[RADIOCARBON, VOL 28, NO. 2A, 1986, P 754–761]

$\delta^{13}C$ AND DIET: ANALYSIS OF NORWEGIAN HUMAN SKELETONS

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ABSTRACT. The relationship between ^{13}C content of human bone and the marine fraction in the individual diet is well established. In the present investigation human skeletons from inland and coastal areas in Norway were analyzed. Both regional and chronologic differences are revealed, and larger variability than expected at specific sites indicate more complex cultural adaptations than earlier recognized. Extremely high $\delta^{13}C$ values, comparable with those obtained from Eskimo sites, are found for material from Early Stone Age fishing/hunting communities.

INTRODUCTION

Recent investigations indicate that measurement of $\delta^{13}C$ values of bone collagen provide valuable information about the amounts of marine or terrestrial protein consumed by humans (Tauber 1981, 1983; Chisholm, Nelson & Schwarcz 1982, 1983a, b; Schoeninger, DeNiro & Tauber 1983). However, if C_4 plants like maize were part of the diet, the picture is distorted. But this problem is not relevant, either for northern Europe or for British Columbia, where most of the evidence used for comparison is derived.

In non-coastal areas of Mexico and North America ratios of $^{13}C/^{12}C$ provide important information about the introduction and amount of maize in the diet (eg, Van der Merwe & Vogel, 1978; Price & Kavanagh, 1982; Bumsted, 1984; Schwarcz *et al,* 1985; Farnsworth *et al,* 1985). In some of the case studies $\delta^{15}N$ is used to supplement information from $\delta^{13}C$ (eg, Schoeninger, DeNiro & Tauber, 1983; Schwarcz *et al,* 1985).

The Canadian data indicate that a 7% difference between the stable carbon isotope ratios for marine and terrestrial carbon reservoirs persists throughout the food chains (Chisholm, Nelson & Schwarcz 1982, 1983a). They conclude (1983a, p 394) that "the $\delta^{13}C$ values of the collagen of pure marine and pure terrestrial consumers are, respectively, about $-13‰$ and 20‰ with an uncertainty on each of about 0, 5% at one standard deviation." However, more recently Chrisholm, Nelson and Schwarcz (1983b, p 396) suggested that end-points of $-12.0‰$ and $-22‰$ might be an alternative.

The main goal of the present study was to evaluate the potential for studying prehistoric and historic diets in Norway. Here as elsewhere quantification of dietary behavior is difficult to assess from archaeologic or historic sources.

Our results from Norwegian samples, and also results from Denmark presented by Tauber (1981, 1983) are in fair agreement with the Canadian evidence. Tauber (1981, p 122–125) lists 21 human collagen measure-

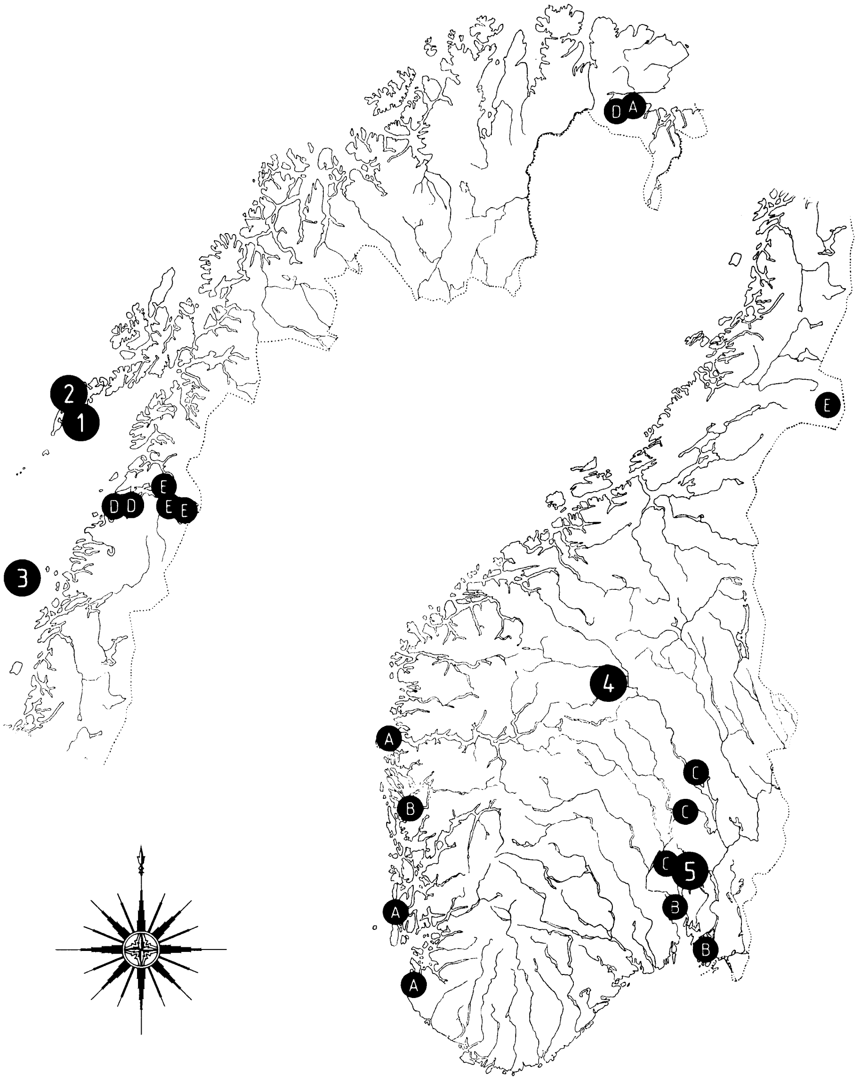

Fig 1. Selected (1–5) and regional (A–E) sites in Norway where $\delta^{13}C$ values for human bone collagen were obtained

ments from Denmark with a range of −11.4 to −22.9‰. The range of the 47 Norwegian measurements presented here is −12.8 to −22.7‰, but 42 values fall between −14.0 and −21.0‰.

METHODS

Skeletons from five prehistoric and historic sites were selected from several ecologic zones and chronologic periods (Nos. 1–5, Fig 1). The skeletons represent 30 individuals. Several $\delta^{13}C$ measurements made with routine ^{14}C dates at the Trondheim Radiocarbon Laboratory were also available; 17 of these were arranged in 5 regional groups, A to E (Fig 1).

The bone material was crushed (<2mm), and the inorganic fraction dissolved in HCl under vacuum. Gelatine was extracted from residue with slightly acidic (pH ~ 3.0) hot water. Dated samples were combusted in a conventional de Vries system, and several were analyzed for $^{13}C/^{12}C$ by R Ryhage, Karolinska Institutet, Stockholm, with an accuracy of ca ±0.5‰. The GMS (Geological Mass Spectrometry) laboratory at the University of Bergen has been measuring $\delta^{13}C$ since 1983. After collagen extraction at the Trondheim laboratory the samples were combusted by the GMS laboratory in a Carlo-Erba N-1500 elemental analyzer.

Unexpectedly large fractionation effects were observed during combustion of the gelatine, clearly demonstrating that reproducible and precise results are obtained only when combustion and CO_2 collection are complete. Reproducibility of measurements from the selected sites was found to be better than 0.1‰.

RESULTS

The $\delta^{13}C$ values in per mil relative to PDB appear in Tables 1 and 2. The tables list mean values for regions and selected sites. The number of samples are in most cases so small that the calculated standard deviation is of limited significance. More informative is the observed range of $\delta^{13}C$ values, also shown in Figure 2, where sites and regions are ranked according to

TABLE 1

$\delta^{13}C$ values for human bone collagen from selected sites

Map ref	Site description	Samples	Lab ref: $\delta^{13}C$ (‰ PDB)	$\delta^{13}C$ (‰ PDB) mean ± 1 SD	$\delta^{13}C$ (‰ PDB) range
1	Flakstad, Nordland I., Stone Age burials in midden	2	T-5076: −12.8 T-5110: −14.0	−13.4 ± 0.8	−14.0 to −12.8
2	Flakstad, Nordland I., Late Iron Age burials	5	FS-1: −18.2 FS-2: −15.9 FS-3: −18.0 FS-4: −16.4 FS-5: −16.9	−17.0 ± 1.0	−18.2 to −15.9
3	Træna, Nordland I., off the coast, Early Medieval burials	11	T-5075: −15.9 T-5082: −16.0 T-5077: −17.3 T-5083: −15.9 T-5078: −17.2 T-5084: −16.7 T-5079: −16.2 T-5085: −15.7 T-5080: −18.5 T-5086: −17.9 T-5081: −19.0	−16.9 ± 1.2	−19.0 to −15.7
4	Heidal, Oppland, inland valley, Medieval burials	10	T-5087: −20.6 T-5092: −21.1 T-5088: −20.9 T-5093: −20.7 T-5089: −20.5 T-5094: −20.8 T-5090: −20.4 T-5095: −19.9 T-5091: −20.7 T-5096: −20.8	−20.6 ± 0.3	−21.1 to −19.9
5	City of Oslo, upper class 17th century burials	2	FS-6: −18.7 FS-7: −18.5	−18.6 ± 0.1	−18.7 to −18.5

TABLE 2
$\delta^{13}C$ values for dated human bone collagen from different regions

Map ref	Site description	Samples	Lab ref: $\delta^{13}C$ (‰ PDB)	$\delta^{13}C$ (‰ PDB) mean ± 1 SD	$\delta^{13}C$ (‰ PDB) range
A	W and N Norway coastal area (no agric), Stone Age	4	T-2882: −16.4 T-3351: −17.1 T-3841: −15.9 T-3723: −15.9	−16.3 ± 0.6	−17.1 to −15.9
B	S Norway coastal area (agric), Stone/Bronze Age	3	T-5220: −19.8 T-2883: −19.0 T-2990: −22.2	−20.3 ± 1.7	−22.2 to −19.0
C	E Norway, inland, Early Iron Age	3	T-2520: −22.0 T-2753: −22.7 T-5074: −20.8	−21.8 ± 1.0	−22.7 to −20.8
D	N Norway coastal area, Medieval and Post-Medieval Sami burials	3	T-5073: −13.0 T-5243: −14.7 T-5244: −17.9	−15.2 ± 2.5	−17.9 to −13.0
E	N central Norway, inland, Medieval and Post-Medieval Sami burials	4	T-4549: −19.1 T-5141: −18.9 T-5142: −18.8 T-5143: −16.6	−18.4 ± 1.2	−19.1 to −16.6

the expected reliance on marine resources, deduced from geographic location and available historic and archaeologic evidence.

DISCUSSION

Selected Sites

1. *Flakstad, Nordland.* The two samples come from Stone Age burials in the midden of Storbåthallaren rock shelter on the Lofoten island, Flakstadøy. Preservation of food remains was excellent at this site (Utne, 1973), and a diet of more than 90% marine food, especially fish, seems likely. The ^{14}C dates of the skeletons, 5020 ± 100 and 4880 ± 200 BP, are earlier than unequivocal evidence of farming in this area. The $\delta^{13}C$ values of −12.8 and −14.0‰ fit in fairly well with two Greenland Eskimo measurements of −12.6 and −13.0‰ given by Tauber (1981, p 125–126). According to Tauber these people probably relied on >90% marine protein. Five Danish Mesolithic skeletons gave a range of values of −11.4 to −15.3‰ (p 122–123).

Chisholm, Nelson and Schwarcz (1982, 1983a) list 42 coastal British Columbia samples with an average $\delta^{13}C$ value of −13.4 ± 0.9‰. Six more samples averaged −13.5 ± 0.99‰. The assumption based on these results, that ca 90% of the protein was obtained from marine sources, is not confirmed in written or archaeologic evidence (Chisholm, Nelson & Schwarcz 1983b, p 397). These authors also note an interesting anomaly between a child and 13 adults from Site ElSx 1, Namu. The average $\delta^{13}C$ value for the adults is −13.04 ± 0.3‰ while the value for the child is −14.46‰. The samples from Storbåthallaren present a very similar picture as the lighter measurement represents a child ca 4 years old. Presumably, the explanation is that children were fed mainly mothers milk, not seafood.

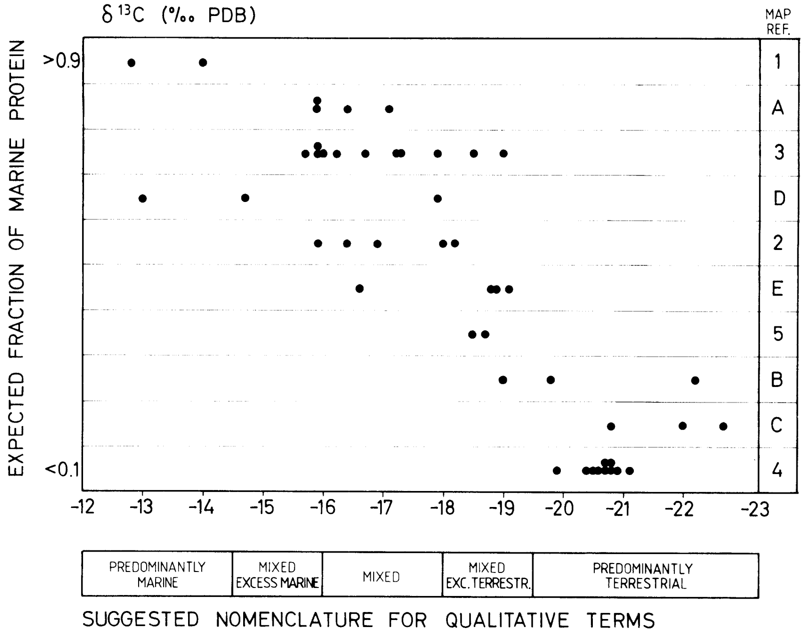

Fig 2. Distribution of $\delta^{13}C$ values obtained for human bone collagen. Sites are ranked according to expected fraction of marine diet.

2. *Flakstad, Nordland.* On the same island as Storbåthallaren, a Late Iron age cemetery (AD 600–1000) of a vicarage was studied. The range of the 5 measurements, −15.9 to −18.2‰, indicates a mixture of marine and terrestrial food. Variability is higher than expected and may be due to social ranking in the Iron Age society, with variable access to terrestrial protein.

Archaeologic studies indicate that the main food resources in the Iron Age in coastal northern Norway were fish, seal, milk, and domestic animals, while cereals were of minor importance (Jørgensen, 1984). For comparison, nine Danish Late Iron Age measurements (Sellevold *et al,* 1984, p 19), yielded a $\delta^{13}C$ range of −17.6 to −20.0‰, indicating heavier reliance on terrestrial food than the Flakstad evidence.

3. *Træna, Nordland.* Træna is a group of islands off the coast of Nordland; the 11 samples come from Medieval burials on the main island, Sanda. These individuals probably died in the 14th century AD from the Black Plague. The $\delta^{13}C$ range of −15.7 to −19.0‰ gives lower values and also higher variability than expected. It was assumed the sea food was always the staple diet in these small islands several kilometers off the coast. However, in the Middle Ages, dried fish from northern Norway was exchanged on a large scale for cereals in Bergen. Inequality in the distribution of wealth (ownership of fishing and transport vessels) and social position (the clergy and lay authorities) provided unequal access to imported cereals. This is the most probable explanation for the variation in $\delta^{13}C$ values, but population mobility may also have played a role.

4. *Heidal, Oppland.* Heidal is a remote valley in the interior of eastern Norway. Ten samples of human bones buried at a Medieval churchyard (ca AD 1100–1500) were measured. According to written records, an inland population living that far away from the coast should hardly have any excess to marine protein at all (Holmsen, 1982, p 62–63). A diet of more than 90% terrestrial food seems likely. The consistency of the Heidal measurements, with a range of −19.9 and −21.1‰, indicates that this site is very suitable for comparison.

To establish a $\delta^{13}C$ value for people extremely dependent on terrestrial food, Chisholm, Nelson & Schwarcz (1982, p 1132) derive an average value of −19.6 ± 0.9‰ for 17 individuals of the Archaic population of the Ottawa valley. An even lower $\delta^{13}C$ value, −21.4‰, was obtained by Van der Merwe and Vogel (1978) from 31 skeletons of the pre-maize stage in eastern North America. Sellevold *et al* (1984, p 19) report 37 Danish measurements from the Iron and Middle Ages with a range of −17.7 to −20.6‰. As much as 28 samples gave lower values than −19.0‰, which is in fair agreement with the assumption that marine protein played a minor role in the diet during these periods.

5. *City of Oslo.* Oslo has a semi-inland terrain at the end of a long fjord. Two measurements were made on human bones from an upper class 17th century churchyard. The values of −18.5 and −18.7‰ compare well with the lower values from Træna and the Flakstad vicarage. (A comparison of $\delta^{13}C$ values for upper and lower classes will be made when more measurements become available.)

Different Regions

A. *Western and Northern Norway.* These samples are from Stone Age sites in coastal areas without agriculture. Two of the 4 skeletons are of Mesolithic age, 7950 ± 110 and 7420 ± 150 BP, and 2 belong to the Neolithic period, 4330 ± 50 and 4070 ± 90 BP; the latter 2 skeletons come from areas where farming is unlikely. Archaeologic studies indicate that boar and red deer were important sources of terrestrial protein in western Norway and reindeer in the north, but in both areas heavy reliance on marine resources is postulated (Hagen, 1983, p 126–127, 174). The range of $\delta^{13}C$ values of −15.9 to −17.1‰ supports the assumption of a mixed diet.

Chisholm, Nelson and Schwarcz (1983a, p 1132) give an average $\delta^{13}C$ value of −15.4 ± 0.3‰ for 5 samples from the Lillooet area in interior British Columbia. These late prehistoric and early historic people had a mixed diet, but with heavy reliance on migratory salmon.

B. *Southern Norway.* These samples are from Stone/Bronze Age sites in coastal areas with agriculture. The values of −19.0, −19.8, and −22.2‰ from individuals who engaged in agriculture are somewhat lower than expected as they come from typical coastal districts. T-2883, eg, from Ruskenes close to Bergen, with a $\delta^{13}C$ value of −19.0‰, is difficult to explain, as the skeleton comes from a midden with a considerable amount of marine food debris (Hagen, 1983, p 111). However, these three measurements may indicate that a considerable change in diet occurred with the introduction of farming. This process is well documented in Denmark (Tauber, 1981).

C. *Eastern Norway.* These three samples are from Early Iron Age inland burials dated between 500 BC and AD 600 gave very low values: −20.8, −22.0 and −22.7‰. It may seem surprising that two samples in this group as well as one in group B gave even lower values than those from Heidal. However, the three measurements were made many years ago at another mass spectrometry laboratory. The possibility of calibration variation between laboratories cannot be excluded (*cf* Chisholm, Nelson & Schwarcz, 1983b, p 397).

D & E. *Northern and North Central Norway.* In the prehistoric and early historic periods the Sami population in northern Scandinavia relied mainly on hunting, gathering, and fishing, both in coastal and inland areas. Four or 5 centuries ago, however, a considerable change occurred when many groups became heavily dependent on domestic reindeer. In Norway present movement with reindeer herds between the coast (summer) and the interior (winter) has a long tradition. Other Sami groups did not change their traditional way of life and combined a maritime adaptation with elements of farming, mainly some sheep or goat herding.

With this culture history background, considerable variation in $\delta^{13}C$ values should be expected in Sami skeletons which is clearly seen from Groups D and E. Two coastal measurements agree most with the results from Storbåthallaren (1); the $\delta^{13}C$ values are −13.0 (T-5073) and −14.7‰ (T-5243). It is worth noting that the dates are 800 ± 60 BP and 450 ± 60 BP, respectively.

Measurements from Sami inland sites range from −16.6 to −19.1‰, *ie,* higher values than all Iron and Middle Age measurements of people of farming cultures of interior eastern Norway (Groups 4 and C). However, the ^{14}C dates for these 4 skeletons indicate that 3 are older than the introduction of domestic reindeer, while the lowest $\delta^{13}C$ value comes from the youngest skeleton.

The data presented here indicate that the past Sami diet is a promising field for application of the $\delta^{13}C$ method.

CONCLUSION

Although there is a wide scatter of values in 47 Norwegian $\delta^{13}C$ measurements, patterns show that this method is most valuable in the study of past human diets. We conclude that these results, when compared with Danish and North American measurements, provide a basis for a fairly exact interpretation of dietary patterns. However, we do not agree with Chisholm, Nelson and Schwarcz (1982, 1983a, b), who specify different types of diet in exact percentages with only small margins. As Tauber points out (1983, p 372), there is considerable scatter in $\delta^{13}C$ values of food, and further "the isotopic fractionation may also have been influenced by species-related or individual differences in the enzymatic processes during metabolism."

We therefore propose to estimate diet in more qualitative terms:

Diet predominantly based on marine protein:

values higher than $-14.5‰$.
Diet predominantly based on terrestrial protein:
values lower than $-19.5‰$.
Mixed diet: values between -16.0 and $-18.0‰$.
Mixed diet with excess of marine protein:
values between -14.5 and $-16.0‰$.
Mixed diet with excess of terrestrial protein:
values between -18.0 and $-19.5‰$.

This scheme should be regarded as tentative and adjustments will be made when more data become available.

ACKNOWLEDGMENTS

Support from the Norwegian Council for Science and the Humanities (NAVF) is gratefully acknowledged. Thanks are due P Holck, University of Oslo, and A Hagen, University of Bergen, for providing both sample material and valuable discussions.

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