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CONSENSUS $\delta^{13}C$ VALUES

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ABSTRACT. Selected stable carbon isotope measurements published in *Radiocarbon* over a 12-year period have been abstracted, plotted, and summarized, to give more reliable estimates of the mean value and range of $\delta^{13}C$ for five classes of natural material (human bone collagen, non-human animal bone collagen, plant materials, wood, and charcoal), and to provide a firmer base line for stable carbon isotope dietary and environmental studies.

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INTRODUCTION

Following Craig (1953; 1954; 1957) most radiocarbon laboratories make corrections to their ^{14}C age measurements on the basis of the small variations in stable carbon isotope ratio ($^{13}C/^{12}C$) shown by the materials used as samples for radiocarbon dating (Olsson and Osadebe, 1974). Not all laboratories have made these corrections to their published ^{14}C measurements from the beginning, some still do not do so, and others do not publish their ^{13}C measurements, but there is now a large amount of data recorded in *Radiocarbon* for a wide range of natural materials of which very little further use has been made (Lerman, 1973). With increasing interest in the relevance of stable carbon isotope measurements (C_4 effects) to the study of ancient diets, prehistoric economies, environmental (vegetational and climatic) change, and the evolution and taxonomy of higher plants, this bank of published data has acquired a new value and importance (see, for example, Brown, 1977; Brown and Smith, 1972; Burleigh and Brothwell, 1978; DeNiro and Epstein, 1978a, b; Lerman and Troughton, 1975; Martinez, Ambel, and Parrondo, 1982; Mazany, Lerman, and Long, 1980; Nambudiri *et al*, 1978; Tauber, 1981; van der Merwe and Vogel, 1978; van der Merwe, Roosevelt, and Vogel, 1981; von Schirnding, van der Merwe, and Vogel, 1982). Here we present a summary of an analysis that we have carried out of these data, which we believe will be of value in providing a base line for these new areas of study.

DATA ANALYZED

The analysis is based on stable carbon isotope ($\delta^{13}C$) measurements published in *Radiocarbon*, volumes 12-23 inclusive (1970-1981), that is, including all the volumes completed when this work was begun, but excluding older data published before 1970. Further major exclusions were: peat because of its inhomogeneity; molluscan shell because of the diversity of species and localities; soft tissues of modern humans associated with bomb-carbon studies (Lyon and Baxter, 1978); and 702 tree-ring measurements (395 measurements of *Pinus aristata*, mean value and standard deviation $-22.0 \pm 2.0‰$, and 307 measurements of *Quercus* sp, mean value and standard deviation $-25.6 \pm 1.3‰$) because some of these were known to reflect fractionation within the laboratory (Suess, 1978, p 4). Measurements that were not made relative to the PDB standard were also excluded. Five main categories were established: human bone collagen; non-human animal bone collagen (excluding fish and other aquatic vertebrates); plant materials other than wood and charcoal; wood; and charcoal. Other information relating to each measurement, but subsidiary to the main purpose of the analysis was also recorded (identification to species where available, sample age, laboratory number). The total number of measurements included was 3249.

Most probably the accuracy of measurements made specifically for stable isotope investigations such as those noted in the Introduction above, will be higher than that of measurements originally made for the purpose of correcting ^{14}C ages. An error of 1.0‰ in $\delta^{13}C$ is equivalent to an error of 16 radiocarbon years independent of absolute sample age, which is small in relation to some of the other sources of error to which radiocarbon dates are subject and (other than by high-precision laboratories) can generally be tolerated. Conversely, a direct C_4 contribution to the diets of humans probably cannot be estimated to within much better than $\pm 10\%$ from even the most precise $\delta^{13}C$ measurements because of other sources of dietary uncertainty and the variations inherent between individuals, although for most archaeological purposes such an accuracy would be quite sufficient. On average, the data recovered from *Radiocarbon* should provide reasonably good estimates of the means and the ranges characteristic of the five main categories of material given above. Although the approximate ranges within which the $\delta^{13}C$ values of these materials normally lie is known (Olsson and Osadebe, 1974; van der Merwe and Vogel, 1978), the potential value of the published data in establishing the more accurate estimates necessary for comparative purposes has up till now been largely neglected.

METHODS

Measurements of $\delta^{13}C$ and relevant subsidiary information for the five categories of material indicated above were recovered from the selected volumes of *Radiocarbon* by a visual search, recorded, and stored on disc in a Hewlett Packard 1000 computer ready for subsequent retrieval, tabulation, plotting, and statistical analysis. Desired sets of measurements for particular materials from given (broad) geographic regions could then be recovered and if appropriate amalgamated with comparable data for the same materials from other regions, to give as many values as possible within each main category.

RESULTS

The $\delta^{13}C$ measurements were retrieved in both printed and plotted form by regions and, within regions, by materials as shown in tables 1-5. Other ways of primary retrieval were also possible, for example, by age, by materials, or by laboratories, but were not used for the main analysis. Subsequently, these data were combined using visual matching of overlaid plots, to give the overall mean values and ranges listed in table 6. Specimen plots for human and animal bone collagen, antler collagen,

TABLE 1

$\delta^{13}C$ values of human bone collagen (‰ rel PDB)

Region	Number (n)	Mean (m)	SD (±)	Range (r)
Europe	98	−19.5	1.6	−17.2 to −24.6
N America	2	−21.5	0.6	−21.1 to −21.9
S America	2	−15.5	1.3	−14.5 to −16.4
N Africa	—	—	—	—
S Africa	6	−11.4	2.4	−8.0 to −12.9
Asia	5	−19.5	0.5	−18.7 to −20.0
Australasia	1	−26.0	—	—
Total	114	−19.1	2.5	−8.0 to −24.6

TABLE 2

$\delta^{13}C$ values of non-human animal bone collagen (‰ rel PDB)

Region	Number (n)	Mean (m)	SD (±)	Range (r)
Europe	245	−21.5	2.4	−12.4 to −32.8
N America	31	−20.0	2.5	−13.9 to −24.1
S America	1	−19.4	—	—
N Africa	2	−19.2	2.8	−17.2 to −21.1
S Africa	10	−17.3	4.5	−11.8 to −24.9
Asia	3	−20.1	1.8	−19.0 to −22.2
Australasia	—	—	—	—
Total	292	−21.2	2.7	−11.8 to −32.8

TABLE 3

$\delta^{13}C$ values of plant material other than wood and charcoal (‰ rel PDB)

Region	Number (n)	Mean (m)	SD (±)	Range (r)
Europe	183	−25.2	3.3	−17.2 to −33.2
N America	63	−20.0	6.6	−9.3 to −30.6
S America	4	−17.6	6.1	−8.7 to −22.5
N Africa	26	−19.2	6.2	−9.8 to −27.3
S Africa	15	−21.0	6.0	−9.2 to −30.8
Asia	14	−24.0	0.7	−22.8 to −25.4
Australasia	9	−22.9	0.6	−21.9 to −24.1
Total	314	−23.2	5.1	−8.7 to −33.2

TABLE 4

$\delta^{13}C$ values of wood (‰ rel PDB)

Region	Number (n)	Mean (m)	SD (±)	Range (r)
Europe	797	−25.7	1.9	−13.3 to −31.4
N America	252	−24.1	2.7	−12.5 to −30.2
S America	6	−24.2	1.6	−22.1 to −26.7
N Africa	41	−24.9	2.7	−19.4 to −29.9
S Africa	40	−23.7	3.4	−10.1 to −27.8
Asia	5	−23.7	4.1	−20.7 to −30.8
Australasia	14	−25.0	0.6	−24.1 to −25.9
Total	1155	−25.2	2.3	−10.1 to −31.4

plant materials (showing the bimodal distribution of C_3 and C_4 pathways), and wood, are shown in figures 1-6.

Different natural materials have their own characteristic $\delta^{13}C$ values so that the spread of measurements observed for a given material such as wood or bone collagen is not simply random. The data listed in tables 1-6 cover the full range of measurements recorded for the five categories of material considered in the analysis, and a comparison of the figures given in the tables (ranges, means, and standard deviations) with the data plotted in figures 1-6 gives a good idea of the respective distributions. As the number of observations is quite large, judicious removal of outliers does not significantly alter mean values, but reduces the standard deviation of the mean (*cf*, for example, values for animal bone collagen and plant materials in table 6, with values of −21.7 ± 1.8‰ and −25.0 ± 1.8‰ when the limits for these materials are reduced to −26 to −16‰ and −30 to −20‰ by the removal of 54 and 69 measurements, respectively). As some at least of the outlying measurements probably arise from a combination of systematic natural variations (C_4 effects, for example), laboratory errors, and perhaps misidentification of materials (there are, for instance, no C_4 trees, yet some values for what was stated to be wood or wood charcoal lay in the C_4 range), discriminate removal of some values does appear to be justified. Practically speaking, the result is more useful as well as being more reliable. Independently of this, some of the data, when plotted, were found to be slightly skewed towards more negative values in a way suggestive of fractionation, but whether this reflects a natural process or arises within laboratories cannot be determined.

TABLE 5

$\delta^{13}C$ values of charcoal (‰ rel PDB)

Region	Number (n)	Mean (m)	SD (±)	Range (r)
Europe	938	−24.8	1.4	−17.7 to −30.8
N America	217	−25.2	2.4	−11.8 to −29.0
S America	24	−24.4	2.5	−17.9 to −28.6
N Africa	18	−25.0	2.0	−21.9 to −27.4
S Africa	141	−23.5	2.8	−10.5 to −29.0
Asia	31	−25.1	1.7	−18.6 to −27.1
Australasia	5	−22.1	0.8	−20.9 to −22.8
Total	1374	−24.7	1.8	−10.5 to −30.8

TABLE 6

Mean $\delta^{13}C$ values of bone collagen and plant materials (‰ rel PDB)

Material	Number (n′)	Mean (m′)	SD (±)	Range (r′)
Human bone (collagen)*	105	−19.5	1.5	−17.2 to −24.6
Non-human animal bone (collagen)	292	−21.2	2.7	−11.8 to −32.8
Plant materials*	2735	−25.0	2.2	−17.2 to −33.2

* Less values showing probable C_4 effect (see text)

The justification for combining data for materials from different geographic regions is that the $\delta^{13}C$ values characteristic of each material are age independent and phylogenetically determined (*ie*, fundamentally via photosynthesis of green plants), geographic and environmental factors being of small secondary importance (and the CAM pathway of desert suc-

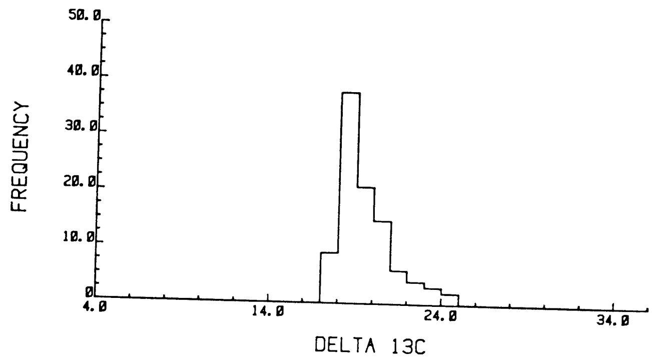

Fig 1. European human bone collagen (98 values)

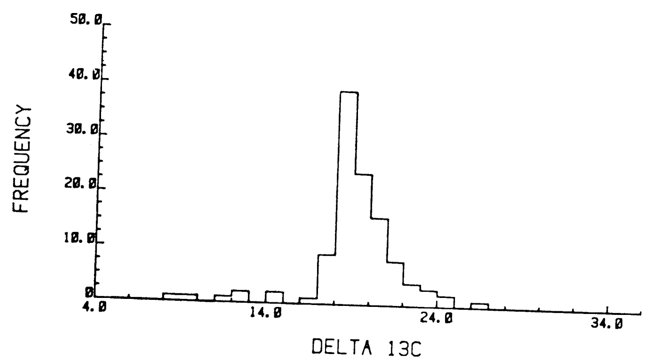

Fig 2. All human bone collagen (114 values) including those showing C_4 effects

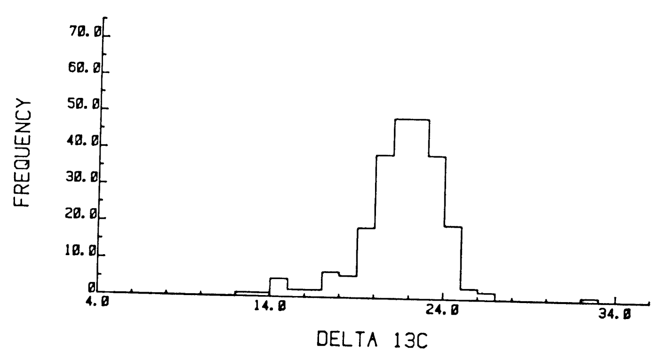

Fig 3. European animal bone collagen (245 values)

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culents, though regulated by the environment, was regarded as numerically unimportant in this analysis). Thus, although the data analyzed are biased by being predominantly European, and additional bias may result from publication of many dates without $\delta^{13}C$ values in the volumes of *Radiocarbon* searched (and perhaps from the exclusion of measurements made before 1970), the results themselves should not be influenced by this.

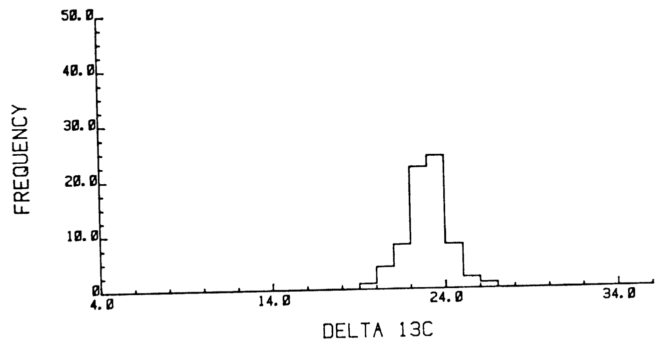

Fig 4. Antler collagen (British Isles; 70 values)

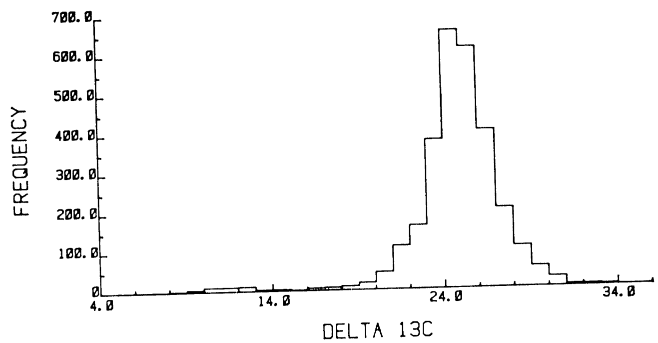

Fig 5. All plant material including wood and charcoal (2843 values; marked bimodality of C_3 and C_4 pathways suppressed by scale)

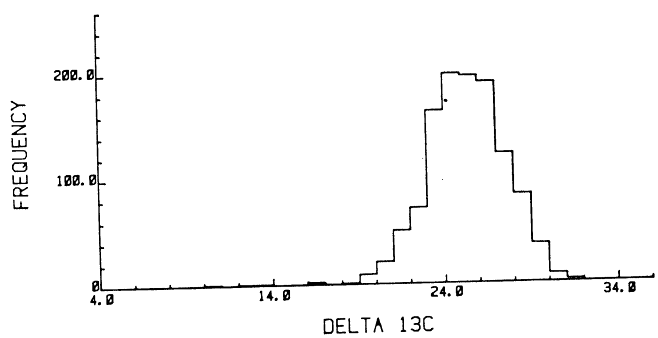

Fig 6. All wood (1155 values)

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CONCLUSIONS

The results obtained (table 6) for plant remains, wood, and charcoal are in close agreement with previous approximations of typical $\delta^{13}C$ values for these materials. The results for bone collagen, and in particular, for human bone collagen, are now much better defined than hitherto. Rigorous selection and analysis of the published data upon which these values are based have given them greater reliance than previous estimates of the range of values found in bone collagen. We believe that these values, and in particular, those for human bone collagen, will provide the most useful base line currently available for stable carbon isotope studies of prehistoric diet (and that these values will be vindicated in turn by these specialized studies).

Two final points that emerge are, first, the evident need for careful specific identification of all the materials used for stable carbon isotope analysis and ^{14}C dating (and by inference, the desideratum of confining any one measurement to a single species and, if possible, to a single individual), and, second, the need for an interlaboratory (C_3) bone collagen standard for stable carbon isotope studies (Erle Nelson, Simon Fraser Univ, pers commun).

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