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Human palaeontology and prehistory

An example of the consequences of human activities on the evolution of subalpine landscapes

Un exemple des conséquences des activités humaines sur l'évolution des paysages subalpins

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A B S T R A C T

A pollen study at Survilly (2235m *asl*, 06° 49′ 12″ E, 45° 59′ 24″ N), a small peatbog located on the Anterne mountain (Upper-Arve Valley, French north-western Alps) highlights the local role of human activities in Holocene vegetation dynamics of the currently treeless subalpine belt and the consecutive resumption of erosion. As early as 8890 cal. years BP (± 122), *Pinus cembra* grew close to the site. Grasslands without shrubs were established at around 4624 ± 86 cal. years BP. Due to human activities, spruces extended little after 3600 cal. BP. The intense grazing that resulted in the current alpine meadows goes back to 1436 cal. years BP (± 81). After 4624 cal. BP three clay layers show that from this period, the erosion became as active as during the first steps of the colonization of the vegetation prior to 10,050 cal. BP. During peat growth only a millimetre of clay at the end of the 9400–9050 cal. BP climatic event was recorded.

R É S U M É

L'étude pollinique d'une petite tourbière située à Survilly (2235 m *asl*, 06° 49′ 12″ E, 45° 59′ 24″ N), sur la montagne d'Anterne (haute vallée de l'Arve) décrit le rôle des activités humaines sur la dynamique végétale de l'étage subalpin des Alpes nord-occidentales françaises et sur la reprise consécutive de l'érosion. Dès 8890 cal. BP (± 122), les pins cembros ont poussé autour du site. À partir de 4624 cal. BP (± 86), les paysages ouverts sans buissons dominent le versant, entraînant une nette reprises des phénomènes érosifs. Les épicéas se sont peu développés dans la zone après 3600 cal. BP. L'accentuation du pâturage conduisant aux pelouses alpines actuelles remonte à 1436 cal. BP (± 81). Après 4624 cal. BP, 3 niveaux d'argile montrent qu'à partir de cette période l'érosion est redevenue aussi active que lors des premières étapes de la colonisation végétale avant 10 050 cal. BP. Seul un niveau millimétrique d'argile est intercalé dans la tourbe à la fin de l'évènement 9400–9050 cal. BP.

Version française abrégée

(Fig. 1) L'analyse pollinique d'une séquence tourbeuse extraite à Survilly (2235m *asl*, 06° 49′ 12″ E, 45° 59′

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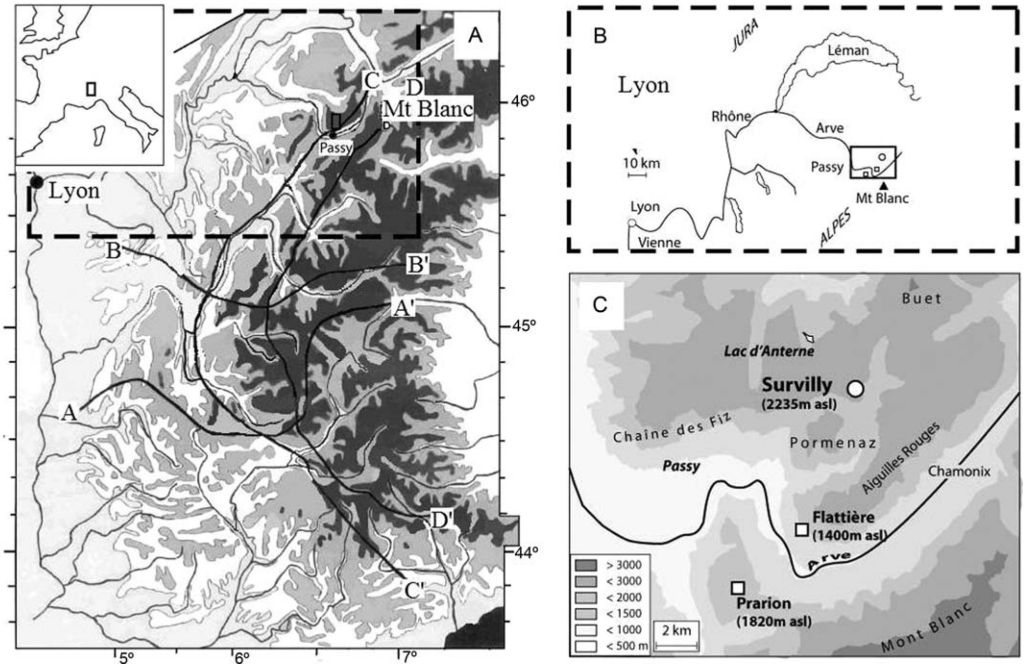

Fig. 1. A) Location and ecological zonation of the French Alps (after Ozenda (Ozenda, 1985)). The pass limit A–A' separates the southern Alps from the northern Alps. To the North of the boundary pass, a transition zone has been defined. B–B' marks the boundary between the transition zone and the unambiguous northern Alps. Eastward increasing continentality has led to the distinction between the Outer Alps (to the west of C–C'), the intermediate Alps (between C–C' and D–D') and the inner Alps (east of D–D'). **B**) Sketch map of northern France showing the location of the study area. **C**) Sketch map of the study area showing the location of the studied peat record (white circles) as well as of Lake Anterne and the peat records previously studied by Beaulieu et al. (de Beaulieu et al., 1993) (white squares).

Fig. 1. A) Localisation et zonation écologique des Alpes françaises (d'après Ozenda, 1985). La limite A–A' sépare les Alpes du Sud des Alpes du Nord. Au nord de la limite, une zone de transition a été définie. B–B' marque la limite entre la zone de transition et les Alpes du Nord sans ambiguïté : vers l'est, l'augmentation de la continentalité conduit à distinguer les Alpes externes (à l'ouest du C–C'), les Alpes intermédiaires (entre C–C' et D–D') et les Alpes internes (à l'est de D–D'). **B**) Carte schématique du Nord de la France montrant la localisation de la zone d'étude. **C**) Carte schématique de la zone d'étude montrant la localisation de la coupe de tourbière étudiée (point blanc), ainsi que le lac d'Anterne et les principales coupes de tourbière étudiées par de Beaulieu et al. (1993) (carrés blancs).

24″ N) sur la montagne d'Anterne (haute vallée de l'Arve) met en évidence la dynamique végétale enregistrée dans l'étage subalpin. La chronologie repose sur neuf dates AMS (Tableau 1). Cette étude fait partie du programme de recherche pluridisciplinaire APHRODYTE 2 sur les interactions homme–climat–environnement pendant l'Holocène dans la haute vallée de l'Arve. L'aire d'étude est située dans la réserve naturelle de Passy qui illustre, sur une surface de 1800 ha, la grande hétérogénéité géologique et écologique des Alpes du Nord. Cette zone marque la limite orientale des Alpes externes (Ozenda, 1985). Un boisement mixte de hêtres épicéas et rares sapins pousse à 1400 m *asl* sur la montagne de Pormenaz, alors que quelques exemplaires de pins cembros, épicéas et mélèzes poussent en situation inaccessible sur les falaises jusqu'à 2200 m *asl*. Ces mélèzes ont une situation remarquable, car au-delà de la zone interne (Ozenda, 1985), autour du site, le paysage est marqué par la dominance des pelouses avec de nombreuses marques d'érosion. En contrebas, les aulnes verts sont localement abondants près des torrents

Table 1
^{14}C calibrated and non-calibrated ages for the nine peat samples studied.
Tableau 1
Âges C^{14} calibrés et non calibrés des 9 échantillons de tourbe analysés.

Sample no.	Sample reference	Nature	C^{14} Age BP	Calibrated age BP 2 sigmas
SacA 7656	Svy 18–20	Peat	1535 ± 30	1436 ± 81
SacA 7657	Svy 28–30	Peat	4080 ± 40	4624 ± 86
SacA 7658	Svy 60–62	Peat	4900 ± 45	5658 ± 71
SacA 7659	Svy 108–110	Peat	5725 ± 30	6536 ± 97
SacA 7660	Svy 136–138	Peat	7240 ± 35	8070 ± 90
SacA 7661	Svy 142–144	Peat	7205 ± 35	8054 ± 100
SacA 7662	Svy 170	Peat	8020 ± 35	8890 ± 122
SacA 8737	Svy 125	Peat	7010 ± 40	7840 ± 97
SacA 8738	Svy 214	Peat	8915 ± 45	10050 ± 150

et seuls quelques exemplaires de sorbiers et de bouleaux poussent rabougris en raison du pâturage de plusieurs centaines de moutons et de plusieurs dizaines de vaches. Une étude précédente a montré que l'épicéa a largement colonisé l'étage subalpin de la région (de Beaulieu et al., 1993). Dans les Alpes du Nord, la limite des boisements a pu atteindre 2400 m *asl*, avant d'être profondément baissée à l'époque romaine (David, 1995a). Cependant, en fonction des paramètres locaux (exposition, climat, action humaine) le couvert végétal a pu évoluer différemment sur de faibles distances (David, 1993a; David, 1995a). L'étage subalpin est une zone favorable pour suivre les fluctuations climatiques holocènes (David, 1997). Nous utilisons ici les données de la synthèse chronologique des fluctuations climatiques holocènes dans les Alpes françaises (Magny, 2004).

Dans ce site, la sédimentation organique débute vers 10 050 cal. BP (± 150) et les premiers arbustes s'installent vers 9000 cal. BP. Cette végétation basse a dominé le paysage pendant une grande partie de l'Holocène et a permis un bon enregistrement pollinique régional. Les premiers sapins sont enregistrés à la fin de l'optimum du noisetier vers 8890 cal. BP (± 122) et les premiers hêtres peu avant 6536 cal. BP (± 97). Les premiers pollens d'épicéa sont enregistrés vers 5658 cal. BP (± 71) avec une progression nette à 3557 cal. BP (± 82), mais ses taux restent faibles (< 18 %) comparés à ceux observés à quelques kilomètres de distance où l'épicéa a constitué des peuplements (de Beaulieu et al., 1993). De tels taux faibles avaient été notés sur le même versant, dans un site très proche de Survilly (Fig. 1, les Ecuelles, 1855 m) (David, 2010). Cela confirme que l'épicéa n'a jamais constitué des peuplements denses sur ce versant et que les raisons de cette absence ne sont pas d'ordre climatique.

L'absence de pollen de mélèze dans toute la séquence semble en contradiction avec la présence actuelle de l'arbre dans les falaises proches. Cette absence peut être liée à sa faible représentation pollinique déjà notée dans de nombreuses études (David, 1995a). Néanmoins, la présence actuelle du mélèze dans la même aire que les hêtres en dehors de la zone interne (Ozenda, 1985) pourrait résulter d'une conquête récente des espaces déboisés. L'expansion des mélézins dans l'étage subalpin des Alpes du Nord est généralement liée aux déboisements de l'époque romaine (David, 1995b).

Des occurrences irrégulières de stomates montrent que seuls les pins cembros ont approché le site dès 8890 cal. BP (± 122), puis successivement à 7840 (± 97), environ 6200 cal. BP et 4624 cal. BP (± 86). Ces phases correspondent à des périodes climatiques favorables (Magny, 2004). Cette altitude 2235 m marquait la limite supérieure des arbres, soit 150 m plus bas que la limite maximale enregistrée dans les Alpes du Nord (David, 1995a). Actuellement, la zone est complètement déboisée. Les indices d'activités anthropiques (Cerealia, Urticaceae, *Rumex, Plantago lanceolata*) sont notés dès 5658 cal. BP (± 71), mais les pourcentages d'*Abies* et de *P. cembra* restent élevés jusqu'à 4624 ± 86 cal. BP. La présence de stomates de pins indique que ces arbres étaient présents autour du site. Les paysages ouverts sans buissons sont mis en place vers 4624 (± 86) cal. BP, quand les pins régressent et les herbacées augmentent, avec une prédominance des Poaceae. Peu après, on enregistre une rétraction générale des sapins à plus basse altitude, mais ce n'est qu'à partir de 1436 cal. BP (± 81), que se mettent en place les pelouses pâturées, semblables aux pelouses actuelles. Ce n'est qu'après la déforestation généralisée enregistrée vers 4624 (± 86) cal. BP, que l'on trouve des traces d'érosion intense des sols sous la forme de trois niveaux argileux, deux avant et après 3557 cal. BP (± 82) et le dernier postérieur à 1436 cal. BP (± 81). Nous ne trouvons de tels niveaux détritiques dans la carotte sédimentaires, qu'à la base de la séquence avant 10 050 cal. BP (± 150) et juste avant 8890 cal. BP (± 122). Ce dernier niveau semble marqué l'empreinte de l'épisode 9050–9400 cal. BP (David, 1997; Magny, 2004). L'absence de niveau détritique entre 8890 cal. BP (± 122) et 4624 cal. BP (± 86) montre que le couvert végétal était suffisamment développé pour que les péjorations climatiques suivantes (David, 1997; Magny, 2004) n'aient pas entraîné d'érosion importante des sols (Fig. 2). La réduction généralisée du couvert végétal est intervenue en dehors de toute période de péjoration climatique, confirmant ainsi son origine anthropique. À partir de 4624 (± 86) cal. BP, l'action anthropique a entraîné une fragilisation des sols qui sont redevenus plus sensibles à l'érosion.

1. Introduction

In temperate regions, the postglacial dynamic processes that built mountain ecosystems were related mainly to climate changes and/or human impact. In south-western Europe and particularly in the Alpine range, the complex topography and diverse influences, climatic and/or anthropogenic, have led to high landscape heterogeneity (Ozenda, 1985; Richard and Tonnel, 1987). This paper presents the results from a palaeoecological study of the sediments of a subalpine peat bog, undertaken as a part of the APHRODYTE 2 program aiming to obtain through a multidisciplinary approach new information on the Holocene human–climate–environment interactions at high altitudes in the higher Arve Valley.

The study area (Fig. 1) is located in the Passy natural reserve (1800 ha). It illustrates the great geological and ecological heterogeneity over a short distance in the northern French Alps (Richard, 1984). The area marks the eastern boundary of the outer Alps (Ozenda, 1985). Most eastern *Fagus* stands are observed at around 1400 m *asl* in Pormenaz Mountain whereas isolated *Picea, Larix* and *Pinus cembra* grow up to 2200 m on inaccessible cliffs. Below the site, green alders grow close to a source of water, whereas *Sorbus* and *Betula* are scarce and regularly grazed. At the present time, several hundred sheep and tens of cows pasture this treeless subalpine vegetation belt and the landscape is strongly marked by erosion figures such as steep outcrops incising the peat bogs.

A previous study of neighbouring massifs sites (Fig. 1) has shown that *Picea* stands may have colonized this altitudinal belt (de Beaulieu et al., 1993). But according to these authors, the proposed Holocene chronology remains imprecise. In the following section, we use the chronological radiocarbon-based dates given by these authors (de Beaulieu et al., 1993) as they were initially published (i.e. non-calibrated) and currently calibrated using Calib 5.0.1 software (Stuiver and Reimer, 1993) and the Intcal04 calibration curve (Reimer et al., 2004) as 2-sigma probability age interval. A mean age for the invasion of *Picea* has been proposed at around 3000 BP. In fact, two ^{14}C ages–3300 ± 170 BP (3980–3080 cal. BP) and 2630 ± 130 BP (3010–2350 cal. BP) – bracket the increasing *Picea* percentages at la Flatière (Fig. 1, 1400m), but *Picea* percentage increases prior to 3360 ± 180 BP (4140–3160 cal. BP) at higher elevation in the subalpine belt (Fig. 1, Prarion 1820 m).

Previous palynological studies have shown that the tree limit reached up to 2400 m in the northern Alps (David, 1995a). This ecotone was sensitive to the climatic deteriorations that occurred during the Holocene (David, 1997). Five phases of tree lowering have been demonstrated in the subalpine zone in the Vanoise-Massif but human activities could have masked and/or re-enforced the climate events (David, 1997). Most palaeodata in the French Alps have shown that the tree limit has been broadly lowered during the Roman period, but we previously showed that neighbouring sites could have different landscape histories (David, 1993a; David, 1995a; David, 1997).

2. Method

The peatbog (20 m × 10 m) was cored with an 8 cm-diameter Russian peat-corer. Samples were taken for a pollen profile at intervals from 2.0 to 10 cm and were prepared for pollen analysis by the standard acetylation and hydrofluoric acid method (Fægri and Iversen, 1989). The pollen sum was at least 500 grains, excluding swamp plants and ferns. The software package Gpalwin (Goeury, 1988) was used to construct pollen diagrams. Nine radiocarbon dates were carried out by the LMC14 laboratory (CNRS), using the French national radiocarbon device *ARTEMIS*. Non-calibrated and calibrated ages are given in Table 1. Only calibrated ages are used in the text (cal. BP refers to before present, where by convention AD 1950 is 'present'). Calibration was performed using Calib 5.0.1 software (Stuiver and Reimer, 1993) and Intcal04 calibration curve (Reimer et al., 2004), calibrated ages are given as 2-sigma probability age intervals (Table 1).

3. Results and discussion

Pollen analysis results are shown in a summarized relative pollen diagram (Fig. 2). Discontinuous stomata occurrences are plotted on the pollen diagram.

3.1. Holocene vegetation history and chronology: Climate and/or human action

At 2235 m *asl* the first organic sediments were deposited over basal clay at 10,200–9900 cal. BP. Cyperaceae and Poaceae increased and the small *Salix* and *Juniperus* percentage may reflect the contribution of these taxa to the formation of soil in the Early Holocene. The first *Pinus cembra* pollen grains are recorded without any evidence of the presence of trees close to the site. The *Pinus sylvestris/uncinata* percentage (less than 30%) and *Corylus* percentage (40%) must be interpreted as pollen transport from lower belts (David, 1993a; David, 1993b; David, 1997). The area appears to have been treeless until the first *Pinus* settled around 9000 cal. BP as indicated by the appearance in the sediment record of stomata (Fig. 2, S2 level 170). This result agrees with the timing of the altitudinal forestation of the subalpine belt of northern French Alps, as inferred from macrofossils and pollen records (David, 1997; David, 1993b). This marks a difference from

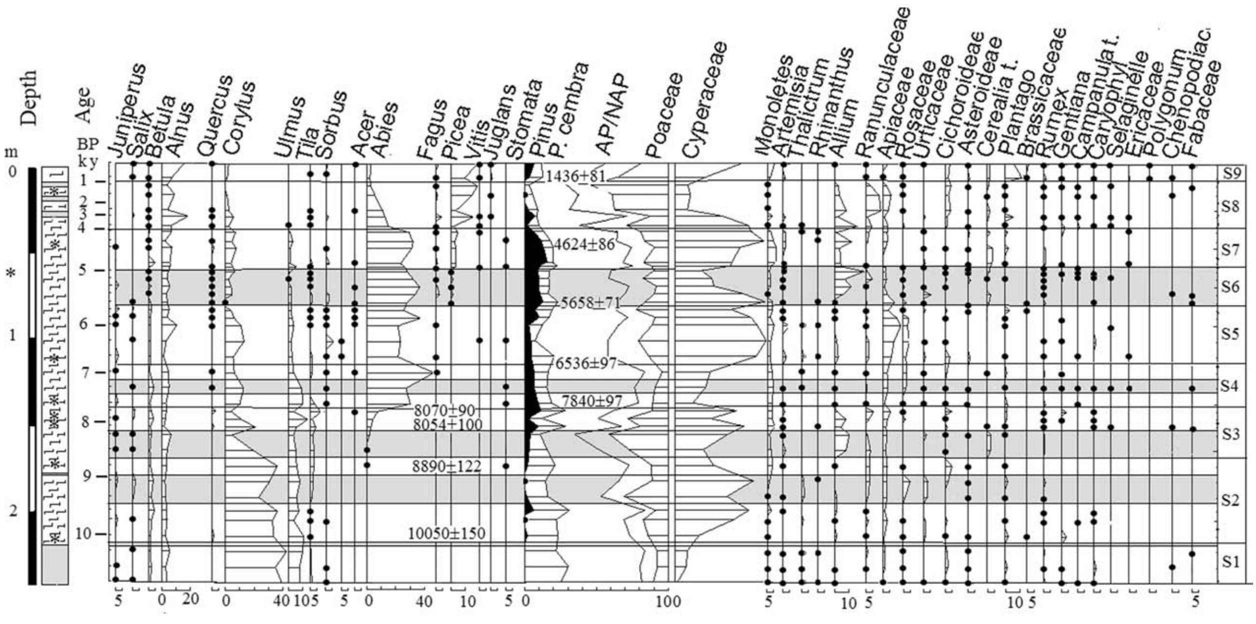

Fig. 2. Simplified relative pollen diagram. Stars indicate the dated levels. The grey bands mark the climate events according to Magny (2004).

Fig. 2. Diagramme politique simplifié avec abondances relatives des espèces. Les étoiles indiquent les niveaux datés.

the central Alps, where studies suggest a nearly simultaneous forestation between 1500 m *asl* and 2340 m *asl*, earlier around 11400 to 11300 cal. BP (Gobet et al., 2005).

Seeds and wood of *P. cembra* (Fig. 1, Table 1) have been dated to 5950 ± 80 cal. BP at Ecuelles (1800 m *asl*) and 5095 ± 110 cal. BP in the catchment area of Lake Anterne (2060 m *asl*) (Table 1). However, the *P. cembra* percentage has never been high (20%) and thus pines might not have constituted a dense tree cover in the area. Findings of *P. cembra* agree with its past and present location in the inner and intermediate zone of the French Alps (David, 1995a; Ozenda, 1985). Indeed, the study area (Fig. 1) is located at the transition between outer and intermediate zones and must have constituted the most western location of P. *cembra*.

The first *Abies* pollen grains are recorded at the end of the *Corylus* optimum (Fig. 2, S2) around 9010–8770 cal. BP (8020 ± 40 BP). *Abies* remained rare for eight hundred years and only increased (Fig. 2, S3) after 8150–7950 cal. BP (7205 ± 35 BP). Those dates indicate a regional expansion of fir after the 8.2 k event (Alley et al., 1997; Magny, 2004). The role of the 8.2 k climate event on the eight hundred year lag between the first *Abies* occurrences and the *Abies* expansion needs investigation. *Alnus* and Poaceae increase and *Corylus* decreases during the period (Fig. 2, S3), which could indicate a wetter climate (Magny, 2004; Seppä et al., 2007). Nevertheless, the precise chronology of fir migration in the Upper Arve Valley requires more dates of fir macroremains at the mountain vegetation belt. Fir could not have developed at 2300 m in the northern French Alps (David, 1995a).

The first *Fagus* grains are recorded during the *Abies* optimum at ca. 6.5 ka cal. BP (6440–6630 cal. BP) (Fig. 2, S4, level 110). *Fagus* records remain low; we note just a slight increase at 5658 cal. BP (Fig. 2, S6) with the first *Picea* pollen. The age of appearance of *Fagus* pollen at Survilly is in agreement with those previously reported (de Beaulieu et al., 1993) at la Flatière (1430 m asl, Fig. 1): 6310–7160 cal. BP (5880 ± 190 BP) as well as at the so-called Prarion site (1820 m asl), where *Fagus* could not have grown: 6510–7470 cal. BP (6160 ± 220 BP). At the present time *Fagus* grows at 1500 m. Nevertheless, the appearance of *Fagus* in the area should be dated in the mountain vegetation belt. The record of the first pollen grains does not

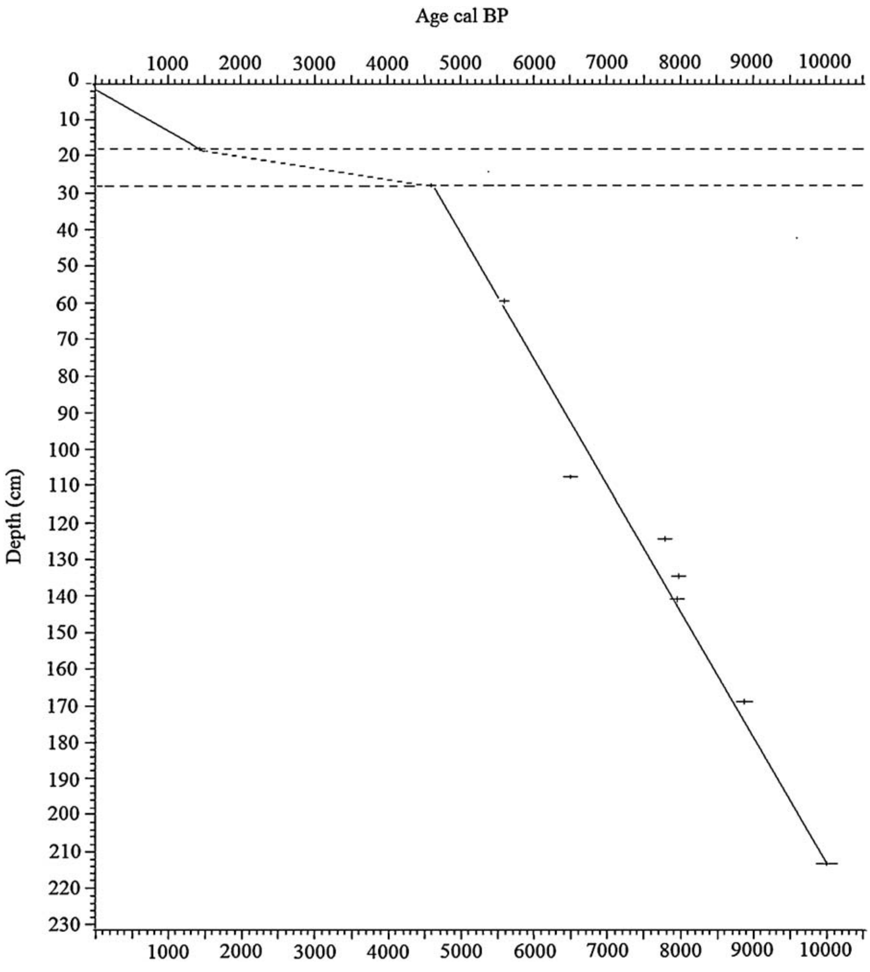

Fig. 3. The age/depth model for Survilly. A clear change in the rate of sedimentation occurred after 4624 cal. BP.

Fig. 3. Modèle âge/profondeur pour Survilly. Un changement net du taux de sédimentation intervient après 4624 cal. BP.

imply the migration of the first trees to the area. It could also be attributed to an opening of the vegetation cover around the site, allowing a better record of pollen of distant origin.

The first *Picea* grains are recorded during the second *Abies* maximum after 5600 cal. BP (Fig. 2, S6), then its percentage significantly increased around 3600 cal. BP. In this area, the only relevant date is for the top of the *Picea* increase (3631 cal. BP, 3360± 190 BP) at Prarion (1820 m) (de Beaulieu et al., 1993). The other dates obtained at lower sites more likely date the opening of the fir forest in the mountain vegetation belt, rather than the immigration of spruce to the subalpine vegetation belt. This prevents any discussion concerning the migration of *Picea* in the area. Moreover, *Picea* percentages never exceeding 18% in our study area (David, 2010) are lower than those recorded at the same altitude a few kilometres away. Indeed, *Picea* percentages reached 70% at Prarion (1820 m) and 40% at Aiguillettes des Houches (2210 m) (Fig. 1) (de Beaulieu et al., 1993). This result indicates that spruce has never constituted forests, whereas few well-developed *Picea* timber stands are currently present on the surrounding cliffs. This shows that human activities and not climate are responsible for the weak presence of spruce in the area.

At the present time, a few *Larix* may be observed on the surrounding cliffs below Survilly. This constitutes the most western stands of *Larix*. The natural range of *Larix* is located in the inner Alps and it should not grow beside *Fagus* (Ozenda, 1985). *Larix* pollen has not been observed in our samples. We already encountered a similar case in previous studies in the northern Alps, in which we reported findings of *Larix* needles whereas no pollen was found (David, 1995a). We cannot deduce the history of *Larix* in the area without a study of macroremains. Nevertheless, this could indicate a recent migration of *Larix* in the deforested area. The great expansion of *Larix* in the subalpine vegetation belt in the northern French Alps was linked to human impact during the Roman period (David, 1995b).

Typical anthropogenic indicators (Cerealia, Urticaceae, *Rumex*, *Plantago lanceolata*) were continuously recorded after 5658 cal. BP (±71) (Fig. 2, S6) but *Abies* and *P. Cembra* percentages remain high prior to 4624 ± 86 cal. BP (Fig. 3). The occurrence of *Pinus stomata* indicates that trees were still present around the site. Grasslands without shrubs were established at 4624 ± 86 cal. BP (Fig. 2, S7), when *Juniperus* was no longer recorded. After this date (Fig. 2, S 8–9), Poaceae became dominant. The strong decrease of tree pollen revealed a generalized deforestation due to clearance in the pine forest in the subalpine belt and later in the fir forest in the mountain belt. The indications of strong pasture leading to the present meadows occurred later at 1436 cal. BP (±81). *Plantago lanceolata* shows the highest percentages (Fig. 2, S 9).

After the general clearings at 4624 ± 86 cal. BP, three clay layers occurred within the peat; two layers brackets 3557 cal. BP (±82) and the third appears after 1436 cal. BP (±81). In this site, apart from the clay that settled at the bottom prior to 10050 cal. BP (±150) (Fig. 2, S1), only a thin clay layer is visible within the peat just prior to 8890 cal. BP (±122) (Fig. 2, S2). The latter corresponds to the 9050–9400 cal. BP climate event (David, 1997; Magny, 2004). No clay level is visible between 8890 cal. BP (±122) and 4624 ± 86 cal. years BP, although at least three climate events occurred (8650–8150 cal. BP, 7550–7150 cal. BP, 4850–5800 cal. BP) (David, 1997; Magny, 2004). A well-developed plant cover can explain this obvious absence of erosion. On the contrary, after 4624 ± 86 cal. years BP human activities disrupted the plant cover enough so that erosion could start again. We must note that the clearings after 4624 ± 86 cal. years BP occurred during a climatically favourable period. Human activities rendered the environment more sensitive to further climate events, thus driving the erosion resumption.

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