12 ISOTOPE ANALYSES, *by Nicky Milner and Oliver Craig*

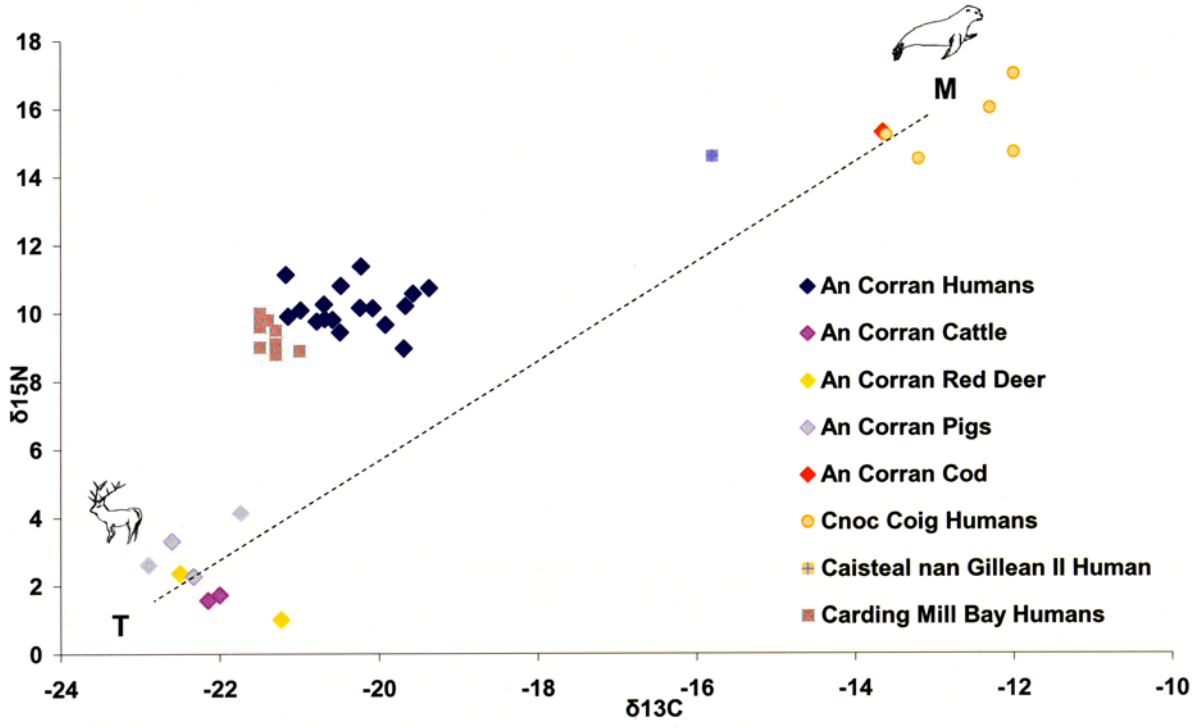
12.1 Introduction

The measurement of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratios in bone collagen has become an important technique in palaeodietary studies. It has been widely applied to reconstruct past human diets from a range of geographical locations and periods. Unlike other forms of palaeodietary evidence, it provides a long-term record of an individual's diet. Studies also suggest that bone collagen isotopes predominantly reflect the protein portion of diet, although this may be modulated by overall nutritional status. Applied to the Mesolithic and Neolithic samples from north-west Europe, stable isotope analysis has been used to distinguish between marine and terrestrial consumers. Carbon derived from marine sources is enriched in $\delta^{13}C$. Marine foods also tend to be at higher trophic levels than terrestrial foods and therefore are also enriched in $\delta^{15}N$. It should be stressed, however, that the absolute values can vary both temporally and geographically and therefore measurements of contemporary marine and terrestrial fauna are important to provide an accurate interpretation of human diets. The $\delta^{13}C$ and $\delta^{15}N$ values of plant foods in the archaeological record are not well characterised (due to lack of preservation), although they may vary substantially, therefore herbivores are often used as proxies.

Stable sulphur isotope ratios ($\delta^{34}S$) are also beginning to be applied to archaeological materials (Craig et al 2006; Richards et al 2001). Sulphur isotope analysis has proved useful in studies of complex food webs in modern marine and estuarine ecosystems. There is only a small offset between food and consumer, and large variations in the sulphur isotope ratios derived from different ecosystems and geographical locations. Marine producers have extremely uniform $\delta^{34}S$ values (*c* +20‰), consistent with values of oceanic sulphates, whereas $\delta^{34}S$ values of terrestrial and freshwater producers are much more variable (*c* –20‰ to +20‰), depending on local sources of sulphates. Richards et al (2001) have demonstrated that sulphur isotopes can be extracted from human bone collagen to discriminate marine and terrestrial diets and that sea spray and coastal precipitation, both high in marine sulphate, can also introduce marine sulphates into the terrestrial food chain (McArdle et al 1998).

12.2 Sampling and methods

The human skeletal remains were sampled initially



Illus 53 Divergent dietary signals from An Corran and other west coast of Scotland $\delta^{15}N$ and $\delta^{13}C$ data. T = terrestrial; m = marine.

Table 37 Stable isotope data

Catalogue No.	Species		Mean $\delta^{13}C$	Mean $\delta^{15}N$	Mean $\delta^{34}S$
0196	Human		–22.9	2.6	
0143	[Human]	juvenile, later identified as pig	–21.7	4.1	19.7
0911	Human		–21.2	11.1	
0278	Human		–21.1	9.9	
0217	Human		–21.0	10.1	
0631	Human		–20.7	10.3	
0118	Human		–20.8	9.8	
0283	Human	small adult	–20.7	9.8	
0632	Human	mature adult (<35)	–20.6	9.8	18.4
0615	Human	small adult	–20.5	9.4	
0912	Human		–20.5	10.8	
0458	Human	mature adult (>40)	–20.2	10.2	18.1
0572	Human		–20.2	11.4	
0279	Human		–20.1	10.1	
0627	Human		–19.9	9.7	18.4
0125	Human		–19.7	9.0	
0629	Human		–19.7	10.2	
0628	Human		–19.6	10.6	
0270	Human	mature adult	–19.4	10.7	
0113	Pig		–22.3	2.3	
0156	Pig		–22.6	3.3	
0096	Red deer		–21.2	1.0	
0147-r	Red deer		–22.5	2.4	
0132-r	Cattle		–22.2	1.6	
0178-r	Cattle		–22.0	1.7	
0055-r	Cod		–13.6	15.3	

with the assumption/hope on our part that these were of Mesolithic date, given that much of the midden material dated to this period. In fact these samples turned out to date to the Neolithic (see dating section); however, they still provide useful information which can be used in wider palaeo-dietary debates (see Milner & Craig 2009 for a discussion of the results in the wider context of the Mesolithic/Neolithic transition in this area).

The human skeletal assemblage at An Corran was highly fragmented, making assessment of the number of individuals represented by the assemblage difficult. Only a minimum of two adult individuals could be established through osteological analysis based on age criteria, out of thirty-nine bones recovered (see the human bone section above). Collagen was extracted from seventeen skeletal elements securely identified as adult human for stable isotope analysis. In addition, seven animal bones recovered from the An Corran midden horizons were included in the stable isotope analysis in order to establish the isotopic values associated with pure terrestrial and marine diets at this specific location, thus providing a framework for interpreting the human stable isotope data. These included terrestrial herbivores (two red deer, two cattle), terrestrial omnivores (two pig) and a marine fish (a single cod vertebra).

Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratios were measured in all the extracted collagen samples using standard methods and procedures. In addition, sulphur isotope ratios ($\delta^{34}S$) were measured in four of the samples (three humans and a pig).

12.3 Results

The results are presented in Table 37 and the carbon and nitrogen isotope data are plotted in illus 53 with other data from the west coast of Scotland. The results for CAT 143, which had been identified as human, appeared to indicate an individual with anomalous diet which plotted with the terrestrial animals. This bone was re-examined by Terry O'Connor and Don Brothwell and was confirmed

(also in agreement with László Bartosiewicz) to be pig rather than human (see Table 37).

The stable isotope values of the other individuals indicate a predominantly terrestrial diet, supplemented with various amounts of marine products as indicated by slightly enriched $\delta^{13}C$ values. These individuals consumed more marine foods than Neolithic humans from either Crarae (Schulting & Richards 2002) or Carding Mill Bay (Connock et al 1992), but did not have 'extreme' marine diets that characterise the humans buried on Oronsay, particularly Cnoc Coig (Milner & Craig 2009).

Another notable feature of the stable isotope data is that the human nitrogen isotope values are much higher than the terrestrial animal values at An Corran (Table 37; mean difference = 7.9‰, minimum difference = 4.8‰, maximum difference = 10.4‰). Although the exact values for $\delta^{15}N$ enrichment between humans and the foods they consume are unknown, values of between 3–5‰ are usually assumed (see Hedges & Reynard 2007 for a review of this issue). The nitrogen isotope data are therefore at odds with the interpretation of diet predominantly composed of terrestrial animals.

There may be several explanations for this discrepancy. First, the relatively high $\delta^{15}N$ values may imply a much greater level of high trophic marine food consumption at An Corran than suggested by the carbon isotope values. It should be noted that the possibility that carbon and nitrogen atoms in bone collagen are derived from different dietary sources, as this implies, has been given serious consideration, specifically in relation to dietary change at the Mesolithic/Neolithic transition (Hedges 2004; 2006; Milner et al 2004), but so far there is no consensus regarding the extent to which this may occur physiologically. Second, freshwater fish with generally high $\delta^{15}N$ values but much lower $\delta^{13}C$ may have been a strong dietary component. This is perhaps less likely given the sites' coastal setting and the fact that salmon which may have been available in nearby rivers have strongly marine isotope signatures. As most of the animal bones dated were found to be several millennia older than the human remains (see Table 36) a final consideration is that the animal bones analysed from An Corran were not isotopically representative of the animals available to the humans at this time. To check this, stable isotope analysis was carried out on two bevel-ended bone tools both securely dated to after 4000 cal BC. The analysis revealed that the $\delta^{15}N$ values were similar to the other animals with earlier dates and therefore this does not seem a likely explanation for the high $\delta^{15}N$ values.

Marine sulphur values are found in all the collagen samples analysed. However, these also include a pig sample with terrestrial C and N values, indicating that sulphur was derived from sea-spray rather than through diet. The results indicate that the humans analysed lived on or near the coast, at least during the last ten years of their lives.

12.4 Discussion

There has been keen debate as to the *rate* and *extent* of the transition from wild foods to domestic plants and animals at the Mesolithic/Neolithic transition in this region. The data have been used to argue for a (more or less) complete shift from marine to terrestrial foods over a short space of time, reinvoking the possibility of colonisation by Neolithic populations with economies dedicated to agriculture and pastoralism. This theory has been criticised (Milner et al 2004) because the interpretation of the isotope data comes from a limited number of available samples, particularly for the Mesolithic period, which is only represented by two very late Mesolithic sites on Oronsay (Milner & Craig 2009). However, the fact that human bones from the west coast of Scotland with dates later than 4000 cal BC have predominantly terrestrial stable carbon isotope signatures cannot be ignored. Furthermore, similar stable isotope data have been recorded from Neolithic coastal sites in England and Wales (Richards & Hedges 1999; Schulting 2009).

Although the extent of consumption of marine versus other foods is difficult to assess, the stable isotope data from An Corran suggest that some marine foods were consumed by the humans buried there well into the 4th millennium. However, the only way to further elucidate palaeodiet and economic changes at this time is to conduct more studies on midden material, particularly in order to determine to what extent the middens were being formed in the 4th millennium and also the timing of the introduction of domesticates.