Sr isotope evidence for population movement within the Hebridean Norse community of NW Scotland

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Abstract: The excavation at Cnip, Isle of Lewis, Scotland of the largest, and only known family, cemetery from the early Norse period in the Hebrides, provided a unique opportunity to use Sr isotope analysis to examine the origins of people who may have been Norwegian Vikings. Sr isotope analysis permits direct investigation of a person's place of origin rather than indirectly through acquired cultural and artefactual affiliations. Sr isotope data suggest that the Norse group at Cnip was of mixed origins. The majority were consistent with indigenous origins but two individuals, of middle-age and different sex, were immigrants. They were, however, not from Norway but were raised separately, most probably on Tertiary volcanic rocks (e.g. the Inner Hebrides or NE Ireland) or, for the female, on marine carbonate rocks.

Keywords: $^{87}Sr/^{86}Sr$, enamel, Viking, Lewisian, teeth.

Sr isotope analysis of tooth enamel provides a means to investigate a person's place of origin directly (Ericson 1985; van der Merwe *et al.* 1990) rather than indirectly through acquired cultural and artefactual affiliations. The application has been used to trace the movements of people in antiquity (Price *et al.* 1994; Price *et al.* 2001; Sealy *et al.* 1995; Sillen *et al.* 1998; Montgomery *et al.* 2000). The method exploits the changes in biosphere signatures, and thus diet, that occur with changes in geological province. The range and distribution of Sr isotope compositions within a geographical area is site specific, hence must be defined before any analysis of human 'localness' or population attribution can be made.

The cemetery at Cnip [NGR: NB 099 364] lies within the Quaternary shell sands (machair) that overlie much of the Lewisian gneiss on the west coast of the Outer Hebrides (Fig. 1). The machair plain extends for up to 2 km inland and throughout much of the prehistory of Lewis was the focus for settlement and agriculture; most of the island interior being covered with uncultivable blanket peat that supports very little indigenous wildlife (Sergeantson 1990; Armit 1996). Radiocarbon dating of the Norse human remains provides an overlapping, calibrated date range of 687-1006AD (2σ), spanning the period of initial Viking raids and subsequent extensive Norse settlement of Lewis during the 9th century AD (Ritchie 1993). To date, four adults (A, C, D & E) and three children (B, F & G) have been excavated, including one female who wore finely-crafted 9th-10th century Norse jewellery. The jewellery must have been imported to Lewis, probably from specialist craft centres in Ireland and Sweden (Welander *et al.* 1987). This rich burial assemblage contrasts sharply with the paucity of grave goods in the other Cnip burials. Unfortunately, due to the circumstances of the discovery, nothing is known of the manner in which burial A was marked. Kerbstones surrounded each of the remaining adult graves whilst the graves of the children were unmarked (Dunwell *et al.* 1996a). Parallels with the graves of the adults at Cnip have been found on Iceland and the Faeroes (Dunwell *et al.* 1996a), and contact between

Iceland and the Hebrides, including settlement of Iceland by Hebrideans, is documented in the Icelandic sagas and through artefactual evidence (Smyth 1979). None of the burials at Cnip exhibit characteristically Christian attributes in either alignment or form, despite Christianity predominating in the Pictish and Scottish areas of western Britain and Ireland prior to the arrival of the pagan Norse (Ritchie 1993; Neighbour *et al.* 2002). The aim of this study was to investigate whether the people buried at Cnip were migrants from Norway.

To establish Lewisian dietary $^{87}Sr/^{86}Sr$ and address the possibility of modern contamination of the environmental samples by pollutants and fertilisers, tooth enamel from archaeological herbivores and earlier prehistoric humans was also analysed. The herbivore samples were obtained from Norse and Iron Age strata at a second coastal, machair site at nearby Bostadh (Fig. 1). Prehistoric human samples were selected from a Bronze Age (1856-1520 cal. BC), short cist, single burial at the Cnip cemetery (Dunwell *et al.* 1996b) and five Iron Age humans from a third coastal, machair burial site approximately 40 km to the north. This long cist cemetery at Galson [NGR: NB 436 594], is believed to be an early Christian burial ground and excavated remains have produced a calibrated radiocarbon date range of 30-410 AD (2σ) (Neighbour *et al.* 2002).

Method. From Cnip, all eight skeletons excavated to date were analysed; seven were Norse (Cnip A – G) and one was Bronze Age (Dunwell *et al.* 1996b). Five Iron Age adult humans (Gals II, IV 74, 93 & 96) from Galson, and four herbivores from Norse and Iron Age strata at Bostadh (Fig. 1), were also analysed (Table 1). Enamel samples were of core enamel only. Once childhood tooth mineralization is complete, core enamel is resistant to subsequent isotopic or elemental changes either during an individual’s lifetime or during burial, whereas dentine reacts with the burial environment (Budd *et al.* 2000). To remove soil-derived particulate on the tooth surface, all enamel surfaces were abraded to a depth >100 μm with acid-cleaned, tungsten carbide dental burrs. All adhering dentine and enamel-dentine junction tissue were also removed entirely. Enamel chips were washed ultrasonically in water (Millipore Alpha Q, <1 ppb total heavy metal content) to remove adhering particulate. No chemical decontamination was carried out as, due to the high resistance of enamel to post-mortem contamination, changes in the bulk ^{87}Sr/^{86}Sr ratio of enamel samples following the use of such procedures has been negligible (Horn *et al.* 1994; Trickett *et al.* 2003). Further evidence of the integrity of the Sr in these samples is provided by: the dentine, which shows the typically elevated Sr concentrations and different isotope ratio caused by reaction with the burial environment; the very low Pb concentrations of many of the samples (<1 ppm); and the Pb isotope ratios which provide no evidence of modern contamination. Details of these data are given in Montgomery (2002).

Six soil/rock samples were obtained from: the Iron Age burial context at Galson; the Norse and Bronze Age burial contexts at Cnip; strata identified as sealed Iron Age and Norse cultivation soils, at Galson and Cnip respectively; and a sample of gneiss from the Cnip headland. The gneiss was washed in water (Millipore Alpha Q) and ground to a coarse powder in a tungsten carbide ball mill.

All enamel and soil samples were transferred in sealed containers to the class 100, HEPA-filtered laboratory at the NERC Isotope Geosciences Laboratory (NIGL), Keyworth, UK. Approximately 2 g of each soil and rock sample was leached overnight with water (Millipore Alpha Q) and a further 2 g leached overnight in dilute acid (10% vol. acetic). Samples were centrifuged and the leachate pipetted out and dried down. The laboratory procedure used ion exchange chromatography and Teflon-distilled reagents to isolate the strontium prior to instrumental analysis. The full method of preparation and analysis is reported in Montgomery (2002). Sr concentrations and compositions were obtained by thermal-ionisation mass spectrometry (TIMS) using a Finnegan Mat 262 multi-collector mass spectrometer. $^{87}Sr/^{86}Sr$ was normalized to a NBS 987 value of 0.710235. The Sr contribution from within-run laboratory blanks was negligible. External reproducibility was estimated at ±0.004% (2σ).

Results. TIMS data (Table 1) are presented on three histograms (Fig. 2). Modern biosphere estimates are derived from soil leaches from the vicinity of the burials and from ancient, buried, cultivation soils (Fig. 2a). The lowest $^{87}Sr/^{86}Sr$ ratios are from dilute acid leaches of carbonate-rich machair soils and are close to modern seawater. Water leaches from the soils show a greater spread of data and higher $^{87}Sr/^{86}Sr$ ratios as water is more likely to remove adhered Sr from the surface of clay minerals. The underlying rocks of Lewis are predominantly the eponymous, Archaean, Lewisian Gneisses of the Lewisian Complex. Although *c.* 2.6 Ga, they are not highly radiogenic because of the Large Ion Lithophile Element depletion they suffered early in their history. Modern day $^{87}Sr/^{86}Sr$ ratios from the Lewisian gneisses give an average value of 0.716 ± 0.016 (1σ, n=13) (Moorbath *et al.* 1975). This suggests that a value of around 0.716 is a reasonable estimate for the averaged contribution of the basement rocks into the overlying biosphere. Such a value is supported by a direct measurement from a water leach of a coarsely ground piece of gneiss from the Cnip headland which gives a $^{87}Sr/^{86}Sr$ ratio of 0.7150.

The Bostadh herbivores, the Cnip Bronze Age burial and three of the Galson burials produced a cluster of $^{87}Sr/^{86}Sr$ ratios between 0.70925-0.71025 (Fig. 2b). All lie within the range obtained from the machair soil leaches from Cnip and Galson. The remaining two Galson humans appear to be outliers and have $^{87}Sr/^{86}Sr$ ratios approaching the Lewisian gneiss leach, indicating a greater dietary contribution from terrestrial Sr during childhood and a reduction in marine/machair-derived inputs. The data, therefore, form a skewed distribution with a minimum value of ~0.7092, a peak between 0.70925-0.7095, and a long tail towards more radiogenic $^{87}Sr/^{86}Sr$ ratios with increasing influence of the basement rocks. However, individual enamel results are the weighted mean of the Sr metabolised from many different dietary components ingested whilst the enamel is mineralising. For human teeth this may take place over a number of years (Boyde 1989). Given the barren island interior and absence of wild, terrestrial mammals other than red deer (Serjeantson 1990), there appears to be no non-machair/marine food resources available of any note with which to modify the ubiquitous machair Sr isotope ratio in this marginal environment. It is possible, therefore, that Gals 93 and IV, rather than being statistical outliers of mixing between the two Sr sources of the machair and the gneiss, may not have originated on the island. This observation is supported by the fact that they are the only individuals from Galson that have enamel Pb isotope ratios consistent with Irish or English ore sources (rather than the thorium-enriched ratios deriving from the gneiss obtained from the herbivores and other prehistoric humans), coupled with the highest Pb concentrations (Montgomery 2002).

The results of the Bostadh herbivores and Galson humans indicate that dietary Sr on Lewis is composed of two principal, but unequal, sources: 1) seawater and precipitates from seawater in the form of calcareous shell (machair) which dominate the food chain; and 2) the Lewisian gneiss of the basement. This observation highlights the critical importance of assessing both Quaternary drift geology and archaeological subsistence evidence when attempting to characterize the dietary variation in such studies.

Enamel $^{87}Sr/^{86}Sr$ data for the seven Norse skeletons are plotted in Fig. 2c. Five individuals (A, B, C, F and G) lie within the range 0.7095-0.7105 showing an almost complete overlap with the herbivores from Bostadh. This is consistent with an origin on the Lewisian machair but cannot rule out alternative locations where similar $^{87}Sr/^{86}Sr$ biosphere values may be obtained. The remaining male (D) and female (E) adults have very unradiogenic $^{87}Sr/^{86}Sr$ ratios, well below the proposed minimum biosphere value of 0.7092.

This strongly implies they were not indigenous and came to Lewis following the mineralization of the adult premolar teeth, i.e. after the age of eight.

Discussion. Constraints can be placed on the possible origins of the two exotic humans D and E. Their Sr concentrations indicate that they are unlikely to have come from the same place. Skeletal Sr concentrations can vary both geographically (Turekian & Kulp 1956; Brudevold & Söremark 1967) and with trophic level, herbivores having higher concentrations than carnivores, because plants are Sr-rich (Tuross *et al.* 1989; Bocherens *et al*. 1994). The Lewisian individuals are typified by relatively high enamel Sr concentrations when compared with British individuals from a range of archaeological sites, e.g. 68 ± 23 ppm (1σ), n = 63 (Montgomery 2002). However, their values are not abnormal as modern human enamel is typically 50-300 ppm, but can reach 600 ppm (Brudevold & Söremark 1967). The reasons for the high Sr concentrations in the Lewis population are unclear, but it may simply reflect a diet proportionally lower in meat and dairy products and higher in plants. Animals grazed on the machair, seaweed used as fodder and fertilizer, consumption of marine mammals and fish and, crucially, *the consumption of crops grown on the machair*, may all contribute to higher enamel Sr concentrations in this maritime, island community. The male skeleton (D) originated from an unradiogenic terrain but his enamel Sr concentration (169 ppm) is similar to the other Lewisian individuals. In contrast, the female skeleton (E) appears to have had an entirely different type of diet and origin. Her enamel Sr concentration (58 ppm) is markedly lower than the other Lewisian burials, and may indicate a childhood diet containing a greater proportion of meat and dairy products. She has a very similar Sr ratio and concentration to Neolithic, Late Roman and Anglo-Saxon burials from the chalk of the Yorkshire Wolds and the South Downs (Montgomery 2002).

Neither D nor E were first generation Vikings from Norway, which is dominated by Precambrian gneisses, granites and Palaeozoic sedimentary rocks. Norwegian mediaeval teeth have produced $^{87}Sr/^{86}Sr$ ratios ranging from 0.71087 for coastal Bergen up to 0.73232 from inland sites (Åberg *et al.* 1998). The low Sr ratios of these two individuals restrict the choice of possible source regions, particularly as enamel Sr compositions result from a mixture of the environmental inputs ingested during childhood, including Sr from local soils and rainwater. As rainwater Sr has the seawater composition of 0.7092 in coastal regions (Capo *et al.* 1998), the land they grew up on will have values lower than their resulting enamel value. Thus, D originates from a region yielding a value <0.7078 and E from a region <0.7086. The two main lithological types that can supply values in this range are basaltic rocks and chalk/limestone. Chalk has a minimum value of 0.7071 (Burke *et al.* 1982) and young basalts can be as low as 0.703 (Dickin 1995). Chalk is a likely substrate for E but not for D, as he is very close to the minimum chalk composition and no skeleton excavated from a chalk burial site has possessed an enamel $^{87}Sr/^{86}Sr$ value <0.7080 (Montgomery 2002). Consequently, the Tertiary Volcanic rocks of the Inner Hebrides, such as Skye and Mull, and Antrim in NE Ireland provide the nearest potential places of origin for D, with more distant contenders being Iceland and the Faeroes (Moorbath & Bell 1965; Wallace *et al.* 1994). Archaeological evidence suggests a considerable degree of contact existed between Lewis and all these regions during the Viking Period (Armit 1996; Smyth 1979). Unfortunately, there is currently no enamel Sr isotope data available for Viking Period individuals from these places with which to compare D and E.

The nearest significant Cretaceous chalk outcrops are found in east and SE England, and in Denmark. Throughout the Viking period contemporary historical accounts attest to the frequent, often hostile, contact between groups of Vikings lead by men of Norse and Danish extraction in the Irish Sea region. However, the Danes principally, though not exclusively, targeted the east coast of England for attack and colonisation, whereas Norwegian Vikings sailed west to Ireland and the Highlands and Islands of Scotland (Fig. 1). Nonetheless, the first Viking raid on England, documented in the Anglo-Saxon Chronicle for 789 AD, occurred on the Dorset coast four years before the attack on Lindisfarne (Loyn 1977). Norwegian Vikings were responsible, providing evidence for early contact between Norway and southern England.

The disparate origins of these two individuals raises the question of how they came to be buried in a Norse cemetery on Lewis. It is possible that they may have been slaves. Great Britain and Ireland were Christian prior to the arrival of the pagan Norse in the 9th century and the Vikings took large numbers of Christian captives from Great Britain and, notably, NE Ireland, often strategically timing their raids to coincide with Christian festivals when many people gathered together (Smyth 1979). Dublin, in particular, was a major Viking slaving colony with small offshore islands being used to hold captives prior to sale (Smyth 1979). The relocation of D and E to Lewis, which occupied an important position on the main shipping route north, may not, therefore, have been a voluntary one, although the apparent care taken to mark their graves with kerbstones suggests they were buried with respect, if scant material wealth.

Conclusions. The results of this study provide direct confirmation that people living near the seaways of the North Atlantic region were mobile during the Norse period. However, the individuals buried on Lewis are clearly not first generation Norwegian settlers. The Sr isotope evidence is consistent with two adults (A & C) and the three young children (B, F & G) being raised on Lewis. Despite the imported Norse jewellery assemblage buried with A, Sr isotopes alone can provide no irrefutable evidence that she was of Norwegian descent, and the observation that the jewellery was of considerable antiquity prior to burial (Welander *et al.*

1987) may be an important factor here. For the middle-aged male (D) and female (E) adults who have Sr ratios below those available from the machair-dominated Lewisian biosphere, we propose separate origins within the North Atlantic Tertiary Volcanic Province for D, and for E, possible origins on Cretaceous chalk. The presence of a female adult migrant on Lewis during this period demonstrates for the first time that both sexes were mobile in the Viking Age and may provide evidence for the historically documented Viking slave economy (Smyth 1979; Graham-Campbell & Batey 1998). The application of Sr isotope analysis described above demonstrates the utility of direct analysis of human remains to provide constraints on origins and support for traditional archaeological methods of investigation.

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Table 1. *$^{87}Sr/^{86}Sr$ and Sr concentrations for archaeological and environmental samples*

Sample	*Sample code*	*Material*	*Sr ppm*	*$^{87}Sr/^{86}Sr$*
Norse humans	Cnip A	Enamel	101	0.710488
	Cnip B	Enamel	152	0.709595
	Cnip C	Enamel	210	0.709526
	Cnip D	Enamel	169	0.707802
	Cnip E	Enamel	58.2	0.708575
	Cnip F	Enamel	165	0.709771
	Cnip G	Enamel	417	0.710190
Bronze Age humans, Cnip	Cnip BA	Enamel	158	0.709460
Iron Age humans, Galson	Gals-93	Enamel	71.4	0.713033
	Gals-96	Enamel	337	0.709345
	Gals-II	Enamel	233	0.709417
	Gals-IV	Enamel	82.1	0.711860
	Gals-74	Enamel	174	0.709379
Animal teeth	Iron Age sheep	Enamel	656	0.709708
	Iron Age deer	Enamel	470	0.709408
	Iron Age cattle	Enamel	429	0.710154
	Norse cattle	Enamel	355	0.709935
Acid leaches of soil	Cnip-S1	Norse burial soil	na	0.709173
	Gals-S4	Iron Age burial soil	na	0.709167
	Cnip-S2	Bronze Age burial soil	na	0.709174
	Gals-S5	Iron Age cultivation soil	na	0.709376
	Cnip-S3	Norse cultivation soil	na	0.709195
Water leaches of soil & rock	Cnip-S1	Norse burial soil	na	0.709675
	Gals-S4	Iron Age burial soil	na	0.709377
	Gals-S5	Iron Age cultivation soil	na	0.710543
	Cnip-S2	Bronze Age burial soil	na	0.710421
	Cnip-S4	Lewisian gneiss bedrock	na	0.715205

na = not analysed

Figures

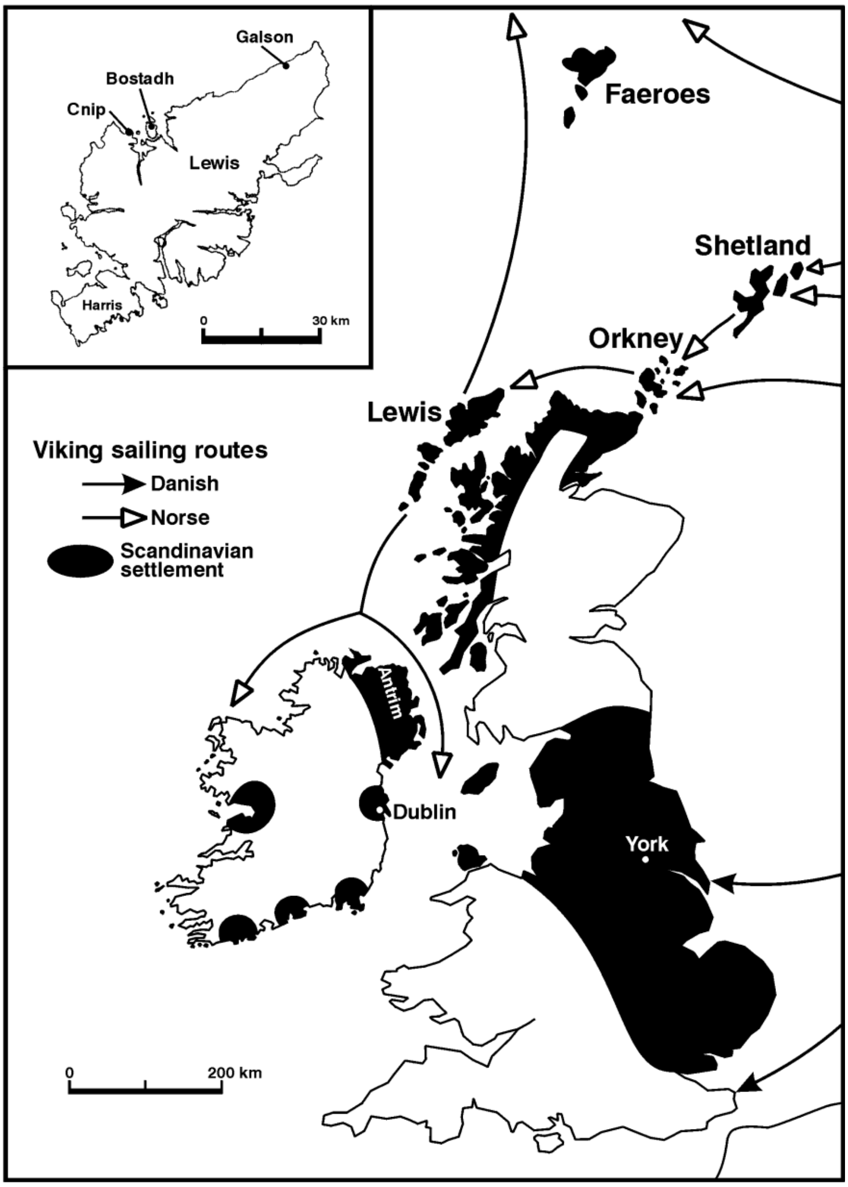

Fig.1. Map of Great Britain and Ireland showing the locations of the sampling sites, Viking sailing routes (after Graham-Campbell & Batey 1998) and main areas of Scandinavian settlement (after Ritchie 1993).

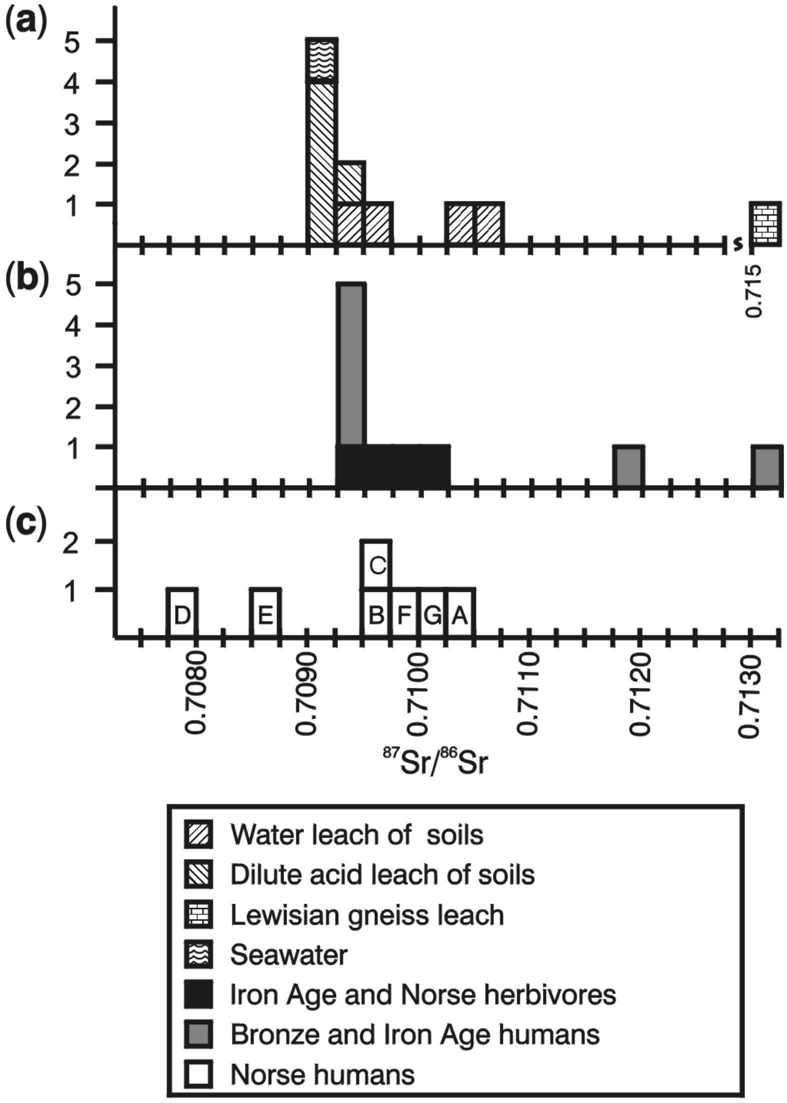

Fig.2. Histograms showing the range of Sr isotope compositions obtained from the Lewisian biosphere. Data displayed are from: (**a**) environmental biosphere samples (note the broken x-axis). Soil samples were machair, sandy soils taken from burial and Norse and Iron Age cultivation strata at Cnip and Galson respectively (see Table 1); (**b**) Bronze and Iron Age tooth enamel from humans and herbivores; (**c**) tooth enamel of the Norse burials from Cnip. The proposed minimum dietary value obtainable from the machair-dominated Lewisian biosphere is approx. 0.7092.