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A METHOD TO ESTIMATE THE MIGRATION TIME OF PLANT SPECIES WITHIN THE TIME RANGE OF ^{14}C-DATING

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Two hundred and fifty ^{14}C dates available in the French Massif Central, in Germany and in High Belgium are discussed in a way different from that previously. It is shown that in an area of the French Massif Central as small as 100x100 km, Holocene pollen features in pollen diagrams are biostratigraphic tools delineating time ranges of several centuries. Larger time ranges characterize the early Holocene warming *(Quercus, Corylus)*, and shorter ones, the middle Holocene *(Tilia, Fagus)*. The method of calculation described in this paper can be applied in any area.

INTRODUCTION

In the Eifel (Germany) and the Massif Central (France), peat-bogs have been investigated intensively for the past decades by palynologists and tephrostratigraphers. In both areas, palynology was often used as a dominant stratigraphic tool: (i) to develop tephrochronologic models (e.g. Reille *et al.*, 1985; Erlenkeuser *et al.*, 1972) ; (ii) to reject ^{14}C dates requested to develop tephrostratigrahic and/or palynostratigraphic models (e.g. Pons *et al.*, 1988; Erlenkeuser *et al.*, 1972). Tephro-, palyno-, and chronostratigraphic models of the post-glacial period in the French Massif Central were published (Beaulieu *et al.*, 1987; Beaulieu *et al.*, 1988; Juvigné *et al.*, 1988; Juvigné, 1991). In all of them, pollen features are supposed to be slightly diachronic stratigraphic markers.

This paper deals with a overall approach of 250 ^{14}C dates which have been published in various papers. Since it has been shown that AMS and 'traditional' ^{14}C dating methods give slightly different ages while dating an isochronous tephra bed (Hajdas *et al.*, 1995), the AMS ^{14}C dates are not consisdered in this paper. Furthermore the 'traditional' ^{14}C dates obtained from paleosols for which reliability is largely uncertain (Delibrias, 1979; Evin, 1992) were also excluded. Finally, the calibration of ^{14}C dates is of no concern to this paper because the goal is not to precisely define the ages of various stratigraphic features, but only to compare data obtained by the same method to delineate time ranges.

RELIABILITY OF ^{14}C-DATING

Self consistency of ^{14}C-dating method

If no lithostratigraphic or palynological disturbance is noted in a sequence (reworking of material is very rare in peat-bogs, except at the margins), a series of ^{14}C dates should increase in age from the surface downwards. In the different peat-bogs of the French Massif Central and the Eifel, among 250 ^{14}C dates, only 13 deviate from their own series (i.e. 5.2%), as shown by an example in Table 1.

Tephrostratigraphy and ^{14}C dates

The Laacher See Tephra (Eifel/Germany) is one of the best documented tephra of the post-glacial time (Bogaard & Schmincke, 1985). Concerning its age, nineteen ^{14}C dates were published in various papers; they are shown in Figure 1.

Bogaard (1983) and Bogaard and Schmincke (1985) demonstrated that the eruption of the Laacher See volcano (East Eifel, Germany) lasted only a few days, but the time range corresponding to the difference between extreme ^{14}C dates (#1 and #19) is 860 years. The following factors may be responsible for deviations (Evin, 1992): (i) in the case of charcoal, the position of the sample in the branch (center or bark); (ii) the fact that at the moment of the eruption, the relevant wood was still alive, or had been lying for a long time on the soil; (iii) in the case of peat samples containing the tephra, the unequal thickness and volume of peat taken above and below the tephra bed, the different compaction of the peat below and above the tephra, and the variation of the sedimentation rate throughout the dated sample; (iv) the different $^{14}C/^{12}C$ ratios present in atmospheric CO_2 during the deposition of the material constituting the sample; (v) the admixing of juvenile magmatic CO_2 (in volcanic areas); (vi) the fresh water effect; (vii) any uncontrolled pollution of the sample. The above cited factors of deviation can be named 'external factors'. The ^{14}C-dating method should be responsible for the remaining deviations, if any.

By discussing the rejection of the individual ^{14}C dates of the Laacher See Tephra at the 1 sigma level (Fig. 1), we can conclude as follows.

3 of the 19 dates of the LST (#1, #18, #19: i.e. 15.7%) do not overlap the range of the weighed mean (10,895±85 yr B.P.). Since the eruption lasted only a few days, it should be pointed out that at the 1 sigma level: (i) there are only 5 dates (#1, #14, #17, #18, #19: :i.e. 26.7%) which do not include the median age 10,960 yr B.P. (Tabl. 1); (ii) 8 of the 19 dates of the LST (#1, #2, #5, #6, #8, #14, #18, #19: :i.e. 42.1%) do not include the precise weighed mean. The mean of the three percentages (15.7%; 26.7%; 42.1%) is 28%.

By excluding the ^{14}C dates of charcoal (#5, #8, #11, #13, #16, #18), the same criteria give respectively 20%, 40% and 50% of rejected dates, i.e. a mean of 37%. The overall mean is roughly one third (32.4%).

PALYNOSTRATIGRAPHY AND CHRONOSTRATIGRAPHY

Diachronism of pollen features

Within the Holocene, the continuous tree pollen curves in pollen diagrams of the French Massif Central usually start in the following order: *Quercus, Corylus, Ulmus, Tilia, Fraxinus, Fagus* and *Abies*. Nevertheless, it has been pointed out that numerous internal inversions occur (Juvigné *et al.*, 1988). This suggests that the appearance and the development of a tree species in a determined area have been recorded diachronously in different nearby peat-bogs. This can be explained for both statistical and ecological reasons: (i) the starting level of any continuous curve depends on the numbers of pollen grains determined; (ii) the relationships between localization of pioneer tree patches and the recording of relevant pollen features in proximal to distal peat-bogs is difficult to constrain. Numerous papers describe the migration of tree species in mountainous areas (e.g. Beaulieu *et al.*, 1992; Tessier *et al.*, 1993; David, 1993). On the one hand short-term diachronism, up to 3 centuries, was accepted by palynologists in developing a detailed palyno-chronozonation in the French Massif Central [Beaulieu *et al.* (1982), Beaulieu *et al.* (1984), Coûteaux (1984), Beaulieu *et al.* (1985), Reille *et al.* (1985), Guenet and Reille (1988), Pons *et al.* (1988)]. Guenet (1993) pointed out that *Fagus* should have appeared six centuries later on the Millevaches Plateau than in the nearby Auvergne. On the other hand long-term diachronism -up to 6000 years- was pointed out for the onset of Spruce in Switzerland (Markgraf, 1970).

Subjectivity of palyno-zonations

Palynologists choose subjectively either a single pollen feature or a combination of several to elaborate their own palyno-zonation. Those features should reflect large scale climatic change. Due to the diachronism of individual pollen features, the limits used in palyno-zonation should also be diachronic. This is supported by examples in both the French Massif Central and the West Eifel (Germany) which show that the most contrasting climatic oscillations of the Late-Glacial were sometimes confused. In other cases, the vegetative response to the complexity of Late Dryas climatic cooling (e.g. Kennett, 1990) should also explain such a confusion. In the same way, a clear separation of chrono- and biozonation was proposed for the Late-Glacial period in Switzerland (Amman and Lotter, 1988).

We have also pointed out wrong interpretations of pollen diagrams evenhough the most contrasted climatic oscillations of the Late-Glacial are concerned.

-In the Massif Central, the same pair of tephras, Godivelle T4 and Godivelle T5 (Juvigné, 1987) were placed either wrongly in the Late Dryas [Reille *et al.* (1985), Guenet and Reille (1988)] or correctly in the Allerød (Bastin *et al.*, 1990) even at similar locations in the same peat-bogs (Graspet, Chambedaze).

-In the West Eifel a single tephra ("Tuffsand"; see above) occurring in different peat-bogs was placed either correctly in the Allerød (Straka, 1958, 1960), or wrongly in the Late Dryas (Straka, 1954, 1955, 1961) to the Preboreal (Straka, 1956).
-The Laacher See Tephra was also placed within the Boreal (Juvigné and Bastin, 1982) and within the Older Dryas (see Juvigné *et al.*, 1995).

MIGRATION TIME OF FOUR TREE SPECIES

Two pairs of typical Holocene pollen features in diagrams of the French Massif Central were chosen for the discussion (Fig. 2A): (i) within the early Holocene, the steeply rising curve for *Corylus* and the beginning of continuous curve for *Quercus;* (ii) within the middle Holocene, the beginning of continuous curves for *Tilia* and the steeply rising curves for *Fagus*. The total number of ^{14}C dates actually available for those pollen features are represented in Table 2 and Figure 1.

Since the 'external factors' responsible for deviations of ^{14}C dates (see above) should give identical deviations in dating either the Laacher See Tephra or pollen features (as far as peat or gyttja samples are concerned in both cases) the diachronism of the latter can be estimated by considering the time ranges separating each pollen curve, and that of the tephra, for any percentage of rejected dates (Fig. 2B). The individual time ranges for each pollen feature are represented in Figure 2C to 2F.

Figure 2 shows that pollen features are stratigraphical tools corresponding to various time ranges. This implies that the essential amount of pollen grains supplied by the relevant tree species were deposited only in the near distance of their source. In the same way, the recording of pollen features in more distal peat-bogs depends on the migration of pioneer tree patches. Figure 2 show that the migration time of the relevant pioneer patches throughout the area are in increasing order: *Tilia, Fagus, Corylus, Quercus*. Nevertheless, the steeply rising curves of *Corylus* and *Fagus* indicate that as soon as their pioneer patches had settled an area, their development was rapid. For any percentage of rejected data, the different time ranges obtained for the four tree species may be linked with the various dynamics of the migration of the relevant trees. Nevertherless, there should be a more important relationship between the duration of the tree migration and the combination of climatic factors triggering the relevant development of the species. A longer duration of the migrations characterized the early Holocene *(Quercus, Corylus)*, and a shorter one, the middle Holocene *(Tilia, Fagus)*. This could be explained by hypothetically larger amplitude of climatic oscillations during the Late Dryas/Holocene warming, than in the middle Holocene. Those time ranges should also be different for various degrees of relief; the investigated area is between 850 m and 1500 m a.s.l.

The main question is now what percentage of ^{14}C dates should be rejected in order to estimate the duration of the diachronism of the individual pollen features? The response to this question is relatively subjective.

On the one hand, the concept of long-term diachronism of tree migrations and the recording of the relevant pollen features could imply that all the ^{14}C dates are acceptable as they stand. In each series of ^{14}C dates, the more ancient one seems to deviate (Tabl. 2; Fig. 2), but they could correspond to localities where earlier tree patches have occurred.

On the other hand, the defenders of low diachronism of pollen features should keep in mind that they completely reject the ^{14}C-dating method which is anyway the most important source of chronostratigraphy for post-glacial time.

Since more bracketed dates were used to date pollen features than to date the LST (Table 2 and Appendix 2, column C - column F), a slight overestimation of time ranges for pollen features might be expected. However there is no correlation between the duration of the four tree species and the coresponding averages of time ranges bracketing the calculated dates. In the same way, although the averaged bracketed time ranges are similar for both the 'instantaneous' Laacher See Tephra and the steeply rising curve for *Fagus,* the latter one is diachronic by about 400 years in comparison the the LST curve.

It has been shown above that the different percentages of unreliable dates might be 28%, 32% or 37%, depending on the severity of the rejection criteria. To avoid arbitrary overestimation of diachronism for pollen features, it is proposed to consider the highest of the three means, i.e. 37%, to estimate the migration time of pollen features (Fig. 2). The latter value assigns the following migration times throughout the French Massif Central of the chosen trees: (i) within the early Holocene, 650 years for *Quercus* and 600 years for *Corylus;* (ii) within the middle Holocene, 150 years for *Tilia* and 400 years for *Fagus.*

CONCLUSION

In spite of the fact that the rejection or the acceptance of ^{14}C dates corresponding to a determined stratigraphic feature is subjective, it is shown that Holocene pollen features of *Quercus, Corylus, Tilia* and *Fagus* are biostratigraphic tools which are acceptable within various time ranges of several centuries in the French Massif Central. Larger times ranges characterize the early Holocene, and shorter ones the middle Holocene.

It is suggested that the ^{14}C-dating method provides roughly about two third of reliable dates. 'External factors' are responsible for most of the one third of deviating dates. The rejection of about 37% of the available ^{14}C dates is suggested to estimate the migration time of four tree species in the French Massif Central.

The method described in this paper can be applied to series of ^{14}C dates corresponding to any pollen feature occurring in pollen diagrams of any determined area. The regression curve of the Laacher See Tephra can be used as a reference curve in all cases. Only the percentage of rejected data should be slighly reduced if less bracketing dates are used to dates the pollen features.

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FIGURE CAPTIONS

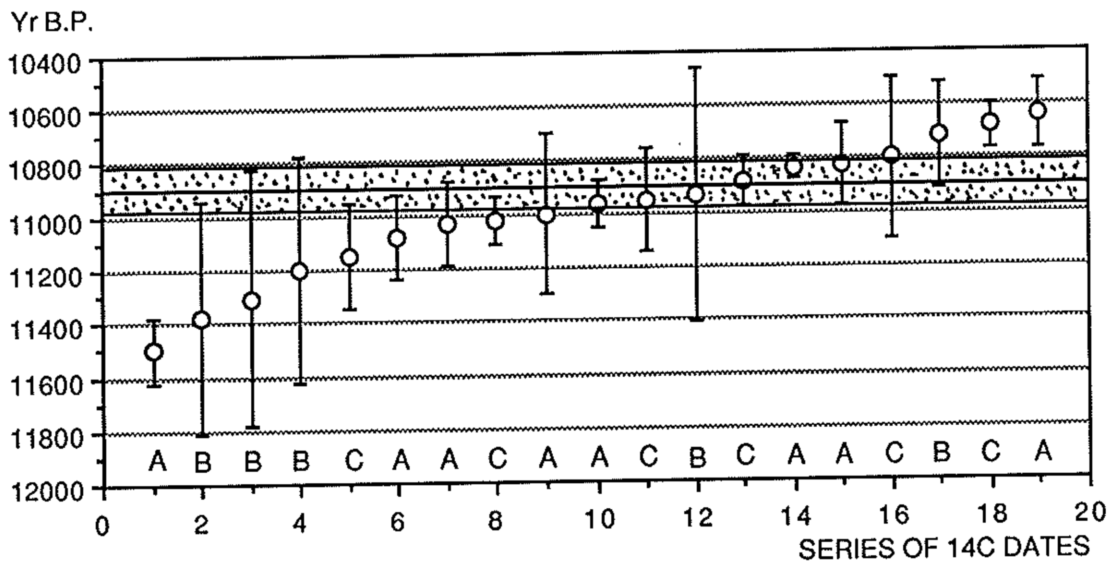
Figure 1.- Diagrams for ^{14}C dates obtained for the Laacher See Tephra (Eifel/ Germany). Each vertical bar is 1 sigma confidence interval (see data in Table 2).
A, date obtained on peat sample including centered LST bed; B, date calculated by using a pair of dated peat samples bracketing the LST bed (detailed method of calculation is described in legend of Appendix 2); C, date obtained on charcoal contained in proximal pyroclastic products of the volcano. The weighed mean of those 19 dates is 10,895±85 yr B.P [calculated from the method of Long and Rippeteau (1974), including the Chauvenet's rejection criteria]; the strippled area represents the range of the weighed mean (10810 to 10980 yr B.P.).

Figure 2.- Estimation of diachronism for four typical pollen features of the French Massif Central.
A.- Chosen pollen features: FAGUS, middle part of the steep rising curve for *Fagus;* TILIA, 2% level for the beginning continuous curve for *Tilia;* CORYLUS, middle part of the steeply rising curve for *Corylus;* QUERCUS, 2% level of the beginning continuous curve for *Quercus*. The pollen features are placed in respect to their stratigraphic order; the length of the cores (depth) is generally from 2 to 10 m.
B to F.- All abscissa correspond to percentage of rejected successive pairs of extreme dates of each series. All ordinates are years.
B. Regression curves were obtained according to values represented in Table 2: (i) ordinate, remaining time ranges between residual dates after rejecting successive pairs of extreme values (columns C, G, K, O, S); (ii) abscissa, percentages of rejected dates (columns D, H, L, P, T). R-squarred of regression curves are: Laacher See Tephra, r^2=0.997; *Fagus*, r^2=0.962; *Tilia*, r^2=0.989; *Corylus*, r^2=0.983; *Quercus*, r^2=0.965.
C to F. Estimation of diachronism for four typical pollen features. Each curve represents the time range comprised between the LST curve and the relevant pollen curve in Figure 2B. The triangles indicate that the percentage of rejected data should be comprised between 15% and 50%, and more likely 37%.

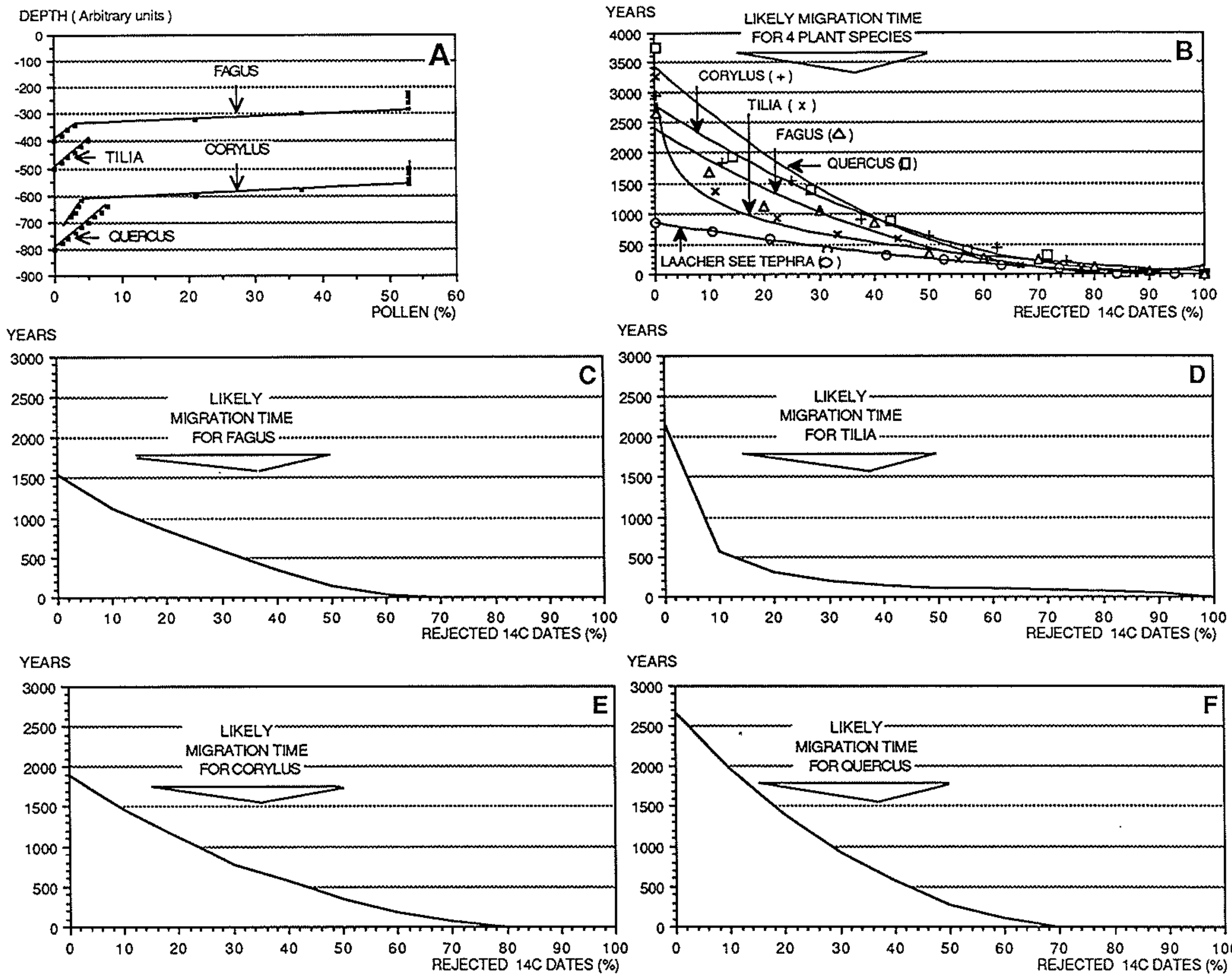
TABLE CAPTIONS

Table 1.- ^{14}C dates of the Late-Glacial to Holocene sequence at Le Suc 2 (French Massif Central). The succession of data is in agreement with the stratigraphic position of the samples from top (#1) to bottom (#9). Column A, reference to literature; Col. B, locality where the core was taken; Col. C, ^{14}C dates; Col. D, standard errors; Col. E, laboratory labels; Col. F, 'Rejected' as considered with adjacent ^{14}C dates.
This table is a part of another one containing 197 ^{14}C dates from localities of the French Massif Central, and 54 dates from the Eifel and the nearby High Belgium.
The complete Table 1 can be obtained from E. Juvigné.

Table 2.- ^{14}C dates obtained for the Laacher See Tephra and four typical pollen features of diagrams in a 100x100 km large area of the French Massif Central [Chaîne des Puys (N) to Aubrac (S), and Artense (W) to Monts du Forez (E)].
Columns A, E, I, M, Q: ^{14}C dates; Col. B, F, J, N, R: standard errors; Col. C, G, K, O, S: residual time ranges obtained by rejecting successive pairs of the extremes values [ex. Col. C, #1: 860= 11500 (Col. A, #1)-10640 (Col. A, #19)]; Col. D, H, L, P, T, numbers of rejected ^{14}C dates in percent, corresponding to the aligned values for residual time ranges [(ex. Col. D, #2: 10.5= 100*2/19 (2 rejected dates/19 available dates)].
References of individual dates and detailed calculation method are given in a detailed table which can be obtained from E. Juvigné. For the LST, 6 of the 19 dates were calculated by using bracketed ^{14}C dates; for the pollen features, one third of the dates correspond to the precise features as represented in Figure 2A, and the other two third were calculated by using bracketed dates.



Juvigné et. al Fig 1.



Juvigné et al Figure 2

	A	B	C	D	E	F
1	Beaulieu et al., 1985	Chaumette	4300	180	Ly 2110	
2			4670	190	Ly 2111	
3			6880	200	Ly 2112	
4			7980	260	Ly 2113	
5			10430	570	Ly 2114	
6			10910	360	Ly 1857	
7			12370	340	Ly 1858	
8			11490	170	Ly 2115	Rejected
9			12810	250	Ly 2116	

Juvigné et al. Tab. 1

$\frac{80}{111} = 60$

	LAACHER SEE T.				QUERCUS				CORYLUS				TILIA				FAGUS			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	11500	120	860	0	12095	721	3755	0	10969	775	2948	0	10111	375	3254	0	6670	110	2660	0
2	11380	435	700	10,5	10430	570	1931	14,3	10025	646	1849	12,5	8310	300	1384	11,1	5885	378	1705	10
3	11305	482	590	21,1	10177	547	1387	28,6	9752	447	1550	25	7885	168	940	22,2	5410	80	1120	20
4	11200	422	400	31,6	9893	240	893	42,9	9689	615	899	37,5	7619	148	666	33,3	5350	210	1050	30
5	11150	200	330	42,1	9784	421	394	57,1	9564	223	634	50	7595	95	579	44,4	5176	147	861	40
6	11080	155	250	52,6	9724	179	328	71,4	9532	188	448	62,5	7290	90	256	55,5	4810	60	340	50
7	11030	160	150	63,2	9629	175	13	85,7	9350	257	214	75	7203	460	137	66,6	4750	60	267	60
8	11025	90	90	73,7	9616	164			9334	216	20	87,5	7170	120	94	77,7	4735	110	235	70
9	11000	300	10	84,2	9396	461			9314	187			7130	104	38	88,8	4675	60	125	80
10	10960	90	0	94,7	9390	277			9136	273			7092	285			4620	110	49	90
11	10950	190			9000	500			9084	187			7076	354			4571	228		
12	10935	475			8790	220			8930	180			7066	167			4550	233		
13	10880	95			8499	182			8790	220			7034	453			4500	173		
14	10830	45			8340	150			8202	815			7016	273			4483	238		
15	10820	150							8176	196			6953	451			4470	80		
16	10800	300							8021	278			6945	302			4315	45		
17	10715	199											6926	309			4300	180		
18	10680	85											6857	247			4290	60		
19	10640	130															4180	85		
20																	4010	170		
21	Yr B.P.	S.E.	Years	%	Yr B.P.	S.E.	Years	%	Yr B.P.	S.E.	Years	%	Yr B.P.	S.E.	Years	%	Yr B.P.	S.E.	Years	%

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