The first settlers of Iceland: an isotopic approach to colonisation

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The colonisation of the North Atlantic from the eighth century AD was the earliest expansion of European populations to the west. Norse and Celtic voyagers are recorded as reaching and settling in Iceland, Greenland and easternmost North America between c. *AD 750 and 1000, but the date of these events and the homeland of the colonists are subjects of some debate. In this project, the birthplaces of 90 early burials from Iceland were sought using strontium isotope analysis. At least nine, and probably thirteen, of these individuals can be distinguished as migrants to Iceland from other places. In addition, there are clear differences to be seen in the diets of the local Icelandic peoples, ranging from largely terrestrial to largely marine consumption.*

Keywords: Iceland, colonisation, settlement, isotopes, strontium, human migration, enamel

Introduction

An extraordinary series of events began in the North Sea and North Atlantic region around the eighth century AD. Norse raiders and settlers from Scandinavia, better known as the Vikings, began expanding to the west, settling in the British Isles and Ireland, including the smaller groups of islands, the Orkneys, Shetlands, Hebrides and the Isle of Man. Stepping across the North Atlantic, Norse colonists reached the Faeroe Islands by around AD 825, Iceland by around AD 875 and Greenland by around AD 895 (Figure 1). Both Iceland and the Faeroe Islands were uninhabited at the time of the Norse colonisation. The Norse also settled briefly in North America at L'Anse aux Meadows, Newfoundland, around AD 1000 (Jones 1986; Wallace 1991). The Greenland colonies were abandoned by around AD 1450 in the face of deteriorating climate and agricultural conditions.

Thirteenth century Icelandic chroniclers reported that the majority of the original settlers came from Norway but they also thought that a significant number came from the British Isles, of both Norse and Celtic origin. There is some written evidence that people from the Hebrides, Ireland and the west coast of Scotland settled in Iceland, although they were likely to have been of Norwegian descent (Loyn 1977). Contact between Iceland and the Hebrides is mentioned in the Icelandic sagas and is known through artefactual evidence. Although written several hundred years later than the events it describes, the *Book of Settlements* refers to Hebridean Norsemen who settled especially in western Iceland (Benediktsson 1968).

There is considerable debate regarding the actual timing of the arrival of the first people, with some evidence indicating human activity in Iceland prior to the date of AD 874

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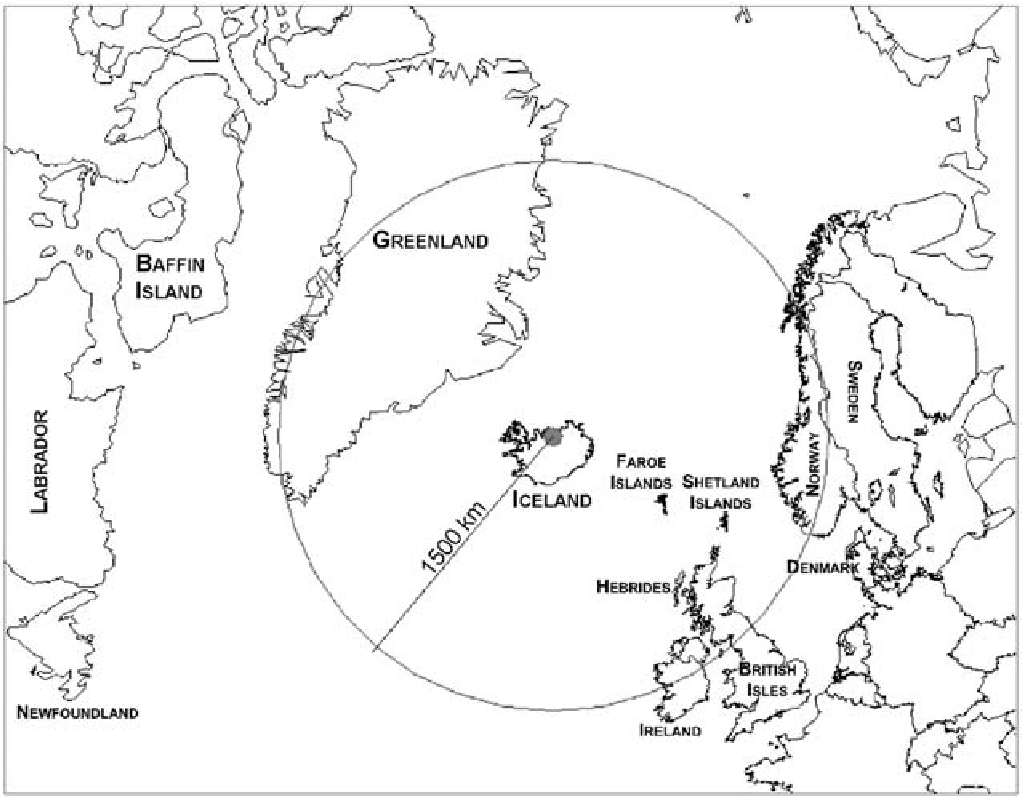

Figure 1. The North Atlantic and the major locations of Norse settlement and colonisation. The circle shows the area within 1500km of Iceland.

suggested by written sources (e.g. Roberts *et al.* 2003), in some instances as much as a century or two (e.g. Hermanns-Audardóttir 1991); however, no evidence of such early settlement has yet been found. Similar types of graves have been found on the Isle of Lewis in the Outer Hebrides and in Iceland (Dunwell *et al.* 1996). However, the homelands of the settlers have long been debated. The *Book of Settlements* also reports that almost all of the colonists came in the first 60 years of settlement and very few thereafter (Benediktsson 1968), again a subject of uncertainty.

Explanations for this expansion have included ship design, population growth, political unrest and favourable climatic conditions. Whatever the reasons, the colonisation remains a fascinating and rather mysterious subject, with population movement likely from several different areas. Isotopic provenancing of human bone and tooth enamel, a relatively new method for the study of human migration, should work well in the investigation of the settlers of the North Atlantic and their homelands. Iceland was selected as the place to begin our investigations for several reasons. A relatively large number of human burials have been excavated there from the period of initial settlement, providing material for analysis. As Iceland has only recently, in geological time, emerged from the sea, created by submarine volcanic mountain building, the strontium isotope ratio of the soil is quite low. This means that migrants to Iceland from elsewhere will be readily distinguishable from those born there.

Table 1. Possible results of isotope analysis of human tooth enamel vs. bone

	Bone isotope ratio	
	Local	**Exotic**
Enamel isotope ratio		
Local	Indigenous	Recent returnee
Exotic	Long-term migrant	Short-term migrant

Isotopic provenancing of human remains

The method of isotopic provenancing of human remains has been in use in archaeology for approximately 15 years. Isotopes of strontium, oxygen and lead have been used in such studies. The basic principle is essentially the same for the different isotopes and involves comparison of isotope ratios in human tooth enamel and bone. The enamel in teeth forms in early childhood and undergoes little subsequent change (Hillson 1996). Post-mortem changes in enamel are minimal. Enamel has been shown to be generally resistant to contamination and a reliable indicator of biogenic levels of strontium isotopes (e.g. Åberg *et al.* 1998; Budd *et al.* 2000; Kohn *et al.* 1996). Human bone is dynamic. The process of bone remodelling turns over the chemical composition of bone in a period of roughly 10 years. Because isotopic ratios vary geographically, values in human teeth (place of birth) that do not match those of bone (place of death) indicate immigrants.

There are four possible outcomes in the comparison of enamel and bone isotope ratios in the same individual (Table 1). If the enamel and bone ratios are similar then the individual probably did not move. If the enamel ratio is distinct from the local ratio, this individual must have moved to the place of death from a geologically distinct homeland. These two situations are most common. In cases where the bone ratio is exotic, either individuals have recently returned to the place of death after a long residence elsewhere (enamel is local), or the individual has only been resident in the place of death for a short time (enamel is exotic). These cases are rare.

The local isotopic signal can be measured in several ways: in human bone from the individuals whose teeth are analysed, from other human bones at the site, from archaeological fauna at the site, or from modern fauna in the vicinity. Because of the expense of the analyses and the fact that bone is subject to contamination, in this study we have measured only enamel from archaeological or modern fauna to establish the bio-available levels of strontium isotopes in the local environment (Price *et al.* 2002).

The research of the Laboratory for Archaeological Chemistry has focused primarily on strontium isotopes. A number of studies have been published documenting the utility of strontium isotope analysis, involving the Anasazi period in Arizona (Price *et al.* 1994a; Ezzo *et al.* 1997), the Neolithic Linearbandkeramik and Bell Beaker periods in southern Germany (e.g. Price *et al.* 1994b, 2001), slaves in the historical period in South Africa (Sealy *et al.* 1991, 1995), and Neolithic and Norse skeletons from the Hebrides (Montgomery *et al.* 1999, 2000, 2003), among others.

The stable isotopes of strontium include ^{84}Sr (~0.56%), ^{86}Sr (~9.87%), and ^{88}Sr (~82.53%). ^{87}Sr is formed over time by the radioactive decay of rubidium (^{87}Rb) and comprises approximately 7.04% of total strontium (Faure & Powell 1972). Variations in strontium isotope compositions in natural materials are conventionally expressed as $^{87}Sr/^{86}Sr$ ratios (the abundance of ^{86}Sr is similar to that of ^{87}Sr). Strontium isotope ratios vary with the age and type of rock as a function of the original $^{87}Rb/^{86}Sr$ ratio of a source and its age (Faure & Powell 1972; Faure 1986). Geological units that are very old (>100m.y.) and had very high original Rb/Sr ratios will have very high $^{87}Sr/^{86}Sr$ ratios today as well as in the recent past (<1m.y.). In contrast, rocks that are geologically young (<1-10m.y.) and that have low Rb/Sr ratios, such as late-Cenozoic volcanic areas, generally have $^{87}Sr/^{86}Sr$ ratios less than 0.706 (e.g. Rogers & Hawkesworth 1989). These variations may seem small, but they are exceptionally large from a geological standpoint and far in excess of analytical error using TIMS, a Thermal Ionisation Mass Spectrometer (± 0.00001 for $^{87}Sr/^{86}Sr$). Differences in the third decimal place are usually significant in terms of human movement.

The permanent first molar is preferred for analysis, both for consistency and the fact that the enamel of this tooth forms during gestation and very early childhood. A small portion of the enamel was removed from the tooth, *c*. 10mg. The tooth samples were mechanically abraded with a dental drill fitted with a sanding bit to remove any visible dirt and/or preservative and ground to remove the enamel layer from the underlying dentine. Tooth enamel samples were then transferred to sterile savilex digestion vials and hot digested in ultrapure concentrated nitric acid, dried in a sterile laminar flow drying box and redissolved in ultrapure 2.5N hydrochloric acid. This procedure was repeated if there were any trace organics remaining in the sample. Strontium was isolated using cation exchange chromatography with 2.5N hydrochloric acid as the mobile phase.

Samples were then mounted on zone-refined tantalum filaments, and strontium was analysed using a thermal ionisation multiple collector mass spectrometer (TIMS) in the Isotope Geochemistry Laboratory at the University of North Carolina, Chapel Hill. $^{87}Sr/^{86}Sr$ ratios were corrected for mass fractionation in the instrument using the exponential mass fractionation law and $^{86}Sr/^{88}Sr = 0.1194$. The samples were measured using a MicroMass Sector 54. $^{87}Sr/^{86}Sr$ analyses ($n = 40$) of the NIST SRM strontium carbonate yielded a value of 0.710259 ± 0.0003 (2 SE). Internal precision (standard error) is typically 0.000006 to 0.000010, based on 100 dynamic cycles of data collection. Analytical procedures are described in greater detail in Ezzo *et al.* (1997) and Bentley *et al.* (2002).

Geological and bioavailable strontium in Iceland and the North Atlantic

An important consideration in the isotope provenancing of human remains is the geological variability present in the study area. In the case of the North Atlantic, and specifically Iceland, the geological context is almost ideal for such a study. Iceland has one of the youngest landscapes on the earth; it is a volcanic island that emerged from the sea over the last 25 million years and one of the few places on earth where a mid-ocean ridge is exposed above sea level (Figure 2). This new volcanic bedrock has a very low strontium isotope signature. Any migrants from northern Europe to the island will exhibit highly distinctive strontium isotope ratios in their tooth enamel, as they will probably have come from geologically older areas, such as northern Norway, the Scottish Isles, Ireland, and the Faeroes.

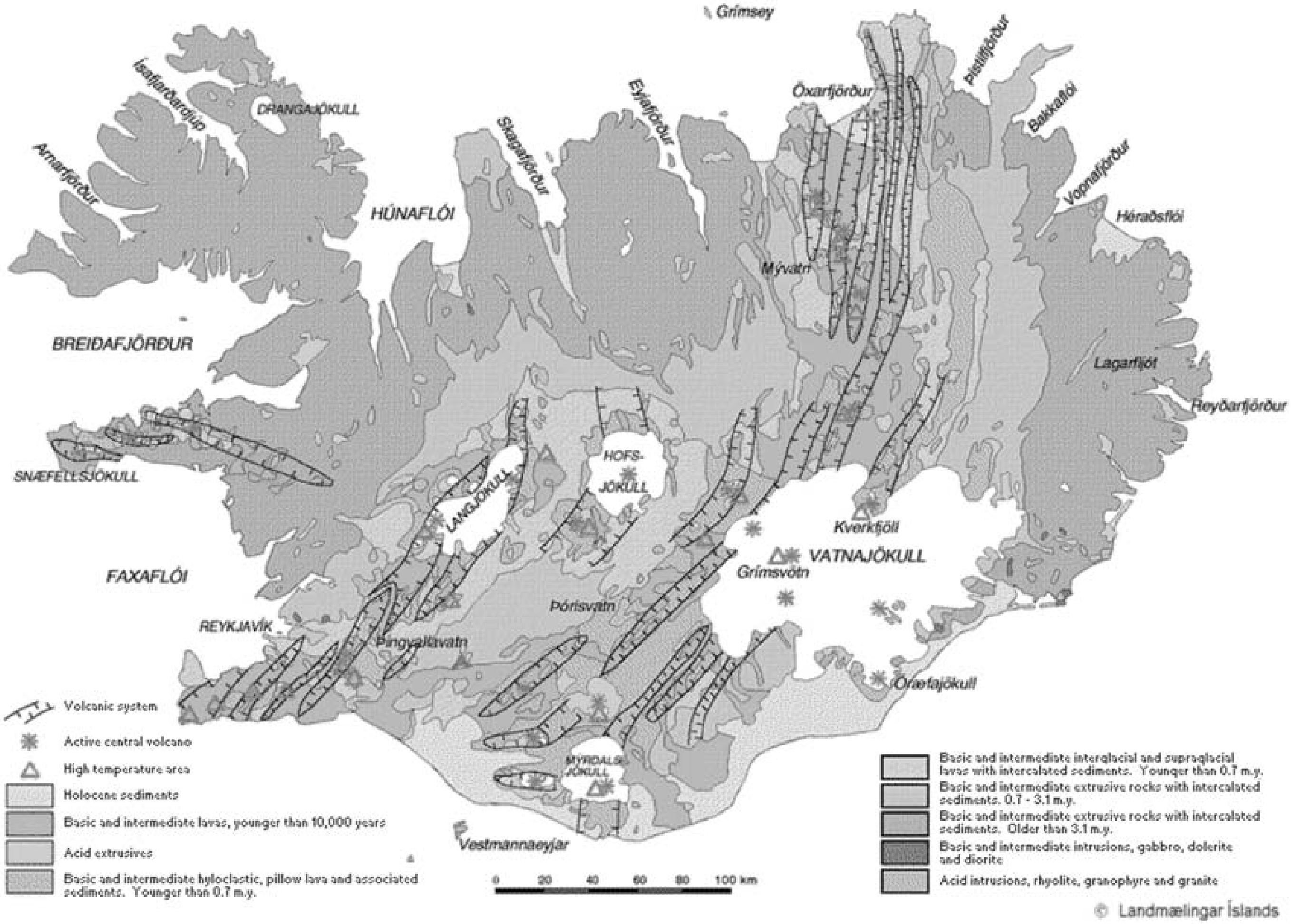

Figure 2. The geology of Iceland.

Table 2. Strontium isotope ratios in modern sheep tooth enamel from Iceland

Place name	Age (in years)	$^{87}Sr/^{86}Sr$ ratio
Brú, Biskupstungum (South Iceland)	6-7	0.706067
Kjóafell, Kjós (West Iceland)	5	0.706384
Ormarsstadir, Fellum (East Iceland)	7-8	0.705922
Jadar, Heggstadanes (North Iceland)	10	0.706965

Table 3. Human tooth enamel measurements from Greenland. Eastern Settlement

KNK221x11, Ruin Group 048, grave 3	Tooth	0.712157
KNK 223x1, Ruin Group 035, churchyard	Tooth	0.706532
KNK223x14, Ruin Group 035, grave 3	Tooth	0.706851
KNK223x15, Ruin Group 035, grave 2	Tooth	0.709542

Baseline strontium isotope ratios for Iceland, estimated on the age and composition of the basalt, suggest a value between 0.703 and 0.704. Measured ratios on geological formations at different locations in Iceland confirm this value as the best estimate for the island as a whole (Dickin 1997; Schilling 1973; Sun & Jahn 1979; Taylor *et al.* 1998; Wood *et al.* 1979).

Strontium isotope ratios in the enamel of modern sheep teeth were measured (Table 2). These originated from various locations in Iceland – Jadar, Heggstadanes (north), Brú, Biskupstungur (south), Ormarsstadir, Fellum (east) and Kjóafell, Kjós (west). These values range between 0.7059 and 0.7069 and are considerably higher than the reported geological values for Iceland. We have also measured modern barley from Iceland and obtained a value of 0.7068. The minimum value for prehistoric human tooth enamel from Iceland, reported below, is 0.7056. Clearly bioavailable strontium isotope ratios are higher than values reported for rock. The reason for this offset is not known at present, but may relate to the effects of sea spray over large parts of the island. Ocean water has an $^{87}Sr/^{86}Sr$ value of 0.7092 and may have raised the bioavailable values.

The most probable places of contact and origin for the Icelandic settlers include Greenland, the Faeroe Islands, the northern British Isles and Ireland, and the west coast of Norway. These areas in the North Atlantic generally have higher strontium isotope ratios than Iceland.

Greenland, for example, contains some of the oldest rocks on earth with high strontium isotopes ratios. Hoppe *et al.* (2003) have estimated Greenland values in the range between 0.725 and 0.755. Minimum values for the Disko Bay region are measured at greater than $\geqslant$0.725 (Kalsbeek & Taylor 1999). There is of course substantial variation within the geological formations of Greenland, but in general $^{87}Sr/^{86}Sr$ values are high. We have measured strontium isotopes in human tooth enamel from several individuals from Greenland (Table 3). These values are highly variable, ranging from 0.706 to 0.712, and may not be representative. Two factors may have caused these values to differ from bioavailable $^{87}Sr/^{86}Sr$ in Greenland. A diet of largely marine foods would move human enamel values toward the known value for seawater. It is also possible that some or all the individuals we have measured were in fact migrants to Greenland from elsewhere.

Further east along the North Atlantic rim, strontium isotope ratios are higher than on Iceland. The Faeroes are part of the mid-Atlantic ridge. The islands are basaltic rock with a thin layer of moraine and peat on the surface (Rasmussen & Noe-Nygaard 1970). Strontium isotope values have not been reported but are likely to be similar to other areas of the North Atlantic Tertiary Volcanic Province (Larsen *et al.* 1999). The northern islands of Britain – the Shetlands, Orkneys, and Hebrides – have varying but generally high $^{87}Sr/^{86}Sr$ values. The geology of Shetland is varied and the islands contain a large and diverse range of rock types – igneous, sedimentary, volcanic, with metamorphic rocks predominant.

The Orkneys, a group of more than 200 islands 16km north of the Scottish coast, are composed largely of Old Red Sandstone from the Devonian. We have measured a single sample of modern barley from the Orkney Islands and obtained a value of 0.7123. Montgomery *et al.* (2003) measured values from a Norse graveyard on the Isle of Lewis in the Hebrides at 0.709. They concluded that one male, with an enamel value around 0.707, had probably migrated to Lewis from within the North Atlantic Tertiary Volcanic Province (e.g. the small Scottish islands of Skye, Mull, Canna, Eigg, and much of County Antrim in Northern Ireland). Much of County Antrim is Tertiary basalt with predictable $^{87}Sr/^{86}Sr$ values around 0.707.

In Great Britain, soil leachate values suggest labile $^{87}Sr/^{86}Sr$ variations among soils overlying sedimentary rocks from about 0.7073 on Cretaceous chalk to 0.7115 on Triassic sandstone (Budd *et al.* 2000). Soils formed on igneous and metamorphic rocks as well as rubidium-rich clay soils are likely to have far higher ratios. Budd *et al.* (2000) report human enamel values from Anglo-Saxon England ranging from 0.708 to 0.712.

Values measured on granites and gneiss in southern Norway range from 0.7087 to 0.7185 and even 0.7519 and higher (Wilson *et al.* 1977). Åberg *et al.* (1998) report values ranging from 0.7077 to 0.7323 for human enamel from localities in southern Norway between Bergen and Oslo.

For the purposes of this study, it is sufficient to know that individuals who went to Iceland from elsewhere in the North Atlantic would have had strontium isotope ratios distinct from the local Icelandic values. For future research, the local values in Norway, the British Isles, Ireland and the Faeroes will be used to try and isolate the places from where these migrant individuals came. In combination with oxygen and lead isotopes we hope to be able to constrain possible places of birth. For the moment, however, we will focus on identifying migrants to Iceland.

The human remains from Iceland

Viking age burials

A typical Icelandic pre-Christian Viking burial place is located on a low piece of land, on a low rise or a small bank. They are normally found some distance from settlement sites, either just outside the home-fields, at settlement boundaries or along ancient roads or tracks (Fridriksson 2004). The burials take three main forms, mounds, graves or a combination of the two, a shallow grave with a low mound on top. All burials are inhumations; cremation graves are unknown. The graves can be oval or round in form, but are often rectangular. They measure typically 150-200cm long and *c*. 50cm wide. The depth of the graves varies from 20-100cm, but the average is about 50cm (Eldjárn 2000). Viking burials are usually chance finds, exposed by soil erosion, road building or other development. This means that the majority of the graves have been disturbed when investigated. Only a very small number of undisturbed graves have been subject to controlled excavation. The main reason for the primarily accidental discovery of Viking graves in Iceland is their unobtrusiveness in the landscape, the low or non-existent mounds, and the unremarkable locations (Fridriksson 2004). Viking graves are frequently orientated north–south, usually with some grave goods, and the body tends to lie on one side, with the legs bent, all features which are unknown in later Christian burials in Iceland. Wooden coffins are rare, but sometimes the grave is outlined with stones. Viking graves are most commonly single burials although there are some instances of multiple burial sites. The largest of these which has been excavated has eleven individuals; only six excavated burial sites contain more than five individuals (Fridriksson 2004).

In Iceland today there are at least 157 known pre-Christian Viking age burial sites, with 316 individual burials and a total of 182 skeletons. Of these about 30 per cent are well preserved. More than 90 per cent of the burials are adults; approximately 68 per cent are male and 32 per cent are female (Gestsdóttir 1998b). A total of 46 skeletons from 36 locations were sampled for this study (Table 4 at http://www.antiquity.ac.uk/projgall/price). Of these 14 were single inhumations, and 6 included both skeletons from double inhumations. The remainder include 1 to 3 skeletons from several burial groups of between 2 and 14 individuals. Age and sex information on these burials is provided in Table 4 and burial locations are shown in Figure 3.

In some instances there is no clear dating evidence for these burials. The pre-Christian period in Iceland is traditionally considered to date from the first settlement towards the end of the ninth century until *c*. AD 1000 and datable grave goods from excavated sites all belong to this time period (Eldjárn 2000). Of the skeletons in this study, 38 (82.6 per cent) had grave goods or were associated with other burials with grave goods, of these 12 (26.1 per cent) had datable grave goods. As yet unpublished radiocarbon dates from five of the Viking age burials in this sample show that none of them predate the middle of the eleventh century (J. Arneborg & J. Heinemeier pers. comm.; M. Church pers. comm.) supporting the theory that this type of burial belongs to the first few centuries following the settlement of Iceland.

Christian burials

The Christian burials come from two cemeteries, Skeljastadir in Thjórsárdalur and Haffjardarey in Haffjördur. Both of these are ecclesiastical sites with small churches surrounded by a cemetery with east–west orientated burials, where the bodies were buried in a supine position with no associated grave goods. The cemetery at Skeljastadir was excavated in 1939 by the then state antiquarian Matthías Thórdarson, as a part of a Nordic project involving the excavation of eight early farms in Thjórsárdalur (Thórdarson 1943). The cemetery had been badly disturbed before the excavation. Records from the last decades of the nineteenth century detail the erosion of the site (Jónsson 1885). Skeljastadir is not

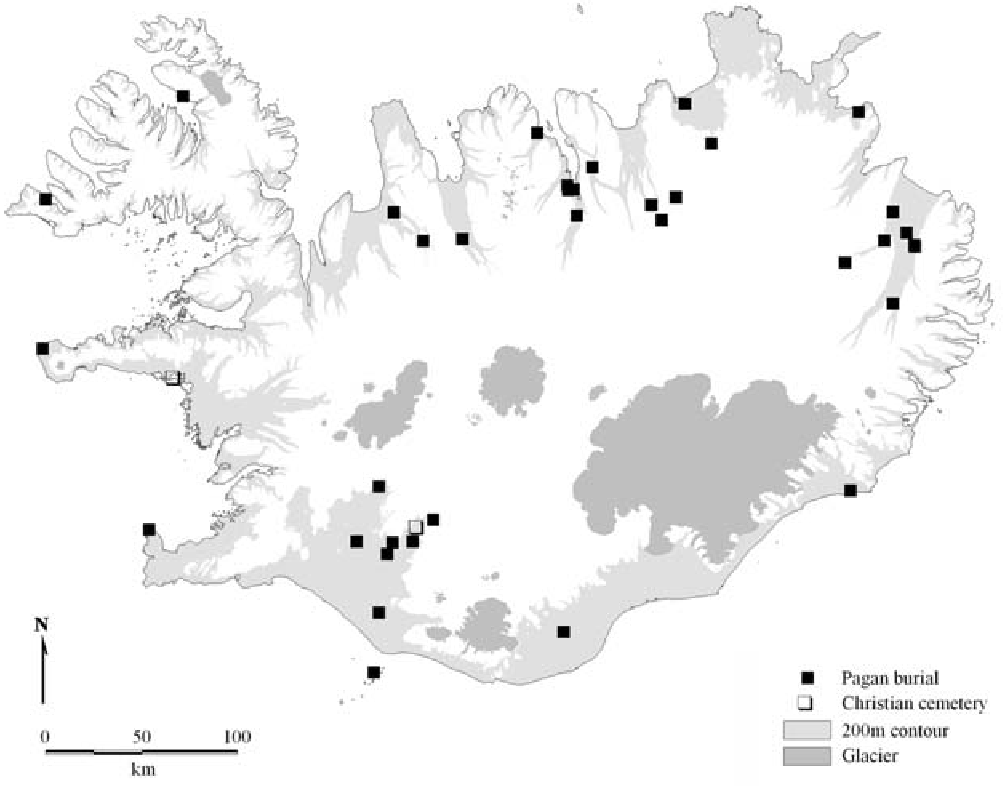

Figure 3. The location of sites with burials used in this study.

mentioned in any documentary sources, but the oral tradition indicates that the cemetery had served all of the Thjórsárdalur (Jónsson 1885). There is no dating evidence for when Skeljastadir cemetery first came into use, but it is likely that burials there ceased when Thjórsárdalur was abandoned due to the AD 1104 eruption of Mt Hekla (Thórarinsson 1968). However, more recent studies at Stöng, a nearby settlement, suggest activities there into the thirteenth century (Vilhjálmsson 1988). The nature of the burials and the fact that there is little or no superpositioning of the graves suggests that the cemetery was not in use for a very long period, perhaps no more than 100 years or so, *c*. AD 1000-1104 (Thórdarson 1943). Fifty-six skeletons from the cemetery at Skeljastadir are preserved in the Icelandic National Museum, and 33 of these were sampled for this project (Table 4, see http://www.antiquity.ac.uk/projgall/price). The ageing and sexing of the skeletons from Skeljastadir was carried out by Gestsdóttir (1998a).

The earliest documented reference to the cemetery in Haffjardarey dates to 1223. It was probably in use for approximately four centuries, *c*. AD 1200-1563 (Steffensen 1945). The island where the site is located is severely affected by erosion. Sources from the early eighteenth century mention exposure of human skeletal remains in the cemetery (Magnússon & Vídalín 1933: 45). Bones were first taken from the cemetery in Haffjardarey in 1905, when Vilhjálmur Stefánsson removed at least 50 skulls that lay on the surface and carried them

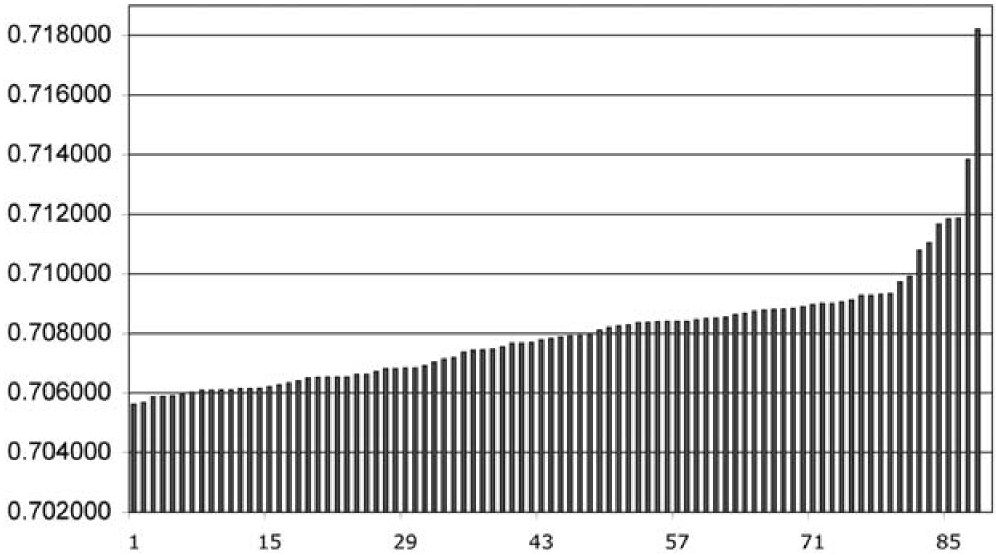

Figure 4. Strontium isotope ratios from Iceland burials in rank order.

with him to the United States. There are also records of medical students removing bones from the site in 1945. Jón Steffensen and Kristján Eldjárn excavated bones from the Haffjardarey cemetery that are today in the Icelandic National Museum. They excavated a total of 24 *in situ* skeletons and, in addition, removed bones representing at least 34 other individuals, so the total collection represents 58 individuals. The extent of the erosion of the cemetery prior to the excavation in 1945 means that it is difficult to determine how large a proportion of the original population this represents (Steffensen 1945). The lack of any dating evidence from the excavation means that it is not known when in the period of use of the cemetery the skeletons excavated date from. The ageing and sexing of the skeletons from Haffjardarey was carried out by Gestsdóttir (2004). A total of 10 skeletons from Haffjardarey were sampled and are listed in Table 4, found at http://www.antiquity.ac.uk/projgall/price.

Results

Enamel samples from 90 individuals were measured for $^{87}Sr/^{86}Sr$ in this study. Only adult individuals, 18 years of age or older, were sampled. The total included 54 males (60 per cent), 32 females (36 per cent) and 4 indeterminate individuals. The first molar was sampled when possible. Teeth displaying pathological lesions or non-metric traits were avoided; first molars remaining in the alveolar bone were not removed and in those cases other teeth were used. The results of the strontium isotope analysis of the human dental enamel are listed in Table 4. The maximum standard error on the isotope ratio measurements is $\pm$ 0.000009.

The distribution of the results, ordered from lowest to highest value, is presented in Figure 4. The majority of the individuals fall between the lowest value at 0.705620 and sample

81 0.709325. There is a clear break between samples 81 and 82 (at 0.709722) and a sharp upward turn in the curve for the last nine samples. It seems clear that these highest nine values belong to individuals who migrated to Iceland from elsewhere. It is also important to note that the values of these nine individuals are not consistent with a single place of origin. The values range from 0.7097 to 0.7119. These nine values fall into at least four groups, indicating that these migrants to Iceland came from several different places.

It is also the case that there are no sources of strontium isotopes in Icelandic foods greater than the value for seawater (0.7092). Thus, any individuals with ratios above that value are likely migrants. That would include four more of the highest values (all above 0.7092) and indicate that 13 of the 90 individuals in the sample (14.4 per cent) probably moved to Iceland from elsewhere. Thus the $^{87}Sr/^{86}Sr$ data indicate that at least nine and probably 13 individuals in our study moved to Iceland from other places.

Twelve of the 13 individuals identified as migrants were from the earliest period of occupation. Seven of these migrants were male, five were female, and one was indeterminate. Given the high proportion of males in the total sample, females are slightly higher than expected among the migrant individuals. These burials come from the sites of Álaugarey, Nesjahreppur, Skaftafellssýsla (AEY-A-1); Kornhóll, Vestmannaeyjar (SVE-B-1); Hrífunes, Skaftártunguhreppur, Skaftártungusýsla (HRS-A-2); three individuals from Sílastadir, Glæsibæjarhreppur, Eyjafjardarsýsla (SSG-A-1, SSG-A-3 & SSG-A-4), Hafurbjarnarstadir, Midneshreppur, Gullbringu- og Kjósarsýsla (HBS-A-6), Skardstangi, Merkurhraun, Rangárvallasýsla (MEH-A-1), Draflastadir, Hálsahreppur, Sudur-Thingeyjarsýsla (DSH-A-1), Dalvík, Dalvíkurhreppur, Eyjafjardarsýsla (DAV-A-9), Kroppur, Hrafnagilshreppur, Eyjafjardarsýsla (KRE-A-1) and Brú, Jökulsdalhreppur, Árnessýsla (BAJ-A-1). With the exception of Merkurhraun, all of these skeletons are from burials associated with grave goods. In the case of Álaugarey, Sílastadir, Hafurbjarnarstadir, Dalvík and Kroppur these are datable grave-goods, including swords, spears, axes, broaches (oval, trefoil and penannular), a ringed pin, beads and a comb, all dating to the tenth century (Eldjárn 2000). In addition, there is an unpublished radiocarbon date from Brú, dating it to the tenth century (J. Arneborg & J. Heinemeier pers. comm.). The only Christian burial is from the cemetery at Skeljastadir, Árnessýsla (ÞSK-A-39). This has been radiocarbon dated to the late tenth-early eleventh century (J. Arneborg & J. Heinemeier pers. comm.)

The range of variation within the local Iceland individuals from 0.7056 to 0.7092 is also of interest. As we have noted, there is a continuous gradation from lowest to highest across these values seen in Figure 4. This range extends from a value close to that measured for the lowest modern sheep on Iceland to the value for seawater. The sheep is clearly eating a terrestrial diet; the highest local Icelandic values almost certainly reflect a diet very high in marine foods. The continuous gradation observed in the local values likely reflects differences in diet along a range from largely terrestrial to largely marine. Such variation could be due to changes in diet over time on Iceland or to site location, whether inland or coastal.

There is a fascinating study of human diet on Greenland during this same period (Arneborg *et al.* 1999). Climatic changes over the last 1400 years revealed in Greenland ice cores document periods of warmer and colder conditions than today (Dansgaard *et al.* 1975). The expansion of the Vikings across the North Atlantic coincided with the Medieval

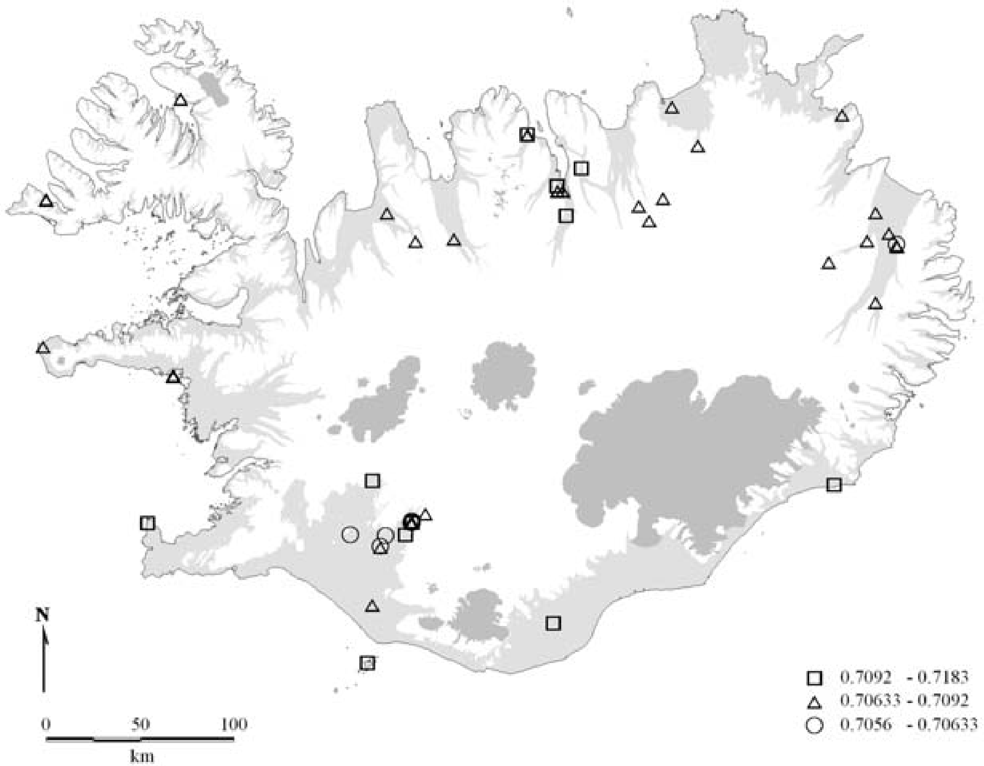

Figure 5. Strontium isotope ratios by range. Key to the symbols is shown in the legend.

Warm Period. The Little Ice Age, however, documents a time of cooler conditions and declining harvests after AD 1300. The carbon isotope evidence from human bone collagen shows a shift from terrestrial to marine diet during this period. By the middle of the fifteenth century Greenland was completely abandoned by the Norse. In the case of the Icelandic individuals, however, all of the dated burials come from the period prior to AD 1200 so that the deterioration of climatic conditions had probably not yet begun.

Location may be a better explanation for the range of values in the local Icelandic strontium isotope ratios. The spatial distribution of the strontium isotope values supports this hypothesis. Figure 5 shows the relationship between site location and isotope ratio. In most instances there is a correlation between the distance to the sea and the strontium isotope signature. The nine highest migrant values clearly cluster in three areas to the north, south, and west, most likely reflecting the areas where most of the samples originate from. Values approaching 0.7092 (seawater/marine diet) are found primarily on the coast although there are two values in the inland areas. More terrestrial values tend to be inland although there are exceptions to this pattern as well.

This relationship is particularly obvious in a comparison of the two Christian cemeteries, Skeljastadir and Haffjardarey (Figure 6). The Skeljastadir cemetery is situated as far inland as settlement is possible within Iceland, while Haffjardarey is located on a small island along

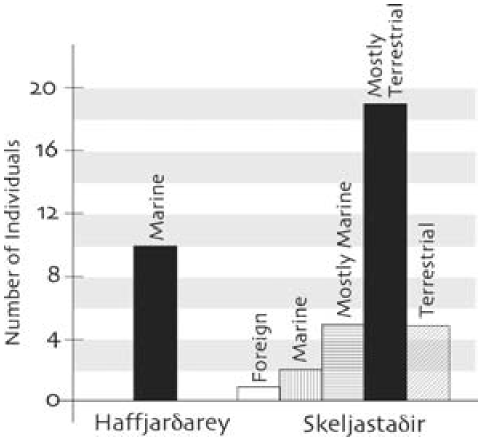

Figure 6. Distribution of strontium isotope ratios (marine vs terrestrial) in the Skeljastadir and Haffjardarey cemeteries.

the west coast. This means that the diet of the people buried in these two locations is likely to have been drastically different, as is reflected in the results of the results of the strontium analysis. The ten skeletons analysed from Haffjardarey have all a strontium isotope signature above 0.7078, towards the higher end of the range for Iceland, suggesting that their diet was mainly marine based. Of the Skeljastadir material, 24 (72.7 per cent) have a strontium isotope signature under 0.7075, or towards the lower end of the normal range, suggesting that their diet was mainly terrestrial based. Of the rest of the Skeljastadir skeletons, 8 (24.2 per cent) have enamel values indicating that their diet during childhood was mainly marine based. These individuals may have moved to the interior from the coast. All of these individuals were consuming some marine food, based on the strontium isotope evidence, but most of the diet must have been terrestrial.

Conclusions and future research

The results of our initial study of strontium isotopes and human migration during the colonisation of Iceland are quite promising. Strontium isotopes have indicated between nine and 13 individuals as migrants among the 90 individuals measured in this study. The ability to identify migrants to Iceland is the primary contribution of our study. The evidence also indicates that these migrants are among the earliest settlers and came from several different places. The data are also interesting in that they show a range of diet from terrestrial to marine among the early inhabitants of Iceland. This diet appears to correlate in part with site location (coast vs. inland), but there are a number of exceptions that might be related to individuals moving up country from the coast or vice versa within Iceland. These data also indicate that marine foods were very important to the population and that some marine foods were eaten in inland locations as well. The strontium isotope data from ancient humans and modern sheep also show an interesting offset from the geological values reported from Iceland that we are investigating.

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References

Åberg, G., G. Fosse & H. Stray. 1998. Man, nutrition and mobility: a comparison of teeth and bone from the Medieval era and the present from Pb and Sr isotopes. *The Science of The Total Environment* 224: 109-19.

Arneborg, J., J. Heinemeier, N. Lynnerup, H.L. Nielsen, N. Raud & Á.E. Sveinbjörnsdóttir. 1999. Change of diet of the Greenland Vikings determined from stable carbon isotope analysis and ^{14}C dating of their bones. *Radiocarbon* 41: 157-68.

Benediktsson, J. 1968. *Íslensk fornrit I. Íslendingabók, Landnámabók*. Reykjavik: Hid íslenska fornritafelag.

Bentley, A., T.D. Price, J. Lüning, D. Gronenborn, J. Wahl & P. Fullager. 2002. Prehistoric migration in Europe: strontium isotope in early Neolithic skeletons. *Current Anthropology* 43: 799-804.

Budd, P., J. Montgomery, J. Evans, C. Chenery & D. Powlesland. 2000. Reconstructing Anglo-Saxon residential mobility from O-, Sr- and Pb-isotope analysis. *Geochimica et Cosmochimica Acta* 66 (S1), A109.

Dansgaard, W., S.J. Johnsen, N. Reeh, N. Gundestrup, H.B. Clausen & C.U. Hammer. 1975. Climatic changes, Norsemen and modern man. *Nature* 255: 24-8.

Dickin, A.P. 1997. *Radiogenic isotope geology.* Cambridge: Cambridge University Press.

Dunwell, A.J., T.G. Cowie, M.F. Bruce, T. Neighbour & A.R. Rees. 1996. A Viking age cemetery at Cnip, Uig, Isle of Lewis. *Proceedings of the Society of Antiquaries of Scotland* 125: 719-52.

Eldjárn, K. 2000. *Kuml og haugfé.* 2nd ed. Reykjavík: Mál og menning.

Ezzo, J., C. Johnson & T.D. Price. 1997. Analytical perspectives on prehistoric migration: a case study from east-central Arizona. *Journal of Archaeological Science* 24: 447-66.

Faure, G. 1986. *Principles of isotope geology.* New York, NY: John Wiley & Sons.

Faure, G. & J.L. Powell. 1972. *Strontium isotope geology*. New York, NY: Springer-Verlag.

Fridriksson, A. 2004. Haugar og heiðni. Minjar um íslenskt járnaldarsamfélag, in Á. Björnsson & H. Róbertsdóttir (ed.) *Hlutavelta tímans. Menningararfur á Þjóðminjasafni.* Reykjavík: National Museum of Iceland.

Gestsdóttir, H. 1998a. *The palaeopathological diagnosis of nutritional disease: a study of the skeletal material from Skeljastadir, Iceland.* MSc Dissertation: University of Bradford.

–1998b. *Kyn- og lífaldursgreiningar á beinum úr íslenskum kumlum*. (Unpublished report of The Institute of Archaeology, Iceland: FS055-98181).

–2004. *The palaeopathology of Iceland: preliminary report 2003. Haffjardarey, Nedranes* & *Videy.* (Unpublished report of The Institute of Archaeology, Iceland: FS225-99192).

Hermanns-Audardóttir, M. 1991. The early settlement of Iceland, with comments. *Norwegian Archaeological Review* 34: 1-33.

Hillson, S. 1996. *Dental anthropology.* Cambridge: Cambridge University Press.

Hoppe, K.A., P.L. Koch & T.T. Furutani. 2003. Assessing the preservation of biogenic strontium in fossil bones and tooth enamel. *International Journal of Osteoarchaeology* 13: 20-8.

Jónsson, B. 1885. Um Thjórsárdal. *Árbók Hins íslenzka fornleifafélags.* 1884-1885: 38-60.

Jones, G. 1986. *The Norse Atlantic saga: being the Norse voyages of discovery and settlement to Iceland, Greenland, and North America*. Oxford: Oxford University Press.

Kalsbeek, F. & P.N. Taylor. 1999. Review of isotope data for precambrian rocks from the Disko Bugt region, West Greenland. *Geology of Greenland Survey Bulletin* 181: 41-7.

Kohn, M.J., M.J. Schoninger & J.W. Valley. 1996. Herbivore tooth oxygen isotope compositions: effects of diet and physiology. *Geochimica et Cosmochimica Acta* 60: 3889-96.

Larsen, L.M., R. Waagstein, A.K. Pedersen & M.S. Storey. 1999. Trans-Atlantic correlation of the Palaeogene volcanic successions in the Faeroe Islands and East Greenland. *Journal of the Geological Society, London* 156: 1081-95.

Loyn, H. 1977. *The Vikings in Britain*. New York, NY: St Martin's Press.

Magnússon, Á. & P. Vídalín. 1933. *Jardabók V. Hnappadals- og Snæfellssýsla*. Copenhagen: S.L.Möller.

Montgomery, J., P. Budd, A. Cox, P. Krause & R.G. Thomas. 1999. LA-ICP-MS evidence for the distribution of Pb and Sr in Romano-British medieval and modern human teeth: implications for life history and exposure reconstruction, in S.M.M. Young, A.M. Pollard, P. Budd & R.A. Ixer (ed.) *Metals in antiquity: proceedings of the international symposium*. Oxford: Archaeopress.

Montgomery, J., P. Budd & J. Evans. 2000. Reconstructing lifetime movements of ancient people: a Neolithic case study from southern England. *European Journal of Archaeology* 3: 407-22.

Montgomery, J., J.A. Evans & T. Neighbour. 2003. Sr isotope evidence for population movement within the Hebridean Norse community NW Scotland. *Journal of the Geological Society* 160: 649-53.

Price, T.D., J. Ezzo, C.A. Johnson, J. Ericson & J. Burton. 1994a. Residential mobility in the prehistoric southwest United States: a preliminary study using strontium isotope analysis. *Journal of Archaeological Science* 21: 315-30.

Price, T.D., G. Grupe & P. Schrorter. 1994b. Reconstruction of migration patterns in the Bell Beaker period by stable strontium isotope analysis. *Applied Geochemistry* 9:413-7.

Price, T.D., R.A. Bentley, D. Gronenborn, J. Lüning & J. Wahl. 2001. Human migration in the Linearbandkeramik of Central Europe. *Antiquity* 75: 593-603.

Price, T.D., J. Burton & R.A. Bentley. 2002. The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry* 44: 117-35.

Rasmussen, J. & A. Noe-Nygaard. 1970. *Geology of the Faeroe islands.* Danmarks Geologiske Undersøgelse, Series I, 25.

Roberts, H.M., M. Snæsdóttir, N. Mehler & Vésteinsson. 2003. Skáli frá víkingaöld í Reykjavík. *Árbók Hins íslenzka fornleifafélags* 2000-2001: 219-34.

Rogers, G. & C.J. Hawkesworth. 1989. A geochemical traverse across the North Chilean Andes: evidence for crust generation from the mantle wedge. *Earth and Planetary Science Letters* 91: 271-85.

Schilling, G. 1973. The Icelandic mantle plume: geochemical study of the Reykjanes ridge. *Nature* 242: 565-71.

Sealy, J.C., N.J. van der Merwe, A. Sillen, F.J. Kruger & H.W. Krueger. 1991. 87Sr/86Sr as a dietary indicator in modern and archaeological bone. *Journal of Archaeological Science* 18: 399-416.

Sealy, J., R. Armstrong & C. Schrire. 1995. Beyond lifetime averages: tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons. *Antiquity* 69: 290-300.

Steffensen, J. 1945. Rannsóknir á kirkjugardinum í Haffjardarey sumarid 1945. *Skírnir* CXX: 144-62.

Sun, S.-S. & B. Jahn. 1975. Lead and strontium isotopes in post-glacial basalts from Iceland. *Nature* 255: 527-30.

–1979. Trace element distribution and isotopic composition of Archean greenstones, in Origin and Distribution of the Elements, Second Symposium. *Physical Chemistry of the Earth*: 597-618.

Taylor, R.N., M.F. Thirlwall, B.J. Murton, D.R. Hilton & M.A.M. Gee. 1998. Isotopic constraints on the influence of the Icelandic plume. *Earth Planet. Sci. Lett.* 148: E1-E8.

Thorarinsson, S. 1968. Beinagrindur og bókarspennsli. *Árbók Hins íslenzka fornleifafélags.* 1967: 50-8.

Thordarson, M. 1943. Skeljastadir, THjórsárdalur, in M. Stenberger (ed.) *Forntida Gårdar i Island.* Copenhagen: Ejnar Munksgaard.

Vilhjálmsson, V.Ö. 1988. Dateringsproblemer i islansk arkæologi. *Hikuin* 14: 313-26.

Wallace, B.L. 1991. L'Anse aux Meadows: gateway to Vinland. *Acta Archaeologica* 61: 166-98.

Wilson, J.R., S. Pedersen, C.R. Berthelsen & B.M. Jacobsen. 1977: New light on the Precambrian Holum granite, South Norway. *Norsk geol. Tidsskr* 57: 347-60.

Wood, D.A., J.L. Joron, M. Treuil, M.J. Norry & J. Tarney. 1979. Elemental and Sr isotope variations in basic lavas from Iceland and the surrounding ocean floor. *Contrib. Mineral. Petrol.* 70: 319-39.