RADIOCARBON AGE OF THE LAACHER SEE TEPHRA: 11,230 ± 40 BP

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ABSTRACT. The Laacher See Tephra (LST) layer provides a unique and invaluable time marker in European sediments with increasing importance because it occurs just before the onset of the Younger Dryas (YD) cold event. As the YD begins *ca.* 200 calendar years after the LST was deposited, accurate determination of the radiocarbon age of this ash layer will lead to a more accurate age assignment for the beginning of the YD. On the basis of 12 terrestrial plant macrofossil ^{14}C ages derived from sediments from Soppensee, Holzmaar and Schlakenmehrener Maar, we found an age of at least 11,230 ± 40 BP for the LST event. This is *ca.* 200 yr older than the often reported age of 11,000 ± 50 BP (van den Bogaard and Schmincke 1985).

INTRODUCTION

The Lacher See Tephra (LST) is a layer of volcanic ash which is found in lake and bog sediments in central and northeastern Europe (Fig. 1). The most often quoted age for this eruption is 11,000 ± 50 BP (van den Bogaard and Schmincke 1985). We present here our attempt to date this notable event more precisely, by using accelerator mass spectrometry (AMS).

The presence of a signal related to the LST event has been suggested but not substantiated in the ice core records (Broecker 1992). Conversely, if the LST could be identified in the Swedish varved sediments, this would allow unequivocal correlation between the varved-sediment lake records of central Europe, *e.g.*, Soppensee (Hajdas *et al.* 1993) and Holzmaar (Hajdas *et al.* 1995), with the Swedish Time Scale (Wohlfarth *et al.* 1993). The age of the LST is especially crucial because of its occurrence just before the beginning of the Younger Dryas (YD). A more precise date for the LST will allow better estimation of the Allerød (AL)/YD transition. With this goal in mind, we dated only short-lived terrestrial plant macrofossils. They were taken from sediment as close as possible to the ash layer itself, in order to obtain a more accurate age for the LST event.

GEOLOGICAL SETTING OF THE LST

The Laacher See is a maar lake located in the East Eifel volcanic field of Western Germany. The Laacher volcanic area has been active since *ca.* 400–11 ka ago (Frechen 1959). The lake itself was formed as the result of both phreatic and phreatomagmatic eruptions as well as caldera collapse processes (Straka 1975). The phreato-plinian eruption during the Allerød sent plumes of phonolitic to mafic phonolitic ash (van den Bogaard 1983; Wörner and Schminke 1984) predominantly in northeastern and southern directions (van den Bogaard and Schmincke 1985) (Fig. 1). The LST has been subdivided into a lower (LLST), middle (MLST) and an upper member (ULST) (van den Bogaard 1983). The final eruption is an example of rapid evacuation of a zoned magma chamber, as shown by the reverse-zoned tephra sequence; with both mafic compositional affinity and phenocryst content increasing upward in the stratigraphic sequence (Wörner and Schminke 1984).

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Proceedings of the 15th International ^{14}C Conference, edited by G. T. Cook, D. D. Harkness, B. F. Miller and E. M. Scott. RADIOCARBON, *Vol. 37, No. 2, 1995, P. 149–154*

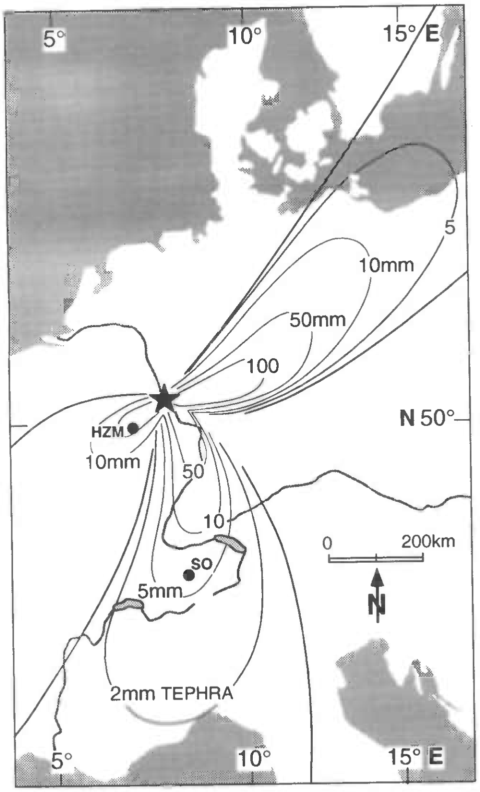

Fig. 1. Map of Western Europe showing the location of the Laacher See eruptive center (star) and the major tephra plume directions, with associated thicknesses of ash deposits (modified from van den Bogaard and Schmincke 1985). The lakes we sampled are shown as SO for Soppensee and HZM for both Holzmaar and Schalkenmehrener Maar.

In Swiss lake sediments, the LST generally appears as a beige to olive green parting *ca.* 0.5–1 cm thick. It has been correlated to the MLST based on glass shard morphology (van den Bogaard and Schmincke 1985). Details on the LST deposit in Holzmaar can be found in Zolitschka (1990). All three LST units were erupted within the short span of a few days to a few weeks (van den Bogaard 1983).

METHODS

The dates we present here are from three different lakes: Soppensee, Holzmaar and Schalkenmehrener Maar (Fig. 1). Our sample preparation followed in its entirety that described in detail in Hajdas *et al.* (1993). Sediment slices *ca.* 1–2 cm thick that contained the LST itself, and from above and below the ash layer, were washed, sieved and the macrofossils selected under a binocular microscope. The macrofossils, including pine needles, seeds, birch catkin scales, leaf fragments and pieces of wood (twigs and bark) were soaked consecutively in acid, base, then acid solutions to remove contamination completely (Olsson 1986). No aquatic plant fragments were selected. Although Holzmaar is a softwater lake (Zolitschka, Haverkamp and Negedank 1992) an offset, due to the hard water effect, of *ca.* 500 yr between aquatic and terrestrial macrofossils from Holzmaar, was measured by Hajdas (1993) and Hajdas *et al.* (1995). Combustion, graphitization and sputter target preparation followed the usual procedure. The targets were measured in a cassette with standards (HOxI and ANU sucrose) and blanks at the ETH/PSI AMS facility. $^{14}C/^{12}C$ and $^{13}C/^{12}C$ ratios were measured quasi-simultaneously (Bonani *et al.* 1987).

RESULTS AND DISCUSSION

In Table 1 we present the measured ^{14}C ages and δ^{13}C values for the plant macrofossils. Conventional ^{14}C ages were calculated according to Stuiver and Polach (1977). The stated uncertainties include both the statistical (counting) uncertainty and the reproducibility of the standards and blanks (Bonani *et al.* 1987). Table 1 also gives information about the core from which the sample was taken and the age relation of the sample to the LST event.

TABLE 1. ^{14}C Ages and δ^{13}C Values Determined by AMS for the Macrofossil and Wood Samples

ETH-no.	Site	Core	^{14}C Age (yr BP)	δ^{13}C (‰)	Relation to LST	Material*	Ref.†
6930	Soppensee	SO89-17	11,190 ± 80	−30.1 ± 1.1	60 yr below	M	1,2
6932	Soppensee	SO89-17	11,160 ± 60	−27.2 ± 1.0	140 yr below	M	1,2
5290‡	Soppensee	SO86-14	10,760 ± 105	−31.4 ± 1.2	20 yr above LST	M	
12617	Soppensee	SO91-13	11,040 ± 90	−27.4 ± 1.5	Contains ash layer	M+W	
12615	Soppensee	SO91-10	11,370 ± 90	−27.0 ± 1.2	Contains ash layer	M+W	
12613§	Soppensee	SO91-20A (a)	11,220 ± 90	−19.7 ± 1.2	Contains ash layer	M+W	
12610§	Soppensee	SO91-20A (b)	11,180 ± 100	−17.0 ± 1.2	Contains ash layer	M+W	
7250-1#	Holzmaar	HZM B/C (13a)	11,210 ± 95	−35.4 ± 1.6	100 yr above	W	1,3
7250-2#	Holzmaar	HZM B/C (13b)	11,380 ± 95	−28.5 ± 1.6	100 yr above	W	1,3
12471	Holzmaar	HZM B/C (30.1+2)	11,250 ± 110	−29.5 ± 1.5	35 yr below	M	
12475	Holzmaar	HZM B/C (32.1)	11,600 ± 140	−16.5 ± 1.2	540 yr below	M	
5741	Schalkenmehrener Maar	SMM 2	10,900 ± 65	−20.2 ± 2.0	300 yr above	W	1

*M=macrofossils; W=wood (or bark)

†References: 1. Hajdas (1993); 2. Hajdas *et al.* (1993); 3. Hajdas *et al.* (1995)

‡Small sample < 1 mg C

§Two separate graphitizations from 1 aliquot CO_2

#Separate dates of different macrofossils from the same sediment sample

The weighted mean for all samples lying within *ca.* 100 varve years of the ash layer (Table 2), gives an age of 11,230 ± 40 BP with a χ^2 of 1.65. The samples ETH-6932, -12475 and -5741 were excluded because they were taken from sediment significantly older or younger than the LST. Sample ETH-5290 was also excluded from the calculation. This sample contained <1 mg C, and thus may be shifted slightly to a younger age due to the relatively higher contribution of the modern contamination into a small sample. However, it is also possible that this too young age is due to the dramatic changes in ^{14}C/^{12}C ratio that seemed to have occurred just at the end of the YD (Burr *et al.* 1994; see also discussion below). Including the small sample age of 10,760 ± 105 BP yields a weighted mean of 11,185 ± 60 BP with a χ^2 of 4.00. Samples ETH-12613 and -12610 were from a single CO_2 combustion, but graphitized separately; thus, they were averaged together before the overall averaging.

For comparison, Table 2 shows ^{14}C dates for LST from various references. Van den Bogaard and Schmincke (1985) give a date of 11,000 ± 50 BP, which is the date most often quoted. The 11,000 BP date was based on the most frequently obtained ^{14}C age from 16 separate conventional ^{14}C determinations (see supplementary Table A from van den Bogaard and Schmincke 1985). Material dated included charcoal fragments from trees entrained in the ash flows, as well as bulk organic lake sediment or peat. A more recent compilation by Zolitschka (1990) contains a greater number of dates determined on charcoal or wood (rather than bulk organic sediment). Zolitschka (1990) gives an

TABLE 2. Radiocarbon Ages for the LST from Various References

Reference	Comment	^{14}C age
This work	Weighted mean of all macrofossil samples within *ca.* 100 varve years of LST	11,185 ± 60
This work	Weighted mean (excluding small sample ETH-5290)	11,230 ± 40
van den Bogaard and Schmincke (1985)	Approximation based on ages in the literature	11,000 ± 50
Zolitschka (1990)	Arithmetic average of ages in the literature	11,130
Zolitschka (1990)	Weighted mean of nine dates from trees killed by the LST pumice fall at Miesenheim	11,310 ± 50

arithmetic average of 11,130 BP for the Laacher eruption (no uncertainty listed). Both of these average ages are somewhat younger than the age of 11,230 ± 40 BP that we have determined here. It may be interesting to note that the aforementioned authors included only ages from sediment overlying the LST in their averages (van den Bogaard and Schmincke 1985; Zolitschka 1990). This is one possible explanation for their averages being a bit younger than the ones that we determined.

Another interesting point of comparison is the age of the LST determined on trees burned and buried as a result of the LST eruption. They were uncovered at a pumice quarry at Miesenheim. We calculated an average for the Miesenhiem data listed in Zolitschka (1990). Excluding the anomalously old age of 11,840 BP, which appears to be an outlier, we obtained a weighted average of 11,310 ± 50 BP.

CONCLUSIONS AND IMPLICATIONS

In summary, we propose that the Laacher See eruption actually occurred by at least 11,230 ± 40 BP rather than at 11,000 ± 50 BP. As discussed in Hajdas (1993) and Hajdas *et al.* (1993), a calendar age for the Laacher eruption may be estimated from the varve time scales in both Soppensee and Holzmaar, which gave 12,350 ± 135 cal BP and 12,201 ± 224 cal BP, respectively. The uncertainties are based on varve counting (see Hajdas (1993) or Hajdas *et al.* (1993) for details).

Figure 2 shows the relation of the LST to the beginning of the YD in three Swiss lakes, delineated by a shift in $\delta^{18}O$ values (Lotter *et al.* 1992). The time separating the eruption of LST and the beginning of the YD based on varve counting or sedimentation rate is *ca.* 200–300 varve years (Lotter and Hölzer 1989; Lotter and Birks 1993). This difference of 200–300 yr between the beginning of the YD and the deposition of the LST is also present in a number of German lakes (Zolitschka, Haverkamp and Negedank 1992). AMS ^{14}C ages of the AL/YD boundary determined on macrofossils from sediments of several Swiss lakes were quoted close to 10,800 BP (Ammann and Lotter 1989). This date compared nicely with the previous ^{14}C dating of the LST, *i.e.*, 11,000 BP (van den Bogaard and Schmincke 1985) suggesting a 1:1 relation between calendar and ^{14}C years. On the other hand, this led to the impression that the transition to the YD was not synchronous in northern and central Europe, *i.e.*, 10,800 is slightly younger than the AL/YD transition at 11,021 ± 25 BP in the Swedish varve chronology (Björck and Möller 1987). Our new dating, which places the eruption of the Laacher See volcano at 11,230 ± 40 BP, implies that the onset of the YD was at *ca.* 11,000 BP throughout Europe (*cf.* Mangerud *et al.* 1974). This holds true if we assume that one calendar year corresponds to one ^{14}C year. As reported by Gulliksen *et al.* (1994), a rapid change in atmospheric ^{14}C level occurred just after the AL/YD transition, but this should not affect the time scale prior to this change. However, such a drop in atmospheric ^{14}C may be the reason for the spread in ^{14}C ages for the YD onset (*e.g.*, ranging from 10,350 ± 120 BP to 11,190 ± 80 BP in Rotsee, Lobsigensee and Soppensee Switzerland; Hajdas (1993) and references therein). As the ^{14}C age is typically deter-

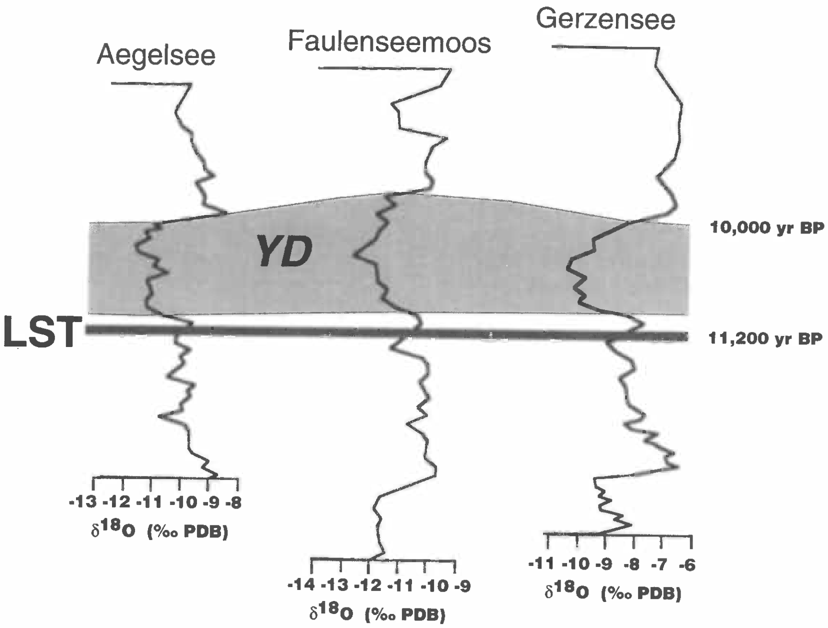

Fig. 2. The δ^{18}O curves for three Swiss lakes shown schematically (modified graphs from Eicher and Siegenthaler (1976, 1982)). The lightly shaded area represents the YD. This figure shows that the onset of the YD postdated the LST eruption.

mined on the closest available sample, even samples lying only slightly above the real transition may give younger ages. The best way to determine precisely the AL/YD transition would be to date material selected from a sediment slice corresponding exactly to the AL/YD boundary.

More recent recognition and dating of the YD advance of the Franz Josef Glacier in New Zealand at 11,050 BP (Denton and Hendy 1994) favors an estimation of the AL/YD age at *ca.* 11,000 BP and strengthens the interpretation of a world wide synchronous cold event (briefly summarized in Peteet *et al.* 1993). The age of this glacial advance is based on 36 separate ^{14}C measurements on 25 wood samples (Denton and Hendy 1994) and may well be the best ^{14}C dating for the onset of the YD. This agrees with our estimate of 11,000 BP for the AL/YD transition, *i.e.,* 200 yr after the LST eruption. As in the case of the LST, ^{14}C dating of macrofossils may be the best method for narrowing the interval of ^{14}C dates for the AL/YD transition in lake sediments.

ACKNOWLEDGMENTS

We thank our tandem crew for cheerful technical support. We would also like to thank Heidi Bolliger for drafting Figure 1. Part of this work was funded by the Paul Scherrer Institut, Villigen and the Swiss National Science Foundation.

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