

Slighting the sea: stable isotope evidence for the transition to farming in northwestern Europe

Rick J. Schulting

Department of Archaeology, University of Reading, Reading

ABSTRACT – While it is accepted that the Neolithic was an intrusive phenomenon across much of Central Europe, the transition to food production on the northwestern fringes of the Continent has been viewed in terms of complex interactions between incoming and indigenous populations, leading to 'continuity' and 'acculturation' rather than replacement. Much current opinion holds that this was in many areas (in particular southern Scandinavia and the British Isles) a gradual process, and that radical changes did not occur in the subsistence economy, which is seen as retaining a fishing-hunting-gathering character. However, such a view is not in accordance with a considerable body of stable isotope evidence, presented and discussed here. This evidence, it is argued, has very different implications for the nature of the transition.

POVZETEK – Velja mnenje, da je bil neolitik v večjem delu Evrope vsiljen pojav, v skrajni severozahodni Evropi pa je bil prehod v pridelovalno gospodarstvo posledica kompleksnih medsebojnih vplivov med prišleki in domorodnim prebivalstvom. Zaradi tega tu ni prišlo do zamenjave, ampak do "kontinuitete" in "akulturacije". Danes so številni arheologi mnenja, da je na mnogih območjih (posebno v južni Skandinaviji in na Britanskem otočju) proces potekal postopoma, brez nenadnih sprememb v gospodarstvu, kar se kaže v ohranjanju ribiško-lovske-nabiralniškega značaja gospodarstva. Vendar pa to stališče ni v skladu z obsežnim sklopom podatkov, ki jih dajejo stabilni izotopi, o čemer bomo govorili v pričujočem članku. Ti podatki kažejo na čisto drugačno naravo prehoda.

INTRODUCTION

This paper addresses the process of neolithisation in selected areas of northwest Europe (Fig. 1), focusing on the nature of subsistence changes across the transition. In the literature of Western Europe since the 1960s, the two periods have been largely defined in terms of the subsistence economy – hunting of wild game, fishing and collection of wild plants in the Mesolithic, versus husbandry of domestic animals and cultivation of domestic cereals in the Neolithic. This is a very general scheme – it works best in areas such as central Europe, where incoming groups appeared with a fully-formed farming 'package', making their archaeological identification relatively straightforward. But the distinction blurs along the peripheries of northwestern Europe, where the process was potentially a long, drawn-out one, possibly including intermediate stages (Zvelebil and Rowley-Conwy 1986). Problems arise in identifying the

basis of the economy using traditional archaeological methods, particularly given the small and potentially unrepresentative faunal assemblages available in the study areas. Plant remains are even less well-represented. The issue is important whether one considers the Mesolithic and Neolithic to be definable by their subsistence economy or not, since the degree to which the various recognised elements of the Neolithic were associated with one another remains a valid and open question. Much of the recent literature downplays the extent of subsistence change across the transition in northwestern Europe. There is a feeling, particularly in Britain, that changes in the subsistence economy lagged behind, or were of secondary importance, to changes in other aspects of society, particularly in worldview or cosmology (Bradley 1993; Hodder 1990; Whittle 1996). The continued importance of 'wild' resources



Fig. 1. Map of Europe showing selected study areas.

has been emphasised, although the evidence for this is really quite limited. I will argue in this paper that there was a significant change in subsistence orientation beginning with the Neolithic even in areas outside of the LBK sphere of influence.

A BRIEF OVERVIEW OF THE STABLE ISOTOPE TECHNIQUE

One of the strongest new lines of subsistence evidence comes from bone chemistry. By directly addressing the long-term diet of the individual, dietary reconstruction using bone chemistry analysis bypasses many of the difficulties associated with more traditional archaeological approaches to subsistence. The technique is based on the natural occurrence of heavier, but stable, isotopes of certain elements, the most important of which are carbon and nitrogen (DeNiro and Epstein 1978; 1981).

There are two situations in which stable carbon isotopes are useful for dietary reconstruction. The first involves the differentiation of systems based on terrestrial C_3 vs. C_4 plants. C_3 and C_4 plants are easily

distinguished by their isotopic signatures, as are any food chains based on them. The classic example of a C_4 plant in the New World is maize, while millet serves as an important Old World example. Neither of these plants are relevant within the study area, nor are there any other C_4 plants of dietary importance among the indigenous plant species of temperate Europe. It is the second application that is important here: that is, that systems based on terrestrial C_3 plants can be easily distinguished from marine systems. The proportion of ^{13}C is higher in the marine carbonate reservoir drawn upon by marine organisms. These initial differences are maintained along their respective food chains; carbon from plants/phytoplankton eaten by herbivores/zoo-plankton is incorporated into the proteins of those organisms, preserving the isotopic signature of their origins, and so on up the food chain. An enrichment of about 5‰ occurs between diet and consumer bone collagen in mammals. Thereafter, trophic level effects are either small (ca. 1‰) or non-existent and need not concern us here. The technique is well-established and has proven very useful in quantifying the human use of marine foods in various parts of the world (Chisholm *et al.* 1983; Hobson and Collier 1984; Lee-Thorpe *et al.* 1989; Lovell *et al.* 1986; Lubell *et al.* 1994; Sealy and van der Merwe 1985; Tauber 1981, 1986; Walker and DeNiro 1986).

Isotopes of stable nitrogen (^{15}N) are also enriched in marine systems relative to terrestrial systems, but more importantly, the degree of trophic level fractionation is significantly greater (ca. 3‰). Thus nitrogen isotopes can be used to characterise the trophic level of the organism in question. There are two situations in which this is particularly useful. The first involves an estimate of the relative importance of plant and animal protein (blood, meat and milk products) in the diet. In a diet based primarily on plant foods, humans will look like herbivores, while in a diet with a substantial terrestrial meat component they will appear as carnivores, and their $\delta^{15}N$ should be about 3‰ higher than seen in herbivores. The second use of the technique takes advantage of the fact that marine food chains are on average much longer than terrestrial chains. Thus a seal, for example, can be a fourth- or fifth-order carnivore – no terrestrial mammals attain such a position. Humans consuming a substantial proportion of fish and/or sea mammals will thus have a far higher stable nitrogen value than is possible to attain in a purely terrestrial system. A reliance on lake fish, would, following the same logic, also result in high-

er stable nitrogen values than expected in a land-based terrestrial system, so that aquatic systems can also be distinguished from land-based terrestrial systems (Katzenberg 1989). In a situation where both marine and freshwater aquatic foods were available, interpretation of stable nitrogen values alone would be problematic; fortunately, this situation would be resolved, in the absence of C^4 plants, by a consideration of stable carbon isotope values.

For true quantification to be possible, it is of course necessary to know the 'endpoints' for the systems under discussion in order to estimate the relative contribution of marine and terrestrial protein, and/or plant and animal protein. For stable carbon, a purely terrestrial C_3 system has been shown to result in human bone collagen values of -20 to -22‰, while a purely marine system will in most cases give values of about -12 to -13‰ (Chisholm *et al.* 1983). Stable nitrogen isotopes undergo a 3 ± 1 ‰ enrich-

ment per trophic level. Air, the standard, has a $\delta^{15}N$ value of 0; most temperate, non-nitrogen fixing plants will have values around +3‰; herbivores (including vegetarian humans) will be about 6‰; first-order carnivores will have values of about 9‰, second-order carnivores 12‰, and so on (Fig. 2). For example, analysis of human and faunal remains from the Iron Gates Mesolithic and Neolithic found an average $\delta^{15}N$ value for 10 bovids of 5.6 ± 1.0 ‰ (Bonsall *et al.* 1997), which fits reasonably well with the expected value of 6‰ for herbivores. There is a degree of regional variability in nitrogen values, and ideally faunal samples from the same sites as human bone samples will act as controls to identify the isotopic position of herbivores and carnivores.

Another important issue to be considered involves the turnover rates of collagen in human bone. An average of five to ten years is often cited, and this

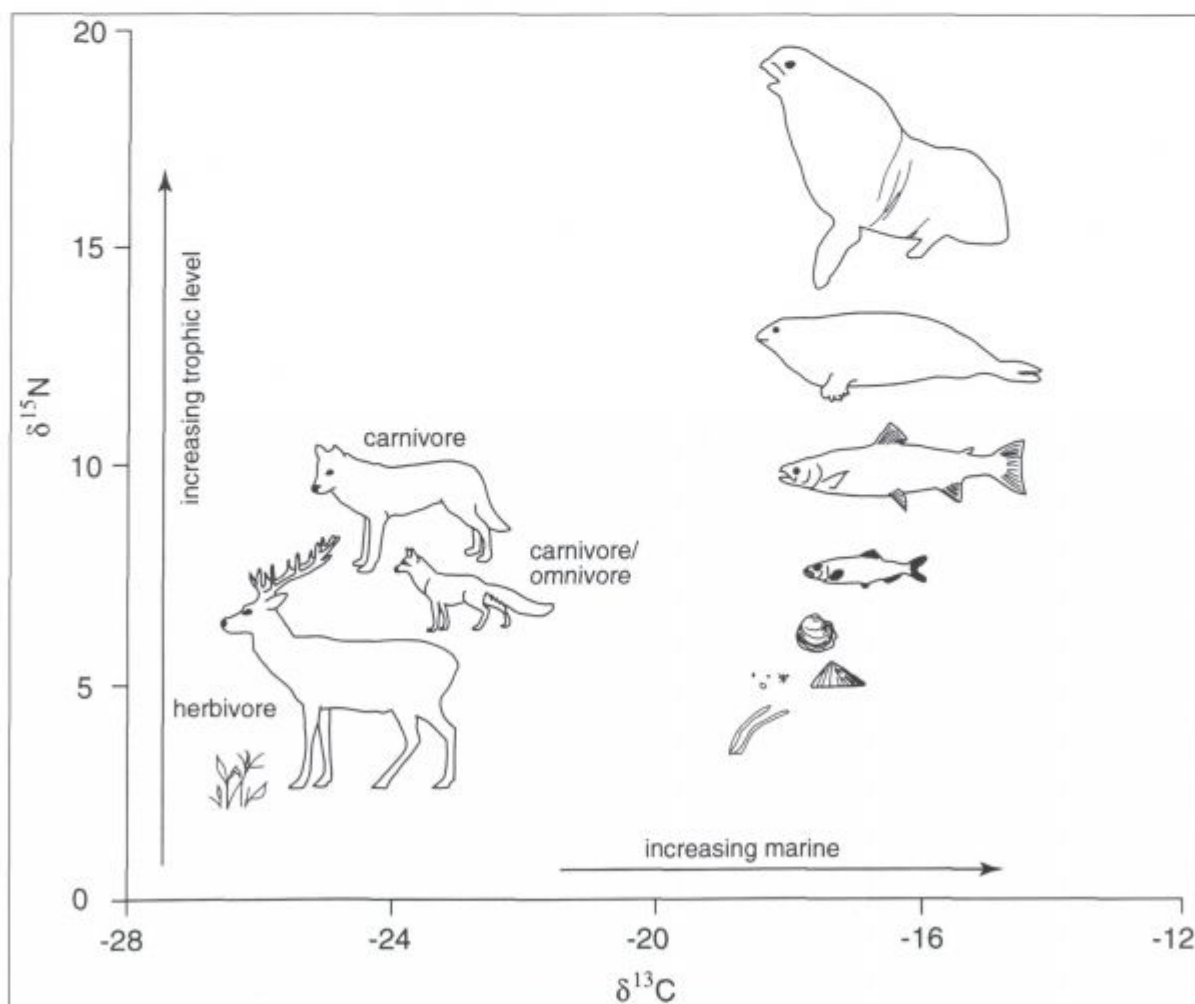


Fig. 2. Simplified summary of stable carbon and nitrogen values for terrestrial and marine ecosystems (values are for flesh; to convert to bone collagen values, 5‰ should be added to $\delta^{13}C$ values; $\delta^{15}N$ values are the same for flesh and bone, but approx. 3‰ must be added to diet item in order to arrive at consumer values); note the higher trophic levels possible in a marine foodchain.

serves well enough for most purposes (*Chisholm 1986*). That is, stable isotope results on human bone reflect on roughly the last five to ten years of that individual's diet. Finally, it must be emphasised that both stable carbon and stable nitrogen values of bone collagen reflect primarily the *protein* component of the diet. This is a critical fact and has often been overlooked by archaeologists, and until quite recently was not accepted by all stable isotope specialists either. It has now been demonstrated by feeding experiments with mice and rats (*Ambrose and Norr 1993; Tieszen and Fagre 1993*). The sources of carbohydrates and lipids – the other two major components of the overall diet and those usually providing most of the daily energy requirements – make a minimal contribution to the carbon in bone

collagen. The $\delta^{13}\text{C}$ values of bone apatite (bioapatite) *do* reflect overall diet (*Kreuger and Sullivan 1984*), but this component is still infrequently measured, and is more difficult to deal with due to problems with diagenesis. The situation with nitrogen is more straightforward, since dietary protein is the only possible source for animals.

We can use our knowledge of the isotopic signatures of various foods, and their caloric and protein contents, to construct a series of model diets and estimate the stable carbon and nitrogen isotope values they would bring about in human bone collagen (Tab. 1 and Fig. 3). A number of points worth noting emerge from this exercise. The contribution of high-starch and low-protein characteristic of many

Diet	Description (% refers to calories)	$\delta^{13}\text{C}_{\text{‰}}$	$\delta^{15}\text{N}_{\text{‰}}$
inland hunter-gatherers			
1	emphasis on game (>70%)	-20.9	8.3
2	game w+ some freshwater fish (20%)	-20.7	9.5
3	emphasis on freshwater fish (50%)	-20.3	11.4
4	emphasis on non-cereal plants (>75%)	-20.9	7.9
coastal fisher-hunter-gatherers			
5	balanced terrestrial/marine (50:50)	-16.5	12.2
6	emphasis on marine fish (>50%)	-13.9	14.0
7	emphasis on marine mammals (>60%)	-13.9	15.8
8	non-cereal plants with marine fish/mammals	-15.2	12.0
farmers			
9	emphasis on domestic animals (>50%)	-20.9	8.9
10	emphasis on cereals (>70%)	-21.0	7.1

Tab. 1. Predicted carbon and nitrogen bone collagen stable isotope values for model human diets.

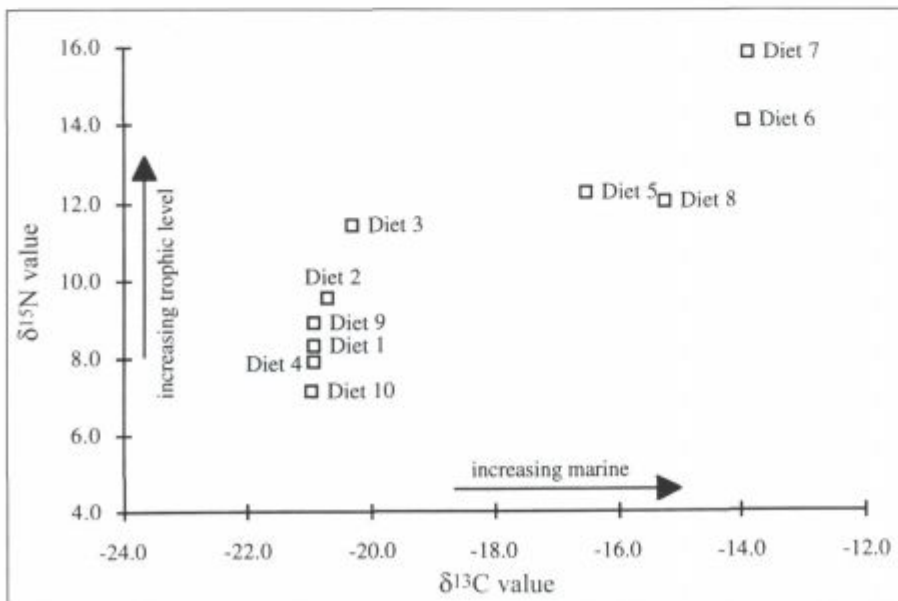


Fig. 3. Plot of stable carbon and nitrogen values for model diets.

tubers and roots has a small impact on the stable isotope values seen in consumer bone collagen, even when they form a significant portion of the overall diet in terms of caloric requirements. For example, a diet in which 80% of the caloric requirements was met by tubers and roots could contribute only 40% or less of the protein intake. Thus the importance of high-energy, low-protein foods will be underestimated by stable isotope measurements *on collagen*. Leafy green vegetable foods, providing both low energy and low protein, do not figure in the diet in the sense of either a major caloric or protein contribution, no matter in what quantity they are consumed. At the other extreme, the importance of low-calorie, high-protein foods will be exaggerated. The protein content of lean fish, one of the best examples, far more significant than its caloric content.

While this greatly undermines our ability to reconstruct overall diet with stable isotopes in certain situations, it could be argued that starchy foods would be of relatively little importance in prehistoric north-temperate Europe. Certainly the ethnographic data summarised by Lee (1968) support such a position. The potential importance of plant foods is receiving increasing attention for the European Mesolithic (Zvelebil 1994). But the food value of plants such as bracken is questionable, in terms of both caloric and protein yields, and also protein quality and digestibility. Because foods such as hazelnuts and especially cereals are higher in protein, they are affected to a far lesser extent, although they are still underrepresented in collagen isotope values compared to game and fish.

Finally, it should be noted that anadromous fish such as salmon spend most of their lives feeding in the sea, and so have a marine isotopic signature. The effects of this on human isotopic values in situations with high reliance on salmon have been dramatically demonstrated on the Northwest Coast and Plateau culture areas of North America, where human bone from archaeological sites hundreds of kilometres from the coast show $\delta^{13}\text{C}$ values indicating a considerable input (up to 50% or more) of marine protein (Lovell *et al.* 1986). The potential importance of salmon in the Mesolithic diet of north-western Europe has often been alluded to, but little direct evidence is available. Human bone from inland contexts is rare within the present study area, and so it is difficult to address this possibility. However, none of the few available $\delta^{13}\text{C}$ values from appropriate inland riverine contexts from either Britain or

the western Continent suggest that salmon were an important resource in either the Mesolithic or the Neolithic (Schulting and Richards *in press*). Another anadromous fish, the sturgeon, seems to have been significant in the diet of the Mesolithic inhabitants of the Iron Gates, but this area is beyond the scope of the present discussion.

STABLE ISOTOPE DATA FROM SELECTED AREAS OF NORTHWEST EUROPE

Denmark

Southern Scandinavia is of special importance in discussions of the Mesolithic-Neolithic transition in northwestern Europe, because of the quality and quantity of its evidence, the long history of research, and the presence of the Late Atlantic period coastline that is elsewhere submerged. Stable carbon isotope studies in Denmark were among the first to be undertaken. They demonstrate a very abrupt change in diet at the Mesolithic-Neolithic transition, from a fairly heavy reliance on marine resources in coastal situations to heavy reliance on terrestrial resources (Tauber 1981; 1986). In fact, with the exception of a few Early Mesolithic individuals, which must be seen as reflecting an inland adaptation, there is a complete lack of overlap in the distribution of values for the two groups (Figure 4). The trend towards increasing $\delta^{13}\text{C}$ values through time in the Mesolithic data can be at least partly attributed to sea-level changes and site survival. Mesolithic dogs follow a remarkably similar pattern to that seen in the humans, with the exception of two late animals (ca. 5250 BP) with exclusively 'terrestrial' signatures. Of these two exceptions, the Prestalyngen dog has been used as evidence for a distinct inland adaptation in the Late Mesolithic (Noe-Nygaard 1988). Various explanations are possible for the 'terrestrial' dog on the coastal site of Ølby Lyng on Zealand (Rowley-Conwy *in press*; Schulting 1998).

One of the most telling examples of the remarkable suddenness of the transition involves three individuals from two graves at Dragsholm in northwest Zealand. One of the two Mesolithic adult females contained in a single grave was dated to 5160 ± 100 BP (K-2224), and they yielded $\delta^{13}\text{C}$ values of -11.5‰ and -12.2‰ (Brinch Petersen 1974). This must be regarded as the endpoint for a marine signature. In other words, essentially all of the protein in the diet of these two individuals over at least the last 10 or so years of their lives came from the sea. The Neoli-

thic individual, an adult male found only a few metres away, has been dated to 4840 ± 100 BP (K-2291), with a $\delta^{13}\text{C}$ value of about -21.5‰ . This value presents a typical terrestrial endpoint – there is no evidence for the consumption of marine protein by this individual. What is most remarkable is that the radiocarbon estimates actually overlap at a 95% confidence interval (*i.e.*, two sigmas), and this becomes even more apparent when a correction for the marine reservoir effect is applied (a complex issue that will not be further explored here; see Schulting 1998 for further discussion). There is little question but that the diets of the ‘Mesolithic’ and ‘Neolithic’ individuals at Dragsholm were diametrically opposed. While these results are quite extreme in terms of the strength of the marine signature of the Mesolithic individuals, the general pattern is one that applies throughout Denmark.

Denmark also saw one of the first applications of stable nitrogen analysis to human remains, which again demonstrates a clear separation of later Mesolithic and Neolithic populations. As would be expected, the stable nitrogen values support the stable carbon results, and are completely non-overlapping for seven Late Mesolithic individuals (averaging 13.9‰) and five Neolithic individuals (averaging 8.9‰) (Schoeninger *et al.* 1983). This is exactly what would be expected given a high reliance on marine fish and mammals in the Mesolithic, versus an emphasis on terrestrial animal protein in the Neolithic. The $\delta^{15}\text{N}$ values for the Neolithic remain relatively high, and do not suggest a high reliance on plant protein; however, contemporary local fauna – both herbivores and carnivores – should be measured before this

conclusion can be regarded as firm, and a closer approximation of the proportions of animal and plant foods given. The Mesolithic average of 13.9‰ , while far higher than expected for a non-aquatic, terrestrial foodchain, is relatively low for a marine system, suggesting that shellfish and fish played a greater role than marine mammals in the protein component of the diet of the individuals measured ($\delta^{15}\text{N}$ values for 19 recent coastal fisher-hunter-gatherers from Greenland and Alaska, for example, averaged 18.7‰ [Schoeninger *et al.* 1983]).

Scotland

Until recently, little use has been made of the stable isotope technique in Britain. Fragmentary human remains found in two shell middens on Oronsay, on the Scottish West Coast have recently been reported (Richards and Mellars 1998). The results from one site, Cnoc Coig, indicate that the protein component of the diet was largely marine-derived. Interestingly, the single sample from the second site, Caisteal nan Gilleann II, yielded a $\delta^{13}\text{C}$ value of -15.8‰ , which is significantly lower (*i.e.*, less marine) than the closely grouped values (averaging -12.6‰) for the five Cnoc Coig specimens (possibly representing only two individuals). A change in diet over time is one possible explanation for the difference in stable carbon between the two sites; while radiocarbon dates show the sites to date to roughly the same period (ca. 5500 BP), there are no dates directly on the human bones (such are being undertaken). The sites are so close to the appearance of the Neolithic on the West Coast that the Caisteal nan Gilleann II individual might conceivably reflect a transitional diet.

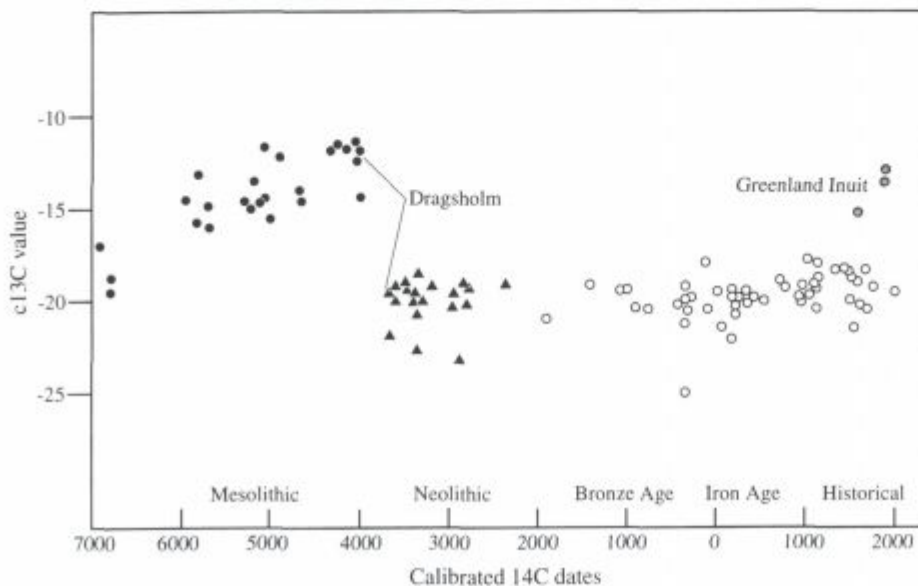
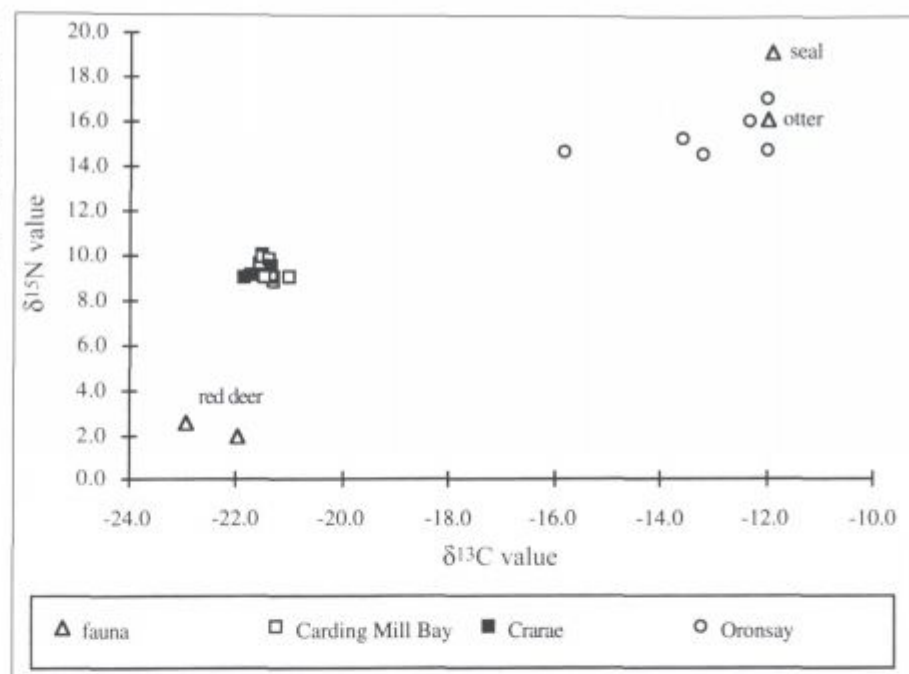


Fig. 4: Stable carbon isotope values associated with radiocarbon dated human bone from Denmark (after Tauber 1986, Figure 3).

Fig. 5. Bone collagen stable carbon and nitrogen isotope values for human and faunal samples from various sites on the West Coast of Scotland (source of Oronsay values: Richards and Mellars 1998).



But there are other possible explanations (Schulting and Richards *in press*). The individual may have spent part of his/her life in an inland situation, later moving to the coast. The number of samples from these sites is too small and the chronological resolution too poor to discuss the various alternatives further at this point.

Human bone samples from two additional sites on the Scottish West Coast have recently been analysed: the shell midden at Carding Mill Bay near Oban, and the Neolithic chambered tomb of Crarae on Loch Fyne. It was hoped that the human remains found in various contexts at the Carding Mill Bay shell midden would span the transition (available radiocarbon dates range from ca. 5200 to 4800 BP [Connock *et al.* 1992]), allowing an investigation of the relative importance of marine resources in the Mesolithic and Neolithic. However, the stable isotope results show no use of marine protein, strongly suggesting that the human remains all date to 5000 BP or later. The low standard deviations for both the stable carbon and nitrogen measurements emphasises the remarkable isotopic homogeneity of the diet of this population. If some of the human remains are indeed associated with the dated 'Obanian'/Mesolithic levels, it would indicate a surprising separate terrestrial adaptation on the Scottish mainland. Alternatively, the remains may be intrusive from a later period, as there is a Bronze Age cist burial near the top of the midden deposits (Connock *et al.* 1992). A series of accelerator dates will resolve this issue.

The stable carbon results from the earlier Neolithic chambered tomb at Crarae on Loch Fyne again show no contribution of marine protein in the diet of these individuals (possibly only one but more likely at least two individuals are represented by the three measurements), despite the proximity of the tomb to the sea and the large numbers (some 5000) of intentionally deposited oyster and other marine shells found both in the tomb and in the forecourt (Scott 1961). This conclusion is further supported by the $\delta^{15}\text{N}$ values, which indicate predominantly terrestrial meat protein, presumably cattle. It is worth noting that the tomb is situated in a relatively fertile pocket of an otherwise rocky, hilly area. This, rather than the site's proximity to marine subsistence resources, may have been a prime factor in the choice of location for the site. Also, the potential importance of the sea as a communication route should not be overlooked.

Comparing the available values from Scotland, the separation between a 'Mesolithic', marine-based diet and a 'Neolithic', terrestrial-based diet is quite striking (Fig. 5). The tight clustering of all human samples from Carding Mill Bay and Crarae strongly implies an isotopically homogeneous diet with minimal input of marine foods. The separation along the $\delta^{15}\text{N}$ axis between the humans and the red deer may be exaggerated (cattle values tend to be higher), but nevertheless it is unlikely that cereals or other plants contributed much to the protein component of the diet. This conclusion is strengthened by the relative absence of habitats suitable for fresh-

water fish on the Scottish West Coast, which could provide an alternative to terrestrial mammals that would be disproportionately reflected in the $\delta^{15}\text{N}$ values. It is likely, then, that the majority of the protein in the diet of these individuals was acquired from domestic animals. By contrast, the Mesolithic values from Cnoc Coig on Oronsay are very similar to the values for otters from Carding Mill Bay and from Oronsay itself, and suggests that the diet of these individuals was similarly dominated by fish.

England and Wales

In England and Wales, a small number of Mesolithic radiocarbon dates with associated $\delta^{13}\text{C}$ values are available from the literature (mainly from the journals *Radiocarbon* and *Archaeometry*). Most belong to the earlier part of the Mesolithic; given changes in sea-levels, these must be seen as representing largely inland adaptations. Nevertheless there is some hint of a pattern, with humans from sites near the modern coast showing slightly higher values (*i.e.*, more marine) than their Neolithic counterparts (Schulting 1998). With one possible exception, no Late Mesolithic burials are known from southern Britain, so that it is not possible to simply measure known burials for their isotopes and compare them to Neolithic individuals. Rather, relevant samples must be actively sought out. Caldey Island was chosen as a promising location: the island would have remained relatively close to the Atlantic period

coastline, so that human communities would have been close enough to the coast to expect the use of marine resources. The mixed cave deposits at a number of sites on the small island contained fragments of human bone together with fauna and tools spanning the Late Pleistocene and most of the Holocene. The site of Ogof-yr-Ychen has already provided the latest Mesolithic date on human bone from any context in England/Wales, ca. 7000 BP (7020 ± 100 BP, OxA-2574) (David 1990). Lithic assemblages also indicate a Late Mesolithic presence at a number of the sites (David 1990; Davies 1989; Lacaille and Grimes 1955; Nederveelde *et al.* 1973). Human bone samples were obtained from five locations on the northeast corner of the island: Nanna's Cave, Potter's Cave, Daylight Rock, Ogof-yr-Ychen, and Ogof-yr-Benlog (see David [1990] and Schulting [1998] for further discussion of the sites).

The isotope results clearly show the presence of individuals with significantly different diets. Values for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ are strongly correlated ($r^2 = 0.81$), both demonstrating that some individuals had diets in which a large part of the protein was acquired from marine resources (Fig. 6). In particular, all five samples from Ogof-yr-Ychen, representing three or possibly four individuals, reflect considerable use of marine protein. This is in marked contrast to the eight human bone samples from Nanna's Cave, none of which indicate any use of marine resources. The same applies to the single sample from Ogof-yr-Benlog, while both Potter's Cave and Daylight Rock

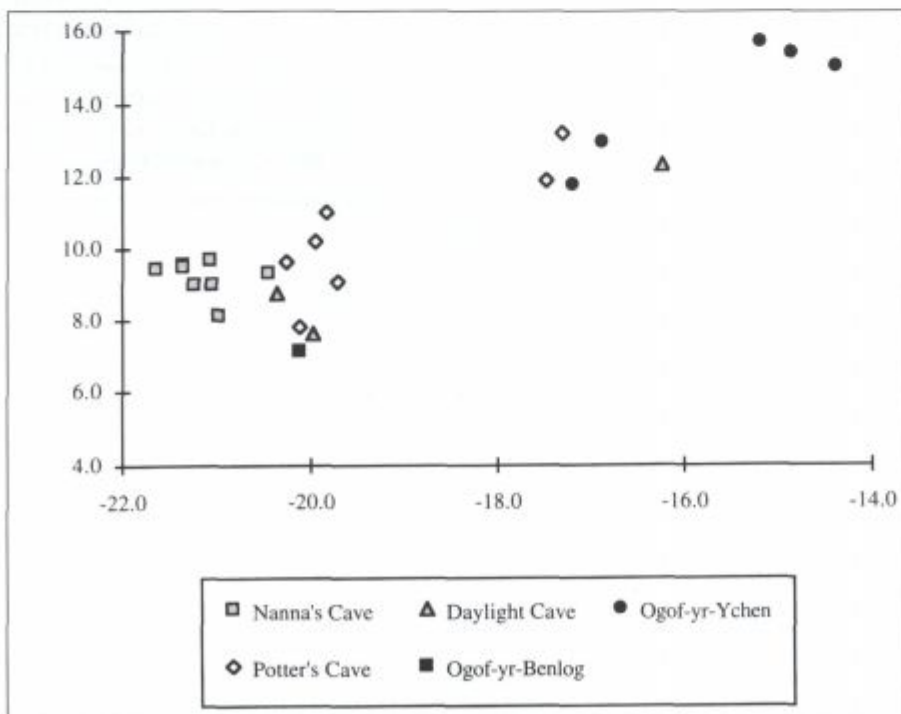


Fig. 6. Bone collagen stable carbon and nitrogen isotope values for human and faunal samples from various sites on Caldey Island, south Wales.

clearly divide into two groups, one of which exhibits an entirely terrestrial diet, while the other shows the use of approximately one-third or more marine-derived protein. It is hypothesised that these differences primarily reflect the date of the human remains, and that, consistent with what is known from elsewhere in western Europe (outside of northern and eastern Scandinavia), those individuals exhibiting high $\delta^{13}\text{C}$ values are of Mesolithic age. No such precise prediction can be made for individuals exhibiting a terrestrial diet – these could either be Palaeolithic/Early Mesolithic (when marine resources may not have been emphasised, and the sea would have been at a considerable distance even if they were), or Neolithic or later, when domesticated resources came to dominate subsistence in both inland and coastal locations.

Those samples demonstrating 'mixed' terrestrial/marine protein (two from Potter's Cave, one from Daylight Cave and two from Ogof-yr-Ychen) are of particular interest, since there are a number of possible interpretations, involving variation within one population at one time, change through time in the degree of use of marine resources, and/or patterns of seasonal movement. AMS dates will help choose between these alternatives.

In contrast, a series of stable carbon isotope values on dated earlier Neolithic individuals from coastal and near-coastal sites in southwest England and Wales show little or no indication of the use of marine-derived protein. While the majority of the values are by-products of accelerator dates, those from the chambered tomb of Parc le Breos Cwm on the Gower Peninsula have been analysed specifically for palaeodiet (Richards in Whittle and Wysocki *in press*), and are consistent with the other values. A few values of around -19.5‰ do suggest some minimal input of marine protein (on the order of 5–10% of protein intake) in the diet of some individuals at Parc le Breos Cwm and Little Hoyle Cave. Little Hoyle Cave is of special interest, since the site is located on the mainland adjacent to Caldey Island. The human remains here span the earlier Neolithic (4930 to 4660 BP) (Hedges *et al.* 1993), yet if anything the two earliest individuals show less indication of a marine signature than the two later individuals, although the difference is insignificant. Thus no trend can be detected, either at Little Hoyle or at Parc le Breos Cwm, for any gradual change in subsistence from a more 'Mesolithic' diet (*i.e.*, one including seafoods) in the Early Neolithic to a more 'Neolithic' diet in the Middle Neolithic. It may be that such a

transition did take place in the few centuries prior to ca. 5000 BP, but since human remains are as yet unknown in this area from the critical period between 7000 and 5000 BP, this possibility must remain open for future investigation.

Brittany

Téviec and Hoëdic are Late Mesolithic shell middens presently located on small islands off the coast of Brittany, although during the Atlantic period sea-levels would have been considerably lower (Schulting 1996). Téviec and Hoëdic are known for their relatively elaborate graves, including single, double and multiple interments, some of which, associated with simple stone cists, are clearly successive in the same tomb (Péquart *et al.* 1937; Péquart and Péquart 1954). Cemeteries present the ideal context for isotopic studies, presenting relatively large numbers of individuals from a single location; they often show continued use through a considerable period of time as well. To take full advantage of the opportunities offered, however, it is essential to analyse as many individuals as possible. Human bone samples were obtained from a total of 25 individuals (14 from Téviec and 11 from Hoëdic) for the purposes of stable isotope analysis and accelerator dating. This represents all the individuals that still exist in museum collections, with the exception of two for which permission was denied. Accelerator dates were obtained on a sub-set of 14 of these individuals, comprising 8 from Téviec and 6 from Hoëdic (Schulting *in press*).

The stable carbon isotope results from Téviec and Hoëdic present a very consistent set of data that make it clear that a significant portion of the protein component of the diet was derived from the sea (Fig. 7). This is particularly the case at Hoëdic, which shows on average a significantly greater reliance on marine-derived protein than seen at Téviec. While the average $\delta^{13}\text{C}$ value of $-14.2 \pm 0.9\text{‰}$ for Hoëdic suggests that from approximately 70 to 90% of the protein in the diet of those individuals measured was from seafoods, the average of $-15.5 \pm 0.9\text{‰}$ from Téviec indicates a more balanced economy incorporating both marine and terrestrial protein sources in near-equal proportions. The $\delta^{13}\text{C}$ results are supported by trend in the $\delta^{15}\text{N}$ results, which are on average higher for Hoëdic than for Téviec.

It is interesting to note that very little in the way of a temporal trend can be detected in the isotopic data (Fig. 8). It might be expected – barring for the moment the appearance of a 'Neolithic' economy – that

the data would show increased use of marine resources through time, if for no other reason than the sea would be moving closer over time. This is clearly not the case, and even the those individuals dating very late in the sequence, when elements of a Neolithic economy might indeed be expected to be making an appearance, show the continuation of a pattern apparently established by at least 7000 BP on the south Breton coast.

Problems arise in addressing the nature and speed of the dietary shift across the transition due to the lack of comparative Neolithic values. Bone preservation in Brittany is poor outside of shell middens, which do not occur in the Neolithic. And the few dates on human bone that have been reported in the literature often do not include stable carbon measurements. There are two exceptions, both of which are flawed. A multi-phase monument at Beg-an-Dorchenn has provided two human bone dates, one of 5490 ± 90 BP (Gif-A92372) and another of 4140 ± 55 BP (OxA-5363). Unfortunately, the earlier date was not associated with a stable carbon isotope value. The later date provides a terrestrial value of -19.5‰ , but this is of little relevance to the transition. A relatively early date of 5270 ± 80 BP (OxA-5974) was obtained on human bone from the passage grave of Ty Floc'h, and yielded a typical terrestrial $\delta^{13}\text{C}$ value of -21.6‰ (Hedges *et al.* 1997). However, this site is located some 25 km inland, and it may be that contemporary sites closer to the coast would show some use of marine resources. Further-

more, both Beg-an-Dorchenn and Ty Floc'h are some distance from the Gulf of Morbihan, where Tévéc and Hoëdic are located.

Late dates (5680 ± 50 BP (OxA-6662), 5755 ± 55 BP (OxA-6710) and 5080 ± 55 BP (OxA-6705)) from Tévéc and Hoëdic, even before correction for the marine reservoir effect, and together with the stable isotope data for these individuals, suggest the continuation of a Mesolithic economy into the period traditionally seen as the Middle Neolithic I of Brittany. But the exact chronological relationship between the two periods or 'cultures' is still poorly understood, and a larger series of accelerator dates and isotope analysis on human bone from early Middle Neolithic contexts is needed. The data presented here suggest that the process of neolithisation might be substantially different in Brittany than in southern Scandinavia. The persistence of a largely marine-oriented economy as inferred from the marine signatures at Tévéc and Hoëdic would seem to indicate one of two possibilities: either the economy of the earliest Neolithic in Brittany was not based on domesticates, or two separate economies survived for a period of time side-by-side. The latter alternative itself presents two variants: a high degree of economic heterogeneity within a single 'Neolithic' society, or the co-existence of two distinct societies, *i.e.*, 'Mesolithic' and 'Neolithic'. The question of the definition of these terms becomes awkward at this stage, but the underlying issue remains important regardless.

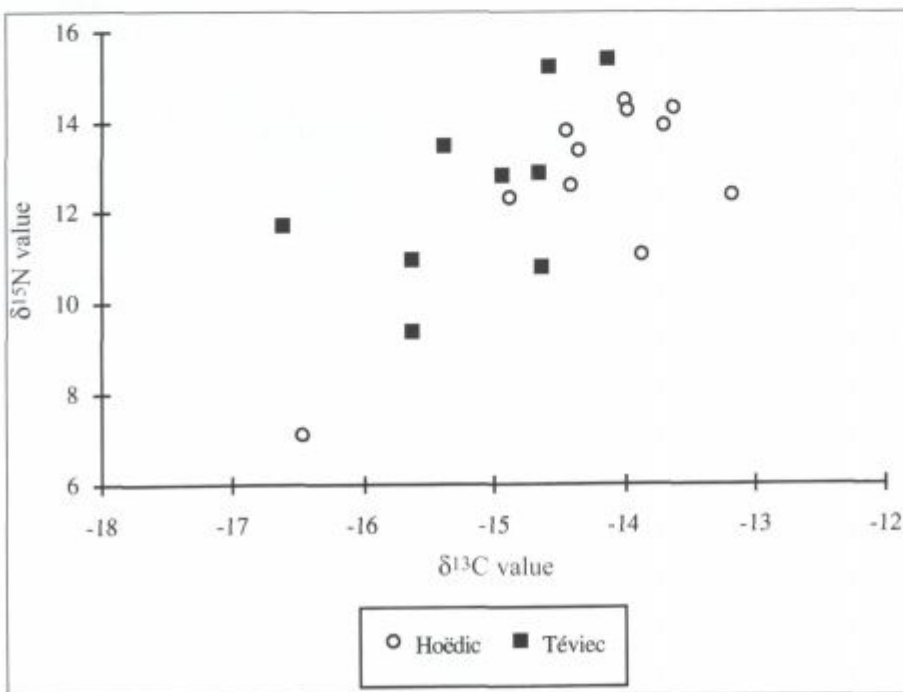


Fig. 7. Bone collagen stable carbon and nitrogen isotope values for human samples from Tévéc and Hoëdic, Brittany.

DISCUSSION

It has been argued here that stable isotope analysis presents the best currently available means of broadly characterising Mesolithic and Neolithic diet, and the shift from the one to the other, particularly in coastal areas. This being the case, it is essential to come to terms with the remarkable swiftness and completeness with which the transition to novel resources appears to have occurred, particularly in Denmark, where the evidence is most abundant, but also in other areas. There are a number of possible explanations:

- 1) the stable isotope technique is providing erroneous results;
- 2) the human bone samples being analysed are not representative of Mesolithic and/or Neolithic society as a whole;
- 3) the fully formed Neolithic subsistence package was introduced by an incoming population;
- 4) changing environmental conditions reached a critical point that dramatically favoured the wholesale and roughly simultaneous adoption of the novel resources by indigenous communities over a wide area;
- 5) a fairly radical shift in ideology or worldview occurred that encouraged the rapid adoption of novel resources;
- 6) manipulation of the socioeconomic system by subgroups within Mesolithic communities resulted in novel resources being preferred to traditional resources.

A number of scholars have recently questioned the stable isotope evidence for southern Scandinavia (e.g., Meiklejohn *et al.* 1998; Midgley 1992; Thorpe 1996). While further research is needed to address some of the concerns raised, others are exaggerated and/or have been largely dealt with elsewhere (Schulting 1998). For example, it is clear that individuals from both coastal and inland locations have been measured from the Neolithic, negating the criticism that the coastal Neolithic is not represented, thereby biasing the comparison made by Tauber (1981, 1986). As some have pointed out (e.g., Tilley 1996), it is not possible to differentiate between wild and domestic sources of terrestrial protein. While this is true, it would be remarkable if Neolithic populations suddenly began ignoring the marine resources their immediate predecessors had been relying on for millennia in order to suddenly begin intensively exploiting wild game and plant foods. Moreover, it is questionable whether such a strategy would even be ecologically possible given the postulated population levels at this time on the Danish islands in particular.

It is conceivable that the Neolithic individuals sampled, while providing accurate measures in themselves, reflect only one stratum of contemporary society, presumably an elite with preferential or even exclusive access to the novel resources. The majority of the Neolithic samples do originate from monumental mortuary structures – earthen long barrows and megalithic tombs. While plausible, this explanation does not seem very likely. There are sim-

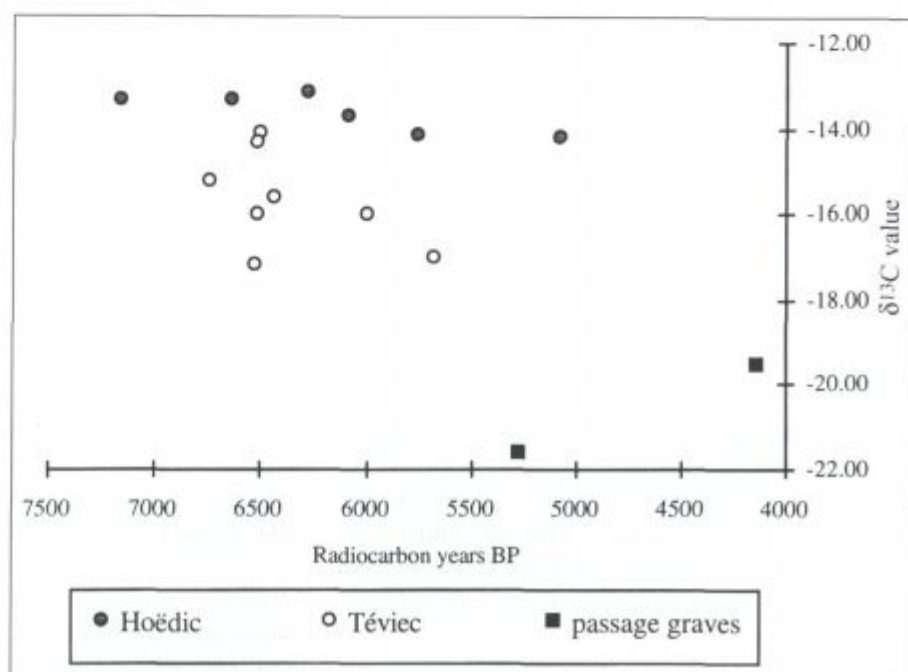


Fig. 8. AMS dates from Téviec and Hoëdic plotted against stable carbon isotope values; the two passage grave points derive from Ty Floc'h and Beg-an-Dor-chenn.

ply too many measurements on Neolithic individuals, *all* of which demonstrate little or no use of the marine resources that totally dominated the diet of preceding coastal Late Mesolithic populations. Nor are all of these individuals from monumental tombs: the Early Neolithic flat grave at Dragsholm shows no marine influence, nor do a series of dated human skeletal remains from bogs on Zealand (*Rahbek and Rasmussen 1995*), at least some of which were found near enough to the coast to expect the incorporation of marine resources if these were being utilised to any extent. From Britain, individuals from caves and mortuary monuments near the coast have been measured, and neither context shows much in way of evidence of marine resource-use. Finally, in Denmark, limited stable carbon isotope measurements on domestic dogs appear to approximate the same shift in diet as seen in humans (*Noe-Nygaard 1988*).

Clearly the remaining possibilities are not mutually exclusive, but they do have differing implications for the nature of the transition and the archaeological evidence that might be expected. None of the possibilities are unproblematic with regards to the archaeological evidence. The idea that an incoming population is responsible for the appearance of the Neolithic in either Britain or southern Scandinavia currently does not hold favour. Nevertheless, adherents of this view remain, and it should not be dismissed out of hand. But a wholesale population replacement seems exceedingly unlikely. There are numerous continuities in technologies, artefact styles and settlement locations (although the relevance of all three as biological population markers may be questioned). Furthermore, the apparent density of Late Mesolithic populations in southern Scandinavia make it inherently unlikely that they could have been swamped by incoming farming groups. This is not to say that small-scale population movements did not occur, particularly if one envisions a rapid knock-on effect, with 'acculturated' groups expanding (whether physically or in terms of cultural influence) locally at the expense of their immediate fisher-hunter-gatherer neighbours, who then rapidly become acculturated themselves and expand in a similar fashion. Solberg (1989), for instance, argues that much of the evidence in southern Scandinavia can be best explained by a merging of incoming late LBK-derived farming groups with the indigenous Ertebølle peoples. However, the rapid dietary change cannot then be explained in terms of a new incoming population.

The view that changing environmental conditions could play such a determining role in the transition has also been strongly criticised (*e.g., Blankholm 1987; Jennbert 1984*), and does appear to fall short of accounting for the extent and timing of the transition. The idea that the changing environment did play some kind of role, however, remains reasonable. But any such model would have to be argued on a broader level than that proposed by Rowley-Conwy (1984), who saw the loss of the critical spring oyster resource as the reason for the transition to food production. The relatively high productivity of Late Atlantic marine ecosystems in the North Sea and southern Baltic region has been repeatedly emphasised (*e.g., Paludan-Müller 1978*), and it is clear that a marine adaptation formed the focus of Late Mesolithic subsistence in Denmark (*Andersen 1995; Fischer 1997*). Indeed, it has been suggested that it was the success of this adaptation that allowed Late Mesolithic communities in southern Scandinavia to persist despite the alternative offered by the nearby presence of mixed farming communities (*Zvelebil and Rowley-Conwy 1986*).

But success comes at a price: populations appear to have been at their densest in Late Atlantic times (compared with earlier periods), with increasing use of previously marginal inland areas (*Knutsson 1995; Paludan-Müller 1978*). A general decline in marine productivity, then, caused by falling sea-levels, could have had disastrous effects, and may have brought about a sudden shift in the relative ranking of the two alternative economic systems – fishing-hunting-gathering and food producing. Faced with the prospect of rapidly diminishing returns, exacerbated by the decline in marine productivity, further intensification or even maintenance of the existing system may have not have been feasible, particularly when an alternative was available (thus contrasting with the Northwest Coast of North America, where suitable domestic resources were not available). Domesticated resources had been ignored, other than as exotic curiosities or high-status luxuries, as long as the costs of switching from one system to the other outweighed the immediate perceived benefits. While making many similar points to Rowley-Conwy's model, this scenario attempts to avoid its overriding emphasis on a single resource (*cf. Larsson 1991*). Rather, it is the two systems as integrated wholes that comprise the alternatives. A critical point – a threshold – may have been reached that made the decision to radically switch over to a reliance on domesticated resources more attractive. Although marine resources continued to play some role in the

Neolithic economy, this role was insignificant in dietary terms compared to the Late Mesolithic. It is possible that, as Rowley-Conwy and Zvelebil have proposed, scheduling conflicts between the two subsistence systems, at the level of production required, were insurmountable. Thus the shift, when it came, was of necessity rapid and complete. The continuation of a specialised marine adaptation alongside the new system was not possible due to competing demands on the highly productive coastal strip by both economic systems. Nor would such a solution be acceptable to groups who were now competing socioeconomically and/or establishing group identity through the use of domesticated resources.

Its proponents frequently support the ideological argument by referring to the gradual nature of subsistence change across the transition, and the continued importance of wild resources (*e.g.*, Bradley 1993; Tilley 1996; Whittle 1996). But, as should be clear from the evidence presented here, this may not have been the case for much of northwestern Europe. A shift in worldview may have been necessary to permit the modification of the landscape and/or the social relations of ownership needed for a serious commitment to agriculture or herding, but it is difficult to see why this should have such sudden, complete and widespread consequences. Nor has the role of the subsistence economy, shown here to be integral to the transition, received sufficient consideration in this model. Similarly, it is difficult to account for the apparent sudden and complete nature of the change in subsistence with a sociopolitical model emphasising elite competition. One of the basic tenets of this model is that novel resources will be employed only on special occasions. Nevertheless the apparent level of sociocultural complexity of Late Mesolithic societies indicates that social dynamics cannot be ignored. Evidence of exchange of what were likely high status objects, such as the Danubian axes, prior to the transition indicates that lines of contact did exist between farmers and foragers, and could have formed the channels along which domesticated resources initially flowed (Fischer 1982).

Thus it is at present difficult to choose decisively between these alternatives. The most plausible scenario may be that a number of factors acted together – perhaps different combinations of factors in different regions. Monocausal explanations, while attractive in their simplicity and elegance, are unlikely to provide adequate accounts of complex events and processes. For example, given the extreme re-

liance on coastal resources seen in Late Mesolithic southern Scandinavia in particular, I suspect that changing ecological conditions *did* play an important role in the transition there. I doubt that they played a similarly important role in Britain or Brittany, due to the much greater interior land masses of these countries relative to their coastlines.

In conclusion, the stable isotope evidence demonstrates that, whatever else was going on, the change in the subsistence economy was an integral part of the Mesolithic-Neolithic transition, as integral as changes in material culture and mortuary practices, with all that that implies concerning religion and sociopolitical organisation. The change in subsistence appears to have been rapid and complete. This is especially the case in southern Scandinavia, but ongoing research is showing that a similar pattern may apply in Britain. The Mesolithic populations of coastal Europe present a unique subsistence economy; no subsequent period saw anything approaching the same intensive use of marine resources. Much has been made recently of the likelihood of regional variation in the neolithisation process, but Neolithic communities everywhere appear to have very quickly turned their backs on the sea.

ACKNOWLEDGMENTS

I would like to thank Professor Mihael Budja for the opportunity to participate in what was a most enjoyable conference. The original isotope data discussed in this paper are the result of a collaborative project with Michael Richards of the Oxford Laboratory for Archaeology.

REFERENCES

- AMBROSE S. H. and NORR L. 1993. Experimental Evidence for the Relationship of the Carbon Isotope Ratios of Whole Diet and Dietary Protein to Those of Bone Collagen and Carbonate. In J. B. Lambert and G. Grupe (eds.), *Prehistoric Human Bone: Archaeology at the Molecular Level: 1-37*. New York.
- ANDERSEN S. H. 1995. Coastal Adaptation and Marine Exploitation in Late Mesolithic Denmark – with Special Emphasis on the Limfjord Region. In A. Fischer (ed.), *Man and Sea in the Mesolithic: 41-66*. Oxford.
- BLANKHOLM H. P. 1987. Late Mesolithic Hunter-Gatherers and the Transition to Farming in Southern Scandinavia. In P. Rowley-Conwy, M. Zvelebil and H. P. Blankholm (eds.), *Mesolithic Northwest Europe: Recent Trends: 155-162*. Sheffield.
- BONSALL C., LENNON R. MCSWEENEY K., HARKNESS D., BORONEANT V., BARTOSIEWICZ L., PAYTON R. and CHAPMAN J. 1997. Mesolithic and Early Neolithic in the Iron Gates: A Palaeodietary Perspective. *Journal of European Archaeology* 5(1): 50-92.
- BRADLEY R. 1993. *Altering the Earth: The Origins of Monuments in Britain and Continental Europe*. Edinburgh.
- BRINCH PETERSEN E. 1974. Gravene ved Dragsholm. Fra Jægere til Bønder for 6000 År Siden. *Nationalmuseets Arbejdsmark* 1974: 112-120.
- CHISHOLM B. E. 1986. Reconstruction of Prehistoric Diet in British Columbia using Stable-Carbon Isotope Analysis. Ph.D. thesis, Simon Fraser University, Burnaby, British Columbia.
- CHISHOLM B. E., NELSON D. E. and SCHWARZ H. P. 1983. Marine and Terrestrial Protein in Prehistoric Diets on the British Columbia Coast. *Current Anthropology* 24(3): 396-98.
- CONNOCK K. D., FINLAYSON B. and MILLS C. M. 1992. A Shell-Midden with Burials at Carding Mill Bay, near Oban, Scotland. *Glasgow Archaeological Journal* 17: 25-38.
- DAVID A. 1990. Palaeolithic and Mesolithic Settlement in Wales with Special Reference to Dyfed. Unpublished Ph.D. Thesis, Dept. of Classics and Archaeology, University of Lancaster.
- DAVIES M. 1989. Recent Advances in Cave Archaeology in Southwest Wales. In T. D. Ford (ed.), *Limestone and Caves of Wales: 79-91*. Cambridge.
- DeNIRO M. J. and EPSTEIN S. 1978. Influence of Diet on the Distribution of Carbon Isotopes in Animals. *Geochimica et Cosmochimica Acta* 42: 495-506.
1981. Influence of Diet on the Distribution of Nitrogen Isotopes in Animals. *Geochimica et Cosmochimica Acta* 45: 341-351.
- FISCHER A. 1982. Trade in Danubian Shaft-Hole Axes and the Introduction of Neolithic Economy in Denmark. *Journal of Danish Archaeology* 1: 7-12.
1997. People and the Sea – Settlement and Fishing along the Mesolithic Coast. In L. Pedersen, A. Fischer and B. Aaby (eds.), *The Danish Storebælt Since the Ice Age: 63-77*. A/S Storebælt Fixed Link, Kalundborg Museum, National Forest and Nature Agency and the National Museum of Denmark, Copenhagen.
- HEDGES R. E. M., HOUSLEY R. A., BRONK RAMSEY C. and VAN KLINKEN G. J. 1993. Radiocarbon Dates from the Oxford AMS System: Archaeometry Datelist 16. *Archaeometry* 35(1): 147-167.
- HEDGES R. E. M., PETTIT P. B., BRONK RAMSEY C. and VAN KLINKEN G. J. 1997. Radiocarbon Dates from the Oxford AMS System: Archaeometry Datelist 24. *Archaeometry* 39(2): 247-262.
- HOBSON K. A. and COLLIER S. 1984. Marine and Terrestrial Protein in Australian Aboriginal Diets. *Current Anthropology* 25: 238-240.
- HODDER I. 1990. *The Domestication of Europe*. Oxford.
- INGOLD T. 1986. *The Appropriation of Nature*. Manchester.
- KATZENBERG M. A. 1989. Stable Isotope Analysis of Archaeological Faunal Remains from Southern Ontario. *Journal of Archaeological Science* 16: 319-329.
- KNUTSSON K. 1995. Mesolithic Research in Sweden 1986-1990. *Current Swedish Archaeology* 3: 7-27.

- KRUEGER H. W. and SULLIVAN C. H. 1984. Models for Carbon Isotope Fractionation between Diet and Bone. In J. R. Turnlund and P. E. Johnson (eds.), *Stable Isotopes in Nutrition: 205–220*. American Chemical Society Symposium Series, Washington, D.C.
- LACAILLE A. D., GRIMES W. F. 1955. The Prehistory of Caldey. *Archaeologia Cambrensis* 104: 85–165.
- LARSSON M. 1991. The Introduction and Establishment of Agriculture. The Moving Family: Aspects of the Early Neolithic in Southern Scania. In B. Berglund (ed.), *The Ystad Project: 315–321*. *Ecological Bulletins* 41.
- LEE R. B. 1968. What Hunters Do for a Living, or, How to Make Out on Scarce Resources. In R. B. Lee and I. Devore (eds.), *Man the Hunter: 30–48*. Aldine, Chicago.
- LEE-THORPE J., SEALY J. and VAN DER MERWE N. J. 1989. Stable Carbon Isotope Ratio Differences Between Bone Collagen and Bone Apatite, and Their Relationship to Diet. *Journal of Archaeological Science* 16: 585–599.
- LOVELL N. C., CHISHOLM B. S., NELSON D. E. and SCHWARCZ H. P. 1986. Prehistoric Salmon Consumption in Interior British Columbia. *Canadian Journal of Archaeology* 10: 99–106.
- LUBELL D., JACKES M., SCHWARCZ H., KNYF M., and MEIKLEJOHN C. 1994. The Mesolithic-Neolithic Transition in Portugal: Isotopic and Dental Evidence of Diet. *Journal of Archaeological Science* 21: 201–216.
- MEIKLEJOHN C., BRINCH PETERSEN E. and ALEXANDERSEN V. 1998. The Later Mesolithic Population of Sjælland, Denmark, and the Neolithic Transition. In M. Zvevlebil, R. Dennell, and L. Domanska (eds.), *Harvesting the Sea, Farming the Forest: The Emergence of Neolithic Societies in the Baltic Region: 203–212*. Sheffield.
- MIDGELY M. S. 1992. *TRB Culture: The First Farmers of the North European Plain*. Edinburgh.
- NEDERVELDE J. VAN, DAVIES M., and JOHN B. S. 1973. Radiocarbon Dating from Ogof-yr-Ychen, a New Pleistocene Site in West Wales. *Nature* 245: 453–454.
- NOE-NYGAARD N. 1988. $\delta^{13}\text{C}$ Values of Dog Bones Reveal the Nature of Changes in Man's Food Resources at the Mesolithic-Neolithic Transition, Denmark. *Isotope Geoscience* 73: 87–96.
- PALUDAN-MÜLLER C. 1978. High Atlantic Food Gathering in North-Western Zealand: Ecological Conditions and Spatial Representation. *Studies in Scandinavian Prehistory and Early History* 1: 120–157.
- PÉQUART M. and PÉQUART S.-J. 1954. *Hoëdic, Deuxième Station-Nécropole du Mésolithique Côtier Armoricaire*. Anvers.
- PÉQUART M., PÉQUART S.-J., BOULE M. and VALLOIS H. 1937. Tévéc, Station-Nécropole du Mésolithique du Morbihan. *Archives de L'Institut de Paléontologie Humaine* XVIII, Paris.
- RAHBEK U. and RASMUSSEN K. L. 1995. Danish Radiocarbon Datings of Archaeological Samples, Copenhagen 1995. *Arkæologiske Udgravninger i Danmark 1995: 298–317*.
- RICHARDS M. P. and MELLARS P. 1998. Stable Isotopes and the Seasonality of the Oronsay Middens. *Antiquity* 72: 178–184.
- ROWLEY-CONWY P. 1984. The Laziness of the Short-Distance Hunter: The Origins of Agriculture in Western Denmark. *Journal of Anthropological Archaeology* 4: 300–324.
- in press. Meat, Furs and Skins: Mesolithic Animal Bones from Ringkloster, a Seasonal Hunting Camp in Jutland. *Journal of Danish Archaeology*.
- SOLBERG B. 1989. The Neolithic Transition in Southern Scandinavia: Internal Development or Migration? *Oxford Journal of Archaeology* 8(3): 261–296.
- SCHOENINGER M. J., DeNIRO M. J. and TAUBER H. 1983. Stable Nitrogen Isotope Ratios of Bone Collagen Reflect Marine and Terrestrial Components of Prehistoric Human Diet. *Science* 220: 1381–1383.
- SCHULTING R. J. 1996. Antlers, Bone Pins and Flint Blades: The Mesolithic Cemeteries of Tévéc and Hoëdic, Brittany. *Antiquity* 70: 335–350.
1998. Slighting the Sea: The Mesolithic-Neolithic Transition in Northwest Europe. Unpublished PhD thesis, Department of Archaeology, University of Reading.

in press. Rapport préliminaire concernant de nouvelles dates AMS obtenues sur les sites de Tévéc et Hoëdic, Quiberon (Morbihan). *Bulletin de la Société Préhistorique Française*.

SCHULTING R. J. and RICHARDS M. P. in press. The Use of Stable Isotopes in Studies of Subsistence and Seasonality in the British Mesolithic. In R. Young (ed.), *Current Research on the British and Irish Mesolithic*. Leicester.

SEALY J. C. and VAN DER MERWE N. J. 1985. Isotope Assessment of Holocene Human Diets in the South-west Cape, South Africa. *Nature* 315: 138-140.

TAUBER H. 1981. ^{13}C Evidence for Dietary Habits of Prehistoric Man in Denmark. *Nature* 292: 332-333.

1986. Analysis of Stable Isotopes in Prehistoric Populations. *Mitteilungen der Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte* 7: 31-38.

THORPE I. J. 1996. *The Origins of Agriculture in Europe*. London.

TIESZEN L. L. and FAGRE T. 1993. Effect of Diet Quality and Composition on the Isotopic Composition of Respiratory CO_2 , Bone Collagen, Bioapatite, and Soft

Tissues. In J. B. Lambert and G. Grupe (eds.), *Prehistoric Human Bone: Archaeology at the Molecular Level: 121-155*. New York.

TILLEY C. 1996. *An Ethnography of the Neolithic: Early Prehistoric Societies in Southern Scandinavia*. Cambridge.

WALKER P. L., DENIRO M. J. 1986. Stable Nitrogen and Carbon Isotope Ratios in Bone Collagen as Indices of Prehistoric Dietary Dependence on Marine and Terrestrial Resources in Southern California. *American Journal of Physical Anthropology* 71: 51-61.

WHITTLE A. 1996. *Europe in the Neolithic: The Creation of New Worlds*. Cambridge.

WHITTLE A. and WYSOCKI M. in press. Parc le Breos Cwm Transepted Long Cairn, Gower, West Glamorgan: Date, Contents and Context. *Proceedings of the Prehistoric Society*.

ZVELEBIL M. 1994. Plant Use in the Mesolithic and Its Role in the Transition to Farming. *Proceedings of the Prehistoric Society* 60: 35-74.

ZVELEBIL M. and ROWLEY-CONWY P. 1986. Foragers and Farmers in Atlantic Europe. In M. Zvelebil (ed.), *Hunters in Transition: 67-93*. Cambridge.