Pact 31 - 10 : J.L. de Beaulieu, J.L. Edouard, P. Ponel, C. Rolando, L. Tessier, M. Thinon and A. Thomas

Timber Line and Human Impact in the French Alps.

The State of the Art and Research Programs

It has been shown that in densely populated regions at middle latitudes, the timber line has long been governed by man's activities.

Mont Lozere, on the south-eastern border of the French Massif Central provides a good illustration of this assumption. There, since the subalpine trees are absent, *Fagus silvatica* constitutes a low forest limit together with *Pinus silvestris*, for which an anthropogenic origin has been demonstrated in the region (Reille & Pons, 1982). At about 1400 m, these trees are replaced by a grassland with *Nardus stricta*, which entirely covers the crests. For phytosociologists this represents a « pseudo alpine stage » whose origin has been much debated since the last century.

At the end of the sixties, pollen analyses of a peat-bog near the summit (Beaulieu & Gilot, 1972) suggested that the *Nardus* grassland resulted mainly from the clearance of a *Fagus silvatica* forest which began during Roman times. Now, 20 years later, the grassland is invaded by young *Pinus silvestris* individuals, which will no doubt form dense populations twenty years hence.

This is a good example of biological revival related to land abandonment and to the utilization of oil, instead of wood, as a heating material. This revival is observed at all altitudes in Southern France, except in places where fire has prevented the development of such dynamics. It confirms a posteriori the palaeoecological demonstration of an artificial origin for the pseudoalpine stage.

In the French Alps, where subalpine species such as *Picea abies, Larix decidua, Pinus cembra* and *P. uncinata* exist and there are large areas at very high altitudes, the natural status of the forest limit is not in question, but the history of the timber line is a complex problem and three questions arise :

1. What was the maximum altitude of the timber line during the Holocene optimum, and which trees were involved ?
2. Is man alone accountable for the lowering of the timber line, or have climate changes, such as, for example, the little ice age, been responsible ?
3. How (and following what chronology) did man's action modify the high altitude environment and what is the real altitudinal potential of Alpine tree species ?

THE TIMBER LINE : THE STATE OF KNOWLEDGE

Present position

By its very definition, the natural upper limit of forest corresponds to the transition between the subalpine and alpine stages. In the French Alps, phytogeographers (Ozenda, 1981, 1985) locate it at around 2200-2300 m.

Below this limit, i.e. in the subalpine stage, phytogeographers distinguish an upper subalpine substage, treeless or with sparse trees, corresponding to the famous « struggle zone », a middle substage with *Larix decidua, Pinus cembra* and *P. uncinata* forests, and a lower substage with *Picea abies* and *Abies alba*. The areas of these different trees frequently overlap in a complex pattern governed by regional climates.

According to Ozenda (1981), it is not always easy to distinguish between the natural limit of forest and the limit resulting from a lowering due to pasture or human action ; but this classical difficulty has generally been overcome, at least by modern authors.

This statement seems optimistic because, although most authors agree that the fall in the timber line varies between 200 and 400 m, this assessment is based on reasonable assumptions rather than on scientific demonstration.

A means of distinguishing the potential timber line from the actual timber line would be to extrapolate the first from the snowline, as it has been established that the latter is at a constant distance of about 800 m from the timber line.

However, the snowline, which is at about 2900 m and often above 3000 m, can only be observed in a few of the highest massifs of the French Alps and cannot be extrapolated to other massifs since it is known, from the example of Switzerland that the snowline does not follow a horizontal line. This dilemma shows that only knowledge of the past can help to define the amplitude of timber line lowering.

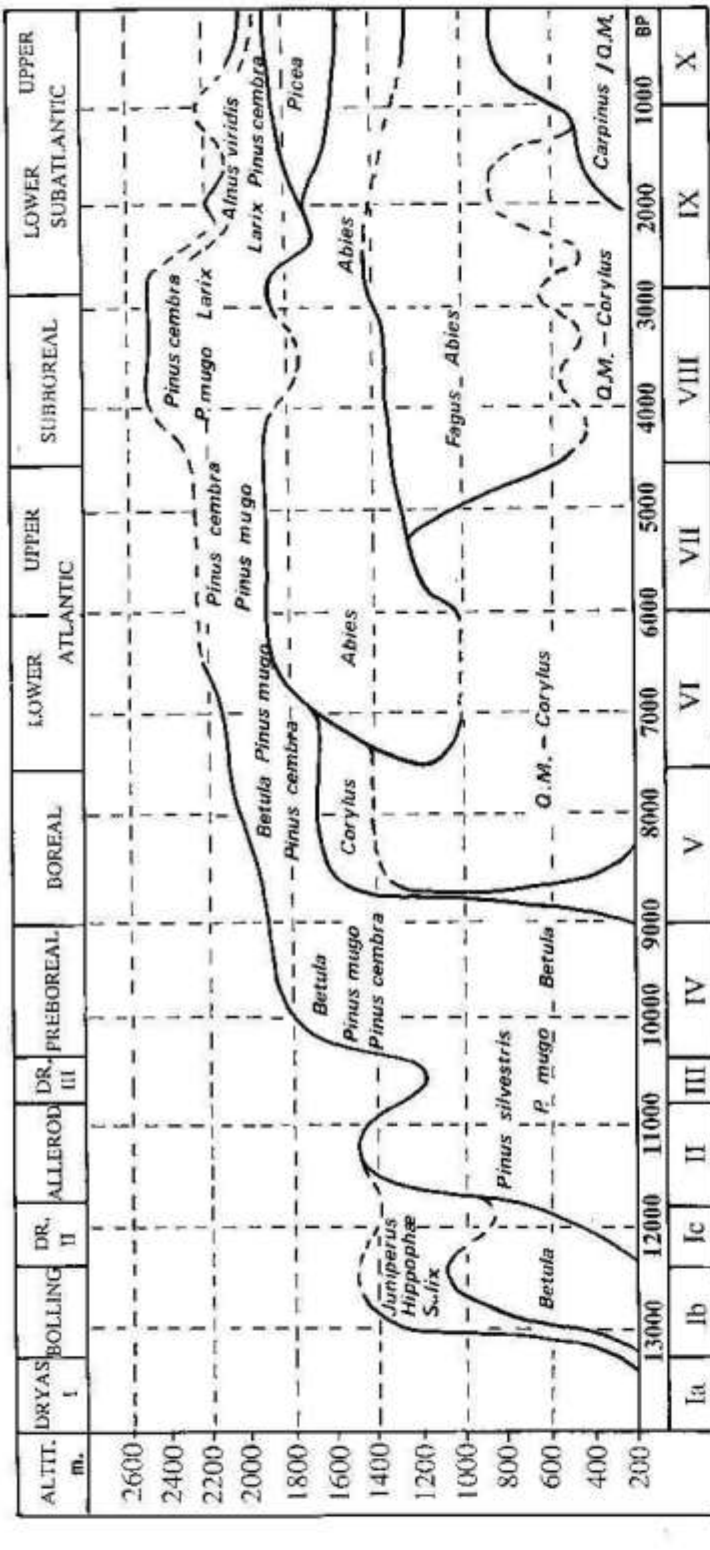


Fig. 1. Late-glacial and holocene fluctuations of vegetation belts and timber line in the Northern Dauphiné. (From Wegmüller, 1977).

Historical data

Archaeological data, which reveal the most important phases of human impact during the prehistorical and historical periods, do not provide much information on this matter, since the severe climate conditions on very high mountains precluded permanent human settlement, and hence archaeological sites are rare at high altitudes.

However, it appears that the archaeological potential of high mountains has not yet been completely exploited. For instance, quite recently, the archaeologist, F. Baille, in Maurienne valley, discovered, at heights of between 1000 m and 2500 m, more than 500 sites (as yet unpublished) with engravings and cupules from the bronze and the iron age (A. Bocquet pers. comm.). This confirms the pressure of population on the upper forest limit in the French Alps from the metal ages onwards.

Palaeoecological data

Among those palaeoecological methods which could potentially be used to elucidate timber line history, only pollen analysis has until now been well developed in the French Alps. However, at mountain sites, pollen transport from lower altitudes sometimes plays an important role and complicates the interpretation of pollen spectra in terms of local woodland.

This evidence has always been emphasized by palynologists, but different interpretations have been given.

In the French Alps, Wegmüller (1977) is the only person who proposed a curve (fig. 1), of timber line fluctuations based on his own pollen diagrams.

Beaulieu (1977) seldom referred to the timber line, because he considers that it is almost impossible to infer its altitude from pollen frequencies alone. However, the pollen percentages of *Abies* recorded during the Atlantic at some sites in the Southern Alps, at about 2000 m, suggest that this taxon could grow at this altitude, that is to say 200 m higher than was estimated by Wegmüller.

Coûteaux (1982 a, b) assumed that during the Alleröd, the site of La Muzelle, at 2100 m altitude in the Oisans massif, was surrounded by a thick forest of *Pinus uncinata*, which places the timber line 600 m higher than suggested by Wegmüller for the same period.

The synthesis recently proposed by Burga (1988) concerning the estimates proposed for the timber line variations in the different regions of the Alps (fig. 2), also shows differences which are not only due to the peculiarities of each region studied, but to the different criteria that are used in interpreting pollen spectra in terms of local vegetation.

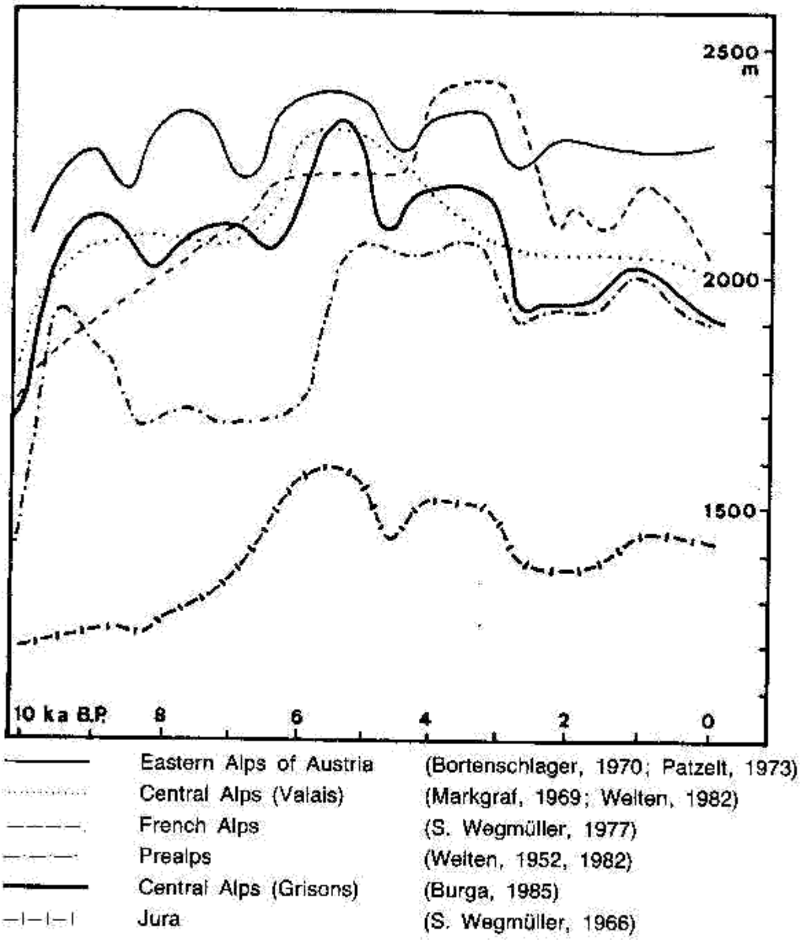


Fig. 2. Timber line fluctuations in the Alps of Switzerland, France and Austria. (From Burga, 1988).

These discrepancies illustrate the difficulties involved in drawing conclusions about the timber line on the basis of pollen analysis alone.

Nevertheless, pollen analysis enables the delimitation of periods of strong human impact on the high altitude environment, as illustrated by a table from Wegmüller (1977) and Beaulieu (1977) (fig. 3). This table indicates relatively few forest openings during the neolithic (probably underestimated), and a succession of periods of marked human impact starting at the beginning of the bronze age.

This short review shows that a variety of palaeoecological methods providing independent but coherent elements of information are necessary to clarify the history of the timber line.

It is with this in mind, that as part of the PIREN (Interdisciplinary Research Programme concerning the Environment and Nature), we undertook researches in the Taillefer Massif.

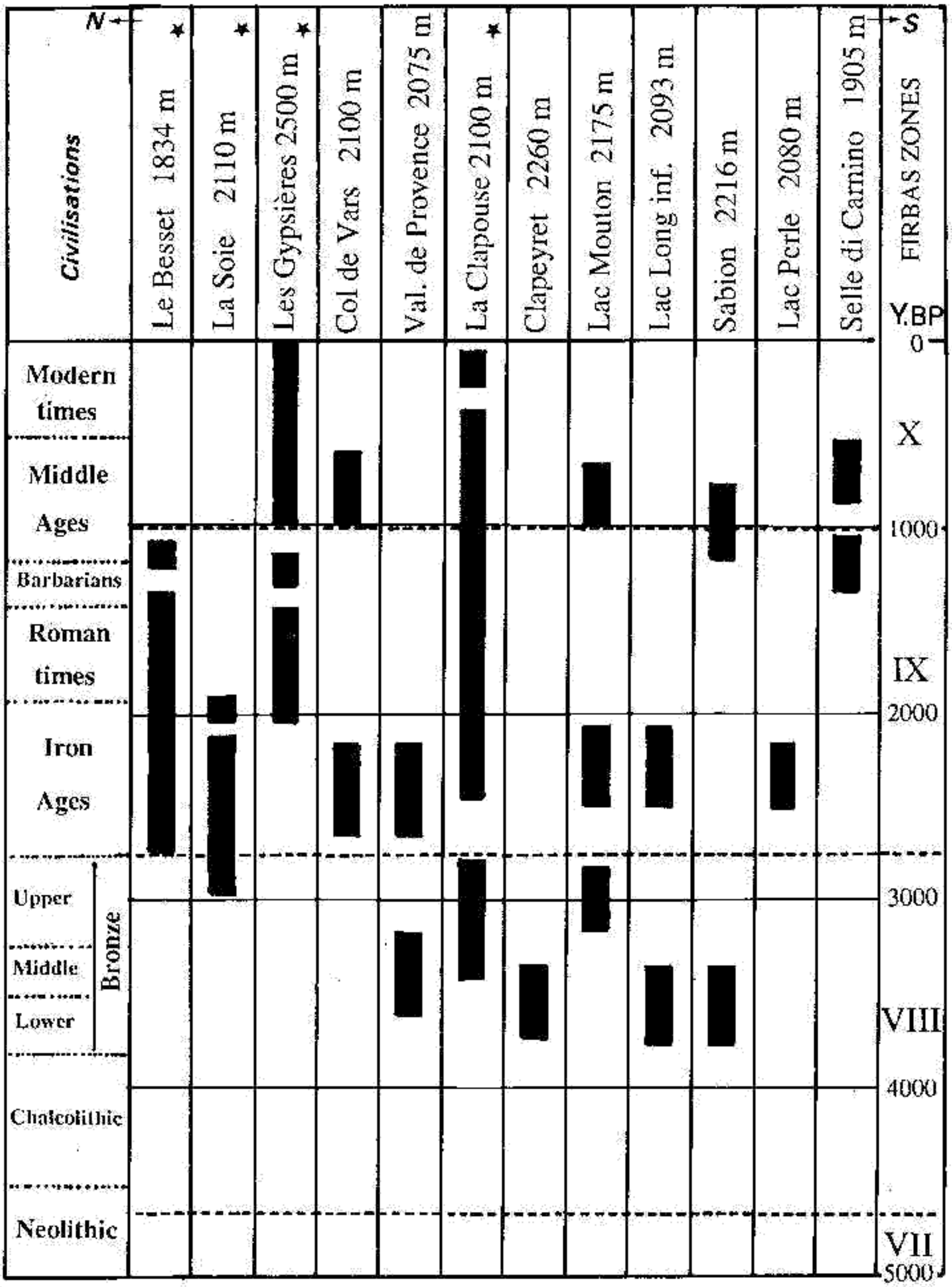


Fig. 3. Human impact in pollen diagrams from high altitude sites in the French Alps. (From Wegmüller, 1977, and Beaulieu, 1977).

THE TAILLEFER PROGRAM

The cristalline Taillefer massif is a southward prolongation of the Belledonne range. It leans against the high Pelvoux massif, which is still covered with active glaciers (fig. 4).

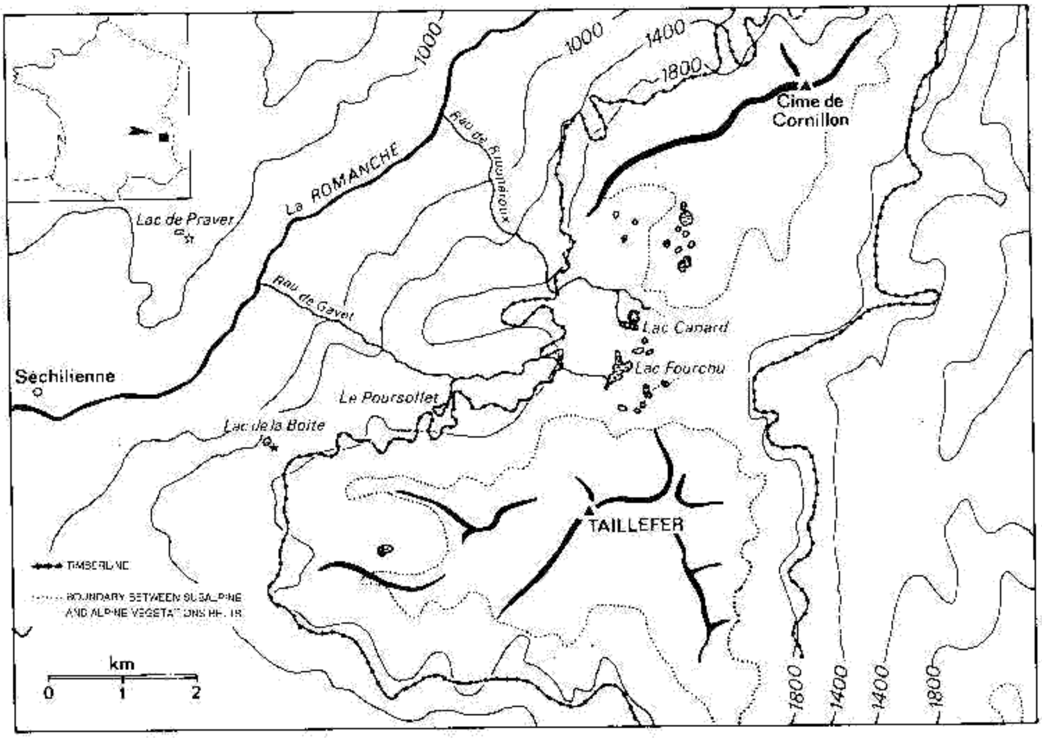


Fig. 4. Location of the Taillefer Massif.

The massif culminates at 2857 m. A huge high plateau extends between 2100 m and 2400 m. It is now above the forest, and scattered with small lakes or mires.

On the northern slope, at about 1700 m, the timber line is formed by a beautiful *Picea* forest, replaced at higher elevation by an *Alnus viridis* heath, with sparse *Pinus cembra*, and some isolated *Picea* (see vegetation map by Ozenda *et al.*, 1968).

It is the finding of numerous *Pinus uncinata* trunks at the surface of peatbogs and in the lakes of the plateau, well above the timber line, which incited us to undertake our research programme and to make excavations in order to try and explain the presence of forests in the past. Dendrochronology, palaeoentomology, pedoanthracology, macrofossil analysis and pollen analysis are all involved in this investigation.

Dendrochronology (Edouard J.L., Tessier L. and Thomas A.)

The first excavations showed a jumble of *P. uncinata* trunks, probably belonging to trees which formerly grew on the edges of the mire. The first ^{14}C datings of some trunks indicate ages ranging between 8,200 B.P. and 2,300 B.P. (fig. 5). The great number of trunks in the peat, the perfect preservation of the wood, the large number of rings observed in many trunks, from 70 to

400 rings (mean 180 rings), will make it possible to establish a continuous ring-width chronology covering a large part of the Holocene.

At the moment, 96 trunk sections, extracted from the peat, have been selected for dendrochronological analysis. For each section a mean chronology has been built using measurements of ring-width along three radii. The synchronization of the 96 mean chronologies has been done using cross correlation coefficients calculated on each possible pair of chronologies, for each possible relative position of the two chronologies (Pilcher, 1973). The

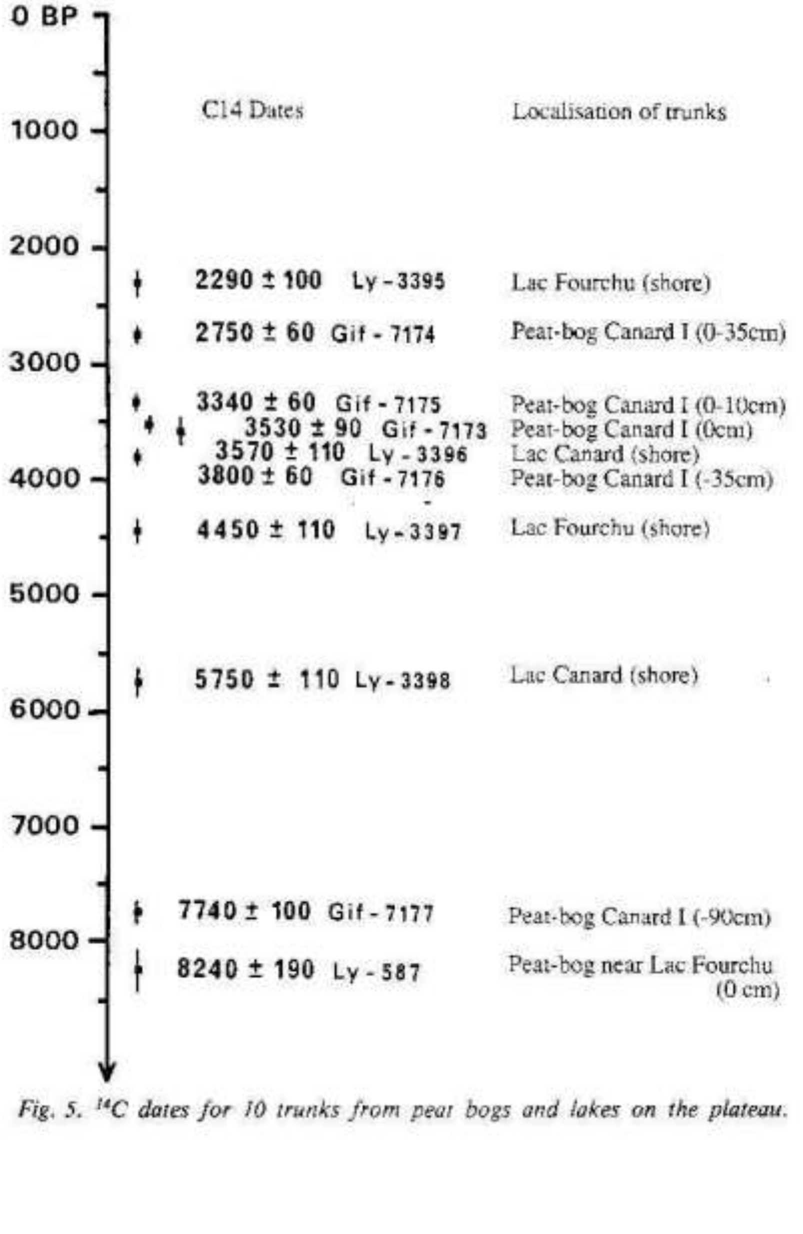


Fig. 5. ^{14}C dates for 10 trunks from peat bogs and lakes on the plateau.

Student T test is applied, and correlation is considered as significant for $T \geq 5$. The position of the synchronization is then verified on the curves.

The 38 chronologies synchronized in 12 floating groups, are illustrated in figure 6. 58 chronologies remain isolated. These 12 groups enable the construction of 12 mean chronologies, two of which are dated by ^{14}C.

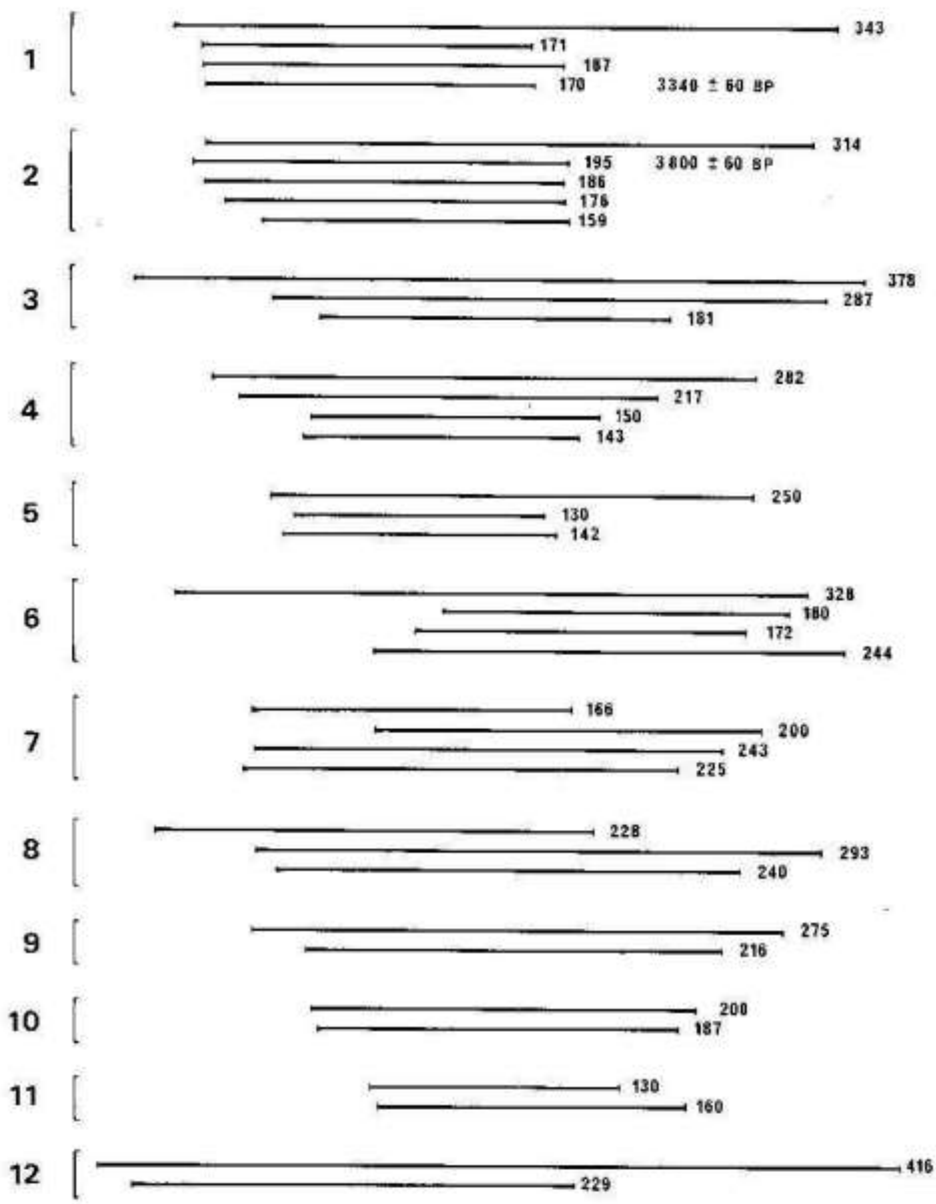


Fig. 6. Dendrochronological analysis of tree-ring series : 38 chronologies are cross-dated in twelve floating groups. Each chronology is the mean of the three measurements made on the trunk section.

It is likely that the repetition of such operations on other trunks extracted from peat or lakes in the area of Taillefer or in the surroundings will make it possible to establish a continuous ring-width chronology covering a large part of the Holocene.

Pollen analysis (de Beaulieu J.L.)

Our palynological results can be compared with the numerous investigations made by Coûteaux (1970, 1982 a-b, 1984 a-e) and Coûteaux and Edouard (1986, 1987) in the nearby Oisans massif.

The first pollen diagram (Canard 1) (fig. 7), comes from one of the holes from which the trunks were extracted, about 200 m to the east of Lac Canard. The stratigraphy above the bedrock is as follows :

— 0-30 cm (surface) : 31 cm of poorly humified Cyperaceae peat without wood remains;
— 31-115 cm : 84 cm of detritus peat, including numerous wood remains, *Pinus uncinata* cones and needles;
— 115-120 cm : 5 cm of silty organic gyttja.

The pollen diagram can be divided into 6 local zones. Taking into account the regional works by Wegmüller (1977), Coûteaux (l.c.) and Clerc (1988), and on the basis of five ^{14}C datings, this diagram allows a chronology to be drawn up for the history of peat accumulation which began at the end of the Boreal (crossing of the *Corylus* and *Abies* curves : zone 1).

Pollen transport from vegetation communities at lower altitudes is more important than expected. The pollen sum of the undoubtedly allochtonous taxa (*Corylus, Ulmus, Acer, Fraxinus, Quercus, Tilia, Vitis, Taxus, Carpinus, Fagus, Olea, Castanea* and *Juglans*) oscillates around 30 %. This abundance does not fully explain the low *Pinus* pollen percentages, around 35-40 % in zones 2, 3 and 4, which are all the more surprising as abundant macrofossils of *P. uncinata* suggest a fairly thick local woodland. At such a high altitude, pollen distortions may partly be due to the snow cover which governs pollen sedimentation, the latter being directly correlated with climate (Tessier *et al.*, 1986).

High pollen percentages of *Abies* during the Atlantic (pollen zone 2) suggest that this tree was growing very near the site.

The early regional appearance of *Fagus* is in good agreement with the data obtained by Clerc (1988) and Wegmüller (1977). At Col Luitel, the first occurrence of *Fagus* is dated at around 6,680 B.P. and the beginning of a continuous curve, slightly before 5,400 B.P. Nevertheless in Canard 1 the two ^{14}C dates 6,520 ± 226 B.P. (77-80 cm) and 2,240 ± 180 B.P. (62-65 cm) corresponding to the bottom and top of the narrow zone 3 respectively sets a chronological problem : they suggest a cessation in sedimentation during the latter part of the Atlantic and the whole Subboreal (more than 4 millennia).

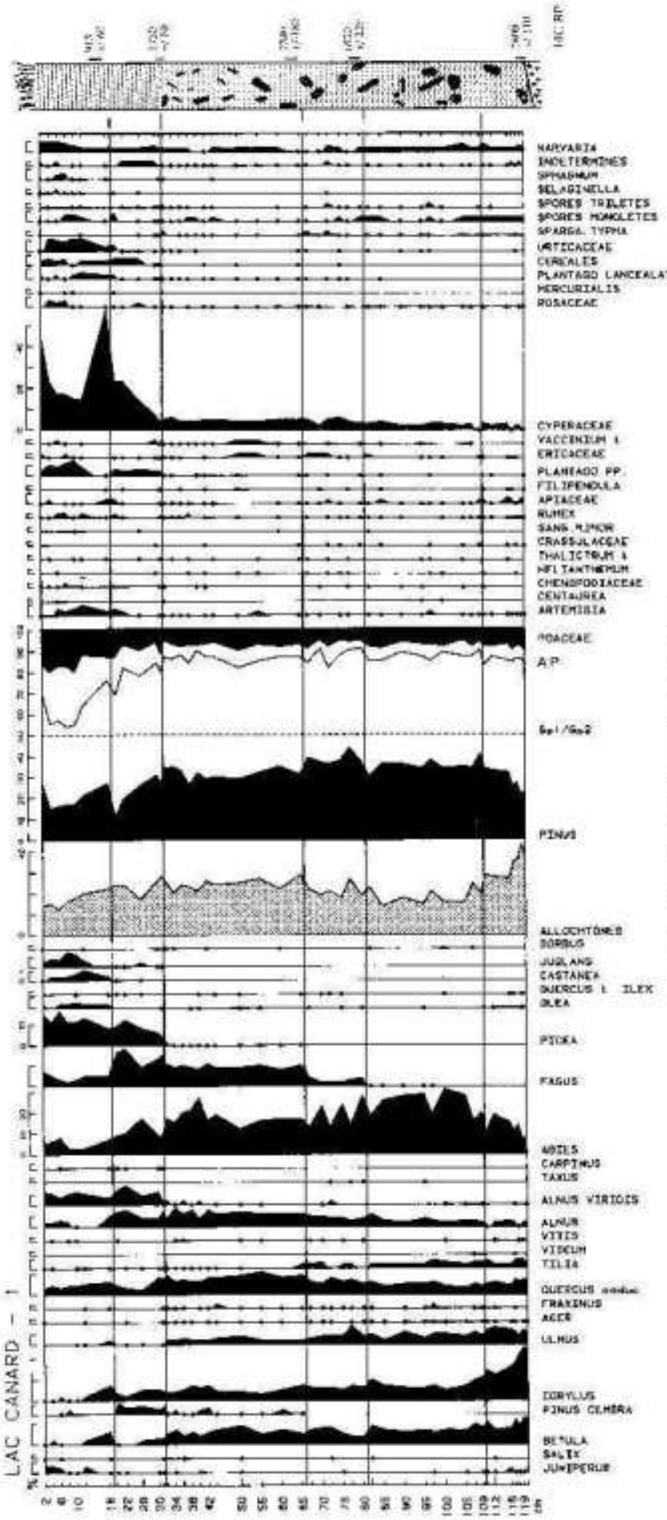


Fig. 7. Canard 1 pollen diagram.

This hiatus does not appear in the lithostratigraphy and is not consistent with the gradual sinking of the trunks in the peat-bog, dated between 5,750 ± 110 B.P. and 2,750 ± 60 B.P. So, the ^{14}C dates obtained for the peat need to be verified.

However, the pollen diagram clearly shows that the establishment of the *Picea* forest, now present at the timber line, took place during Roman times (1,750 ± 80 B.P.), as did the main local clearing episode (reduction of *Pinus* expansion of *Alnus viridis*, absence of wood in the peat).

Pinus cembra is also present from the onset of the Subatlantic, perhaps replacing of the destroyed *P. uncinata* stands.

Macrofossil analysis

As has already been mentioned, not only trunks but also pieces of bark, cones and needles of *Pinus uncinata* were found and localised in the stratigraphy. Pieces of *Betula* wood pieces, with characteristic bark, were present in the lower part of the sections. In the upper part a very few *Pinus cembra* seeds and needles were picked out. A systematic study of the macro remains, long delayed because of the absence of specialists in France, is now being made by dr. K. Tobolski, on a sedimentary column from an excavation (Canard A10) 60 m distant from Canard 1.

Pedoanthracology (Rolando C. and Thinon M.)

This discipline has been developed in Marseille (Thinon, 1978, 1979) and is based on the botanical identification and dating of wood charcoal found in soils resulting from fires mainly of anthropogenic origin. Pedoanthracology enables one to reconstruct, over the last millennia, the ligneous local vegetation evolution, which is often related to human activities.

After digging a pedological trench, samples of sediments, from 5 to 10 kg, are taken at different levels. The pieces of wood charcoal, which are generally no more than 4 to 5 mm in length, are extracted by sieving in water through a 400 micrometer-mesh screen; then they are cleaned and dried. Botanical identification is made on the basis of anatomical characteristics observed on the 3 wood planes, transverse, tangential and radial using an incident light microscope with differential interference contrast or, if necessary, a scanning electron microscope. The anatomical characteristics have been codified from a study of reference samples and are checked by microcomputer. In most cases, identification to species is possible.

The small amount of pedoanthracological material, just a few milligrams even for the largest charcoal pieces, makes radiocarbon dating possible only by mass spectrometry. This type of dating has only been used very recently and only limited results have been obtained so far. Nevertheless, the first series of dates (Thinon, 1978) suggests that there is a certain chronological stratification of charcoal in soils. Moreover pedoanthracological investigations can provide information on the past presence of trees at any altitude in the supraforest belt.

For example, in the Southern Alps, several pedoanthracological profiles from beneath grassland characterizing the Alpine stage with *Alopecurus gerardi, Trifolium alpinum, Nardus stricta, Ranunculus pyrenaeus, Carex sempervirens* etc., have revealed charcoal of tree and shrub species from the Subalpine belt :

— 2290 m Vallon de la Boucharde : *Larix* (*L. decidua*), *Juniperus nana, Laburnum alpinum.*

— 2280 m Col de la Cayolle : *Pinus cembra, Larix* (*L. decidua*).

— 2280 m Vallée des Merveilles : *Pinus cembra, Juniperus nana.*

— 2650 m La Foux d'Allos : *Larix* (*L. decidua*).

This charcoal shows that these alpine pastures, which today have no trees or shrubs and are located several hundred meters above the present timber line, were formerly colonized by forest species.

In the Taillefer Programme, the first studies show that the soil samples are fairly rich in charcoal, in particular there is a fire-layer, from 11 cm to 18 cm, in a profile at 2100 m. The lower levels contain charcoal of *Pinus cembra, Betula verrucosa* and *Betula* sp. ; the upper levels indicate an obvious opening of the environment with abundant charcoal of *Juniperus nana* and *Vaccinium myrtillus* — the present vegetation.

Palaeoentomology (Ponel P.)

A study is being carried out of a whole sediment sequence sampled in parallel with the pollen profile Canard I.

To date, two levels have been investigated : The first one is a 10 cm thick surface section and the second an accumulation of needles of Atlantic age. 93 taxa belonging to 26 families have been identified.

1. In the surface layer, 3 groups of species are recorded :
   — Species linked to open landscape (in this case alpine grass-land) : *Notiophilus aquaticus, Bembidion* (*Princidium*) *bipunctatum, B.* (*Testediolum*) (cfr. Jacqueti).
   — Dung-beetles (Scarabaeidae and Staphylinidae).
   — A great number of small winged, arboricolous species suggesting upward wind transport. These species belong to the Staphylinidae, Scolytidae and Curculionidae families (ex. : *Rhynchaenus quercus* which lives on oak). This group represents the regional influx in the pollen analytical sense.

2. In the accumulation of needles two groups of species are present :
   — Species indicative of a wooded environment. The great size of these beetles and their sedentary behaviour strongly suggests a local origin. These species are for example : *Trichotichnus nitens* and *Calathus micropterus* (Carabidae), *Ampedus balteatus* (Elateridae), *Pytho depressus* (Pythidae) and *Chrysochloa speciosa* (Chrysomelidae).
   — A great number of arboricolous species whose local origin cannot be proved. These species (*Eusphalerum* sp. and *Anthophagus* sp. (Staphylinidae), *Ditoma crenata* (Colydiidae), *Hypophloeus linearis* (Tenebrionidae), *Hylastes ater* and *Anthonomus varians* (Curculionidae)) may also have been transported by wind, just as those referred to in the surface sample.

Lastly, a recent finding of *Ceruchus chrysomelinus* (Col. Lucanidae) has been made in an Atlantic level. This beetle lives specifically in dead stumps and trunks of *Abies* in damp forests.

If one excludes from the analysis all those species which may have been transported by wind, the spectra derived from the two levels show striking differences (fig. 8) :

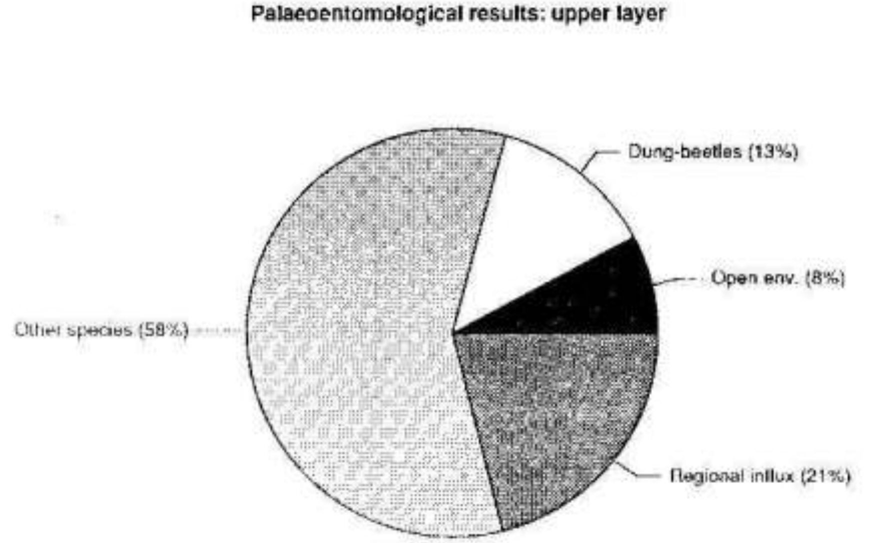
1. In the upper level, taxa indicative of open environments are abundant, as are for example, dung-beetles related to cattle.
2. In contrast, in the lower level, taxa from open environments are absent while the presence of large forest taxa, not easily transported by winds, confirms the presence of forest in the past. Thus, palaeoentomology proves to be an efficient method for demonstrating timber line fluctuations.

SYNTHESIS

Although, the different studies undertaken have by no means been completed, the sum of the results obtained so far gives a synoptic view of the vegetation in the Taillefer massif.

At the end of the Boreal, the presence of *Pinus uncinata* is attested by the presence of both needles and trunks (the later dated 8,240 B.P. and 7,740 B.P.). There is no information available for older times. The commencement of peat accumulation can be dated on the basis of the regional vegetation such as revealed by pollen analysis. The very low percentages of *Pinus* pollen do not prove the local presence of this tree.

On the basis of pollen analysis, deforestation is dated to about 1,720 B.P., the date at which the regional expansion of *Picea* took place. The dates obtained for the trunks cover the whole period from 8,240 B.P. to 2,320 B.P. Therefore it seems that forest was continuously present until Roman times.



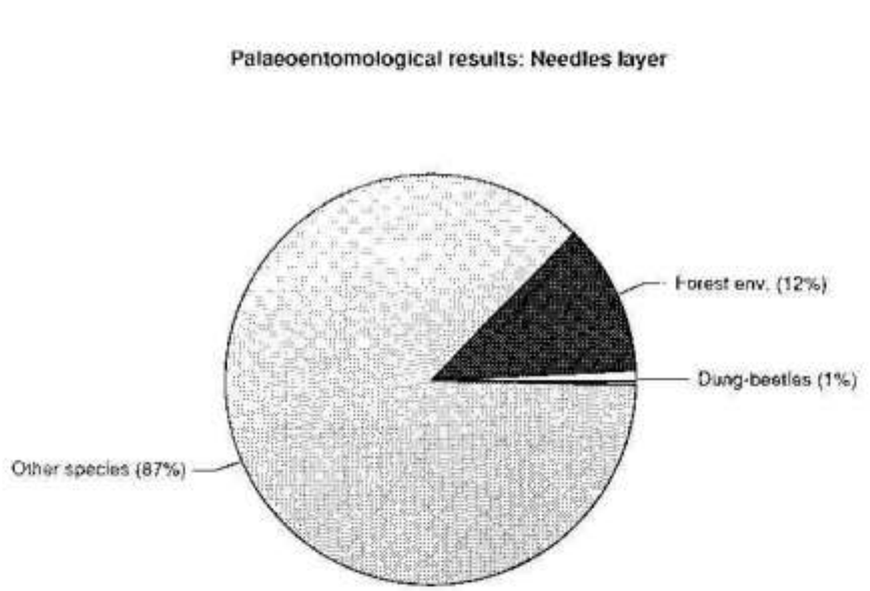


Figure 8. Frequency of beetles assemblages in two horizons of the Canard 1 section. (The upper is close to the surface — the lower is from an accumulation of needles).

If we consider only subfossil trunks, then the local forest around the peatbogs or lakes was composed of *Pinus uncinata*. Nevertheless the continuous and abundant presence of *Betula* is also attested by branches, bark and a few trunks. No trunks were found of other tree-species. However, information derived from other diciplines gives a much more complex picture. Firstly, the finding of insects living on *Abies* wood attests to the local presence of this species in the Atlantic at the time of its maximum pollen frequencies. Secondly, the presence of *Pinus cembra* is demonstrated by the presence of seeds in the peat and abundant charcoal in the soils near peatbogs and lakes. As a matter of fact, the absence of ^{14}C dates do not allow any conclusions as to whether *P. uncinata* and *P. cembra* were locally present together or occurred in successive stages. Pollen analysis rather favours the second hypothesis since an optimum of *P. cembra* coincides with the disappearance of *P. uncinata* during Roman times. In the upper levels the abundance of dung-beetles, the high percentages of pollen of anthropogenic origin and the presence of charcoal of *Juniperus* and *Vaccinium* attest to the strong impact of human activities.

In conclusion it seems that the Taillefer plateau was always situated within the forest belt from 8,000 B.P. to Roman time.

This confirms the artificial character of the present timber line.

The dendrochronological sequences, which do not overlap in a continuous reference chronology, and are too poorly replicated, do not allow the tree ring to be interpreted in terms of climate. On the other hand, additional and more detailed information is needed to obtain a large spatial view of the altitudinal vegetation belts around the site and at a regional scale.

Conclusion

We are far from being able to provide conclusions as yet. The programme, which seems well adapted to the complexity of the problems, will involve further investigations at the site and will also have to be extended to include other alpine massifs.

In the first place at the site itself, a greater number of trunks is needed to build a continuous and well replicated master tree-ring chronology. The analysis of plant macrofossils, insects remains and soil charcoal has to be carried out on the whole stratigraphic sequence. In addition, the collection of other stratigraphical series, which is now being made along an altitudinal transect from 1200 m to 2400 m will provide better knowledge of the fluctuations of the vegetation belts and particularly of the timber line.

Secondly, this multidisciplinary approach should be extended to cover a large set of sites representing contrasting climatic conditions. Some such sites have already been prospected in the Northern and Southern French Alps.

Besides, the field is quite open to other methodologies such as isotopic analyses (C13/C12, O16/O18 and D/H) or the direct evidence of human activity through archaeological prospecting.

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