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Radiocarbon reservoir effects in human bone collagen from northern Iceland

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ABSTRACT

Human bone collagen from a series of Icelandic human pagan graves was radiocarbon (^{14}C) dated to aid understanding of early settlement (*landnám*) chronologies in northern Iceland. These individuals potentially consumed marine protein. The ^{14}C age of samples containing marine carbon requires a correction for the marine ^{14}C reservoir effect. The proportion of non-terrestrial sample carbon was quantified via measurement of carbon stable isotopes ($\delta^{13}C$) using a simple mixing model, based on $\delta^{13}C$ measurements of archaeofaunal samples. Non-terrestrial carbon was also quantified in six pig bones from the archaeofaunal dataset. Assuming all non-terrestrial carbon in human and pig bone collagen was marine-derived, calibrated age ranges calculated using a mixed IntCal09/Marine09 calibration curve were consistent with an early settlement date close to *landnám*, but several samples returned pre-*landnám* age ranges. Measurements of nitrogen stable isotopes ($\delta^{15}N$) strongly suggest that many of the human bone collagen samples contain freshwater diet-derived carbon. Icelandic freshwater systems frequently display large freshwater ^{14}C reservoir effects, of the order of 10,000 ^{14}C years, and we suggest that the presence of freshwater carbon is responsible for the anomalously early ages within our dataset. In pig samples, the majority of non-terrestrial carbon is freshwater in origin, but in human samples the proportion of freshwater carbon is within the error of the marine component (±10%). This presents a major obstacle to assessing temporal patterns in the ages of human remains from sampled graves, although the majority of grave ages are within the same, broad, calibrated range.

1. Introduction

The pristine landscape of Iceland was colonised from AD 871 ± 2 (Grönvold et al., 1995) as part of the Viking (early Norse) *landnám* across the North Atlantic (Dugmore et al., 2005). Post- *landnám* Icelandic landscapes experienced large-scale human environmental impacts, climatic variation and societal changes (Vésteinsson, 1998, 2000; Buckland, 2000; Andrews et al., 2001; Dugmore et al., 2007; Lawson et al., 2007), yet a lack of detailed contemporary historical records means archaeological and palaeoenvironmental data are crucial for studying this initial settlement period. A key question is verifying the rapid timing of inland settlement; midden deposits from various excavated settlements are in direct contact with the *landnám* tephra at Mývatnssveit (i.e. the region surrounding Lake Mývatn; Fig. 1), c. 60 km from the coast (McGovern et al., 2006a, 2007). This is parallelled by a considerable number of pagan graves running from the north Icelandic coast to the interior highlands (Fig. 1; Gestsdóttir, 1998; Eldjárn, 2000; Roberts, 2008). These pagan graves are likely to contain early inhabitants of Iceland, pre-dating the Christian conversion around AD 1000. To establish if these interments represented a single age range, or spatially variable ages dependent on the distance from the coast, bone collagen from human and animal bone from the graves was radiocarbon (^{14}C) dated as part of the 'Landscapes circum-*landnám*' project (Edwards et al., 2004; Dugmore et al., 2005).

A major consideration when ^{14}C dating human bone is whether any sample carbon (C) originated from a non-terrestrial reservoir. Terrestrial carbon sources include protein from domesticated land

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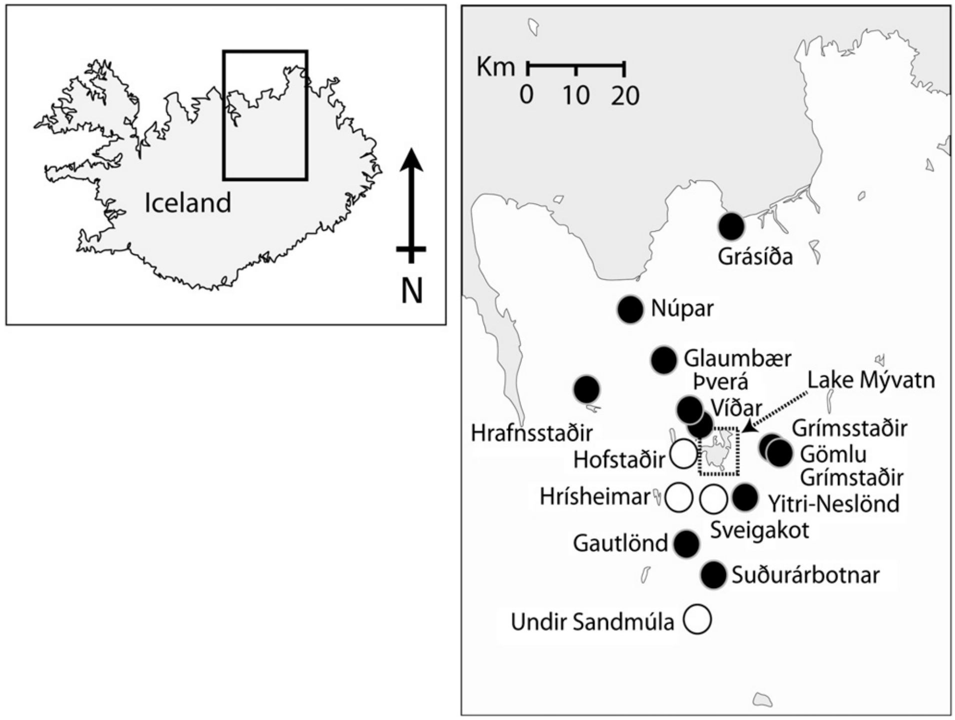

Fig. 1. Locations of sites from which material was obtained for stable isotope ($\delta^{13}C$ and $\delta^{15}N$) and radiocarbon (^{14}C) measurement. Left hand image indicates the study area within Iceland. Pagan grave sites are indicated by black circles, archaeofaunal sampling sites are indicated by white circles.

mammals (e.g. cattle), while non-terrestrial carbon sources include marine and freshwater fish and birds, and marine mammals (e.g. seals). The ^{14}C age of samples from the atmospheric and terrestrial biospheric carbon reservoirs are calibrated to a calendar year age span with the IntCal09 atmospheric curve (Reimer et al., 2009), but the ^{14}C age of samples from other C reservoirs can be offset from that of contemporaneous atmospheric/terrestrial samples. This offset is known as a 'reservoir effect' and must be corrected for in order to produce accurate calibrated age ranges. The marine ^{14}C reservoir effect (MRE) results from radioactive decay of ^{14}C atoms during deep ocean water circulation (Stuiver and Braziunas, 1993; Ascough et al., 2005). In 100% marine samples, the MRE is quantified by calibration with the separate Marine09 curve, plus an additional local offset from the global average MRE, known as ΔR (Stuiver and Braziunas, 1993; Ascough et al., 2005; Reimer et al., 2009). The ^{14}C age of bone collagen is a time-averaged integration of ^{14}C in dietary protein consumed over ~10–30 years prior to death (Ambrose and Norr, 1993; Hedges et al., 2007), meaning ^{14}C ages from individuals that consumed large quantities of marine protein appear older than those of contemporaneous individuals that consumed 100% terrestrial diets (cf. Tauber, 1983; Yoneda et al., 2002; Bayliss et al., 2004). The importance of marine resources to Norse communities, even when located many kilometres inland (Einarsson, 1994; McGovern et al., 2006a), means that ^{14}C dating in the Viking Age North Atlantic can be problematic (e.g. Arneborg et al., 1999; Barrett et al., 2000; Ascough et al., 2006; Sveinbjörnsdóttir et al., 2010). Samples in this study were therefore assessed to identify ^{14}C measurements affected by the MRE and correction applied to the ages where possible.

^{14}C ages of bone collagen containing both terrestrial and marine C can be calibrated with a mixed IntCal09 and Marine09 calibration curve (Bronk Ramsey, 1998). The amount of marine carbon in the sample must be quantified, usually via its $^{13}C/^{12}C$ stable isotope ratio ($\delta^{13}C$ value) (Coplen, 1995). Bone collagen $\delta^{13}C$ values predominantly reflect the $\delta^{13}C$ of dietary protein; this is significantly different for marine and terrestrial protein, where the $\delta^{13}C$ of terrestrial herbivore tissue is typically c. −23 to −20‰ (e.g. DeNiro and Epstein, 1978), compared to c. −15 to −17‰ for marine fish (e.g. Ambrose and Norr, 1993; Jim et al., 2004; DeNiro and Epstein, 1978; Hobson, 1990). The proportion of marine C in bone collagen of terrestrial omnivores can be assessed on a mass balance basis:

$$\delta_M = f_{Terr} \times \delta_{Terr} + f_{Mar} \times \delta_{Mar}$$

Where: δ_M = isotopic value of the mixture in the sample; f_{Terr}, f_{Mar} = fraction of terrestrial and marine C, respectively (where $f_{Terr} + f_{Mar} = 1$); δ_{Terr}, δ_{Mar} = isotope values of terrestrial and marine C, respectively.

The simplest approach to calculate f_{Mar} is via a linear mixing model, as previously used to successfully calibrate ^{14}C ages of human bone collagen, including Viking period samples from the North Atlantic (cf. Arneborg et al., 1999; Sveinbjörnsdóttir et al., 2010). This approach requires $\delta^{13}C$ end-member values for the bone collagen of a consumer existing on i) 100% terrestrial protein, and ii) 100% marine protein. These can be obtained from individuals known to have existed on the diets in question, or from measurements of dietary resources that are corrected for the diet-consumer trophic level fractionation. In either case, the accuracy of the calculated marine C proportions depends upon the selected end-member values (Dewar and Pfeiffer, 2010), which must be obtained from the same geographical region as the samples themselves (Hobson, 1999). This is because plant $\delta^{13}C$ values, and hence herbivore tissue $\delta^{13}C$ values, show wide geographical variation (McCarroll and Loader, 2004). In this study we measured the $\delta^{13}C$ in geographically and temporally relevant samples of major terrestrial and marine protein sources. For a single species population accessing the same food resources, uncertainty in stable isotope-based dietary reconstructions can result from the range in isotopic values. This appears to be a consequence of individual