Quaternaire
Revue de l'Association française pour l'étude du Quaternaire

vol. 18/2 | 2007
Q5 Le Quaternaire, Limites et spécificités - Deuxième partie

Advantages and limits of radiocarbon dating applied to peat inception during the end of the Lateglacial and the Holocene: the example of mires in the Eastern Massif Central (France)

Intérêts et limites de la datation par le radiocarbone pour le calage chronologique de l'apparition des tourbières à la fin du Tardiglaciaire et au début de l'Holocène : l'exemple du démarrage de la turfigenèse dans le Massif Central oriental (France)

Hervé Cubizolle, Pierre Bonnel, Christine Oberlin, Arnaud Tourman and Jérôme Porteret

Electronic version
URL: http://journals.openedition.org/quaternaire/1049
DOI: 10.4000/quaternaire.1049
ISSN: 1965-0795

Publisher
Association française pour l'étude du quaternaire

Printed version
Date of publication: 1 June 2007
Number of pages: 187-208
ISSN: 1142-2904

Electronic reference
Hervé Cubizolle, Pierre Bonnel, Christine Oberlin, Arnaud Tourman and Jérôme Porteret, « Advantages and limits of radiocarbon dating applied to peat inception during the end of the Lateglacial and the Holocene: the example of mires in the Eastern Massif Central (France) », *Quaternaire* [Online], vol. 18/2 | 2007, Online since 01 June 2010, connection on 19 April 2019. URL : http://journals.openedition.org/quaternaire/1049 ; DOI : 10.4000/quaternaire.1049

Quaternaire, **18**, (2), *2007*, p. 187-208

ADVANTAGES AND LIMITS OF RADIOCARBON DATING APPLIED TO PEAT INCEPTION DURING THE END OF THE LATE GLACIAL AND THE HOLOCENE: THE EXAMPLE OF MIRES IN THE EASTERN MASSIF CENTRAL (FRANCE)

■

Hervé CUBIZOLLE[1], Pierre BONNEL[1], Christine OBERLIN[2], Arnaud TOURMAN[1] & Jérôme PORTERET[1]

ABSTRACT

The origins of mires and the initiation of peat inception during the last 12 000 years has been widely interpreted in terms of macroclimatic change or land-use changes associated with human activities. One objective of our palaeoenvironnemental studies in the eastern Massif Central in France was to accurately date basal peat layers at a great number of sites. These radiocarbon dates of peat inception must then be confronted with palaeocological and archaeological data.

Although radiocarbon dating is currently used to date peat initiation, various difficulties can be encountered when attempting to identify and sample the oldest basal layers in a mire, and these problems are rarely addressed. This paper proposes a methodology based on detailed investigation by means of stratigraphical, sedimentological and micromorphological analyses. Five mires were studied: 3 bogs, and 2 fens.

As a main result we illustrated the great importance of micromorphological analysis. We also show that many radiocarbon dates are required to obtain accurate age estimations of the chronology of peat inception, precise enough to be confronted with other palaeoenvironmental data.

Key-words: mire, peat initiation, sedimentology, micromorphology, radiocarbon dating, Holocene, Massif Central, France.

RÉSUMÉ

INTÉRÊTS ET LIMITES DE LA DATATION PAR LE RADIOCARBONE POUR LE CALAGE CHRONOLOGIQUE DE L'APPARITION DES TOURBIÈRES À LA FIN DU TARDIGLACIAIRE ET À L'HOLOCÈNE: L'EXEMPLE DU DÉMARRAGE DE LA TURFIGENÈSE DANS LE MASSIF CENTRAL ORIENTAL (FRANCE)

L'apparition des tourbières au cours des 12000 dernières années est révélatrice de changements environnementaux importants, tant d'origine climatique que d'origine anthropique. Aussi, est-il fondamental, dans le but d'une reconstitution paléoenvironnementale, de pouvoir caler chronologiquement le démarrage de la turfigenèse sur un grand nombre de sites. La répartition dans le temps des dates obtenues peut ensuite être confrontée aux données géomorphologiques, paléoécologiques et archéologiques locales et régionales pour tenter de retracer l'évolution des paysages et des sociétés humaines qui les ont façonnés.

Néanmoins, si la datation par le radiocarbone est l'outil le plus adapté au travail de calage chronologique des couches basales des tourbières, l'entreprise est complexe et pose un certain nombre de problèmes méthodologiques très rarement abordés dans la bibliographie. Une première difficulté est d'identifier le faciès qui, sur la stratigraphie, matérialise le démarrage de la turfigenèse. Il convient ensuite de déterminer le ou les secteurs de la tourbière où la tourbe a commencé à s'accumuler.

Cet article propose une méthode d'échantillonnage des couches basales de tourbe fondée sur un travail minutieux de restitution des stratigraphies couplé à des analyses sédimentologiques et à des examens micromorphologiques. Cinq sites pilotes ont été retenus: trois tourbières bombées et deux tourbières basses.

Parmi les résultats notables de l'étude, on insistera sur l'apport de l'analyse micromorphologique. Par ailleurs, le grand nombre de datations par le radiocarbone qui ont été réalisées a permis d'apprécier la précision que l'on est en droit d'attendre d'un tel travail de calage chronologique, une information déterminante avant d'entreprendre la confrontation avec les autres données paléoenvironnementales.

Mots-clés : tourbière, démarrage de la turfigenèse, sédimentologie, micromorphologie, datation par le radiocarbone, Holocène, Massif Central, France.

1 - INTRODUCTION

In the field of palaeoenvironmental studies, it is the palaeoecological archives that are stored in peat that are exploited, essentially through palynological analysis and tephrostratigraphy. However the study of mires is also of interest when reconstructing the evolution of environments during the Late Glacial and the Holocene. Mire formation requires a shift from a negative hydrological balance to a null or positive hydrological balance, and such an event implies notable changes in the functioning of a site's watershed. These changes, be

[1] *UMR CNRS 5600, CRENAM, 6 rue Basse des Rives, 42023 Saint Etienne cedex 2.* E-mail: herve.cubizolle@univ-st-etienne.fr, pierre.bonnel@univ-st-etienne.fr, arnaud.tourman@univ-st-etienne.fr, jerome.porteret@univ-st-etienne.fr
[2] *Centre de Datation par le Radiocarbone, Université Claude Bernard, Lyon I, 40 boulevard Niels Bohr, 69 622 Villeurbanne Cedex.*

Manuscrit reçu le 23/05/2006, accepté le 23/11/2006

they geomorphologic, hydrological, biogeographical, or ecological in nature, may possibly be linked to climate change, to volcanic activity, or to Man's actions affecting vegetation and/or the circulation of water. Eliminating volcanic activity as there was no significant volcanic phenomena in the granitic eastern Massif Central during the last 15000 years, we operated on the hypothesis that the initiation of peat inception could have either a palaeo-climatic signification, or else be indicative of the impacts of human societies on the ecosystems of this region (Cubizolle *et al.,* 2003; Cubizolle, 2005). This idea has been the foundation of several studies conducted primarily by Anglo-Saxon authors during the second half of the 20th century (Pearsall, 1950; Conway, 1954; Smith, 1970; Moore, 1975, 1993; Korhola, 1995; Payette & Rochefort, 2001; Charman, 2002; Cubizolle *et al*., 2003; Cubizolle & Argant, 2006).

This demonstration is based on interdisciplinary research combining geomorphologic analysis, archaeological studies, and palaeoecological analysis for the most part (Cubizolle *et al*., 2004a; Cubizolle, 2005). The construction of a body of data is based in large part on radiocarbon dating, applied not only to palaeoecological and archaeological findings, but also used to date the initiation of peat accumulation. The approach can be summarized in the following steps:

– select, following detailed field recognizance, a sample of sites so as to be representative of the variety of mires in the given geographical area,

– reconstruct mire stratigraphy, using topographical measurement with a tacheometer, radar profiles, and coring,

– identify the basal layer, based on laboratory analysis and micromorphology expertise, and sample it for dating,

– study the temporal distribution of the radiocarbon dates obtained,

– and confront this distribution of dates with the other palaeoenvironmental data available.

Presenting all these operations and the results obtained by comparing these different methods would be too ambitious for one paper. A detailed synthesis of results was recently compiled in French for the granitic eastern Massif Central (Cubizolle, 2005). Here we focus on one of the most difficult aspects of the approach: determining the date at which peat inception initiated. This essential task raises three main problems:

– how does one determine, in the field on the stratigraphy of fresh cores, what layer is the basal layer, *i.e.* the layer corresponding to the first appearance of peat?

– How does one identify the sector(s) within a site where peat inception first began?

– How precise can we expect the radiocarbon dates to be? Are they precise enough to establish a chronology upon which the palaeoenvironmental reconstruction of the mire can be based?

Although radiocarbon dating has been used since the 1970's, answering these questions is rather difficult because the development of a standardized methodology for sampling basal layers is still at a preliminary stage. Very few authors give detailed explanation of how samples were selected (Charman, 2002). Moreover, the number of dates of basal layers in particular remains quite small (Payette & Rochefort, 2001). Also, there are very few regional synthesises of basal layer dates, even in Great Britain where palaeoecological and archaeological research has produced a great number of dates (Moore, 1975, 1993; Moore *et al.*, 1984; Tallis, 1991). In the French Massif Central no prior research specifically focused on peat inception and the dating of basal layers, althought many mires have been studied by palynologists and tephrochronologists (Etlicher *et al*., 1987; Beaulieu de *et al*., 1988; Juvigné, 1992; Juvigné *et al*., 1996).

Some other syntheses are also available for Scandinavia (Foster *et al*., 1988; Foster & Wright, 1990; Foster & Jacobson, 1990; Korhola, 1992, 1995), for Quebec and Labrador (Payette & Rochefort, 2001), for Kalimantan (Morley, 1981; Sieffermann *et al.,* 1988; Rieley *et al*., 1992) and for Indonesia (Neuzil, 1997).

2 - USEFULNESS AND LIMITATIONS OF RADIOCARBON DATING

We do not present the method of radiocarbon dating here. Extensive literature is available to which the reader can refer (Evin & Oberlin, 1998; Evin *et al*., 1999; Evin, 2002; Fontugne, 2002, 2004). Radiocarbon dating is a remarkable, widely used tool that has revolutionised archaeological and palaeoenvironmental studies. It is nonetheless a tool that should be used appropriately and with caution, requiring:

– a concise scientific question and clear understanding of how dating can help progress on the reasoning pertaining to that question, or as Gaston Bachelard put it, "*measurement should be based on thought and not thought on measurement*" (Bachelard, 1977). Obviously, this also requires sufficient understanding of how radiocarbon dating works.

– rigorous, methodical sampling: in the present case, this implies determining in the field what stratigraphic layer to sample and how much material to collect. We followed the recommendations of Olsson (1986) who states that one should avoid samples that contain material from more than one facies. This implies that one has to clearly identify limits between one facies and the next in the field. But one should also keep in mind that deposits can be disturbed, *i.e.* cinders and woody debris may not be of the same age as surrounding materials. Also foreign materials can be introduced in the sample during coring or when extracting samples from cores. One should therefore be very attentive to how equipment and sampled material is handled during sampling (wash and wipe of the corer before each coring, always use a clean knife to separate sections, wrap samples in clean plastic bags and do not reuse them, label samples carefully in the field, and store samples in a cool place). In low mires with comparatively thin peat accumulations, also check that there are no plant roots that are currently growing on the surface of the mire.

– select the most significant material in relation to sampling goals. For example peat, cinders and woody debris can be mixed together in the sample. One should establish with the carbon dating centre which material should best be dated or how many different dates should be done on the sample.

Once date has been obtained, its interpretation will be enhanced by taking into account the following points:

– like any physically based measurement, a ^{14}C dating is automatically associated with a degree of uncertainty as was demonstrated by the comparison between ^{14}C dates and tephrochronological data (Juvigné *et al.*, 1996). This is due to the difficulties in fine-tuning the settings of the apparatuses used in different steps of the dating process, to statistically random error inherent to radioactivity (Evin & Oberlin, 1998), and to the so-called "reservoir effect" by which hollow fibres accumulate fine material from other sources, this is a particular problem in basal peat facies and underlying sandy organic facies (Kilian *et al.*, 1995; Blaauw *et al.*, 2004).

– the existence of radiocarbon thresholds increases the degree of imprecision for certain periods, namely during the 15th millennium cal. yr. B.P., between 11800 cal. yr. BP and 8900 cal. yr. BP., as well as between 2750 cal. yr. BP and 2100 cal. yr. BP.

– the small differences in ^{14}C ages obtained for periods prior to 12 800 BP must be interpreted with great prudence as the curve of ^{14}C age corrections is less precise before that date, and becomes very imprecise beyond 25 000 BP.

– pollution induced by human or animal interventions, or during handling of the sample is always possible.

Moreover, irregularities in the curves used to calibrate radiocarbon dates induce variations in the probability of the occurrence of the calibrated dates. It is therefore possible to use dates that have higher probabilities of occurring than others as a working hypothesis, but one should keep in mind that this is an artefact of the dating technique and does not correspond to the true probable ages of sampled materials.

3 - DEFINITION AND SAMPLING OF MIRE BASAL LAYERS TO BE DATED

It is unanimously recognized that identifying and characterizing in the field one or more layers corresponding to the beginning of peat inception is a difficult task (Charman, 2002). To date there is no general agreement as to how to identify and describe these layers. Following a synthesis of approaches in the literature, we use five examples to show how this was done in the mires of the granitic eastern Massif Central.

3.1 - WHAT CAN BE RETAINED FROM THE DIVERSITY OF METHODOLOGICAL APPROACHES?

Charman (2002) recalls that the initiation of peat inception is a major change in pedology, shifting from a mineral soil to an organic one. This process can take place at various rates, but is generally thought to take a century or more (Payette & Rochefort, 2001). The transition from peat layers to sandy organic or silty organic facies and then to the mineral facies underlying them may appear to be quite simple at first, but is often quite subtle. Moreover peat inception is not an irreversible process, particular during its initial phases. A preliminary layer of peat may have become degraded or been overlain by mineral deposits before a new organic layer developed, that initiated the development of the studied mire (Cuikshank & Cruikshank, 1981).

Charman (2002) concludes that defining the basal layer should be based on three types of information: macroscopic observation of stratigraphy, organic matter content, and the nature of pollen and plant remains. We also include the microscopic observation of basal facies as recommended by Korhola (1995). These are the four criteria we used to study the initiation of peat inception in the granitic eastern Massif Central (Cubizolle, 2005).

Although most authors seem to agree with these general recommendations, opinions diverge if one attempts to establish more precise criteria. Regarding the description of basal layers, the extreme diversity of facies in the lower strata of mire formations makes it impossible to define standard references for basal layer properties. Sediment colour determined using the Munsell code (1992), and the degree of peat decomposition, estimated by the von Post test (Payette & Rochefort, 2001), are only two criteria that can be used in a relatively objective manner. Characterizing texture is done in the field by touching and tasting the material. Also, description would be more precise if one extracts and analyses several cores. Thus field experience plays a key role in successfully identifying and characterizing basal layers.

Further work in the laboratory focuses on the composition of the samples: granulometry is measured separately for both the mineral content and the fibre content. This can be complicated due to the presence of mineral sediment in sapric peat, and to the presence of organic matter in the underlying mineral facies. And there are several difficulties when applying the ignition loss method to evaluate mean organic matter content from dry ash. First the presence of mineral elements of various sizes unevenly distributed in basal peat layers can cause great variations in values obtained by ignition loss within a given layer. The presence of woody elements can also perturb measures made on the sediment facies, yielding much higher organic matter content than sandy sapric peat formations. Also, the success of fire-loss measurements depends on many other parameters (Chapman, 1964; Mörnsjö, 1968; Zoltaï & Johnson, 1985) including the nature of the vegetation from which the deposit originated, the degree of decomposition of the organic matter, the quality of the waters flowing into the mire, and to the input of volcanic cinders, as well as mineral and organic particles transported by winds. Hence it is illusory to establish a precise limit for organic matter content separating peat formations from other deposits. Moreover, there is no consensus on a minimum amount of organic matter content that could be used to distinguish peat from other formations: proposed values range from 25% to 70%! For these reasons, most authors rely solely on field observation of mire stratigraphy to identify the basal layer. Some authors also consider a minimum required level of organic matter content. For example Korhola (1992, 1995), chose a value of 70% in studies on the origins of Finnish mires, based on the work of Kaule (1976) and Andreyko *et al.* (1983). For our part, we see the estimation of organic matter content from the base upwards along a core sample as a means of verifying our field interpretation as to the amount of change in pedology from mineral to peat formations. In the cores we have studied, this change from sandy or silty organic facies to peat facies occurs when the amount of organic matter content is on the order of 30%.

It is difficult to do systematic analysis of pollen grains or of plant remains when studying a large number of mires. This type of analysis was conducted on about a dozen sites, whereas dating has been done for 64 sites (Cubizolle, 2005). Our palynological results were presented in a separate publication (Argant & Cubizolle, 2005; Cubizolle *et al*., 2005).

Although the analysis of micromorphology is common place for mineral soils (Fedoroff & Courty, 1992), it is much less frequently done on histosol (Castel, 1991; Lusiana *et al*., 2002). In general, soil micromorphology involves using a microscope to study soil characteristics in order to understand the origins of soils, to retrace their history and to better understand how they function (Courty & Fedoroff, 2002).

I.I.Y. Castel (1991) did one of the rare studies in which micromorphology was used to analyse the transition from peat formations to wind born deposits in dunes in the northern part of the Netherlands, and also to assess the reliability of ^{14}C dates obtained for the contact between peat formations and sand formations. Micromorphologic analysis is more commonly used to reconstruct local palaeoenvironmental settings, often in conjunction with other methods in palaeoecology (Puffe & Grosse-Brauckman, 1963; Babel, 1975; Lee 1983; Davis & Wickham, 1987; Bouma *et al*., 1988).

However there is no single way of describing thin plates. According to Bhiry (2001), the most widely-used approach to describing thin plates is based on genetic description, while recognizing that there is also a morphological approach. Nor is there any reference book that brings together examples or gives interpretations of soil characteristics, so this information must be repeatedly searched for in the literature (Bonnel, 2004, 2005). In our studies, thin plates made by the Soil Sciences Laboratory of the University of Gand in Belgium followed the protocol by Fitzpatrick (1993).

The lack of chronological precision can also be worsened by the thickness of the sediment sample taken for dating and analysis. This thickness varies considerably from one author to another, and is not always indicated. Because the material at the base of mires has sometimes been compacted considerably, 1 cm can represent tens of years in some cases, but thousands of years in others. Some researchers proposed the solution of dating by AMS. However for *Sphagnum* peat, which does not present a reservoir effect (Blaauw *et al.,* 2004), the use of AMS is not justified. In composite organic facies with substantial mineral content, using AMS requires sorting types of organic materials (wood, leaf, other organic remains…) to do separate dating on each of them. This is technically difficult and can become very costly when applied to numerous cores. And in the end, one must chose among the many dates obtained at a given level to attribute an age to the initiation of peat inception, a choice that is not necessarily obvious and can even be somewhat arbitrary.

We chose to do the dating with peat samples ranging from 1 to 3 cm thick, forming a half-cylinder 55 mm diameter, which corresponds to section of Russian hand corer. Thus the volume of our samples ranges from 10 to 25 cm^3, *i.e.* enough to obtain a conventional dating, which is faster and less expensive than AMS. AMS date was used on samples with too little organic matter for conventional dating, or for dating in relation to pollen analysis. Again conventional dating on greater volumes also reduces the risk that any minor pollution corrupts the dating of the sample, while offering sufficient precision given our analysis objectives. Using the same corer, Korhola (1992) selected samples between 6 and 10 cm thick, and took the risk of mixing materials from two neighbouring cores that presented similar stratigraphies, but we never did this.

Finally, the empirical nature of the methods used to identify the basal layer implies a certain degree of subjectivity. It is impossible to be certain that all researchers truly dated the layers that correspond to the beginning of peat inception at all of the sites they have studied. This makes comparison between studies rather delicate.

3.2 - DEVELOPMENT AND APPLICATION OF THE METHOD USED IN THE GRANITIC EASTERN MASSIF CENTRAL MIRES

Here three mires from the eastern part of the Massif Central are presented in order to illustrate (fig.1) methodological discussion.

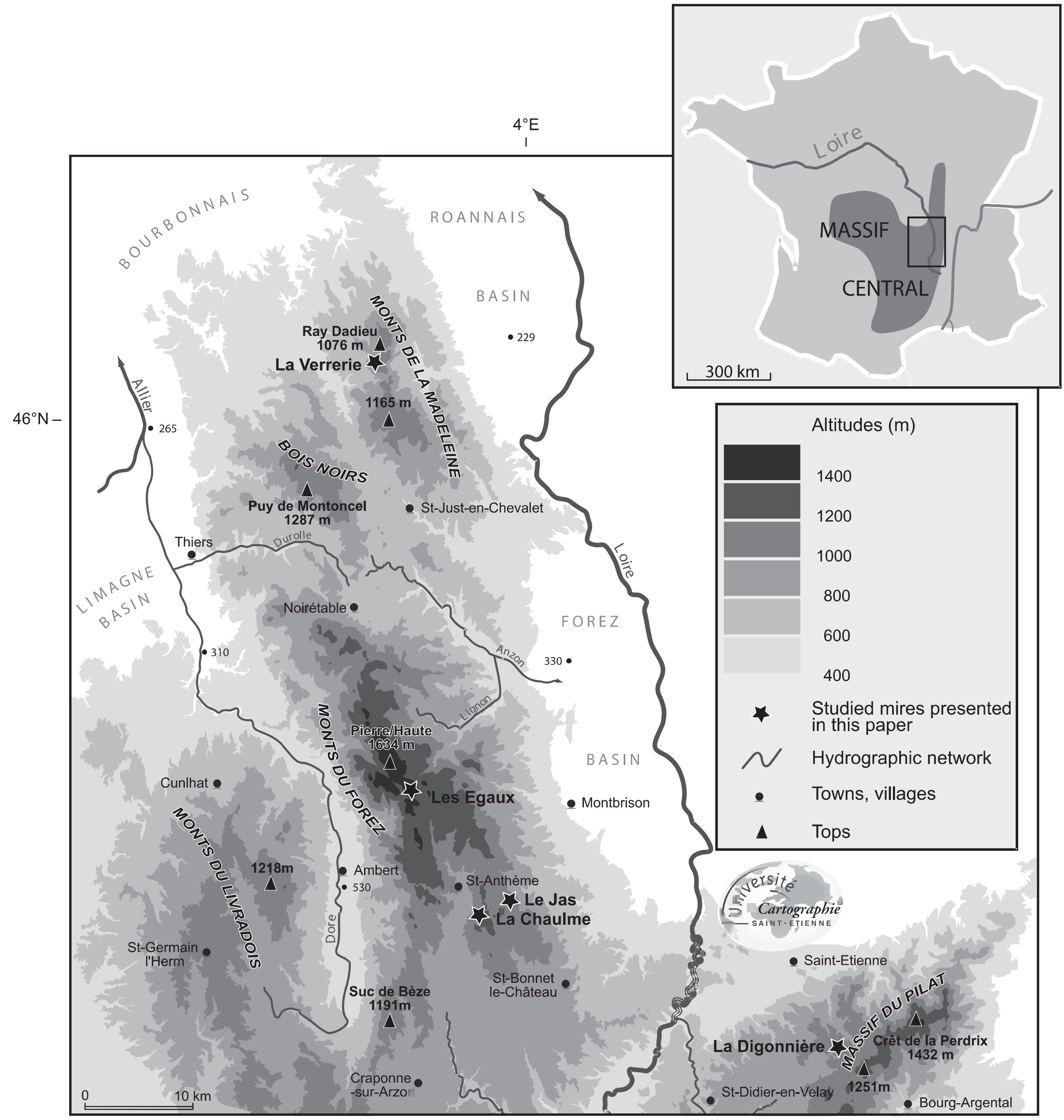

Fig. 1: **Location of mires studied in this paper**.
Fig. 1: *Localisation des tourbières étudiées dans le cadre de cet article.*

Dating the initation of peat inception in the Verrerie bog (Monts de la Madeleine, alt. 1115 m) and at Egaux (Monts du Forez, alt. 1405 m)

At the Verrerie bog, three cores separated by 15 cm were extracted from the basal layers in the portion of the mire where the peat formation was thickest: one core was for pollen analysis and ^{14}C dating (C-7019bis1), one for ignition loss (C-7019 bis 2), and one for micromorphology analysis (C-7019 bis 3). The stratigraphy was remarkably constant among the three cores.

Macroscopic description indicates a first change of facies around –435 cm, passing progressively from mesic peat to sapric peat (fig. 2). The latter, becoming sandy at its base, overlies of sand organic layer 8 cm thick constituted primarily by sandy to gravelly material. The bottom of the core made contact with sandy-loamy colluvium containing wood cinders. The later two discontinuities are very distinct. In core C-7109 bis 3 we note within the colluvial formation an oblique contact between an upper gray-brown facies (10YR 3/1) and a lighter coloured lower facies (10YR 4/2) (fig. 3). The evolution of water content and organic matter content in core C-7109 bis 2 clearly confirms the key position of the sandy organic facies in the

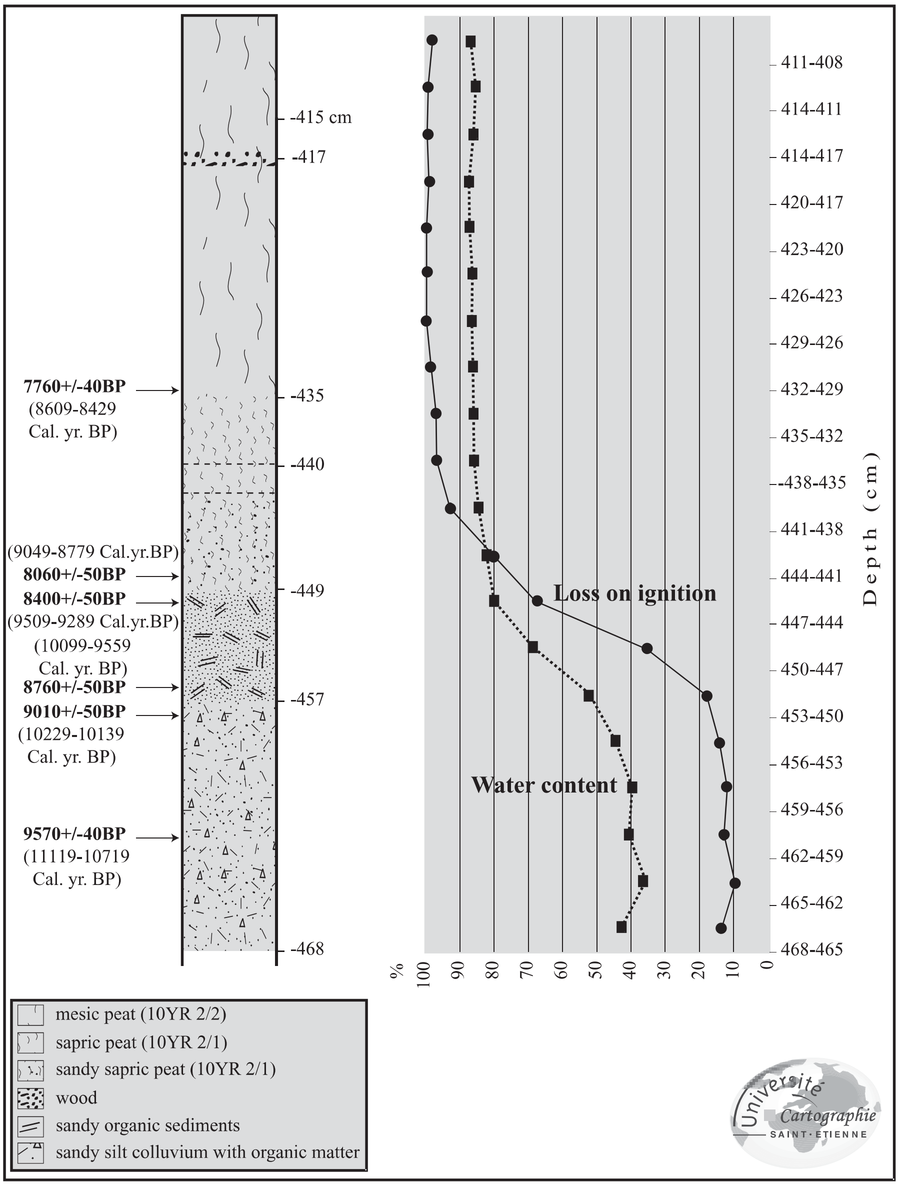

Fig. 2: **Stratigraphy, loss on ignition, radiocarbon dating of cores C-7109 bis 1 and 2, peat bog of la Verrerie, Monts de la Madeleine, alt. 1015 m.**
Fig. 2: Stratigraphie, estimation des pertes au feu et datations par le radiocarbone des carottes C-7109 bis 1 et bis 2 extraites de la tourbière de la Verrerie (Monts de la Madeleine, alt. 1015 m).

initiation of peat inception (fig. 2), because in this formation organic matter content jumps suddenly from 12% to 32% (fig. 2). No significant difference was observed between the 2 colluvial microfacies (fig. 2).

Thin plate analysis of core C-7019 bis 3 confirms the oblique contact within the colluvial formation. It separates a sandy-loamy low layer comprising microfacies 1, 2, and 3 from a more gravelly overlying formation corresponding to microfacies 4 and 5 (fig. 3). A similar contact, but not visible by the eye, was noted between the colluvial formation – microfacies 5 - and the sandy organic formation - microfacies 6 - that becomes progressively richer in organic matter content towards its top - microfacies 7 to 11 - (fig. 3). In contrast, the transition to the sapric peat formation is close to horizontal at its lower limit, situated in the field at - 449 cm, and was placed at the contact between microfacies 10 and 11 (fig. 3). The sandy organic formation was found to be highly mineral in places, microfacies 8 showing greater resemblance with the colluvium in microfacies 5 than with microfacies 6, 7, and 9.

The micro-stratigraphic diagram shows the specificity of the colluvial microfacies 3 to 5: abundance of wood cinders, scats, phytoliths, scletorium and plant remains (fig. 3). The sandy organic facies also contains many soil fauna scats, but is distinguished from the colluvial facies by a much lower percentage of inorganic content, and the presence of woody debris. At the top of the column in the sapric peat formation, wood is much more abundant whereas the inorganic fraction is substantially reduced and scats are absent. Lastly, worn rounded mineral particles (wearing due to transport) were observed at MPol, becoming more numerous we worked upwards through the stratigraphy, from the colluvium to the sapric peat.

Fig. 3: **Stratigraphy and micromorphological diagram of core C-7109 bis 3, peat bog of la Verrerie, Monts de la Madeleine, alt. 1015 m.**
Fig. 3: *Stratigraphie et diagramme micromorphologique de la carotte C-7109 bis 3 extraite de la tourbière de la Verrerie (Monts de la Madeleine, alt. 1015 m).*

The results of the micromorphologic analysis agreed well with the macroscopic description, except for certain contacts that seemed abrupt to the naked eye were found to be more progressive, particularly the transition from the colluvium to the sandy organic facies. The transitional nature of this contact is further explained by the presence of scats, indicating an environment that was not water logged, and therefore no peat formation could have occurred, whereas the absence of scats in overlying formations coincides with a rapid increase in organic matter content (> 65% at the contact with the sapric peat formation) (fig. 3). Note also that the presence of scats signifies that bioturbation occurred in these formations, which implies that trying to obtain a precise chronology for these formations using AMS makes no sense. Also, peat inception clearly began with microfacies 11, around –449 cm (fig. 3).

Based on these observations, dating was done on six samples taken from core C-7109 bis 1 (fig. 2, tab. 1) to date zones of contact. Thus, although the microfacies in core C-7109 bis 1 correspond well to those of the core examined by microscope, samples –455 cm / –456 cm and, to a lesser degree, –463 cm / –464 cm are composed of a mixture of 2 adjacent microfacies. This illustrates the inconvenience of working on more than one core.

The results in table 1 show good coherency, without any inversion in the chronology. In calibrated ages, the intervals of time proposed range from 540 years to 90 years, this variability being due to ^{14}C thresholds. An erroneous evaluation of the level at which peat inception began, *i.e.* placed too high or to low on the core, would give older or more recent ages by about 400 to 450 years. Peat inception began around 8060 +/– 50 BP, *i.e.* 9049-8779 cal. yr. BP. (tab. 1). The top of the sandy organic facies was dated to 8400 +/– 50 BP, *i.e.* 9509-9289 cal. yr. BP., so we can estimate that it took less than 5 centuries for pedological conditions to change and for a histosol to develop.

The example of the Egaux mire is not presented in detail as the conclusions are very similar to the case described above. But the case does present a particularity, there were no major difficulties in describing the cores as the contacts between facies are quite evident, but microscopic analysis showed major perturbations in the succession of microfacies (fig. 4). The sandy organic facies is most affected, but the stratigraphy is also perturbed in the sapric peat formation (fig. 4).

La Verrerie, Monts de la Madeleine, alt. 1015 m

sample and laboratory number	datation	$\delta^{13}C$ ‰ *	material	depth (cm)	Years ^{14}C BP	Cal. yr B.P.
VER-71009/bis1-1 Beta-193714	AMS	-27,4	basal layer of mesic peat *	434/435	7760 +/- 40 BP	8609-8429
VER-71009/bis1-2 Beta-189918	**AMS**	**-27,9**	**basal layer of sapric peat**	**447/448**	**8060 +/- 50 BP**	**9049-8779**
VER-71009/bis1-3 Beta-189917	AMS	-28,1	top of sandy/silty organic sediments	450/451	8400 +/- 50 BP	9509-9289
VER-71009/bis1-4 Beta-189916	AMS	-28,2	basal layer of sandy/silty organic sediments	455/456	8760 +/- 50 BP	10099-9559
VER-71009/bis1-5 Beta-189915	AMS	-28	top of organic colluvium	458/459	9010 +/- 50 BP	10229-10139
VER-71009/bis1-6 Beta-189914	AMS	-28,4	organic colluvium	463/464	9570 +/- 40 BP	11119-10719
Les Egaux, Monts du Forez, alt. 1405 m						
Egaux 8016-1GrN-27577	radiometric	-27,34	basal layer of mesic peat	342/344	5700 +/- 60 BP	6658-6316
Egaux 8016-2LY-2062 (OXA)	**AMS**	**-28,5**	**basal layer of sapric peat**	**359/361**	**6185 +/- 50 BP**	**7244-6913**
Egaux 8016-3LY-11649	radiometric	-27,58	organic colluvium	388,5/392	6640 +/- 60 BP	7509-7427
La Chaulme, Monts du Forez, alt. 1130 m						
LACH 52018 LY-12234	radiometric	-29,64	**basal layer of sapric peat**	207/209,5	11350 +/- 110 BP	13479-13140
LACH 52018LY-12235	**radiometric**	**-29,56**	**top of sandy/silty organic sediments**	**211/213,5**	**10215 +/- 105 BP**	**12587-11341**
LACH 52018 LY-12236	radiometric	-29,41	basal layer of sandy/silty organic sediments	213,5/215	10655 +/-125 BP	12945-12340
LACH 52018 LY-2506 (Poz)	AMS	-28,66	basal layer of organic colluvium	217/219	10760 +/- 75 BP	12956-12655
LACH 52018 LY-12015	radiometric	-29,28	top of little organic colluvium	223/225	10680 +/- 105 BP	12928-12372
* measured on CO_2 after combustion * undifferentiated peat *(Carex, Sphagnum, Eriophorum)*						

Tab. 1: **Radiocarbon dates concerning the basal layers of the peat bog of la Verrerie (C-7109 bis-1, Monts de la Madeleine, alt. 1015 m), les Egaux peat bog (C-8016, Monts du Forez, alt. 1405 m), la Chaulme fen (C-52018, Monts du Forez, alt. 1130 m). The oldest radiocarbon dates of peat inception are in bold print.**

Tab. 1 : Datations par le radiocarbone obtenues à la base des tourbières bombées de la Verrerie (C-7109-bis-1, Monts de la Madeleine, alt. 1015 m), des Egaux (C-8016, Monts du Forez, alt. 1405 m) et de la Chaulme (C-52018, Monts du Forez, alt. 1130 m). Les dates retenues comme marquant le démarrage de la turfigenèse sont en gras.

In this core, the limits of microfacies between –350 cm and –365 cm are very difficult to define. In contrast a wedged-shaped form is clearly visible below –355 cm, perforating microfacies 12 to 7 (fig. 4). Thus the passage between the sandy organic formation and the sapric peat was completely disturbed, whereas the contact between the sandy organic formation and the underlying colluvium were sub horizontal and quite rapid.

In the microstratigraphic diagram (fig. 4), the colluvium with low organic content is clearly distinguished, with only a few fragments of wood in the sandy-loamy deposit. However the other facies were not well differentiated because the structural perturbations made it difficult to distinguish between formations or obtain relevant samples. The diagram shows a sudden drop starting from microfacies 8 in the percentage of both organic and inorganic material. Like at the Verrerie site, there were wood cinders in the colluvial formations.

The dates obtained indicate that peat started to accumulate around 6185 +/– 50 BP *i.e.* 7244-6913 cal. yr. BP., and that about 439 year went by between the last colluvial deposits and the formation of the first layer of peat.

The microscopic study of the basal layers of the Egaux mire show that substantial perturbations may have affected the different facies that form the zone of contact between peat and the underlying mineral deposits. The naked eye generally perceives these contacts as a transition from one facies to another. This has three consequences regarding the choice of the samples to be dated:

– because of the perturbations observed at the contact between peat and sandy organic facies, it is not possible to obtain precise dates,

– for these same reasons, it is not pertinent to use organic matter to select levels to be sampled either,

– an approximate evaluation of the contact between formations would displace the sample 2 or 3 cm above or below the exact limit having not affect on the precision of the dating.

The problem dating the beginning of peat inception at Chaulme fen (Monts du Forez, alt. 1130 m)

The micromorphologic study of the Chaulme fen core showed perfect concordance with field and laboratory observations (fig. 5). The perturbations in the micro-stratigraphy were very minor, and microfacies

Fig. 4: **Stratigraphy and micromorphological diagram of basal layers cored (C-8016) in the peat bog of les Egaux (Monts du Forez, alt. 1405 m).**
Fig. 4: Stratigraphie et diagramme micromorphologique de la carotteC-8016 prélevée dans la tourbière bombée des Egaux (Monts du Forez, alt. 1405 m).

appeared as a succession of distinct subhorizontal layers. However we noted very irregular limits between microfacies 2 and 3, corresponding to the contact between colluvial and sandy-organic formations (fig. 5). We also found a great deal of wood in microfacies 9, 10, 11 and 12, which correspond to the upper part of the sapric peat formation for microfacies 9, and to mesic peat for the other three.

The choice of samples to be dated was simple. However ^{14}C results were surprising (tab. 1 and fig. 5), showing inversions in the succession of dates: the date obtained at the base of the peat formations at –207/ –209.5 cm is the oldest and the date just below it, at the summit of the sandy organic facies, is more recent by 1135 years BP. Below these levels there are other inversions but the differences are quite small.

Obviously one must take into account the imprecision of ^{14}C calibration for this period of transition between the Late Glacial and the Holocene. However palynological results for these two facies (sandy organic and peat) indicate a cold dry climate that seemingly corresponds to the recent Dryas (J. Argant, pers. comm). But dating the peat at 11350 BP corresponds to the Alleröd, at the beginning of the phase of *Betula* and *Pinus* (Beaulieu *et al.*, 1988). We can therefore suspect that the peat formation has been polluted by older organic matter from surrounding slopes or the watershed upstream, as the fen is located in a small alluvial plain. In consequence, we chose the date of the summit of the sandy organic facies to situate the beginning of peat inception for this fen, *i.e.* 10215 +/– 105 BP (12587-11341 cal. yr. BP.).

This example shows that the dates obtained for some sites can be relatively imprecise 200 to 400 years in this case often it is impossible to be understand what caused the ^{14}C dates to be overestimated.

4 - IDENTIFYING THE OLDEST PARTS OF MIRES

Once the stratigraphic layer to be dated has been identified, one must determine where the oldest part of the mire is, the part where the peat started to form first, and that we want to date to determine when peat inception began.

The most reliable way to ensure dating the sector(s) where the earliest peat inception began is to increase the number of cores and dates obtained at each mire. However this in not financially feasible when studying more than just a few mires. Indeed, the few studies on an international scale that exploit a large number of

Fig. 5: **Stratigraphy and micromorphological diagram of basal layers cored in the fen of la Chaulme (Monts du Forez, alt. 1130 m).**
Fig. 5: *Stratigraphie et diagramme micromorphologique de la carotte prélevée dans la tourbière basse de la Chaulme (Monts du Forez, alt. 1130 m).*

sites are often based on data collected over several decades (Zoltai, 1995), because of the effort and expense involved.

Here the idea was to optimize sampling effort based on a model of mire development. We tested this model at 4 pilot sites.

4.1 - THE MODEL OF MOORE AND BELLAMY (1974)

Moore and Bellamy (1974) proposed that we distinguish 3 types of *mire systems* each of which correspond to a model of the initiation and expansion of peat formations, processes which are in turn conditioned by the climatic, geomorphologic and hydrological contexts of mires.

The primary mires – "*Primary peats and hence primary mire systems*" are mires that originated due to both a favourable geomorphic setting and favourable macroclimatic conditions. They are situated in the lowest, most depressed parts of depressions and valleys, in sectors where hydromorphy is likely to occur, *i.e.* positive or null hydrological balances. That is why this type of mire can even be found in tropical regions with long dry seasons.

Secondary mires – "*Secondary peats and hence secondary mire system*" develop under relatively humid climates, which limits their geographical distribution somewhat. In this case, peat formation occurs outside the most depressed sites, thereby increasing the surface of water retention. However these mires do not extend beyond the valley or depression they are located in, and depend on the water table level for the development.

Tertiary mires –"*Tertiary peats and hence tertiary mire systems*" are only found at mid latitudes, not high latitudes. Moore and Bellamy (1974) describe 11 categories for which the common characteristic is that the mires extend beyond the limits of the topographic depression they first appeared in. Under adequate climate conditions, peat accumulations grow, eventually reaching a stage where the mire is no longer fully dependant on the local water table level. These mires are therefore ombrotrophic and in most cases raised bogs.

It appears that the three systems described above can be seen as corresponding to successive stages in the development of mires under ideal climatic conditions, although this idea is not explicitly stated by the authors. Ombrogenous mires or bogs are the only case in which peat inception can occur both in depressions and in comparatively higher positions at the same time.

Thus, according to this model, mires originate in one or more low spots within a depressed topography, and then, depending on climate conditions, they are either restricted to their initial extent, or can undergo 1 or 2 successive stages of expansion. We can therefore conclude that in order to locate the oldest layers of a mire, we must search for the lowest points underlying the peat accumulation. Reconstructing palaeotopography and mire stratigraphy are essential steps in locating these low points, as what may appear today to be a single large mire may in fact result from the expansion and connection of what was initially more than one mire, spreading out from different points, and possibly originating at different periods. Local and site specific climate and hydro-geomorphological conditions can explain why the initiation of peat inception was not concomitant between A and B, and how differing growth rates lead to a thicker accumulation today in the younger of the two initial mires.

This model was tested on four sites with differing characteristics.

4.2 - THE DISTRIBUTION OF RADIOCARBON AGES IN THE BASAL LAYERS OF THE VERRERIE BOGS (Monts de la Madeleine, alt. 1115 m)

A total of 3.7 km of topographic profiles was collected, and a total of 25 radiocarbon dates were obtained (tab. 2). The thickest part of the peat accumulation spans ESE to WNW in a zone corresponding to the talweg of the small palaeo-valley (fig. 6A). Analysis of the dates showed that the oldest age obtained for the basal layer is 8060 +/– 50 BP. This date is obtained in the deepest part of the mire, under the zone of schlenken (fig. 6B and tab. 2) and was confirmed by pollen analysis of the core (Argant & Cubizolle, 2005). However, we obtained a date of 7660 +/– 60 BP at the same depth, only about 10 m to the west of the first core. More generally, the correlation between the ages obtained for the cores and the depth at which samples were taken is not very convincing (fig. 7). Note however that this situation is very similar to the one described by Korhola for finnish bogs (1992, fig. 48, p. 79).

Thus in the Verrerie bogs, samples made at depths of around 450 cm yield very different ages, from 8060 +/– 50 BP to 6490 +/–45 BP, *i.e.* a difference of 1570 years BP. Moreover very similar ages, 7130 +/– 75 BP and 7245 +/– 65 BP were obtained at depths of –343/–341 cm and –259/–257 cm respectively. Also, like in the Chaulme mire example above, two cores gave radiocarbon ages at the base of the sapric peat formation that were 200 to 400 year older that ages obtained for the underlying sandy organic facies, but no additional evidence was found to provide a satisfactory explanation of these inversions.

4.3 - THE DISTRIBUTION OF RADIOCARBON AGES IN THE BASAL LAYERS OF THE EGAUX BOG (Monts du Forez, alt. 1405 m)

Previously we described the particularly disturbed basal layers of the Egaux bog. Here we present the chronology of this perturbed formation initially observed via miocromorphologic analysis.

Similar to the Verrerie mire, the initiation of peat inception was based on the age obtained for the base of the sapric peat formation, except for core 1071, where

Fig. 6: **The raised bog of la Verrerie in les Monts de la Madeleine, alt. 1015 m**: **A, distribution of vegetation and depth of peat ; B, distribution of radiocarbon dates obtained from the basal layers of peat accumulation.**
Fig. 6: *La tourbière bombée de la Verrerie dans les Monts de la Madeleine, alt. 1015 m*: *A, répartition des principales formations végétales et courbes d'égale épaisseur de tourbe ; B, répartition des dates radiocarbone obtenues à la base de la tourbière.*

sample and laboratory number	datation	δ ^{13}C ‰ *	material	depth (cm)	Years ^{14}C BP	Cal. yr B.P.
VER-70035/2 LY-11966	**radiometric**	**-28,55**	**basal layer of sapric peat ***	**220/218**	**4160 +/- 45 BP**	**4832-4531**
VER-70036/1 LY-11967	**radiometric**	**-28,31**	**basal layer of sapric peat**	**383/380**	**6240 +/- 50 BP**	**7265-7003**
VER-70065/3 LY-12803	**radiometric**	**-28,56**	**basal layer of sapric peat**	**423/419**	**6115 +/- 60 BP**	**7178-6764**
VER-70065/2 LY-12802	radiometric	-28,87	top of sandy/silty organic sediments	425/423	6670 +/- 80 BP	7669-7426
VER-70065/1 LY-11968	radiometric	-28,76	basal layer of sandy/silty organic sediments	427/425	7225 +/- 80 BP	8177-7870
VER-70002/1 LY-11970	**radiometric**	**-28,84**	**basal layer of sapric peat**	**317/315**	**5615 +/- 55 BP**	**6495-6293**
VER-70067/1 LY-11969	**radiometric**	**28,97**	**basal layer of sapric peat**	**136/134**	**3820 +/- 45 BP**	**4405-4088**
VER-71026/1 GrN-27589	**radiometric**	**n.c.**	**basal layer of sapric peat**	**300/297**	**6890 +/- 60 BP**	**7836-7590**
VER-71003/2 LY-11972	**radiometric**	**-27,93**	**basal layer of sapric peat**	**381/379**	**6895 +/- 80 BP**	**7924-7587**
VER-71003/1 LY-11971	radiometric	-27,93	basal layer of sandy/silty organic sediments	383/381	6400 +/- 95 BP	7475-7034
VER-71005/1 LY-11973	radiometric	-28,72	basal layer of sandy/silty organic sediments	255/253	5285 +/- 75 BP	6277-5911
VER-71006/1 LY-11974	**radiometric**	**-28,75**	**basal layer of sapric peat**	**157/155**	**3870 +/- 70 BP**	**4505-4088**
VER-71008/2 LY-2309 (OxA)	**radiometric**	**n.c. ***	**basal layer of sapric peat**	**445/443**	**6490 +/- 45 BP**	**7560-7315**
VER-71009/bis6 Beta-193714	AMS	-27,4	basal layer of mesic peat	434/435	7760 +/- 40 BP	8609-8429
VER-71009/bis5 Beta-189918	**AMS**	**-27,9**	**basal layer of sapric peat**	**447/448**	**8060 +/- 50 BP**	**9049-8779**
VER-71009/bis4 Beta-189917	AMS	-28,1	top of sandy/silty organic sediments	450/451	8400 +/- 50 BP	9509-9289
VER-71009/bis3 Beta-189916	AMS	-28,2	basal layer of sandy/silty organic sediments	455/456	8760 +/- 50 BP	10099-9559
VER-71009/bis2 Beta-189915	AMS	-28	top of organic colluvium	458/459	9010 +/- 50 BP	10229-10139
VER-71009/bis1 Beta-189914	AMS	-28,4	organic colluvium	463/464	9570 +/- 40 BP	11119-10719
VER-71009/2 LY-11976	**radiometric**	**-29,15**	**basal layer of sapric peat**	**448/450**	**7760 +/- 70 BP**	**8589-8350**
VER-710012/1 LY-11977	**radiometric**	**-28,28**	**basal layer of sapric peat**	**341/343**	**7130 +/- 75 BP**	**8108-7764**
VER-71013/1 LY-11978	**radiometric**	**-28,34**	**basal layer of sapric peat**	**259/257**	**7245 +/- 65 BP**	**8176-7883**
VER-palyno1 LY-2239 (OxA)	AMS	n.c.	organic colluvium	418/416	7180 +/- 60 BP	8149-7868
VER-palyno2 LY-11571	radiometric	-28,34	sandy/silty organic sediments	404/402	5520 +/- 105 BP	6498-6000
VER-palyno3 LY-11930	radiometric	-26,73	mesic peat	374/372	5070 +/- 75 BP	5985-5617
* measured on CO_2 after combustion						
* undifferentiated peat *(Carex, Sphagnum, Eriophorum)*						

Tab. 2: Radiocarbon dates obtained from the basal layers of the raised bog of la Verrerie in les Monts de la Madeleine, alt. 1015 m. The oldest radiocarbon dates of peat inception are in bold print.
Tab. 2 : Datations radiocarbone obtenues dans les couches basales de la tourbière bombée de la Verrerie (Monts de la Madeleine, alt. 1015m). Les dates retenues comme marquant le démarrage de la turfigenèse sont en gras.

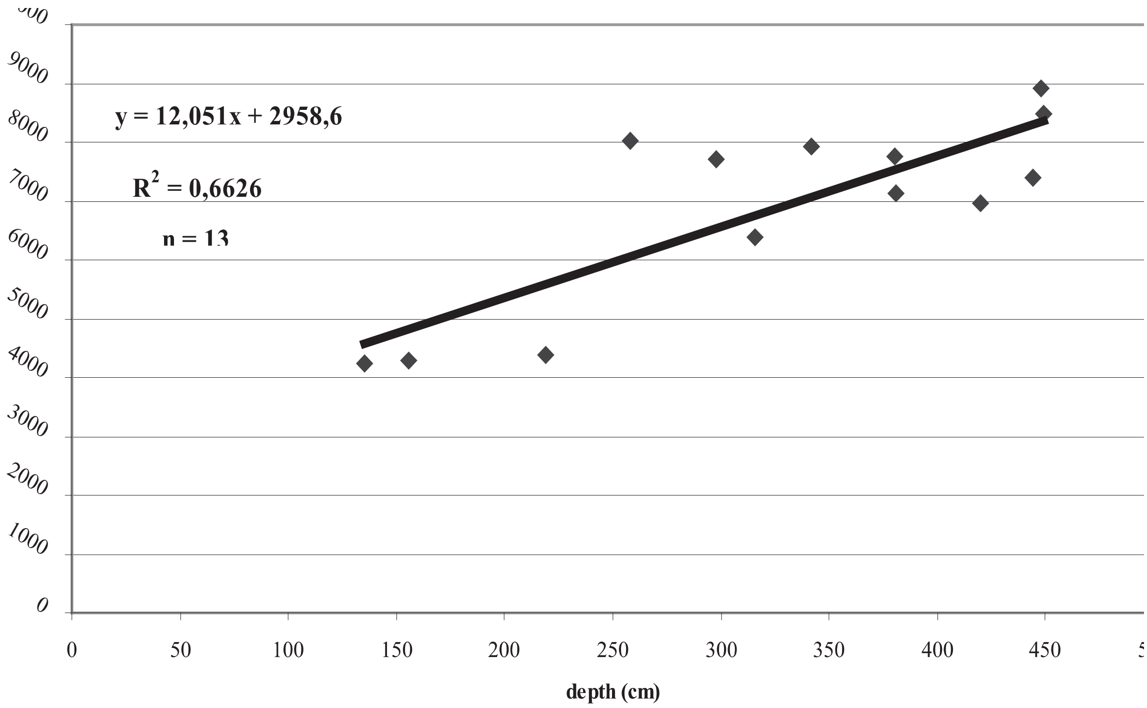

Fig. 7: **The raised bog of la Verrerie in les Monts de la Madeleine, alt. 1015 m**: **relationship between radiocarbon ages BP obtain in the basal layers and the depth of dated samples.**
Fig. 7: *La tourbière bombée de la Verrerie, Monts de la Madeleine, alt. 1015 m*: *relation entre les âges radiocarbone BP obtenus dans les couches basales et la profondeur des échantillons datés.*

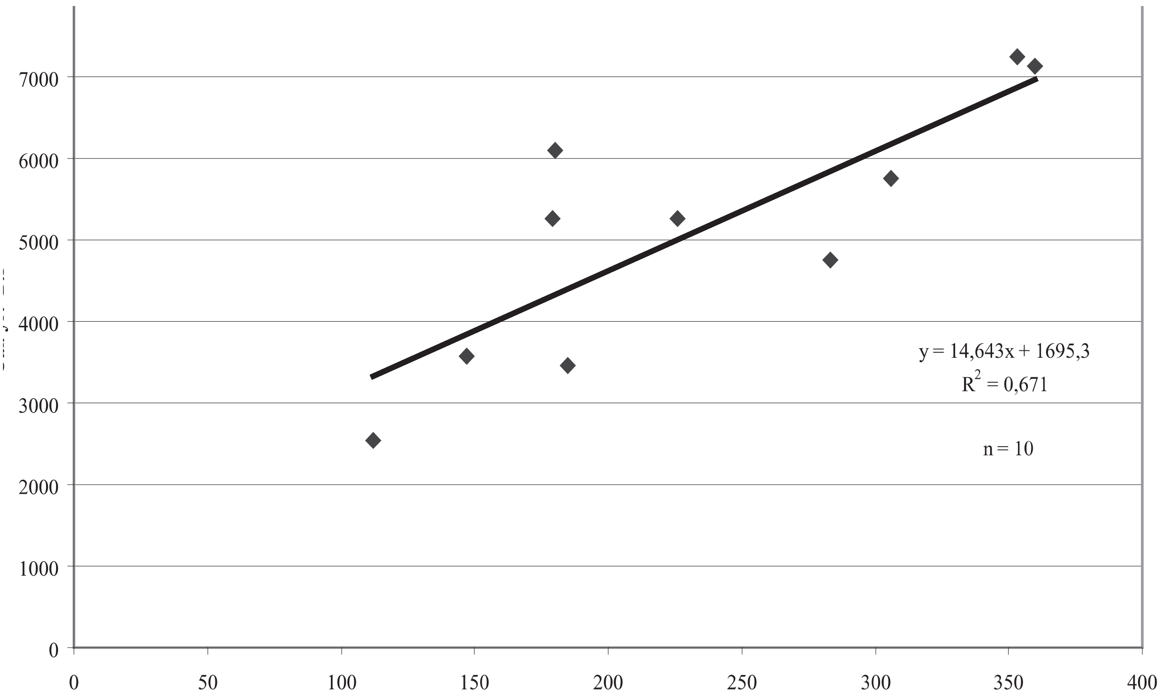

Fig. 8: **The raised bog of les Egaux in les Monts du Forez, alt. 1405 m**: **relationship between radiocarbon ages BP obtained from the basal layers and the depth of dated samples.**
Fig. 8: *La tourbière bombée des Egaux, Monts du Forez, alt. 1405 m*: *relation entre les âges radiocarbone BP obtenus dans les couches basales et la profondeur des échantillons datés.*

sample and laboratory number	datation	$\delta^{13}C$ ‰ *	material	depth (cm)	Years ^{14}C BP	Cal. yr B.P.
Egaux 8016 LY-11649	radiometric	-27,58	organic colluvium	388,5/392	6640 +/- 60 BP	7509-7427
Egaux 8014 LY-12685	**radiometric**	**-27,81**	**basal layer of sapric peat ***	**284/282**	**4250 +/- 50 BP**	**4867-4648**
Egaux 8012 LY-2271(Poz)	**AMS**	**nc**	**basal layer of sapric peat**	**148/145**	**3340 +/- 40 BP**	**3686-3469**
Egaux 1071 LY-12276	radiometric	-27,02	top of sapric peat	212/215	3665 +/- 40 BP	4141-3871
Egaux 1071 LY-12276	**radiometric**	**-27,49**	**top of sandy/silty organic sediments**	**225/228**	**4245 +/- 50 BP**	**4867-4648**
Egaux 1018 LY-11992	**radiometric**	**-28,93**	**basal layer of sapric peat**	**178/181**	**4605 +/- 55 BP**	**5466-5053**
Egaux 3125 LY-11996	**radiometric**	**-27,45**	**top of sandy/silty organic sediments**	**184/187**	**3225 +/- 40 BP**	**3548-3363**
Egaux 3080 LY-12275	**radiometric**	**-28,89**	**basal layer of sapric peat**	**179/181**	**5300 +/- 65 BP**	**6274-5923**
Egaux 3080 LY-11994	radiometric	-28,48	organic colluvium	190/192	6175 +/- 100 BP	7306-8708
Egaux 8023 LY-11995	**radiometric**	**-27,86**	**basal layer of sapric peat**	**113/111**	**2470 +/- 35 BP**	**2726-2358**
Egaux- 8019 LY-11997	**radiometric**	**-28,9**	**basal layer of sapric peat**	**307/305**	**5005 +/- 90 BP**	**5925-5590**
Egaux-8000 LY-9685	**radiometric**	**-28,05**	**basal layer of sapric peat**	**354/351**	**6685 +/- 50 BP**	**7655-7434**
Egaux 8016 GrN-27577	radiometric	-27,34	basal layer of mesic peat	342/344	5700 +/- 60 BP	6658-6316
Egaux 8016 LY-2062(OXA)	**AMS**	**-28,5**	**basal layer of sapric peat**	**359/361**	**6185 +/- 50 BP**	**7244-6913**

* measured on CO_2 after combustion

* undifferentiated peat *(Carex, Sphagnum, Eriophorum)*

Tab. 3: **Radiocarbon dates obtained from the basal layers of the raised bog of les Egaux in les Monts du Forez, alt. 1405 m. The oldest radiocarbon dates of peat inception are in bold print.**
Tab. 3 : Datations par le radiocarbone obtenues à la base de la tourbière bombée des Egaux dans les Monts du Forez (alt. 1405 m). Les dates retenues comme marquant le démarrage de la turfigenèse sont en gras.

it was situated between two dates corresponding respectively to the end of the deposit of the underlying sandy organic formation, and the end of the accumulation of sapric peat in the overlying formation (tab. 3). The oldest age was indeed found in the part of the mire where the peat is thickest, in the schlenken zone. However, the sample taken from a slightly higher level was dated to 6685 +/– 50 BP in core 8000 compared to the date at 6185 +/– 50 BP in core 8016. The graph in figure 8 indicates that the link between depth and age is also inconsistent at this site.

The dates obtained for cores 8000 and 8016 agree well with conclusions from pollen analysis done by Janssen and van Straten (1982). Although the stratigraphic location of the samples studied is not clearly indicated by these Dutch authors, the depth they give of 3.4 m necessarily situates the sample in the same part of the mire as core 8016. At the base of the column, the palynological diagram shows pollens typical of the transition between lower Atlantic and upper Atlantic, characterised by an increase of *Quercus*, followed shortly thereafter by *Ulmus* and *Tilia*, and final *Fraxinus* a bit later.

4.4 - THE DISTRIBUTION OF RADIOCARBON AGES IN THE BASAL LAYERS OF THE DIGONNIÈRE BOG (Massif du Pilat, alt. 1055 m)

Ten dates of the basal layer were made for the Digonnière bog in the Pilat mountains (tab. 4) of which eight are from the base of the mound, and two from the base of the bog encroaching on the bog to its north, and north northwest (fig. 9).

In the graph in figure 10 showing the relationship between these radiocarbon ages and sample depth, we can see that the dates of the bog's basal layer show less dispersion than in the cases of the Verrerie and Egaux bogs. However a date of 9140 +/– 70 BP, i.e. 10490-10188 cal. yr. BP, was obtained for the basal layer of the lagg to SSW of the bog (fig. 9). This is the oldest date obtained at this site, even thought the sample dated was only at a depth of –95/–92 cm. The sample was clearly from a peat formation, as this fine peat contains 85.7% organic matter. However the difference with the date of 9000 +/– 40 BP, i.e. 10220-9909 cal. yr. BP, obtained for the base of the bog is quite small, as the

sample and laboratory number	datation	$\delta^{13}C$ ‰ *	material	depth (cm)	Years ^{14}C BP	Cal. yr B.P.
Digo-C LY-9593	**radiometric**	**-28,69**	**basal layer of sapric peat ***	**222/219**	**8245 +/- 85 BP**	**9469-9011**
Digo-17014 bis LY-11686	**radiometric**	**-28,59**	**basal layer of sapric peat**	**58/56**	**5970 +/- 75 BP**	**6989-6642**
Digo-17026 LY-11831	**radiometric**	**-29,35**	**basal layer of sapric peat**	**219/216**	**7975 +/- 80 BP**	**9027-8593**
Digo-17035 LY-11832	**radiometric**	**-25 estimated**	**basal layer of sapric peat**	**201/199**	**8450 +/- 65 BP**	**9539-9304**
Digo-17043 LY-11833	**radiometric**	**-28,35**	**basal layer of mesic peat**	**154/151**	**8015 +/- 90 BP**	**9267-8597**
Digo-21042 LY-11685	**radiometric**	**-28,07**	**basal layer of sapric peat**	**84/82**	**5460 +/- 50 BP**	**6377-6120**
Digo-21035 LY-11684	**radiometric**	**-27,58**	**basal layer of sapric peat**	**100/97**	**7300+/- 80 BP**	**8325-7957**
Digo-21030 LY-11687	**radiometric**	**-28,59**	**basal layer of sapric peat**	**170/168**	**8255 +/- 80 BP**	**9469-9014**
Digo-5 LY-10859	**radiometric**	**-28,85**	**basal layer of sapric peat**	**204/202,5**	**8270 +/- 85 BP**	**9473-9014**
Digo-20005-B LY-2015(OxA)	**radiometric**	**-29,53**	**top of sapric peat**	**248/246**	**9000 +/- 40 BP**	**10220-9909**
Digo-21016 LY-11682	radiometric	-28,58	top of sandy/silty organic sediments	203/201	8630 +/- 90 BP	9904-9474
Digo-21022 LY-11683	radiometric	-29,91	basal layer of sapric peat	95/92	9140 +/- 70 BP	10490-10188
* measured on CO_2 after combustion * undifferentiated peat *(Carex, Sphagnum, Eriophorum)*						

Tab. 4: Radiocarbon dates obtained from the basal layers of the raised bog of la Digonnière in le Massif du Pilat, alt. 1055 m. The oldest radiocarbon dates of peat inception are in bold print.
Tab. 4 : Datations par le radiocarbone obtenues à la base de la tourbière bombée de la Digonnière dans le Massif du Pilat (alt. 1055 m). Les dates retenues comme marquant le démarrage de la turfigenèse sont en gras.

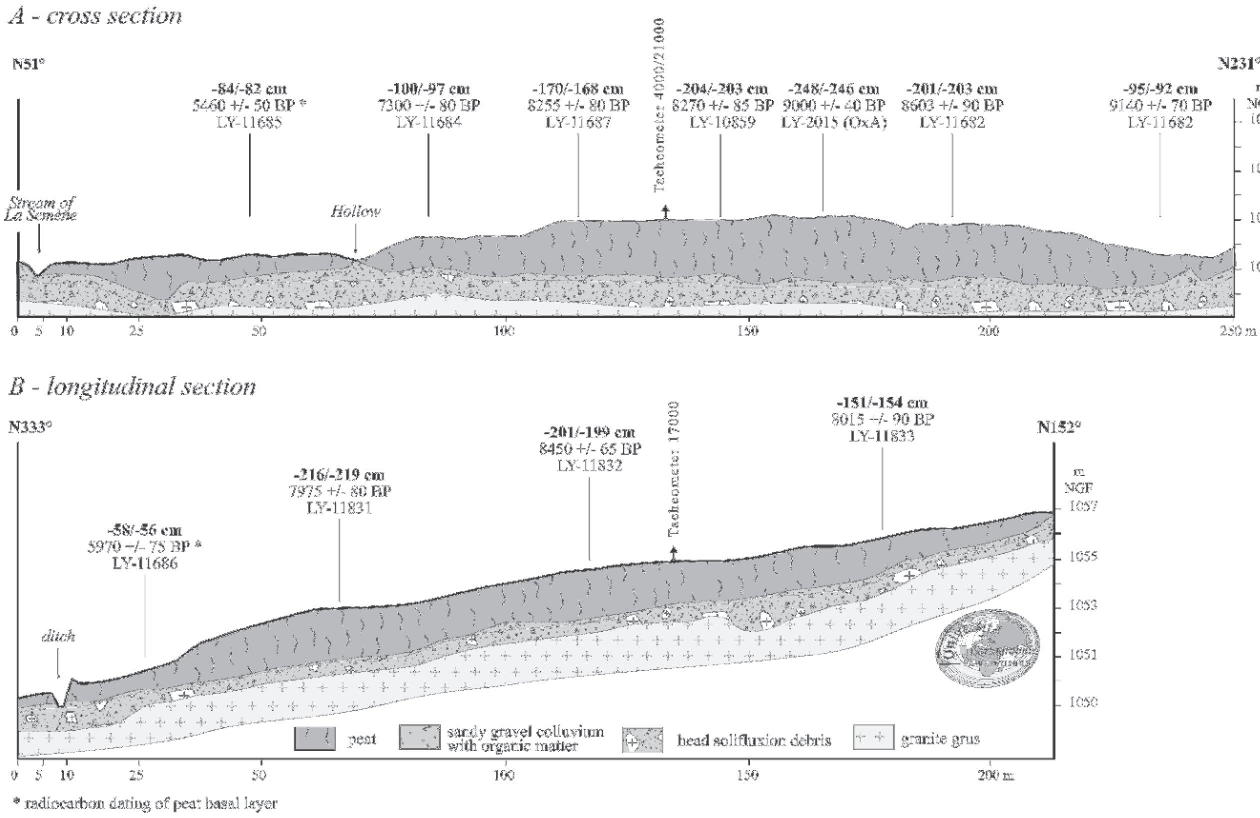

Fig. 9: **Cross sections of the raised bog of la Digonnière in Massif du Pilat (alt. 1055 m) and the oldest radiocarbon dates obtained from the basal layers.**
Fig. 9: *Profils topo-stratigraphiques de la tourbière bombée de la Digonnière dans le massif du Pilat (alt. 1055 m) et datations les plus anciennes obtenues dans la couche basale de tourbe.*

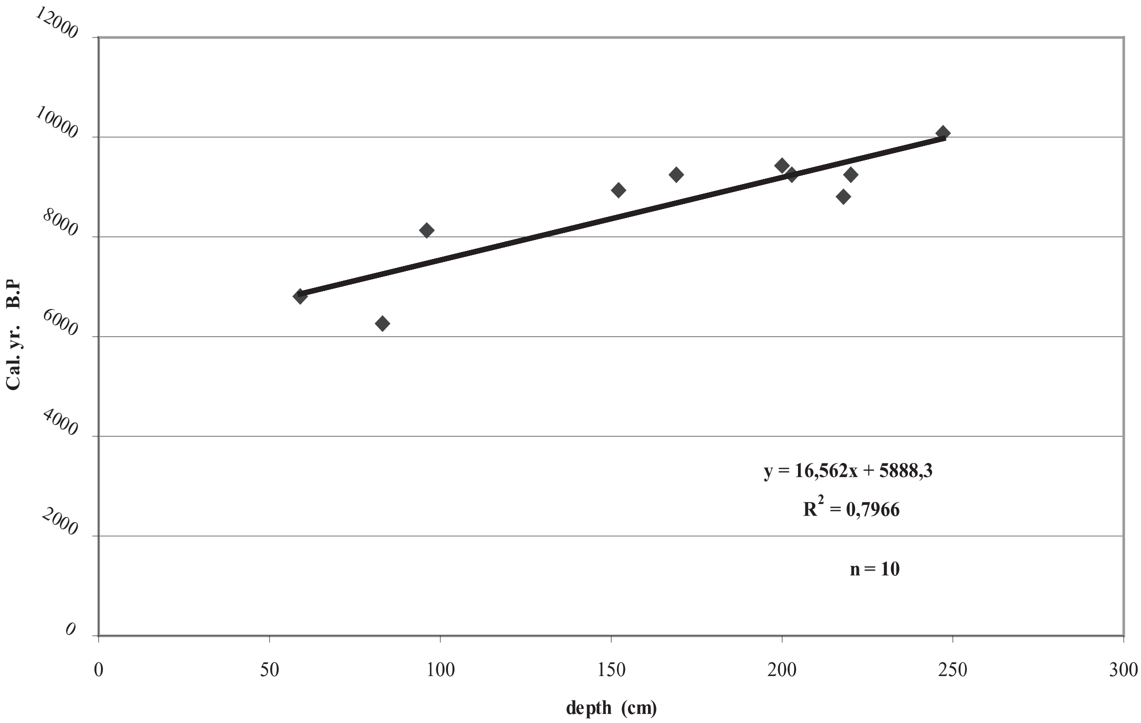

Fig. 10: **The raised bog of la Digonniere in le Massif du Pilat, alt. 1055 m**: **relationship between radiocarbon ages BP obtained from the basal layers and the depth of dated samples.**
Fig. 10: *La tourbière de la Digonnière, Massif du Pilat, alt. 1055 m*: *relation entre les âges radiocarbone BP obtenus dans les couches basales et la profondeur des échantillons datés.*

intervals of incertitude in real years overlap. Moreover, these ages coincide with a ^{14}C threshold, so we must consider the two samples as being contemporary to each other. Somehow the circulation of water was modified, impeding the accumulation of peat in what became a lagg, whereas peat inception continued over the rest of the site.

4.5 - THE DISTRIBUTION OF RADIOCARBON AGES IN THE BASAL LAYERS OF THE JAS FEN (Monts du Forez, alt. 1075 m)

Here is an example of a fen initiated by human intervention, similar to the many mires that formed following human modifications of the environment in the eastern Massif Central. (Cubizolle *et al.*, 2004b). This fen is situated in a depression of about 1000 m^2, dug out by humans (fig. 11). A total of six samples were dated, five were taken every 6 meters along a cross-section, and the sixth located 22 m downstream of the cross-section, at the deepest part of the fen. Resulting dates are given in table 5.

First we see that the two samples from core JAS-E, of which JAS-E2 is the deepest sample collected at this site, are both modern aged samples, whereas all the other dates correspond to the Middle Ages. These samples appear to have been polluted. In man-made sites, generally very small and situated in an agricultural environment from their very beginning, we can imagine a great number of possible sources for such pollution: attempts to flush out solid materials from artificial reservoirs, but also drainage, tree planting, getting a tractor stuck in the fen, etc. For the other dates we see that regardless of the depth, the ages differ very little. Calibration shows that all dates except JAS-DG fit within the fork between 1170 cal. yr. BP and 1071 cal. yr. BP.

5 - DISCUSSION AND CONCLUSION

Identifying the layer of peat that, once dated, will provide an estimation of the age of a mire is not an easy task, and explanations given in the literature offer little help as they are both rare and incomplete in general.

Our experience indicates that it is impossible to define a single criteria for selecting samples to date. Even measures of organic matter content are not reliable. One should therefore rely primarily on microscopic description, the only method that can easily be applied to a large number of sites. This approach should be based on a large number of cores per site to identify the facies

sample and laboratory number	datation	$\delta^{13}C$ ‰ *	material	depth (cm)	Years ^{14}C BP	Cal. yr B.P.
JAS-1043 GrN-27579	radiometric	-29,06	basal layer of sapric peat *	101/103	1030 +/- 70 BP	1166-762
JAS 101718 GrN-27580	radiometric	-28,58	basal layer of sapric peat	230/233	1280 +/- 50 BP	1290-1070
JAS-clôture LY-12092	radiometric	-25 (estimated)	basal layer of sapric peat	277/280	1225 +/- 50 BP	1268-994
JAS-102324 GrN-27581	radiometric	-28,46	basal layer of sapric peat	240/242	1080 +/- 60 BP	1170-798
JAS-DG Beta-192965	AMS	-27,8	basal layer of sapric peat	143/145	940 +/- 50 BP	949-739
JAS-E2 LY-12748	radiometric	-29,25	basal layer of sapric peat	295/297	Modern*	-
JAS-E1 LY-12747	radiometric	-25 (estimated)	top of mesic peat	258/260	Modern*	-
* measured on CO_2 after combustion						
* undifferentiated peat *(Carex, Sphagnum, Eriophorum)*						

Tab. 5: Radiocarbon dates obtained from the basal layers of the fen of le Jas in les Monts du Forez, alt. 1075 m. The oldest radiocarbon dates of peat inception are in bold print.
Tab. 5 : Datations par le radiocarbone obtenues à la base de la tourbière basse du Jas dans les Monts du Forez (alt. 1075 m).

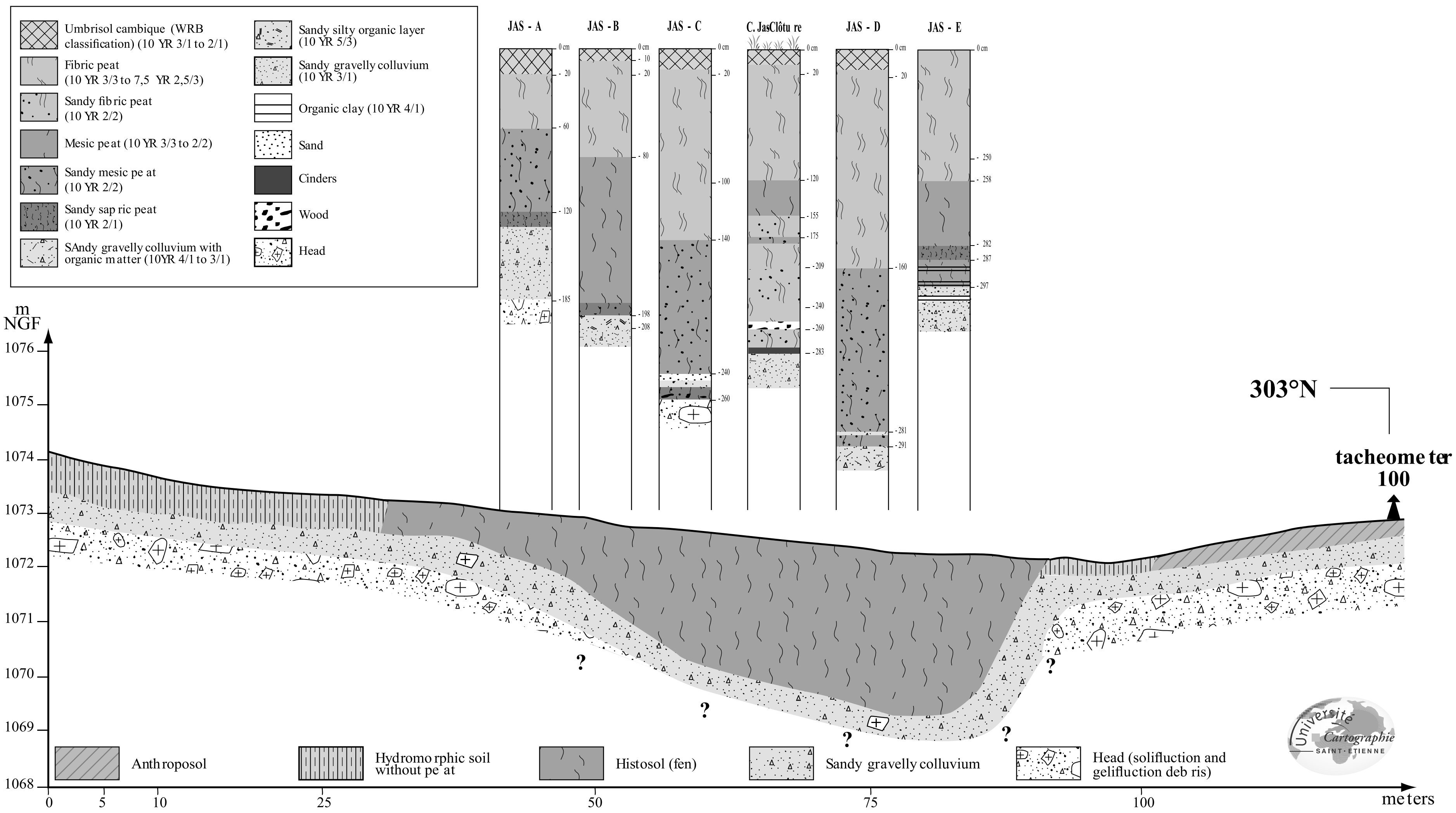

Fig. 11: **Longitudinal section and stratigraphy of the fen of le Jas in the Monts du Forez (alt. 1075 m).**
Fig. 11: Profil longitudinal et stratigraphie de la tourbière basse du Jas dans les Monts du Forez (alt. 1075 m).

that corresponds to the beginning of peat inception. Furthermore, the transition between peat layers and underlying mineral formations must be completed by analysis of dry ash content obtained by ignition loss, and by micromorphologic analysis. It is only by using this combination of methods that can one be sure to identify the basal layer with certainty.

Thus the usefulness of micromorphologic analysis is evident. In general, it provides verification of initial field interpretations of core stratigraphy. It has also shown that considerable disturbance of the transition between peat formations and underlying mineral formations is not so rare, at least in our study area. When such disturbance is observed, it implies that obtaining a precise date of the beginning of peat inception is at best improbable, and more likely impossible. On the other hand the micromorphologic analysis shows that a sample 2 cm thick is a good choice.

In spite of the great precautions taken, misjudging the contacts between facies and thereby the sample to be dated is always possible. This can induce errors in the dates attributed to basal layer formation on the order of a few years to a few centuries. However our experience has shown that once researchers have obtained in depth knowledge and understanding of the mires in their study area, samples can be collected at a level of precision of about 1 cm. In our work, this implies that, depending on the estimations obtained and the number of samples dated, the range of uncertainty of the ages attributed to the initiation of peat inception is on average about 120 calendar years, the median being 72 years (Cubizolle, 2005).

Correctly situating the beginning of peat inception requires radiocarbon dating of a good number of samples from different points at each site. Samples must be selected from the basal layer of peat formations, but also from the underlying sandy organic formations, and from overlying peat formations. Indeed the experience obtained from different sites has provided greater understanding of site structure:

– first, the oldest ages are generally obtained where the peat accumulations are thickest, but this in not always the case. Moreover, the relationship between depth and age is not linear. The correlation we observe between age and depth is virtually identical to the relationship observed by Korhola (1992, p. 78-79, fig. 48) for Finnish bogs. Therefore one should ideally obtain as many dates as possible, particular for larger mires as we sometimes found that different locations in larger mires yielded very different ages at comparable depths, or similar ages at very different depths. Regarding the implications of these cases, we agree with the conclusions of Korhola (1992). Undoubtedly, irregularities in the topography of the initial site in which the mire developed explain in large part these variations among the dates at which peat inception initiated within a given mire. For comparatively small mires, on the order of 1000 m^2 or less, the number of dates can be much smaller as the underlying topography of smaller mires is generally simpler than for larger mires. In the case of small bogs resulting form human intervention however, the risk of extensive disturbance is much greater as we saw in the Jas example, so such cases require more dates in relation to the total surface to obtain a solid estimation of the age of the peat formations.

– secondly, we have to admit that it is difficult to determine where peat inception began simply by examining the surface of a mire. In the Egaux example, inception began in the centre of the mire, but in the Verrerie case the point of initiation is far from the centre. It is interesting to note however that in bogs, the oldest dates are obtained beneath the schlenken zone, when this zone exists (fig. 6).

– thirdly, regarding the interpretation of the ages obtained, one should keep in mind that inversions can be due to the inclusion of older exogenous materials in upper layers, to the inclusion of more recent materials in older layers, or to pollution during coring or the handling of samples. Also, excluding such perturbations, the oldest date obtained corresponds technically to the minimum approximate age of the mire, but perhaps even older ages could have been obtained elsewhere in the mire, and theoretically it is even possible that an older peat accumulation was somehow removed from the site prior to the initiation of the present peat accumulation, be it by erosion or by human intervention (Cubizolle, 2005).

Thus there are many possible sources of imprecision, linked to both the dating process itself and to sampling. Nonetheless, the precision of the dates of the initiation of peat inception we obtained appear to be satisfactory as the processes leading to the initiation of a mire span one or more centuries (Payette & Rochefort, 2001), implying that an error of a few decades is negligible and an error of a few centuries is tolerable. However one should be prudent when interpreting the ages of peat formations in relation to palaeoenvironmental reconstruction. Comparison with palaeoclimatic, palaeoecological and archaeological results must take into account the relative uncertainty of the dating process.

AKNOWLEDGEMENTS

This study was supported through the CNRS Long Term Ecological Research "Bassin versant de la Loire", the Loire Conseil Général and the Rhône-Alpes Conseil Régional. We would also like to thank Peter van den Haute of the Soils Sciences Laboratory of the University of Gand in Belgium. He provided us with thin plates of very good quality. Finally, the authors would like express theirs thanks to E. Juvigné and M. Fontugne for the constructive remarks.

REFERENCES

ANDREYKO M.J., FIENNE F., & COHEN A.D., 1983 - Comparison of ashing techniques for determination of inorganic content of peats. *In* P.M. Jarret (ed.), *Testing of peats and organic soils*. ASTM 820, American Society for testing and Materials, *Ann Arbor*, Michigan, 5-20.

ARGANT J., & CUBIZOLLE H., 2005 - L'évolution holocène de la végétation des Monts de la Madeleine, du Forez, du Livradois et du Pilat (Massif Central oriental, France): l'apport d'une nouvelle série d'analyses palynologiques. *Quaternaire*, **16** (2), 119-142.

BABEL U., 1975 - Micromorphology of soil organic matter. *In* H.E. Gieseking (ed.), *Soil components*. Springer-Verlag, New-York, **1**, 369-473.

BACHELARD G., 1977 - *La formation de l'esprit scientifique*. Librairie philosophique J. Vrin, 256 p.

BEAULIEU de J.L., PONS A., & REILLE M., 1988 - Histoire de la flore et de la végétation du Massif Central (France) depuis la fin de la dernière glaciation. *Cahiers de Micropaléontologie*, **3**, 5-36.

BHIRY N., 2001 - Analyse micromorphologique de la tourbe. *In* S. Payette & L. Rochefort (dir.), *L'écologie des tourbières du Québec-Labrador.* Les Presses Universitaire de Laval, 276-288.

BLAAUW M., PLICHT van der J., & GEEL van B., 2004 - Radiocarbon dating of bulk peat samples from raised bogs: non-existence of a previously reported "reservoir effect"? *Quaternary Science Reviews*, **23**, 1537-1542.

BONNEL P., 2004 - *Le démarrage de la turfigenèse à l'Holocène*: *apport de l'analyse micromorphologique.* Mémoire de Maîtrise de Géographie, Université Jean Monnet, St-Etienne, 128 p.

BONNEL P., 2005 - L'apport de l'analyse micromorphologique dans la mise en place des tourbières du Pays de Bitche (Vosges du Nord): élaboration d'un protocole analytique. Mémoire de MASTER 2ème année, Université Jean Monnet, St-Etienne, 64 p.

BOUMA J., FOX C.A., & MIEDEMA R., 1988 - Micromorphology of hydromorphic soils: applications for soil genesis and land evaluation. *In Proceedings of the VIIIth International Working Meeting of Soil Micromorphology*, San-Antonio, Texas, 257-278.

CASTEL I.I.Y., 1991 - Micromorphology of the transition peat-Holocene drift sand deposits in the northern Netherlands. *Zeitschrift für Geomorphologie*, **90**, 29-43.

CHAPMAN S.B., 1964 - The ecology of Coom Rigg Moss, Northumberland. II. The chemistry of peat profiles and the development of the bog system. *Journal of Ecology*, **52**, 315-323.

CHARMAN D., 2002 - *Peatlands and environnemental changes*. Edited by Wiley, 301 p.

CONWAY V.M., 1954 - Stratigraphy and pollen analysis of southern Pennine blanket peats. *Journal of Ecology*, **42**, 117-147.

COURTY M.A., & FEDOROFF N., 2002 - Micromorphologie des sols et sédiments archéologiques. *In* J.C. Miskovsky (dir.), *Géologie de la Préhistoire.* GEOPRE, Presses Universitaires de Perpignan, 511-534.

CRUIKSHANK J.G., & CRUIKSHANK N.M., 1981 - The development of humus-iron podzol profiles linked by radiocarbon dating and pollen analysis to vegetation history. *Oikos*, **36**, 238-253.

CUBIZOLLE H., 2005 - *Paléoenvironnements et turfigenèse. L'apport de l'étude des tourbières à la connaissance de l'évolution holocène des milieux montagnards du Massif Central oriental granitique*. Habilitation à Diriger des Recherches, Université de Limoges, 750 p.

CUBIZOLLE H., TOURMAN A., ARGANT J., PORTERET J., OBERLIN C., & SERIEYSSOL K., 2003 - Origins of European biodiversity: palaeo-geographic signification of peat inception during the Holocene in the granitic eastern Massif Central (France). *Landscape Ecology*, special issue, **18**, 227-238.

CUBIZOLLE H., GEORGES V., & ARGANT J., 2004a - Changements environnementaux et sociétés humaines dans les moyennes montagnes granitiques du Massif central oriental au cours de l'Holocène: les enseignements tirés du croisement des données géomorphologiques, palynologiques et archéologiques. *Revue d'Archéométrie*, **28**, 57-70.

CUBIZOLLE H., GEORGES V., LATOUR C., ARGANT J., & SERIEYSSOL K., 2004b - La turfigenèse à la fin du Subboréal et au Subatlantique dans les tourbières basses du Massif Central oriental granitique (France): une manifestation de l'action humaine? *Quaternaire*, **15**, 343-359.

CUBIZOLLE H., SERIEYSSOL K., & ARGANT J., 2005 - Holocene vegetation dynamics and human impact on the peatland of Virennes (french Massif Central). *Diatoms Research*, **20**, 257-273.

CUBIZOLLE H., & ARGANT J., 2006 - Les facteurs de la mise en place des tourbières du Massif Central oriental granitique à l'Holocène. *In* Y. Miras & F. Surmely (dir.), *Environnement et peuplement de le moyenne montagne, du Tardiglaciaire à nos jours.* Actes de la table ronde de Pierrefort, juin 2003, Besançon, Presses Universitaires de Franche-Comté, Annales Littéraires 799, Série « Environenment, sociétés et archéologie », **9**, 93-108.

DAVIS A.M., & WICKHAM S.M., 1987 - The microstratigraphy of two peat sequences from northeastern Newfoundland. *Géographie Physique et Quaternaire*, **41**, 355-364.

ETLICHER B., JANSSEN C.R., JUVIGNE E., & LEEUWEN van J.F.N., 1987 - Le Haut-Forez (Massif Central, France) après le Pléniglaciaire würmien: environnement et téphra du volcan de la Nugère. *Bulletin de l'Association Française pour l'Etude du Quaternaire*, **7**, 229-239.

EVIN J., 2002 - *Le Radiocarbone*. *In* J.C. Miskovsky (dir.), Géologie de la Préhistoire. GEOPRE, Presses Universitaires de Perpignan, 1181-1197.

EVIN J., & OBERLIN C., 1998 - *La méthode de datation par le radiocarbone.* In J. Evin, J.N. Lambert, L. Langouët, P. Lanos, & C. Oberlin (eds.), *La datation en laboratoire.* Errance, collection « Archéologiques », 75-117.

EVIN J., OBERLIN C., DAUGAS J.-P., & SALLES J.-F. (dir.), 1999 - *^{14}C et archéologie*. Mémoires de la Société Préhistorique Française, XXVI, *Revue d'Archéométrie*, Suppl. 1999, 480 p.

FEDOROFF N., & COURTY M.A., 1992 - *Organisation du sol aux échelles microscopiques.* Laboratoire des Sciences des Sols et Hydrologie, Institut National de la Recherche Agronomique (INRA), Paris, 45 p.

FITZPATRICK E.A., 1993 - *Soil microscopy and micromorphology.* Eds. John Wiley and Sons Ltd, Chichester, 304 p.

FONTUGNE M., 2002 - La dérive des âges carbone 14? *In* J.C. Miskovsky (dir.), *Géologie de la Préhistoire.* GEOPRE, Presses Universitaires de Perpignan, 1199-1207.

FONTUGNE M., 2004 - Les derniers progrès du calibrage des âges radiocarbone permettent-ils une révision des chronologies entre 25 et 50 000 ans BP? *Quaternaire*, **15**, 245-252.

FOSTER D.R., & JACOBSON H.A., 1990 - The comparative development of bogs and fens in central Sweden: evaluating the role of climate change and ecosystem development. *Aquilo*, *Series Botanica*, **28**, 15-26.

FOSTER D.R., & WRIGHT H.E. Jr., 1990 - Role of ecosystem development and climate change in bog formation in central Sweden. *Ecology*, **71**, 450-463.

FOSTER D.R., WRIGHT H.E. Jr., THELAUS M., & KING G.A., 1988 - Bog development and landform dynamics in central Sweden and south-eastern Labrador, Canada. *Journal of Ecology*, **76**, 1164-1185.

JANSSEN C.R., & STRATEN van R., 1982 - Premiers résultats des recherches palynologiques en Forez, plateau central. *Comptes-Rendus de l'Académie des Sciences*, Paris, **294**, série II, 155-158.

JUVIGNÉ E., 1992 - Distribution of widespread Late Glacial and Holocene tephra beds in the french Central Massif. *Quaternary International*, **13/14**, 181-185.

JUVIGNÉ E., BASTIN B., DELIBRIAS G., EVIN J., GEWEL T., GILOT E., & STREEL M., 1996 - A comprehensive pollen and tephra-based chronostratigraphic model for the Late Glacial and Holocene period in the French Massif Central. *Quaternary International*, **34-36**, 113-120.

KAULE von G., 1976 - Begriffsbestimmungen anhand der Moortypen Mitteleuropas. *In* K. Göttlich (ed.), *Moor and Torfkunde.* E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1-21.

KILIAN M.R., PLICHT van der J., GEEL van B., 1995 - Dating raised bogs: new aspects of AMS 14C wiggle matching, a reservoir effect and climatic change. *Quaternary Science Reviews*, **14**, 959-966.

KORHOLA A., 1992 - Mire induction, ecosystem dynamics and lateral extension on raised bogs in the southern coastal area of Finland. *Fennia*, **170**, 25-94.

KORHOLA A., 1995 - Holocene climatic variations in southern Finland reconstructed from peat-initiation data. *The Holocene*, **5**, 43-58.

LEE G.B., 1983 - The micromorphology of peat. *In* P. Bullock & C.P. Murphy (ed.), *Soil micromorphology.* AB Academic Press, Berkhamsted, 485-501.

LUSIANA F., WIDIATMAKA S., & HARDJOWIGENO S., 2002 - Macromorphology and micromorphology of coastal peatland from Kapuas/Barito and Kahayan river areas, central Kalimantan. *In* J. Rieley & S. Page (eds.), *Peatlands for people natural resources function and sustainable management.* Jakarta Symposium Proceeding On, Jakarta, 22-23 august 2001, Indonesia, 68-74.

MOORE P.D., 1975 - Origin of blanket mires. *Nature,* **256**, 267-269.

MOORE P.D., 1993 - The origin of blanket mire, revisited. *In* F.M. Chambers (ed.), *Climate change and human impact on landscape.* Chapman & Hall, London, 217-224.

MOORE P.D., & BELLAMY D.J., 1974 - *Peatlands*. Elek Science, Londres, 221 p.

MOORE P.D., MERRYFIELD D.L., & PRICE M.D.R., 1984 - The vegetation and development of blanket mires. *In* P.D. Moore (ed.), *European mires*. Academic Press, London, 203-235.

MORLEY R.J., 1981 - Development and vegetation dynamics of a lowland ombrogenous peat swamp in Kalimantan-Tengah, Indonesia. *Journal of Biogeography*, **8**, 383.

MÖRNSJÖ T., 1968 - Stratigraphical and chemical studies on two peatlands in Scania, South Sweden. *Botaniska Notiser*, **121**, 343-360.

MUNSELL COLOR Co., 1992 - *Munsell soil color charts*. Revised edition, Newburgh, New York, USA.

NEUZIL S.G., 1997 - Onset and rate of carbon accumulation in four domed ombrogenous peat deposits, Indonesia. *In* J.O. Reily & S.E. Page (eds.), *Biodiversity and Sustainability of Tropical Peatlands*. Samara Publishing, Cardigan, 55-72.

OLSSON I.U., 1986 - Radiometric dating. *In* B.E. Berglund (ed.), *Handbook of Holocene Palaeoecology and Palaeohydrology.* John Wiley & Sons, Chichester, 273-312.

PAYETTE S., & ROCHEFORT L., 2001 - *L'écologie des tourbières du Québec-Labrador.* Les Presses Universitaire de Laval, 621 p.

PEARSALL W.H., 1950 - *Mountains and Moorlands*. New Naturalist Series, Colins, Londres, 312 p.

PUFFE D., & GROSSE-BRAUCKMAN G., 1963 - Micromorphologische Untersuchungen an Torfen. *Zeitschrift fur Kulturtechnik und Flurbereinigung*, **4**, 159-188.

RIELEY J.O., SIEFFERMANN R.G., & PAGE S.E., 1992 - The origin, development, present status and importance of the lowland peat swamp forests of Borneo. *Suo*, **43**, 241-244.

SIEFFERMANN G., FOURNIER M., TRUITOMO S., SADELMAN M.T., & SEMAH A.M., 1988 - Velocity of tropical forest peat accumulation in Central Kalimantan Province, Indonesia (Borneo). *Proceedings of the 8th International Peat Congress*, Leningrad, Section **1**, 90-98.

SMITH A.G., 1970 - The influence of Mesolithic and Neolithic man on British vegetation. *In* D. Walker & R.G. West (eds.), *Studies in the vegetational history of the British isles.* Cambridge University Press, 81-96.

SOIL CONSERVATION SERVICE, 1975 - Soil taxonomy. U. S. Depart. Agriculture, Agriculture *Handbook*, **436**, 754.

TALLIS J.H., 1991 - Forest and moorland in the south Pennine uplands in the mid-Flandrian period. 3. The spread of moorland local regional and national. *Journal of Ecology*, **79**, 401-415.

ZOLTAI S.C., 1995 - Permafrost distribution in peatlands of west-central Canada during the Holocene warm period 6000 years BP. *Géographie Physique et Quaternaire*, **49**, 45-54.

ZOLTAI S.C., & JOHNSON J.D., 1985 - Development of treed bog island in a minerotrophic fen. *Canadian Journal of Botany*, **63**, 1076-1085.