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Palynostratigraphy of some Pleistocene deposits in the Western Alps: A review

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Abstract

In the Alps, interglacial and interstadial deposits are rarely preserved due to the intense erosive effect of glaciers in the valleys. Fortunately, some outcrops and cored sequences located in the field area ranging from Lyon to Evian provided sedimentary profiles datable by palynostratigraphy in a highly documented geomorphological context. An overview of several palynological sequences studied in this large area is proposed, and their position in a general chronostratigraphical pattern is discussed. Particular attention is paid to palynostratigraphical evidence whose relevance is tested with systematic comparisons with long reference European pollen sequences spanning several glacial cycles. Minimum ages are suggested for non-glacial episodes corresponding to the deposits studied.

1. Introduction

Since de Saussure (1779–1796), information on past glaciers dynamics has expanded over the past thirty years as the scientific community endeavoured to assess the Late Pleistocene climatic oscillations. A rapid review of regional glacial records from the Eurasian mountains could easily indicate that the presumed synchronicity between continental and mountain glaciations is not unanimously supported. Today, it remains difficult to form a consensus as to the geometry and chronologies of glaciers before and during the LGM, especially in the Alps. In this context, dating is a crucial point.

Palaeoenvironmental records are often hindered by a lack of datable material and are eroded/or covered by advances of glaciers during the LGM. Records spanning pre-LGM glacial and interglacial times are therefore very exceptional and there is rarely uninterrupted record of one climatic cycle. In such context, chronological assignment of remaining Quaternary deposits can be problematic. More-

over, considering the limits of the ¹⁴C dating method, ages of pre-LGM deposits might be underestimated. Lastly, interstadial and/or interglacial layers might have been reworked by further glaciers pulses. Therefore, it is difficult to assume that sediments studied are undoubtedly *in situ*.

In the Alps, since the pioneer works of Penck and Brückner (1901–1909), glacial theories were gradually supported by various chronological proxies and pollen profiles played a major role as a relative dating method, particularly for periods prior to the maximum age limit of the ¹⁴C dating method, i.e. ca. 35,000 BP (Evin, 1990). However, the relevance of this method is conditioned by

- (1) well-established palynostratigraphical reference patterns,
- (2) the use of decisive criteria,
- (3) the nature of sediments analysed —*which must not be reworked*.

The third point is probably the most difficult to assess although pollen analysis can demonstrate sedimentary discordances. As a result, palynostratigraphical interpretations require caution and inter-site comparisons are of vital importance for supporting chronological framework.

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Several long pollen sequences are available in Europe for the Late Pleistocene, while continuous pollen profiles from the Middle Pleistocene are rare. The sequence of Les Echets is a reference spanning the last climatic cycle (Beaulieu and Reille, 1984, 1989) for the west-alpine lowlands (Fig. 1). In particular, the Eemian (MIS 5e) and the following temperate episodes Saint Germain I (MIS 5c) and Saint Germain II (MIS 5b) are well-documented at Les Echets which remained unglaciated throughout the last glaciation.

The sequences of the Velay plateau cover at least four climatic cycles prior to the Holocene (Beaulieu and Reille, 1992; Reille and Beaulieu, 1995; Reille et al., 2000; Beaulieu et al., 2001) and represents also a solid biostratigraphical framework for:

- older interglacials, corresponding to the OIS 11 (Pracaux interglacial), OIS 9 (Landos interglacial) and OIS 7 (Bouchet Interglacial Complex); and
- several interstadials (Jagonas 1 and 2, Ussel, Amargiers) not well-documented elsewhere in Central Europe.

Correlations with long Pleistocene pollen records can be problematic, owing to biogeographical, altitudinal and latitudinal differences between the sites (Grüger, 1996). Distances to glacial refugia must also be considered as a major parameter that modulated in various ways post-glacial dynamics of meso- and thermophilous trees. This paper refers to a set of relevant alpine pollen records in

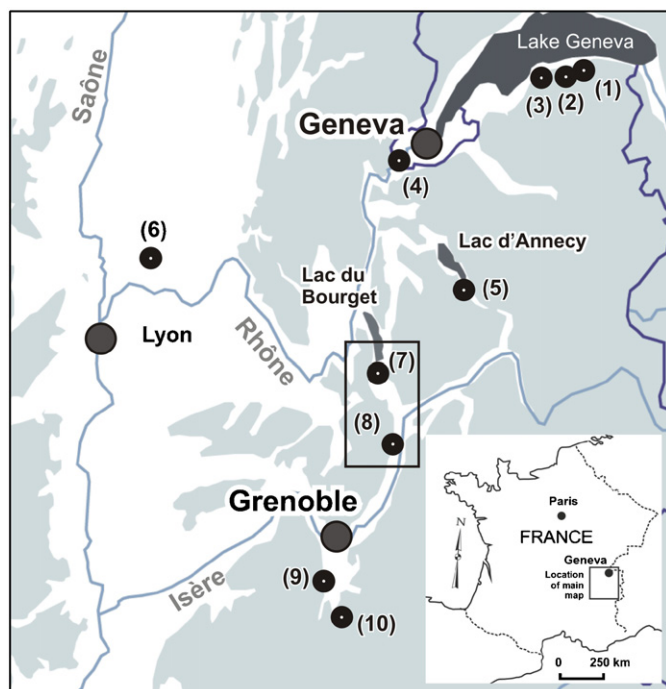


Fig. 1. General map showing locations of pollen profiles compiled in the present review: (1) Sionnex and SP3-Les Ingels profiles; (2) peats of Maravant; (3) organic layers of Armoiy (Dranse valley); (4) lignites of Montfleury; (5) lignites of Annecy; (6) Les Echets; (7) lignites of Chambéry; (8) lignites of North Grésivaudan; (9) La Côte; and (10) Le Ruisseau de l'Amourette.

Switzerland (Welten, 1982, 1988; Wegmüller, 1992; Drescher-Schneider et al., 2007), in the French Alps (Field et al., 2000) and in Austria (Drescher-Schneider, 2000). Particular attention was paid to the abundance of *Abies*, *Picea*, *Fagus* and *Carpinus*.

The purpose of this review is to help the alpine Quaternary community construct future geomorphological syntheses. In Switzerland, such an investigation was carried out with a re-interpretation of Pleistocene pollen diagram of Meikirch in the light of luminescence dating (Preusser et al., 2005). This effort should be attempted throughout the Alps so that more Mid-European overviews become achievable. The present paper reviews the palynostratigraphy of several organic deposits imbedded between glacial units in the Evian area and in the French Western Alps (Fig. 1).

2. From Armoiy to the Evian Plateau: disentangling interglacial from interstadial organic layers in the Evian area

In the French Western Alps, the question about plurality of glaciations has been very much debated since Morlot (1858) studied the Quaternary deposits of the Evian Plateau (Fig. 2). At the same time, several lignites interbedded between tills were found in the Dranse valley (Favre, 1867) and later in the Isère valley, near Chambéry (Vivien, 1895), confirming that non-glacial periods were recorded inside huge glacial sedimentary complexes. These organic layers were further studied by pollen analysts (Lemée and Bourdier, 1950; Gremmen, 1982; Brun, 2000; Guiter, 2003). Since that time, debates about chronologies of alpine glaciers never ended and were recurrently fuelled by palynological investigations and controversial reviews.

Recently, perfectly preserved peats (Fig. 3) were discovered on the Evian Plateau underneath remnants of a Würmian till. These peats provided a large number of fir macrofossils and a continuous record of a mixed *Abies/Picea* forest dated to the Late Eemian (Guiter, 2003; Guiter et al., 2005). This study allowed then to re-evaluate regional pioneer studies on “old and famous” organic deposits discovered in the surroundings.

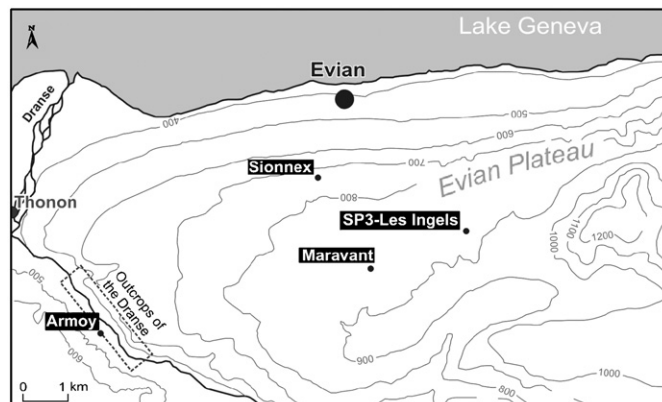


Fig. 2. Location of sites in the Evian region discussed in this review.

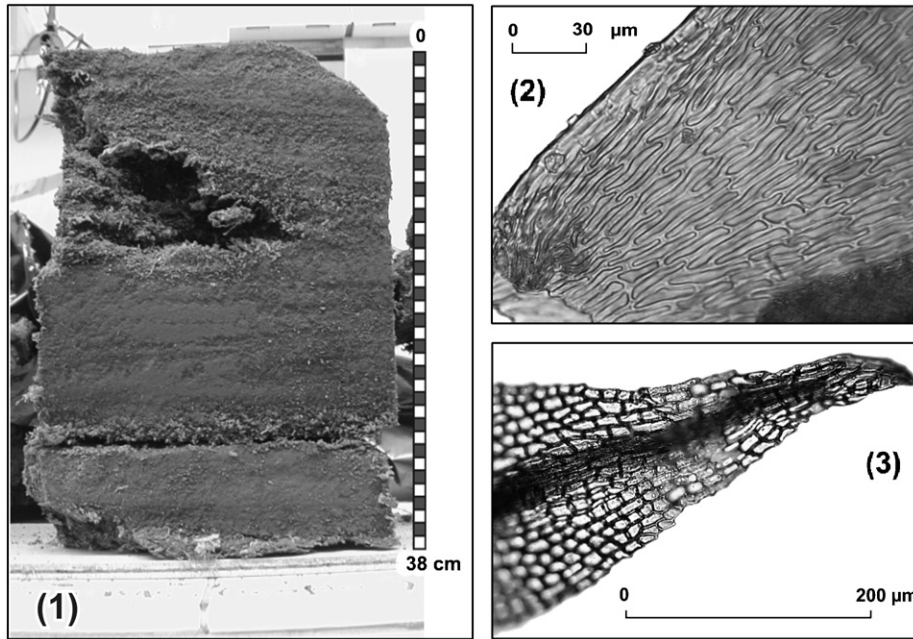


Fig. 3. (1) Picture of peats sampled at Maravant in perfect state of preservation and exclusively made up of fossils of (2) *Calliergon trifarium* and (3) *Meesia triquetra*, mosses (pictures of apical leaves).

2.1. Peats and lignites of Armoy

Favre (1867) was the first who described lignites and organic layers intercalated between two glacial units in the Evian region. These organic deposits (1.5 m thick) cropped out over 300m laterally in the Dranse valley and were particularly rich in *Abies* fossils such as wood fragments and strobiles. Later, the lignite layers were buried by slumping, preventing the opportunity of further palynostratigraphical study.

However, these abundant paleobotanical remains of fir indicated that dense *Abies* forests occupied the surroundings of the Dranse River (altitude ca. 400 m) and probably the Evian plateau. *Abies* is a telocratic tree which does not tolerate cold winter temperatures (Zagwin, 1996; Tzedakis et al., 2001). The local abundance of fir in the region is therefore strong evidence for assigning the lignites of Armoy to an interglacial period or to a warm-temperate episode. It remained however difficult to assign undoubtedly these deposits to a specific interglacial (or even interstadial) without pollen analysis.

One century later, new organic deposits called “peats” were discovered underneath Armoy (Lemée and Bourdier, 1950; Bourdier, 1962). Bourdier (1962) firstly supposed that these layers were contemporaneous with the lignites described by Favre (1867). Nevertheless, the pollen analysis showed high percentages of *Picea* and *Pinus*, whereas *Abies* was rare, and *Fagus* and *Carpinus* were totally absent (Lemée and Bourdier, 1950).

Lemée and Bourdier (1950) thus studied some organic layers which cannot be correlated with the “Lignites d’Armoy” (described by Favre, 1867) in the light of the pollen assemblages, suggesting that these peaty sediments

probably belonged to an interstadial complex. These deposits also disappeared from the Dranse outcrop after sudden erosion episodes (at present, it is impossible to accurately locate the sites).

Further palynostratigraphical investigations were carried out on organic layers outcropping between two glacial complexes at Armoy, above the presumed position of the lignites described by Favre (1867). Studies distinguished two types of sediments:

- One dominated by high values of *Abies* (reaching 70.7%) associated with *Picea* (reaching ca. 17%) (Brun and Delibrias, 1967; Brun, 1977) and
- one characterized by pollen spectra dominated by *Picea* (reaching a maximum at 78%) and *Pinus* associated with *Juniperus*, *Hippophae* and other steppics (Chenopodiaceae, Poaceae, *Artemisia*) typical of interstadial periods (Brun, 1966; Arn, 1984). These organic layers could be contemporaneous with one interstadial dated to the first half of the Würmian Pleniglacial *sensu lato* (Brun, 1966).

These diagrams are generally based on very low number of pollen spectra and poor pollen assemblages. Moreover, floristic composition observed in the “Armoy interstadial formations” is not always discriminative. In such circumstances, any chronological assignment remains risky.

Recently, a regional review was proposed by Brun (2000) concluding that some organic layers discovered at Armoy might have been deposited during MIS 7, MIS 9 or even during the Holsteinian. This hypothesis is based on the dominance of *Abies* and the presence of *Picea* and *Fagus* in sandy layers. This proposal is rejected, as similar pollen assemblages can also be found in several Late Eemian

European reference pollen profiles. For example, at Les Echets, a phase with *Abies* predominating associated with *Picea* and *Fagus* can be observed in the later part of the Eemian (see palynozones B6a and B8 in Beaulieu and Reille, 1984). Postulating that the organic deposits from Armoiy are not reworked (contrary to the hypothesis of Arn, 1984), a Holsteinian age cannot be established for these formations: at Armoiy, the absence of relevant pollen taxa such as *Pterocarya* or *Taxus* and the low percentages of *Fagus* (while *Abies* is dominant) is not compatible with alpine Holsteinian pollen records from La Côte (Field et al., 2000) and from Thalgut (Welten, 1988). Moreover the high *Abies* pollen percentages are only observed at Armoiy in three spectra (Brun and Delibrias, 1967; Brun, 1977).

Hydrogeological cores on the southern bank of Lake Geneva (Blavoux, 1966, 1988; Triganon, 2002; Triganon et al., 2005) and geomorphological investigations carried out in the Dranse valley (Burri, 1963, 1977; Olive, 1981) indicated lithological contacts between the substratum and remnants of Rissian tills, and between the substratum and the Würmian glacial complexes in the Evian region. In this context, hypothesis of the presence of pre-Rissian organic deposits (especially of Holsteinian age) in the Dranse valley is speculative.

In conclusion, (1) recent evidence of the presence of Late Eemian peats in the Evian area (Guiter, 2003; Guiter et al., 2005), (2) observations of *Abies* cones made by Favre (1867) underneath Armoiy and (3) high pollen percentages of *Abies* and *Picea* identified in some peats in the Dranse valley (Brun and Delibrias, 1967) strongly suggest that Eemian lignites and peats formerly outcropped at Armoiy. Lastly, some peats of Armoiy characterized by pollen assemblages dominated by *Picea* and *Pinus* (Lemée and Bourdier, 1950; Bourdier, 1962; Brun, 1966; Arn, 1984)

could be assigned to post-Eemian interstadial episodes (probably to the boundary MIS 5/MIS 4). This however cannot be firmly established.

A new pollen study on lignite fragments sampled at Armoiy by M. Dray in the 1950s (personal communication) was attempted in order to disentangle the matter. Unfortunately, the pollen record was characterized by very poor pollen assemblages and was dominated by a low number of corroded saccate grains of *Picea*, *Pinus* and *Abies*. At present, the outcrop is buried by a landslide and the organic deposits of Armoiy are not accessible.

2.2. "Intra-glacial organic layers" of the Evian Plateau

During hydrogeological investigations carried out in the Evian plateau (Blavoux, 1966; Triganon, 2002), several organic layers were discovered in interstadial complexes intercalated between Würmian glacial formations and were studied by pollen analysts (Blavoux and Brun, 1966; Brun, 2000; Guiter, 2003). Fig. 4 presents a summary diagram of the Sionnex profile studied by Blavoux and Brun (1966). The pollen record is dominated by trees, principally by *Pinus* (reaching 80% of the total pollen sum at its optimum) associated with *Abies* and *Picea* (two sporadic peaks, respectively, at ca. 26% and 12% in the pollen zone 5, Fig. 4) and is very poor in herbaceous taxa. Pollen grains were rare and much corroded, and taxonomic determinations remained difficult (Brun, personal communication). As a result, the diagram is characterized by a low number of taxa. Moreover, the pollen record is discontinuous: Interstadial Complex I (dominated by alternations of organic layers and sandy-gravelly deposits, see Fig. 3) is marked by fragmented pollen curves.

Fig. 5 shows the "SP3-Les Ingels" pollen profile (Guiter, 2003) of an interstadial complex identified by Triganon

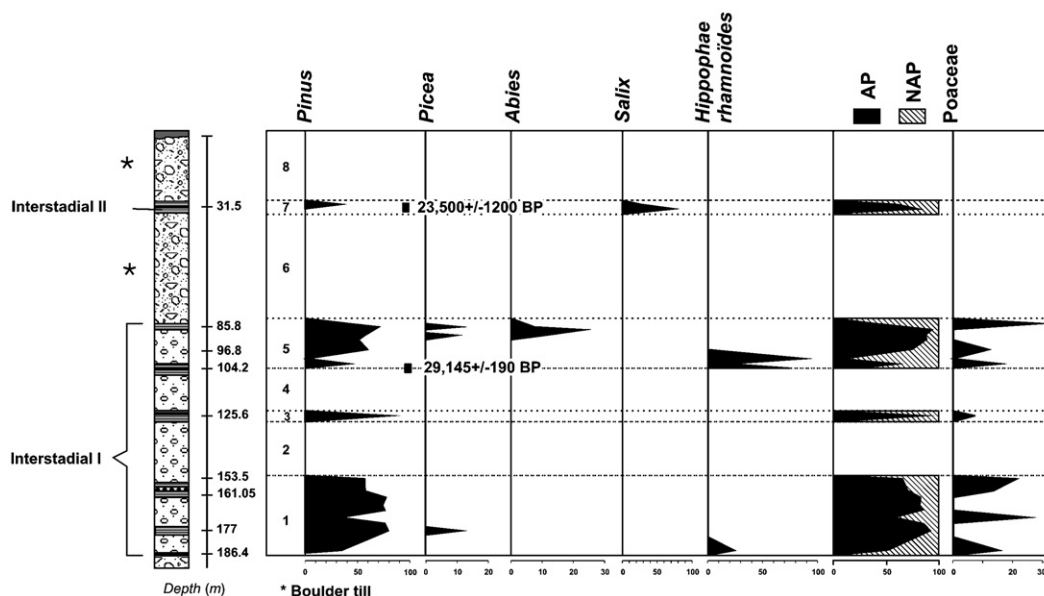


Fig. 4. Simplified pollen diagram of Sionnex (modified from Blavoux and Brun, 1966). The interstadial I is characterized by alternation of organic and sandy-gravelly layers.

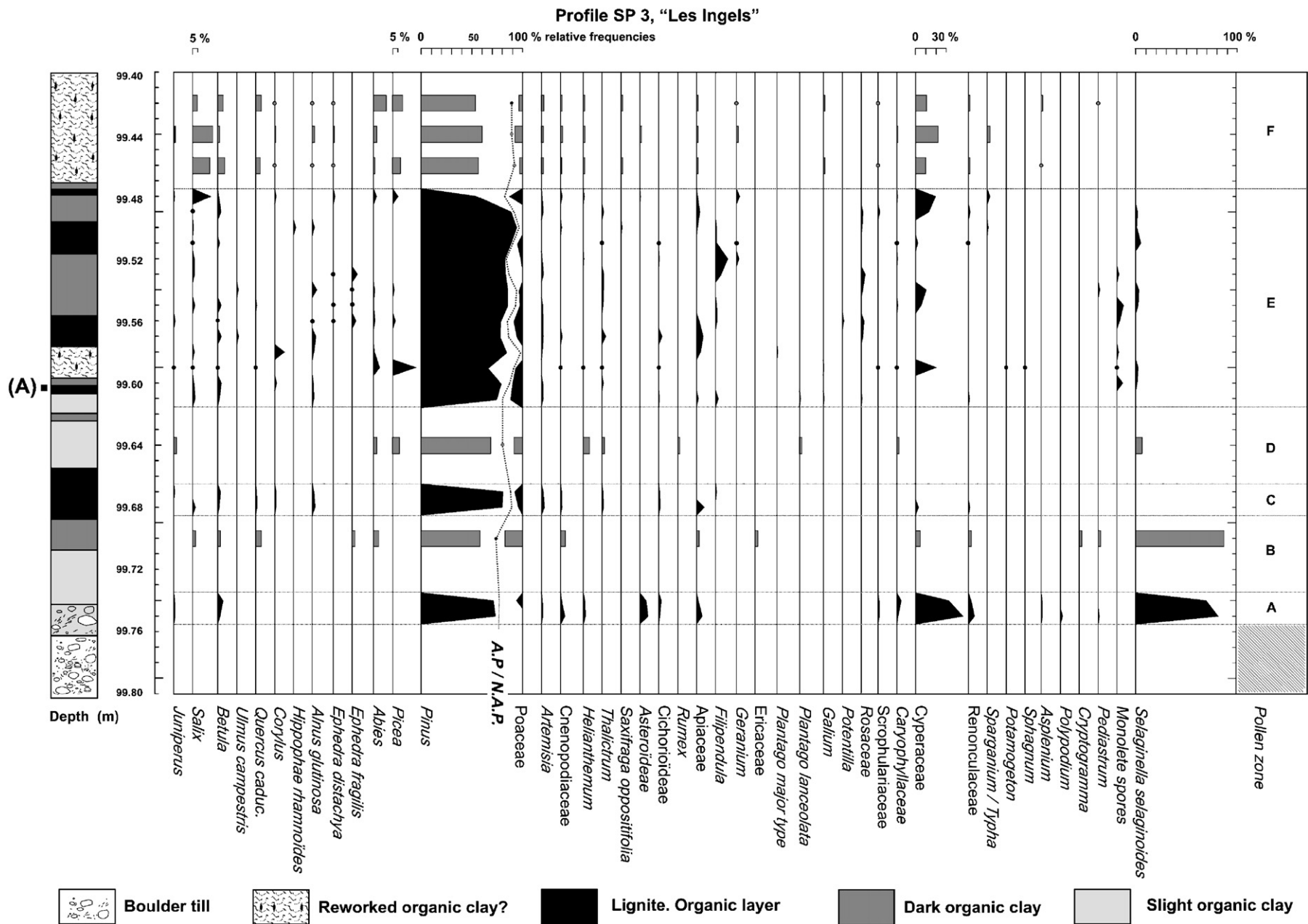


Fig. 5. Simplified pollen diagram of SP 3-Les Ingels (modified from Guiter, 2003); grey rectangles represent pollen spectra isolated by hiatuses. (A) Organic level ¹⁴C dated ≥ 54,000 years BP.

(2002) in a huge Würmian glacial unit covering the Evian Plateau. The quality of the pollen record is similar to that observed in the Sionnex diagram: pollen assemblages are dominated by *Pinus* (AP/NAP ratio is constantly higher than 80%), and pollen grains are deeply eroded (Guiter, 2003). Pollen curves are also discontinuous in the less organic layers of the interstadial sedimentary complex. *Picea* and *Abies* are significantly represented in the pollen record (*Picea* maximum at 23% in the pollen zone E, *Abies* maximum at 11.5% in the pollen zone F, Fig. 5).

Both pollen analyses showed vegetation dominated by *Pinus*, with steppic herbaceous taxa (Poaceae, Chenopodiaceae, *Artemisia*) associated with significant values of *Picea* and *Abies*. Pollen assemblages in the Sionnex profile were assigned by Brun (2000) to the transition between the Saint Germain II (OIS 5a) and the Lower Würmian Pleniglacial (OIS 4). This transition is similarly documented in some profiles from Switzerland (Welten, 1982; Wegmüller, 1992), and in south-western Germany at Jammertal (Müller, 2000), but with low percentages of *Abies*. Fir is also sparsely represented at Les Echets after the Eemian except during the Saint Germain I, where it is associated with high values of beech (Beaulieu and Reille, 1984). The sporadic maxima of *Abies* and *Picea* recorded in both Sionnex and “SP3-Les Ingels” interstadial complexes are problematic. Stratigraphies appear deeply disturbed as suggested by discontinuities of the pollen curves: pollen spectra dominated by *Abies* are isolated between large hiatuses and correspond to sandy-gravelly formations (Figs. 4 and 5). Consequently, there are reservations about any chronology based on these pollen data, especially concerning the palynostratigraphical significance of *Abies* and *Picea* in these interstadial layers.

Radiocarbon dates on some organic layers provided ages between $29,145 \pm 190$ BP (on a wood fragment, ref. LYON-876-OXA in Triganon et al., 2005) and $23,500 \pm 1200$ BP (on peat, ref. GIF-333 in Blavoux, 1966) for Sionnex interstadial formations (Fig. 3) and $\geq 54,000$ BP (on a *Pinus* wood, ref. Gif sur Yvette Div 2000–008 in Guiter, 2003) for “SP3-Les Ingels” interstadial (Fig. 4). The ages obtained at Sionnex are in contradiction with the palynostratigraphy proposed by Brun (2000). The infinite age obtained for SP3 profile is obviously problematic. This suggests, however, that the Sionnex interstadial and the SP3 interstadial might not be contemporaneous.

Can these organic layers correspond to “true” interstadial episodes? Chaotic pollen curves and alternation of organic silts and gravelly formations may indicate that the sedimentation basin was not a true peat-bog but rather an ephemeral mire recurrently disturbed by large detrital phases. It is highly probable that margins of the Rhone glacier rapidly fluctuated on the Plateau at that time (Triganon et al., 2005). As a result, profiles from Sionnex (Blavoux and Brun, 1966) and “SP3-Les Ingels” (Guiter, 2003) could have recorded this great instability of repeated ice retreats on the Plateau during rapid Würmian

temperate phases. In this context, the biostratigraphical relevance of these pollen diagrams is very uncertain.

The presence of Late Eemian peats was recently noted on the Evian Plateau: pollen and plant macroremains of *Abies* and *Picea* were very abundant in perfectly preserved peats interbedded between two glacial units (Guiter, 2003; Guiter et al., 2005). These peats could be correlated with the oldest organic layers identified in the Dranse valley, at Armoiy (Favre, 1867; Brun and Delibrias, 1967). Some “Peats of Armoiy” (studied by Lemée and Bourdier, 1950; Arn, 1984) could be contemporaneous with early Würmian temperate episodes.

The “interstadial” formations (SP3-Les Ingels and Sionnex “interstadials”) identified in the Evian plateau could be dated to the Würmian Pleniglacial *sensu lato* (Fig. 5) (Blavoux and Brun, 1966; Brun, 1966, 2000; Guiter, 2003). These episodes probably correspond to periods of great instability of a declining Rhône glacier during the last glacial cycle.

Fig. 6 attempts chronostratigraphical correlations between organic deposits from the Evian area. Considering discordant dates obtained at Sionnex and SP3-Les Ingels and the overall low quality of the pollen data, this scheme is a proposal that remains debatable.

3. Lignites of Montfleury: which interglacial?

The Lignites of Montfleury were discovered in the Geneva basin during hydrogeological coring in 1946 and

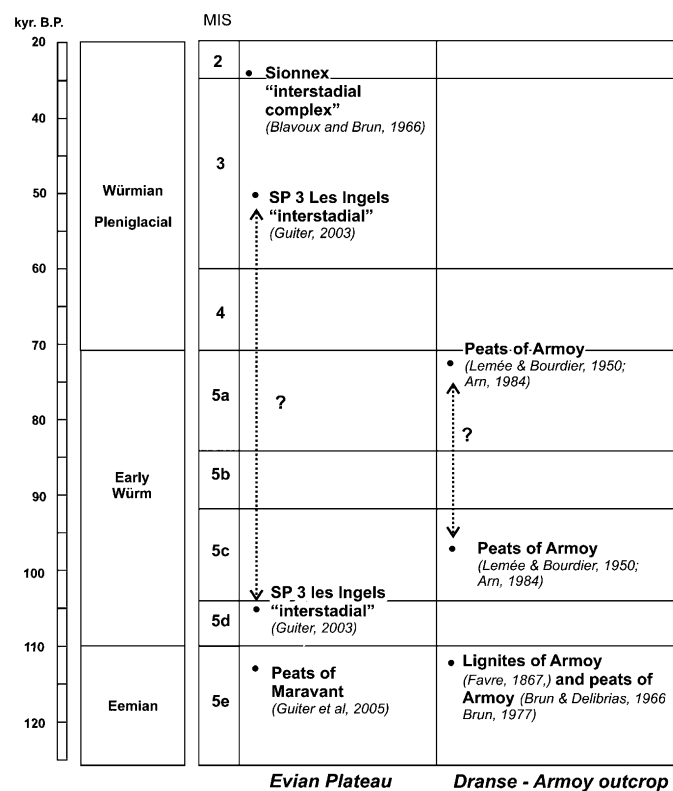


Fig. 6. Proposal of chronostratigraphical correlations of intra-glacial organic layers discovered in the Evian plateau and in the Dranse valley, at Armoiy.

studied initially by Lüdi (1953). These deposits underlie a 54-m-thick deposit of sandy–gravelly formations. Malacological and palynological analyses indicated forested and paludal environments (Lanterno et al., 1981). Pollen assemblages were dominated by *Picea* and *Abies* associated with thermophilous trees such as *Carpinus*, *Fagus* and *Tilia*. The age of the formations remained problematic: according to the reference work of Woillard (1978), Lanterno et al. (1981) correlated the lignites to the Eemian.

Later, a new core provided a long detailed pollen profile (Wegmüller et al., 1995). The pollen diagram is dominated by *Picea* and *Pinus* in association with *Abies* and some thermophilous taxa such as *Carpinus*, *Tilia*, *Buxus*, *Juglans* and *Fagus*. Very corroded stephanoporate grains (similar to *Pterocarya* pollen type) were also detected. Considering the poor preservation of pollen, the authors did not interpret these occurrences.

Wegmüller et al. (1995) assigned the Lignites of Montfleury to the Holsteinian interglacial. They observed the early development of *Picea* prior to the *Abies* phase, the presence of *Fagus* and *Buxus*, and high values of *Tilia*, at the base of the pollen profile.

The interglacial formations of Montfleury remain difficult to integrate in a robust palynostratigraphical framework. Ruling out the hypothetical presence of *Pterocarya*, it must be conceded that pollen assemblages observed at Montfleury are not incompatible with characteristics of the Eemian interglacial, even of the Saint Germain I and II interstadials. Occurrences of *Buxus* are recorded in several European Eemian profiles (Beaulieu and Reille, 1984; Wegmüller, 1992; Drescher-Schneider, 2000). *Tilia* is also well-represented, associated with *Fagus* during the Saint Germain II (Beaulieu and Reille, 1989). High values of *Fagus* are recorded during the Saint Germain II at Les Echets (Beaulieu and Reille, 1984) and in Italy (Follieri et al., 1988; Allen and Huntley, 2000; Allen et al., 2000).

Lastly, the pollen diagram from Montfleury is not characterized by well-marked vegetation dynamics. It is difficult to identify a noticeable expansion of *Picea* preceding an *Abies* phase.

The lithology of the interglacial formations of Montfleury should be considered with caution: lignite layers are scarce and scattered within thick sandy–gravelly formations. Wegmüller et al. (1995) identified in the sedimentary profile (sic) “une structure tourmentée” i.e. a disturbed structure, with pebbles intercalated. The authors proposed that Eemian deposits were completely eroded by successive Würmian ice advances. This is also what probably occurred with older organic deposits before the penultimate glaciation (unanimously considered as more intense and erosive than the last one). Accordingly, each glacial/deglacial pulse could have reworked and re-deposited organic sediments older than the pulse itself.

Thus, the pollen record could have been polluted by pollen reworked from older interglacial and/or interstadials. The presence of corroded stephanoporate grains of

Pterocarya and *Juglans* is possible. Palynostratigraphical interpretation remains difficult: the formations of Montfleury could be contemporaneous either with the last interglacial, the penultimate interglacial or be even older.

4. Lignites of the Annecy Basin

Annecy Lake was eroded during the Last Glaciation, at the confluence of local glaciers and the larger Arve glacier which contributed to the French Rhone main ice stream. The basin fill recorded several phases of erosion and deposition since the onset of the deglaciation of the area (Van Rensbergen et al., 1998). Lignites were discovered in silty–clayey formations underneath moraines on the margins of the present lake. These sediments were deposited in a large palaeolake that occupied the basin during the last interglacial (Manalt, 1998; Brun et al., 1999).

The first palaeobotanical investigations recognized an abundance of macrofossils (wood and cones) and pollen of *Picea* in the lignites (Le Roux, 1920; Lemée, 1951). The main outcrops of Nanceau and Bornette (Fig. 7) were studied and provided five pollen records characterized by significant values of mesophilous trees (*Corylus*, *Ulmus*, *Tilia*, *Quercus*, *Carpinus*, *Pinus* and *Picea*) (Brun and Hanns, 1987; Brun, 1995; Brun et al., 1999, 2000). Following Brun (1995, 2000), these profiles are assigned to the period ranging from the Saint Germain I to the boundary MIS 5/MIS 4.

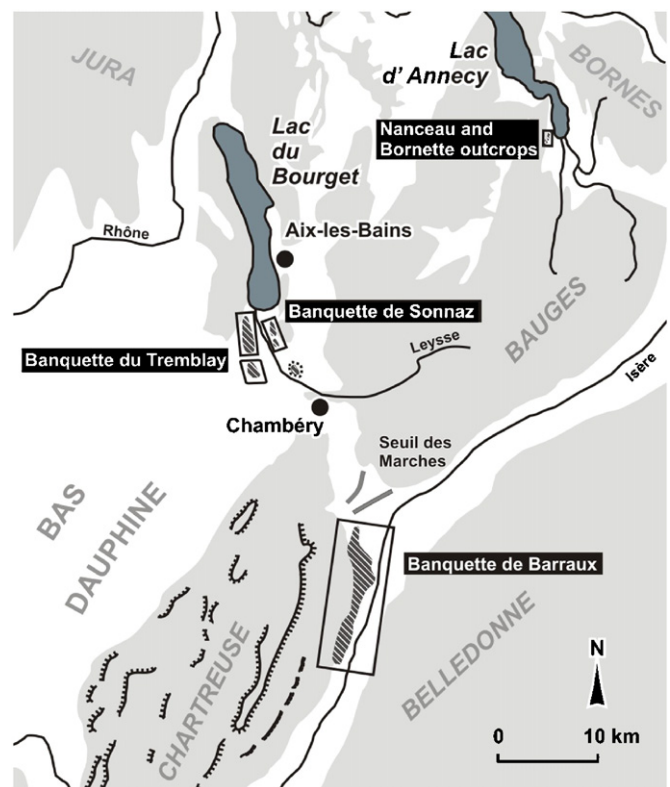


Fig. 7. Location of the different “banquettes savoyardes à lignites” (lignites of North Gresivaudan, lignites of Chambéry and lignites of Annecy).

Nearby, a core was sampled at LaThuile (Hannss, personal communication). Pollen analysis was carried out but diagrams were not included in two publications about the site (Pesckhe, unpublished in Pross et al., 2000; Klotz et al., 2003). Nevertheless, two different ages of the LaThuile profile were proposed. Pross et al. (2000) proposed a Holsteinian age, but in Klotz et al. (2003), the LaThuile profile is assigned to the transition Eemian/Early Würm. These suggestions cannot be evaluated without a published pollen diagram. However, pollen data (Brun, 1995; Brun et al., 2000) and macrofossils described by Le Roux (1920) clearly indicate that mixed *Pinus-Picea* forests surrounded the Annecy palaeolake, probably at the transition between the last interglacial and the early phases of the last glaciation (Brun et al., 1999).

5. Lignites of Chambéry

The Chambéry area was invaded by the Arc and the Isère glaciers which joined the main ice stream of the Rhone glacier. The Chambéry basin is an alluvial plain with lignite formations outcropping on bordering slopes between 240 and 340 m altitude (Hannss, 1982). The stratigraphy of these deposits, located south of the Bourget Lake, is summarized below:

- basal till, covered by glacio-lacustrine deposits;
- sandy formations rich in lignite; and
- fluvio-glacial sediments covered by discontinuous glacial sediment.

The lignite formations were investigated by geomorphologists (Nicoud, 1981; Hannss, 1982) and pollen analysts (Lemée, 1951; Gremmen, 1982). The question of the ages of these lignites was raised as expected (Hannss and Pesckhe, 1992; Gremmen and Hannss, 1994).

5.1. La Banquette de Tremblay

Gremmen (1982) studied two profiles at “La Banquette de Tremblay” (Figs. 1 and 7): “Ruisseau des Combes” and “La Motte-Servolex” profiles.

5.1.1. Ruisseau des Combes

The pollen record of Ruisseau des Combes is characterized by high values of *Abies* and *Alnus*, associated with *Carpinus* and *Buxus* at the base; followed by a significant increase of *Picea* percentages while *Abies* remains stable and *Carpinus* values decrease. The uppermost part shows a decrease of tree taxa and the development of steppic plants (*Artemisia* and Poaceae).

Gremmen (1982) assigned these deposits to the transition between the Late Eemian and an early Würmian interstadial, i.e. the Saint Germain I (Hannss and Pesckhe, 1992; Gremmen and Hannss, 1994). Beaulieu et al. (1992), later supported this hypothesis by comparison with Les Echets pollen record. However, comparison with the Les

Echets profile also shows that the pollen record of Ruisseau des Combes comprises hiatuses, as the *Abies/Picea* phase (typical of the Late Eemian vegetation dynamics) is incompletely recorded.

5.1.2. La Motte-Servolex

The site of La Motte-Servolex was firstly investigated by Gremmen (1982) and later by Gremmen and Hannss (1994). This last study provided a detailed pollen record. The pollen diagram (Fig. 8) is characterized by a first expansion of *Alnus* (pollen zones 1–3) followed by a phase with *Picea* predominant (pollen zone 4). *Abies*, *Carpinus*, *Ulmus* and *Acer* are also present during this phase. Then, *Pinus* became abundant while *Picea* percentages progressively declined (pollen zone 5). Following Gremmen and Hannss (1994), the first half of the pollen record (pollen zones 1–5) is correlated to the Late Eemian interglacial.

The second part of the pollen diagram is characterized by rapid episodes dominated by *Picea* (associated with *Abies* and *Carpinus*) alternating with periods of *Alnus* and *Betula* expansion (pollen zones 6–11). The very end of the pollen record is marked by a return of *Pinus* (pollen zones 11 and 12) followed by *Artemisia* (pollen zone 13), while other trees decline dramatically. Therefore, Gremmen and Hannss (1994) assigned this part of the pollen record to the Saint Germain I interstadial.

The second part of the pollen record is more difficult to interpret. The vegetation dynamics seems to be cut off, abruptly interrupted, and even sometimes “repeated” in the record. Previously, Beaulieu et al. (1992) noticed this feature in the first diagram studied by Gremmen (1982), and suggested that slumping might have occurred in the outcrop. The pollen record probably comprises hiatuses as well: the lower part of the pollen record seems disturbed (see pollen zones 1 and 2, Fig. 8) and the Melisey I stadial (OIS 5d) is missing. These hiatuses or sediment reworking may have occurred during the Mélisey stadials.

Lastly, it must be noticed that *Alnus* percentages fluctuate substantially. This may induce distortion of the pollen representation of other tree taxa. Accordingly, the second half of the pollen record at Servolex could be partly altered.

5.2. La Banquette de Sonnaz

Gremmen (1982) also studied several profiles sampled in “La Banquette de Sonnaz” (Figs. 1 and 7). All pollen records were characterized by high values of *Picea* and *Pinus*, suggesting that the lignites were deposited during the earliest phases of the Würm *sensu lato*. However, discontinuities in the diagrams, erratic pollen curves and high percentages of local pollen taxa (*Betula*, *Alnus*, Cyperaceae) necessitate caution in the chronological interpretation. For example, in the Voglans pollen records (Fig. 9), vegetation dynamics are marked in both diagrams by irregular peaks of *Pinus*, *Betula* and *Alnus*, while *Picea* remains abundant. A phase dominated by steppe herbs

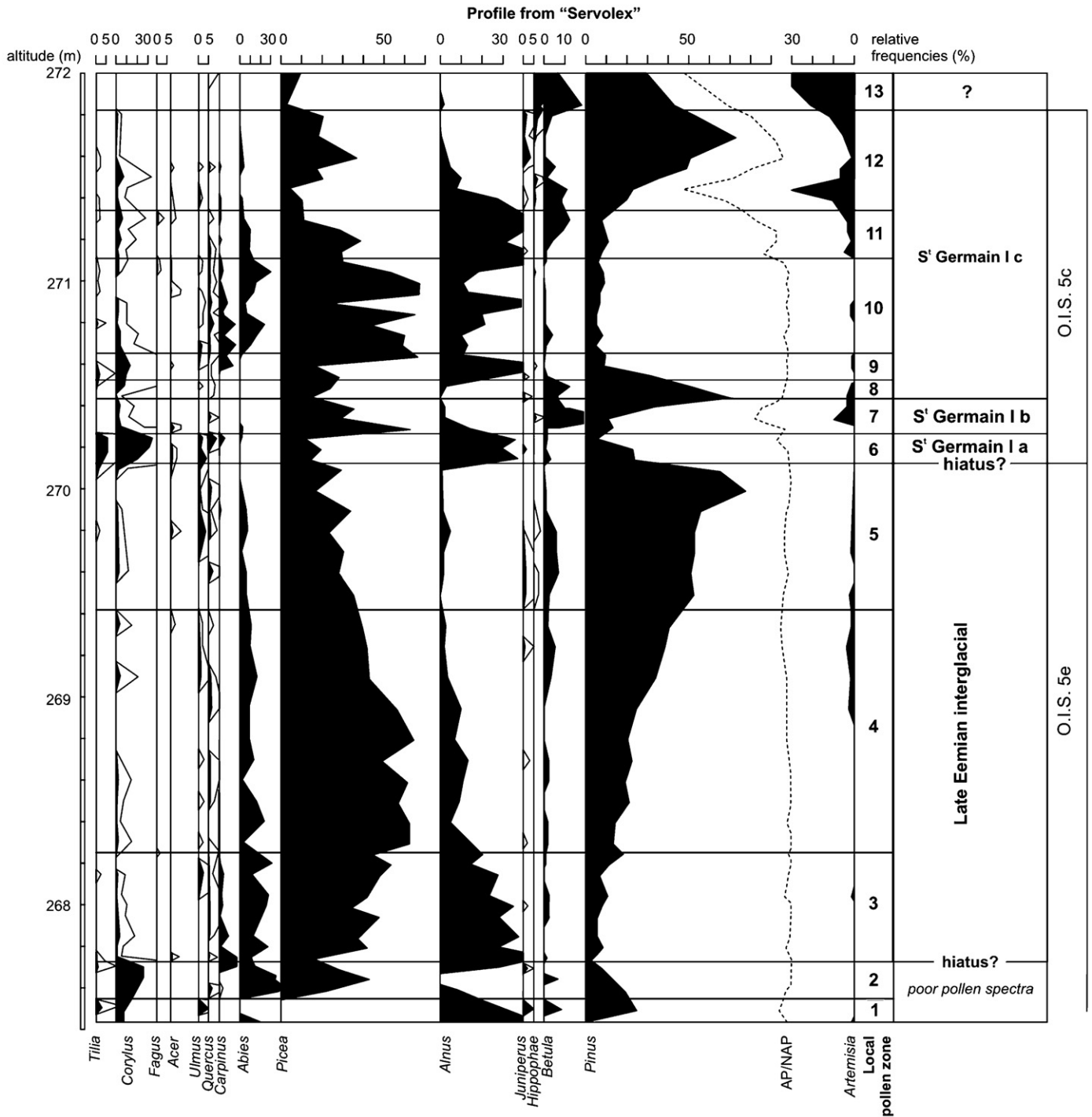


Fig. 8. Simplified pollen diagram of Servolex -"Lignites of Chambéry" (modified from Gremmen and Hannss, 1994).

(*Artemisia*, Chenopodiaceae) is also recorded at the very top of Voglans I profile.

It is difficult to identify two distinct temperate episodes in the light of these pollen data. Following Beaulieu et al. (1988), the vegetation successions recorded at Voglans are not clear enough to permit any chronological assessment. Moreover, Gremmen (1982) probably underestimated post-sedimentary disturbance, and it is highly probable that Voglans I and III profiles belonged to the same

stratigraphical unit. This could explain the similarity of both pollen records.

In conclusion, the lignites located between Chambéry and Bourget Lake are difficult to date with accuracy. They could be contemporaneous with the transition Eemian/early Würm but the lithostratigraphical correlations proposed by Gremmen (1982) cannot be accepted. According to Gremmen, six early Würmian interstadial temperate periods could be defined. Now, long pollen

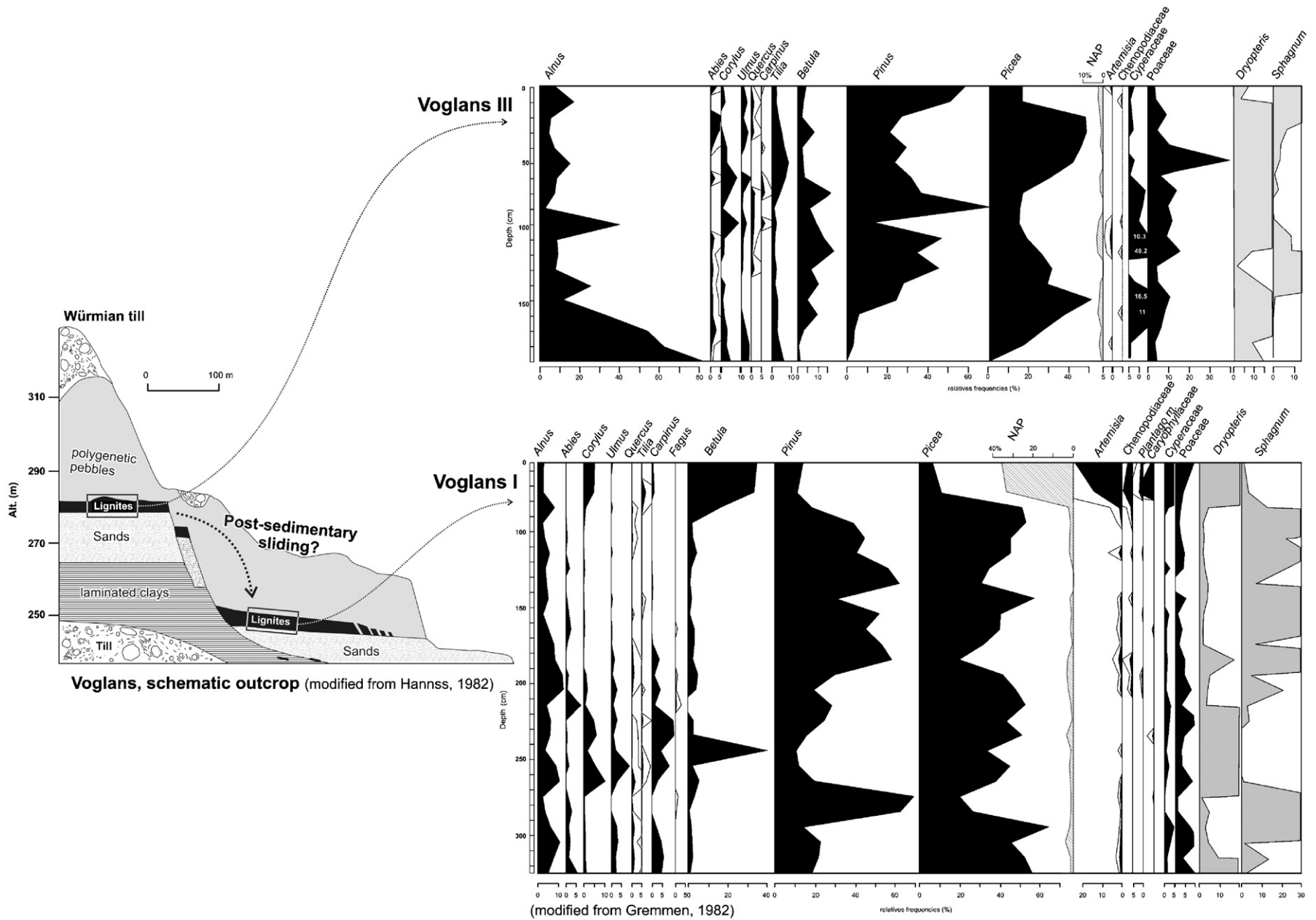


Fig. 9. Simplified lithology and pollen diagrams of Voglans, (modified from Gremmen, 1982; Hannss, 1982); grey curves represent taxa excluded from pollen sum.

reference profiles provided evidence of only four forested post-Eemian episodes, i.e. Saint Germain I and II, and the controversial Dürnten interstadials *sensu* Welten (1982) which might be correlated with Ognon I and Ognon II interstadials recorded at la Grande Pile (Guiter et al., 2003). The site “Servolex” provided the most detailed pollen profile for the area (Gremmen and Hanns, 1994), but the presence of hiatuses remains problematic.

A recent palaeobotanical study carried out in Switzerland at Niederweningen demonstrated that an open tundra forest with *Picea abies*, *Larix* and *Betula* recurrently occupied the area during the Middle Würmian Pleniglacial (MIS 3) around 45,000 BP (Drescher-Schneider et al., 2007). Some lignites of Chambéry (characterized dominance of *Pinus* and *Picea*) could possibly be contemporaneous with the peats of Niederweningen, suggesting that Lake Bourget was unglaciated at that time. However, as pointed out by Beaulieu et al. (1992), slumps have probably disturbed the outcrops of the Chambéry area by creating “stratigraphic doublings”. Any chronostratigraphical correlations would be exceedingly speculative.

6. Lignites of North Grésivaudan

North Grésivaudan is located north-east of Grenoble and corresponds to the alluvial plain of the Isère. As in the Chambéry area, this plain is bordered by alluvium terraces called “Banquette de Barraux” on the right bank of the Isère (Fig. 7). Pioneer studies on this famous geological formation described lignite layers intercalated into alluvium (Gras, 1852; Lory, 1864). The first palaeobotanical investigation was carried out one century later by Depape and Bourdier (1952): they discovered leaf imprints and fructifications of *Buxus sempervirens*, *Abies alba*, *Carpinus betulus*, *Tilia*, *Acer* and *Rhododendron ponticum*. As pointed out by Tralau (1963), identification of *Rhododendron* species is not possible from leaf morphology. However, the rest of the palaeoflora is easy to determine from leaves. Therefore, the presence of meso- and thermophilous tree fossils clearly shows that the lignites studied by Depape and Bourdier (1952) were deposited during an interglacial period. Subsequently, pollen analyses carried out at La Flachère confirmed this hypothesis.

6.1. La Flachère

Gremmen (1982) carried out palynological investigations on a new profile sampled in the “Banquette de Barraux”, called La Flachère. He described an alternation of lignites and clays underneath moraines. Following Fourneaux (1976); Gremmen (1982) proposed that the deposits of “La Flachère” were deposited on the margins of a huge interglacial lake covering the Grésivaudan. During low lake-level periods, marshy vegetation was developed and fossilized (lignites). When lake-level was high, sedimentary

processes were dominated by minerogenic and detrital input (clays).

Pollen analysis indicated that lignite layers are dominated by tree taxa, *Picea* at the base of the profile and *Pinus* in the upper part. Thermophilous taxa (*Carpinus*, *Quercus*, *Ulmus* and *Tilia*) are represented regularly. Herbs were dominated by Poaceae, Cyperaceae and *Artemisia*.

Later, a more detailed study was carried out by Peschke et al. (2000) from 10 m thick sediments underneath the La Flachère profile studied by Gremmen (1982). As a result, Peschke et al. (2000) proposed a synthetic diagram (Fig. 10) composed of the new profile at the base, and the pollen diagram from Gremmen (1982) for the upper part. This composite diagram is the most detailed for the Banquette de Barraux. It describes the vegetation dynamics in the North Grésivaudan between the end of Eemian and the onset on the Last Pleniglacial (Peschke et al., 2000).

The base of the pollen record is fairly comparable to the Late Eemian recorded at Les Echets (Beaulieu and Reille, 1984, 1989), with high percentages of *Picea* (to 60%) and significant values of *Abies* (5–10%). Fir values are less high than in the Maravant record (where *Abies* reaches 60%), but it is likely that this difference was due to local conditions and to the altitudinal difference of 300 m between the two sites.

The end of the lower profile is characterized initially by a lowering of the AP/NAP pollen curve and a development of *Artemisia*, corresponding to the Melisey I stadial (OIS 5d). Subsequently, a moderate re-expansion of *Picea* associated with occurrences of *Ulmus*, *Abies*, *Fagus* and *Carpinus* characterizes a return of temperate conditions (Saint Germain I). The upper spectra (probably incomplete) are assigned by Peschke et al. (2000) to the Melisey II. The upper “La Flachère” profile (Gremmen, 1982) is dominated by *Pinus* together with *Picea*, corresponding to the transition between the Saint Germain II and the oldest pine-spruce interstadial of the Würm.

Following Gremmen (1982) and Peschke et al. (2000), the lower deposits probably represent the period between the end of the last interglacial and the beginning of the Lower Würmian Pleniglacial. This diagram is certainly the most complete record of the vegetation dynamics for this period in the Isère valley.

6.2. Cotagnier and Brignoud profiles

Gremmen (1982) studied other pollen profiles from sites located in the North Grésivaudan: Cotagnier and Brignoud. The first one was unfortunately composed of only five spectra that do not allow any consistent palynostratigraphical assignment.

At Brignoud, pollen profiles are difficult to date since pollen records are very discontinuous. They are dominated by *Picea* and *Pinus* together with steppe plants (*Artemisia*,

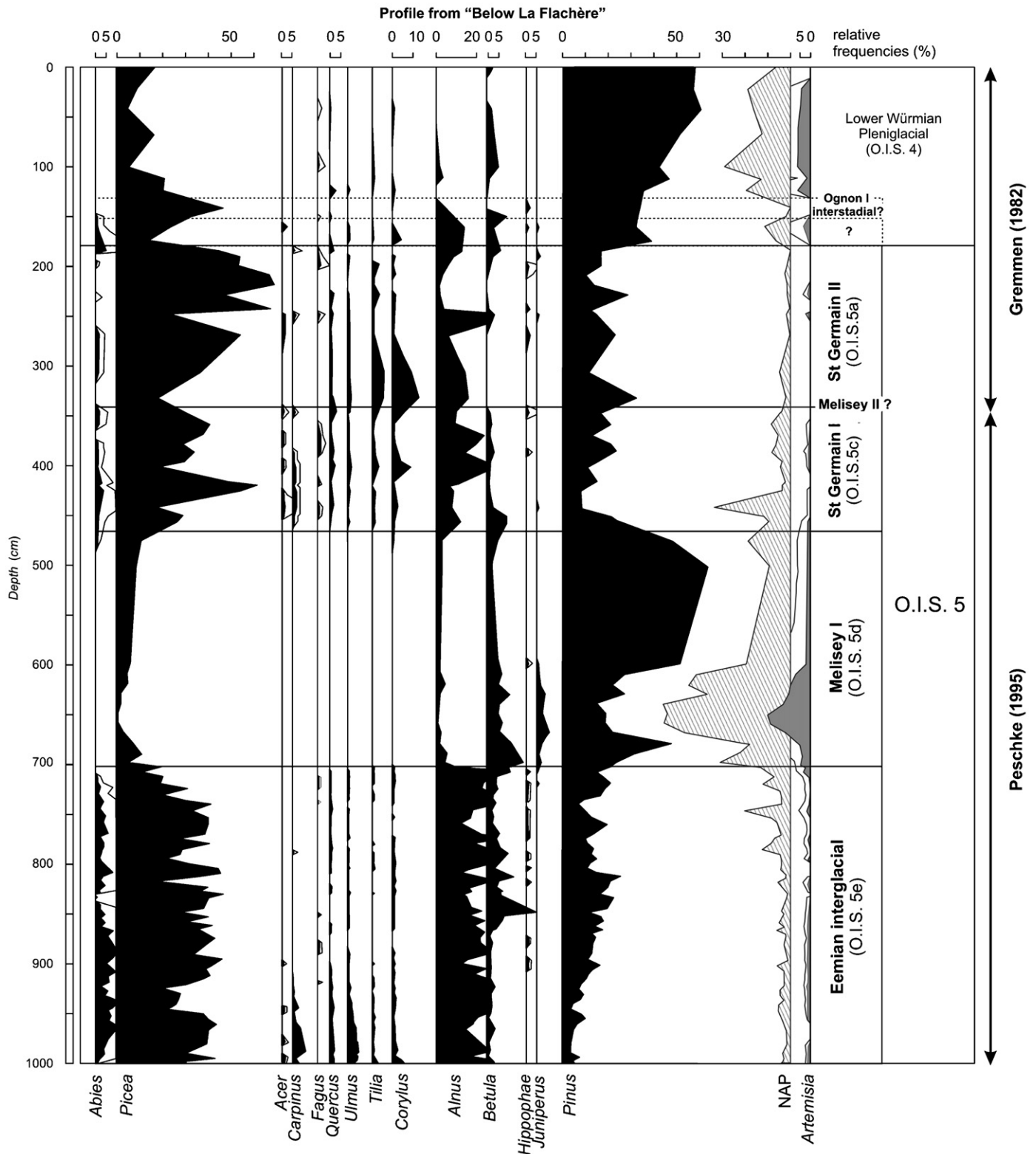


Fig. 10. Simplified pollen diagram of "Below La Flachère" (modified from Peschke et al., 2000).

Poaceae): *Artemisia* values commonly reach 30%. Following Gremmen (1982), this vegetation is characteristic of a stadial period, probably the Melisey I or II. The hypothesis of reworked pollen assemblages is highly probable.

7. Ruisseau de L'Amourette

In the intra-alpine basin of Trièves, south of Grenoble, clayish-silty deposits were identified under glacial deposits

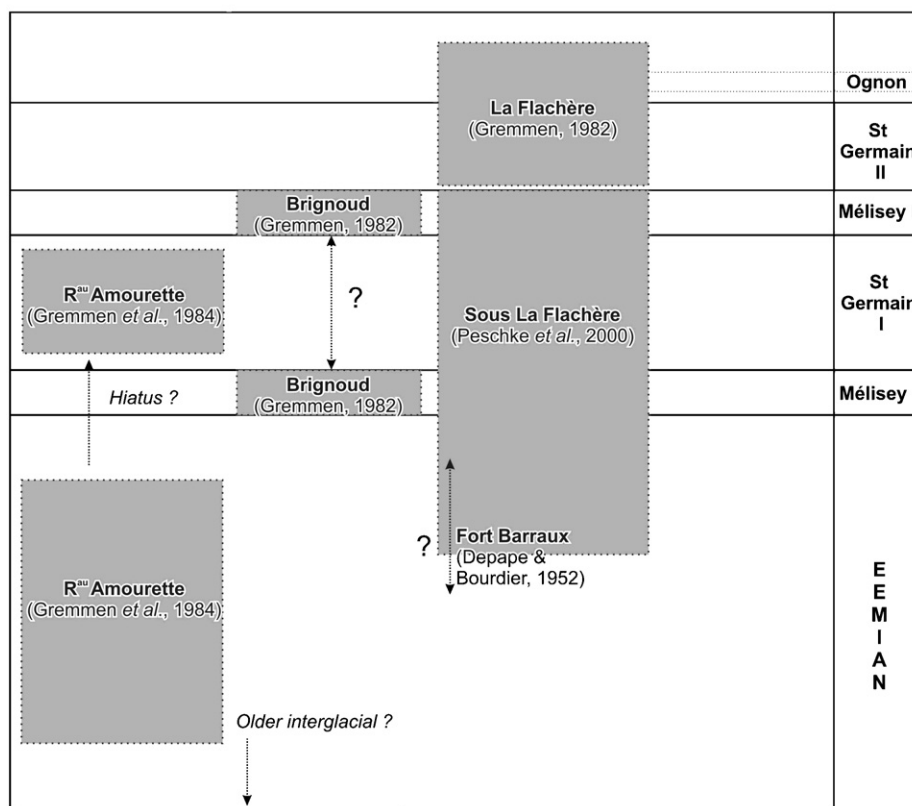


Fig. 11. Chronostratigraphical correlations of lignite formations studied in the Grésivaudan by Gremmen (1982), Gremmen et al. (1984) and Peschke et al. (2000).

with crystalline clasts, at Ruisseau de l'Amourette (between 700 and 900 m altitude). Palynological and malacological investigations (Gremmen et al., 1984) showed that at least two major warm phases could be identified, probably belonging to the Eemian and to an Early Würmian interstadial.

The pollen record showed a typical interglacial dynamics with a first phase dominated by *Ulmus*, followed by an expansion of *Quercus* and *Corylus*. Subsequently, the presence of *Carpinus*, *Abies* and a slight increase of *Fagus*, following a strong decrease of *Corylus* percentages are noted. The overlying episode is characterized by high values of *Picea* and *Abies*. The final phase was marked by a significant expansion of *Fagus* (reaching 33%) associated with *Abies* and *Picea*.

At Les Echets, but also at Ribains (Beaulieu et al., 2001), *Fagus* did not experience such great expansion at the end of the last interglacial. Substantial expansion of *Fagus* is recorded during the Saint Germain I in Les Echets record (Beaulieu and Reille, 1989). However, values of *Fagus* recorded in the interglacial deposits of Le Ruisseau de l'Amourette are amazingly high compared to what it is observed during the Eemian at Les Echets and in the Velay (Beaulieu et al., 2001). It is true that the altitude of Ruisseau de l'Amourette is very favourable to beech development.

The possibility of an older interglacial could be raised. For example, expansion of *Fagus* is also observed during the Bouchet interglacial Complex in the Velay (Beaulieu et al., 2001) and even during the Holsteinian at la Côte (Field et al., 2000) and at Thalgut (Welten, 1988) where it is associated with high values of *Abies*. A new multi-proxy investigation (including pollen and fossil Coleoptera) of the outcrop of Le Ruisseau de l'Amourette is planned in order to improve the understanding of this atypical interglacial formation.

Following Gremmen et al. (1984), the pollen record of Ruisseau de l'Amourette might overlap the Eemian interglacial period and partially the Saint Germain I interstadial. Hiatuses separate the Eemian part from the Saint Germain I (Gremmen et al., 1984) suggesting that interruptions in the sedimentation probably occurred, especially during the Mélisey I. Fig. 11 summarizes a hypothesis for the chronology of the deposits studied by Gremmen (1982) and Gremmen et al. (1984) in the surroundings of Grenoble.

8. Conclusion

At the end of this review, which is naturally not exhaustive, it must be noticed that a rich collection of organic deposits imbedded into huge glacial sediments is

available in the Western Alps. Since Erdtman (1921), many palynologists and geomorphologists have combined their forces for improving the understanding of the Quaternary environments, especially with studies of lignites. For each organic layer discovered, the challenge is to place it in a relevant chronostratigraphical framework. In this context, knowledge of long continuous pollen reference profiles is necessary.

However, at most sites only fragmentary archives are available because successive fluvio-glacial erosion phases profoundly disturbed stratigraphies. Moreover, some pioneer studies were usually based on very poor pollen assemblages and/or low number of spectra. Consequently, any interpretation remains weak. In the Dranse valley (Evian region), this problem is crucial since the outcrops of Armoiy have disappeared under slumps. The prospect of re-investigating the “Lignites and Peats of Armoiy” is compromised for the moment.

The question of the chronology of sediments studied in the Grésivaudan, the Chambéry and the Annecy basins is also quite difficult to answer with accuracy, as some pollen records are discontinuous (hiatus, slumps) or are composed of insufficient data for supporting any robust chronological hypothesis. Studies in the Isère and in the Belledone valleys (Hannss, personal communication) are in progress or to be published with reference to original interglacial formations.

In spite of the complexity of the outcrops in these regions, the general framework is:

- (1) The Isère, the Arve, the Drac and the Arc glaciers deeply eroded the valleys during glaciations prior to the Eemian and created great depressions (Montjuvent and Nicoud, 1987).
- (2) At the end of the Riss, a huge palaeolake covered a large area.
- (3) This palaeolake was rapidly filled by laminated clays, then by organic layers during the O.I.S. 5 *sl*.
- (4) Lastly, Würmian glaciers eroded these lacustrine/paludal deposits, except a few which are laterally preserved.

Today, the best record of this palaeoenvironmental history is undoubtedly the composite diagram of La Flachère (Peschke et al., 2000).

The main goal of the present paper was to re-interpret the main available pollen records from the west-alpine organic profiles within a revised palynostratigraphical framework. However palynostratigraphy cannot support by itself alpine glacial chronologies, since the pollen analyst can only work on what glaciers did not sweep away!

A well-documented geomorphological context and mostly, various means of dating are of vital importance to take up the challenge of dating sequences floating within huge glacial deposits. Efforts should be made for re-investigating these organic layers within a multidisciplinary framework, including new geomorphological prospecting.

Acknowledgments

We thank Ch. Hannss who showed us preliminary results of their great “in progress” alpine diagrams. We hope that publications will be soon available, confirming that pollen studies on organic profiles underneath moraines are still of great importance for understanding vegetation dynamics and glaciers histories in the Western Alps.

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