Supplementary text and figures and tables in support of Isotope evidence

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Methods

Carbon and nitrogen isotopes

Collagen samples were measured in duplicate in the University of Bradford Stable Light Isotope Laboratory along with laboratory and international standards. The international standards were: IAEA 600, CH6, CH7, N1, and N2. The laboratory standards, fish gelatin and bovine liver, were calibrated against the international standards. The dentine samples were combusted in a Thermo Flash EA 1112 and the resulting N_2 and CO_2 was introduced to a Delta plus XL via a Conflo III interface. This instrument was used for the incremental dentine samples because it can analyse smaller (e.g. 0.5 mg) samples. Carbon and nitrogen isotope ratios ($\delta^{13}C$, $\delta^{15}N$) are reported in per mil (‰) relative to VPDB and AIR standards respectively. Analytical uncertainty determined by repeated analysis of the standards was better than +/- 0.2 ‰ (1σ).

Oxygen isotopes

Oxygen and carbon isotope ratios were measured in enamel carbonate following the method of Chenery *et al.* (2012) at NIGL, Keyworth, Nottingham. Isotope ratios are reported as delta (δ) values, in parts per thousand (per mil; ‰) normalized to the VPDB scale using an in-

house carbonate reference material, Keyworth Carrera Marble (KCM) calibrated against NBS19. Analytical uncertainty determined by repeat analysis of the standard was estimated to be ± 0.09 ‰ (1 σ) for $\delta^{18}O$ and ± 0.04 ‰ (1 σ) for $\delta^{13}C$. $\delta^{18}O_{carbonate}$ values were normalized to VSMOW using the equation of Coplen (1988). Conversion between $\delta^{18}O_{carbonate}$ to $\delta^{18}O_{phosphate}$ was then undertaken using the regression equation of Daux Eq. 6 (2008) introducing an error of +/- 0.28 ‰ (1sd) (Chenery et al. 2012).

Lead and strontium isotopes

Samples of core enamel were removed from the M2 tooth, mechanically cleaned of all adhering dentine and surface contamination to produce c. 10 mg samples of cleaned enamel for strontium and lead isotopes and elemental concentrations. The samples were transferred to the clean class 100, HEPA©-filtered laboratory at the NERC Isotope Geosciences Laboratory (NIGL), Keyworth, Nottingham where strontium and lead were isolated using standard laboratory column chemistry separation procedures (Lamb et al. 2014).

In short, lead isotope ratios were measured in solution using a thallium spike and a Nu Industries *Nu Plasma* multi-collector inductively-coupled plasma mass spectrometer (MC-ICP-MS) and compared to known values of NBS981 Pb standard (Thirlwall, 2002). The precision and accuracy of the method was determined by repeated analysis of 50 ppb NBS standards to be: $^{206}Pb/^{204}Pb$ ±0.010; $^{207}Pb/^{204}Pb$ ±0.017; $^{208}Pb/^{204}Pb$ ±0.020; $^{207}Pb/^{206}Pb$ ± 0.010; $^{208}Pb/^{206}Pb$ ±0.012.

Strontium spiked with an ^{84}Sr tracer was loaded onto a single Re filament with TaF following the method of Birck (1986). Strontium isotope ratios and concentrations were measured using a *Thermo Triton* multi-collector mass spectrometer (TIMS). The international standard for $^{87}Sr/^{86}Sr$, NBS987, gave a value of 0.71025±0.00001 (n=8, 2s) during the analysis of these samples. Blanks were in the region of 100 pg.

Results

Carbon and nitrogen isotopes

Collagen was obtained from sequential dentine sections of the M2 using the method given by Beaumont et al. (2013). C:N ratios and %C and %N of the resulting collagen were deemed of acceptable quality according to van Klinken (1999). The carbon and nitrogen isotope ratio profiles indicate a largely terrestrial diet, i.e. $\delta^{13}C$ below -20 ‰, between the ages of 2 and 15

years (figure X1). Such values and apparent absence of evidence for any significant marine protein consumption are typical for pre-Viking Age humans in northern Britain even when excavated in coastal regions (Barrett & Richards 2004; Buckberry et al. 2014; Curtis-Summer et al. 2014; Müldner & Richards 2007; Müldner et al. 2009) and the Ardnamurchan burial sits within the range of values obtained for Pictish and medieval burials in the Hebrides, Orkneys, and east and west coast of northern Britain (figure X1). The increase in marine protein consumption in the Viking Age (9th-11th centuries AD) in Scotland has been linked to Norse settlement and influence (Barrett and Richards 2004) and is seen in two Viking male burials (11 and 12) from Westness and to a lesser extent in the female (A) found with a Viking burial assemblage at Cnip (figure X1). However, individuals with little or no isotopic evidence for marine protein consumption are also found in Scandinavia at this time amongst those with significant marine diets, and children appear to have lower marine protein consumption than adults (Kosiba et al. 2007; Naumann et al. 2014). As the dentine data obtained for the Ardnamurchan individual reflect diet up to the age of approximately 15 years of age, the largely terrestrial-based diet found for the Ardnamurchan individual does not, of itself, rule out Scandinavian origins. There is a peak in both the carbon and nitrogen isotope profiles between the ages of approximately 3 and 5 years suggesting a shift to a higher trophic level diet at this time (figure 9 in main article). Such a change in diet could be explained by the consumption of an increased proportion of either terrestrial (meat or milk) or marine animal protein, although the trend in the data for a positive correlation between carbon and nitrogen isotopes, rather than just an increase in nitrogen isotope ratios, would suggest the latter (figure 9 in main article), but it is not sufficient to take the $\delta^{13}C$ values outside the range for terrestrial protein.

Strontium and oxygen isotopes
There is little comparative strontium isotope data from the west coast of mainland northern Scotland from any period as the survival of skeletal materials is generally poor. It is significantly better in soils dominated by the coastal shell sands found in the Western and Northern Isles and particularly the Old Red Sandstones of Orkney. A comparison with humans from these places indicates that the combined strontium isotope and concentration of the tooth enamel from the Ardnamurchan individual is not consistent with origins in the Outer Hebrides, Orkney or Shetland nor on basaltic or limestone terrains (Montgomery et al. 2010). The strontium isotope ratio of 0.7112 obtained from the second molar cannot rule out origins in the Ardnamurchan peninsular as the complex geology of the region could provide a

wide range of biosphere values from 0.705 up to 0.714 (Evans et al. 2010) and consumption of food grown on such varied geological terrain could result in an averaged value of 0.7112 (Montgomery 2010). However, the oxygen isotope ratio of 16.7 ‰ is too low for humans from the entire western seaboard of Britain (including the Northern and Western Isles) which have a 2 sd range of 17.2 - 19.2 ‰ (Evans et al. 2012). For example, four surviving skeletons from the nearby islands of Tiree, Mull and Skye range from 17.5 to 18.0 ‰ (Armit et al. 2015; Evans et al. 2012). A similar combination to the strontium and oxygen isotopes obtained from the Ardnamurchan individual have also been found in other burials of Viking Age (indicated by the red oval in figure 10 in the main article) that are also inconsistent with their place of burial such as the female Cnip A (Montgomery et al. 2014) and one of the decapitated Viking period males found at Weymouth in Dorset (Chenery et al. 2014). A $\delta^{18}O$ value of 16.7 ‰ is nonetheless consistent with origins in eastern Britain (2 sd range = 15.9 to 18.5 ‰, Evans et al. 2010) and other Viking burials such as 11 and 12 from Westness and two from Dublin have much lower oxygen isotopes which do fall outside the range for Britain and Ireland. As a consequence, the oxygen isotopes demonstrate that it is highly unlikely that the Ardnamurchan individual originated on the western seaboard of Britain and must have travelled there either during life or for burial from a region with lower $\delta^{18}O$ precipitation values. This place of origin will be to the east, including eastern Britain, or to the north in Scandinavia. Other possibilities include eastern Ireland and central Europe. The strontium isotope ratio would not rule out any of these places although it is of note that it falls within the large range of values reported for Viking period burials from coastal Norway: 0.7092 to 0.7175 (Naumann et al. 2014). Origins in Denmark which is predominantly limestones overlain by till and hosts a strontium isotope biosphere between 0.7081 and 0.7111 (Frei and Frei 2011) would, however, be difficult to reconcile with the strontium isotope ratio of 0.7112 obtained from the Ardnamurchan individual.

Lead isotopes
The amount of lead in the enamel of the Ardnamurchan individual is 0.4 mg/kg which is below the limit of exposure to solely natural sources proposed by Montgomery et al. (2010) and figure X2 shows that the $^{207}Pb/^{206}Pb$ ratio is higher than the English/Welsh lead ore ratios $^{207}Pb/^{206}Pb$ of ~ 0.846 found with much higher levels of lead in Viking period burials in England such as those from Repton and Riccall. As a consequence, origins in England and Wales at this time when the majority of people with enamel lead > 0.5 mg/kg had a $^{207}Pb/^{206}Pb$ ratio of ~ 0.846 can be ruled out. A similar combination of lead level and ratio to

the Ardnamurchan individual has been found in prehistoric individuals from the Outer Hebrides. Whilst the strontium and oxygen isotopes rule out the Outer Hebrides as a place of origin, this does suggest that the Ardnamurchan individual grew up in a region of ancient Precambrian geology with little or no environmental lead pollution. Given there are no significant lead deposits in Denmark, southern Norway or western Sweden (Reimann et al. 2012), and Scandinavia lay outside the Roman Empire which heralded the advent of increased lead levels in humans in first millennium AD Britain (Montgomery et al. 2010), lead levels below 0.5 mg/kg have been proposed as an indicator of Scandinavian origins in Viking period burials in Britain (Montgomery et al. 2014). However, such low lead exposure may also be true of northern Scotland which was also beyond the zone of direct Roman influence and has comparably ancient geology.

To investigate this further, figure X3 compares the $^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ ratios of the Ardnamurchan individual with data for Scottish and Irish lead deposits. The Ardnamurchan individual sits within the field of both Scottish and Irish ores (Rohl 1996) in Figure X3a ($^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$) which indicates exposure to an ancient Precambrian source of lead but falls largely outside both these fields in Figure X3b ($^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$) when both ore fields drop below the Stacey-Kramer (1975) curve for conformable lead ore deposits. Only a few Irish ore sources appear to be able to provide lead isotope ratios consistent with the Ardnamurchan individual. The human with the most similar ratios on both plots is a female Pictish burial from Kilpheder South Uist who is also unlikely to be indigenous to the Outer Hebrides but who has a much lower and incompatible strontium isotope ratio (Montgomery and Evans 2006). None of the Viking period burials in figure X3 have comparable lead isotope ratios: all have higher ratios indicative of younger sources of lead such as the Palaeozoic ores of England and Wales and in northern Europe outside of Norway and Sweden. Whilst it is not possible when all the isotope data are taken together to rule out origins in north or eastern Ireland, neither is it currently possible to rule out origins in eastern Scotland, Norway and Sweden as little is currently known about the lead isotopes that humans exposed to only natural levels of lead, in an analogous manner to strontium ingestion, from soils and plants on the ancient rocks of these places.

Conclusion

Currently, no direct comparator can be found in Britain for the lead isotope ratios obtained from the Ardnamurchan individual but this evidence and that from other isotopes strongly points to origins not at Ardnamurchan nor the western seaboard of Britain, but in a region of

ancient Precambrian geology to the north of the Roman Empire. The isotope data would all be consistent with origins in Norway or Sweden but equally with north or eastern Ireland and possibly eastern mainland Scotland.

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Figure captions to accompany supplemental data

Figure X1. Carbon and nitrogen isotope bi-plot comparing the Ardnamurchan burial to other medieval humans from coastal sites in northern Britain. The green line indicates the suggested upper limit for $\delta^{13}C$ of -20 ‰ for solely terrestrial diets in prehistoric northern Britain (Bonsall et al. 2009). Analytical uncertainty is shown at +/- 0.2 ‰ (1σ). Data sources: Carlisle: McCarthy 2014; Cnip: Montgomery unpublished data; 2010 Portmahomack: Curtis-Summers et al. 2014; St. Bees: Knüsel et al. 2010; Westness: Barrett & Richards 2004; Whithorn: Müldner et al. 2009.

Figure X2. Enamel lead isotope ratios and concentrations for the Ardnamurchan individual compared to other prehistoric individuals and Viking period burials from Britain. The dashed line indicates the upper ~0.5 mg/kg limit of enamel lead burdens of individuals not exposed to anthropogenic pollutant lead sources and the individuals with high lead levels have values of ~0.846 which is characteristic of English and Welsh lead ores (Montgomery et al. 2010; 2014).

Figure X3. Enamel lead isotope plots of the Ardnamurchan individual compared to Scottish and Irish ore fields (data from Rohl 1996 and sources therein), the Stacey and Kramer (1975) growth curve for conformable lead ore deposits, and other humans from the Viking period or the Western and Northern Isles (data from Montgomery et al. 2010; 2014) Error bars indicate 2σ analytical uncertainty for TIMS.

Tables

Table X1. Incremental and mean carbon and nitrogen isotope data from the second molar. *Estimated ages are calculated according to Beaumont and Montgomery (2015).

section number (from crown)	$\delta^{15}N$ ‰	$\delta^{13}C$ ‰	Amt%N	Amt%C	C:N	age in years*
ARD1	10.6	-21.2	13.4	40.5	3.5	2.5
ARD2	11.9	-20.5	14.2	40.7	3.4	3.5
ARD3	12.5	-20.2	14.6	42.1	3.4	4.5
ARD4	12.8	-20.0	14.3	41.6	3.4	5.5
ARD5	11.4	-20.4	14.3	41.2	3.4	6.5
ARD6	11.0	-20.7	14.2	41.1	3.4	7.5
ARD7	11.0	-20.6	14.2	41.4	3.4	8.5
ARD8	10.5	-20.7	14.4	41.5	3.3	9.5
ARD9	10.2	-20.9	14.2	41.1	3.4	10.5
ARD10	10.0	-20.7	13.8	40.5	3.4	11.5
ARD11	10.2	-20.8	13.8	40.4	3.4	12.5
ARD12	10.6	-20.8	13.9	40.8	3.4	13.5
ARD13	10.4	-21.2	13.5	40.8	3.5	14.5
Mean for crown (1-6)	11.7	-20.5				
Mean for root (7-13)	10.4	-20.8				
Mean for tooth	11.0	-20.7				

Table X2. Oxygen and carbon isotope data measured and calculated from the second molar enamel.

	$\delta^{13}C_{PDB}$	δO^{18}_{PDB}	$\delta^{18}O_{VSMOW}$	$\delta^{18}O_{VSMOW}$	δO^{18}_{VSMOW}
	carbonate	carbonate	carbonate	phosphate	precipitation
Equation			Coplen (1988)	Chenery et al. (2012)	Daux et al. (2008) Eq. 6
Units	‰	‰	‰	‰	‰
ARDV-1	-15.2	-5.2	25.6	16.7	-8.0

Table X3. Strontium and lead isotopes and concentrations from the second molar enamel.

	Sr mg/kg	$^{87}Sr/^{86}Sr$	Pb mg/kg	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
ARDV-1	142	0.71122	0.4	18.044	15.629	37.890	0.8661	2.0999