[RADIOCARBON, VOL. 34, NO. 3, 1992, P. 792–797]

A NEW TREE-RING WIDTH, $\delta^{13}C$ AND ^{14}C INVESTIGATION OF THE TWO CREEKS SITE

STEVEN W. LEAVITT

Laboratory of Tree-Ring Research

and

ROBERT M. KALIN[1]

Laboratory of Isotope Geochemistry, Department of Geosciences, The University of Arizona
Tucson, Arizona 85721 USA

ABSTRACT. We have made isotopic and dendrochronologic measurements on material collected from the Two Creeks site. Radiocarbon dating of outside wood of four logs yielded an average age of 11,760 ± 100 BP, in good agreement with results of Broecker and Farrand (1963) over 25 years ago. The range of 11,640 ± 160 to 11,900 ± 160 BP suggests a period of forest growth of 200–300 years, consistent with a ring-width chronology established by Kaiser (1987). Ring counting of five specimens gave a range of individual tree ages from 110 to 182 years, and width measurements indicate very low year-to-year variation in ring size. However, preliminary cross-dating of five samples produced a 202-year floating chronology. Stable-carbon isotope chronologies on cellulose from five-year ring groups show $\delta^{13}C$ scatter among trees typical of that found within modern sites, with some matches of isotopic maxima and minima. Some downward $\delta^{13}C$ trends may result from physiological response to rising lake levels (and/or cooling temperatures) at the site, which also produced very narrow rings in the outer *ca.* 50 ± 20 years.

INTRODUCTION

Credit for the discovery of the Two Creeks forest bed along Wisconsin's Lake Michigan shoreline in 1905 goes to Goldthwait (1907), who recognized it as an "interglacial forest bed." The forest is directly underlain and overlain by lake sediments, above which the red Kewaunee (Two Rivers) till represents the final glacial advance in east-central Wisconsin. Wilson (1932, 1936) described flora and fauna of the site, including initial tree-ring analysis on six logs. Wood at the site is *Picea glauca* (white spruce) and/or *Picea mariana* (black spruce), both of which are found in the site pollen. The oldest individual of the six logs had 82 rings, but Wilson later reported a tree with 142 rings. Five of the trees showed a marked ring-width decline in their final 12 years, and the sixth, found in the till, had larger rings and showed a decline only in the final year, suggesting to Wilson that it had died earlier than the others. The sequence of mollusks that Wilson found represents transitions from wet sediments, to a moist and then dry forest, and finally to a flooding regime, as water rose in response, to a glacial advance blocking northward drainage of glacial Lake Chicago. Fossil *Coleoptera* (beetles) indicate boreal conditions at the site with moist and dry substrates perhaps related to local topographical influences (Morgan & Morgan 1979).

Kaiser (1987) examined *ca.* 50 samples from the site, and developed a 224-year cross-dated chronology from seven trees. He believes reaction wood found in some specimens is a consequence of tilting as the soils became increasingly saturated. Kaiser also thinks the duration of substrate saturation based on ring sizes was a minimum of 80 years. Most of the trees seem to have died within a few years of each other.

Libby (1955) obtained the first radiocarbon dates on Two Creeks wood of 10,700–12,200 BP from this site and two other equivalent-age sites. Broecker and Farrand (1963) reviewed the radiocarbon

[1]Present address: Center for Applied Isotope Studies, The University of Georgia, Athens, Georgia 30605 USA

https://doi.org/10.1017/S0033822200064092 Published online by Cambridge University Press

dates of the site and made precise new measurements on six wood samples, and concluded that actual age (11,850 ± 140 BP) is several centuries older than had been previously accepted.

In this study, we revisit the Two Creeks assemblage with a new collection of samples following recent site erosion accelerated by high Lake Michigan water levels in the mid-1980s. We provide: 1) a new look at some of the ring-width characteristics of the trees; 2) new ^{14}C dates on Two Creeks wood fractions and soil; and 3) new, long stable-carbon isotope chronologies from the tree rings.

Methods

We collected *ca.* 60 specimens from the Two Creeks site on three occasions between September 1988 and June 1990, 41 of which were retained for tree-ring examination. The exposure along Lake Michigan has largely been covered by slumping (down-slope soil movement) in recent years, so most of the samples were found weathered out of the deposit. Samples were slowly air-dried, after which cross-sections were sanded for microscopic ring examination. Additional splits of 5 of these 41 samples were set aside for ^{14}C dating, along with a sample of organic matter from the soil horizon exposed at the site. ^{14}C ages were obtained on acid-base-acid (AAA) treated samples, and on the base-soluble fraction (BSF) of three of the samples *via* liquid scintillation counting. In the standard AAA pretreatment, the selected outer set of rings was first pulverized, followed by warming in 1 N HCl, rinsing with distilled water, warming in 2% NaOH until hot, decanting and saving the liquid (for BSF); the sample was then rinsed with distilled water until clear (again saving the liquid for BSF), neutralized with 1 N HCl, and finally rinsed to neutral pH. The soil sample was pretreated in a similar manner. Stable-carbon isotopic analysis was performed on the holocellulose fraction from five-year ring groups, obtained by first extracting the ground wood with toluene-ethanol, and then isolating the cellulose using an acidified sodium chlorite solution.

Results and Discussion

Radiocarbon Ages

Table 1 contains ^{14}C age determinations of cross-sections used in this study. The average ^{14}C age of the AAA-treated samples is 11,760 ± 100 BP. Further, seven analyses of a homogenized mixture of all the wood we collected for the IAEA Intercomparison Study yielded an average age of 11,770 ± 170 BP (Kalin & Long, unpublished data). International analyses in the IAEA Intercomparison Study of this homogenized Two Creeks wood gave an average age (for the most sensitive ^{14}C laboratories) of 11,788 BP. Fifteen analyses of another specimen collected more than 30 years ago dated at 11,900 ± 40 BP (Long & Kalin 1990). All of these analyses compare favorably with the conclusions of Broecker and Farrand (1963). The ^{14}C age of the Two C eeks soil sample is *ca.* 1 ka older than the wood, dating at 12,960 ± 120 BP.

These new ^{14}C dates and the data presented in Broecker and Farrand (1963) suggest that the Two Creeks Forest was short-lived, 11,900–11,640 BP. Stuiver *et al.* (1991) compiled a series of spline curves from tree-ring and lake-sediment records, which can be used to estimate the calendric age of samples from the Pleistocene-Holocene boundary. The estimated calendric time range suggested by ^{14}C dating of wood from Two Creeks is 12,800–12,600 BP. The estimated calendric age of the paleosoil horizon from the type locality is 13,800 BP. True calendric ages cannot be assigned until the calibrated radiocarbon time scale is extended back to this time period, however.

Tree Rings

Table 2 summarizes ring characteristics of five specimens. For three of the specimens, ring widths

https://doi.org/10.1017/S0033822200064092 Published online by Cambridge University Press

TABLE 1. Summary of ^{14}C Dating of Two Creeks Samples

Sample no.	A-no.	Treatment	Conventional ^{14}C date	$\delta^{13}C$
TCSL-64	5550	AAA	11,750 ± 90	−27.0
	5550.1	BSF	*Too small*	−27.2
TCSL-75	5553	AAA	*In process*	−26.4
	5553.1	BSF	11,250 ± 120	−27.0
	5553.1.2	BSF	11,370 ± 120	−26.0
TCSL-72	5551	AAA	11,800 ± 160	−24.1
	5551.1	BSF	10,150 ± 170	−25.4
TCSL-74	5552	AAA	11,640 ± 160	−26.4
	5552.1	BSF	8750 ± 170	−27.2
TCSL-71	Calib 99	AAA	11,850 ± 110	−25.0
Soil	5962	AAA	12,960 ± 120	−20.2

TABLE 2. Summary of Characteristics of Ring-Width Series

Sample	Diameter (cm)	No. of rings	Mean width	Std. dev.	Mean sensitivity
TCSL-71	22	182	0.66	0.32	0.17
TCSL-72*	32	154	1.07	0.50	0.17
TCSL-74*	12	111	0.51	0.37	0.23
TCSL-82*	12	110	0.61	0.45	0.19
TCSL-102	15	181	0.42	0.27	0.22
	Reaction wood			*Outer suppressed zone*	
TCSL-71	Yes; 1 direction			27 rings	
TCSL-72	No			None	
TCSL-74	No			46 rings	
TCSL-82	No			61 rings	
TCSL-102	Yes; 2 directions			*ca.* 75 rings	

*Single radius measured for each, others represent 2 radii.

were measured along a single radius, whereas for TCSL-71 and -102, ring widths were measured along two radii. The relatively small diameters of these specimens and large number of rings indicate fairly slow growth. This is also indicated in mean ring widths, most of which are between 0.5 and 1.1 mm. Mean sensitivity is a measure of year-to-year changes in ring width, and in general, the higher the mean sensitivity (ms = 2.0 is the largest possible value), the more "sensitive" the site and the greater potential for climate reconstructions. Sensitivity of the Two Creeks spruce wood is quite low at about 0.2. For comparison, western trees used in dendrochronology, such as bristlecone pine, have mean sensitivities of *ca.* 0.4, and pinyon pine have values of *ca.* 0.6.

One of the fairly common characteristics of the Two Creeks wood is the presence of reaction wood, which probably is evidence of a soft (saturated) substrate. This would allow relatively easy tilting of a tree, after which the tree would respond by developing reaction wood as it attempts to right itself. Of the 41 specimens, 21 have reaction wood, and of these, 10 have reaction wood in more than one direction.

https://doi.org/10.1017/S0033822200064092 Published online by Cambridge University Press

More evidence that supports the previous conclusion of death by flooding is extremely narrow outer rings. Of the 41 specimens, 34 show narrow outer rings, ranging from 13 to 93 years of suppressed growth (mean = 52 yr, standard deviation = 19 yr). Table 2 gives the specific reaction wood and suppression characteristics of the specimens studied in detail.

Our initial attempts to cross-date five of the samples proved to be difficult because of the limited year-to-year ring width variability ("complacency"). However, our best cross-matching suggests these five specimens (Table 2) represent a cumulative total of 202 years, with TCSL-71 growing first and TCSL-102 dying last.

Stable-Carbon Isotopes

These Two Creeks samples enable us to explore $\delta^{13}C$ variation in tree rings of Pleistocene trees, perhaps stressed during at least part of their lifetimes by flooding of their roots. Stable-carbon isotope chronologies were developed from five trees. Four of the chronologies were from samples along single radii, and the fifth (TCSL-102) was developed from material pooled from two opposite radii. Figure 1 shows these isotopic measurements on five-year ring groups, together with analyses reported by Yapp and Epstein (1977). The ends of each chronology have been matched under the initial assumption of approximately synchronous death, as suggested by Kaiser's (1987) ring-width chronology. TCSL-71 and -72, especially, show good correspondence of patterns, particularly of minima, as do the TCSL-74 and -82 pair, to a lesser degree. Our cross-dating indicates that all four of those trees died within *ca.* 12 years of each other. The cross-dating indicates that TCSL-102 died *ca.* 25 years after TCSL-72, so the position of its isotopic curve should be advanced *ca.* 4–6 pentads for a proper position. The range of absolute values at the site is consistent with that observed in stands of modern conifers (Leavitt & Long 1989).

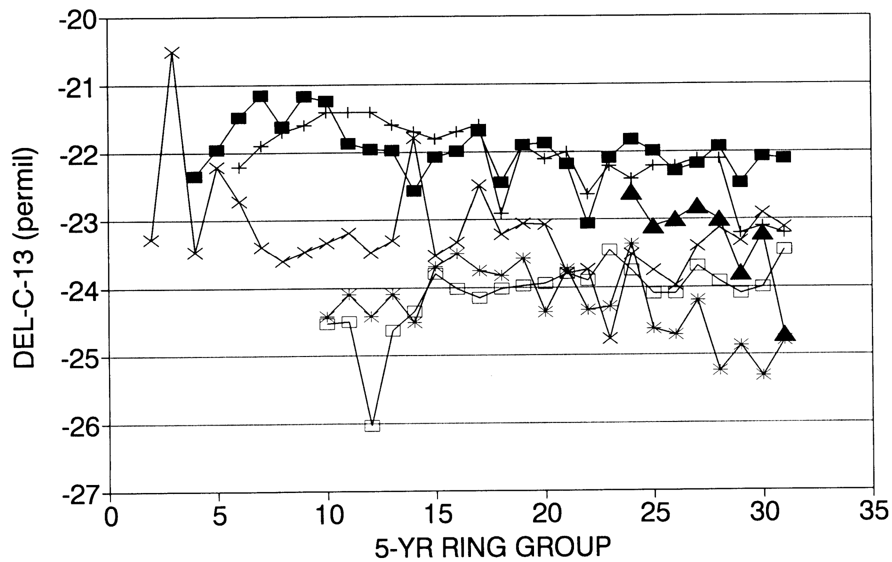

Fig 1. $\delta^{13}C$ chronologies from cellulose of five-year ring groups of Two Creeks specimens listed in Table 2. An assumption of synchronous date of death is made to match up ends, but cross-dating indicates some offset in ring size chronologies (see text). ■ = TC-71; + = TC-72; ✳ = TC-74; □ = TC-82; × = TC-102; ▲ = Yapp-Epstein (1977).

https://doi.org/10.1017/S0033822200064092 Published online by Cambridge University Press

One of the more interesting features of these curves is that four of them show some sort of downward $\delta^{13}C$ curve, whereas TCSL-82 shows an increase. Such a downward trend has also been observed in many modern trees, and is interpreted as a response to changing $\delta^{13}C$ of increasing atmospheric CO_2 (Leavitt & Long 1988). The Francey and Farquhar (1982) model suggests $\delta^{13}C$ of trees may be reduced by increased rates of stomatal conductance or decreased rates of CO_2 fixation. Experimental evidence supports reduced growth with flooding of ash seedlings (Gomes & Kozlowski 1980), elm seedlings (Angeles, Evert & Kozlowski 1986) and roots of pine seedlings (Topa & McLeod 1986). However, reduced stomatal conductance in elm seedlings also occurred with flooding (Gomes & Kozlowski 1980). If both decreased stomatal conductance and reduced carbon fixation are taking place, then the decreasing $\delta^{13}C$ values may indicate that fixation decreases more rapidly than conductance. The presence of cooling conditions from an advancing glacier may play an additional role in driving physiological responses to cause these isotopic changes.

Lastly, the $\delta^{13}C$ of the wood measured during ^{14}C dating (Table 1) is typically −24 to −27‰ (AAA-treated). The soil, on the other hand, is −20‰, *i.e.*, *ca.* 4–7‰ heavier. This may, at least in part, represent ^{13}C enrichment in soil organic carbon during humification rather than the existence of early pioneering by C_4 grasses, which would be unusual, given the inferred boreal environment of the site. Dzurec *et al.* (1985) have found that microbial decomposition during humification may enrich the soil in ^{13}C by 1–3‰.

Conclusions

The ^{14}C dating of additional wood samples from the Two Creeks site confirms the dating of Broecker and Farrand (1963). The duration of the growth at the site is estimated at 200–300 years, based on dating of four samples and 182 rings counted in one of the specimens alone. Ring-width analysis indicates the trees are very complacent and it may be difficult to extract climate information from standard dendroclimatological techniques. Stable-carbon analysis of 5-year rings from five specimens reveal short-term isotopic fluctuations, and evidence of a downward trend in 4 of 5 specimens, perhaps related to the rising lake levels that may have killed the forest.

Acknowledgments

We thank Deb Kalin for helping to collect the wood, Paul Dickfoss for helping to surface the samples, Shelley Danzer for isotopic preparation of samples, Klaus Kaiser for providing his site ring-width chronology and Greg McMullin for helping to cross-date our samples. Austin Long kindly provided our access to the Laboratory of Isotope Geochemistry at the University of Arizona and the use of unpublished quality assurance data. This study was partially funded by the State of Arizona and by NSF Grant No. ATM-8906112/ATM-9096319.

https://doi.org/10.1017/S0033822200064092 Published online by Cambridge University Press

REFERENCES

Angeles, G., Evert, R. F. and Kozlowski, T. T. 1986 Development of lenticels and adventitious roots in flooded *Ulmus americana* seedlings. *Canadian Journal of Forest Research* 16: 585–590.

Broecker, W. S. and Farrand, W. R. 1963 Radiocarbon age of the Two Creeks forest bed, Wisconsin. *Geological Society of America Bulletin* 74: 795–802.

Dzurec, R. S., Boutton, T. W., Caldwell, M. M. and Smith, B. N. 1985 Carbon isotope ratios of soil organic matter and their use in assessing community composition changes in Carlew Valley, Utah. *Oecologia* 66: 17–24.

Francey, R. J. and Farquhar, G. D. 1982 An explanation of C–13/C–12 variations in tree rings. *Nature* 297: 28–31.

Goldthwait, J. S. 1907 The abandoned shorelines of eastern Wisconsin. *Wisconsin Geological Survey Bulletin* 17: 134 p.

Gomes, A. R. S. and Kozlowski, T. T. 1980 Growth responses and adaptions of *Fraxinus pennsylvanica* seedlings to flooding. *Plant Physiology* 66: 267–271.

Kaiser, K. F. 1987 Late glacial reforestation in the Swiss Mittelland and in Wisconsin illustrated by the Daettnau and the Two Creeks buried forest. *In* Jacoby, G. C. and Hornbeck, J. W., eds., *International Symposium on Ecological Aspects of Tree-Ring Analysis. DOE Publication* #CONF-8608144: 291–297e.

Leavitt, S. W. and Long, A. 1988 Stable carbon isotope chronologies from trees in the southwestern United States. *Global Biogeochemical Cycles* 2: 189–198.

_____1989 Intertree variability of $\delta^{13}C$ in tree rings. *In* Rundel, P. W., Ehleringer, J. R. and Nagy, K. A., eds., *Stable Isotopes in Ecological Research.* New York, Springer-Verlag: 95–104.

Libby, W. F. 1955 *Radiocarbon Dating*, 2nd edition. Chicago, University of Chicago Press: 175 p.

Long, A. and Kalin, R. M. 1990 A suggested quality assurance protocol for radiocarbon dating laboratories. *In* Scott, E. M., Long, A. and Kra, R. S., eds., Proceedings of the International Workshop on Intercomparison of Radiocarbon Laboratories. *Radiocarbon* 32(3): 329–334.

Morgan, A. V. and Morgan A. 1979 The fossil Coleoptera of the Two Creeks forest bed, Wisconsin. *Quaternary Research* 12: 226–240.

Stuiver, M., Braziunas, T. F., Becker, B., and Kromer, B. 1991 Climatic, solar, oceanic and geomagnetic influences on late-glacial and Holocene atmospheric $^{14}C/^{12}C$ change. *Quaternary Research* 35: 1–24.

Topa, M. A. and McLeod, K. W. 1986 Responses of *Pinus clausa, Pinus serotina* and *Pinus taeda* seedlings to anaerobic solution culture. II. Changes in tissue nutrient concentration and net acquisition. *Physiologia Plantarum* 68: 532–539.

Wilson, L. R. 1932 The Two Creeks forest bed, Manitowoc County, Wisconsin. *Wisconsin Academy of Science, Arts and Letters Transactions* 27: 31–46.

_____1936 Further studies of the Two Creeks forest bed, Manitowoc County, Wisconsin. *Torrey Botanical Club Bulletin* 63: 317–325.

Yapp, C. J. and Epstein, S. 1977 Climatic implications of D/H ratios of meteoric water over North America (9500–22,000 BP) as inferred from ancient wood cellulose C-H hydrogen. *Earth and Planetary Science Letters* 34: 333–350.

https://doi.org/10.1017/S0033822200064092 Published online by Cambridge University Press