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A COMPREHENSIVE POLLEN- AND TEPHRA-BASED CHRONOSTRATIGRAPHIC MODEL FOR THE LATE GLACIAL AND HOLOCENE PERIOD IN THE FRENCH MASSIF CENTRAL

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This paper discusses about 250 conventional ^{14}C ages obtained on peat and gyttja samples that apply to pollen features or tephra beds in the Massif Central region of France. A method to estimate the migration periods of eight Late Glacial to Holocene pollen features typical of the Massif Central is described. A review of all ^{14}C ages pertaining to tephras of this region enabled the most appropriate age, or age range, of the tephras to be estimated. The chronostratigraphic relationships between pollen features and tephras are discussed and a new comprehensive stratigraphic model is presented. The model shows that pollen features are diachronous and should not be used therefore as proxy stratigraphic markers. Copyright © 1996 INQUA/ Elsevier Science Ltd

INTRODUCTION

In the French Massif Central (FMC; Fig. 1), peat bogs have been intensively investigated for the last decade by palynologists and tephrostratigraphers. Furthermore, about 250 ^{14}C ages were obtained by various laboratories on peat and gyttja samples for dating pollen features and tephra beds. Chronostratigraphic models of the Late Glacial and Holocene period, based on tephrostratigraphy or palynostratigraphy, or both, were published (Beaulieu *et al.*, 1987, 1988; Juvigné *et al.*, 1988; Juvigné, 1991). Inconsistencies in these models were pointed out by Juvigné *et al.* (1988, 1994a), and Bastin *et al.* (1990) and by comparing tephrostratigraphy with palynostratigraphy used by palynologists as a chronozonation tool. A new, combined stratigraphic model that attempts to solve those inconsistencies is proposed below.

AIM AND METHOD

The aim of this paper is to combine respective stratigraphic positions of pollen features and tephras of the FMC, rather than to precisely define their ages. Hence, we discuss only ^{14}C ages that were obtained using the same method, i.e. conventional ^{14}C dating (old half-life basis), to date all the above cited stratigraphic markers.

The following ^{14}C ages, which represent less than 5% of the total data in the literature, were not considered in the discussion: (i) ^{14}C ages obtained by accelerator mass spectrometry, because they give ages slightly different from those obtained by conventional ^{14}C dating methods when applied to the isochronous Laacher See Tephra (LST) (Hajdas *et al.*, in press); (ii) conventional ^{14}C ages obtained from palaeosols on various tephra beds of the FMC because their reliability is largely uncertain in comparison with those from peat or gyttja samples (Delibrias, 1979; Evin, 1992); and (iii) ^{14}C ages obtained on charcoal for various tephras are not taken into account for comparison with the ages for pollen features, because no charcoal ages have been obtained for such features in the FMC.

The calibration of ^{14}C ages is irrelevant in the discussion of the relative stratigraphic positions of pollen features and tephras, but in the final chronostratigraphic model, the time scale shows ages in both radiocarbon and calibrated (calendar) years (see Fig. 8 below).

MIGRATION PERIODS OF EIGHT POLLEN FEATURES

Eight pollen features of the FMC (Fig. 2) were dated between 11 and 19 times (Fig. 3). The migration time of

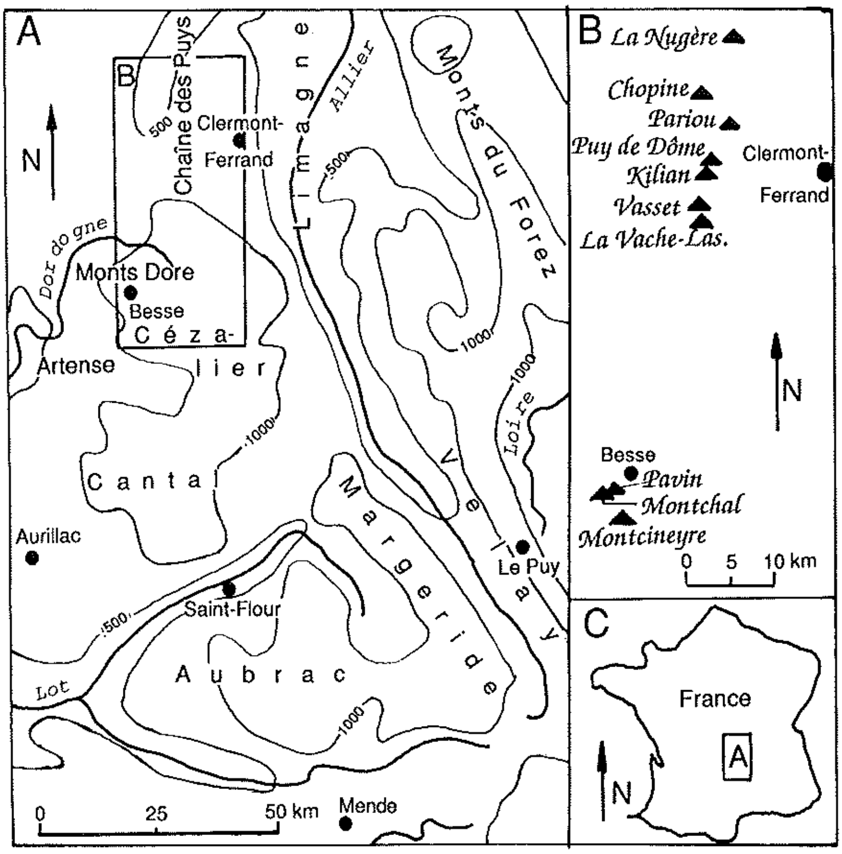

FIG. 1. Location sketch map. (A) Regions of the French Massif Central cited in this paper; (B) Late Glacial and Holocene volcanoes cited in this paper; (C) location of the area studied in France.

four of these pollen features was estimated by comparing the associated series of ^{14}C ages with that of the Laacher See Tephra (Juvigné *et al.*, in press a and Fig. 4A). The method was described in detail by Juvigné *et al.* (in press a) and applied to four pollen features as defined in Fig. 2 for *Quercus*, *Corylus*, *Tilia* and *Fagus*. The same method

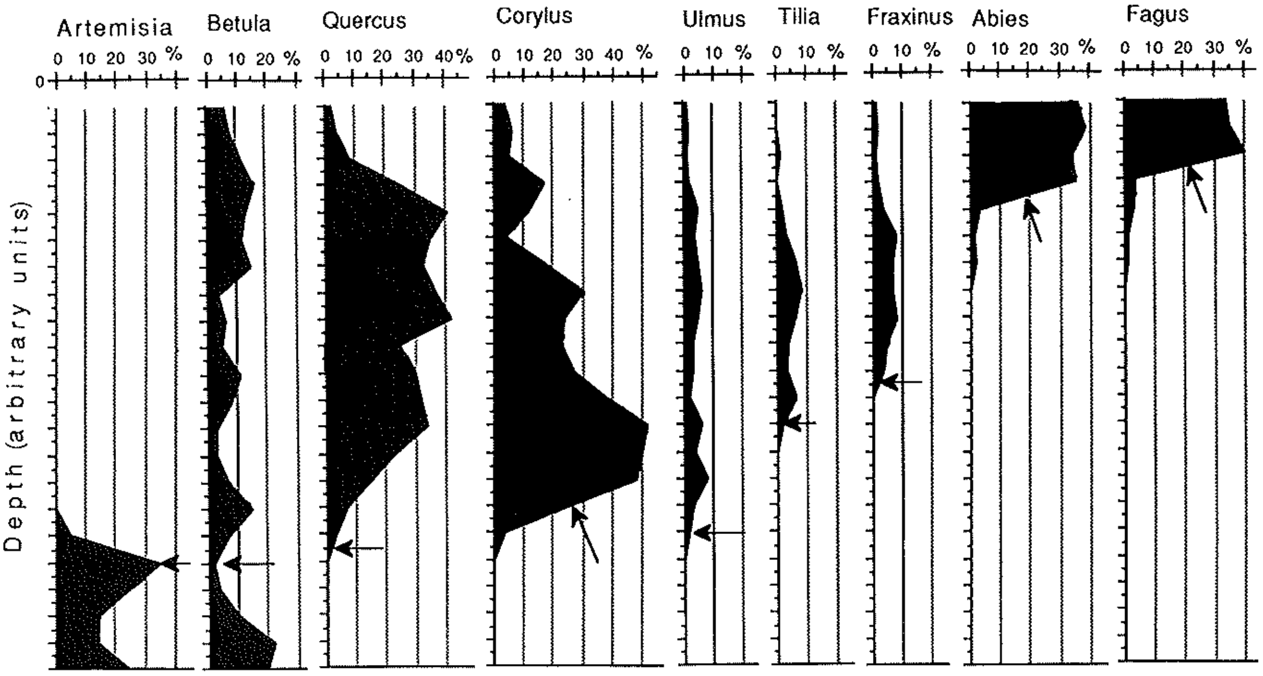

FIG. 2. Representative pollen curves of the Late Glacial and Holocene period in the French Massif Central. Upper parts of the curves are not represented because their pollen features are mostly linked to human factors that are of no concern to this paper. Depth is generally between 2 and 10 m at coring sites. Typical pollen features (marked by arrows) were chosen to estimate their migration time and period of migration: (i) the Late Dryas peak of *Artemisia* curve (corresponding to a low of *Betula* curve); (ii) the beginning of the continuous curves (2% level: Juvigné *et al.*, 1988) for *Quercus*, *Ulmus*, *Fraxinus* and *Tilia*; (iii) the middle of the steeply rising curves for *Corylus*, *Fagus* and *Abies*.

is applied in this paper to another four pollen features as defined in Fig. 2 for *Artemisia, Betula, Ulmus, Fraxinus* and *Abies* (Fig. 4B). All the results obtained are shown in Table 1, column B.

In addition, the migration period for each pollen feature was estimated. The middle part of each plateau (Fig. 3) is taken to represent the mid-period of migration of the relevant pollen feature. By splitting the migration time on both sides of that mid-period, the migration period can be constrained.

In four cases, the time range delineated by the plateau is larger than the migration period (*Fagus, Abies, Tilia* and *Artemisia*). This might indicate that the migration period should be larger than estimated. The example of *Abies* is of special interest in that way, because: (i) there is no plateau in the distribution of its ^{14}C ages; (ii) the diachronism between its extreme values is about 3000 years; and (iii) a long-term diachronism (up to 6000 years) was pointed out for the onset of *Abies* in Switzerland (Markgraf, 1970). In four other cases, the migration period is larger than the time range delineated by the plateau (*Fraxinus, Ulmus, Corylus* and *Quercus*). This suggests that the relevant migration periods might be shorter than estimated.

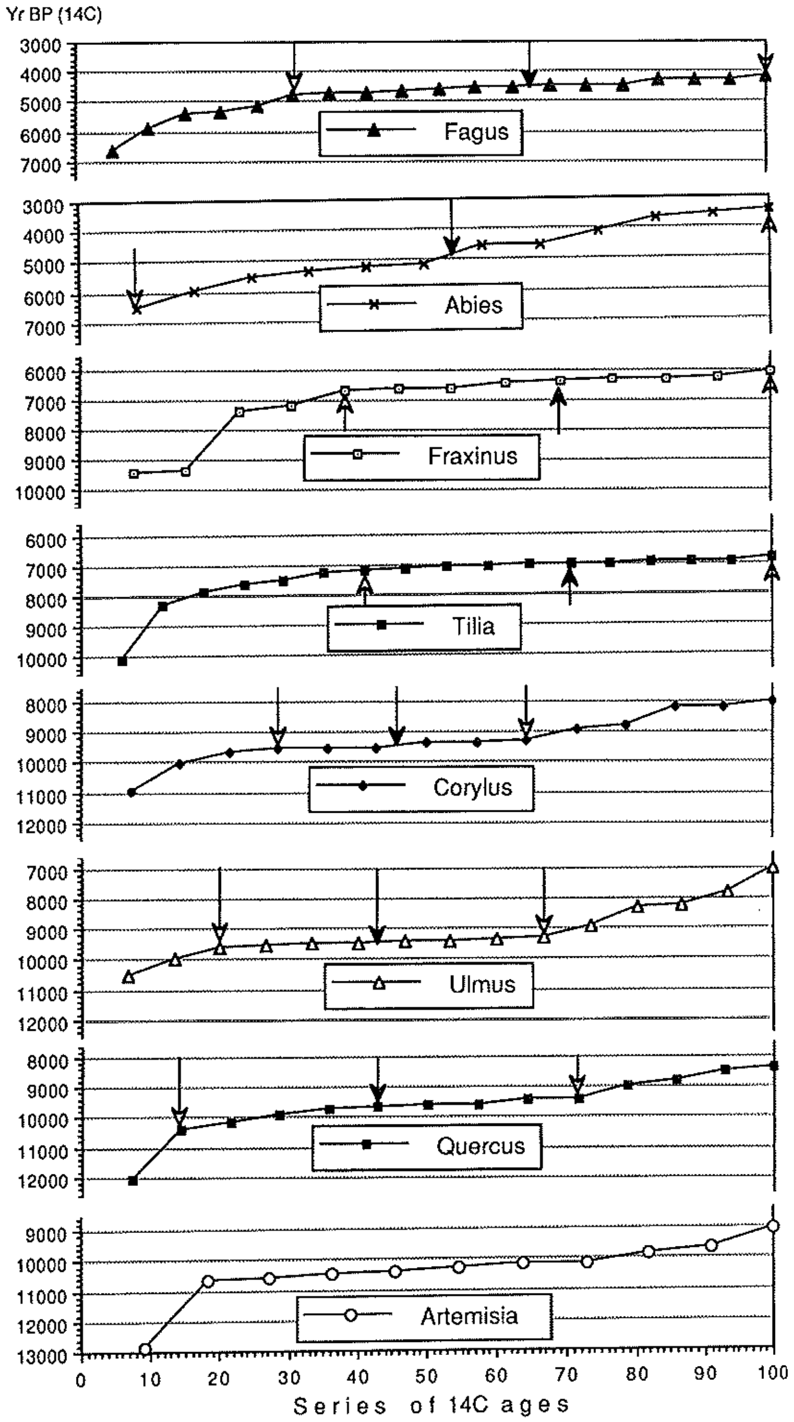

FIG. 3. Series of ^{14}C dates for the pollen features as defined in Fig. 2. Open arrows delineate the plateau (see values in Table 1, column C). Heavy black arrows show the median of plateau (see values in Table 1, column D).

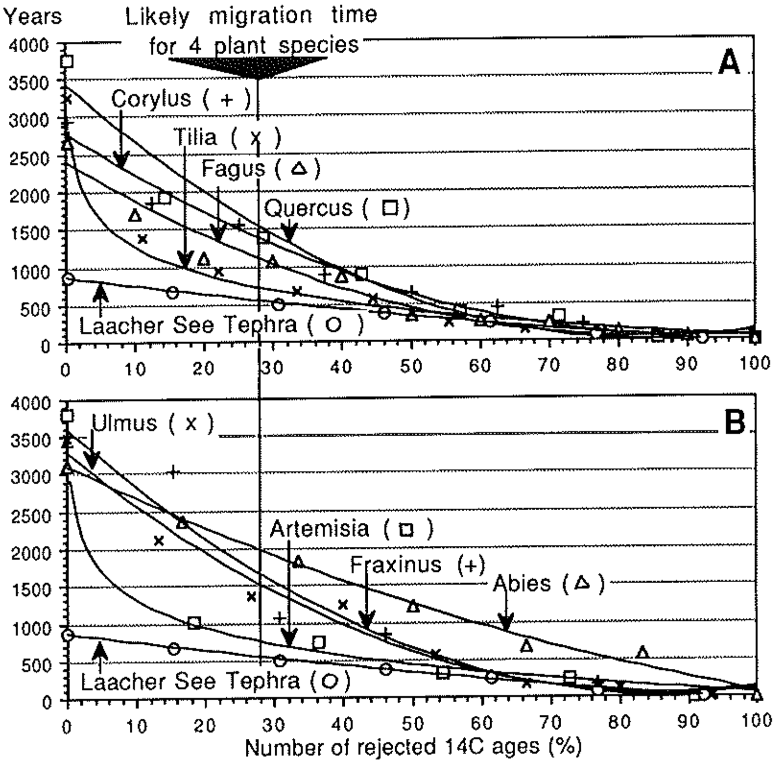

FIG. 4. Estimation of migration time for the pollen features as defined in Fig. 2. (A), modified after Juvigné *et al.* (in press a); (B) this paper. Ordinate is the remaining time range between residual dates after rejecting successive pairs of extreme ages of each series as represented in Fig. 3. Abscissa corresponds to percentage of rejected successive pairs of extreme ages. For the most appropriate level of rejection (black triangle and vertical bar throughout both figures), see Juvigné *et al.* (in press a). Example for *Artemisia*: Series of 11 ages (^{14}C years BP): 12,850; 10,680; 10,600; 10,450; 10,410; 10,270; 10,160; 10,140; 9840; 9670; 9050. Time range between successive pairs of extreme values: 3800 (=12,850–9050); 1010 (=10,680–9670); 750; 310; 250; 0. The corresponding percentages of rejected ages are: 0 (0 × 100/11), 18 (2 × 100/11), 36, 54, 72, 100. For the series of ages concerning the Laacher See Tephra, see Juvigné *et al.* (in press a). Among the ca. 40 ^{14}C ages published for the LST, only those obtained by conventional ^{14}C dating on peat and gyttja were taken into account because the pollen features involved were dated in a similar way. More explanations about the method are available in Juvigné *et al.* (in press a). A table containing detailed data for all pollen features, method of calculation of intermediate dates, and references to literature of individual ^{14}C dates, can be obtained from E. Juvigné on request.

TEPHRA-BASED CHRONOSTRATIGRAPHIC MODEL

Background comments on the tephrostratigraphy of the FMC are as follows. (i) Detailed information on the distribution, magma composition, and mineral content of the tephras considered below have been published in various papers during the past decade and reviewed by Juvigné (1993). (ii) A few thermoluminescence ages were obtained for lava flows and tephras linked with the volcanoes that erupted the tephras under consideration. These ages are not discussed in this paper in order to avoid comment on calibration of ^{14}C ages that is of no concern in this paper (see above). This has been done already by Juvigné *et al.* (in press b). (iii) The individual tephras considered below were deposited within a very short time span (days to weeks) that lies well within the chronostratigraphic periods delineated below.

La Nugère Tephra

In the peat bog 'Gour des Aillères' (Monts du Forez), the La Nugère tephra bed is bracketed by ^{14}C ages from samples of overlying and underlying gyttja (Etlicher *et al.*, 1987): 11,490 BP and 11,340 BP (Fig. 5: #4 and #5). In Limagne, three ages between 12,370 BP and 11,340 BP were obtained by Juvigné *et al.* (1992) on peat/gyttja samples underlying the tephra bed in various peat bogs (Fig. 5: #1, #2, #3). These five ages are consistent with an age of about 11,400 BP for the La Nugère Tephra.

Godivelle Tephra 5 (T5) and Godivelle Tephra 4 (T4)

Both tephras were identified in peat bogs of the Monts Dore and the Cézallier (Juvigné, 1987a; Bastin *et al.*, 1990). Tephra beds that were subsequently demonstrated to be T4 and T5 were also represented in pollen diagrams where they are placed either within the Allerød (Bastin *et al.*, 1990) or within the Late Dryas (Reille *et al.*, 1985; Guenet and Reille, 1988). A few centimetres of gyttja lie between the upper tephra bed (T4) and the lower one (T5). Gyttja samples containing each tephra bed in a centered position were dated.

Concerning T5, three ages (Fig. 5: #7, #8, #9) cover the time range 10,860 to 10,610 BP for one standard error. Another one (Fig. 5: #6) deviates largely from the series and should be rejected. Hence an age of about 10,700 BP can be allocated to the Godivelle Tephra 5. Concerning T4, three ages (Fig. 5: #11, #12, #13) contain the time range 10,340 to 10,240 BP, but age #10 deviates by a few

TABLE 1. Migration time and period of migration of eight pollen features throughout the French Massif Central[a]

A. Pollen feature	B. Migration time (years)	C. Limits of plateau (years BP/^{14}C)	D. Median of plateau (years BP/^{14}C)	E. Migration period (years BP/^{14}C)
Fagus	500	4810 to 4180	4525	4775 to 4275
Abies	1400	6520 to 3420	4970	5670 to 4270
Fraxinus	1100	6620 to 6300	6410	6960 to 5860
Tilia	150	7170 to 6860	7000	7075 to 6925
Ulmus	900	9530 to 9310	9350	9750 to 8950
Corylus	800	9590 to 9310	9460	9960 to 9060
Quercus	950	9720 to 9390	9620	10,095 to 9145
Artemisia	200	10,680 to 10,140	10,410	10,510 to 10,310

[a] A, pollen features as defined in Fig. 2. B, migration time obtained from Fig. 4 (A) and (B) at the 28% level of rejection (vertical bar), i.e. the time range between individual pollen curves and LST curve. C, time range delineating the plateau (Fig. 3). D, median age within the plateau (Fig. 3). E, period of migration obtained in equally splitting the migration time (column B) on both sides of the median date (column D).

decades. Hence an age of about 10,300 BP can be allocated to the Godivelle Tephra 4.

Puy de Dôme Tephra

There is only one ^{14}C age (9790 ± 175 BP) available for the Puy de Dôme Tephra, which was identified by Juvigné and Gewelt (1987) in the Narse d'Ampoix (southern Chaîne des Puys).

Trachytic tephra layers

In roadcuts of the Chaîne des Puys, three trachytic layers have been distinguished: (i) the pyroxene-, titanite-bearing Chopine Tephra; (ii) the amphibole-, biotite-bearing Kilian Tephra; and (iii) Vasset Tephra. ^{14}C ages were allocated to each of them (Camus, 1975). Since these tephras have never been observed together in a single outcrop or core, the stratigraphic succession is unknown.

Furthermore, a tephra bed of trachytic composition containing all the above cited minerals (La Taphanel Tephra) was found in peat bogs of Limagne, Monts Dore, Artense, Cézallier, and Cantal (Juvigné, 1983, 1987b; Juvigné *et al.*, 1992). This mineralogical association is supposedly derived from a mixture of material of the Chopine Tephra and the Kilian and/or Vasset Tephra (Juvigné *et al.*, 1992). Because the La Taphanel Tephra is a single mm-thick bed in peat bogs that have a rate of peat sedimentation of a few centimetres per century, the Chopine Tephra and the Kilian Tephra and/or the Vasset Tephra should have been deposited within a very short time span at ca. 8540 ± 150 BP, i.e. the weighted mean of the sixteen ^{14}C ages of Fig. 6 (calculation after Long and Rippeteau, 1974).

The difference between the extreme ages of the series is 1120 years. This is more than the deviation obtained for the series of ages of the 'instantaneous' LST (860 years; see above). This possibly indicates that the individual trachytic tephras might have erupted at different times within about 260 years (1120–860 years). If so, the mineralogical association of the La Taphanel Tephra might not correspond to a mixture of the trachytic layers as considered previously.

Pariou Tephra

An occurrence of the Pariou Tephra was found in a palaeolake deposit of Limagne (Juvigné *et al.*, 1992). Because the tephra bed overlies immediately (no intervening lacustrine sediment) a trachytic tephra bed of mixed mineralogical composition (see above), the age of about 8540 ± 150 BP should also be applicable for the Pariou Tephra, with the additional condition that this tephra postdates the trachytic layers.

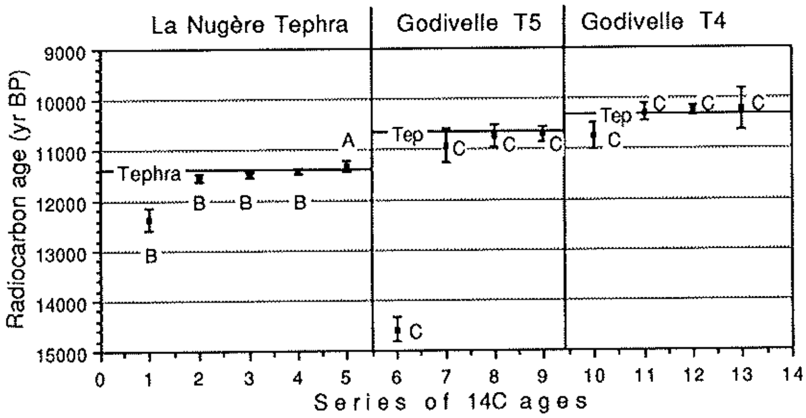

FIG. 5. ^{14}C dates for the La Nugère Tephra, Godivelle Tephra 5, and Godivelle Tephra 4. B, peat sample taken immediately below the tephra bed; C, tephra bed centered in the peat sample; A, peat sample taken immediately above the tephra bed.

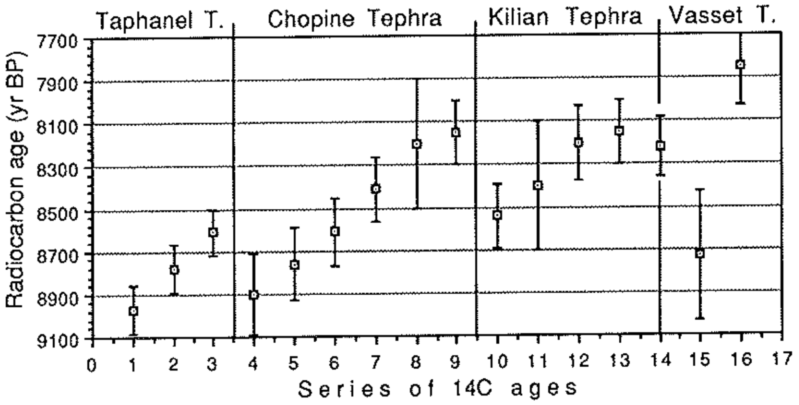

FIG. 6. ^{14}C dates for the trachytic tephra layers of the Chaîne des Puys. All samples dating the La Taphanel Tephra consist of peat containing the tephra bed in a centred position. All samples for Chopine, Kilian, and Vasset tephras consist of charcoal incorporated in proximal pyroclastic products of the relevant sources. Age #14 corresponds to a sample of lacustrine sediment in which the Kilian T. or the Vasset T. was centred (Juvigné and Bastin, in press).

La Vache-Lassolas Tephra

There is only one ^{14}C age available for the La Vache-Lassolas Tephra, which was found in the Narse d'Ampoix/southern Chaîne des Puys: 7930 ± 125 BP (Juvigné and Gewelt, 1987). For the one confidence interval, this age is consistent with the age of a piece of wood (7650 ± 350 BP; Pelletier *et al.*, 1959) buried in fluviatile sediments underlying a lava flow from the same volcano.

The Besse-en-Chandesse volcano group

As demonstrated by Camus *et al.* (1973) and Bourdier (1980), Montcineyre, Estivadoux, Montchal, and Pavin volcanoes erupted successively in the cited order. Both the Montcineyre Tephra and the Pavin Tephra are present in peat bogs of Monts Dore and Cézallier where they are separated by only a few centimetres of intervening peat. This implies that the Besse-en-Chandesse volcano group erupted within a short time span, estimated at about 175 years (Juvigné and Gilot, 1986). The Montchal Tephra is present in peat bogs west of the volcano (Juvigné and Bastin, in press). Consideration of the chronostratigraphic position allocated to the tephras in Fig. 7 (5950 to 6100 BP) demonstrates that only three of the 13 ages deviate (#4, #10, and #11).

PALYNOLOGICAL AND TEPHRA-BASED CHRONOSTRATIGRAPHIC MODEL

The model represented in Fig. 8 is proposed as a conclusion of this paper.

In contrast to previous models (Beaulieu *et al.*, 1987, 1988; Juvigné *et al.*, 1988; Juvigné, 1991), this one shows that a specific pollen feature is diachronous enough to occupy various stratigraphic positions in comparison with a tephra bed, which is a sharp time marker. It is also an attempt to provide a new solution to controversial papers that were published during the past decade: (i) those by Reille *et al.* (1985), Guenet (1986a, b, 1993) and Guenet and Reille (1988); and (ii) those by Juvigné and Gilot (1986), Juvigné *et al.* (1988), and Bastin *et al.* (1990).

The Montcineyre, Montchal, and Pavin tephra group should always occur stratigraphically above the beginning of the continuous curve for *Tilia*. In contrast, the same group of tephras, or one of the tephras within the group, should occur below or above the steeply rising curve for *Abies* and/or the beginning of the continuous curve for *Fraxinus*. Two examples of the latter case exist in the literature: the continuous curve for *Fraxinus* begins generally below the Pavin-Montchal-Montcineyre tephra group in the Cézallier, but above the Pavin Tephra at

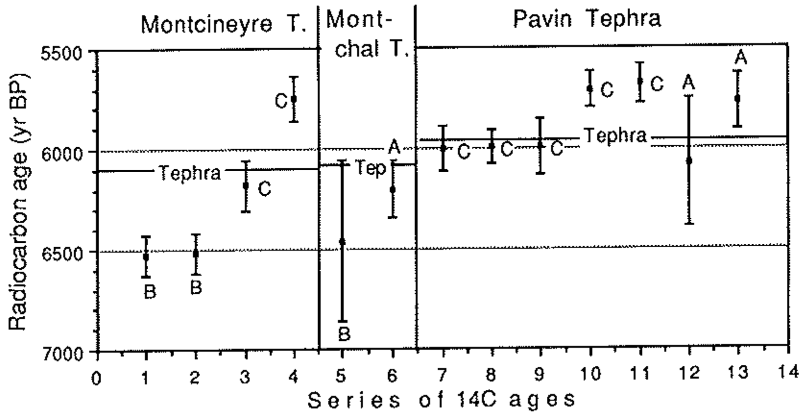

FIG. 7. ^{14}C dates for the Montcineyre, Montchal, and Pavin tephras. Key as for Fig. 5.

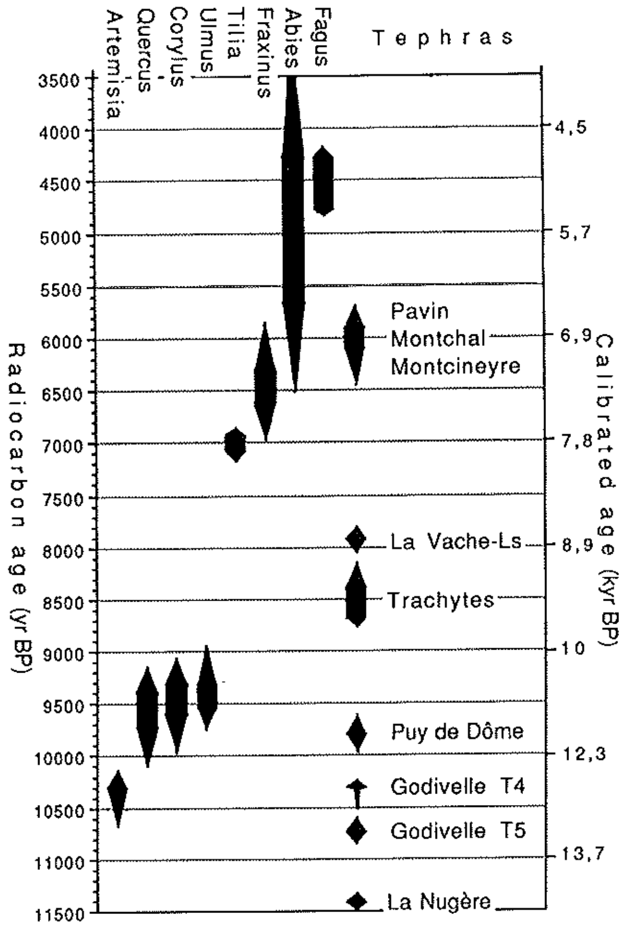

FIG. 8. Palyno-, tephro-, and chronostratigraphic model for the Late Glacial and Holocene period in the French Massif Central according to results obtained in peat bogs. The pollen features are defined in Fig. 3. The migration time of individual pollen features is represented according to the values of Table 1, columns C and E. The shorter migration time (C or E) is represented by a quadrangle, and the possible extension (E or C) by adjacent triangles. The individual tephras were deposited within a very short time span (hours to weeks) within the relevant period delineated in this figure. The ^{14}C time scale (left scale) was calibrated (right scale) after Stuiver *et al.* (1993). TL-ages were published for the following tephras or corresponding lava flows: (i) Pariou, 8.18 ± 0.35 ka (Guérin, 1983) and 8.7 ± 0.9 ka (Raynal *et al.*, 1989); (ii) La Vache-Lassolas, 8.1 ± 1.15 ka (Guérin and Valadas, 1980); (iii) Puy de Dôme, 10.8 ± 1.1 ka (Fain *et al.*, 1986).

Graspet (Reille *et al.*, 1985) and above the Montchal Tephra at La Barthe (Juvigné and Bastin, in press).

The La Vache-Lassolas Tephra and the trachytic layers of the Chaîne des Puys should occur: (i) above the beginning of the continuous curve for *Ulmus* and *Quercus*, as well as above the steeply rising curves for *Corylus*; and (ii) below the beginning of the continuous curves (2% level) for *Tilia* and *Fraxinus*.

At the sole locality where the Puy de Dôme Tephra have been found in a peat bog, it is present in a palynostratigraphic position that is consistent with the model.

The stratigraphic relationship between the Godivelle Tephra 4 and the peak of *Artemisia* curve (≈ low of *Betula*) is more controversial. The peak of *Artemisia* curve (≈ low of *Betula* curve) is supposed to correspond to the Late Dryas oscillation in the FMC. On the one hand, the more likely migration period of the Late Dryas *Artemisia* peak runs from 10,510 to 10,310 BP. On the other hand, T4 occurs below the *Artemisia* peak within the Allerød at all localities where both features were found, but has a ^{14}C age between 10,340 and 10,240 BP (Fig. 5). The above time ranges are in reverse stratigraphic order; furthermore, they constrain the Allerød/Late Dryas transition. This inconsistency can be considered in different ways as follows.

1. An age of about 10,340 BP might be allocated to T4, and the two ^{14}C ages of the *Artemisia* peak of between 10,510 and 10,340 BP (Fig. 3) should be rejected.
2. An age of about 10,340 BP might be allocated to T4, while accepting that the Late Dryas cooling pulses that triggered the development of *Artemisia* (=retreat of *Betula*) in the FMC took place shortly prior to 10,510 BP, but had no perceptible impact on the vegetation of the Cézallier (where T4 fallout is present) until about 10,300 BP.
3. The ^{14}C age of T4 might be underestimated by about two centuries, but not more, because the underlying T5 has an age of about 10,700 BP (Fig. 5).
4. It might be emphasized that any of the above compromises corresponds to an Allerød/Late Dryas transition that is a few centuries more recent than the ages proposed by other authors (referring to conventional ^{14}C ages), e.g. (i) Mangerud *et al.* (1974), 11,000 BP; (ii) Gilot *et al.* (1969), 10,850 BP; (iii) Beaulieu *et al.* (1982), 10,700 BP.

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