created links between Frisia and other parts of Europe, as demonstrated by the 'Frisian quarters' found in trading centres such as Birka, York and Mainz (Heidinga 1997). The isotopic variability at Oosterbeintum highlights the dichotomy between the cultural isolation of the *terp* region, and the 'cosmopolitanism' of a trading community (Heidinga 1999). The potential availability (and need) of imported food resources could also explain the number of Oosterbeintum inhabitants with ^{87}Sr/^{86}Sr below the range that would be expected from a coastal salt-marsh community. This study has revealed new information on the interaction between the salt-marsh environment of northern Europe and those who inhabited it. The evidence of migration, particularly from such distant locations, contributes to a broader understanding of relationships and trade between regions throughout the North Sea area and highlights the important role of coastal regions in early medieval Europe.

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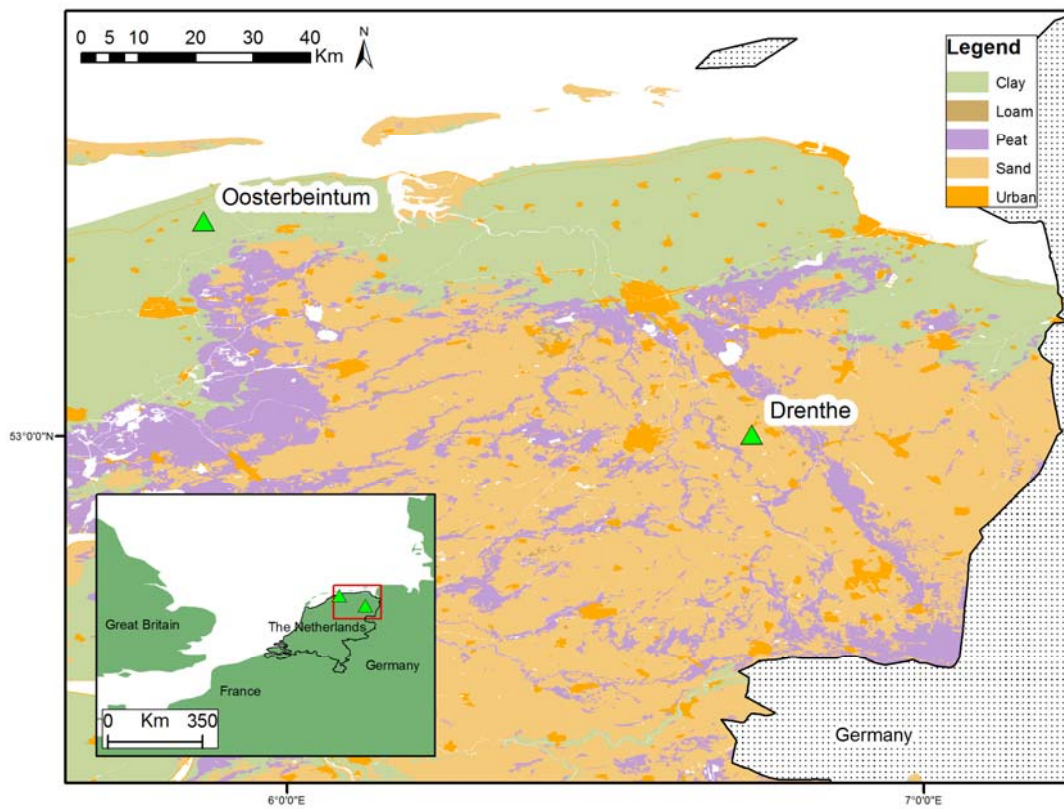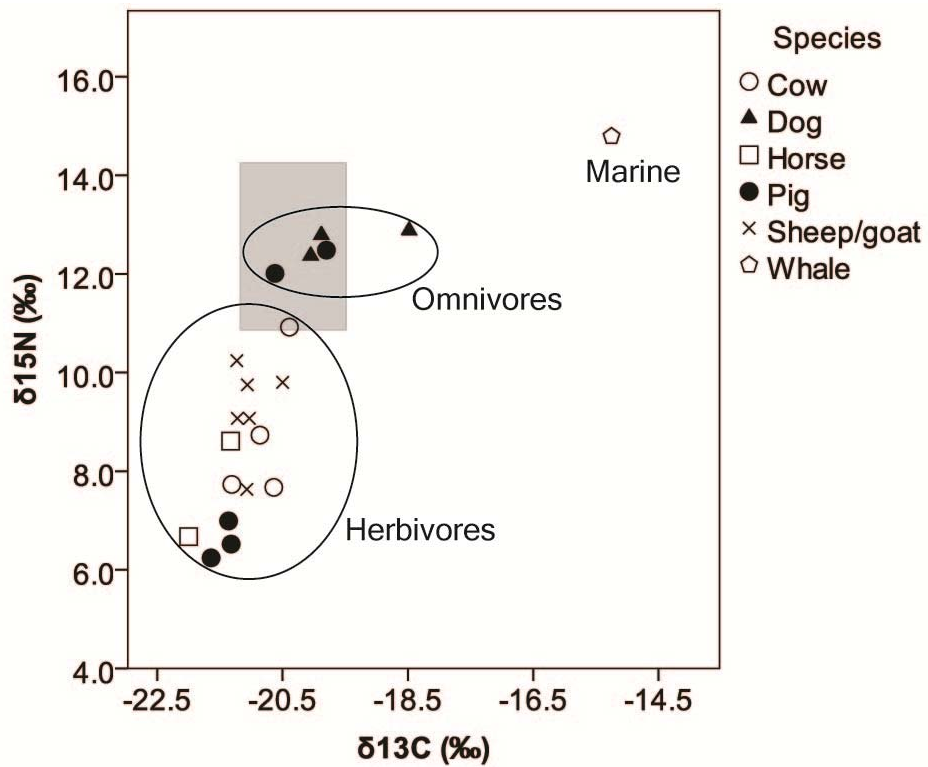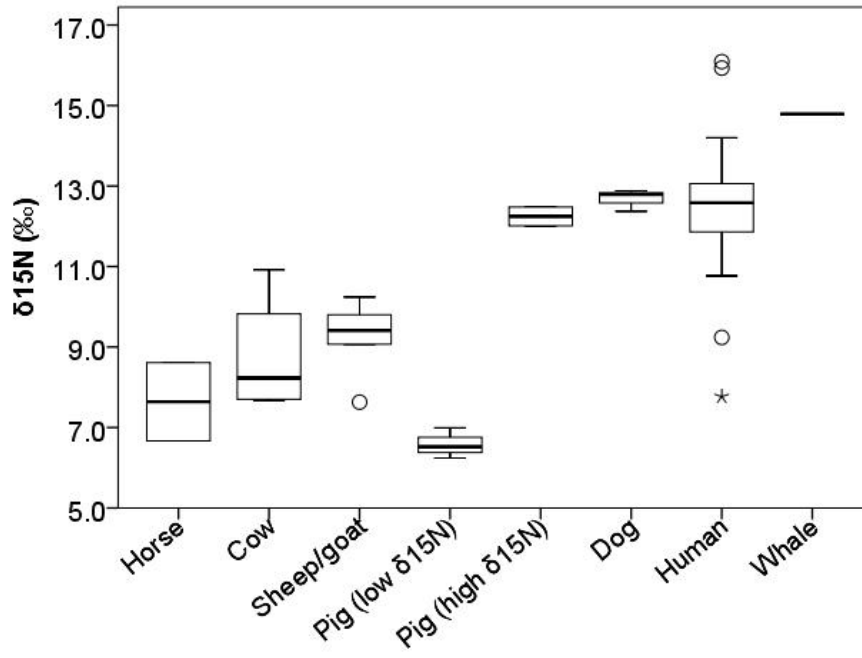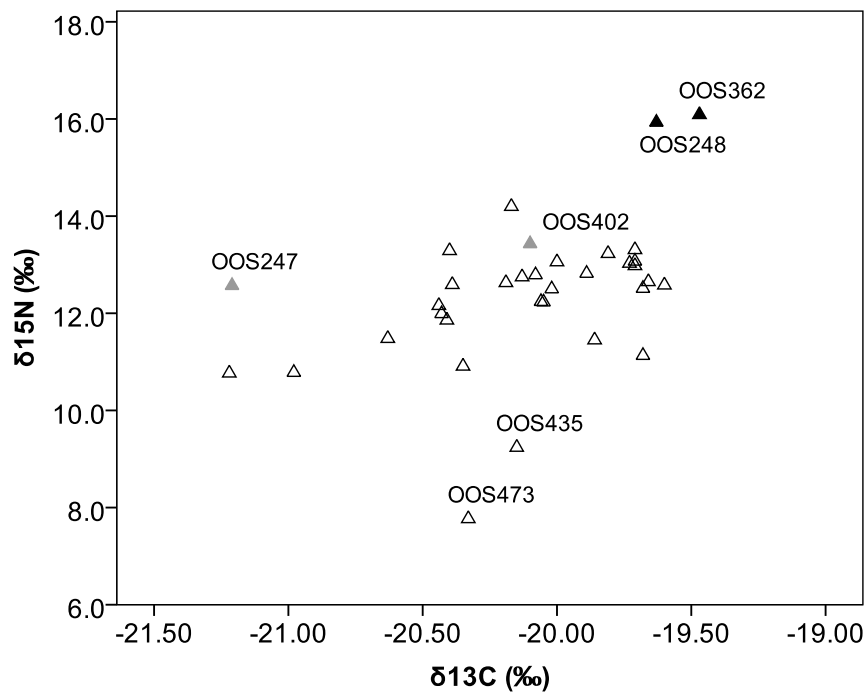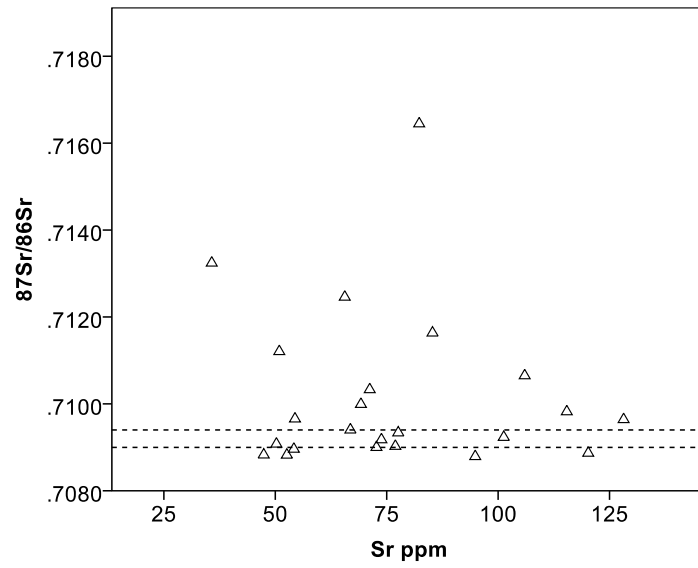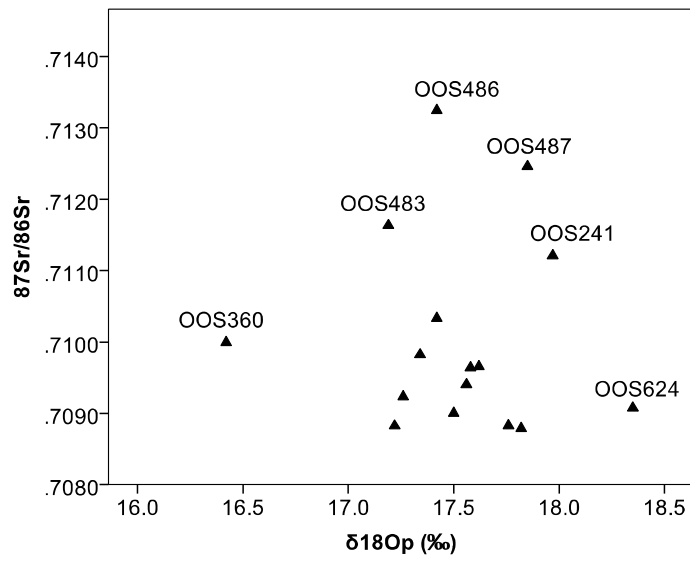
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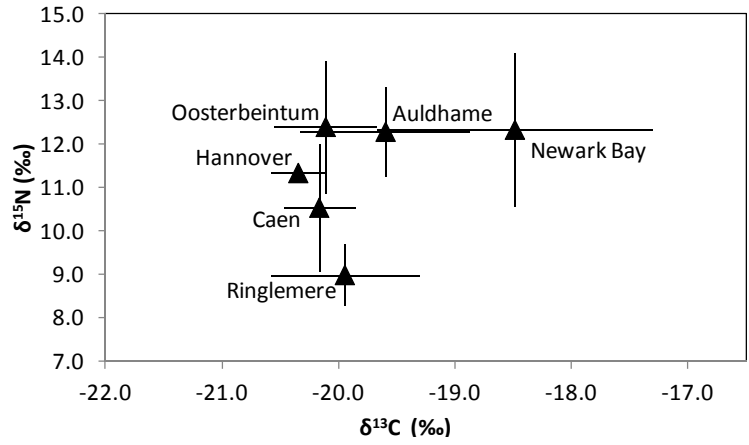
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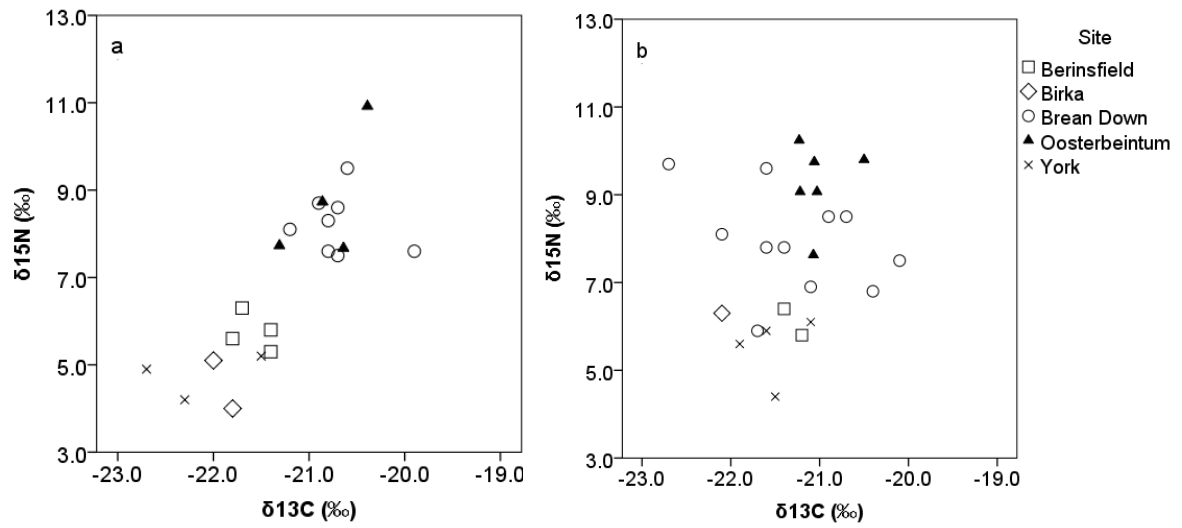
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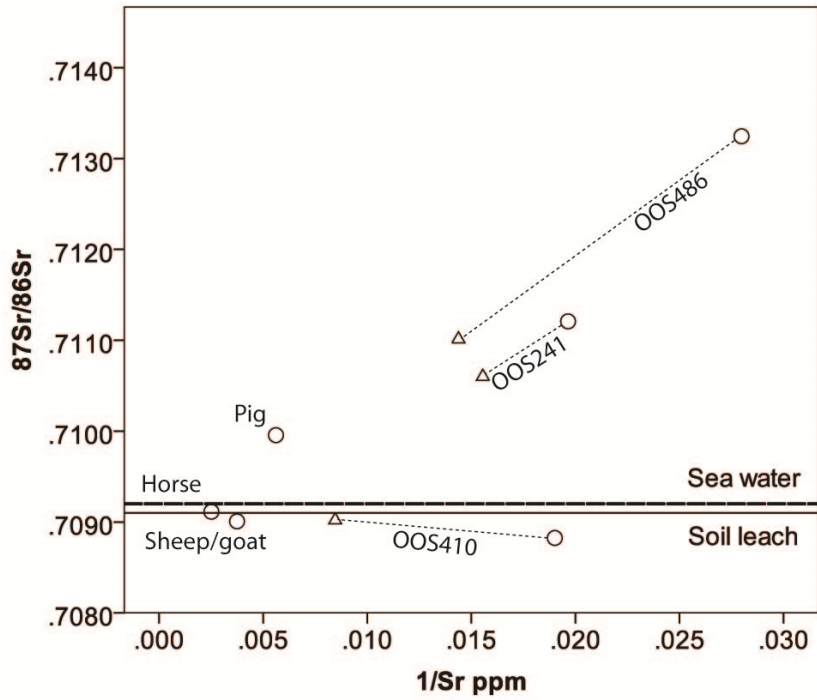
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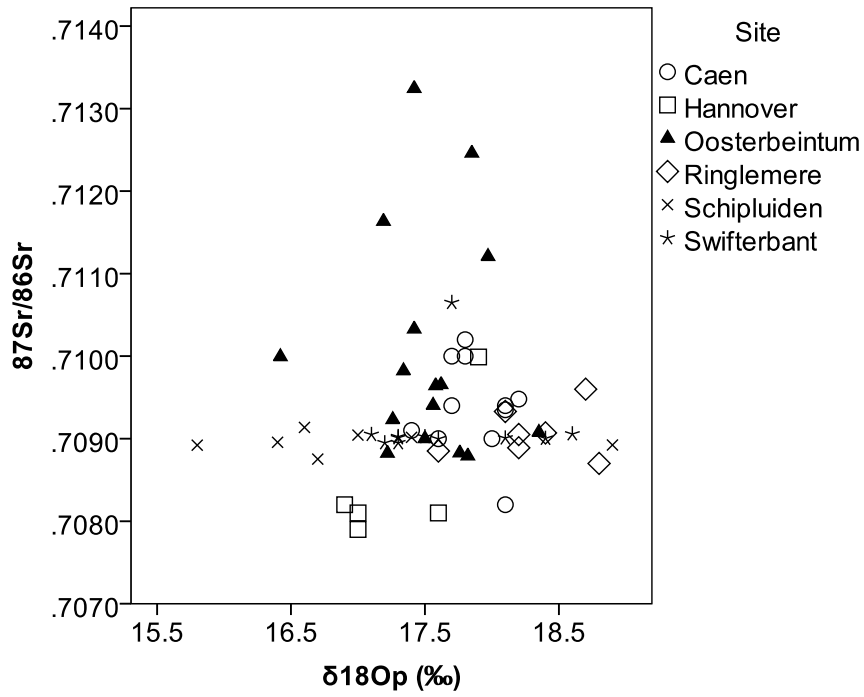
Figure 11
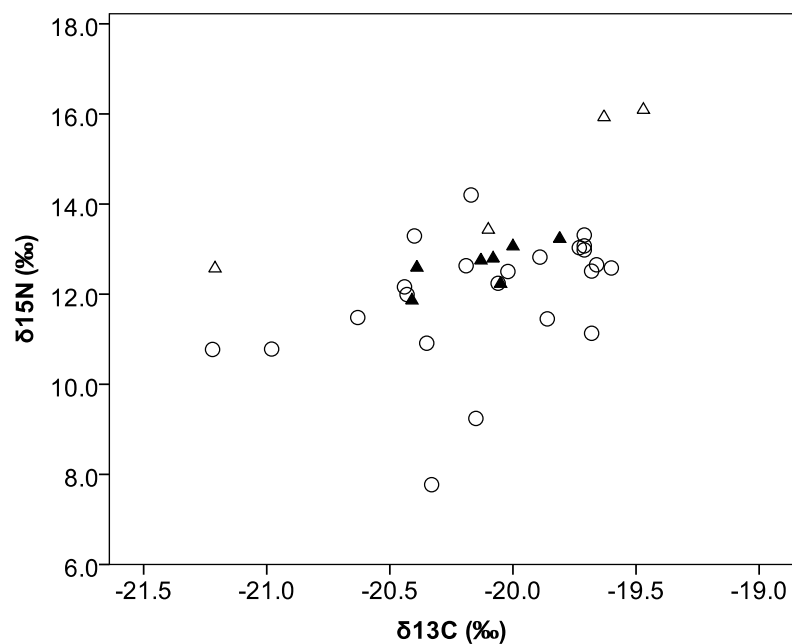
Captions for figures:

Figure 1. Simplified soil map of study region showing sampling locations. Data from Wageningen UR - Alterra, *Grondsoortenkaart 2006 - Simplified Soil Map of the Netherlands*, DANS.

Figure 2. Faunal $\delta^{15}N$ and $\delta^{13}C$ data showing expected trophic differences between species. Shaded box represents the human range of isotope values (excluding $\delta^{15}N$ outliers [see Figure 3]).

Figure 3. Box and whisker diagram of all $\delta^{15}N$ data showing the distinct groupings of the pig samples.

Figure 4. Human $\delta^{13}C$ and $\delta^{15}N$ results. Sample codes provided for outliers and juveniles. Black triangles indicate juveniles 4-5 years of age; grey triangles indicate juveniles ~6 years of age.

Figure 5. Human enamel $^{87}Sr/^{86}Sr$ data. Dotted lines represent the potential 'local' $^{87}Sr/^{86}Sr$ range of 0.7090-0.7094 based on faunal, dentine and soil leach data.

Figure 6. Human $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ data.

Figure 7. $\delta^{13}C$ and $\delta^{15}N$ data human from early Medieval sites at Caen, France; Hannover-Anderten, Germany, Ringlemere, England; Newark Bay, Orkney (Richards et al. 2006) and Auldhame, Scotland (Lamb et al. 2012).

Figure 8. High δ^{15}N values of Oosterbeintum (a) cattle and (b) sheep/goats compared to other early Medieval European sites (Privat et al. 2002, Linderholm et al. 2008, Muldner and Richards 2007), and Brean Down salt-marsh (Britton et al. 2008).

Figure 9. ^{87}Sr/^{86}Sr against the inverse of strontium concentration for enamel-dentine pairs (dotted lines) and faunal enamel samples. The solid line represents the ^{87}Sr/^{86}Sr of the soil leach and the dashed line represents the ^{87}Sr/^{86}Sr of sea water. The enamel-dentine pairs, soil leach and faunal data converge at approximately 0.7091.

Figure 10. ^{87}Sr/^{86}Sr data from Oosterbeintum and other early Medieval European sites (Smits et al. 2010, Brettell et al. 2012). Data from Sannerville and Giberville (Brettell et al. 2012) have been combined due to the sites' geographic proximity and are presented as Caen.

Figure 11. δ^{13}C and δ^{15}N for all Oosterbeintum humans, with juveniles represented by open triangles. ^{87}Sr/^{86}Sr and δ^{18}O outliers (shown as closed triangles) all fall within average range of δ^{13}C and δ^{15}N for site.

Table 1. Human isotope data.

Sample number	Site	Sex	Age	$\delta^{15}N$ collagen[#]	$\delta^{13}C$ collagen[#]	C:N	Collagen yield (wt%)	$^{87}Sr/^{86}Sr$ enamel	Sr/ppm enamel	$^{87}Sr/^{86}Sr$ dentine	Sr/ppm dentine	$d^{18}O_p$ enamel
OOS060	Oosterbeintum	F	35-45+	14.2	-20.2	3.5	0.8	0.70982	115	--	--	17.3
OOS100	Oosterbeintum	M	30-40	13.3	-19.7	3.5	0.5	0.70887	120	--	--	--
OOS241	Oosterbeintum	F	45+	12.8*	-20.1*	3.3*	2.4*	0.71121	51	0.71060	64	18.0
OOS247	Oosterbeintum	Unknown	6	12.6	-21.2	3.4	1.5	--	--	--	--	--
OOS248	Oosterbeintum	Unknown	4-5	15.9*	-19.6*	3.3*	2.2*	--	--	--	--	--
OOS273	Oosterbeintum	Unknown	25-35	12.6	-19.6	3.3	2.9	--	--	--	--	--
OOS335	Oosterbeintum	M	30-40	12.5	-19.7	3.4	1.6	0.70923	101	--	--	17.3
OOS360	Oosterbeintum	F	40-50	12.6	-20.4	3.6	0.6	0.70999	69	--	--	16.4
OOS362	Oosterbeintum	Unknown	4-5	16.1	-19.5	3.3	1.1	--	--	--	--	--
OOS374	Oosterbeintum	F	30-45	12.5	-20.0	3.4	1.0	--	--	--	--	--
OOS393	Oosterbeintum	F	45+	13.0	-19.7	3.4	0.7	--	--	--	--	--
OOS398	Oosterbeintum	MF	35-45	13.3	-20.4	3.4	1.4	0.71033	71	--	--	17.4
OOS402	Oosterbeintum	Unknown	6	13.4	-20.1	3.3	1.6	--	--	--	--	--
OOS405	Oosterbeintum	Unknown	17-19	11.5	-19.9	3.3	1.2	0.70964	128	--	--	17.6
OOS410	Oosterbeintum	M	40-50	10.9	-20.4	3.4	0.6	0.70882	53	0.70902	118	17.2
OOS420	Oosterbeintum	M	35-45	12.6	-20.2	3.4	0.5	0.70940	67	--	--	17.6
OOS424	Oosterbeintum	F	45+	12.2	-20.1	3.5	1.2	--	--	--	--	--
OOS428	Oosterbeintum	F	25-35	10.8	-21.2	3.2	5.4	--	--	--	--	--

OOS433	Oosterbeintum	Unknown	25-30	12.8	-19.9	3.3	2.3	0.70918	74	--	--	--
OOS435	Oosterbeintum	M	19	9.2	-20.2	3.6	1.1	0.70934	78	--	--	--
OOS451	Oosterbeintum	M	35-45	12.7	-19.7	3.2	2.2	0.70896	54	--	--	--
OOS458	Oosterbeintum	M	35-45	12.2	-20.4	3.4	0.8	0.70903	77	--	--	--
OOS460	Oosterbeintum	M	20-30	12.8	-20.1	3.4	0.9	0.71645	82	--	--	--
OOS461	Oosterbeintum	F	Adult	11.1	-19.7	3.3	1.0	--	--	--	--	--
OOS473	Oosterbeintum	?F	40-50	7.8*	-20.3*	3.3*	2.4*	0.70883	47	--	--	17.8
OOS474	Oosterbeintum	?F	30-40	11.5**	-20.6**	3.2**	4.5**	0.70966	54	--	--	17.6
OOS483	Oosterbeintum	F	30-40	12.2	-20.1	3.2	3.7	0.71163	85	--	--	17.2
OOS486	Oosterbeintum	?M	45+	13.2	-19.8	3.3	3.3	0.71325	36	0.71101	70	17.4
OOS487	Oosterbeintum	Unknown	45+	13.1	-20.0	3.3	2.7	0.71246	66	--	--	17.9
OOS501	Oosterbeintum	F	25-35	12.0*	-20.4*	3.5*	0.6*	0.71065	106	--	--	--
OOS570	Oosterbeintum	?F	45+	13.0	-19.7	3.4	1.1	0.70879	95	--	--	17.8
OOS605	Oosterbeintum	?M	45+	13.1*	-19.7*	3.2*	5.8*	0.70900	73	--	--	17.5
OOS606	Oosterbeintum	F	25-35	10.8	-21.0	3.2	6.2	--	--	--	--	--
OOS624	Oosterbeintum	Unknown	16-18	11.9	-20.4	3.4	0.9	0.70910	50	--	--	18.4
Glm 121	Giberville	F	30-40	8.7	-20.9	3.3	5.4	--	--	--	--	--
Glm 218	Giberville	F	18-30	9.8	-20.3	3.2	4.9	--	--	--	--	--
Glm 304	Giberville	M	Unknown	13.2	-20.4	3.2	4.7	--	--	--	--	--
Glm 319	Giberville	M	70+	12.9	20.1	3.3	4.3	--	--	--	--	--
San 034	Sannerville	?M	18-25	10.7	-20.2	3.3	5.7	--	--	--	--	--
San 087	Sannerville	?F	Unknown	10.4	-19.9	3.3	3.5	--	--	--	--	--
San 089	Sannerville	?M	18-25	10.2	-20.0	3.2	5.1	--	--	--	--	--

San 096	Sannerville	M	Unknown	9.5	-20.0	3.3	4.7	--	--	--	--	--
San 107	Sannerville	M	20-30	9.2	-20.0	3.2	5.1	--	--	--	--	--
San 119	Sannerville	F	40-50	10.9	-19.9	3.2	5.9	--	--	--	--	--
Ring 008	Ringlemere	?F	50+	9.5	-20.4	3.4	3.7	--	--	--	--	--
Ring 039	Ringlemere	??F	18-35	8.5	-19.5	3.3	3.1	--	--	--	--	--
And 012	Hannover	M	Adult	11.4	-20.50	3.5	3.9	--	--	--	--	--
And 064	Hannover	M	Mature/middle adult	11.4	-20.10	3.3	5.2	--	--	--	--	--
And 074	Hannover	M	~75	11.4	-20.60	3.3	6.8	--	--	--	--	--
And 102	Hannover	M	~35	11.2	-20.20	3.3	5.4	--	--	--	--	--

[#] Bone sampled for carbon and nitrogen isotope analysis taken from the rib unless specified: *long bone (radius/fibula/ulna); ** cranium

Table 2. Faunal and environmental isotope data.

Sample number	Site	Species	$\delta^{15}N$ collagen	$\delta^{13}C$ collagen	C:N	Collagen yield (wt%)	$^{87}Sr/^{86}Sr$ enamel	Sr/ppm enamel
OOSSG1	Oosterbeintum	Sheep/goat	9.1	-21.2	3.2	6.0	0.70901	267
OOSSG2	Oosterbeintum	Sheep/goat	9.8	-20.5	3.2	7.0	--	--
OOSSG3	Oosterbeintum	Sheep/goat	7.6	-21.1	3.3	4.3	--	--
OOSSG4	Oosterbeintum	Sheep/goat	9.8	-21.1	3.2	3.7	--	--
OOSSG5	Oosterbeintum	Sheep/goat	9.1	-21.0	3.2	7.9	--	--
OOSSG6	Oosterbeintum	Sheep/goat	10.2	-21.2	3.2	4.9	--	--
OOSCOW261	Oosterbeintum	Cattle	7.7	-21.3	3.2	6.2	--	--
OOSCOW310	Oosterbeintum	Cattle	7.7	-20.6	3.3	2.9	--	--
OOSCOW479	Oosterbeintum	Cattle	8.7	-20.9	3.2	4.9	--	--
OOSCOW631	Oosterbeintum	Cattle	10.9	-20.4	3.2	3.8	--	--
OOSDOG340	Oosterbeintum	Dog	12.9	-18.5	3.2	3.9	--	--
OOSDOG404	Oosterbeintum	Dog	12.8	-19.9	3.4	1.8	--	--
OOSDOG480	Oosterbeintum	Dog	12.4	-20.1	3.3	1.0	--	--

OOSH430	Oosterbeintum	Horse	8.6	-21.3	3.3	4.9	0.70911	398
OOSH490	Oosterbeintum	Horse	6.7	-22.0	3.2	2.2	--	--
OOSPIG176	Oosterbeintum	Pig	6.2	-21.6	3.2	3.8	--	--
OOSPIG201	Oosterbeintum	Pig	12.5	-19.8	3.4	2.2	--	--
OOSPIG216	Oosterbeintum	Pig	7.0	-21.4	3.3	5.3	--	--
OOSPIG302	Oosterbeintum	Pig	6.5	-21.3	3.4	1.2	--	--
OOSPIG310	Oosterbeintum	Pig	12.0	-20.6	3.3	3.9	--	--
OOSPIGE	Oosterbeintum	Pig	--	--	--	--	0.70996	178
OOSW164	Oosterbeintum	Whale	14.8	-15.3	3.3	2.1	--	--
OOS_SOIL	Oosterbeintum	Soil leach	--	--	--	--	0.70910	--
HOL-01	Drenthe	Plant	--	--	--	--	0.7126	--
HOL-02	Drenthe	Plant	--	--	--	--	0.7142	--
HOL-03	Drenthe	Plant	--	--	--	--	0.7124	--
HOL-04	Drenthe	Plant	--	--	--	--	0.7140	--
HOL-05	Drenthe	Plant	--	--	--	--	0.7136	--
HOL-06	Drenthe	Plant	--	--	--	--	0.7156	--

| HOL-08 | Drenthe | Plant | -- | -- | -- | -- | 0.7113 | -- |