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Carbon isotope records in Wisconsin trees

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ABSTRACT

The carbon isotope records of the growth rings of three Wisconsin bur oaks (*Quercus macrocarpa*) have been studied. In addition a study of the earlywood and latewood of one tree showed no significant difference in the $\delta^{13}C$ values of the separate components. A small, but not statistically significant correlation was found between the average $\delta^{13}C$ values for the three trees and an average summer temperature. The $\delta^{13}C$ values for the trees did not show a steady downward trend with time as has been suggested to occur because of proposed long-term increases in the concentration of atmospheric CO_2 as the result of the burning of fossil fuels and forest clearing.

1. Introduction

The stable carbon isotope ratios in a tree can show variations based on changes in the isotope ratios of the carbon in atmospheric carbon dioxide incorporated by the tree and changes in the metabolic fractionation by the tree itself. Numerous studies of the stable carbon isotope ratios in trees have already been reported. Attempts have been made to correlate the isotope ratios with climatic parameters (Pearman et al., 1976; Wilson and Grinsted, 1977; Arnold, 1978; Farmer, 1979; Grinsted et al., 1979; Mazany et al., 1980; Tans and Mook, 1980) and with the postulated increase in global atmospheric carbon dioxide concentration (Farmer and Baxter, 1974; Stuiver, 1978; de Silva, 1979; Freyer, 1979; Tans and Mook, 1980) which has been suggested to be the result of increases in the burning of fossil fuel and from changes in the size of the global biospheric carbon reservoir. If these correlations can be firmly established, much information can be extracted from tree rings concerning climatic history for periods and localities for which recorded data are not available, and changes in the concentration of the global atmospheric carbon dioxide could be traced. The published results have, however, not been consistent.

Our primary study included the measurement of the annual carbon isotope ratios of both earlywood and latewood separately for a Wisconsin tree, inasmuch as the two types of wood are physically distinct and the climatic parameters are different for the two growth periods. The response of the tree can lag behind the climatic episode with the result that the temperature and precipitation of various seasons may affect earlywood and latewood differently (Fritts, 1976). Seasonal variations in the concentration and isotopic value of the atmospheric CO_2 which might also affect the $\delta^{13}C$ values of the two separate growth types of wood have been documented (Keeling, 1958, 1961; Verma and Rosenberg, 1976). One study of the isotope ratios of earlywood and latewood of three annual rings of *Pinus radiata* has already been reported (Wilson and Grinsted, 1977).

Three additional cores were also obtained, one a different radius of the first tree, the others from two additional trees in the same stand of trees. The isotope ratios of whole growth rings from the additional trees were measured. The carbon isotope records of the three trees have been compared with local climatic records.

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2. Data

Three trees were studied, all bur oaks (*Quercus macrocarpa*). The trees were mature specimens, free standing at the time of sampling, within a 0·2 to 0·3 km^2 moderately populated stand in a rural area 25 km southeast of Madison, Wisconsin (42°55′N, 89°05′W). By dendrochronological analysis all trees proved to be 200 ± 25 years old. The period of analysis for SA104NE from which both earlywood and latewood were studied was 1895 to 1975. This sample came from a main branch 5 to 7 m above ground level with growth rings beginning at about 1760. Whole growth rings were cut from an additional core (SA104E) from this same tree and from cores from two other trees (SA101N and SA105NW) and isotopic measurements were made which spanned the 1900 to 1978 period.

The isotopic measurements were made on whole wood extracted with an acetone–water mixture to remove lipids and contamination by handling from the samples. Some samples of SA104NE were also reduced to alpha-cellulose and the isotope ratios of the cellulose compared with those of the acetone extracted samples.

3. Methods

The samples of earlywood and latewood were obtained by shaving successive layers of wood and discarding any overlapping cells. Two successive 24 h extractions at room temperature with a 9:1 acetone–water solution were followed by hot water washes and oven drying at 70 °C. The cellulose samples were reduced to α cellulose by the method of Green (1964).

Combustion of the samples was effected in a Parr bomb combustion chamber and the isotope ratios of the CO_2 produced were measured by means of a Nuclide RMS 6-60 isotope ratio mass spectrometer. Replicate combustions of individual samples indicated the combined precision of combustion and mass spectrometer measurement to be $\pm 0.3‰$.

The isotope ratios are expressed in the conventional manner and are compared to the PDB standard.

$$\delta^{13}C\ (‰) = \left[\frac{(^{13}C/^{12}C)\ \text{sample}}{(^{13}C/^{12}C)\ \text{standard}} - 1 \right] \times 1000$$

4. Results

In Fig. 1 the isotope ratios of extracted whole wood and cellulose are shown for both earlywood and latewood of SA104NE 1900 to 1904 and 1964 to 1967 growth rings. The cellulose as expected has higher δ values than the whole wood which contains lignin. There is, however, no major difference in the trends and there is also no great

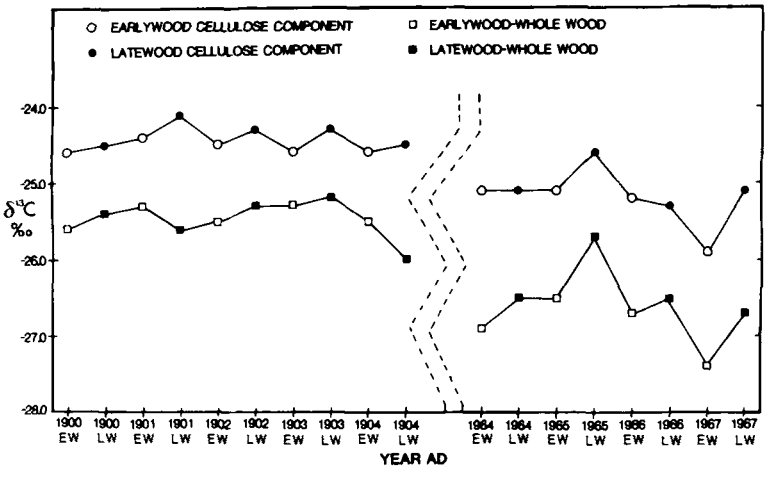

Fig. 1. $\delta^{13}C$ values of the carbon in cellulose and whole wood of the earlywood (EW) and latewood (LW) of a Wisconsin bur oak (*Quercus macrocarpa*) for the 1900 to 1904 and 1964 to 1967 growth periods.

difference in the δ values of the earlywood versus latewood in either sample preparation.

The $\delta^{13}C$ values for earlywood and latewood of SA104NE are shown in Fig. 2. The trends are obviously the same for the two fractions; moreover the mean value for the earlywood is $-26.21‰$, standard deviation $\pm 0.62‰$, for the latewood the mean value is $-26.27‰$, standard deviation $\pm 0.70‰$. Results of linear regressions of the $\delta^{13}C$ values with growth ring age also showed no significant difference between results for earlywood and latewood components. The earlywood ^{13}C showed an overall decrease of $0.023‰$ per year, the latewood a decrease of $0.016‰$ per year.

In the study of Wilson and Grinsted (1977) a consistent difference was found between the δ values of earlywood and latewood of a pine, with the latewood values more negative than those of the earlywood in the 3-year growth period studied. We have found, however, that, while there were periods of 3 or more years when the latewood $\delta^{13}C$ value was more negative than that of the earlywood, there were also periods of 3 or more years when the latewood $\delta^{13}C$ values were the more positive.

Fig. 3 shows the $\delta^{13}C$ values of three trees, SA101N, SA105NW (2-year growth rings) and SA104NE, the average earlywood and latewood averaged with the whole growth ring of SA104E. While the average values of the three trees are quite consistent with the results of another study of North American trees (de Silva, 1979), it obvious that results from individual trees can vary markedly. The three trees studied, of the same species from a single stand, show very similar trends from 1905 to 1940, quite divergent trends in the 1940 to 1958 period, and then again parallel trends from 1958 to 1978.

The marked difference in the trends of the isotope values of the three trees from 1940 to 1958 suggests that an effect other than the global decrease in the $\delta^{13}C$ of the atmospheric CO_2 as the result of the increasing concentration of CO_2 from the burning of fossil fuels caused the observed variations. The influencing factor(s) is not known at this time. The three trees were separated by less than 1 km within the stand and it seems obvious that a very local external effect is to be held responsible or that separate physiological changes took place in the trees with a resulting change in the carbon isotope fractionation.

There is a small downward trend to the average $\delta^{13}C$ values of the three trees over the whole period from 1900 to 1978, but its significance is at best questionable at this time considering the limited data set. The results shown by the three tree average is more in line with the report by Francey (1981) who

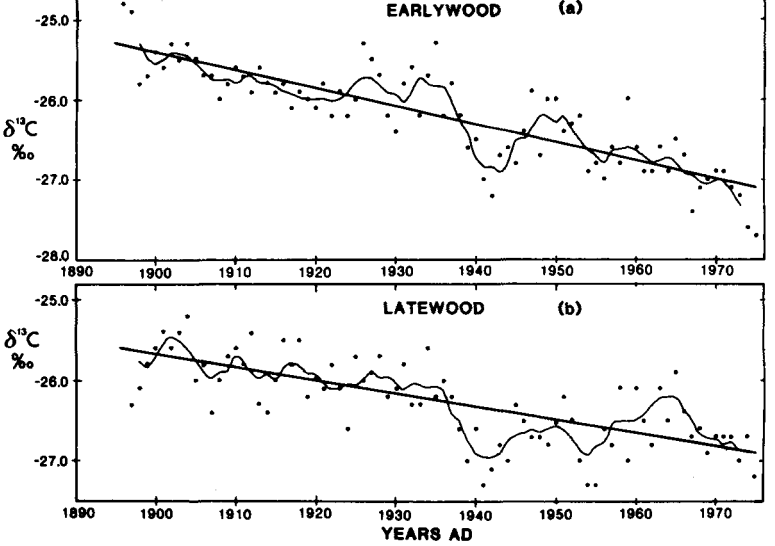

Fig. 2. The $\delta^{13}C$ records of earlywood (a) and latewood (b) of annual rings of a Wisconsin bur oak. Actual values of δ^{13} C for each growth ring are shown by dots, curving line is 5-year running average of the data. The straight sloping line is a linear least squares fit to the data.

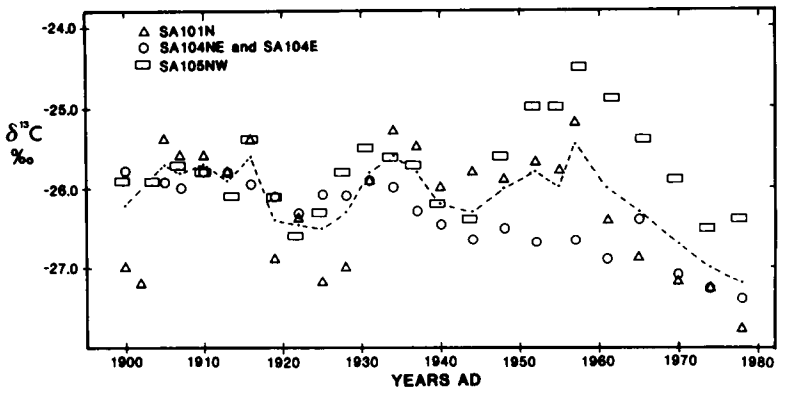

Fig. 3. The $\delta^{13}C$ values of three bur oaks (*Quercus macrocarpa*) from the same area in Wisconsin. The dashed line is the average of the values of the three trees.

questioned the interpretation of tree ring isotopic trends as a response to global trends in the concentration of atmospheric CO_2.

From about 1958 to 1978, however, all trees showed a consistent decline in the $\delta^{13}C$ values, the average $\delta^{13}C$ decline being about 1.7‰. This is larger than the 0.65‰ decrease reported by Keeling et al. (1979) for the period 1 January 1956 to 1 January 1978 (corrected value by Mook, pers. comm.). Again, while all trees showed decreases, there were variations in the magnitude of the decrease. While SA104NE and SA104E showed a decline of approximately 0.7‰, which corresponds well with the results of Keeling et al., the other two trees showed much larger decreases in $^{13}C/^{12}C$ ratio.

Table 1. *Correlations of average $\delta^{13}C$ values with climatic records*

Seasonal temperature	Correlation coefficient
Previous autumn	0.30
Winter	0.28
Spring	≃0
Summer	0.49
Seasonal precipitation	
Previous autumn	0.15
Winter	≃0
Spring	−0.32
Summer	−0.26

An attempt was made to correlate the $\delta^{13}C$ values of these trees with temperature and precipitation from a local weather station at Madison, Wisconsin, approximately 25 km northwest of the tree site. Correlations were attempted for the earlywood and latewood fractions with a number of different temperature and precipitation sets but none were found to be significant. The linear correlation coefficients between the average $\delta^{13}C$ values of all trees and several temperature and precipitation records are shown in Table 1. The largest coefficients were found with the summer seasonal temperature and with the previous autumn seasonal temperature. Even these were not significant using the statistical 'analysis of variance, F test' method at the 5% level. The correlations with precipitation records showed even less significance and correlations with ring widths of individual trees and with the standard tree ring index showed no relationship at all.

5. Conclusion

The lack of any significant relationship of the $\delta^{13}C$ values of the carbon contained in the growth rings of the trees studied with temperature, precipitation and ring width suggests that the fractionation mechanism of these trees does not undergo much change with stress related to temperature and precipitation or evidenced by

changes in the ring width. The differences in the $\delta^{13}C$ records of these trees, however, suggests that there are local external, or tree specific, factors which can produce large changes in the character of individual tree $\delta^{13}C$ records. Thus, until the factors which produce the shifts in the fractionation mechanism of the trees can be clearly recognized, it does not seem advisable to try to attribute changes in a $\delta^{13}C$ record from single trees or small groups of trees to changes in the atmospheric CO_2 isotope ratio or to climatic changes.

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REFERENCES

Arnold, L. D. 1978. The climatic response in the $\delta^{13}C$ values of Juniper trees from the American southwest. Short papers of the Fourth International Conference, Geochronology, Cosmochronology, Isotope geology. Geol. Survey Open-File Report 78-701.

de Silva, M. P. 1979. ^{13}Carbon-isotope decrease in annual-rings of twentieth-century trees. *Z. Naturforsch. 34 C*, 644–646.

Farmer, J. G. and Baxter, M. S. 1974. Atmospheric carbon dioxide levels as indicated by the stable isotope record in wood. *Nature 247*, 273–275.

Farmer, J. G. 1979. Problems in interpreting tree rings $\delta^{13}C$ records. *Nature 279*, 229–231.

Francey, R. J. 1981. Tasmanian tree rings belie suggested anthropogenic $^{13}C/^{12}C$ trends. *Nature 290*, 232–235.

Freyer, J. D. 1979. On the ^{13}C record in tree rings. Part I. ^{13}C variations in northern hemispheric trees during the last 150 years. *Tellus 31*, 124–137.

Fritts, H. C. 1976. *Tree rings and climate.* London: Academic Press, 567 pp.

Green, J. W. 1964. Wood cellulose. In *Methods in carbohydrate chemistry*, Vol. III (ed. R. L. Whistler). New York: Academic Press, 9–21.

Grinsted, M. J., Wilson, A. T. and Ferguson, C. W. 1979. $^{13}C/^{12}C$ ratio variations in *Pinus longaeva* (Bristlecone pine) cellulose during the last millennium. *Earth and Planetary Science Letters 42*, 251–253.

Keeling, C. D. 1958. The concentration and isotopic abundances of atmospheric carbon dioxide in rural areas. *Geochim. Cosmochim. Acta 13*, 332–334.

Keeling, C. D. 1961. The concentration and isotopic abundances in rural and marine air. *Geochim. Cosmochim. Acta 24*, 277–298.

Keeling, C. D., Mook, W. G. and Tans, P. P. 1979. Recent trends in the $^{13}C/^{12}C$ ratio of atmospheric carbon dioxide. *Nature 277*, 121–123.

Mazany, T., Lerman, J. C. and Long, A. 1980. Carbon-13 in tree-ring cellulose as an indicator of past climates. *Nature 287*, 432–435.

Pearman, G. I., Francey, R. J. and Fraser, P. J. B. 1976. Climatic implications of stable carbon isotopes in tree rings. *Nature 260*, 771–773.

Stuiver, M. 1978. Atmospheric carbon dioxide and carbon reservoir changes. *Science 199*, 253–258.

Tans, P. P. and Mook, W. G. 1980. Past atmospheric levels and the $^{13}C/^{12}C$ ratios in tree rings. *Tellus 32*, 268–283.

Verma, S. B. and Rosenberg, N. J. 1976. Carbon dioxide concentration and flux in a large agricultural region of the Great Plains of North America. *J. Geophys. Res. 81*, 399–405.

Wilson, A. T. and Grinsted, M. J. 1977. $^{12}C/^{13}C$ in cellulose and lignin as palaeothermometers. *Nature 265*, 133–135.