Pleistocene and Holocene environmental changes on the Massif Central uplands (FRANCE)

Excursion guide for the

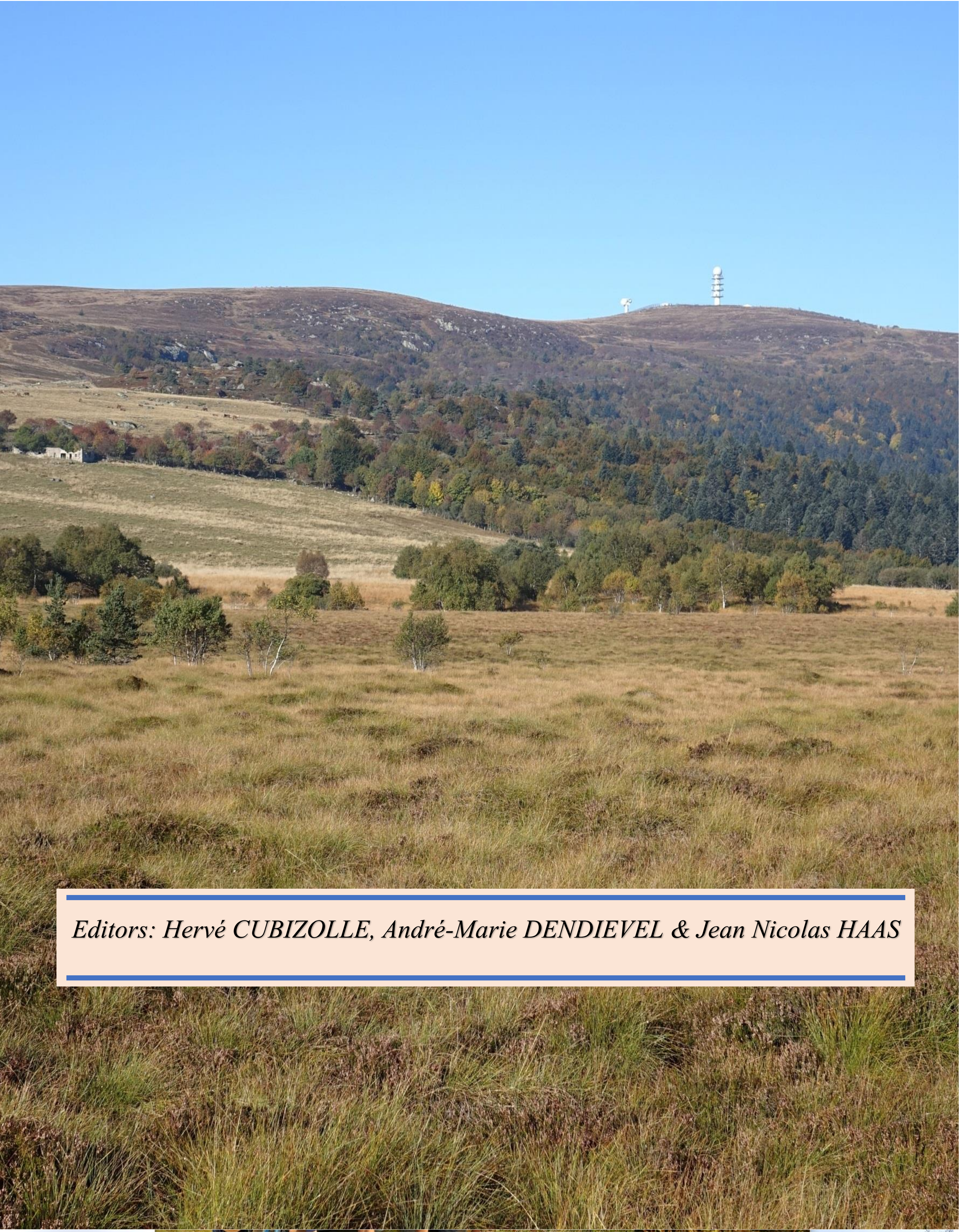
XLI International Moor Excursion 2017

(41.Internationale Moorexkursion)

through the Massif Central (France)

(Monts du Forez-Chaîne des Puys-Aubrac-Devès-Mézenc)

September 3-9, 2017



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XLI International Moor Excursion (IME 2017)

MASSIF CENTRAL, FRANCE

Monts du Forez – Chaîne des Puys – Aubrac – Devès – Mézenc

3 – 9 September 2017

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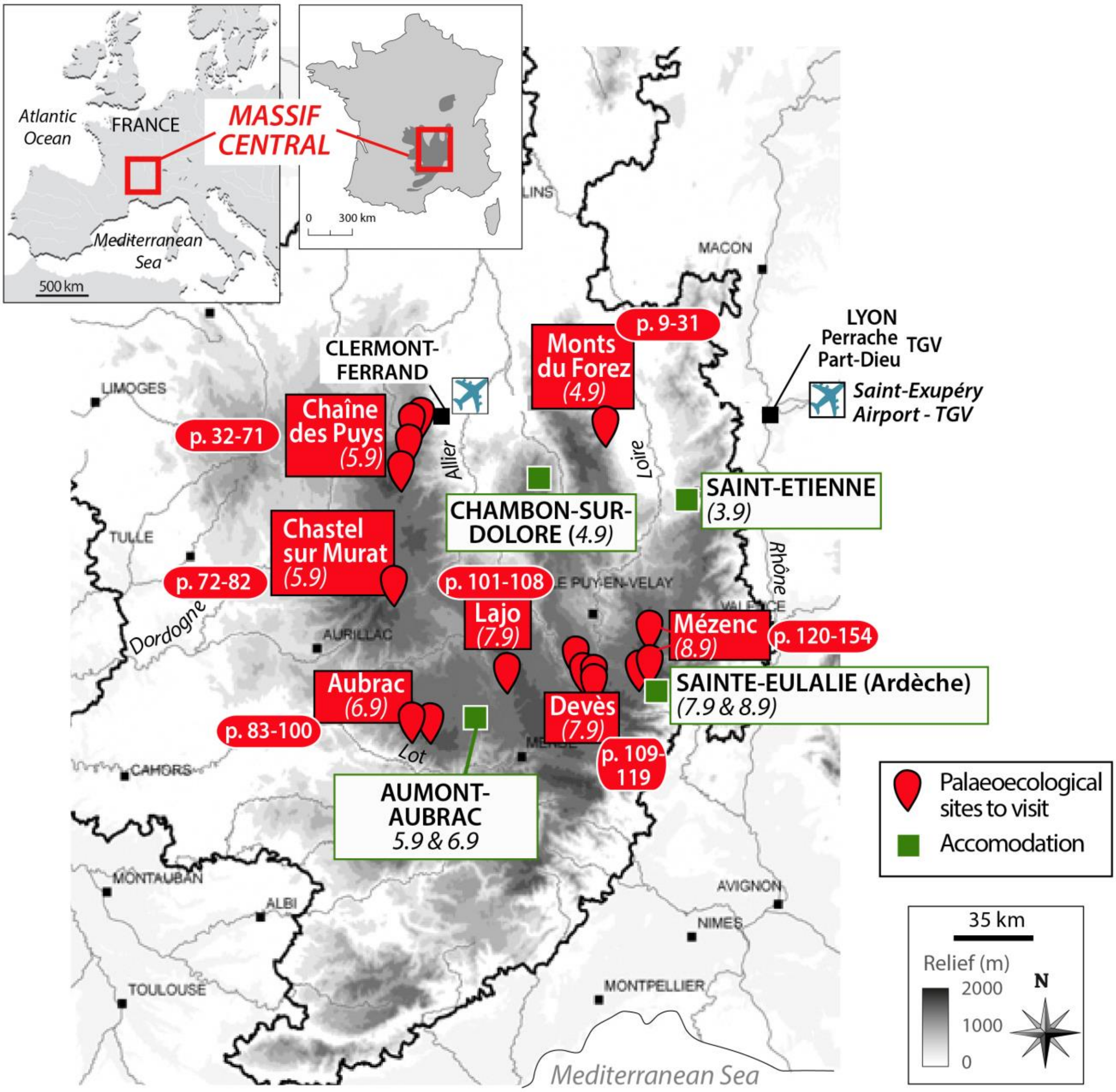
SESSION DESCRIPTION

During this International Moor Excursion (IME-2017), we will visit 7 areas of the French Massif Central with a journey including several sites, as shown on the following map.



3.9.2017 (Day 1) - Arrival at **Saint-Etienne**, Cheval Noir Hotel

4.9.2017 (Day 2) - **Monts du Forez**: *Gourd des Aillères fen - Gros Fumé bog - Gourgon mires*

Night: Hotel La Clairière in ***Chambon-sur-Dolore*** / Hotel de France ***St Germain-l'Herm***

5.9.2017 (Day 3) - **Chaîne des Puys**: *Lake Aydat- La Narse d'Espinasse fen - Lake Chambon - Lake Pavin*

Chastel-sur-Murat: *Lake Lapsou ;*

Night: Logis Chez Camillou in ***Aumont-Aubrac***

6.9.2017 (Day 4) - **Aubrac**: *La Vergne Noire peatland - Les Roustières fen/Brameloup*

Night: Logis Chez Camillou in ***Aumont-Aubrac***

7.9.2017 (Day 5) - **Lajo; Devès**: *Lac du Bouchet - Ribains - Pratclaux - La Sauvetat*

Night: Hotel du Nord / Les Violettes in ***Sainte Eulalie (Ardèche)***

8.9.2017 (Day 6) - **Mézenc**: *Saint-Front Lake - Pré-du-Bois swamp - La Narce du Béage fen*

Night: Hotel du Nord / Les Violettes in ***Sainte Eulalie (Ardèche)***

9.9.2017 - Return to **Saint-Etienne**

INTRODUCTION: A PRESENTATION OF PHYSICAL FEATURES OF THE FRENCH MASSIF CENTRAL UPLANDS (FRANCE)

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Summarized and adapted mainly from Etlicher 2005, Faure et al., 2009 and Ledru et al., 2001

1. GEOLOGICAL CONTEXT

The French Massif Central uplands were built by the Hercynian orogenyesis, the second phase of the Variscan orogenesis (Etlicher, 2005). It occupies one-sixth of the area of France and shows various sedimentological, volcanos and granito-metamorphic landscapes (**Figure 1**).

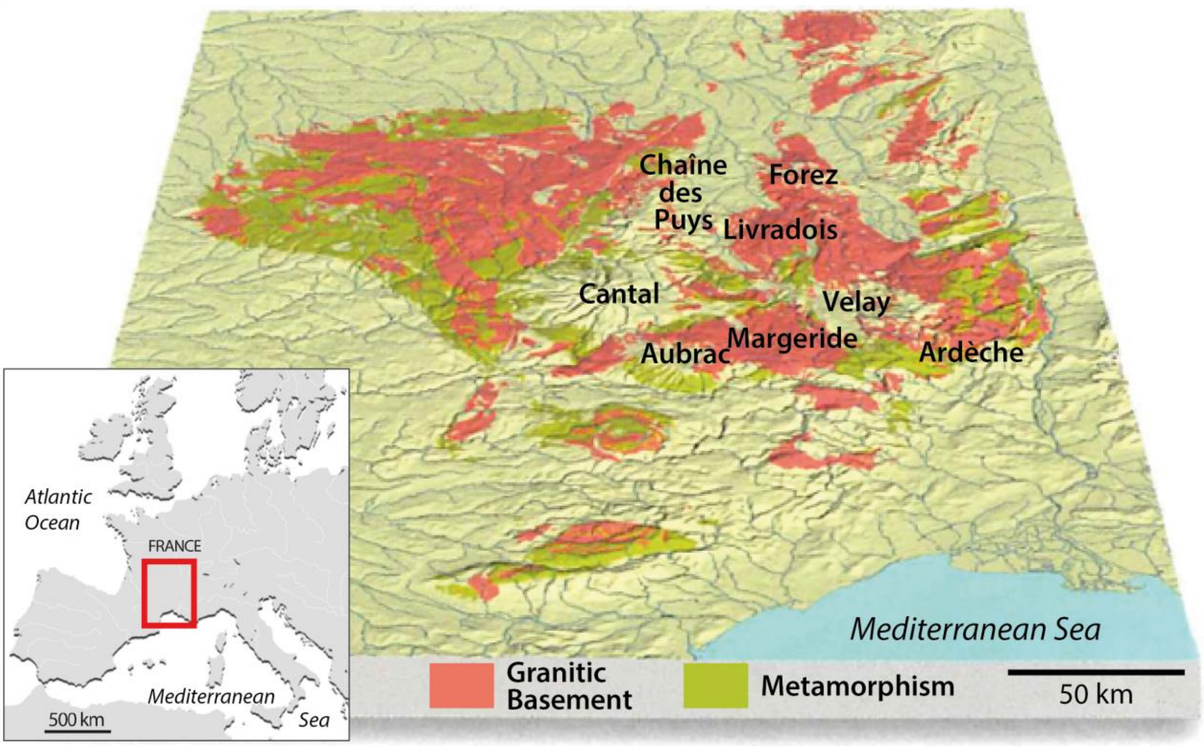

Figure 1*: The French Massif Central and its granite and metamorphic regions (after Michel, 2012 – adapted by A.-M. Dendievel)*

The Massif Central is located on the collision zone of the Hercynian (Variscan) orogenesis. It is the largest area in France composed of Variscan metamorphic and plutonic rocks. The entire Massif Central belongs to the northern Gondwanian margin, which corresponds to the southern continent involved in the Variscan collision (Faure *et al.*, 2009). The Massif Central is a stack of metamorphic nappes with 4 units. The Early Paleozoic tectonic event takes place at ca. 410-400 Ma, during the Devonian. Nevertheless, most of the Massif Central formed between 380 Ma and 300 Ma (**Figure 2**).

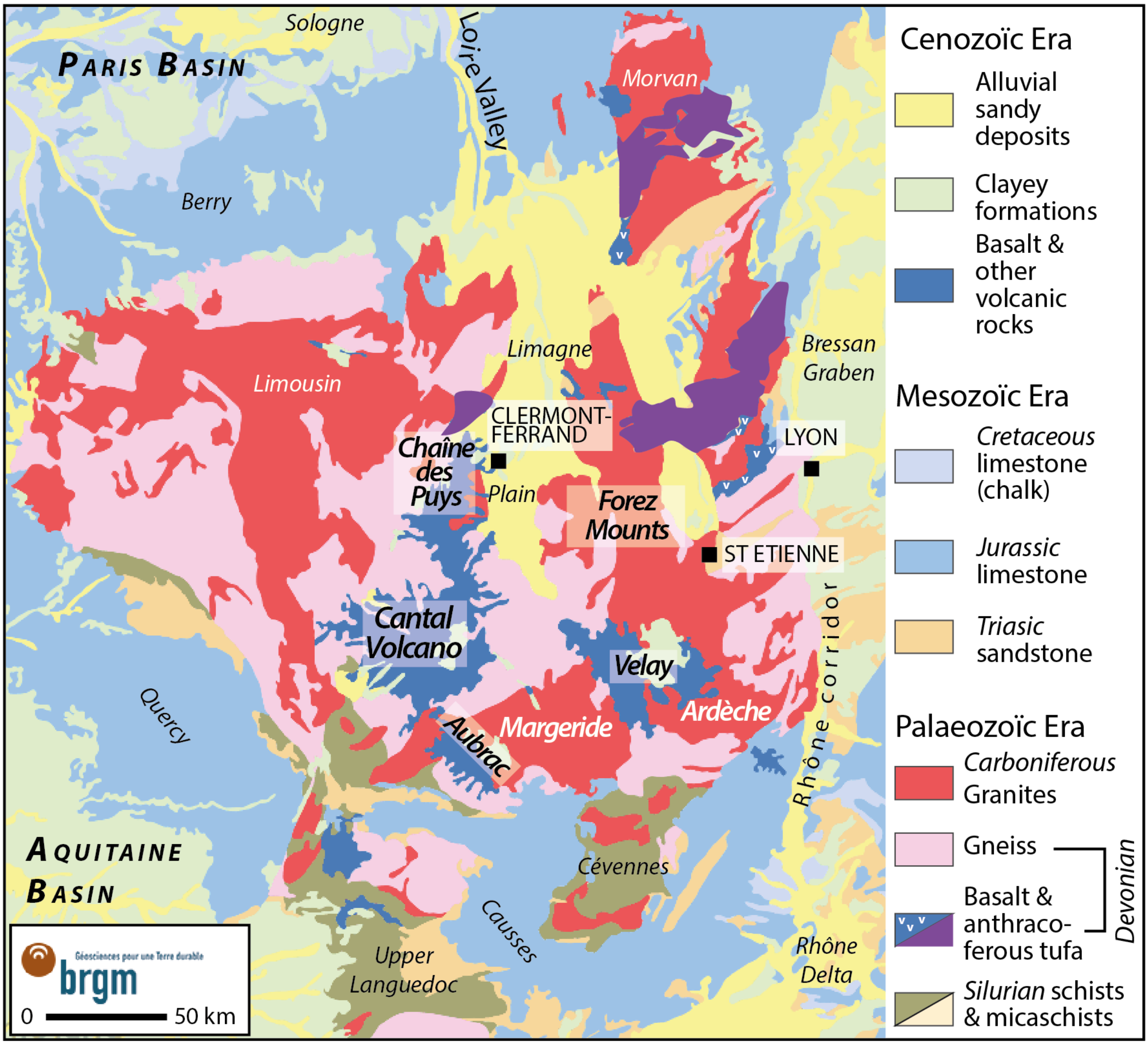

Figure 2*: Structural map of the French Massif Central (© BRGM – adapted by A.-M. Dendievel)*

<u>The formation of the Hercynian basement was concluded by a major event, the post-Hercynian peneplanation, which generated erosion of igneous rocks</u>. A relative tectonic stability allowed a long duration of dolomitization, albitization, ferruginous deposits, pedimentation in the upper parts and evaporation in lower parts. Several marine transgressions and regressions took part during this Mesozoic evolution. A last episode of planation occurred 50 Ma ago, at the end of the Mesozoic and the beginning of the Cenozoic. This main Early Tertiary event is well known and called the Eogene planation (Baulig, 1928; Klein, 1990; Etlicher, 2005).

<u>From the Eocene to the Early Miocene, the peneplain was completed when a major event, the Oligocene rifting, disrupted the Variscan basement of Western Europe</u>. Related to the opening of the Atlantic Ocean, a rifting began during the Eocene as a result of a Pyrenean compression phase. Tectonic faulting and subsidence created the meridian rift valleys of the Rhine (Alsace), Loire (Forez),

Allier (Limagne), Saône (Bresse) and Rhône. This episode underwent a maximal development during the Oligocene (35-30 Ma) and was followed by a major compressive phase. An important horst uplift occurred, separating the rift valley. This uplift was responsible for the present main regional units of landforms (Chafchafi, 1997; Etlicher, 2005). As a consequence, erosion was reactivated with a tendency towards valleys deepening and sediment accumulation in the graben (basins). Sedimentation is characterized by the presence of strongly weathered residual deposits, as well as mainly pebbles and gravel benches, which were due to fluvial activity at the periphery of basins. Sands and clay fill the center of the basins.

Tectonic style and environmental conditions changes completely during the Miocene with a strong compressive tectonic phase which replaced the Oligocene rifting episode. Because of the uplifting of the Alps, horst uplift was more active in the eastern part of the Massif Central. Rivers and valleys were considerably deepened. Chemical weathering changed after 8 Ma in relation with the transition from a subtropical to a temperate climate. Sedimentation in the graben was mainly composed by clay and lacustrine limestones with pebbles and gravel layers at the periphery of the basins.

Volcanic activity was present from the end of the Palaeocene to the Late Quaternary (Defive, 1996). The most ancient episode occurred between 60-40 Ma, in the Sioule and Limagne valleys and also in the Forez region. The last events took place in the Mid- to Late Holocene period with the Montcineyre and Pariou eruptions. Several more recent events were recently detected between 6500 cal. BC and 4500 cal. BC but are less well-known. Three types of landforms were constructed:

- large stratified cones in the Auvergne, Mont-Dore and Cantal (16 to 1 Ma);
- major lava fields in the Cezalier, Devès, Aubrac and Coiron;
- Systems of phonolite domes, Strombolian cones, maars and lava flows of Pliocene and Quaternary age in the Velay, Ardèche and Western Auvergne.

2. GEOMORPHOLOGICAL CONTEXT

An important physical characteristic of the Massif Central comes from the extent of Quaternary glaciations. Even if we do not know very well the number of glacial events and their extent, several sites are now major chronostratigraphical references for Western Europe (Veyret, 1981; Valadas, 1984; Etlicher, 1986; Vergne 1989).

Ice cap extended in the main valleys of the volcanic area of the Cantal, Mont-Dore, Aubrac and Cézalier. These western massifs, exposed to the wind from the Atlantic, were covered by an 80 km long piedmont glacier at low altitude. Terminal moraines are described in several sectors (Aurillac basin, Dordogne Valley and volcanic surfaces – planèzes- of Saint-Flour). As contrary, the eastern massifs of Forez, Mezenc, Lozère, Margeride, and Tanargue are characterized by a small extension of high altitudes surfaces, and more continental and dry conditions. Consequently, ice extent was moderate, and glacial development was limited in valley tongues and small ice caps on the highest plateau of the Forez, Margeride and, perhaps, Lozère (Etlicher, 2005). Glacial features are of modest extension and only in few valleys and at the upper part of few catchment basins. Some valleys have a U-shaped profile, mainly in the Forez Mountains (Etlicher, 1986). Several glacial episodes were recognized but the correlation with the glacial history of Western Europe is still uncertain because of poor dating possibilities. In the Forez Mountains, only the last Würm (Wechselian) glaciation is clearly identified and has been well studied (Etlicher, 1986).

In non-glaciated areas, landforms are strongly affected by Quaternary frost action. This action may lead to an especially severe denudation of regolith through frost shattering, nivation, gelifluction, and runoff. Nivation is a major phenomenon from 800 m up to 1200 m. Slope deposits are abundant and various especially when the granitic sand cover is thick. Frost action generated a complex sequence of displaced slope deposits with three main superposed from *in situ* regolith to bedded grus and head.

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DAY 1: SUNDAY THE 3RD SEPTEMBER 2017
ARRIVAL AT SAINT-ETIENNE

DAY 2: MONDAY THE 4TH SEPTEMBER 2017
LES MONTS DU FOREZ EXCURSION

IME- Site 1: Le Gourd des Aillères mire (1360 m a.s.l.) – Roche – Loire Department

PALAEOENVIRONMENTAL STUDY OF LE GOURD DES AILLERES MIRE (MONTS DU FOREZ, FRANCE): CLIMATE AND VEGETATION CHANGES DURING THE LATE GLACIAL AND THE EARLY HOLOCENE

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INTRODUCTION

We chose to lead you to this mire because in the granitic part of the eastern French Massif Central, this mire is the only natural limnogenous mire and, for this reason, also one of the rare sequences which have recorded completly the Lateglacial. Indeed, the stratigraphy is composed by 3 meters of peat, then gyttja and mineral lacustrine sediments which lie on at least 1 meter of proglacial sediments. Unfortunatly it is very hard to go into these proglacial sediments even with a motorized sediment corer. Finally, the longest sequence extracted and studied reaches exactly 6.56 m, with only 5 cm of proglacial sediments. At this moment, we finished the study of the sequence from 6.56 m up to 2.60 m because we are mainly interested by the Lateglacial and the onset of the Holocene.

We hope that this sequence will be a reference for this region. Added with the similar study carried out in the Mézenc volcanic massif by André-Marie Dendievel, 150 km to the south, we will have a good knowledge of the Lateglacial and early Holocene for the eastern part of the Massif Central (Dendievel, 2017).

Geological and geomorphological setting

The mire of Le Gourd des Aillères is at an average altitude of 1360 m. We are just below the highest point of the region, Pierre-sur-Haute with 1642 m a.s.l. This mountain is a Hercynian mountain mainly formed of granit and gneiss.

We are here in an old glacial valley which was occupied by a glacier during the last glaciation, the Würm (or Weichselian) glaciation. The mire occupes a glacial depression, an ombilic. « Gourd » in local language means « depression with water ». But, because of the meridional position of Les Monts du Forez, glacial features are of modest extension and only in few valleys and at the upper part of few catchment basins. On the plateau of les Monts du Forez, glacier occupied around 60 km² between 1400 and 1550 m a.s.l. In the valley glacier reached 1350 m a.s.l. The thickness of ice reached only around 30 meters. Therefore, Pierre-sur-Haute massif was above the glacier; it was a nunatak.

In this ombilic, a small lake took place after the melting (thawing) of the glacier and, little by little, lacustrine sediment then gyttje and, finally, peat filled up the depression. A creek is running accross the mire. The actual mire is an ombrotrophic and acidic *Sphagnum* mire. Human impact on this mire bas been very low, because any cattle have grazed on this mire for a long time.

METHODOLOGY AND RESULTS

2.1. Coring and sedimentological analysis

The core is 6.56 m in length and it presents four facies (**Figure 1**):

- **peat** from the top to the depth of 335 cm;
- **gyttja** from -335 cm to -490 cm;
- **lacustrine sediments** from -490 cm to -651 cm;
- **proglacial sediments** from -651 cm to -656 cm.

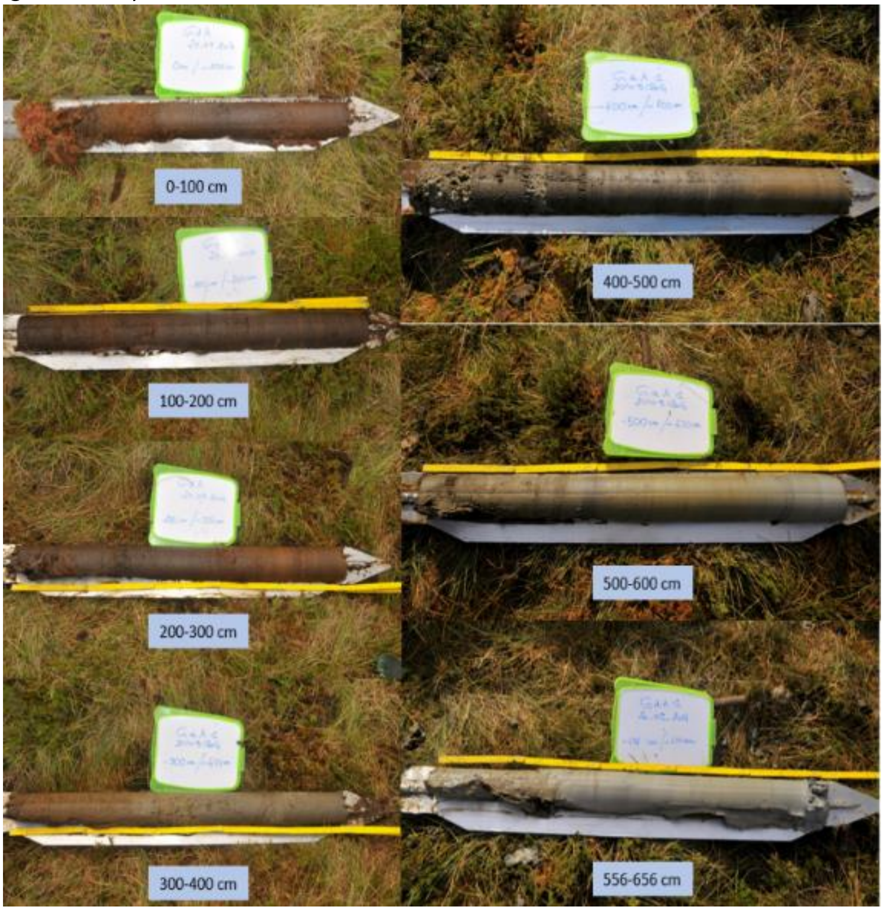

***Figure 1**: The core of Le Gourd des Aillères from the top to bottom. In the presentation the only section from -260 cm to -656 cm was studied.*

Several sedimentological analyses were carried out (**Figure 2**):

- **Magnetic susceptibility** in order to recognize thephra levels (*Bartington*™ *MS2* meter and *MS2E1* sensor system);

- **Loss on ignition** as an estimate of organic matter;

- **Laser diffraction granulometry** as a study of mineral particles size;

- Geochemical analysis (XRF method).

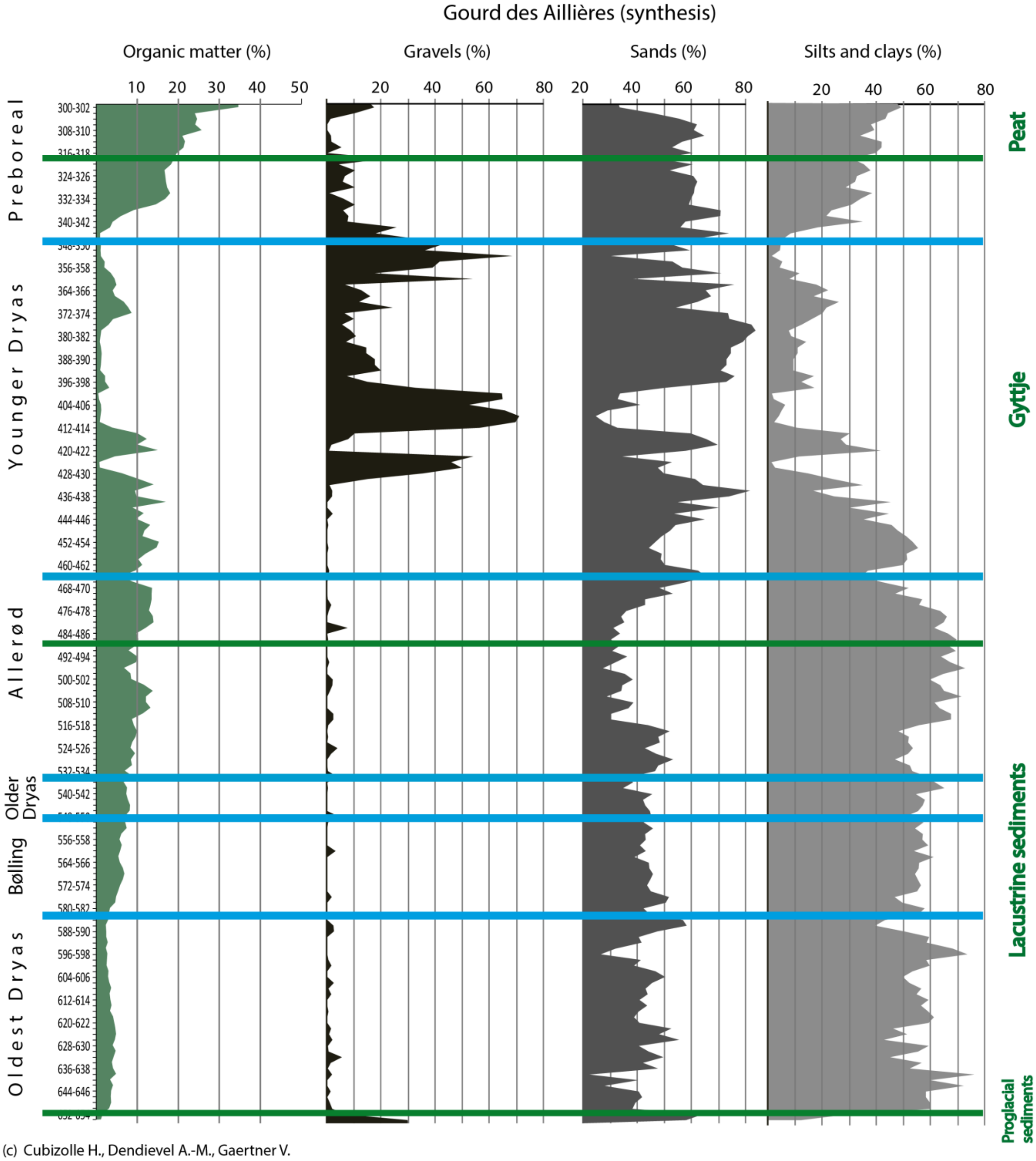

Figure 2*: Main results related to sedimentological analysis of the sediments from the Gourd des Aillères sequence*

2.2. Radiocarbon dating

Two laboratories carried out the radiocarbon dating (**table 1**):

- Our usual partners of Lyon 1 University, the Radiocarbon Dating Centre associated with the laboratory of the University of Groningen and the University of Paris VI (ARTEMIS);
- The laboratory of the Swiss Federal Institute of Technology of Zürich, which helped us to date the basal layers of the sequence and especially the contact between the lacustrine and the proglacial sediments.
- Finally, 12 radiocarbon ages were obtained and 3 are in progress (**Table 1:** datings in progress are in italics). Four dates are true with the palaeoecological data (**Table 1 & Figure 3:** indicated in red).

Table 1*: Radiocarbon ages obtained on the Le Gourd des Aillères sequence (Forez Mounts, France)*

Sample	Laboratory code	Material	Depth (cm)	^{14}C age (BP)	Calibrated age (cal. BP, 2 σ)
GDA-1	*in progress*	*macrofossils*	*260*		
GDA-2	Lyon-13527(GrA)	wood	306	9270 +/- 50	10578-10279
GDA-3	*in progress*	*macrofossils*	*325-328*		
GDA-4	Lyon-1163(GrA)	undetermined organic sediments	415	10470 +/- 50	12563-12136
GDA-5	Lyon-11635(GrA)	undetermined organic sediments	431	11210 +/- 50	13182-12985
GDA-6	Lyon-12469 (SacA43633)	bryophyts stems and leaves fragments	459-460	11190 +/- 50	13160-12934
GDA-7	Lyon-11634(GrA)	undetermined organic sediments	470-471	10920 +/- 50	12916-12701
GDA-8	Lyon-12468 (SacA42632)	bryophyts stems and wood fragments of *Pinus*	491-492	11030 +/- 50	13036-12751
GDA-9	Lyon-11633(GrA)	bryophyts stems and herbaceous fragments	531	12040 +/- 60	14064-13752
GDA-10	Lyon-12467 (SacA43631)	bryophyts stems	535-536	11990 +/- 60	14051-13716
GDA-11	Lyon-12631 (SacA44284)	bryophyts stems, Caryophyllaceae and leaves fragments	581-583	11955 +/- 50	13996-13601
GDA-13	ETH-70608	Macrofossils (Juniperus nana + Bryophyts)	621	12395 +/- 40	14765-14168
GDA-14	ETH-70609	Macrofossils (*Juniperus nana* + Bryophyts)	644	12937 +/- 36	15659-15268
GDA-15	*in progress (Zurick – ETH)*	*macrofossils*	*648-649*		
GDA-12	Lyon-12314 (SacA42842)	bryophyts stems (mainly Polytrichum) & herbaceous stems	651-656	10120 +/- 50	12109-11407

Given the obtained radiocarbon dates we carried out an age/depth model (**Figure 3**)

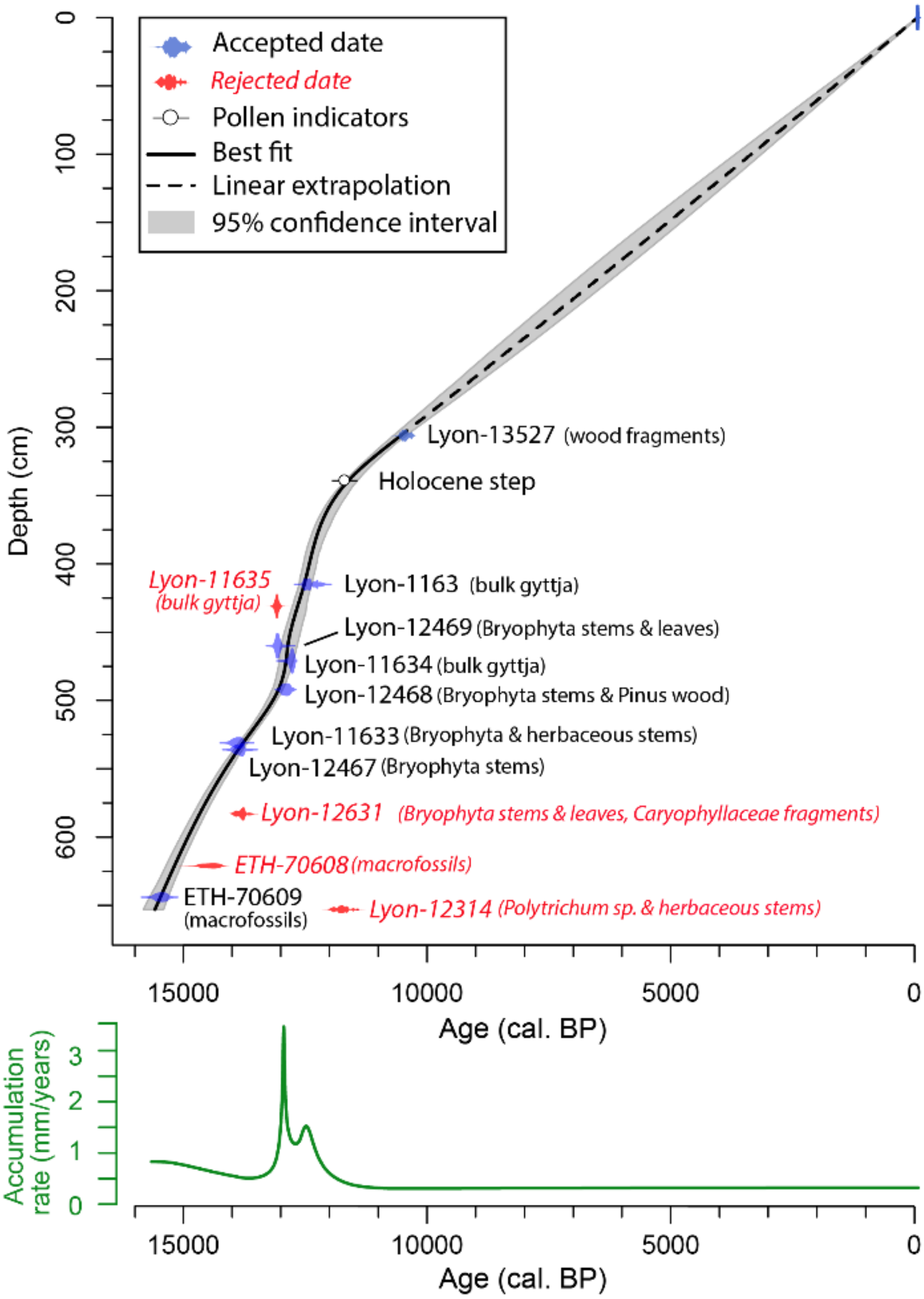

***Figure 3**: Age/depth model obtained on the Gourd des Aillères sequence from the bottom to 260 cm in depth.*

2.3. Pollen analysis

The extraction of all pollen and spores was done using the liquid concentration method with a density of 2. A mean of 543 pollen grains (AP + NAP) per sample were determined and counted, using a sediment sampling at all 2 cm depth, which even was narrowed down to 1 cm for certain levels. Percentage values were calculated according to International standards and by using a 100% reference sum made out of the total of arboreal (AP) and non-arboreal (NAP) pollen, but by excluding local taxa such as sedges (Cyperaceae), aquatic plants and all spore producing taxa (e.g. ferns, *Sphagnum*...). Please note that damaged saccate pollen was counted as one, and that agglutinations of pollen from one and the same taxa were also counted as one. Palynological determination followed Reille (1999). The palynological diagrams were plotted using the graphical computer programme PSIMPOLL (Bennett 2000). Statistical zonation of the according pollen and spore finds into local pollen assemblage zones (LPAZ) was performed by using the CONISS analysis (Grimm 1987).

The pollen zones used are the classical ones employed in the Massif Central in France (Beaulieu *et al.* 1988) and in Europe in general (Bourquin-Mignot *et al.*, 1999), also calibrated to calendar ages in order to allow wider chronological comparisons:

- Beginning of the Boreal chronozone, 9000 BP = about 10100 cal. BP.
- Beginning of the Preboreal chronozone, 10000 BP = about 11700 cal. BP.
- Beginning of the Younger Dryas chronozone, 10800 BP = about 12700 cal. BP.
- Beginning of the Allerød chronozone, 11800 BP = about 13700 cal.
- Beginning of the Older Dryas chronozone, 12000 BP = about 13900 cal. BP.
- Beginning of the Bølling chronozone, 12700 BP = about 15000 cal. BP.
- Beginning of the Oldest Dryas chronozone, 15000 BP = about 18200 cal. BP.

The palynological record obtained for the Late Glacial period and the beginning of the Holocene can be divided in 7 main zones with 5 subzones (Figure 4).

LPAZ 1 (depth 656-583 cm, from about 15400 cal. BP to 14600 cal BP)**: Oldest Dryas,** steppic herbs and pioneer shrubs; archaeological period: Palaeolithic.

Two subzones:

LPAZ 1a (depth 656-606 cm; about from 15400 to 14900 cal. BP): Herbs are dominating with Poaceae, *Artemisia*, Chenopodiaceae, *Helianthemum, Thalictrum*, *Plantago*, various Asteraceae and Cyperaceae. Some shrubs are also growing: *Ephedra*, *Betula nana*, *Juniperus*. *Salix* appears sporadically. *Pinus* is relatively abundant but doesn't exceed 30%. Some water plants and *Botryococcus* indicate a free water surface around which Cyperaceae developed.

LPAZ 1b (depth 606-583 cm; from about 14900 to 14600 cal. BP): *Pinus* and *Artemisia* decrease significantly while other herbs increase (Poaceae, Asteraceae and *Plantago*), Cyperaceae develop and *Typha/Sparganium* arises.

The occurrence of *Quercus* pollen as well as mesophilous trees, puts forward the question of the origin of this pollen, incompatible with the climatic conditions of this period. Several assumptions can be considered: regional input of pollen coming from lower altitude; long way transport of pollen from southern countries; or as often observed, reworking of ancient sediments. This latter interpretation is probable considering the presence of sand inside the clay deposits (cf. macro remains study, F. Fassion)

LPAZ 2 (depth **583-550 cm;** from about 14600 to 14100 cal. BP**): Bølling**, increase of *Juniperus* and *Betula*; archaeological period: Palaeolithic.

The very rapid arrival of *Juniperus* is closely followed by *Betula* and the decline of *Pinus*. As for the herbs, pollen of *Artemisia* and of the other steppic plants is decreasing. The landscape remains open. Marsh and aquatic vegetation expands, including algae (*Pediastrum).* Between 560 and 570 cm (from 14400 to 14300 cal. BP) *Pinus, Betula, Juniperus* are rapidly decreasing, which indicates possibly the *Intra Bølling Cold Phase* detected at this time in the ice cores of Greenland (Stuiver *et al.*, 1995).

LPAZ 3 (depth **550-532 cm,** from about 14100 to 13800 cal. BP): **Dryas II (Older Dryas)**; archaeological period: Palaeolithic/Epipalaeolithic

Juniperus and *Betula* clearly decrease while *Pinus* progression stops. *Artemisia*, Chenopodiaceae and particularly Apiaceae, *Plantago* and the Cyperaceae do increase. Wet prairies do develop close to the lake. All this clearly demonstrate a cooling corresponding to the Older Dryas.

LPAZ 4 (depth **532-467 cm;** from about 13800 to 12800 cal. BP**)**: **Allerød**; archaeological period: Epipaleolithic. This LPAZ is subdivided in three subzones.

LPAZ 4a, depth 532 to 492 cm, age about 13800 to 13000 cal. BP: *Pinus* develops slowly and coexists with birch and juniper which remain stable up to depth of 500 cm. *Artemisia* and other steppic plants decrease, while tall herbs expand (e.g. Apiaceae).

During the following LPAZ 4b and 4c there are no big changes among the herbs. *Pinus* takes the first place but its percentages remain low (often < 30%). *Betula* and *Juniperus* reduce significantly. During LPAZ 4b (depth 492 to 480 cm age about 13000 to 12900 cal. BP) we can observe two peaks in the curve of *Pinus.* One of these peaks could correspond to the Gerzensee oscillation (*Intra Allerød Cold Phase*).

LPAZ 5 (depth **467-347 cm,** from about 12800 to 11800-11600 cal. BP): **Younger Dryas –** Epipalaeolithic. *Artemisia* values increase slightly, as well as Apiaceae and *Plantago*. *Pediastrum* values are strongly reduced pointing to changes in the lake (e.g. reduced surface). All this suggests climatic conditions cooler than during the LPAZ 4, but without a clear impact on the vegetation.

LPAZ 6 (depth **347- 290 cm;** from about 11800-11600 to 9960 cal. BP**): Preboreal** – Mesolithic.

This LPAZ is characterized by the clear increase in AP, particularly *Pinus* and *Betula* and by a continuous curve of *Quercus, Corylus* and then *Ulmus.* In the same time *Artemisia*, Poaceae and steppic plants decrease while *Rumex* and the Ranunculaceae expanded around the lake; hydrophytes and algae suggest a free water surface.

LPAZ 7 (depth **290- ...** analysis in progress**): Boreal**. This LPAZ is characterized by the classical rapid and strong expansion of *Corylus,* contemporaneous with the collapse of *Pinus* and the establishment of *Quercus* and *Ulmus.* A marsh occupied by Cyperaceae and other hygrophilous plants takes place of the lake.

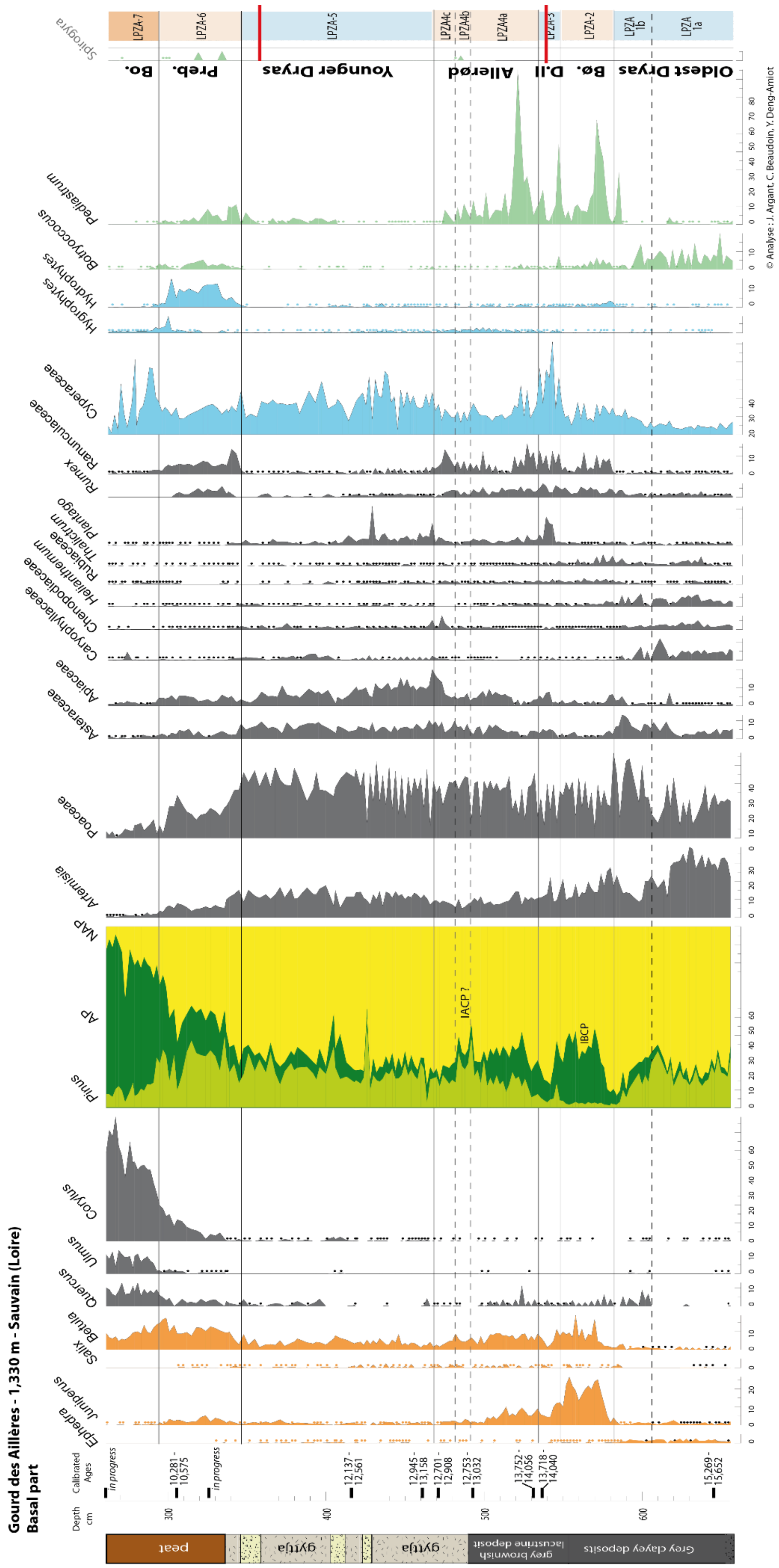

***Figure 4**: First palynological results obtained on the Gourd-des-Aillères core (© J. Argant)*

2.4. Diatom analysis

In a methodological point of view, sample were processed using a standard method by slow heating the sample with 30% H2O2, then rinsed a minimum of 3 time but several more time if a lot of clay is present. Then a small amount of the cleaned material was mounted on a slide with Naprhax. For most samples, a minimum of 400 valves were counted with an Axioskop 2 using 1000 x magnification.

PCA separate the samples in to three main groups based on *Aulacoseira* taxa and certain Fragilarioid and Achnanthoid diatoms (**Figure 5**). Group 1 was dominated by certain *Fragilaria* (*Fragilaria brevistriata*, *F. construens* v. *venter*, and *F. pinnata*), Group 2 had a series of Achnanthoid taxa and *Aulacoseira alpigena* while in Group 3 major components were *Aulacoseira* valida and *Tabellaria flocculosa* and *F. construens* v *subsalina*. Group 1 corresponds to the oldest samples (G 654 – G 515), Group 2 the middle section (G511 – G 346) while Groups 3 contains samples from the youngest part of the core (G342 – G 287 & G-281). Above G-281, most sample were devoid of diatoms.

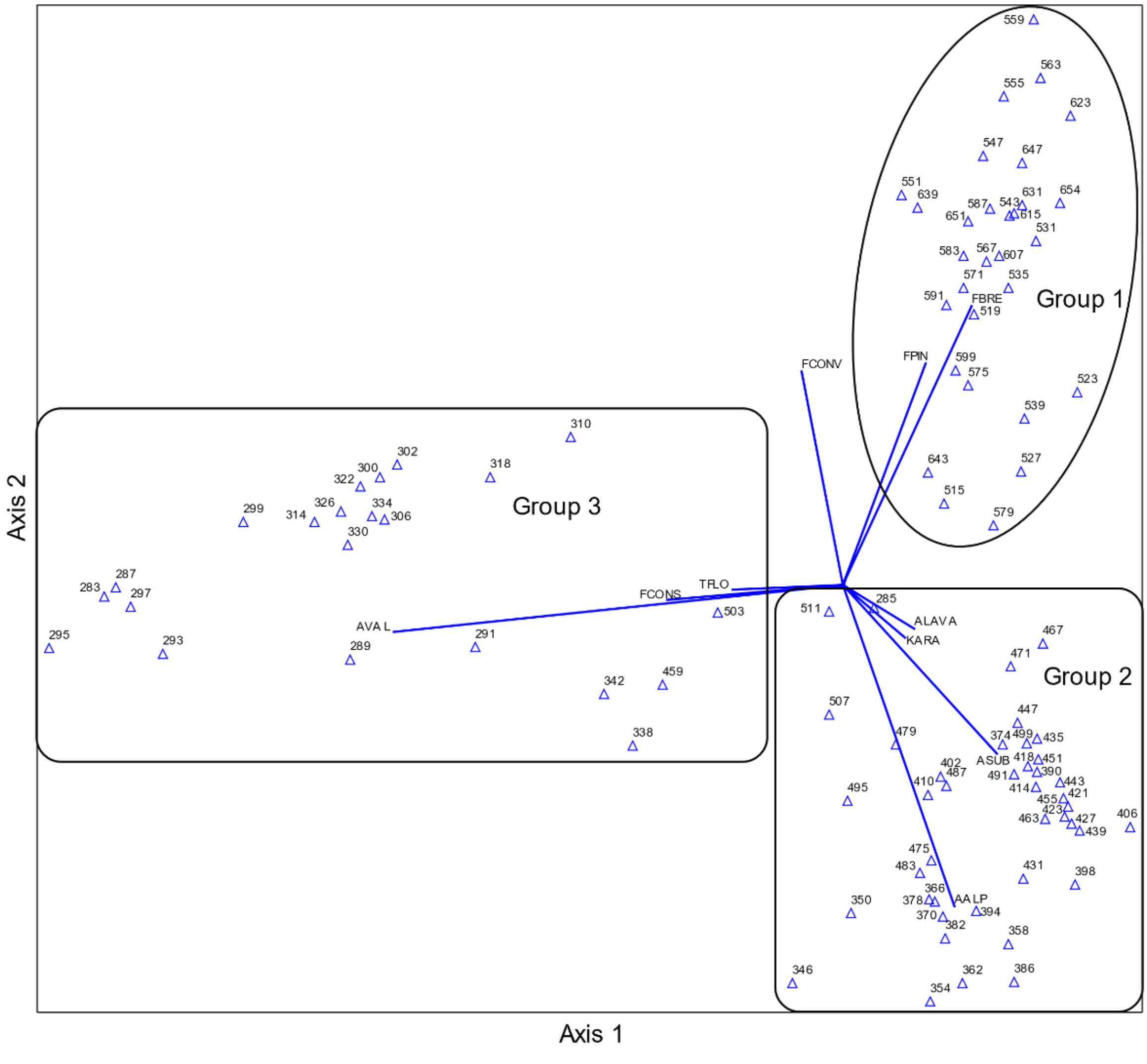

Figure 5*: Principal compound analysis of Gourd des Aillères (with variance/covariance, distance-based biplot, and randomization options, based on species occurring in more than 1 sample with greater than 1% - © K. Serieyssol).*

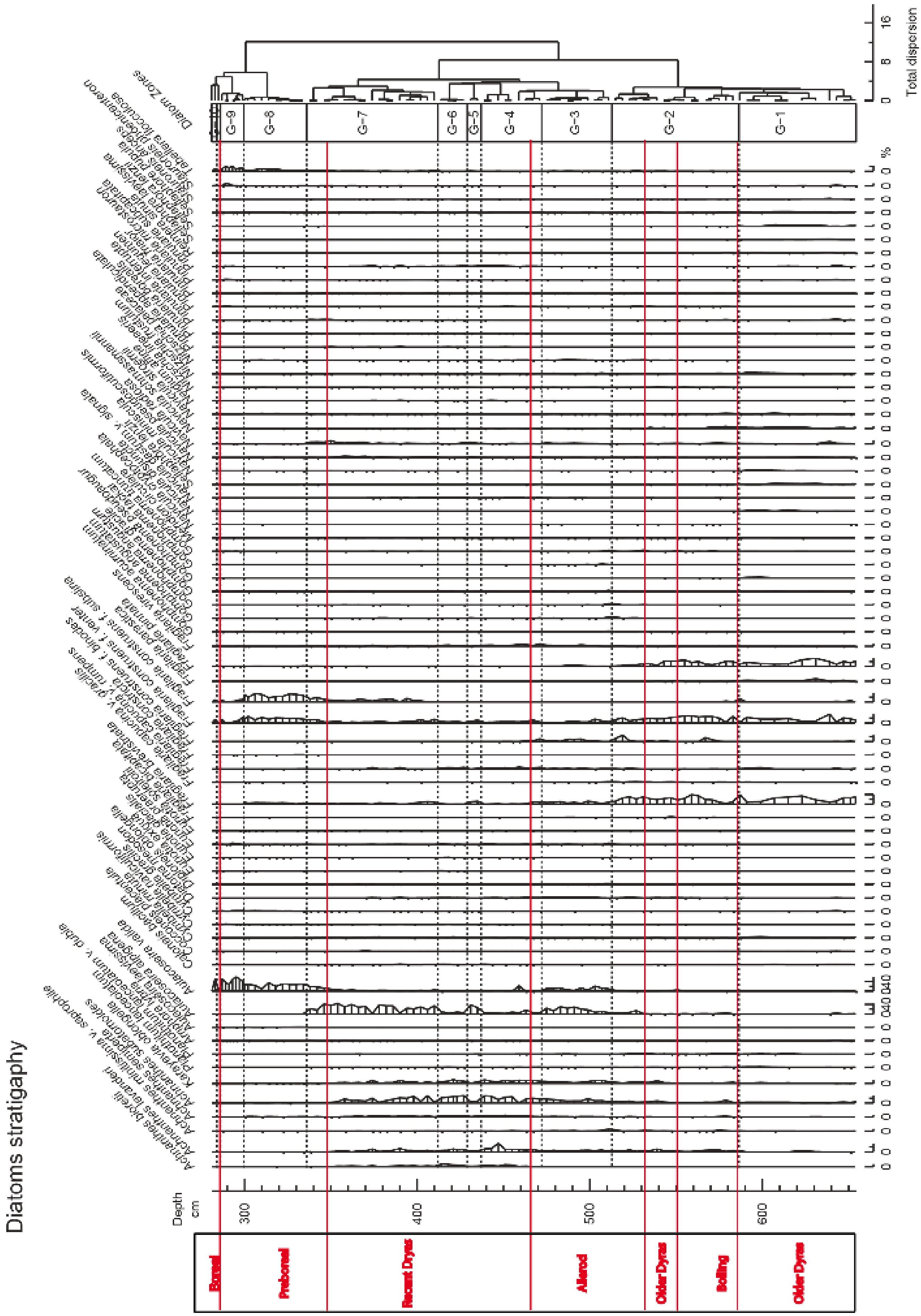

Figure 6*: Diatom Stratigraphy of the Gourd des Aillères (© K. Serieyssol).*

Ten zones were determined using Psimpoll 4.26 (Bennet, 2002) using zonation with constrained cluster analysis by sum of squares (Coniss) (**Figure 6**). Zone G-1 had many Fragilarioid taxa (*F. brevistriata, F. construens f. venter* and *F. pinnata*) with a series of *Navicula* taxa. In Zone G-2, *Aulacoseira alpigena* and a number of Achnanthoid taxa increase with small peaks. In Zone G-3, Achanthoid species and *A. alpigena* along with *Aulacoseira valida* increased while *F. pinnata* almost disappears. Zone G-4 and G-6 are analogous with a decrease in *Aulacoseira* taxa and continued presence with Achnanthoid species. But Zone G-5 had a similar composition as found in Zone G-3. In Zone 7, *A. alpigena* increases but disappears from the sediment in the upper zones while *A. valida* becomes more important towards the top of this zone and very important in the next. In Zone 8, along with *A. valida,* another planktonic, *Tabellaria flocculosa* appeared in the sediments. *Fragilaria construens* v. *venter* and v. *subsalina* also marked this zone. Zone 9 was dominated *by A. valida*. The *Fragilaria* taxa diminish in importance. Sample 285 was void of diatoms but Sample 283 (zone 10) had the same species as Zone 9.

Douglas and Smol (2007) noted the influence of ice and snow cover on high arctic lakes. During colder periods, ice cover is more extensive and often only a small zone around the edge of the pond will melt (moat). This leads to a lower overall diatom production and "taxa characteristic of very shallow littoral and semi-terrestrial environments tend to be relatively more common". During warmer years, ice cover shrinks and overall production increases so that taxa of deeper water substrates and planktonic habitats could become more abundant. Therefore, with longer ice free season, new substrates may become available, such as mosses, hence more complex and diverse aquatic communities (Douglas and Smol 2007). Smol (1988) suggested that the periphytic to planktonic diatom ratio is closely related to duration and extent of ice cover. Arctic tundra regions were dominated by small, benthic, pennate taxa (e.g. *Fragilaria, Navicula* and *Achnanthes*). Lotter *et al.* (1999) found that small periphytic, probably tychoplanktonic taxa, such as *F. construens, F. pinnata, F. brevistriata* and *A. minutissima* are more important above 1000-1500 m asl. Pienitz *et al.* (1995) found *Fragilaria* species were usually found at the cold end of the temperature gradient.
Tentatively, the zones seem to correspond to major climatic changes registered during the end of the Pleistocene and beginning Holocene (**Figure 7**). Zone G-1 seems to correspond to the cold Older Dryas with periphytic and tychoplanktonic species. Zone G-2 saw the arrival of planktonic species. This marked the beginning of a warming period with the Bølling and continued warming with the Allerød in Zone G-3 with planktonic species becoming important. The Younger Dryas is a known cold period and zones G-4 and G-6 had lower amounts of planktonic species and the loss of *F. pinnata* and less amounts of *F. construens* complex. It appears that there is short warming phase registered in zone G-5 with a small increase in planktonic tychoplanktonic species. In Zone 7, planktonic *A.*

alpigena increases but disappears from the sediment in the upper zones while *A. valida* increases towards the top of this zone and becomes important in the next. This zone marks a change from the cold Pleistocene regime to a warmer Holocene. In Zone 8, along with *A. valida, F. construens* v. *venter* and v. *subsalina* also mark this zone. Zone 9 is dominated by *A. valida*. The *Fragilaria* taxa diminish in importance. Sample G-285 was void of diatoms but Sample G-283 (zone 10) had the same species as Zone 9. From sample G-281 upper ward the sediment was almost devoid to diatoms.

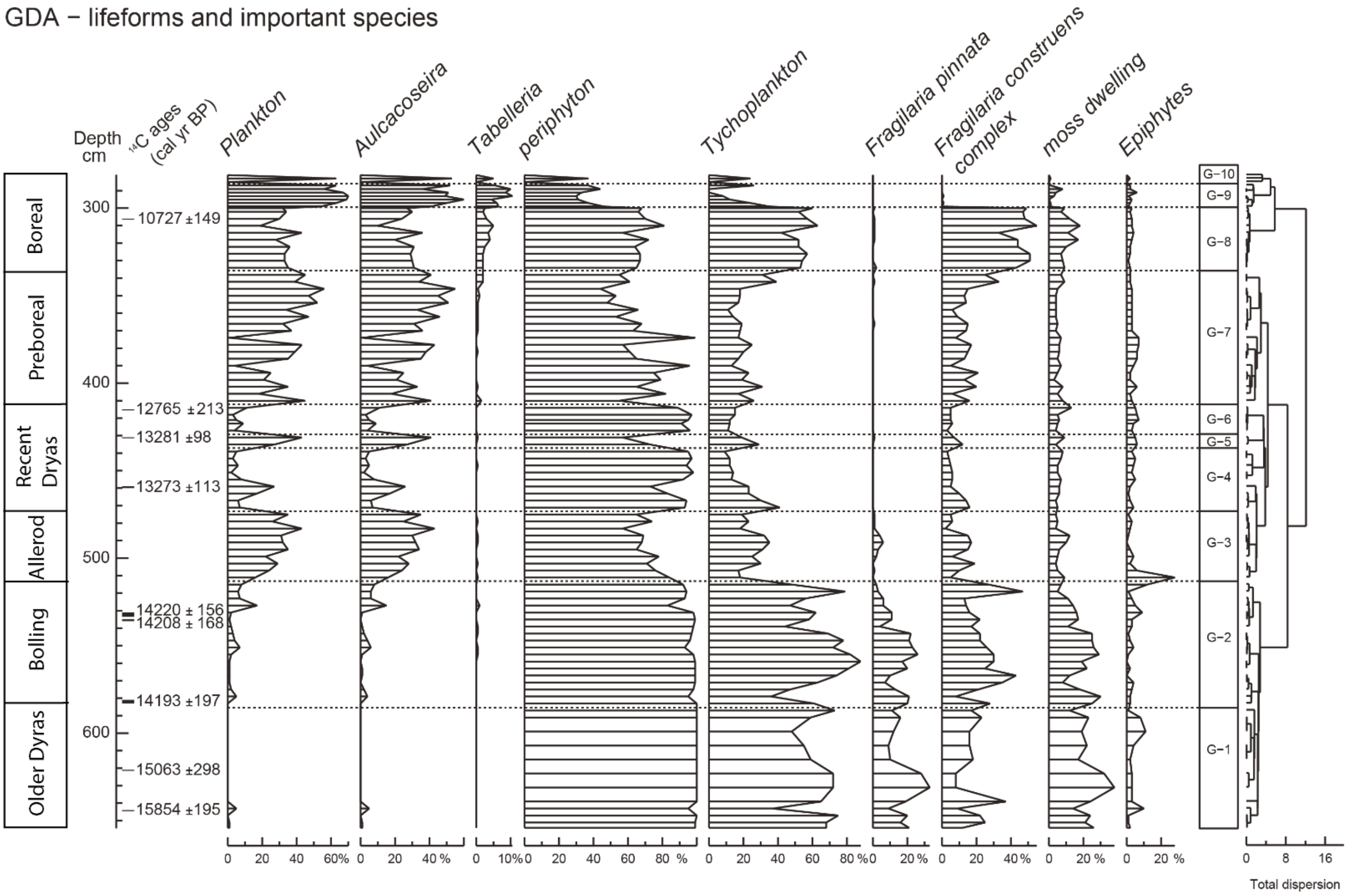

Figure 7*: The stratigraphic diagram of the main lifeform groups and the important species within the different groups. Plankton (Aulacoseira and Tabelleria), periphyton (moss dwelling and epiphytes), tychoplankton (F. pinnata, F. construens complex).*

2.5. Macrofossils analysis

Forty seven samples were taken from the core at 8 cm intervals between 656 cm to 334 cm and every centimeters intervals according to the facies encountered. Preliminary results are presented in this comment and the attached diagram (**Figure 8**). Ten samples located at the lake/bog transition are being analyzed. The identification of plant macroremains is based on collections and atlas of references (Berggren, 1969; Cappers *et al.*, 2012; Lévesque *et al.*, 1988; Bastien & Garneau, 1997; Crum & Anderson, 1981; Daniels & Eddy, 1990; Ireland, 1982; Mauquoy & van Geel, 2007; Smith, 1996; UNIVEGE - Herbiers Universitaires de Clermont-Ferrand).

Zone A (656-591 cm)

Oospores of *Nitella confervacea/flexilis/gracilis/hyalina* discovered at the bottom layers indicate the existence of a lake which should not exceed 5 meters deep (Haas, 1994). It's also in this part and up to 575 cm deep that one meets *Daphnia* which develops on parts of clear and stagnant water.

From 650 and 649 cm, few seeds of *Carex* sp. and *Juncus* sp. shown the presence of wet grasslands on the edge of the lake or closed to the lake.

Moreover, the high number of sand in the bottom layers, which have a diameter superior to 1 cm, gives evidence to the presence of soil without vegetation closed to the lake and large water supplies likely to mobilize coarse materials.

Zone B (591-543 cm)

If wet grasslands are still present in this area, we also note the consistent increase of *Nitella confervacea/flexilis/gracilis/hyalina* and the appearance of new species of mosses and sphagnum encountered in wetlands and peatland sometimes submerged (*Drepanocladus exannulatus/fluitans*, *Drepanocladus aduncus* var. *capillifolius, Aulacomnium palustre, Calliergon stramineum*). This diversification of the mire and aquatic flora is also well documented by palynological analysis.

The presence of the fungus *Cenoccocum* sp. indicates poor storage conditions of organic matter. Moreover, the occurrence of charcoal - with a diameter of less than 0.2 mm - attests the presence of fires in this area. Moreover, all these elements seem to have affected the quality of the water, which led to the disappearance of *Daphnia*.

Finally, the absence of coarse particles identical to those encountered in zone A suggests a constant supply by runoff and not during a torrential episode, and / or the development of vegetation which has limited mobilization of the most voluminous elements.

Zone C (543-495 cm)

Cenoccocum sp. increases considerably from 541 cm deep. This increase is synchronous with a modest increase of charcoals which have a maximal diameter of 0.425 mm. Their almost constant presence in this zone attests the existence of frequent fires close to this area.

In this zone, we show an important increase of *Nitella confervacea/flexilis/gracilis/hyaline*. We also observe the development of *Callitriche*, a lacustre plant, and *Scorpidium scorpoides,* which occur in shallow, submerged or floating water.

Moreover, we note the presence of plants developing on drier environments and on rocks (*Cerastium* sp., *Hygrohypnum eugyrium*). Their discovery in the lake environment must be associated with a greater contribution of runoff water as shown by an important input of sand where a peak of coarser particles is clearly identified between 519 and 503 cm depth.

Zone D (495-362 cm)

This zone marks changes in the composition of the plant landscape characterizing the progressive filling of the lake. If numerous plants developing in wet submerged habitats are still in place, such as *Drepanocladus exannulatus/fluitans, Drepanocladus aduncus* var. *capillifolius* or *Aulacominum palustre*, the disappearance of *Callitriche* and *Nitella confervacea/flexilis/gracilis/hyalina* is also observed. Three hypotheses can then be advanced: an insufficiency in the water level, a more rigorous climatic period, or a combination of these two factors. In addition, their disappearance is followed by an important increase of *Cenoccocum* sp., which attests poor conditions of conservation. This period is also characterized by a large number of fine and coarse sands. Finally, the last 20 cm of this zone mark a tilting of the organic matter components conserved in favor of the Herbaceae.

Zone E (362-334 cm)

This zone is a continuation of the phenomena initiated at the end of zone D. However, the remains of mosses and *Sphagnum* are less numerous in favor of Herbaceae (*Carex* sp., *Juncus* sp., *Potentilla* sp.). This area also shows a rapid decline in the number of *Cenoccocum* sp, which indicate better conservation conditions of organic matter.

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For references see reference list after the next article.

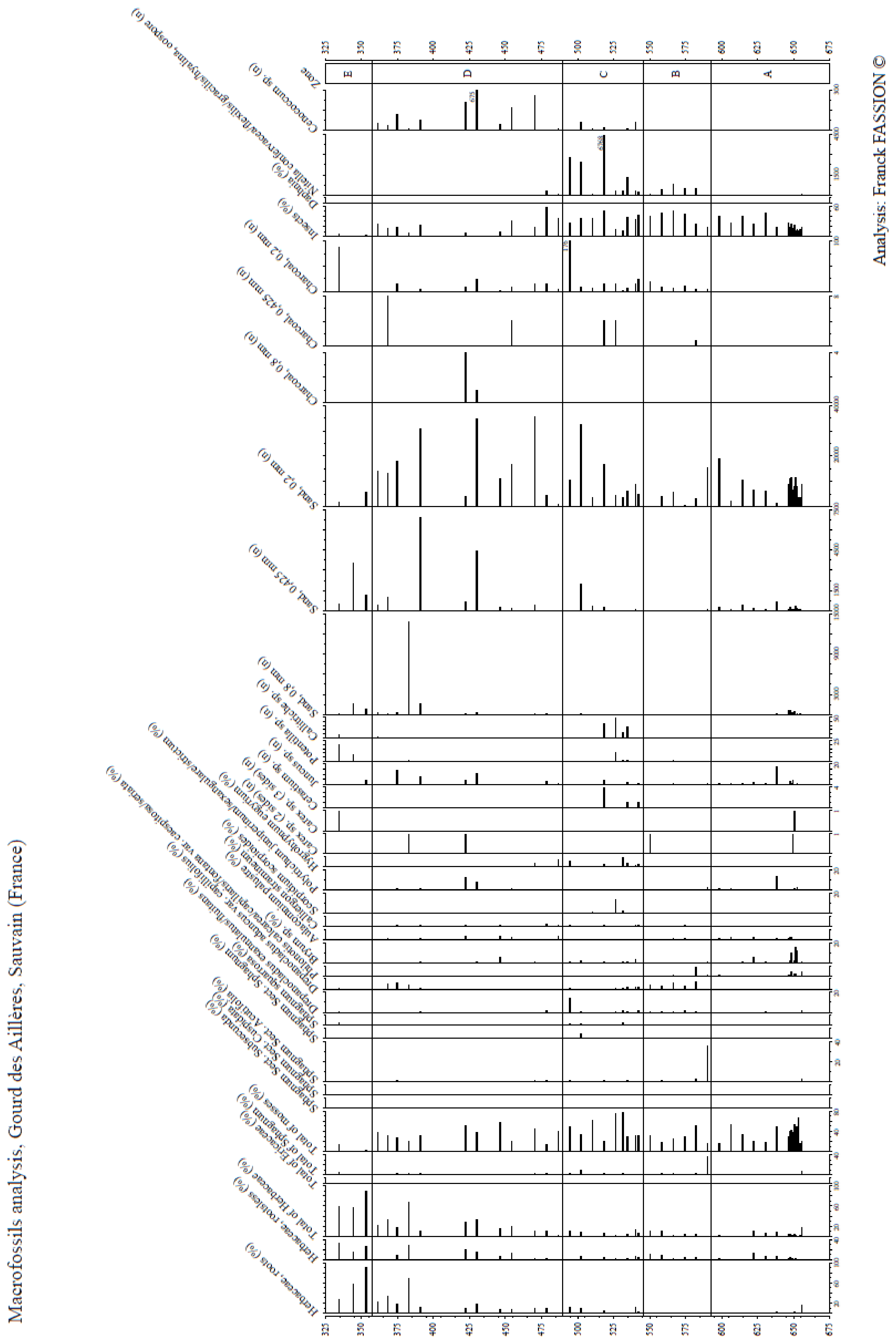

Figure 8*: Macrofossil selected taxa (© Fassion)*

Holocene environmental changes in Les Monts du Forez (France): focus on the development of the agro-pastoral activities and their impact on the subalpine heath

Hervé CUBIZOLLE[1], Jacqueline ARGANT[2], Franck FASSION[3], Catherine LATOUR-ARGANT[4], Yun DENG-AMIOT[5] and Benjamin DIETRE[6]

(see the full paper Cubizolle *et al*. 2014 in the review *Quaternaire* as a supplement)

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ABSTRACT

This paper discusses the results of three new palynological analyses and one macrofossil analysis (**Figure 1 and 2**). The study concerns three peat sequences extracted from mires in les Monts du Forez mountain range in the eastern part of the French Massif Central. The results have been compared with all other results obtained over twelve years in this mountainous region. The knowledge related to the evolution of the vegetation, the initiation of agro-pastoralism systems and the history of upper-forest heathland could make a lot of progress. Firstly we can accurately date around 5000 cal. BP the start of *Fagus* distribution, quickly followed by *Abies* and their development over the course of the Sub-Boreal period. Secondly we witness that the first evidence concerning the land-use occurred much later than in other geographical sectors of the Massif Central such as the Limousin and Cantal: only during the middle Neolithic and the late Neolithic between 5700 cal. BP and 5000 cal. BP. Thirdly we demonstrated the climatic origin of heathland above an altitude of 1350-1400 m. Agro-pastoralism activities have only contributed to modify the respective shares of each plant type by supporting heathlands to the detriment of the grasslands. Thus, the importance of trees has changed according to the nature and the intensity of human pressure.

Keywords: Holocene, vegetation history, climatic changes, anthropisation, palynological and macrofossil analyses, Massif Central, France

1. *Pollen analysis*

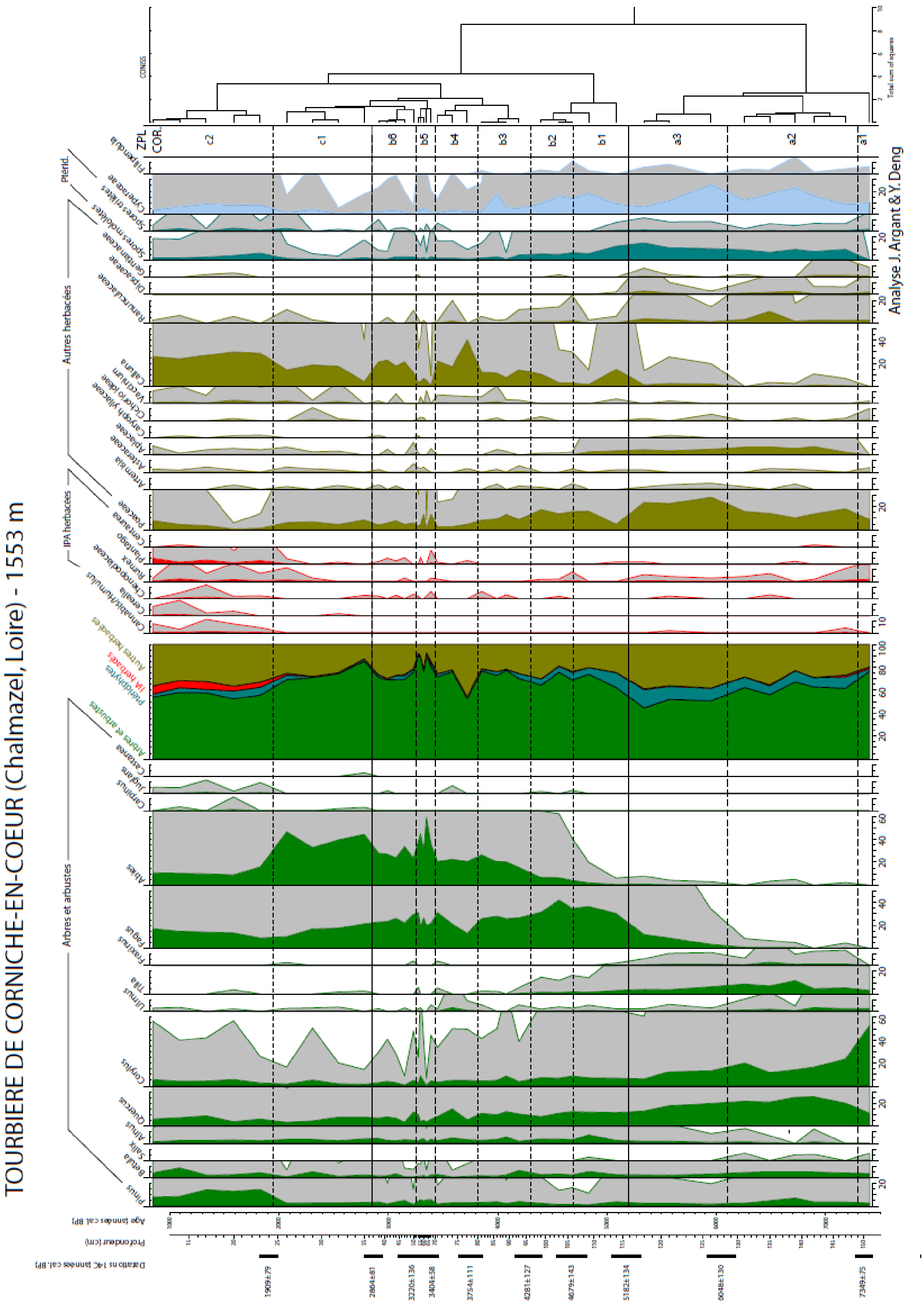

Figure 1*: Palynological diagram of Corniche-en-Coeur in les Monts du Forez (1553 m a.s.l.)*

2. Macrofossils analysis

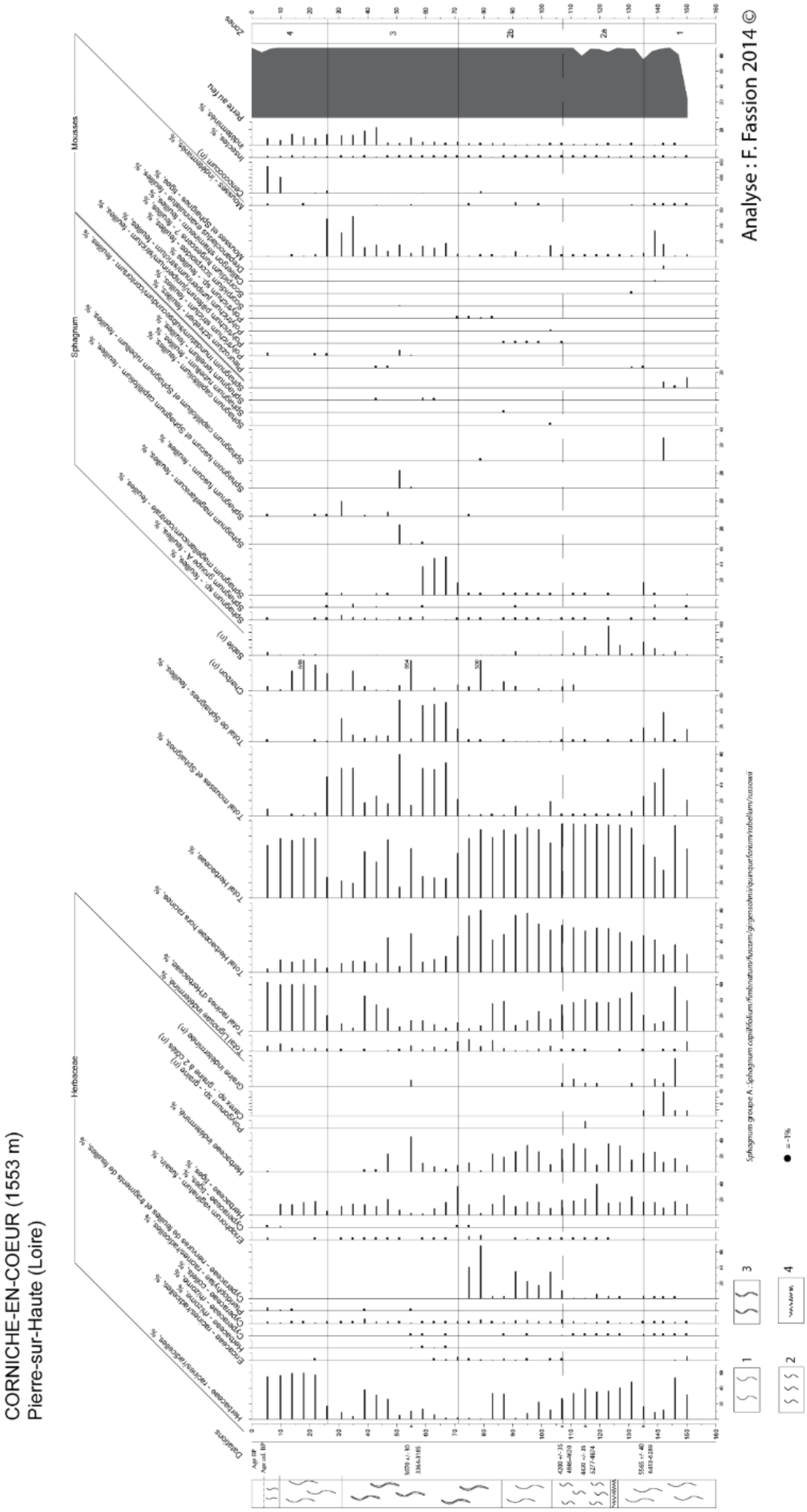

***Figure 2**: Macrofossils diagram of Corniche-en-Coeur in Les Monts du Forez (1553 m a.s.l.)*

3. Archaeological research (work in progress since May 2016).

Antoine SCHOLTES, PhD student, University of Lyon, EVS UMR 5600 CNRS, Saint-Etienne

A geoarchaeological research program has been initiated since 2016 in the uplands of Les Monts du Forez, from the plateau of Le Gros Fumé to the top of Pierre-sur-Haute (1642 m). The main purpose is to characterize the past human settlements and the socio-economic dynamics of the upland above the forest line (so called “Hautes-Chaumes”) of the Monts du Forez (**Figure 3**). Indeed, the whole archaeological and palaeoecological investigations concern the thousand years old history of agro-pastoral activities held in this middle mountain range. Besides, another issue will be to understand the links of cause and effect between these dynamics and the environmental and climatic constraints that have crossed them since Neolithic times and how were the relationships between those past societies and their natural environment.

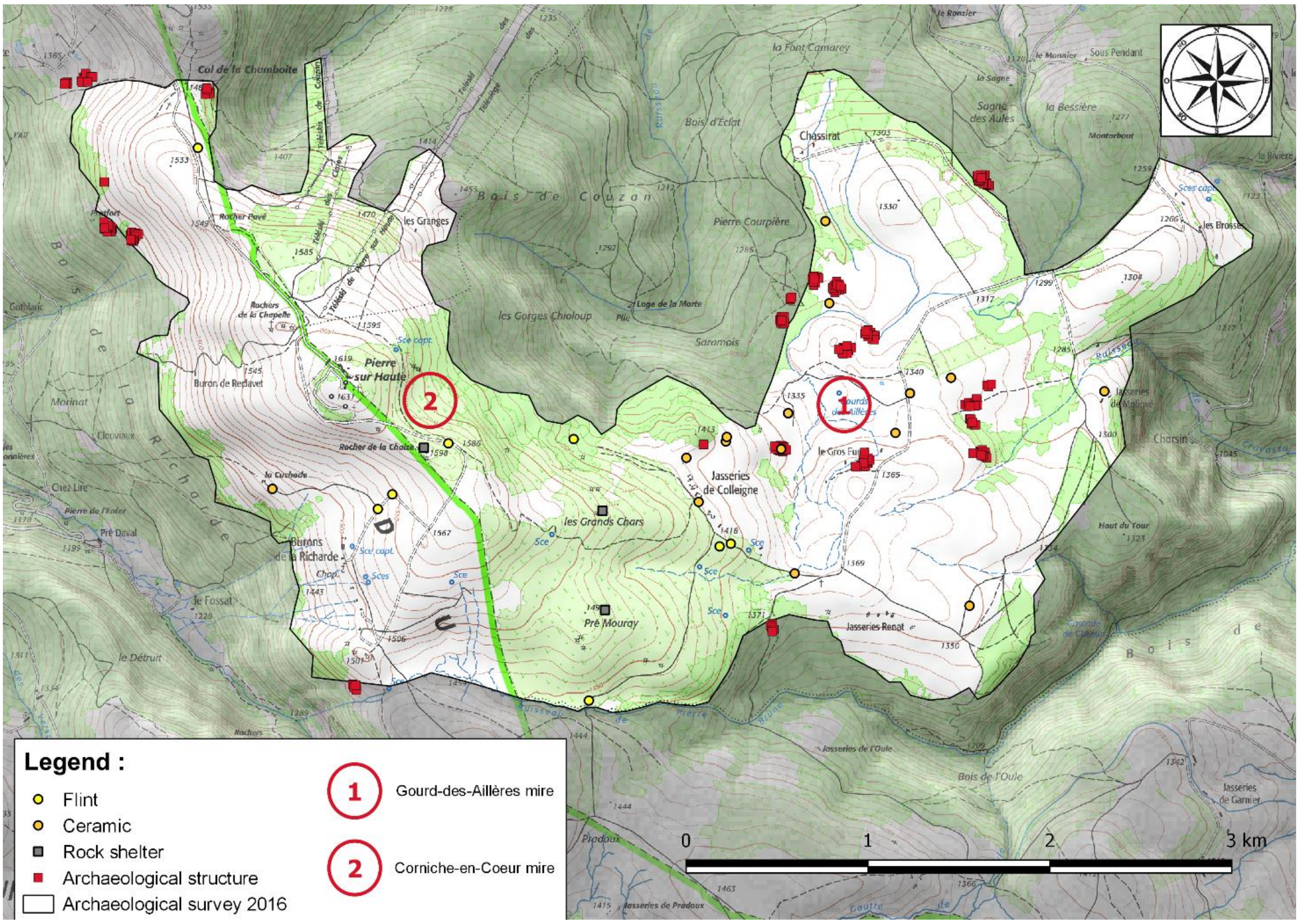

***Figure 3**: Location of archaeological structures discovered during the last two years in Les Monts du Forez uplands close to the top of Pierre-sur-Haute*

Therefore, the main archaeological problem is to highlight the evolution of local agro-pastoral systems in the broad sense of the term. Concerning the plateau of Le Gros Fumé, the investigations hold more than 100 semi-buried hollow structures, distributed in about twenty sites (**Figure 4**).

The holding of archaeological excavations in June 2017 on these structures will make it possible to identify initial hypotheses concerning their typology and their chronology (**Figure 5 and 6**). From a diachronic point of view, their number suggests a relative mobility of the habitat, according to the pattern indicated by the medieval and modern texts, marked by abandonments, displacements or reconstructions.

In addition, the discovery of ceramics and flints during the surveys makes it possible to estimate some phases of the past settlements that will have to be confirmed and completed with the excavations and by the continuation of the prospections. And thus, the partial results obtained provide the basis for a broad chronology, from the Middle / End Neolithic to the 19th century, with occurrences for the Bronze Age, Iron Age, Roman Times, Middle Ages and The Modern era. However, these findings are limited by the current vegetation component, which makes the land difficult to read (heaths and forests).

To conclude, most of the paleoenvironmental indicators (microfossils and macrofossils) reflect a societal pressure on the environment since at least the Neolithic (clearing, pastures and crops). These clues will have to be confirmed with further archaeological investigations.

Figure 4*: Example of structure found in Monts du Forez uplands*

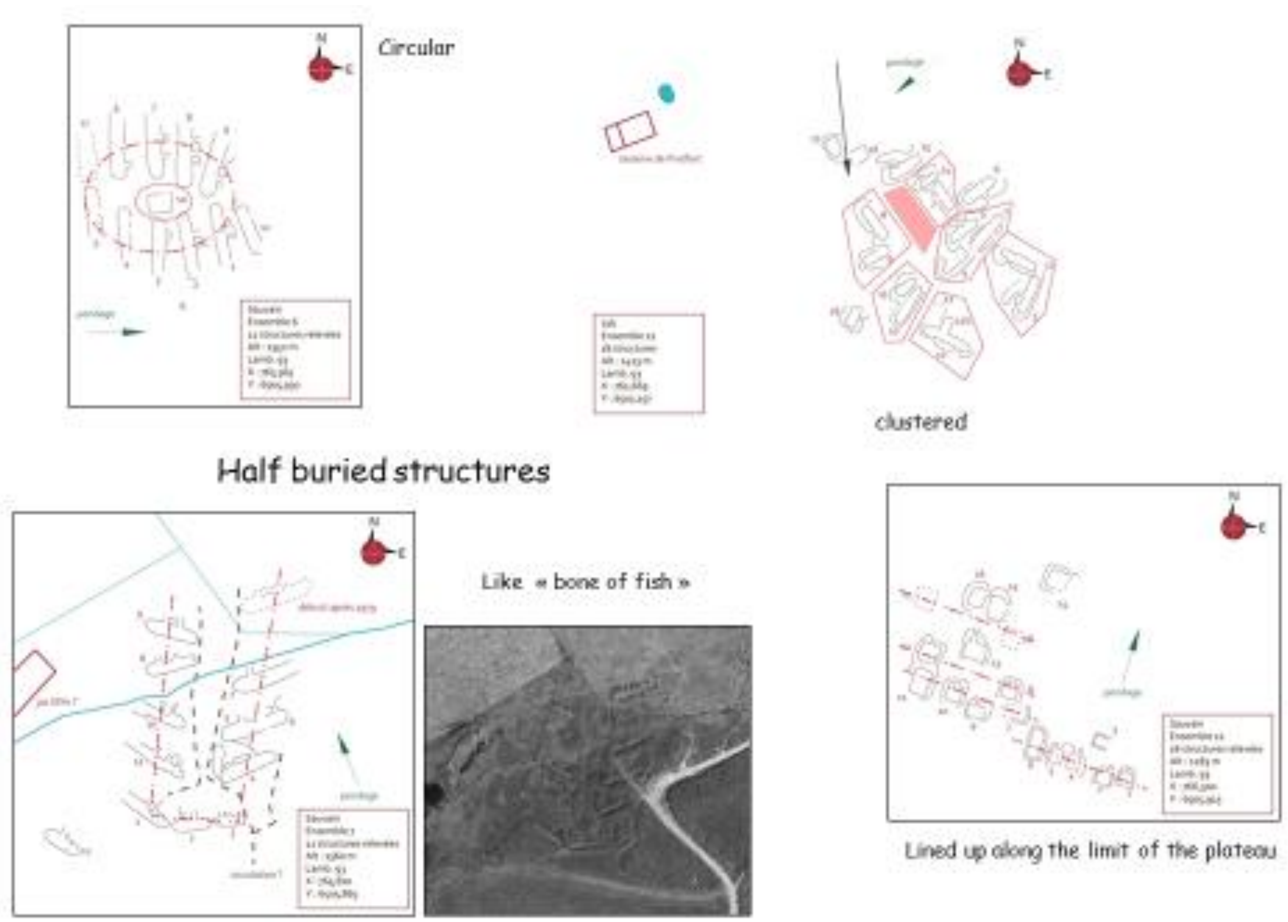

Figure 5*: Typology of structures listed in les Monts du Forez*

Figure 6*: Excavations in June 2017 just above the mire of Gourd des Aillères (1390 m a.s.l.)*

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IME-Site 2: Lake Aydat (850 m a.s.l.) – Aydat – Puy-de-Dôme Department

PALAEO-ECOLOGICAL STUDIES OF THE LAKE AYDAT (AUVERGNE, FRANCE): 6700 YEARS OF HISTORY

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1. INTRODUCTION

Lake Aydat, part of the Chaîne de Puys volcanic range situated in Auvergne is under constant pressure between keeping environmental quality and socio-economic development (**Figure 1**). Thus, diatom, pollen and non-pollen palynomorphs studies were undertaken as part of a paleoecological investigation with the aim to develop prospective models of ecosystem functioning and landscape evolution, in order to guarantee environment quality in future development. The lake has been and is being effected by human influence where high eutrophication levels often result in the prohibition of swimming during the summer. Local and regional authorities are particularly interested in lake restoration while allowing ecotourism (Miras *et al.,* 2015).

The overall objectives of this paper are the presentation of the long term assessment of the complex and diversified land use systems and their environmental consequences on the Lake Aydat catchment, based on pollen and non-pollen palynomorph assemblages, diatom community and cyanobacteria akinetes.

2. INVESTIGATION AREA

The eutrophic Lake Aydat (mean depth: 7.4 m; area: 6.105 m2; maximum depth: 15 m; N 45°39.809′/E 2°59.106′/837 m a.s.l.) is located at the southern boundary of the Chaîne des Puys volcanic range (French Massif Central), ca. 25 km SW of Clermont-Ferrand (**Figure 2**). The region is characterised by an oceanic–montane climate with a mean annual temperature of ca. 12 °C and a mean annual rainfall of ca. 800 mm (Bouchet, 1987). A detailed description of the Lake Aydat features (*e.g.* geological and geomorphological settings, the bathymetric map) is given in Lavrieux *et al.* (2013a). The lake, which originated from the damning of the Veyre River by a basaltic flow dated from 8551 ± 400 cal. yr BP, issued from the Puy de la Vache and Puy Lassolas volcanoes, lies on a plutonic and metamorphic substratum (granodiorites), partially covered by Late Glacial to Holocene volcanic deposits (Boivin *et al.*, 2004).

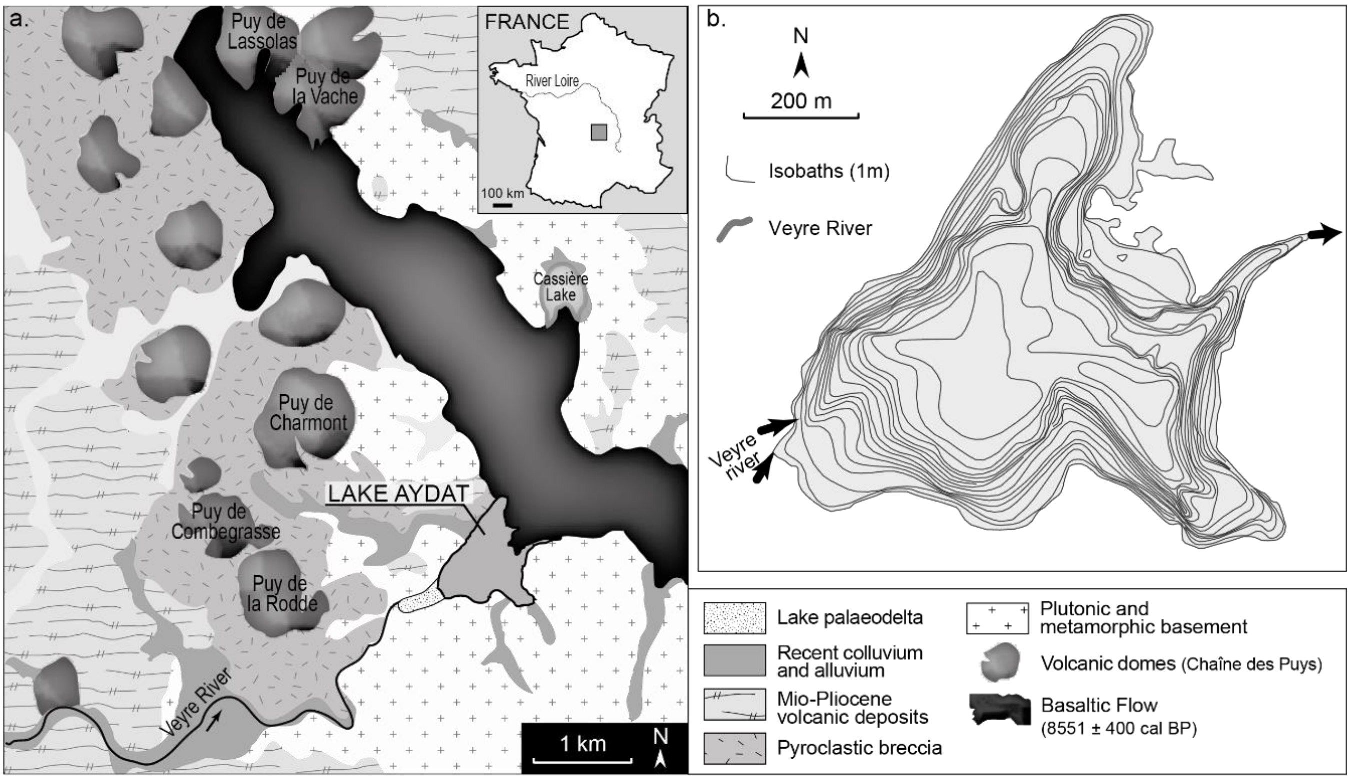

Figure 1*: Location of Lake Aydat in the French Massif Central. The core position in Lake Aydat with seismic profiles.*

3. MATERIALS AND METHODS

This study was performed as part of a multi-proxy palaeoecological research programme and the full methodology is detailed in Lavrieux *et al.* (2013a). Coring was carried out in the central and deepest part of the basin, close to the Veyre River delta. A continuous sequence was retrieved in 2- and 3-m sections at 14.5 m water depth with a UWITEC coring platform. On the basis of sedimentological features, the record is divided into 2 main units separated by a mass wasting deposit (**Table 1; Figure 2**): (i) the lower one (1076–1974 cm depth which corresponds to 777–1600 cm in the master core) and (ii) the upper unit (0–829 cm depth which corresponds to 0–775 cm in the master core) (Lavrieux *et al.*, 2013a). The palynological and diatom studies only concern the lower and the upper units.

Table 1:*AMS radiocarbon dates and 137Cs results obtained from the Lake Aydat core.*

Datation method	Type of material	Master core depth (cm) Uncorrected	Master core depth (cm) Corrected	Radiocarbon age (BP)	Calibrated age (2σ; years cal. BP)	Laboratory Name	
^{137}Cs	Bulk sediment	20	19	-	- 36 (1986 AD)	-	
^{137}Cs	Bulk sediment	30	29	-	- 13 (1963 AD)	-	
^{14}C	Twig	349.7	332.7	520 ± 30	570 ± 40	SacA 21687	
^{14}C	Twig	387.7	370.7	700 ± 30	650 ± 50	SacA 21688	
^{14}C	*Twig*	*467.5*	*433.2*	*1330 ± 30*	*1270 ± 80*	*SacA 16355*	*Excluded (reworked debris)*
^{14}C	Twig	705.8	656.8	1265 ± 30	1230 ± 40	SacA 21685	
^{14}C	Twig	782.1	727.5	1575 ± 30	1480 ± 40	SacA 21686	
^{14}C	Twig	790.1	735.5	1630 ± 30	1520 ± 60	SacA 21689	
^{14}C	Leaf	820.3	766.5	1825 ± 30	1780 ± 40	SacA 21690	
^{14}C	*Leaf*	*1056*	-	*2440 ± 30*	*2530 ± 260*	*SacA 16356*	*Excluded (intermediate unit)*
^{14}C	Charcoal	1094.2	780.5	3005 ± 30	3210 ± 100	SacA 16357	
^{14}C	Leaf	1136.5	823.5	3190 ± 30	3420 ± 60	SacA 16362	
^{14}C	Leaf	1297.2	979.5	3605 ± 30	3920 ± 80	SacA 16363	
^{14}C	Leaf	1389.2	1071.5	3840 ± 30	4260 ± 140	SacA 16364	
^{14}C	Twig	1401.2	1083.5	4000 ± 30	4480 ± 80	SacA 16358	
^{14}C	Seed (?)	1576 ± 5	1258.7 ± 5	4615 ± 30	5380 ± 120	SacA 16365	
^{14}C	Leaf	1644.7	1327.5	4750 ± 30	5510 ± 120	SacA 16359	
^{14}C	Leaf (?)	1685.2	1368	4800 ± 35	5540 ± 100	SacA 16360	
^{14}C	Twig	1767.7	1449.5	5280 ± 30	6080 ± 140	SacA 16366	
^{14}C	*Twig*	*934*	-	*2270 ± 30*	*2270 ± 140*	*SacA 16361*	*Excluded (intermediate unit)*

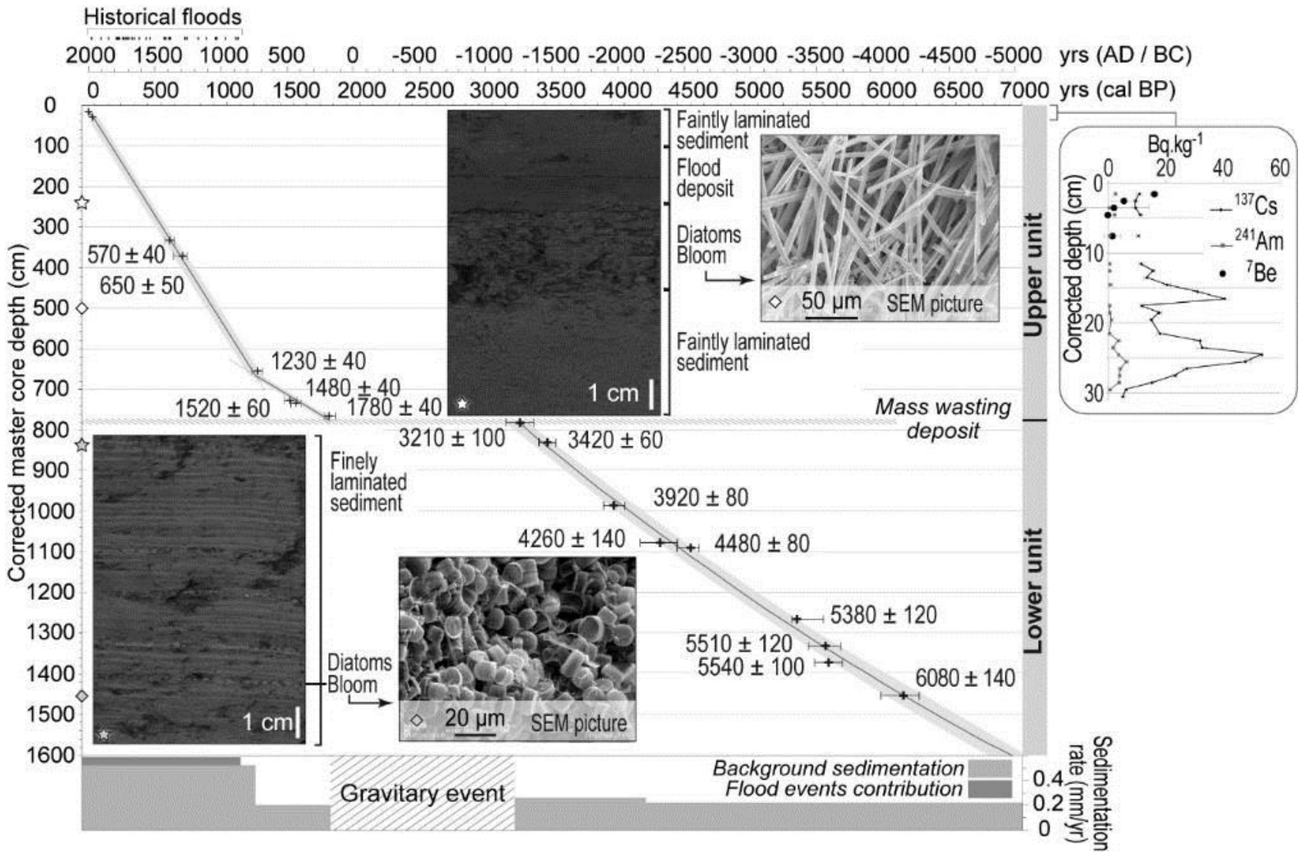

Figure 2*: Age–depth model, correlation with historical floods, sedimentation rates and sedimentological units. Stars and diamonds locate the depths of the pictures presented. 137Cs, 241Am and 7Be of the top of the core are provided on the right (from Lavrieux et al., 2013a).*

4. RESULTS AND DISCUSSION

Eight main pollen zones were observed (**Figures 3 & 4**) and seven were determined for diatoms (**Figure 5 and 6**).

4.1 Neolithic and Bronze Age periods: the lower unit:

From 6722 cal BP until 3227 cal BP:

During this period, two phases of nutrient enrichment of Lake Aydat are noted between ca. 4900 and 4600 cal. yr BP (from 1200 to 1140 cm depth) and ca. 3922–3500 cal. yr BP (from 962 to 853 cm depth) related to pollen and NPP that alternate with resilience phases.

During the Neolithic and the Early Bronze Age the impact of human activity gradually increased in intensity, but was characterised by temporary forms of land use. In both cases, pollen data clearly indicate regeneration of woodland after the abandonment of the area. There is a continuous presence of akinetes in the sediments along with two minor peaks occurring.

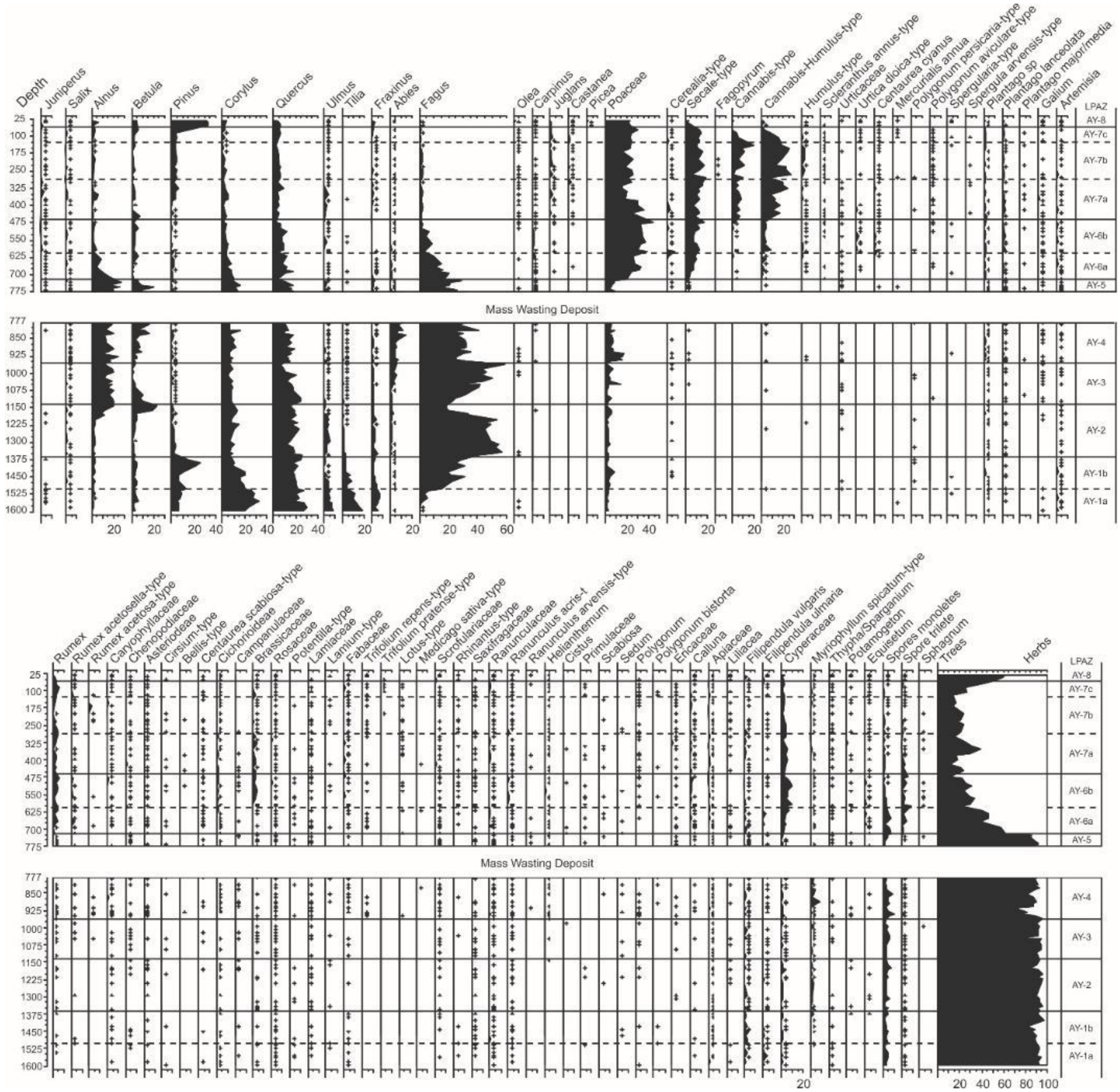

***Figure 3**: Main pollen and spore percentage diagram of the Lake Aydat sequence (from Miras et al. 2015).*

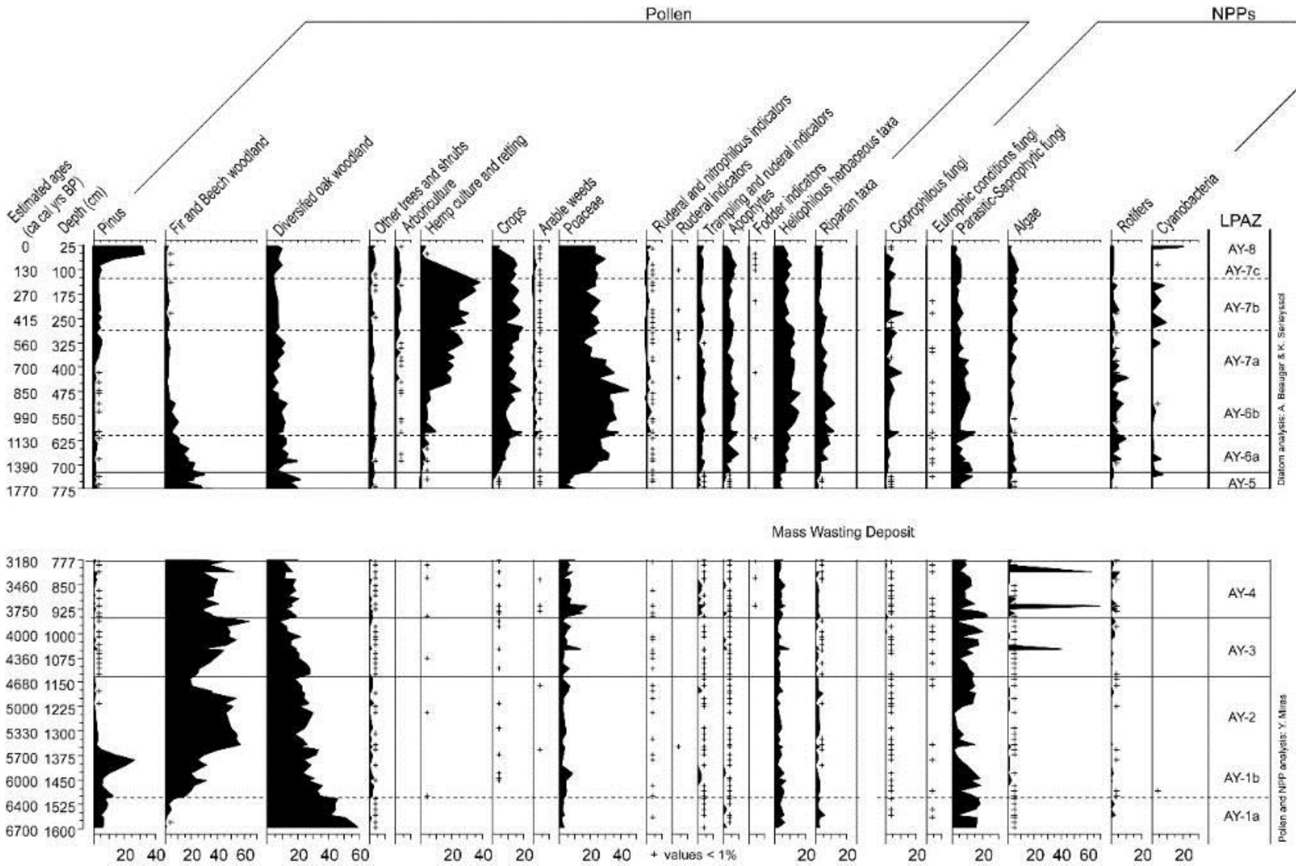

***Figure 4**: Lake Aydat simplified diagram of pollen, non-pollen palynomorphs and diatom ecological traits plotted against mean calibrated ages (from Miras et al. 2015).*

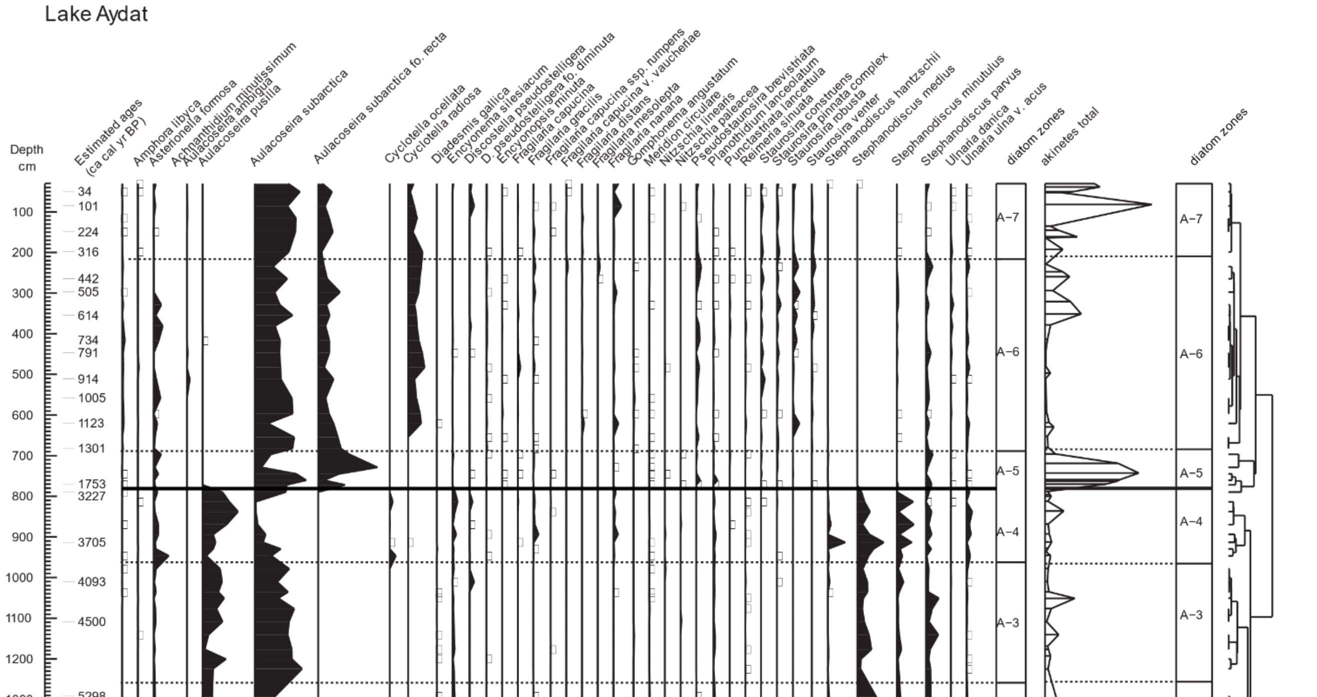

***Figure 5**: Lake Aydat diatom stratigraphic zonation with akinetes total count associated with the diatom zones. Zonation determined using Psimpoll 4.26. Heavy thick line marks mass-wasting event.*

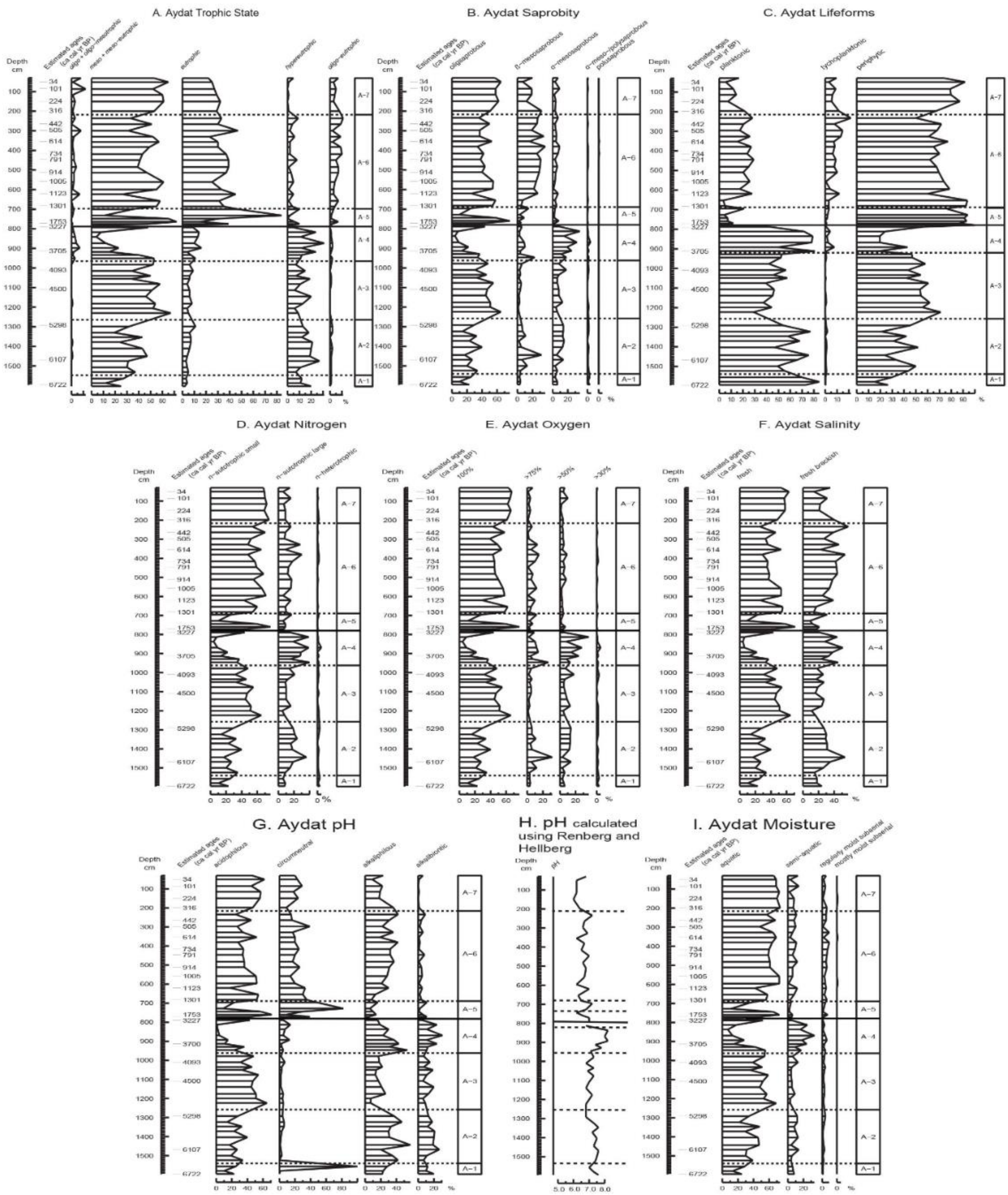

***Figure 6**: The different ecological indicator values based on the percentage of species belonging to a particular indicator value as observed along the core. A. Trophic States, B. Saprobity, C. Lifeforms, planktonic, tychoplanktonic, periphytic, D. Nitrogen uptake metabolism (autotrophic small, tolerating very small concentration of organic bound nitrogen, autotrophic large, tolerating elevated concentration), E. Oxygen requirement (percent of water saturation), F. Salinity (Fresh = <0.2‰, fresh*-brackish = <0.9*), G. pH preference, H. ph calculated using Renberg and Hellberg, I. Moisture preference.*

Pollen zones AY-1 & AY-2 and diatom zones A-1 & A-2:

Mean Arboreal Pollen (AP: 90%) values characterise this zone. *Quercus* and *Corylus* (30%) are predominant within the arboreal types which also include *Tilia* (up to 20%), *Ulmus* (5%), *Fraxinus* (5%), *Pinus* (5%) and *Betula* (3%) (AY-1).

Between ca. 6000 and 5750 cal. yr BP, a phase of high detrital input was previously related to a period of lower solar activity (Lavrieux *et al.*, 2013a). Cooler and more humid conditions favouring enhanced soil erosion in the catchment could be responsible for the higher trophic state of Lake Aydat implied by the domination of resting egg morphotypes of rotifers, which are often found in such conditions like (e.g. *Conochilus hippocrepis*, *Brachionus* and *Keratella* [Barbiero and Warren, 2011]), by the significant rise in *Diporotheca rhizophila*, *Valsaria variospora* and Turbellarieae (*e.g. Mycodalyellia armigera*) (Haas, 1996; Van Geel, 2001; Van Geel *et al.*, 2003; Hillbrand *et al.*, 2012) and planktonic, hypereutrophic and eutrophic diatoms such as *S. minutulus, S. parvus, S. hantzschii* and *A. pusilla*. The first periods of nutrient enrichment were observed.

Pollen zones AY-3 & AY-4 and diatom zones A-3, A-4:

Fagus, Abies, Betula are the dominant species and there is a progressive decrease in *Corylus* associated with an important increase in the eutrophic species *A. subarctica* (A-3) and hypereutrophic taxa *S. parvus*.

For the Bronze Age, a higher trophic state is mainly indicated by high values of *Pediastrum*, a common green alga of eutrophic lakes (Bradbury *et al.*, 2004; Argant *et al.*, 2006) and by a significant increase and diversification of the assemblages of the rotifer resting egg morphotypes which include *Trichocerca cylindrica, Brachionus, Keratella* and *Conochilus hippocrepis* (AY-4). Both *Brachionus* and *Keratella* are also good indicators of high turbidity (Sousa *et al.*, 2008) and *Brachionus* – often recognised as a hypereutrophic species (Duggan *et al.*, 2001) – suggests the higher intensity of this trophic change. Fungal spores such as *Ustilago*, which peaks during this event, are often associated to *Keratella* for identifying phosphorus input (Turton and McAndrews, 2006). Presence of dung-related fungal spores (i.e. *Sporormiella*-type and *Sordaria*) and rotifers as *Conochilus hippocrepisi* and associated to soil disturbance as *Diporotheca rhizophila* which are related to human activities and the presence of cattle. At this period, linked to human activities, there is a radical decrease of *A. subarctica* and increase in eutrophic species as *A. pusilla, Asterionella formosa, S. medius,* and *S. minutulus,* with the continued appearance of the *S. parvus* and the appearance of *Ulnaria ulna* v. acus, *F. gracilis* and *F. nanana.*

After this second event, reported to the Early Bronze Age, the subsequent temporary extinction of the resting egg morphotype of *Anuraeopis fissa* – rotifer often considered as a eutrophic indicator (Balvay, 1989) – coincides with a spread of *Spirogyra* algae spores and a broad maintaining of different morphotypes of rotifer resting eggs such as *Keratella, Brachionus, Conochilus hippocrepis* (end of AY-4). The trophic change evidenced in this case is towards less eutrophic conditions. Diatom data confirm this trend as *Stephanodiscus* slightly decrease. As previously described in Lake Nussbaumersee in Switzerland (Hillbrand *et al.*, 2014), these changes amongst the NPP assemblages express a loss of resilience in the lake ecosystem caused by more intense and repeated human disturbances during the Bronze Age.

4.2 The last 2 millenia: Upper unit: The eutrophication of the water of the lake increases leading to a loss of resilience.

Above the mass-wasting event (AY-5 & A-5; 2th century AD- 6th century AD) *A. pusilla* and certain *Stephanodiscus* species *(S. hantzschii, S. medius,* and *S. minutulus*) disappear and are replaced by eutrophic species as *Aulacoseira subarctica* f. *recta* (Kauppila 2006; Rioual 2000; Sienkiewicz & Gąsiorowski, 2014). *Asterionella formosa* and *S. parvus* remains are common while *A. subarctica* resumes a dominant member of the community. A series of "*Fragilaria*" species (*Fragilaria capucina Desmazieres, F. gracilis, Pseudostaurosira brevistriata* Grun. *In* Van Heurck Williams & Round), *Staurosira construens* Ehrenberg, *Staurosira pinnata* complex Ehrenberg) became prevalent. An important concentration of akinetes was observed coinciding with the highest percentage of *Aulacoseira subarctica* f. *recta* that indicate higher phosphorous concentrations than *A. subarctica* (Kauppila 2006; Hoff *et al.,* 2015).

This period is characterized by a first drop in *Fagus* percentages (mean values around 20%) while other arboreal taxa's percentages remain stable especially *Alnus* (up to 27%) and *Quercus* (ca. 20%). The percentages of Poaceae, heliophilous herbaceous taxa and Cyperaceae increase gradually towards the top of the zone. A decline in saprophytic and parasitic fungi of beech wood – *Triposporium elegans, Ustulina deusta* and *Asterosporium* – is quoted with occurrences of *Glomus*.

The first evidence of hemp cultivation started at the top of this zone. Human occupation was marked by a roman villa near the lake (Miras *et al.,* 2015). This is a transition zone from a mosaic woody environment to an agricultural one.

Pollen zones AY-6 & AY-7a and diatom zone A-6 (6th century AD – 16th century AD):

This period represent grass and crop lands that are associated with meso- to eutrophic diatoms such as *Aulacoseira ambigua* (Grunow) Simonsen, *A. subarctica* f. *recta*, *Eolimna minima, Navicula radiosa, P. brevistriata, S. construens*, a mixture of planktonic and littoral species suggesting growth of marginal plants (Selby & Brown, 2007). A new impulse of the regression of *Fagus* values (to 10%) is followed by the regression of other tree taxa (mainly *Alnus* and *Corylus*). This explains the declining trend of the AP/T ratio (from 80 to 60 and then to 20%). The continuous curve of *Secale* starts with the first regular notations of *Cannabis/Humulus*-type and *Cannabis*-type. Poaceae (ca. 28%) and other herbs characteristic of pastoral activities become more abundant throughout the zone. Different rotifers and coprophilus fungi as *Conochilus hippocrepis* and *Sordaria* are associated with planktonic taxa (*A. ambigua, A. subarctica* f. *recta*) and a large number of periphytic species (i.e. *Achnanthidium minutissimum* (Kütz.) Czarnecki, *Encyonopsis minuta* Krammer & Reichardt, *E. silesiacum, Reimeria sinuata* (Gregory) Kociolek & Stoermer) and tychoplanktonic fragilarioid taxa (*Fragilaria distans, F. gracilis, F. nanana, Staurosira construens, Staurosira construens* Ehr. v. *binodis* (Ehr.) Hamilton and *S. pinnata* complex).

Blooms of akinetes of *Anabaena* also coincided with pollen evidence of hemp cultivation from the 5th century AD. With the retting of hemp, the lake composition permitted the development of *C. radiosa*. This human activity spread during the Carolingian period and hemp retting started in Lake Aydat during the 12th century (Lavrieux *et al.*, 2013b) (AY-6b). Pollen frequencies of *Cannabis* and *Cannabis/Humulus*-type as well as regular notations of the common weeds of this culture (*Carduus*-type and *Cirsium*) testify to hemp cultivation occurring in the catchment and around the lake.

Pollen zones AY-7b, c & AY-8 and diatom zones A-7 (16th century AD – actually):

At this period, agriculture (including tree planting in *Juglans* and *Castanea*), hemp cultivation and retting are linked to the development of different meso- to eutrophic diatoms as *A. subarctica, C. radiosa, F. capucina var.vaucheriae* and *S. venter*. Cyanobacteria *Anabaena* and the fungal spores i.e. *Sporormiella* are associated with the development of these eutrophic diatoms (*A. subarctica* and *C. radiosa*) and different tychoplanktonic fragilarioid diatoms (*i.e. F. capucina v. vaucheriae*, *P. brevistriata* and *S. venter*). Higher amounts of akinetes were observed in the sediment.

Maximal pollen values of hemp, mainly during the 17th and the 18th centuries suggesting a strong connection between them (AY-7b). Hemp's need for nitrogen, phosphorus and potassium is high (Barron *et al.*, 2003) and its cultivation requires nitrogen fertilisation, causing eutrophication of the lake which is explained by increased nutrient loading through terrestrial erosion. Since *Anabaena* is a nitrogen fixer, the cyanobacteria bloomed. Hemp retting is also well known to provoke degradation of the water quality (Van Geel *et al.*, 1994). At approximately 150 cal. yr BP, hemp cultivation and retting are abandoned and less grazing and agricultural pressure is noted in the pollen and NPP data (AY-7c). At the top of the core (pollen zone AY-8), the renewal of *Pinus* values (up to 35%) explains the AP/T ratio at high values (60%). Exotic tree (*Picea*) is quoted. Herbaceous taxa mainly cereals and other API decline noticeably.

5. CONCLUSIONS

This paper has succeeded in demonstrating that multi-proxy palaeoenvironmental research can provide fresh insights into the understanding of present-day mountain environments. Lessons can be learned for the design of mitigation strategies and sustainable policies. The data presented here clearly illustrate that the modern landscapes and lacustrine systems of Auvergne exist as a synthesis of the cumulative influence of ancient anthropogenic impacts (Neolithic or Metal Age). Indeed this underlines the high vulnerability of these ecosystems and demonstrates that they are by no means fixed. This study provides a good understanding of the long-term response of ecosystems to cumulative changes caused by climate variations and human activities. The long-term accumulation of climate/human impacts could make the ecosystems more sensitive to further climate events; a fact that must be taken into account for the management of the present-day landscape and lake ecosystem. Eutrophication of Lake Aydat therefore appears to have been principally controlled by anthropogenic forcing during the Late Holocene, especially since 1200 cal. yr BP.

The long-term human-induced disturbances, gradual increase of human impact, and the diversification of activities could explain a loss of resilience and thus constitute a ratchet effect (Leroy, 2013) which prevents the return to oligo-mesotrophic conditions.

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IME-Site 2: Lake Aydat (850 m a.s.l.) – Aydat – Puy-de-Dôme Department

IME-Site 4: Lake Chambon (880 m a.s.l.) – Chambon-sur-Lac – Puy-de-Dôme Department

IME- Site 5: Lake Pavin (1200 m a.s.l.) – Besse-et-Saint-Anastaise – Puy-de-Dôme Department

SOME GEOMORPHOLOGICAL AND SEDIMENTOLOGICAL SPECIFICITIES OF VOLCANIC LAKES AYDAT, CHAMBON AND PAVIN, ALLOWING BETTER RECONSTRUCTION OF HOLOCENE ENVIRONMENTAL CHANGES IN THE PUY DE SANCY AREA OF THE FRENCH MASSIF CENTRAL

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ABSTRACT

Lake Aydat (**Figure 1**) was formed 8500 cal yrs ago by a lava flow that dammed a paleo canyon of the Veyre River (**Figures 2 & 3**) As a result, a lake formed and its infill has been mapped to optimize the location of a 19m long piston core. This core is extending back to 6500 cal BP and composed (i) of a lower unit dominated by diatomite deposits, (ii) a thick mass wasting deposits deposited in ca. AD200 (1800 cal BP) and of unknown origin, and (iii) an upper unit made of diatomite and frequent hyperpycnal flood deposits matching historical floods of the Loire River (**Figure 4 to 7**). These floods are essentially reflecting a change in the vegetation cover of the catchment area of Lake Aydat due to increasing human activity. Most of the data presented during the excursion are published in Lavrieux *et al.* (2013).

Lake Chambon (**Figure 1**) was formed during the late Holocene by the largest landslide documented in the French Massif central, that dammed the river draining the Chaudefour valley of glacial origin (**Figure 8**). When glaciers were melting during the Late Glacial period, an eruption formed the Tartaret stratovolcano and a much larger lake formed ca. 12 000 yrs BP. This lake was partly filled by deltaic and lacustrine deposits, and drained during the early Holocene period around 8500 yr BP according to previous studies (Maquaire *et al.,* 1992). Deposits from this Tartaret paleolake (**Figure 8**) are today only partly covered by Lake Chambon, its modern delta and several alluvial fans. Lake Chambon is today very shallow (3 m maximum depth) but gas rich sediments are preventing any acoustic mapping technics to document its geometry (**Figure 9**). In order to date more precisely the

age of the Lake Chambon landslide and its possible relation with Lake Aydat subaquatic mass wasting deposit, we recently collected a core in Lacasou lake: a small lake formed on top of the landslide near Lake Chambon where the topography is hummucky. Ongoing radiocarbon dating and sedimentological measurements at the base of the Lacassou gravity core will provide key elements to date the formation of Lake Chambon and to better understand the triggering factors of landslides in this part of the Massif Central.

Lake Pavin (**Figures 1 & 10**) is the youngest maar lake from the French metropole (7500 cal BP) and has been extensively studied over the last decades because of its meromicticity and potential risk of anoxic deep water degassing events (limnic eruptions). Several papers and a book were recently published and only Lake Pavin sedimentation will be presented here to document environmental changes. In particular we will summarize the sediment and pollen profiles from a 14 m long piston core recently retrieved in the deep central basin 92 m deep (**Figure 10**). This core, together with other available piston cores from a subaquatic plateau and several gravity cores across the lake, allow calibrating high resolution acoustic data (multibeam bathymetric maps, seismic profiles) and is key to reconstruct environmental changes and to discuss the impact and origin of subaquatic slope failures in AD 600 and AD 1300 (**Table 1; Figures 11 & 12**). The first event in AD 600 was associated with a catastrophic crater outburst event and associated with a lake level drop. This first event in lake Pavin may have strongly influence the development of its meromicticity. A regional correlation of subaquatic slope failures in nearby lakes (Chauvet, Pavin, Montcineyre, Guéry; (**Figure 16**) allow also to identify a regional paleo earthquake in ca. AD 1300 (**Figure 17**). The specific geomorphology of Lake Pavin and its exposure to human impact will be discussed based on pollen data (**Table 2; Figure 13**) and soil erosion proxies (**Figures 14 & 15**).

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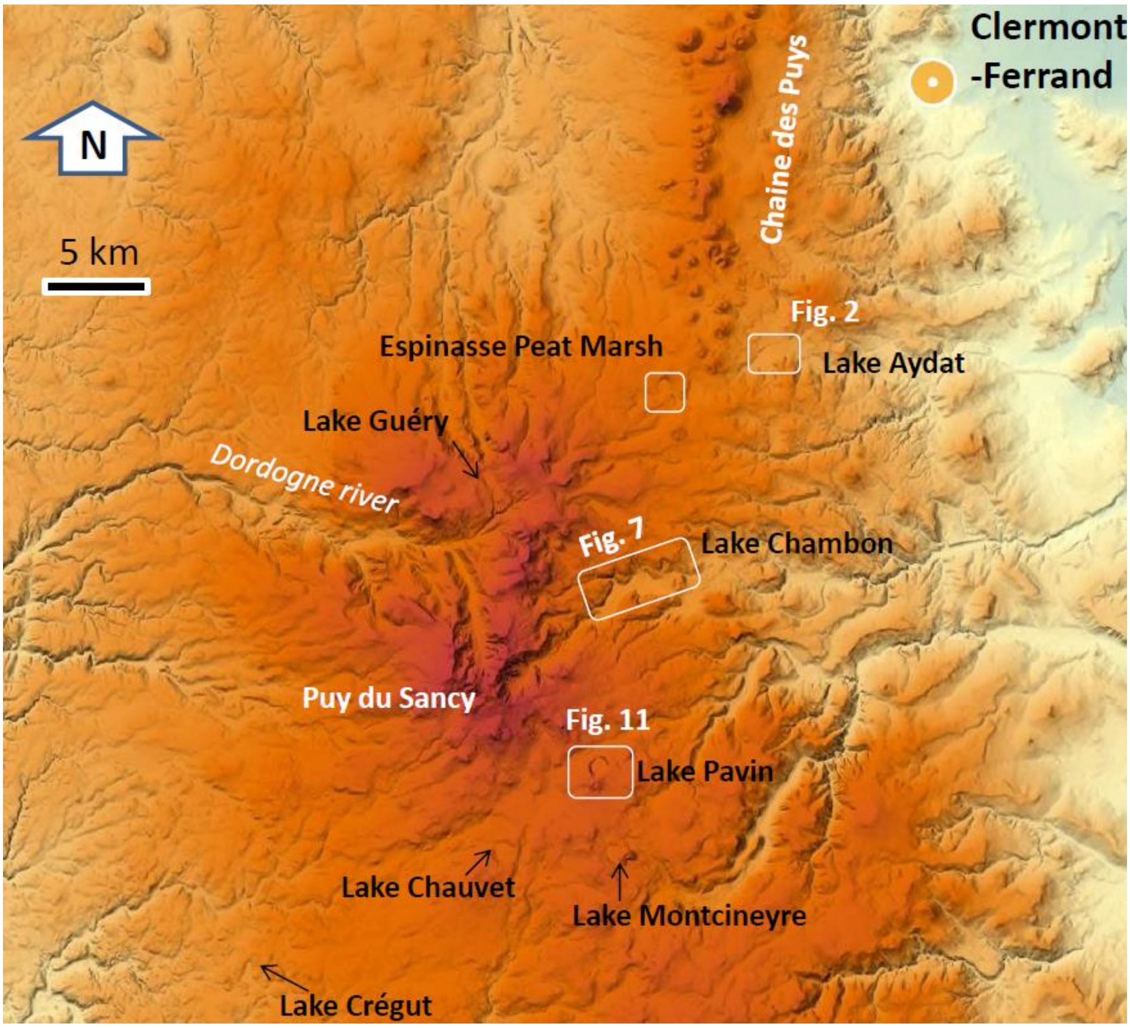

Figure 1*: Digital elevation model and location of studied lakes in the Sancy area (after IGN, Géoportail.fr)*

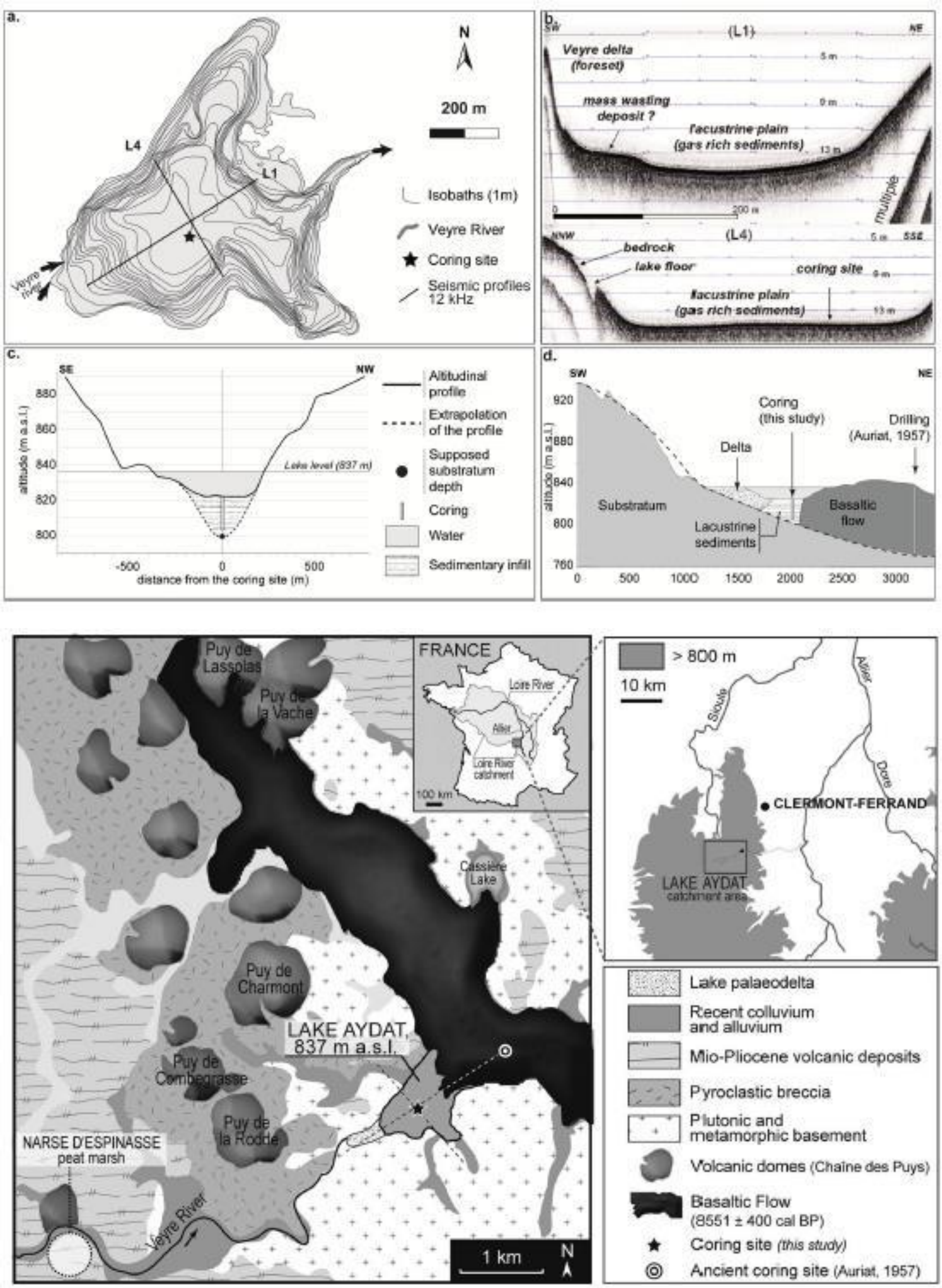

***Figure 2**: Geomorphological context of Lake Aydat (modified from Lavrieux et al. 2013)*

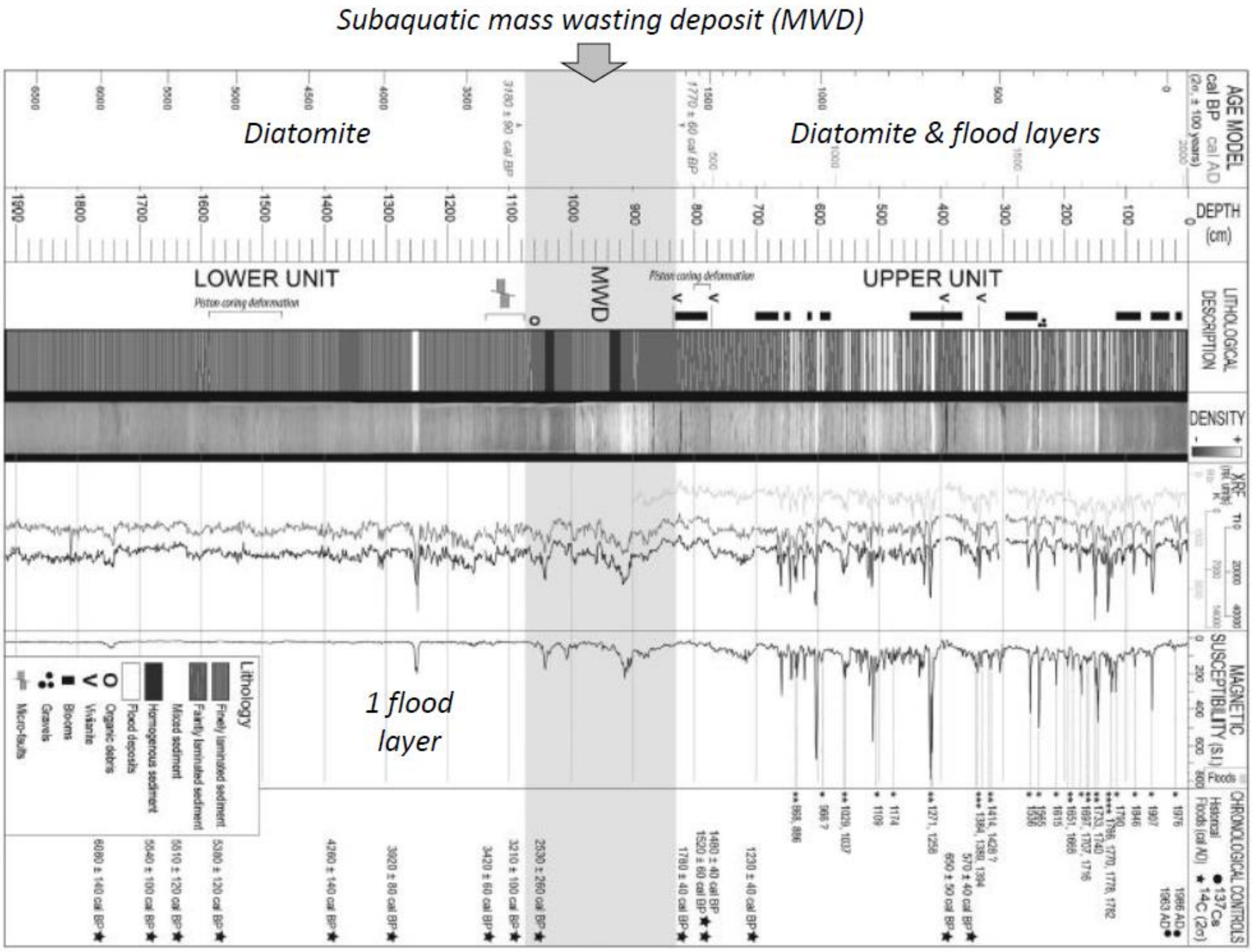

Figure 3: *Lithology and chronology of Lake Aydat coring site AYD09 (from Lavrieux et al, 2013)*

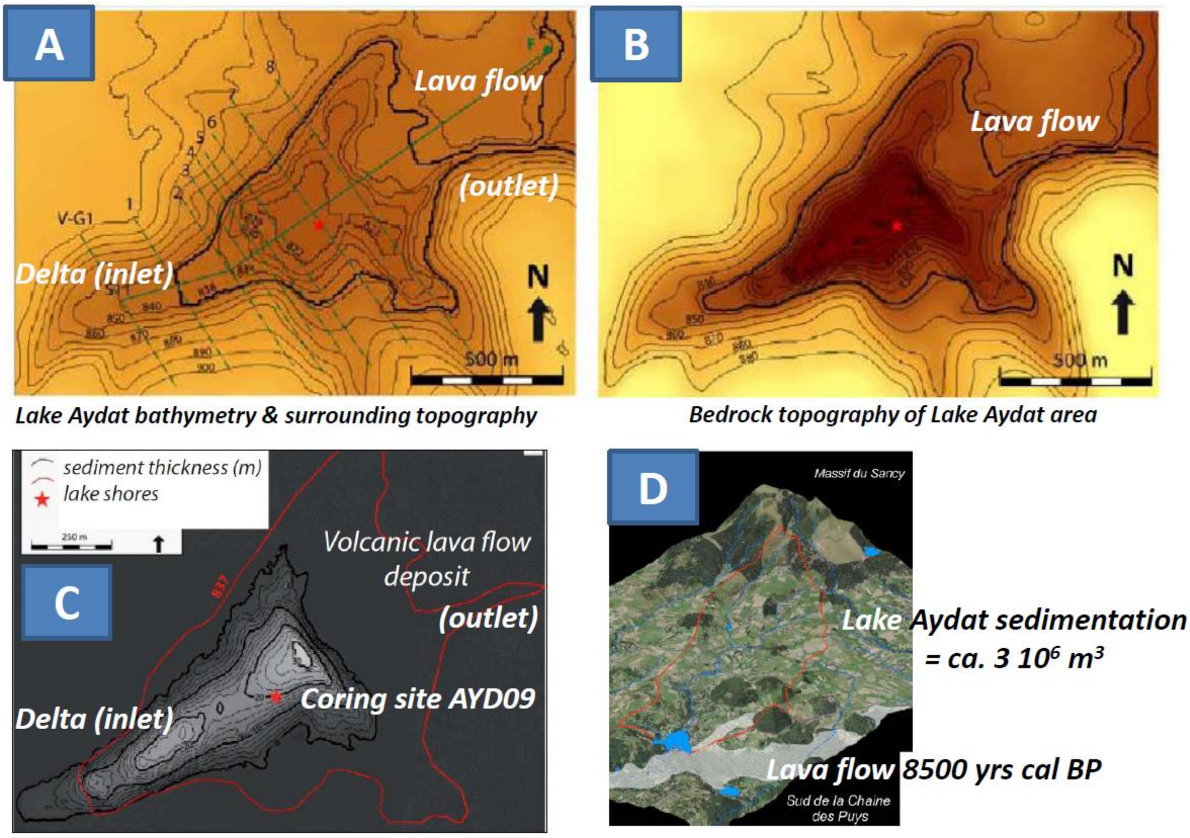

Figure 4: *Lake Aydat sedimentation based on GIS & AYD09 coring site (modified from Janvier, 2010 & Foucher, 2010)*

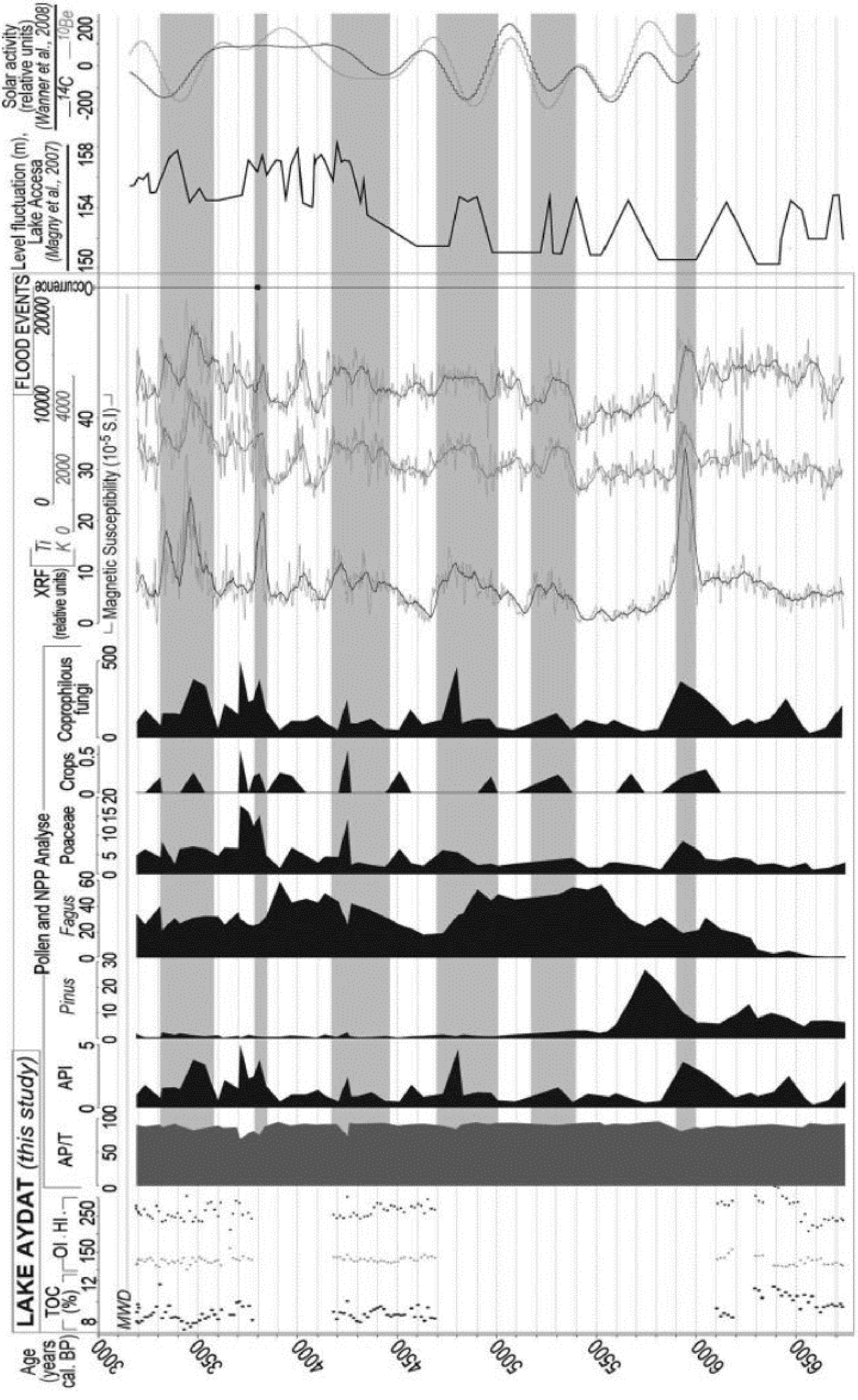

Figure 5*: Multiproxy characterization of Lake Aydat lower unit (after Lavrieux et al, 2013)*

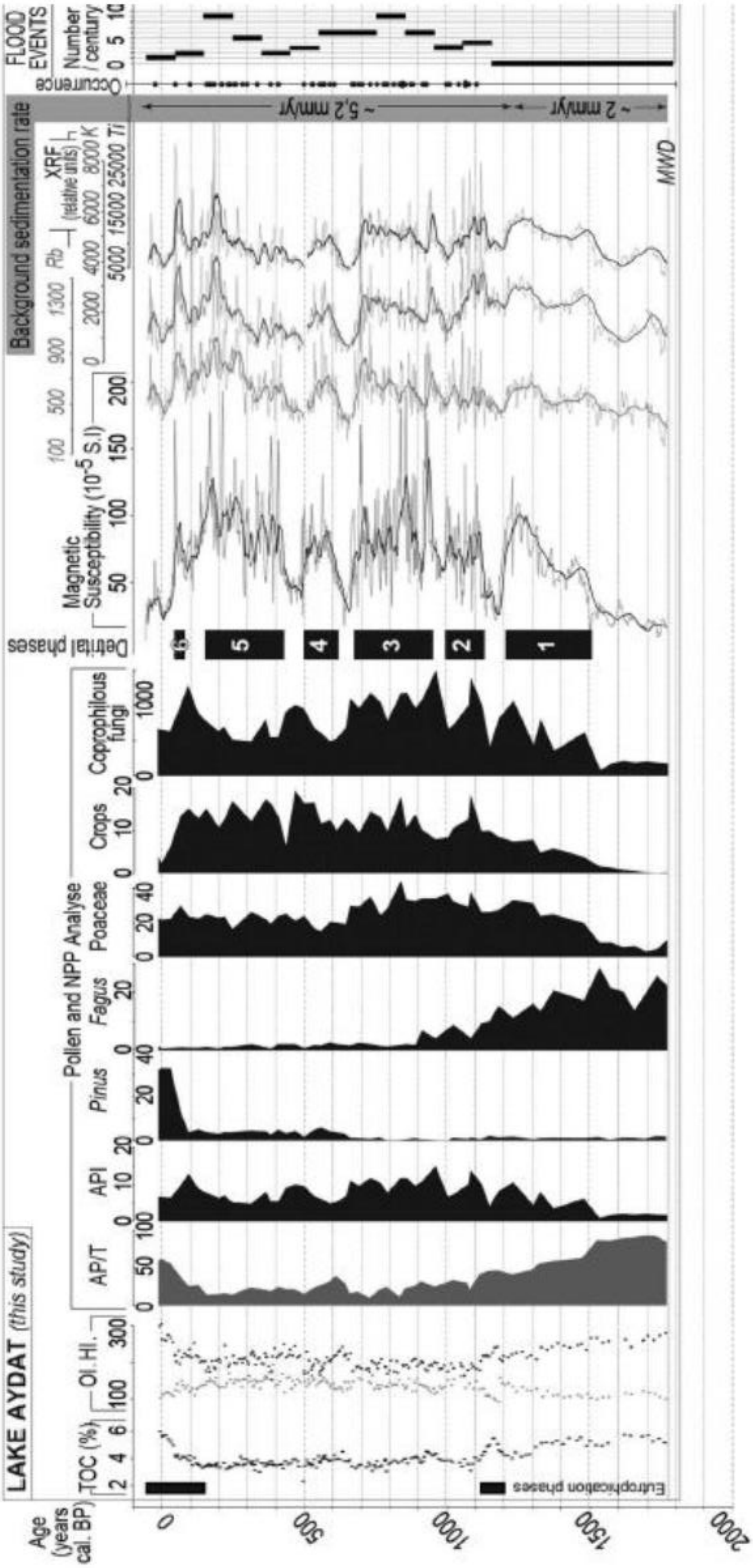

***Figure 6**: Multiproxy characterization of Lake Aydat background sediments from the upper unit (modified from Lavrieux et al, 2013)*

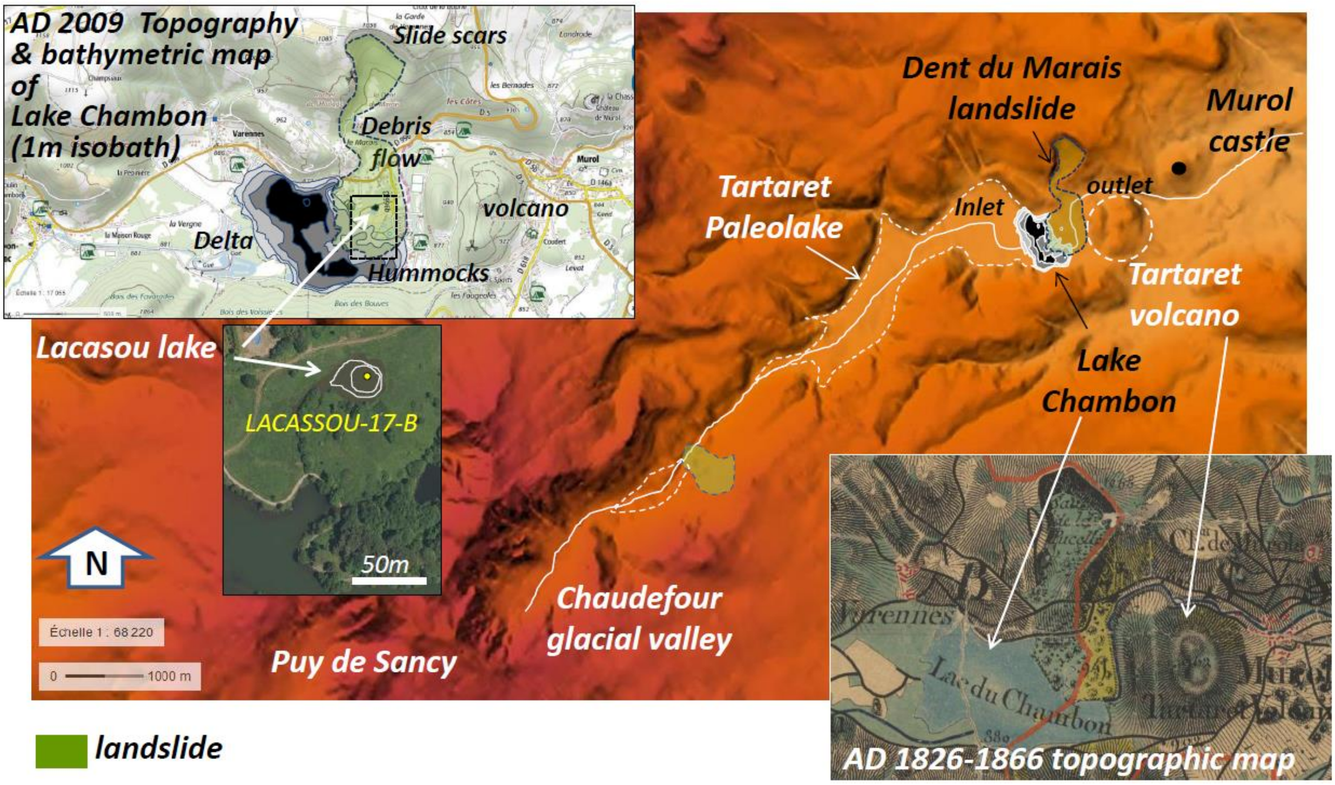

Figure 7: *Geomorphological context of Lake Chambon (modified from Maquaire et al, 1992 & Gay, 1995) and bathymetric maps of lakes Chambon and Lacasou (this study). The location of Lacasou sediment core is also indicated.*

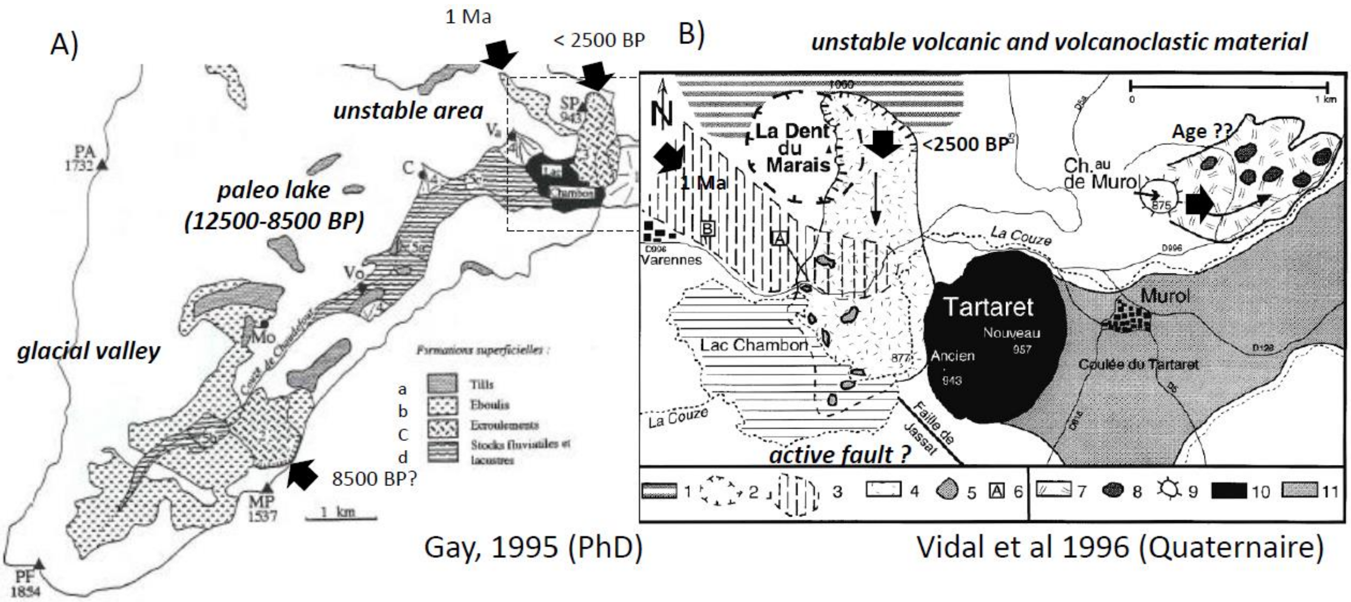

Figure 8: *Geological context of Lake Chambon catchment area (A) after Gay (1995) and detailed map of the two types of dams (B) that formed lakes Tartaret and Chambon (from Vidal et al. 1996). Rockfalls & landslides are underlined by a black arrow together with supposed age. Legend in A: (a) tills; (b) mass mouvements; (c) rockfalls; (d) fluvial and lacustrine deposits. Legend in B: (1) Pliocene lava; (2) Dent du Marais volcanic pipe; (3) Fontenille debris avalanche (1 Ma); (4) Dent du Marais landslide (ca. 2500 BP?); (5) Hummocks; (7) Landslide of Murol castle hill; (8) basaltic hummocks; (9) Murol castle neck (or residual hill); (10) Scoria cone; (11) Basaltic lava flow (12500 BP)*

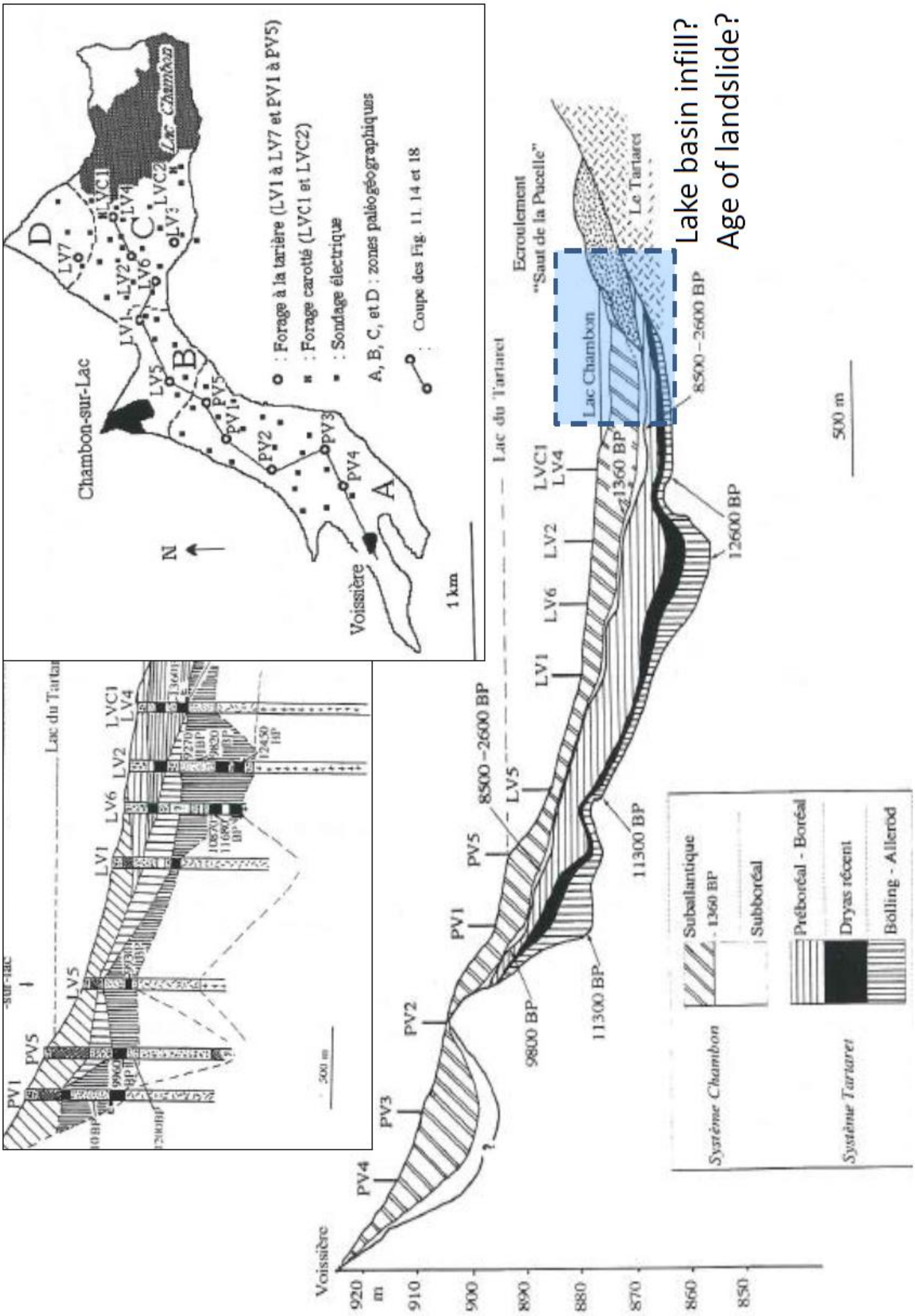

Figure 9*: Geomorphological context of Lake Chambon based on available chronological and sedimentological data (modified from Maquaire et al, 1992 & Gay, 1995)*

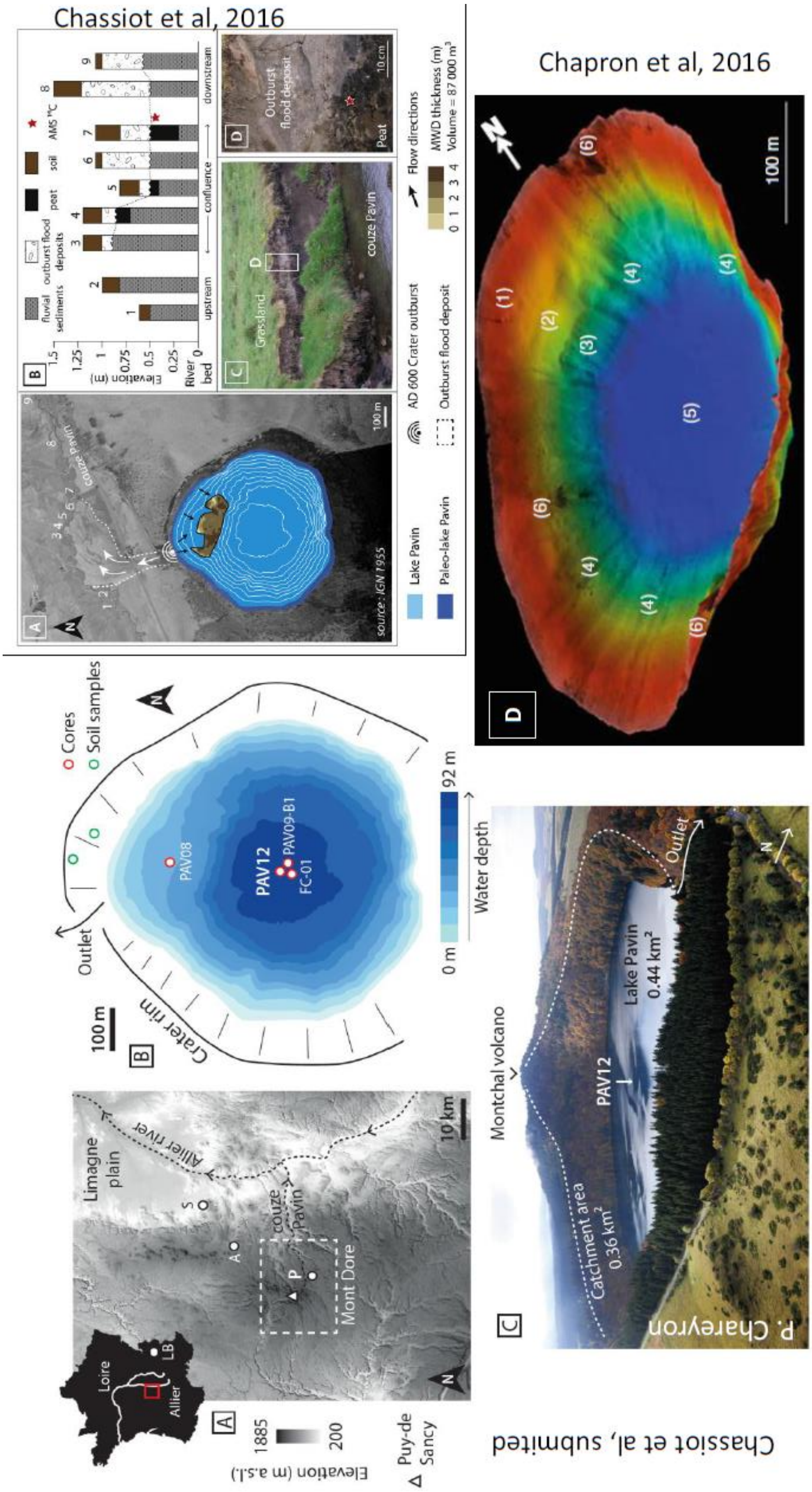

Figure 10*: (A) Digital Elevation Model of the Auvergne region displaying the location of lakes Pavin (P), Aydat (A) and Sarliève (S). (B) Schematic map of Pavin crater rim with location of soil samples along with position of core PAV08 on the plateau and cores PAV12, PAV09-B1 and FC01 in the deep waters of Lake Pavin. (C) Aerial photography illustrating the forested topographic catchment area of Lake Pavin. (D) View of Lake Pavin multibeam bathymetry illustrating a plateau (2), a slide scar (3), canyons (4), a flat basin (5) & outcroping volcanic rocks (6). A crater outburst flood deposit is also identified in the Pavin valley and younger than 1760+/-50 cal BP (red star in upper right panel) following Chassiot et al 2016*

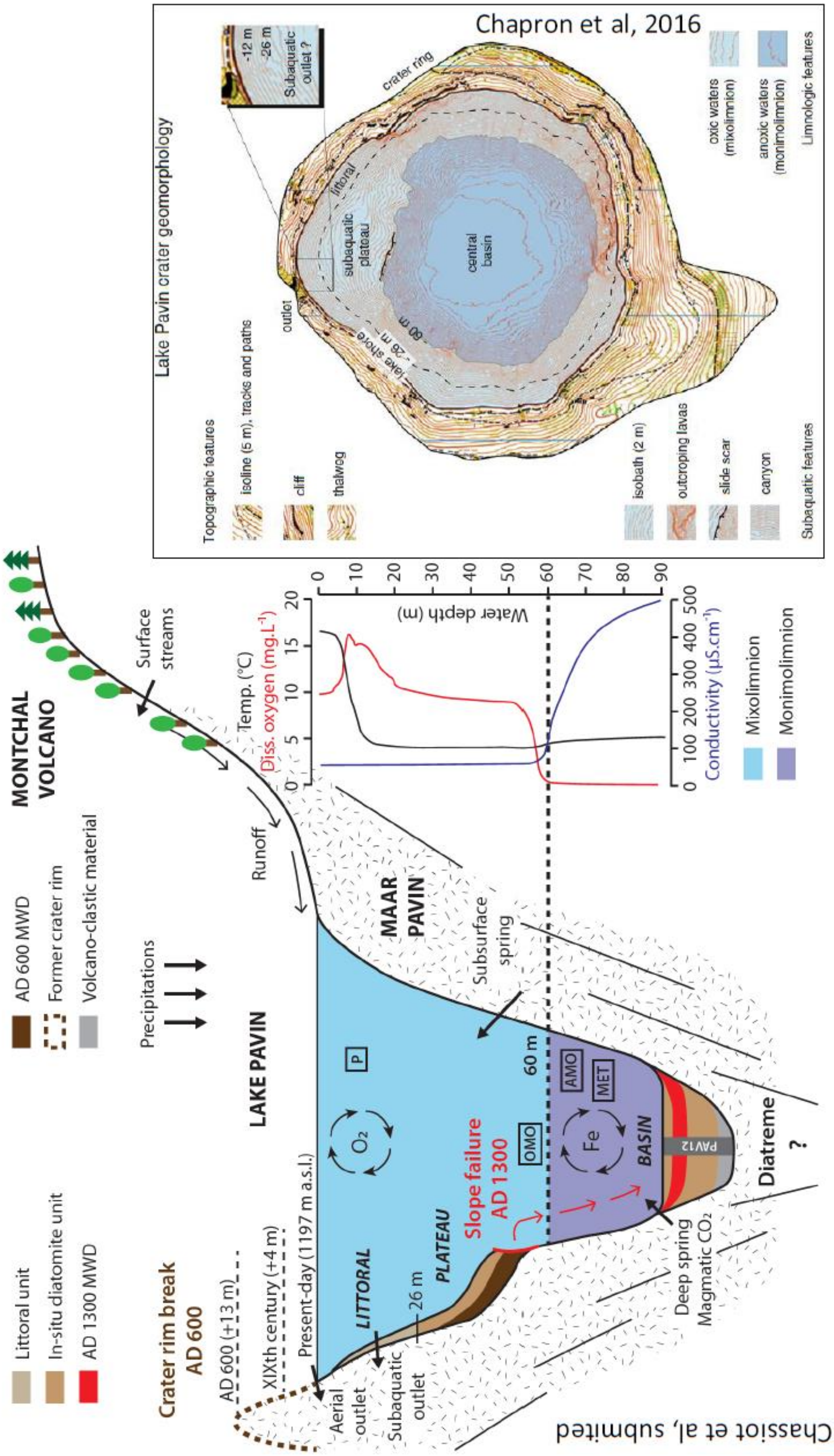

Figure 11: *Schematic drawing resuming the limnogeology (A) and geomorphology (B) of maar Lake Pavin. Sedimentary units develop on three environments: the littoral (0 - 26 m water depth), the plateau (26 - 55 m) and the deep anoxic basin (90 m)*

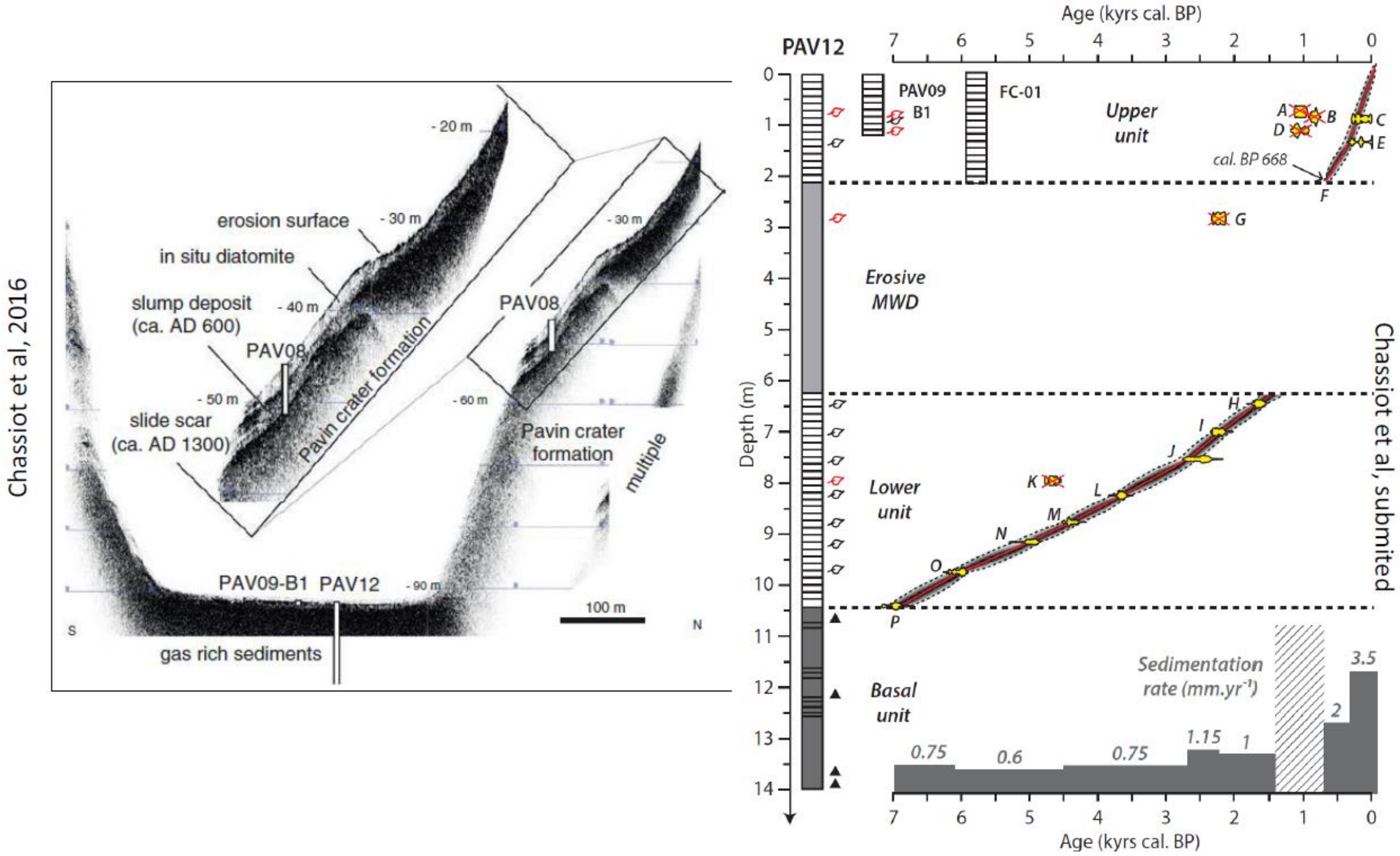

Figure 12: *Synthetic seismic stratigraphy (A), lithology and chronology of core PAV12 (B). The letters refer to Table1 where more information is given about conventional radiocarbon ages of PAV12 and others chronological constrains. Red leaves indicate rejected samples.*

Reference letter	Core	Depth (cm)	Laboratory reference	Material	Radiocarbon age (BP)	2σ (cal. BP)
A*	PAV12	81	Beta-336274	Leaf	1190 ± 30	1120 ± 65
B*	PAV09-B1	94.5	SacA-19661	Leaf	440 ± 35	495 ± 40
C	PAV09-B1	96.5	Poz-33126	Leaf	150 ± 30	200 ± 35
D*	PAV09-B1	113	Poz-33125	Leaf	1010 ± 30	940 ± 35
E	PAV12	137	Lyon-10961	Leaf	220 ± 30	285 ± 20
F	FC01	206	Calendar age from varve counting = 668 cal. BP			
G*	PAV12	287 - 289	Beta-336272	Leaf	2210 ± 30	2235 ± 85
H	PAV12	645 - 646	SacA34984	Leaf	1730 ± 30	1635 ± 70
I	PAV12	701	Lyon-10963	Leaf	2195 ± 35	2220 ± 95
J	PAV12	755	Beta-336273	Leaf	2400 ± 30	2420 ± 70
K*	PAV12	798	SacA34983	Leaf	4170 ± 30	4690 ± 90
L	PAV12	827	Beta-335372	Leaf	3400 ± 30	3640 ± 70
M	PAV12	880 - 881	Beta-335371	Leaf	3940 ± 30	4365 ± 80
N	PAV12	919	Beta-335370	Leaf	4400 ± 40	4960 ± 100
O	PAV12	978.5	Lyon-10962	Leaf	5250 ± 35	5980 ± 55
P	PAV08	476 - 479	Poz-27052	Bulk	6090 ± 40	6940 ± 90

Table 1: *PAV12 core radiocarbon samples and calibrated ages for cores PAV12 and PAV09-B1 with other chronological information from previous studies by Schettler et al. (2007) for FC01 and Chapron et al. (2010) for PAV08. Asterisks on the reference letters refer to samples that have been rejected for the age-depth model of core PAV12 (Fig. 13).*

Groups	Pollen types
Diversified Oak Woodland	Quercus, Tilia, Ulmus, Acer
Mountain Woodland	Fagus, Abies
Riparian Woodland	Alnus, Salix, Fraxinus, Populus
Coniferous Woodland	Pinus, Juniperus
Grasslands	Poaceae
Agriculture	Cerealia, Secale, Fagopyrum
Anthropogenic Pollen Indicators	Scleranthus-type, Centaurea cyanus, Mercurialis annua, Urticaceae, Polygonum persicaria, Polygonum aviculare, Galium, Artemisia, Rumex, Rumex acetosella-type, Rumex acetosa-type, Chenopodiaceae, Cirsium, Carduus, Spergularia, Plantago, Plantago lanceolata, Plantago major/media, Bellis-type, Artemisia
Groups	**Non-Pollen Palynomorphs types**
Coprophilous fungi	Sporormiella (HdV-113), Sordaria (HdV-55), Coniochaeta cf ligniaria (HdV-172), Coniochaeta B (TM-211), Podospora (HdV-368), Dellitshia (TM-023A/B)

Table 2: *PAV12 core main pollen and non-pollen palynomorphs gathered according to their ecological affinities. HdV: Hugo de Vries; TM: Toulouse-Mirail*

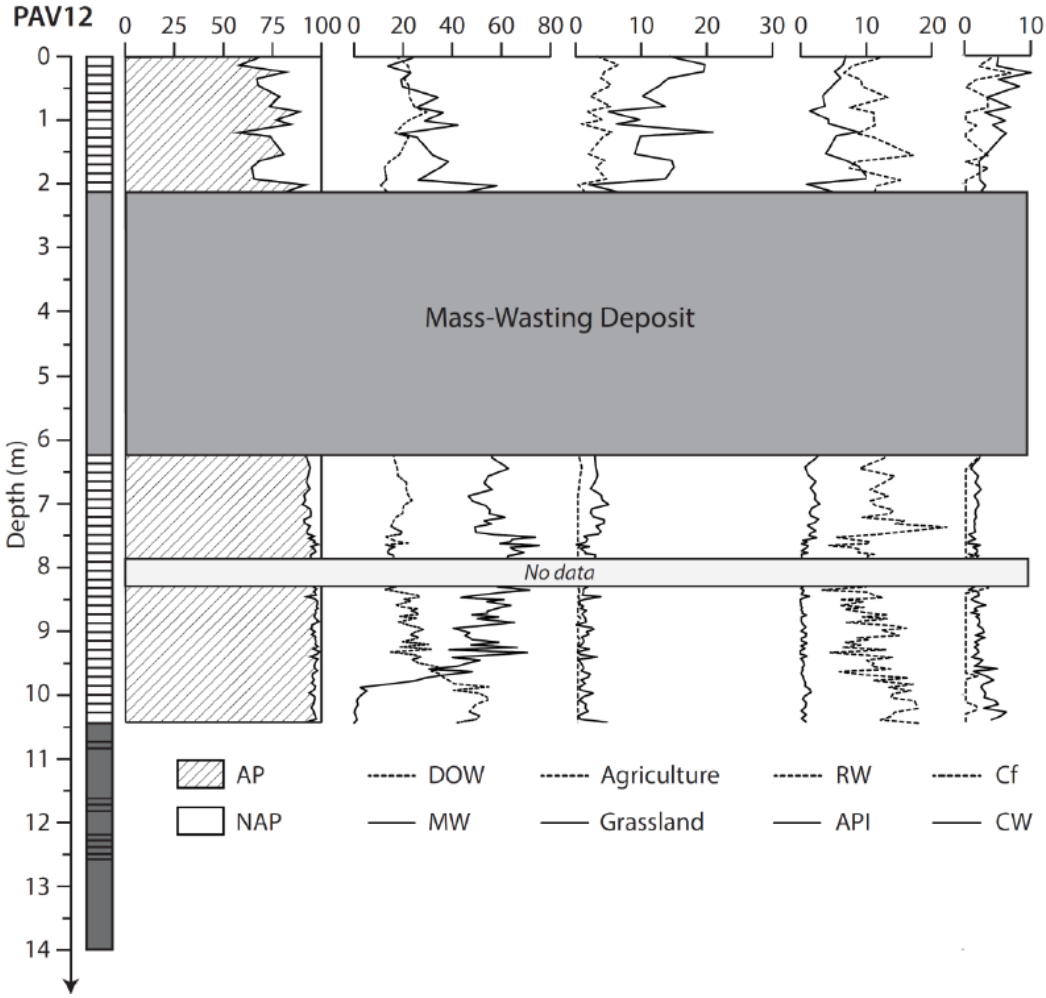

Figure 13: *Simplified pollen diagram of core PAV12. Results are expressed in percentage. AP: Arboreal Pollen; NAP: Non-Arboreal Pollen; DOW: Diversified Oak Woodland; MW: Mountainous Woodland; RW: Riparian Woodland; API: Anthropogenic Pollen Indicators; Cf: Coprophilous fungi; CW: Coniferous Woodland. A coefficient of ten is applied to the scale of Cf. (Chassiot et al., submitted)*

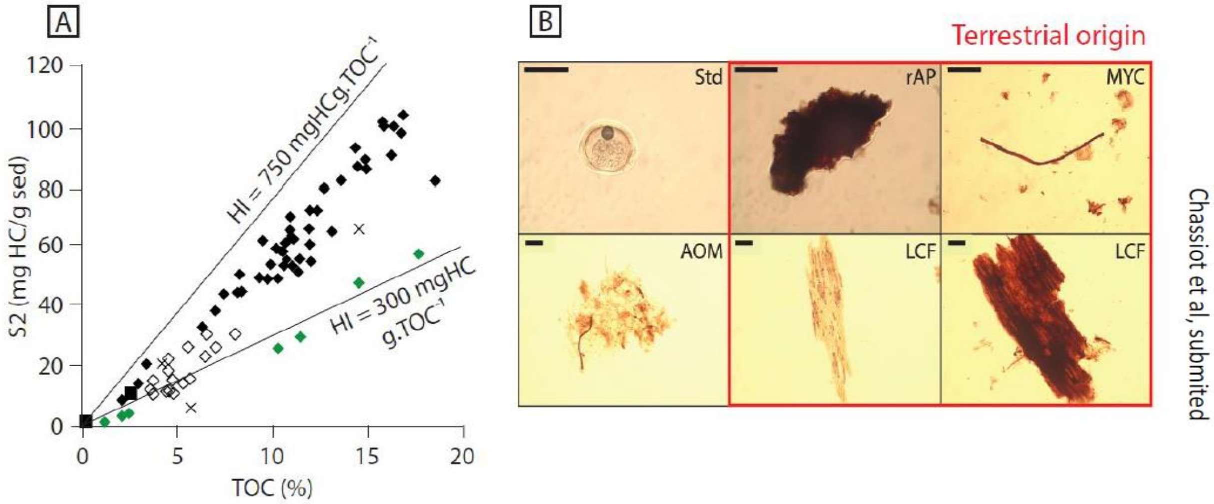

Figure 14: *(A) S2 vs. TOC plot. Green dots: soil samples taken under deciduous and coniferous forest (Fig. 1B). Squares: samples from the basal unit. Black diamonds: samples from the lower unit. Crosses: samples from the MWD. White diamonds: samples from the upper unit. (B) Internal Standard (Std) and non-palynomorph microfossils observed under transmitted light (AOM: Amorphous Organic Matter; rAP: Red Amorphous Particle; LCF: Ligno-Cellulosic Fragment; MYC: Mycelium).*

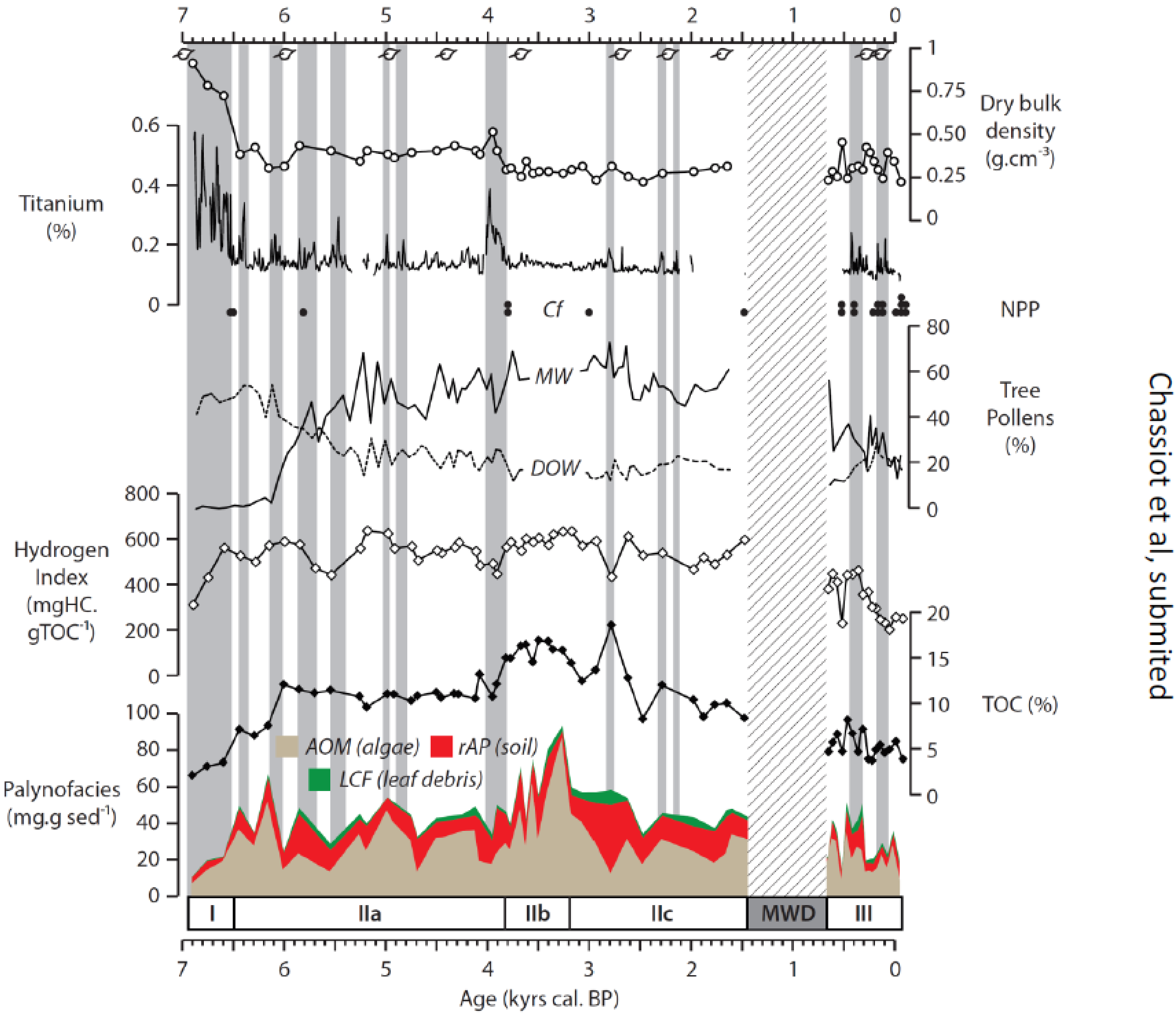

Figure 15: *PAV12 core multi-proxy characterization of lower (I and II) and upper (III) units for the last 7,000 years. Enhanced mineral inputs underlined by the Ti content are indicated by grey bars that generally match higher soil markers (rAP) content in the organic fraction. Leaves represent radiocarbon dating performed throughout the core.*

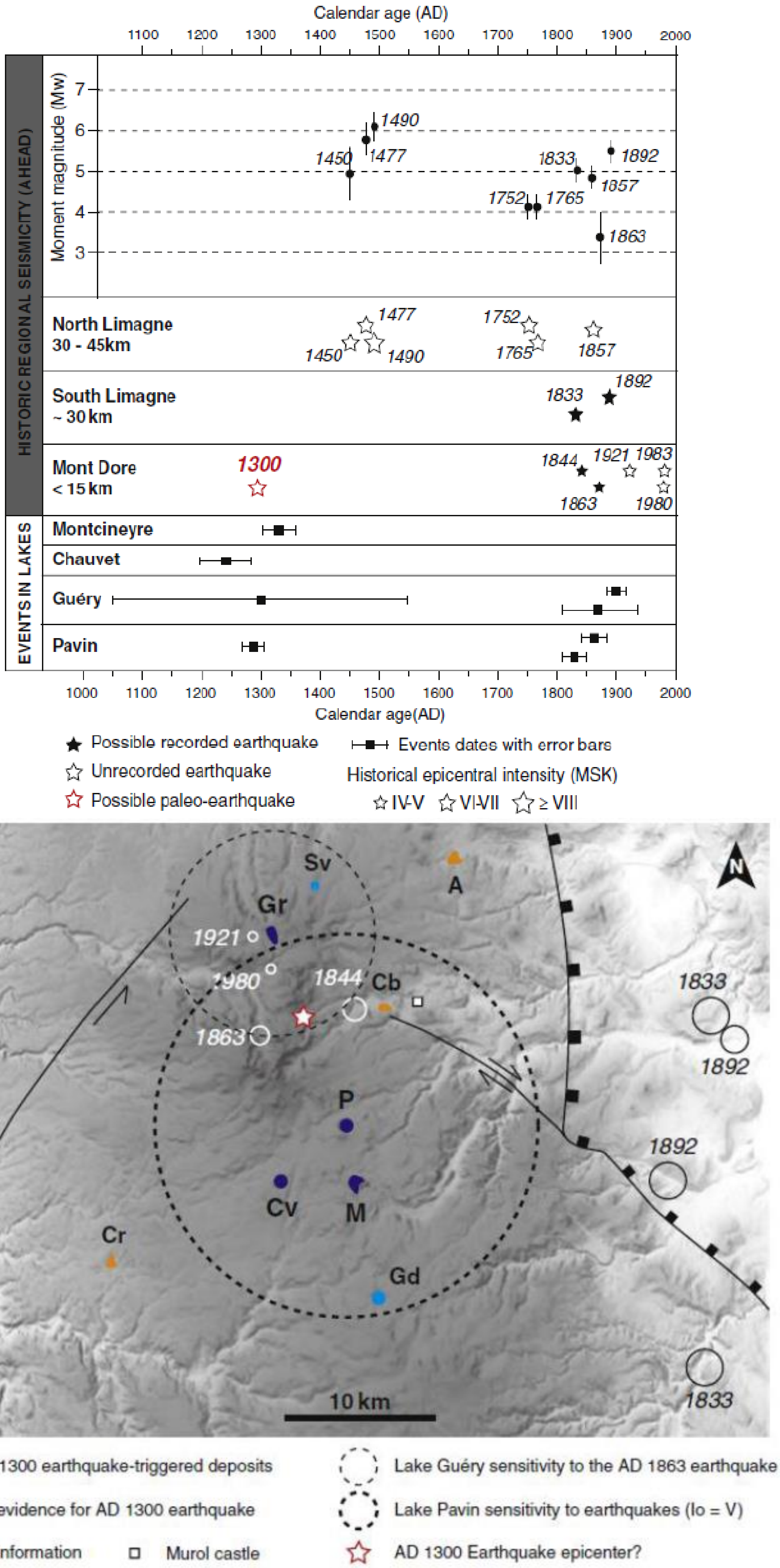

Figure 16: *Signature of regional earthquakes in volcanic lakes from Massif Central (Pavin, Chauvet, Montcineyre & Guréry, see Figure 1 for location). (A) Dates, magnitude and distance of historical earthquakes to lake Pavin. (B) Epicentres (white circles) of Mont Dore area historical events and possible location of a paleo earthquake epicenter ca. AD1300 (common area between circles in a central position amongst lakes where it has been recorded). Chassiot et al 2016.*

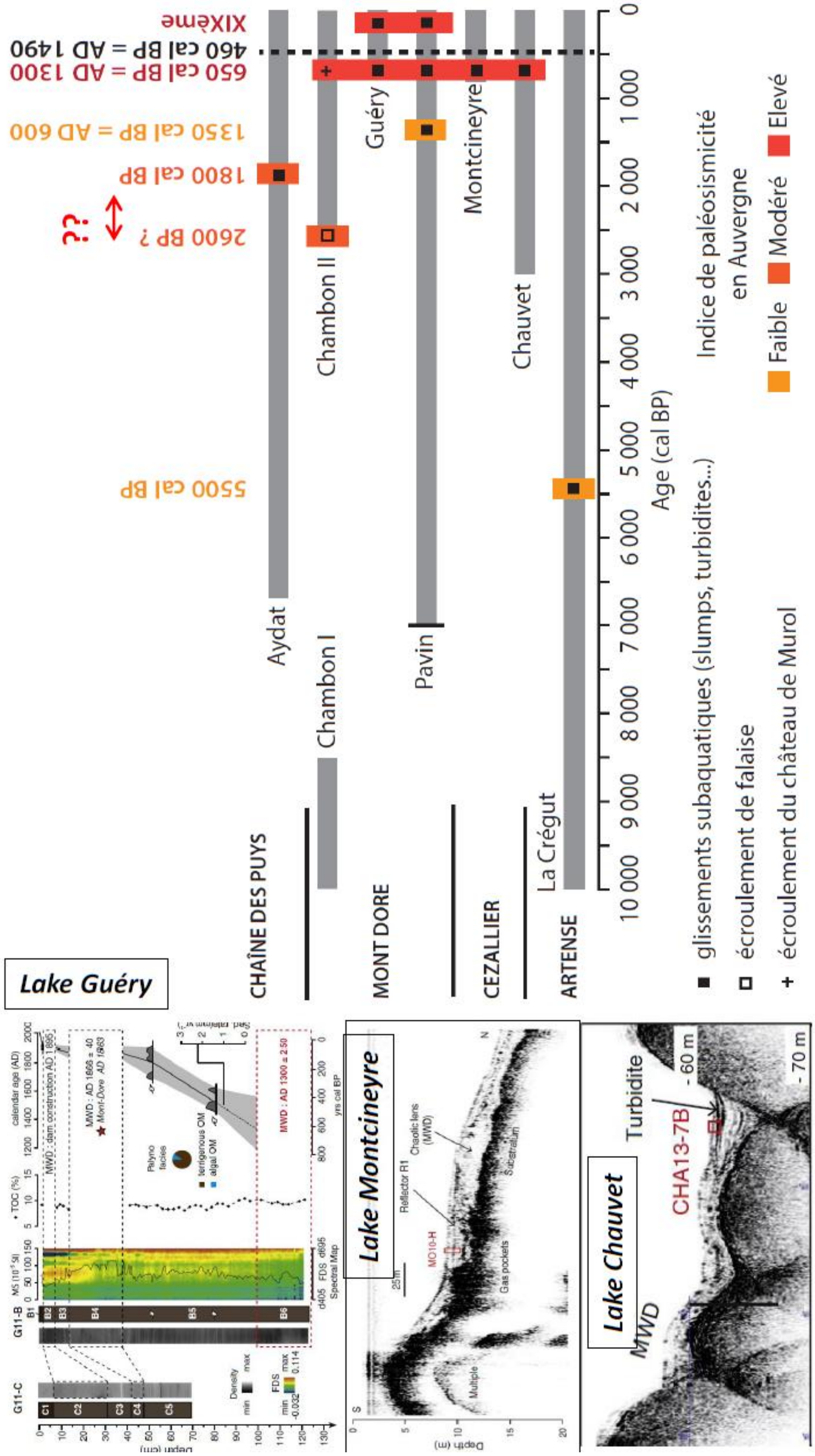

***Figure 17:** Examples of coeval slides in lakes (left) and (right) timeline of lake sediment records displaying the occurrence of subaquatic mass-movements (black dots), aerial landslides (white dot) and the collapse of the Murol Castle near Lake Chambon (cross). Co-eval events suggest a common and regional tectonic trigger (Chassiot, 2015). The dashed line refers to the major AD 1490 earthquake (Io = VIII) unrecorded in the yet studied sedimentary archives.*

YOUNG LAKE PAVIN

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BACKGROUND

For the first time the interdisciplinary project 'Natural climate variations from 10,000 years BP to the present day' (=KIHZ; 2000-2003) was attempting to achieve a physically consistent, spatial and chronological interpolation of proxy-data, based on interrelationships between proxy-data and large scale climatic anomalies (Negendank *et al.* 2001). Within this project, high-resolution palaeobotanical investigations were conducted on a short core from Lac du Pavin (Stebich *et al.,* 2005). Furthermore, changes in sub-surface inflow of mineralized waters into Lac Pavin were studied by detailed geochemical analysis of the sediments (Schettler *et al.,* 2007). Both geochemical and palynological investigations allowed for disentangling climatic and anthropogenic signals and estimations of palaeo-hydrological changes over the past 700 years.

MATERIAL RECOVERY

During a coring campaign in 1999, organized by the GFZ German Research Centre for Geosciences, Potsdam, several short gravity cores were taken at Lac du Pavin. Additionally, the uppermost 92 cm of unconsolidated surface sediments were recovered by freeze-core technique. Overlapping sediment sections were used to define the continuous composite profile of 182 cm. The sediments were sub-sampled at a resolution of 1 cm for a multiproxy-approach (geochemistry, pollen, and physical properties). The sequence was sub-sampled at a lower resolution (5cm) for diatoms. The methods for sample preparations are described in detail in Stebich *et al.* (2005) and Schettler *et al.* (2007).

SEDIMENT COMPOSITION

The sedimentation of Lac du Pavin is characterized by unusual high net accumulation of biogenic silica (100-500 g m^{-2} yr^{-1} SiO_2) and autochthonous Fe-precipitates (2-200 g $m^{-2}yr^{-1}$ Fe). The biogenic opal concentrations vary between 20 and 70 wt-% SiO_2. TOC typically ranges between 4 and 9 wt-% with one TOC-peak of 11.5 wt-% at 150 cm. There is coinciding increase of TOC/N for most of the TOC-peaks but not in general, whereas the variation pattern of TOC and $bSiO_2$ distinctly differ from each other (**Figure 1**). In principle, the lake receives influx of dissolved Fe and nutrients by groundwater inflow into the mixolimnion and monilimnion.

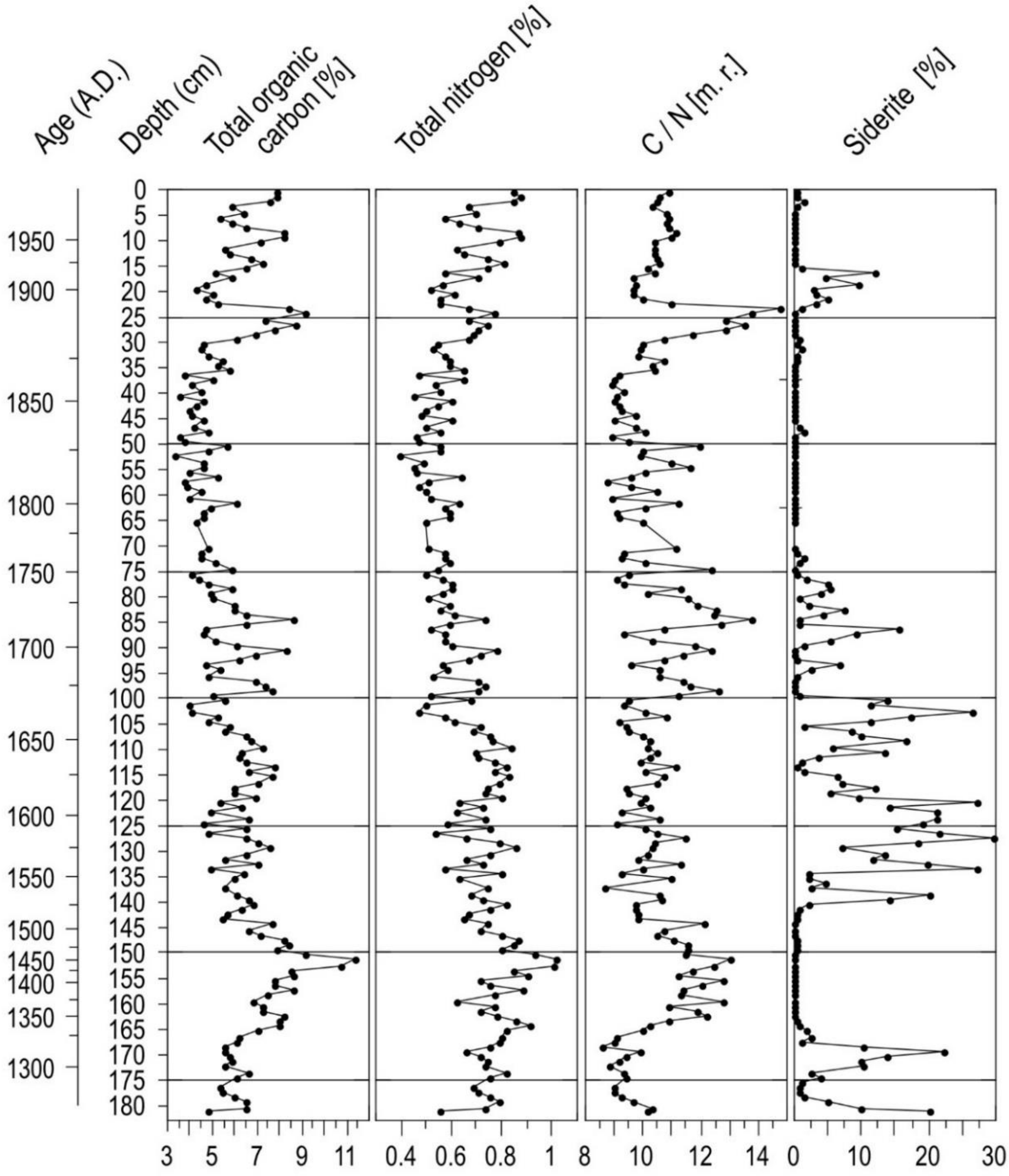

***Figure 1**: Selected geochemical parameters of the Lac du Pavin sedimentary sequence.*

The silty sediments are distinctly laminated. The layers consist mainly of *Aulacoseira* spp. and/or *Asterionella* spp./*Stephanodiscus* spp. blooms alternating with layers comprising mostly benthic species like *Epithemia* spp., *Pinnularia* spp., *Fragillaria* spp., *Rhopalodia* spp., and others as well as siderite, vivianite, and organic particles. In total, more than 100 diatom species representing 24 genera were identified in the sequence. The percentages of selected diatom taxa and the diatom concentrations are shown in **Figure 2**. Three major diatom zones (DZ) were recognized on the basis of the dominance of planktonic diatom taxa.

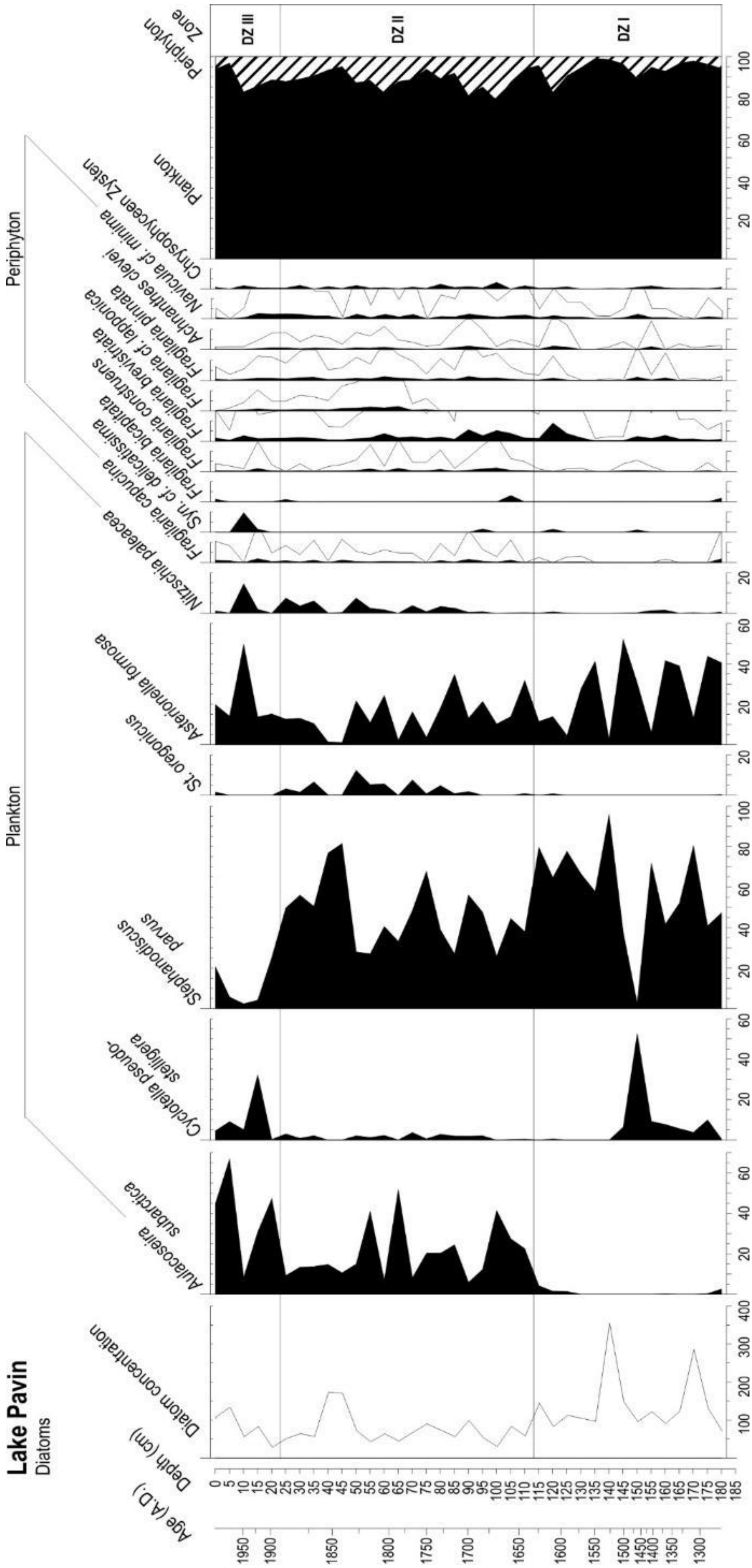

***Figure 2**: Diatom concentration and relative frequencies of the most common diatom taxa.*

DATING

Because of the seasonal nature of the diatom blooms the laminations are considered to represent varves. Thus, the age of the sedimentary sequence was mainly determined by layer counting. The investigation and counting of the sediment laminae was performed on a continuous series of overlapping large-scale thin sections (**Figure 3**).

In those parts of the sequence where laminae preservation was too poor to enable counting, the average thicknesses of the layers above and below the problematic section were used to estimate the period represented. The age model is cross-checked by radiometric age determinations (^{14}C, ^{137}Cs). However, AMS radiocarbon data show an inverse age–sediment depth relation possibly due to volcanic CO_2 sources. According to the resulting chronology, the studied sedimentary sequence covers the past 700 years. The mean sedimentation rate between AD 1530 and 1890 is 3.7 mm yr^{-1} and makes the varved Pavin sediments to a highly time resolved palaeoenvironmental record. The age-depth model for the Pavin sequence is illustrated in **Figure 4**.

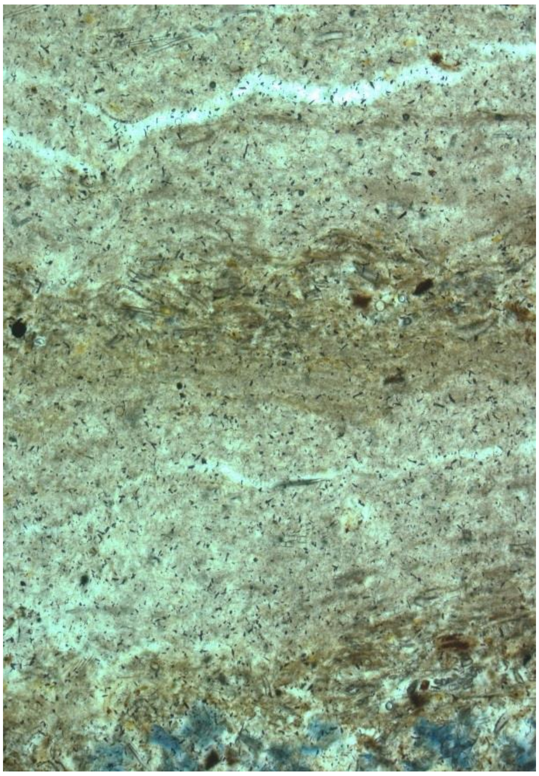

***Figure 3**: Thin section photograph of individual layers from the investigated sediments.*

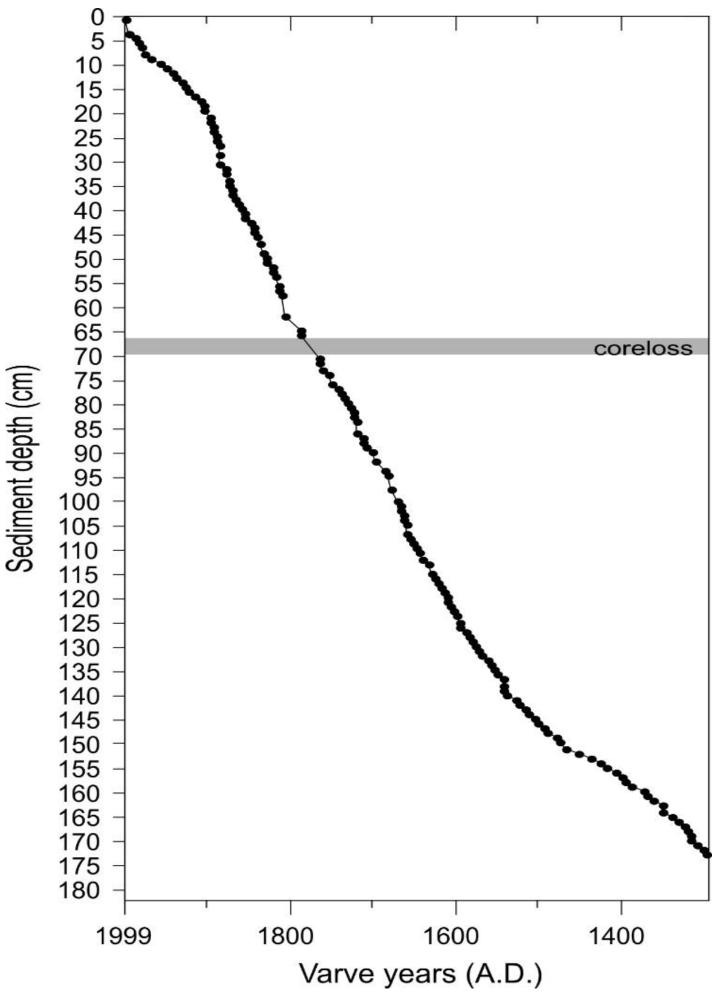

***Figure 4**: Age-depth diagram of the Pavin sequence.*

PALYNOLOGICAL RESULTS AND DISCUSSION

According to the chronology, the pollen diagram for the short core from Lac du Pavin reflects the vegetation history of the study site from the Late Medieval onwards. The diagram presented here (**Figure 5**) is simplified, showing only the most important arboreal taxa and summary curves of selected herbs and shrubs. All the arboreal pollen spectra, except that from the youngest pollen zone, are co-dominated by *Fagus* and *Quercus*. However, whilst the *Quercus* curve is relative stable, several significant, temporary fluctuations are visible in the *Fagus* curve. Open ground taxa are also relatively well represented and exhibit distinct, if somewhat limited variability. The pollen signatures of herbs, including Gramineae, cereals, *Rumex acetosa* type and *Humulus*/*Cannabis* type, clearly indicate vegetation influenced by anthropogenic activity. While the main clearance phases in the Auvergne have already occurred before the 14th century (Lang and Trautmann, 1961; Reille, 1991; Eusebio, 1925), our pollen record documents changing intensity of human impact on landscape development during the last seven centuries.

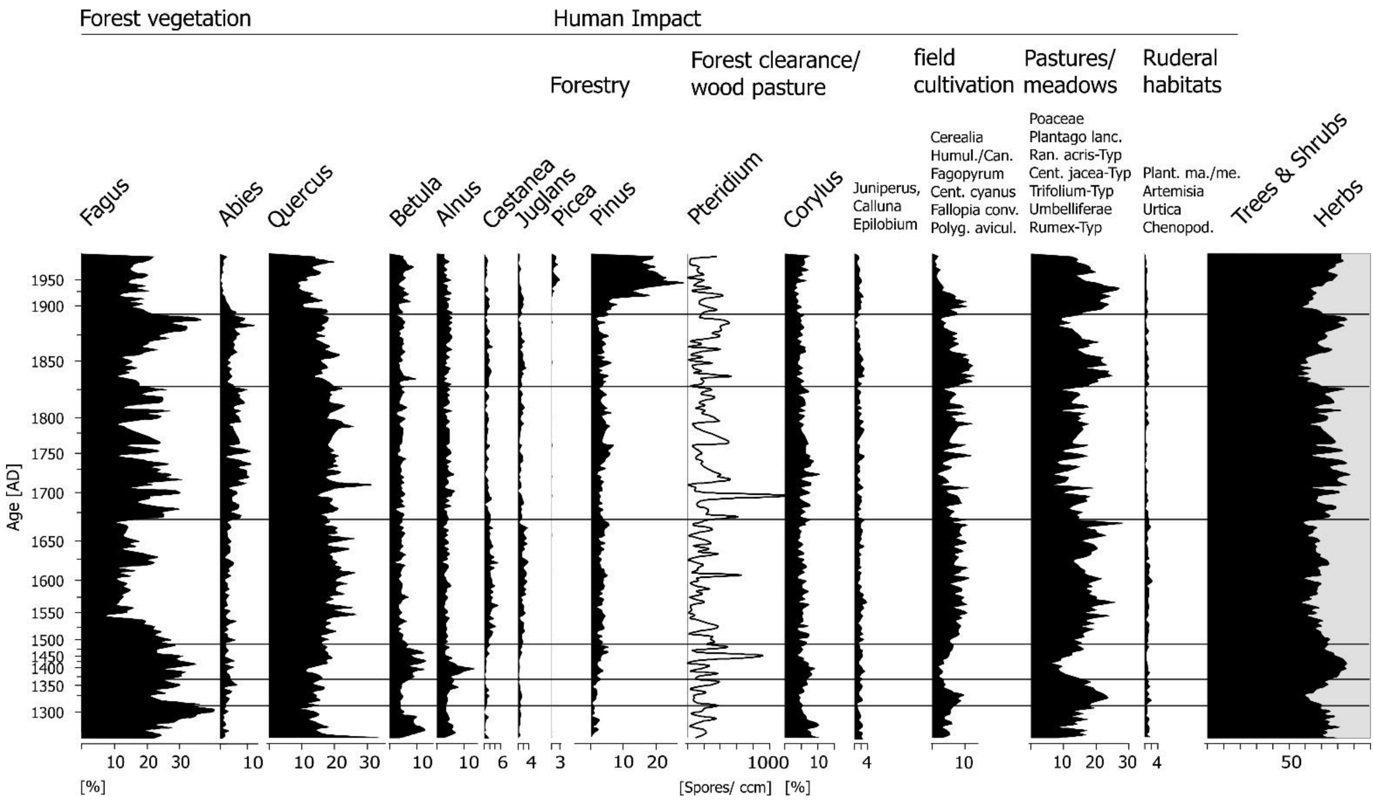

Figure 5: Simplified pollen diagram of the Pavin sequence.

In the late 13th century, a succession of pioneer trees (*Betula*, *Alnus* and *Corylus*), combined with the presence of the climax tree species *Fagus* suggests a local rearrangement of forest patches close to the lake. An abrupt drop in *Fagus* during the early 14th century reveals a clearance phase and/or a climatic deterioration. A contemporaneous increase in the main human impact indicators indicates that woodland areas were converted into farmland. However, the postulated phase of intensified cultural impact only lasted for about 25 years (between approximately 1315 and 1340 A.D.). This short-term event is accompanied by a temporary peak in diatom concentration values, which are dominated by the eutrophic taxon *Stephanodiscus parvus*.

During the period between approximately 1350 and 1475 A.D., the overall frequency of human impact indicators reaches its minimum values. Simultaneously, increases in *Fagus*, *Betula*, *Alnus* and *Corylus* suggest that once cultivated land reverted back to woodland, as human pressure was reduced. This feature corresponds to a general demographic decline and land abandonment phase that affected the whole Massif Central during the Hundred Years War and after the Black Death of 1348. The diatom flora also clearly reflects these changing environmental conditions, since decreasing diatom concentrations and a recurrence of the oligotrophic *Cyclotella pseudostelligera*, indicate reduced nutrient loadings in Lake Pavin.

Rises in the main anthropogenic indicators (wild grasses, cereals, *Plantago lanceolata* and *Rumex*-type) between 1475 and 1540 A.D. reveal increased human impact, which prevented successful woodland regeneration. Since this period, no expansion of pioneer woodland can be recognised. Once again, this change in vegetation coverage affected the water quality of Lac du Pavin, resulting in another peak in *Stephanodiscus parvus* and an overall increase in diatom concentrations. Whilst the anthropogenic indicators remain at about their previous levels between 1540 and 1670 A.D., *Fagus* values fall to a minimum. The period between 1670 and 1830 A.D. is characterized by variable *Fagus* values, possibly affected by unsettled climatic conditions (see below). Gramineae, cerealia and *Rumex acetosa*-type seem less abundant, probably because of the higher proportions of *Fagus* and *Abies* pollen.

Increases in cultural activity at around 1830 A.D. are observed both in the diatom and pollen records. The lower abundances of anthropogenic indicators and the recovery of *Fagus* during the later part of the 19th century probably reflect the progressive demographic decline and land abandonment that occurred at this time. Increases in *Pinus* and *Picea* during the 20th century indicate the establishment of forestry plantations. Therefore, during the last 170 years the influence of climate becomes less clear, probably because of strong human inference and the overrepresentation of *Pinus*.

One particularly *interesting feature* of the pollen diagram is the dynamics of *Fagus*. Not including the period of variable *Fagus* values between 100 and 50 cm, the beech pollen curve exhibits several abrupt declines of at least 10% in just 5-20 years, and recoveries of the same magnitude (**Figure 6**). Since there is no clear evidence of local clearing events or tree population replacement, it seems likely that these rapid changes in the *Fagus* curve actually indicate variations in pollen production. As demonstrated by various studies, pollen production rates for an individual plant can vary enormously from year to year.

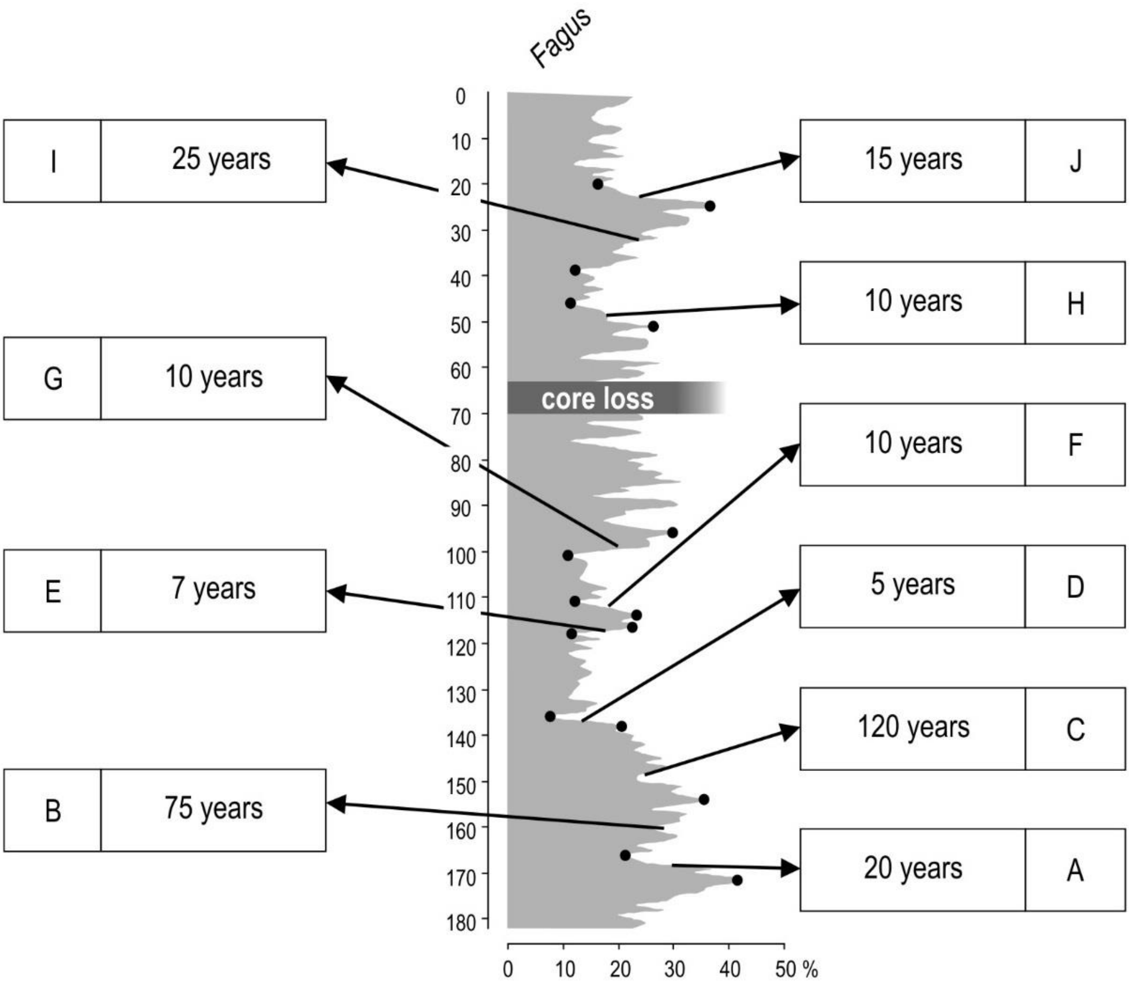

Figure 6*: Temporal characteristics of the Fagus-curve.*

According to Huntley *et al.* (1989), mean January and July temperatures of -1 and 18 °C, respectively, represent the optimum pollen production conditions for European *Fagus sylvatica*. Pollen abundance values fall significantly with decreasing January temperatures and *F. sylvatica* does not occur where the mean temperature of the coldest month is below -3 °C. Furthermore, a correlation between summer temperature and flowering intensity of *Fagus* in the following year, a negative correlation of precipitation from July to November with *Fagus* pollen accumulation rates in the ensuing year, and a damaging effect of spring frost on the flowers of beech was observed (Pidek *et al.,* 2010 and papers cited therein). Given the sub-optimal growing conditions for *Fagus* at the study site today (0 to -2°C in winter, 10-15°C in summer), relative wetter and cooler periods during the Little Ice Age can explain the temporary reduced pollen precipitation of beech (Stebich *et al.,* 2005).

Geochemical data support the *Fagus* pollen-based climate implication and demonstrate the close linkage between vegetation and groundwater conditions. Distinct short term variability of beech is characterized by an inverse correlation with autochthonous Fe-precipitates. The high net accumulation of dissolved Fe is sustained by Fe-influx via sub-lacustrine springs. Total sub-surface inflow and its variability are closely correlated with seepage of meteoric water and therefore reflect climate changes (**Figure 7**; Schettler *et al.,* 2007). Variations in annual rainfall for modern climatic conditions are largely associated with rainfall in spring, autumn and winter. Presuming that seepage of winter precipitation largely discharges by surface run-off in spring, winter rainfall is considered to be of minor importance for feeding the sub-lacustrine springs. By contrast, the rainfall during the vegetation period may have strong impact on nutrient and Fe input. Beyond climatic conditions, high EVPT, associated with closer forest coverage distinctly reduces the recharges of groundwater and makes the Fe-flux less sensitive for short term climate variations.

Modern groundwater discharge does not sustain the balanced Fe-flux for sedimentation before AD 1890. As a result of re-forestation in the second half of the 19th century, influx of dissolved Fe obviously declined on similar low levels as obtained in the 15th century when local woodland had recovered. Groundwater inflow was generally higher between 1525 and 1850 A.D. Two periods with overall wetter and cooler conditions in the growing season were derived: ca. 1525-1600 and 1630-1660 A.D. Both, *Fagus* and siderite fluctuations indicate distinct short-term variability between wet-cold and dry-warm conditions during the Late Maunder Minimum (AD 1675-1715) at the study site.

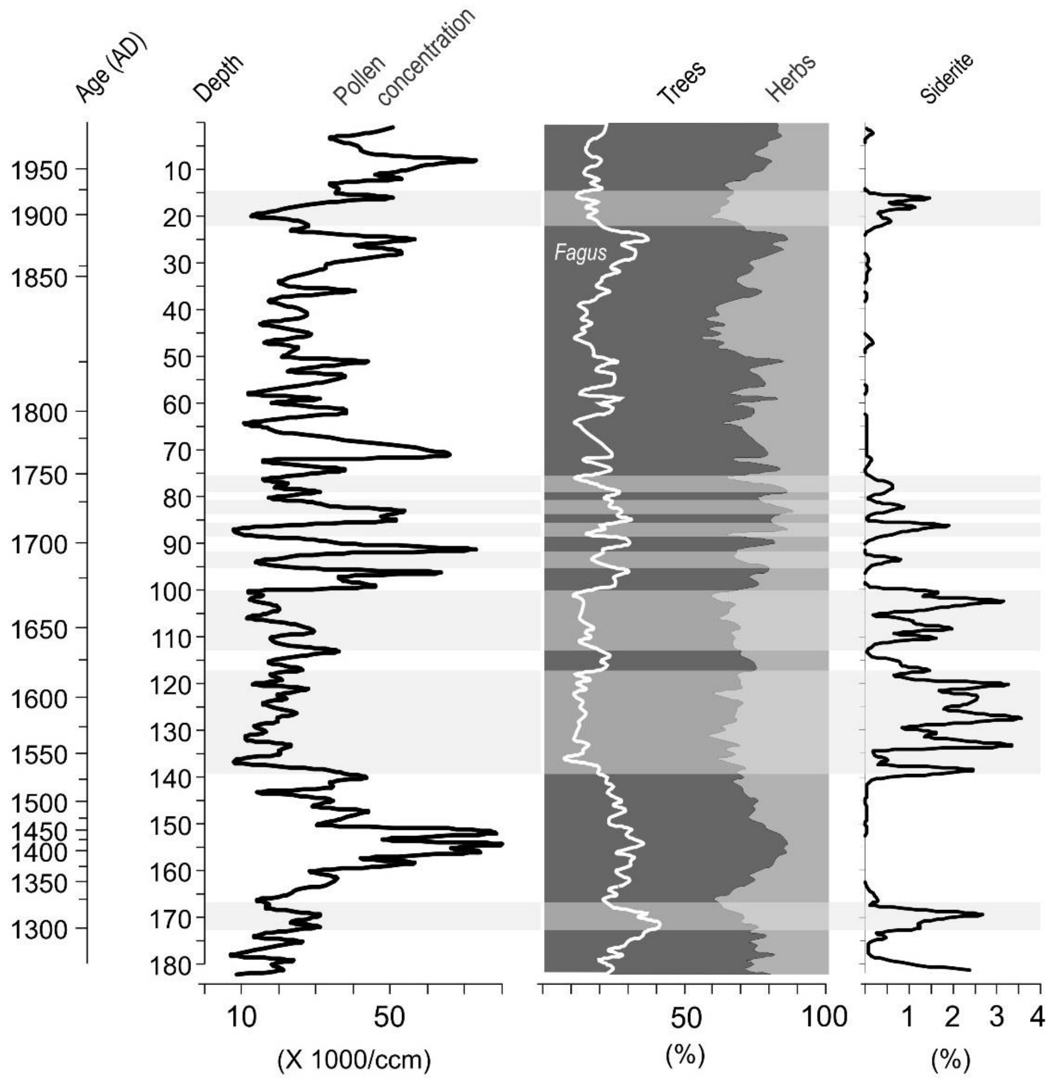

***Figure 7**: Pollen and siderite profile.*

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Palaeo-Maar La Narse d'Espinasse: Agro-Pastoral Activities since the Neolithic

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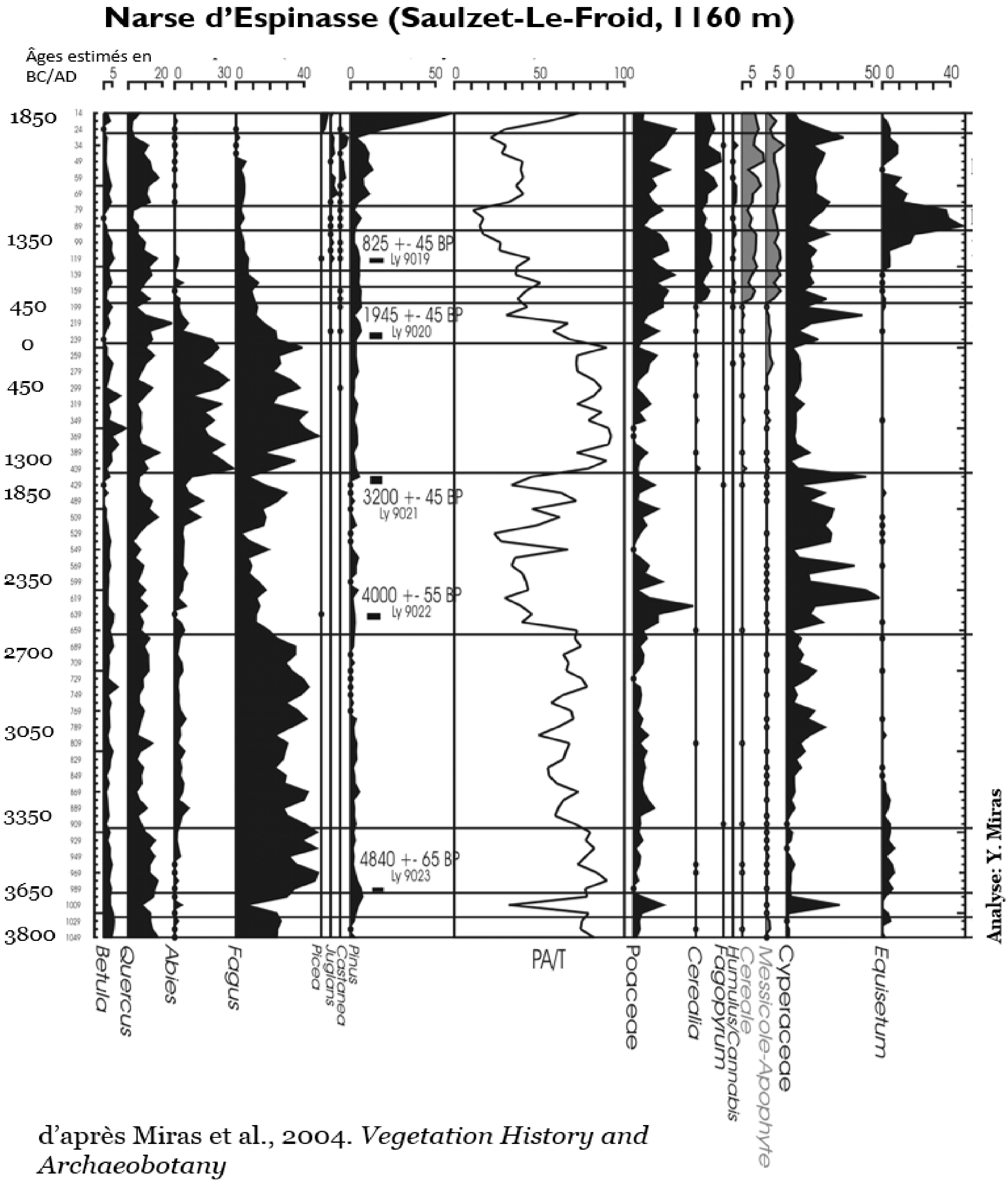
(See paper by Miras et al. 2004 – attached)

ABSTRACT

The "Narse" or peat marsh of Espinasse (Saulzet- le-Froid district) situated in the southern part of the Chaîne des Puys has been the subject of a new pollen analysis concentrating on the anthropogenic impact on vegetation evolution since the Sub-Boreal. Human occupation of the surroundings of the Narse is dated as early as the Neolithic, which is usual for the region. There is nevertheless an isolated record of *Fagopyrum* related to the Neolithic (**Figure 1**). This is a unique occurrence in the Massif Central. For successive periods and up to the recent past, a dynamic of various anthropisation phases has been reconstructed.

The combination of palynological data (**Figure 2**) with archaeological and historical sources has for certain periods, mainly from the 11th to 13th centuries, provided new insights on the social and technical management of the territory. Furthermore, geochemical and micromorphological characterisation of sedimentary organic matter has led to the identification of erosive crises and silting which would have followed massive tree cutting in the region. On the local scale, the highly degraded organic matter at the top of the peat profile is the consequence of the current drainage of the marsh.



d'après Miras et al., 2004. *Vegetation History and Archaeobotany*

***Figure 1**: Simplified version of the palynogram from the Narse d'Espinasse* (Puy-de-Dôme, France) *after Miras et al. 2004.*

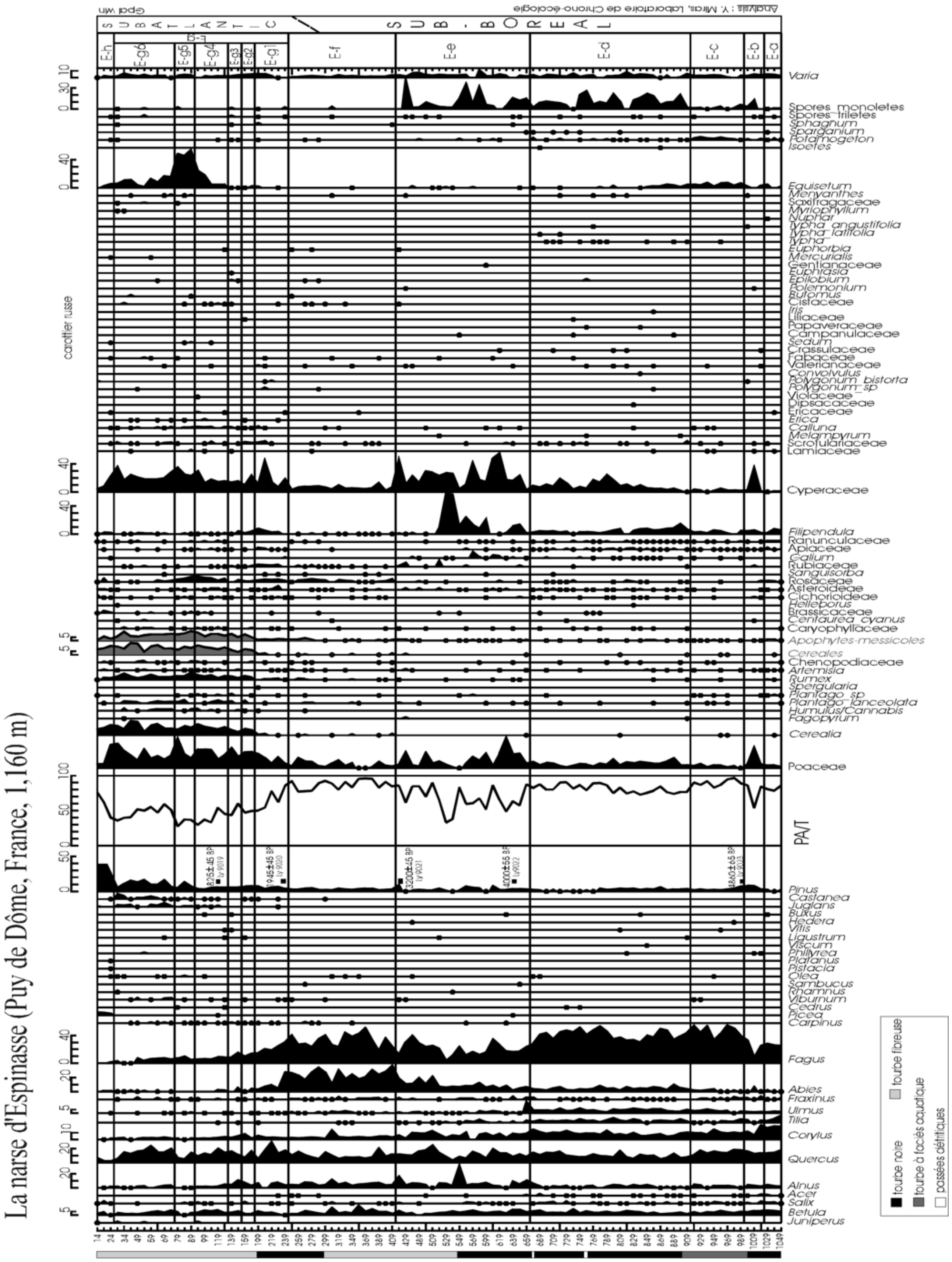


***Figure 2**: Detailed version of the palynogram from the Narse d'Espinasse* (Puy-de-Dôme, France) *after Miras et al. 2004.*

VEGETATION AND FIRE RESPONSES TO ABRUPT CLIMATE CHANGES OF THE LATE GLACIAL (14.7 – 11.7 KA CAL. BP): THE LAPSOU RECORD (EASTERN MASSIF CENTRAL)

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INTRODUCTION

The characterization of the high-frequency climate variability of the Late Glacial (14.7-11.7 ka cal. BP; Lowe *et al.*, 2008) recorded in the NGRIP $\delta^{18}O$ (Walker *et al.*, 1999; Lowe *et al.*, 2008) and its impacts on terrestrial environments can be reconstructed from the study of lake and peatland sediments. The Massif Central was largely affected by short-lived changes in the North-Atlantic climate and it is rich in exploitable lakes. For these reasons, this region is part of a network of paleoenvironmental sites from the Pyrenees to the Jura and the Alps (Millet *et al.*, 2012; Magny *et al.*, 2006; Heiri & Millet, 2005; Doyen *et al.*, 2015; Rius *et al.*, 2014). They allow to characterize the Late Glacial climate variability and environment responses centralized in Western Europe.

Environment responses include changes in vegetation, fire regime or hydrology. That is why it is necessary to adopt a multi-proxy approach based on pollen (vegetation), charcoal (fire regime – Carcaillet *et al.*, 2001; Peters & Higuera, 2007; Whitlock & Larsen, 2001) and chironomidae (July temperature: Heiri *et al.*, 2011; Millet *et al.*, 2012). Here we investigate a core from the Lapsou paleolake, which archived continuously the local environment dynamics between 14.7 and 11.7 ka cal. BP. Objectives of the presentation are:

- To present high temporal resolution pollen and charcoal records of the Late Glacial period from the Lapsou paleolake.
- To characterize the vegetation dynamics and changes in the local fire regimes in link with short-lived climate changes of the Late Glacial.

STUDY SITE

The Lapsou palaeolake (45°08'36.15"N, 2°51'11.58"E, 1207 m a.s.l.) is located in the Eastern Massif Central (Cantal) close to the Puy Mary volcano (**Figure 1**). This region is in an intermediate position between three air masses: a westward one from the North-Atlantic, a southward one from the Mediterranean and northward winds. These peculiarities lead to a local subalpine-to-alpine climate characterized by temperate temperatures (T_{ann} = 10.2°C) and high precipitations (P_{ann} = 1200 mm after *www.meteofrance.com*). The siliceous nature of the region is largely explained by the volcanic history of the Massif Central (de Beaulieu *et al.,* 1982). The Lapsou paleolake results from glacial depressions, which occurred during the Quaternary, and is now a peatland. The local mountain-to-subalpine vegetation is dominated by birches (*Betula pendula*) and open landscape herbs (Poaceae).

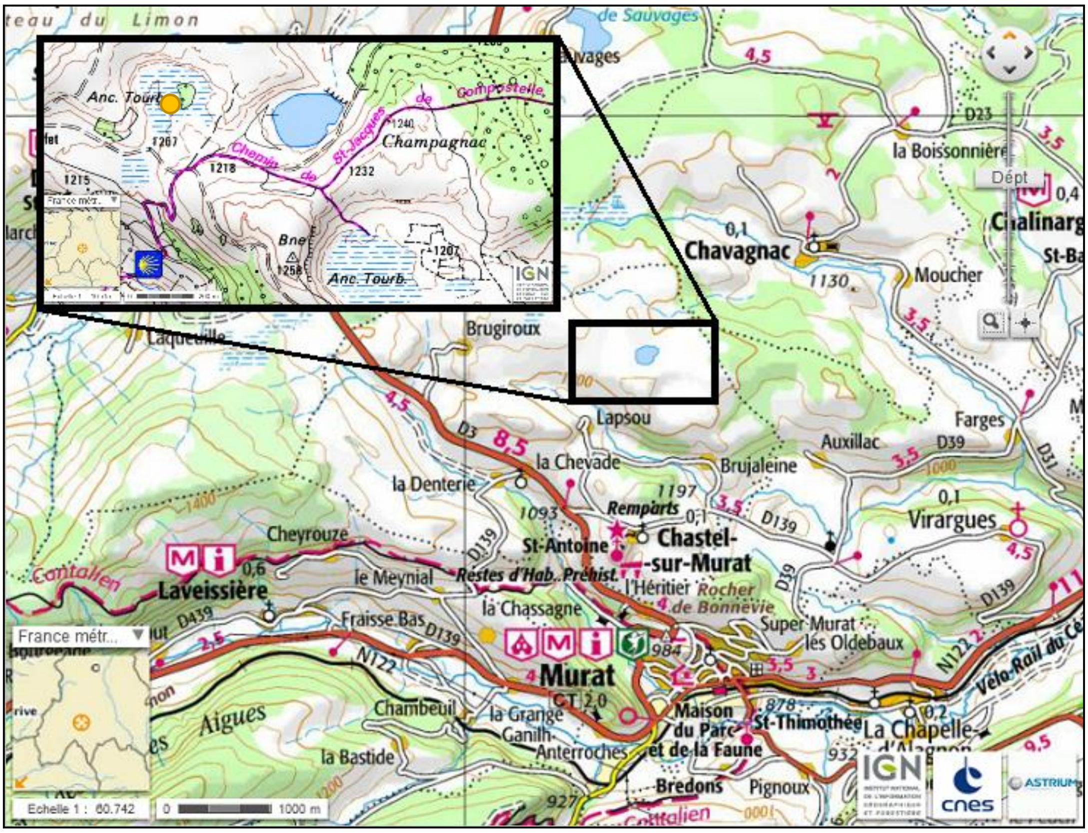

Figure 1*: Location of the Lapsou paleolake study site.*

The position of the coring is indicated by an orange point (source: Géoportail.fr)

MATERIAL & METHODS

2.1. Coring and chronology

Twin cores were retrieved in april 2013 at the center of the Lapsou peatland, using a russian peat corer (L: 100 cm, Ø: 6,3 cm). A 9 m long Master Core was then built using geophysical (magnetic susceptibility; Sédilog with GEOTEK Multi Sensor Core Logger systems at Besançon) and geochemistry (K, Si, Ti... acquiered by XRF measurements at Chambéry).

The chronology was built on 5 AMS radiocarbon dates (**Table 1**) from macroremains calibrated with IntCal13 (Reimer *et al*. 2013) and 2 tephra layers detected in the magnetic susceptibility and the potassium. They are attributed to the Puy de la Nugère eruptions dated at 13.3 ka cal. BP (Vernet 2011; Juvigné *et al.* 1996). The age-depth model in **Figure 2** was built using CLAM (Blaauw, 2010).

__Table 1__: AMS radiocarbon dates from the Lapsou core

Depth (cm)	Dated Material	AMS dates (BP)	Calibrated ages (2σ, cal. BP)
619.5	birch seed	9900±70	11200-11610
719.5	unknown macroremain	10850±50	12600-12890
773.5	*flower bud*	*420±30**	*333-523*
783.5	*unknown macroremain*	*9770±170**	*10600-11765*
819.5	wood	12510±140	14110-15150

**rejected dates*

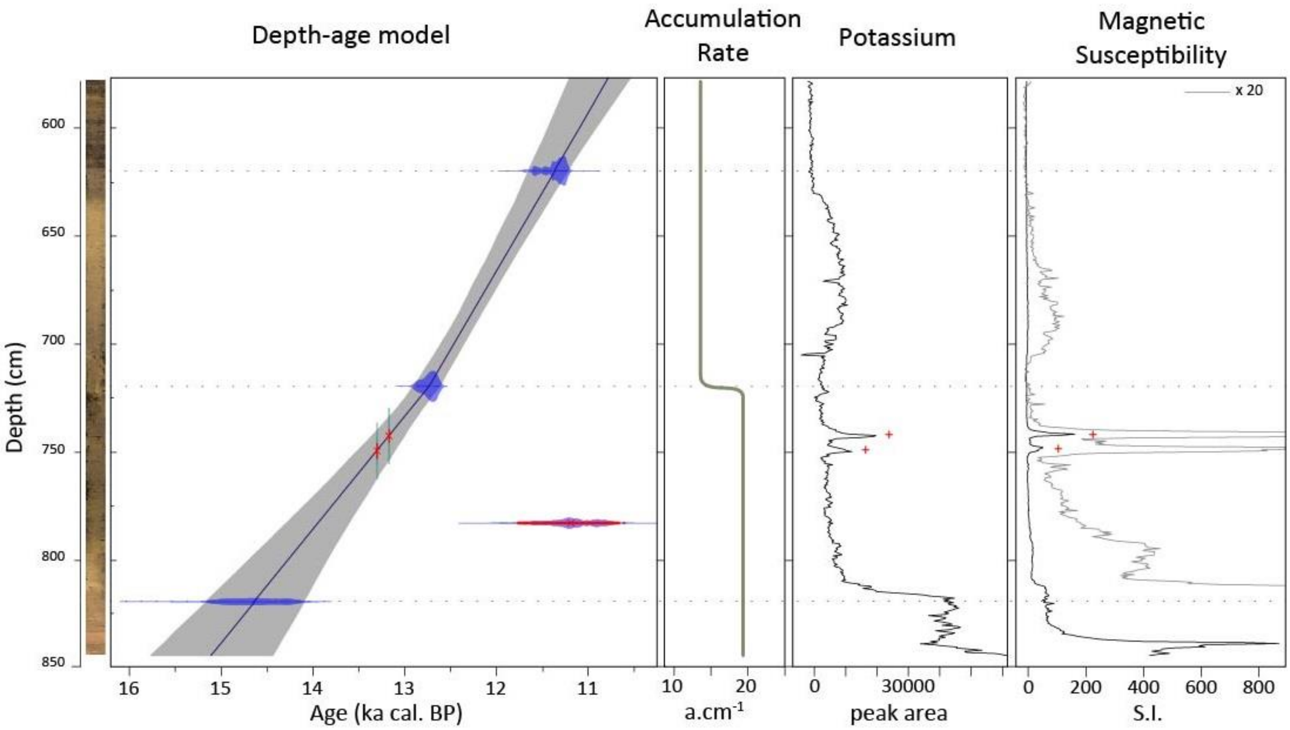

***Figure 2**: from left to right: depth-age model of the Lapsou core based on the radiocarbon dates (blue) and the two tephras (red cross). The rejected dates is indicated in red; accumulation rate; Potassium index; Magnetic Susceptibility – grey curve represents a x20 expansion.*

2.2. Proxy analysis

Pollen analysis was carried out on 41 samples of 2 cm^3. We follow the standard method by Faegri and Iversen (1989) with addition of 4 *Lycopodium* tablets (Stockmarr, 1971). The counting was carried out at x400 magnification (min = 300; max = 700; average = 500 pollen counted). Aquatic plants were excluded from the total pollen sum and only taxa > 1% in at least one sample were included in pollen diagrams. The zonation was determined by the CONISS method (Grimm, 1987) and a brokenstick model (Bennett, 1996).

Charcoal analysis was carried out on 2 cm^3 samples, retrieved continuously every one cm along the core. Only charcoals >150 µm, accounting for local fires, were counted.

Chironomidae analysis was carried out on the same samples than pollen (41 samples, 2 cm^3). The summer temperature (July) was calculated using a transfer function developed by Heiri *et al.* (2011). We characterize the landscape dynamics in response to climate changes on the base of the intra- and inter-proxy relationships. For this, we used a series of statistical analysis, such as Principal Component Analysis - PCA (pollen), Correspondance Analysis – AFC (chironomidae), Spearman test (pollen-charcoal) and diversity indexes (Shannon).

RESULTS

3.1. Lithology

The geophysical and geochemical data presented in **Figure 2** show two sedimentary features:

- 15.2 - 14.2 and 12 – 11.5 ka cal. BP periods are marked by high rates of terrigenous elements.
- Inversely, 14.2 – 12 ka cal. BP period is marked by the lowest rates in terrigenous elements and an increase in the organic matter.

3.2. Pollen record and vegetation history

Five pollen biozones (LAP-) were identified in the Lapsou record (**Figure 3 and 4**), reflecting different landscapes on the base of the tree-shrub/herb ratio:

- LAP-4 (15.2 – 14.7 ka cal. BP): herbs dominate the pollen community (80%), mainly *Artemisia* and Poaceae (21% and 32%). Some shrubs are also present (*Ephedra distachya* and *Juniperus* (≈ 1%)), trees are essentially represented by *Pinus* (up to 18%). Pollen influxes are low (1500 $\#.cm^{-2}.a^{-1}$). This pollen assemblage largely dominated by steppe taxa is typical of the Oldest Dryas.

- LAP-3.b (14.7 – 14.1 ka cal. BP): this period start with a short *Juniperus* peak (52%). Then, shrubs and some herbs decrease drastically to 45%, in favor of *Betula* (reaching 21% at 14.3 ka cal. BP) and a few herbs (*Rumex*, Ranunculaceae). *Pinus* decreases to 2% (14.3 ka cal. BP) before increasing. Moreover, pollen influxes are important. This pollen dynamics to an end arboreal taxa domination could reflect a progressive forest development typically observed at the Bölling.

- LAP-3.a (14.1 – 12.6 ka cal. BP): it is an arboreal phase: trees percentages increase to 55% (*Betula*: 30%; Pinus: 34%; *Quercus*: traces). Herbs and shrubs are still present but in very lesser extent than trees (resp. 45 and <5%). Pollen influxes fluctuate with minima at 13.8, 13.2 and 12.8 ka cal. BP. Pollen assemblages reflect the establishment of a mixed forest (birch-pine) typical of the Alleröd.

- LAP-2 (12.6 – 11.6 ka cal. BP): this phase is marked by the domination and the reappearance of herbs (ex: *Artemisia*) and in lesser extent shrubs (Ericaceae, *Ephedra distachia*). Ranunculaceae dominate firstly herb taxa (de 10 à 14 % up to 11.9 ka cal. BP) before *Artemisia* (20% at 11.8 ka cal. BP). Inversely trees strongly decrease (ex: *Betula* to 2%). Influxes decrease to 850 $\#.cm^{-2}.an^{-1}$. This pollen phase, with the reappearance of a steppe landscape, corresponds to the Younger Dryas.

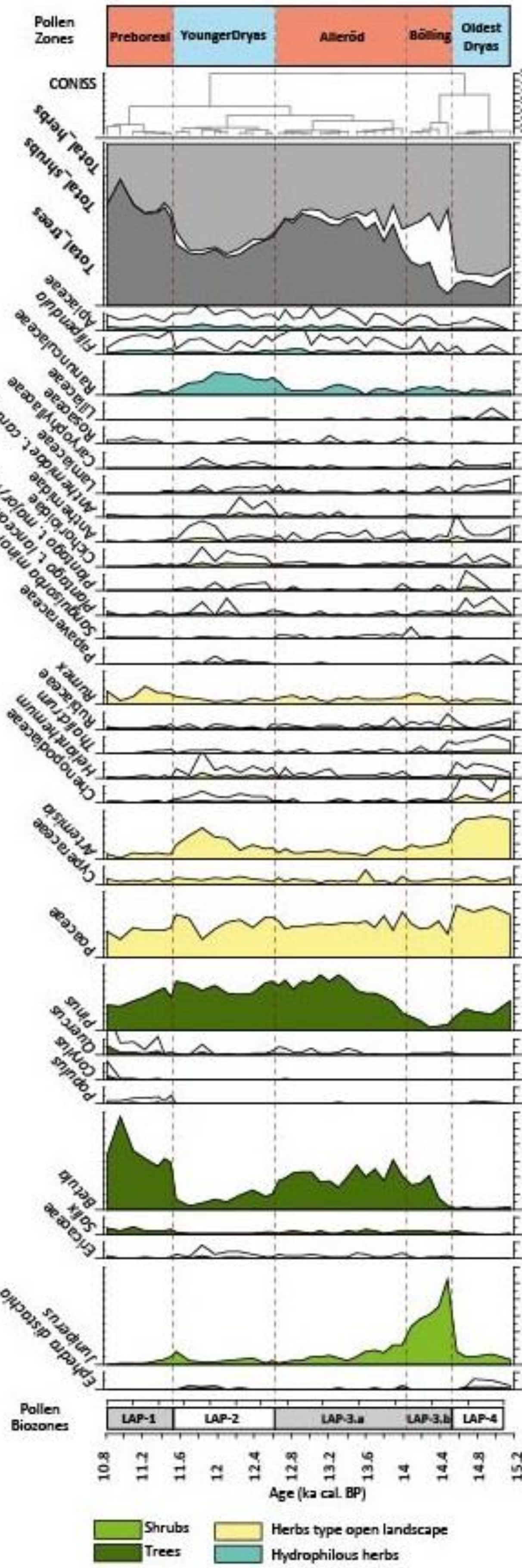

__Figure 3:__ Pollen Diagram of the main taxa (%). Only taxa < 1% for at least one sample are plotted. White curves represent a 5x exaggeration. Pollen biozones (LAP-) were definied with the CONISS method.

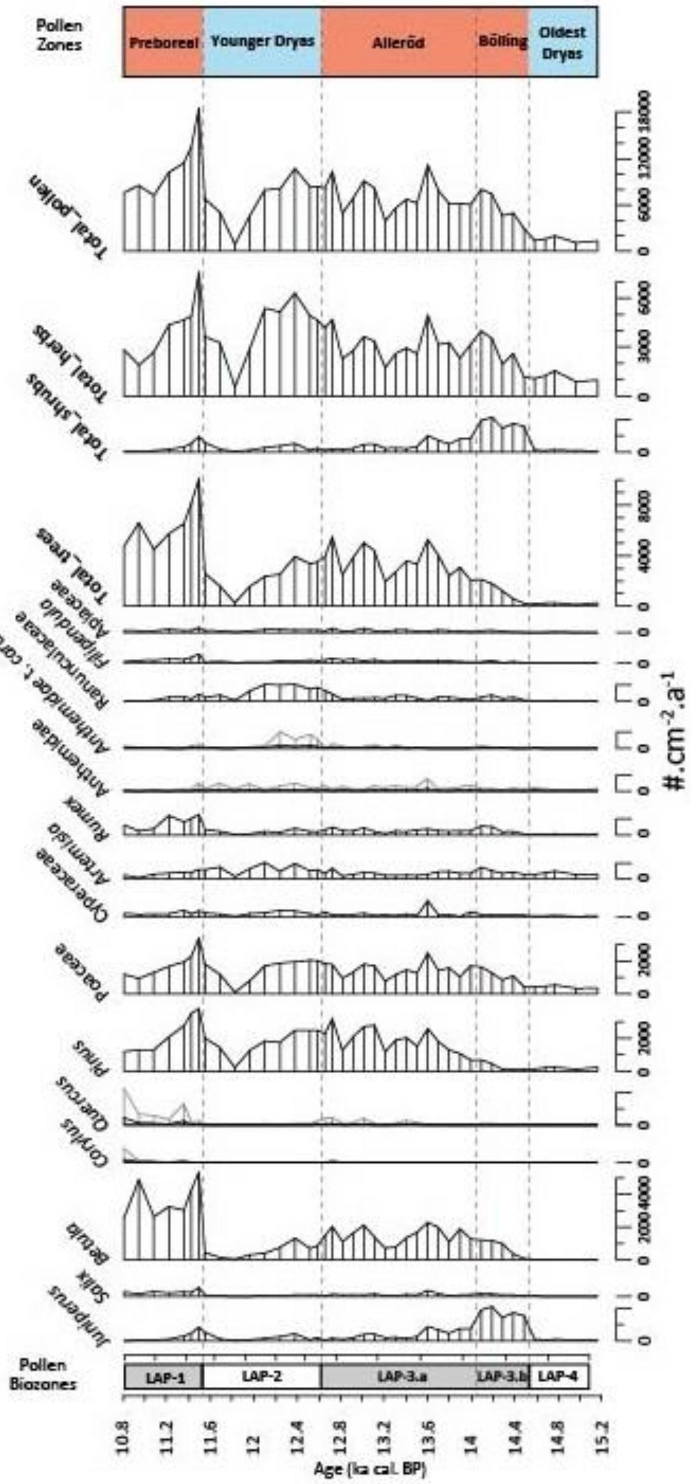

__Figure 4:__ Pollen Diagram of the main taxa in influx (n.cm-2.year-1). Taxa with too low values were excluded from the diagram. Gray bars represent a 5x exageration.

- <u>LAP-1 (11.6 – 10.8 ka cal. BP):</u> This biozone is marked by increases in *Betula* (to 30% and to 57%), and mostly in *Quercus* (6%) and *Corylus* (2%). Almost all herbs, except *Rumex*, strongly decrease, mainly *Artemisia* (3.5%), Ranunculaceae and Poaceae (11%). The appearance of meso-thermophilous species (*Quercus* and *Corylus*) could correspond to the Preboreal transition.

In a global review, an opposition of trends is observed between steppe taxa (*Artemisia*, Chenopodiaceae,...) and some trees (*Corylus* and *Quercus, Betula* and *Salix*), differentiating two landscape types: steppe and forest. The PCA (**Figure 5**) confirms this opposition. Spearman indexes confirm correlation between taxa (ex: *Artemisia* and Poaceae and also *Helianthemum* ($r_{Artemisia-}$ = 0.61, $r_{Poaceae-}$ = 0.48)) and opposite taxa dynamics (ex: steppe taxa and trees (*Betula*: $r_{Artemisia-}$ = -0.88, $r_{Poaceae-}$ = -0.59; *Quercus*: r < -0.50). However trees are associated with *Rumex* ($r_{Betula-}$ = 0.54, $r_{Quercus-}$ = 0.41). Finally, *Pinus*-Ranunculaceae and *Juniperus*-Rubiaceae complexes are independant of the rest of the pollen community.

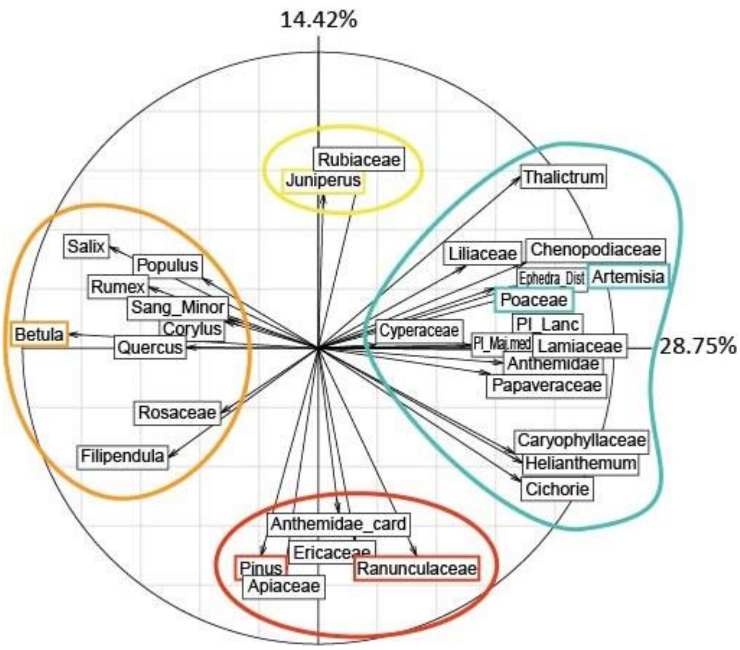

Figure 5*: Correlation circle of the PCA applied on pollen data (%). Colored circles characterize different vegetation groups/types: orange = birch forest, yellow = juniper heathland, blue = steppe, red = pine forest.*

DISCUSSION

4.1. Vegetation dynamics and local climate

The Lapsou pollen record shows vegetation dynamics typical of the Late Glacial for the Massif Central region. At the plurimillennial-to-millennial scale, the record reflects four successive features:

a) A first increase in pioneer taxa (*Juniperus*) at 14.7 ka cal. BP consistent with the beginning of the Late Glacial interstadial (*i.e.* Bölling; GI-1e) and also detected in marine records (Beaudoin *et al.,* 2005). This reflects a vegetation response to more humid and warmer climate conditions at the regional scale.

b) Scrublands contributing to soil development are replaced by mixed forests (*Betula* and *Pinus*) up to the end of the Alleröd (GI-1a.c). We suggest these trees migrated from refuges of the Iberian Peninsula and the Balkans (Cheddadi *et al.*, 2006).

c) The reappearance of local steppes at the Younger Dryas (GS-1) puts an end to the forest development. This suggests abrupt dryer and colder local climate conditions. Moreover, low and open landscapes result in an increase of the erosion reflected by sediments rich in terrigenous elements (**Figure 6**).

d) From 11.6 ka cal. BP (Preboreal), meso-thermophilic forests (*Corylus*, *Quercus*) develop, reflecting drastic increases in temperature (Brewer *et al.,* 2002). This rapid change could be explained by a modest Younger Dryas, which contrasts with other European regions (Millet *et al.,* 2012).

Climate changes recorded in the GRIP and chironomidae are synchronous with vegetation changes (**Figure 6**). This confirms a global climate control of the European vegetation already sustained by studies on the Jura (Magny *et al.,* 2006), the Balkans (Bozilova & Tonkov, 2000) and the Alps (van Mourik *et al.,* 2013; Finsinger *et al.,* 2006).

At the secular scale, we detected some short-lived changes in the Lapsou pollen record:

- The decreases in pollen diversity and influxes at around 14 ka cal. BP (**Figure 6**) could reflect the local imprint of the Older Dryas (GI-1d).
- The decreases in *Betula* pollen and fire occurrences (see below) at 13.5-13.2 ka cal. BP are consistent with climate conditions of the GI-1b (Gerzensee oscilllation, Lotter *et al.*, 2000).
- The Younger Dryas vegetation seems to evolve in two times, that is surprising with the global glacial conditions of this period. We suggest a diversification of the landscape with the coexistence of different plant types (Ranunculaceae, arboreal taa, herbs…) in an attempt to adapt to glacial conditions (Lindbladh *et al.,* 2003; Meltov *et al.,* 2011). But this dynamics is stopped by colder and colder climate conditions leading finally to the development of a steppe mainly dominated by *Artemisia*. This vegetation dynamics could be also explained by an increase in the seasonality (Bordon *et al.,* 2009, Lotter *et al.,* 2010; Bromley *et al.,* 2013) reflected in the chironomidae record (cold winters and temperate summers).

4.2. Fire history

Changes in charcoal occurrences reflect a fire regime variability. An intense fire regime characterizes the Alleröd and Preboreal, when trees are largely dominant. Fire regime are generally in agreement with pollen results. Hence fire has a crucial role in local vegetation dynamics (Higuera *et al.,* 2009). However, we observed a time lag between the *Betula* appearance in the Lapsou pollen record (14.4 ka cal. BP) and first fire occurrences (13.8 ka cal. BP). We suggest that fire cannot occur as long as a threshold of biomass quantity is not reached. Hence, *Betula* pollen detected before first fires could not be attributed to local trees, and come from low shrubs (*Betula nana*) or long-distance inputs.

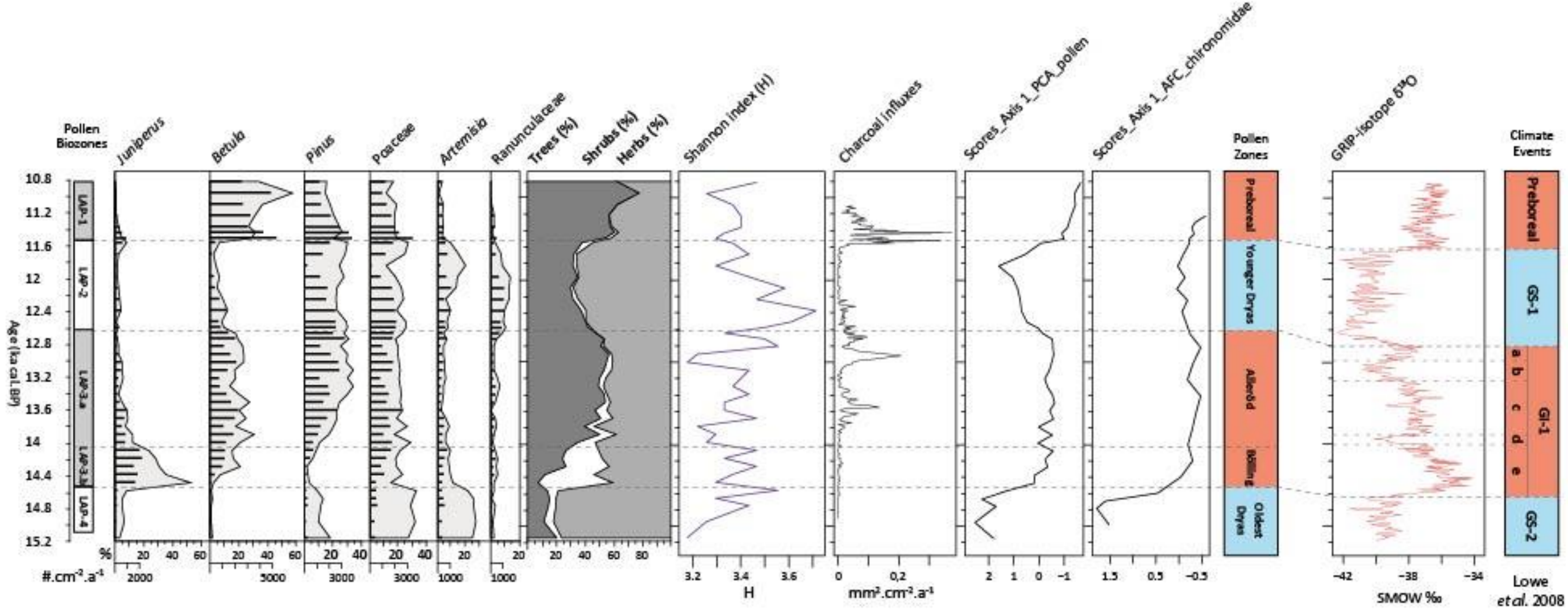

Figure 6: *Comparison between all the proxy dynamics and statistical analysis from the Lapsou core.*

CONCLUSIONS

This study of the Lapsou record allowed us to characterize the vegetation variability in response to the climatic changes of the 14.7 – 11.7 ka cal. BP period, from the plurimillennial to the secular scale. The multi-proxy approach using pollen, charcoal and chironomidae allowed to detect links between changes in the climate, vegetation and fire. Main results are:

1) Vegetation successions (*Juniperus-Betula-Pinus*) are controlled by the global climate, at the plurimillennial-to-millennial scale.

2) Secular cold climate events (GI-1b and d) seem to be recorded in the pollen record.

3) Vegetation dynamics of the Younger Dryas evolves in two periods, with a colder second phase than the first one.

4) Fire regime seems to be directly controlled by the local vegetation, and particularly the available biomass fuel.

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IME-Site 7: La Vergne Noire peatland (1300 m a.s.l.) – Laguiole – Aveyron Department

ANTHROPISATION DYNAMICS OF THE AUBRAC (MASSIF CENTRAL, FRANCE) DURING THE HOLOCENE. PALYNOLOGICAL APPROACH OF LANDSCAPE HISTORY AND SPATIAL VARIABILITY IN A MIDDLE MOUNTAIN RANGE: THE EXAMPLE OF THE LA VERGNE NOIRE PEATLAND.

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ABSTRACT:

Based upon an approach centred on palynology, the aim of this presentation is to better understand the long-term interactions in human/vegetation processes in the mountainous region of Aubrac (Massif Central, France; **Figure 1**). Four sedimentary records, supported by 17 radiocarbon dates, have been studied using comparisons with available archaeological and historical data, in order to characterize local human impacts on landscape, in particular rythms, breaks and thresholds concerning anthropisation dynamics. Here we focus on the palaeoecological studies performed at the La Vergne Noire peatland (**Table 1, Figures 1–8**), According to our analysis of all studied sites, the first signs of human impact on vegetation appear in the Aubrac during the middle Neolithic period, while evidence of human activities seems to extend during the Late Neolithic (**Figure 9 & 10**). The Iron Age and Early Antiquity periods are characterized by a large scale deforestation correlated with the increase of the agro-pastoral pressure (**Figure 11 & 12**). Our data further suggests that the medieval and modern periods consolidate the types of landscape that have been created in earlier periods. The dynamics that have been highlighted suggest an important degree of spatial variability of land use. The analyzed territory presents common trends that correspond to colonization trajectories generally encountered in mountain areas.

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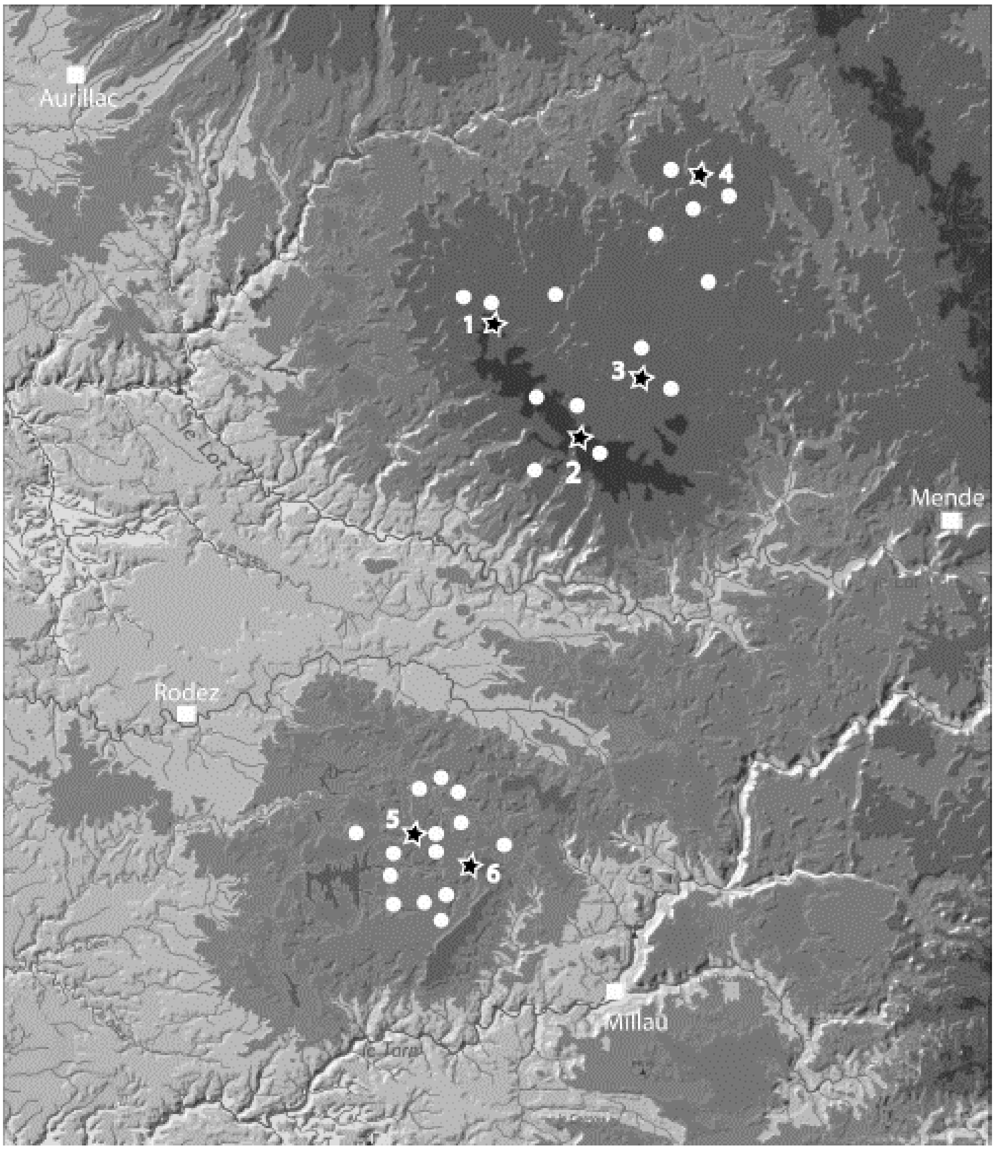

***Figure 1**: Location of the different study areas. 1: Vergne Noire, 2: Trois Airelles, 3: Lac de Born, 4: Roustières, 5: Plaine des Rauzes, 6: Mauriac (Faure 2012).*

Réf. Labo	Prof. (cm)	Matériel	Datation radiocarbone (BP)	Calibration BP (2 σ)
Poz-32116	59,5-60,5	Tourbe	550±30	512 [572] 643
Poz-32119	269,5-270,5	Tourbe	3900±35	4226 [4336] 4439
Poz-32115	359,5-360,5	Limon organique	5170±40	5759 [5927] 6006
Poz-32109	519,5-520,5	Limon organique	9030±60	9823 [10070]10182

***Table 1**: AMS Radiocarbon dates performed on peat and organic sediments of the La Vergne Noire peatland (Faure 2012).*

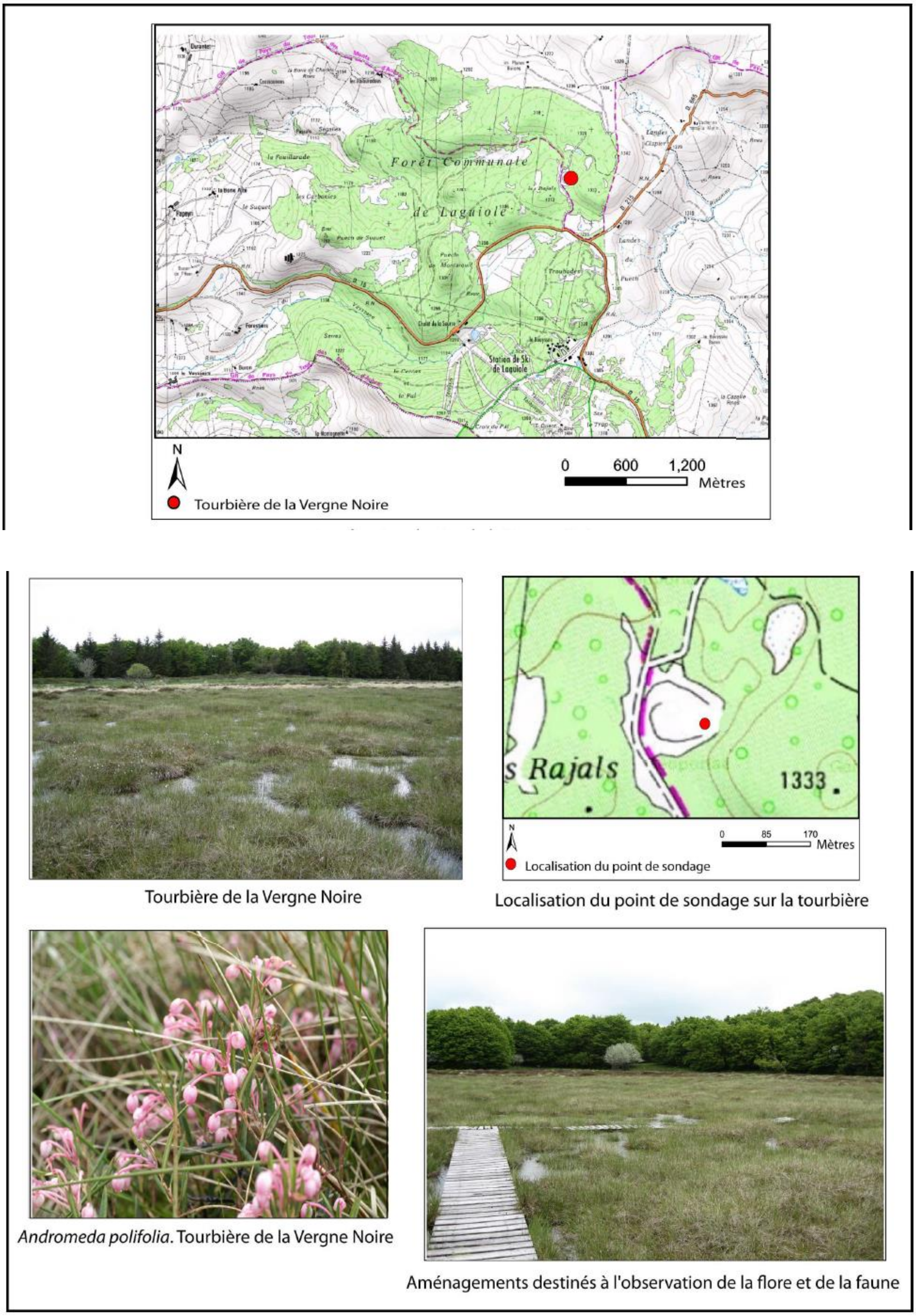

***Figure 2**: Location and presentation of the La Vergne Noire peatland (Faure 2012).*

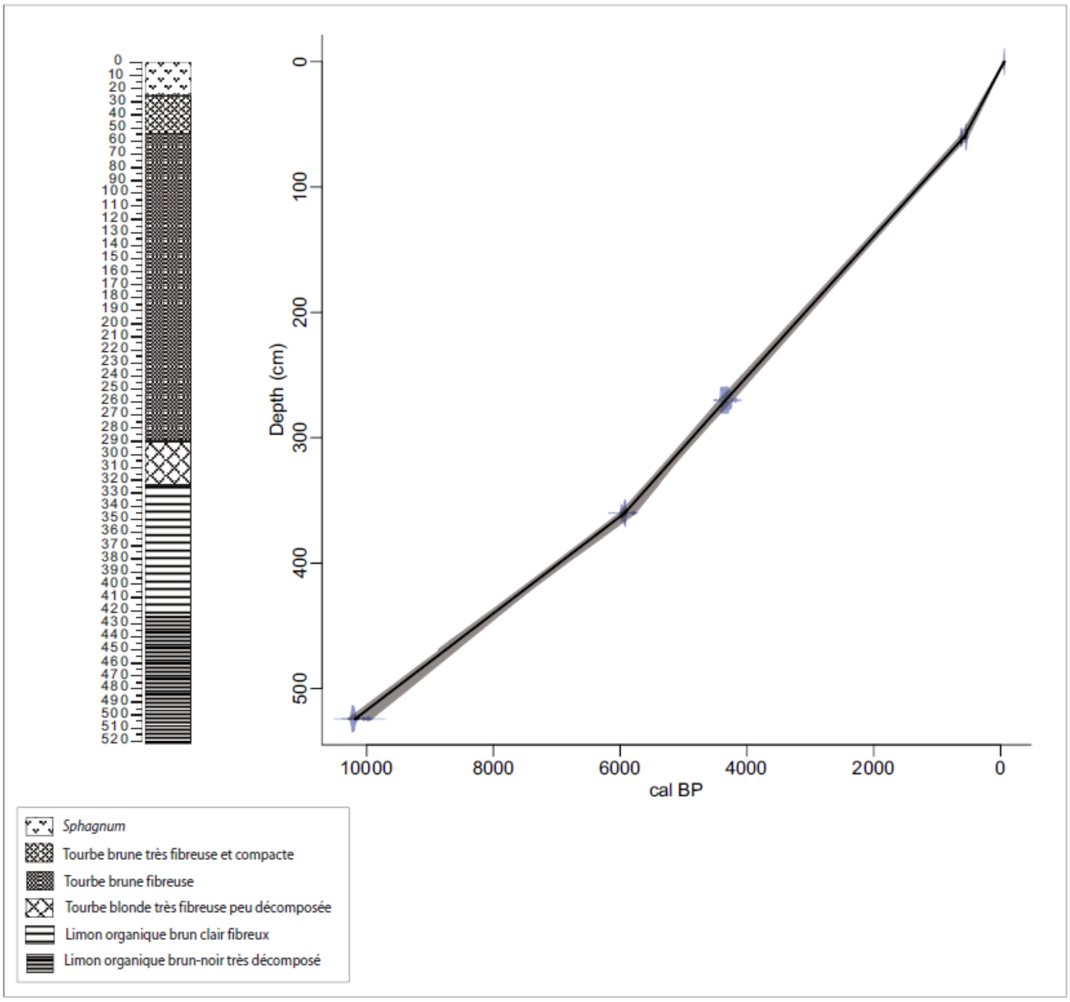

Figure 3: *Age-Depth model for the stratigraphy of the La Vergne Noire peatland (Faure 2012).*

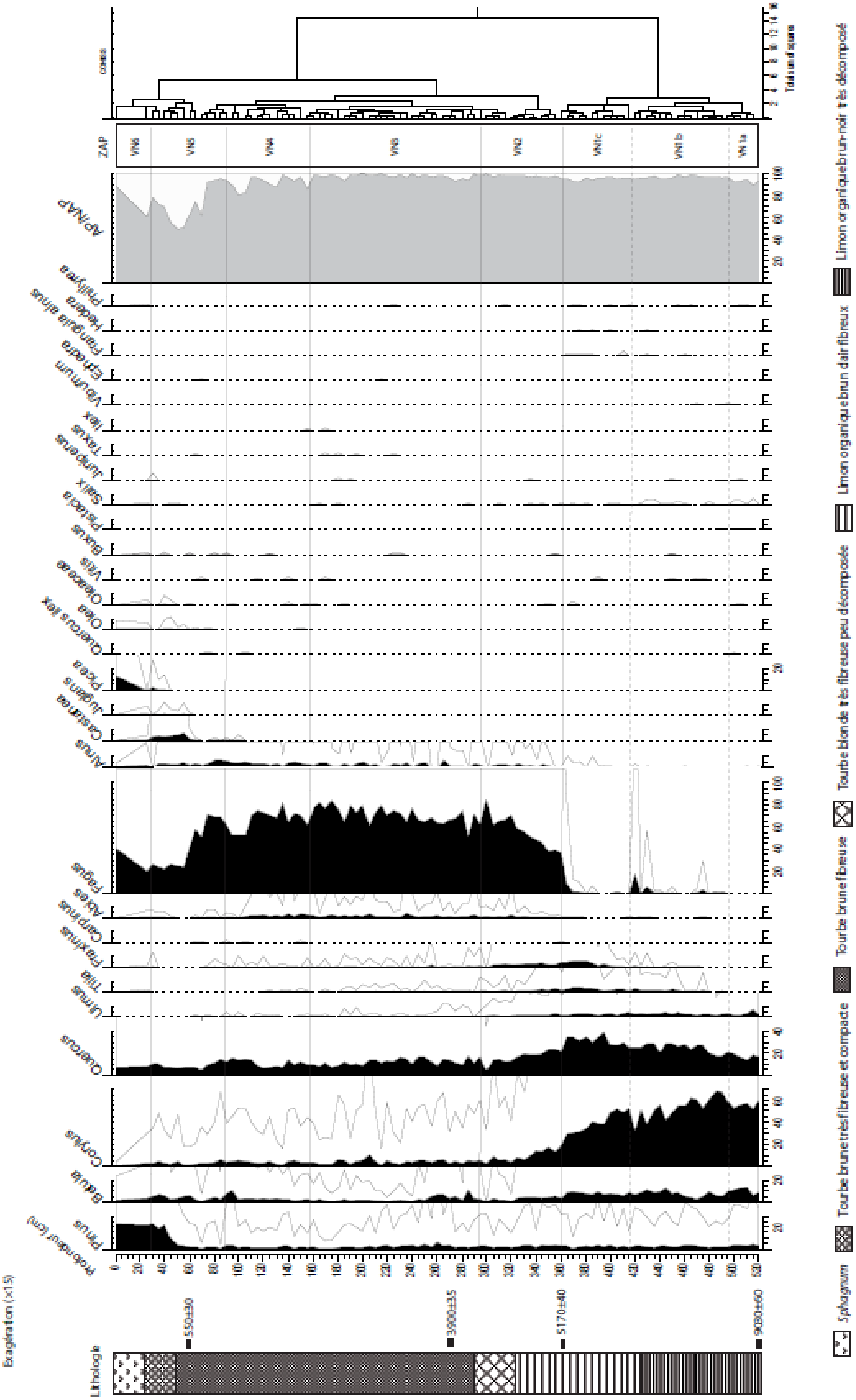

***Figure 4**: Palynological diagram (arboreal and shrup taxa) for the stratigraphy of the La Vergne Noire peatland (Faure 2012).*

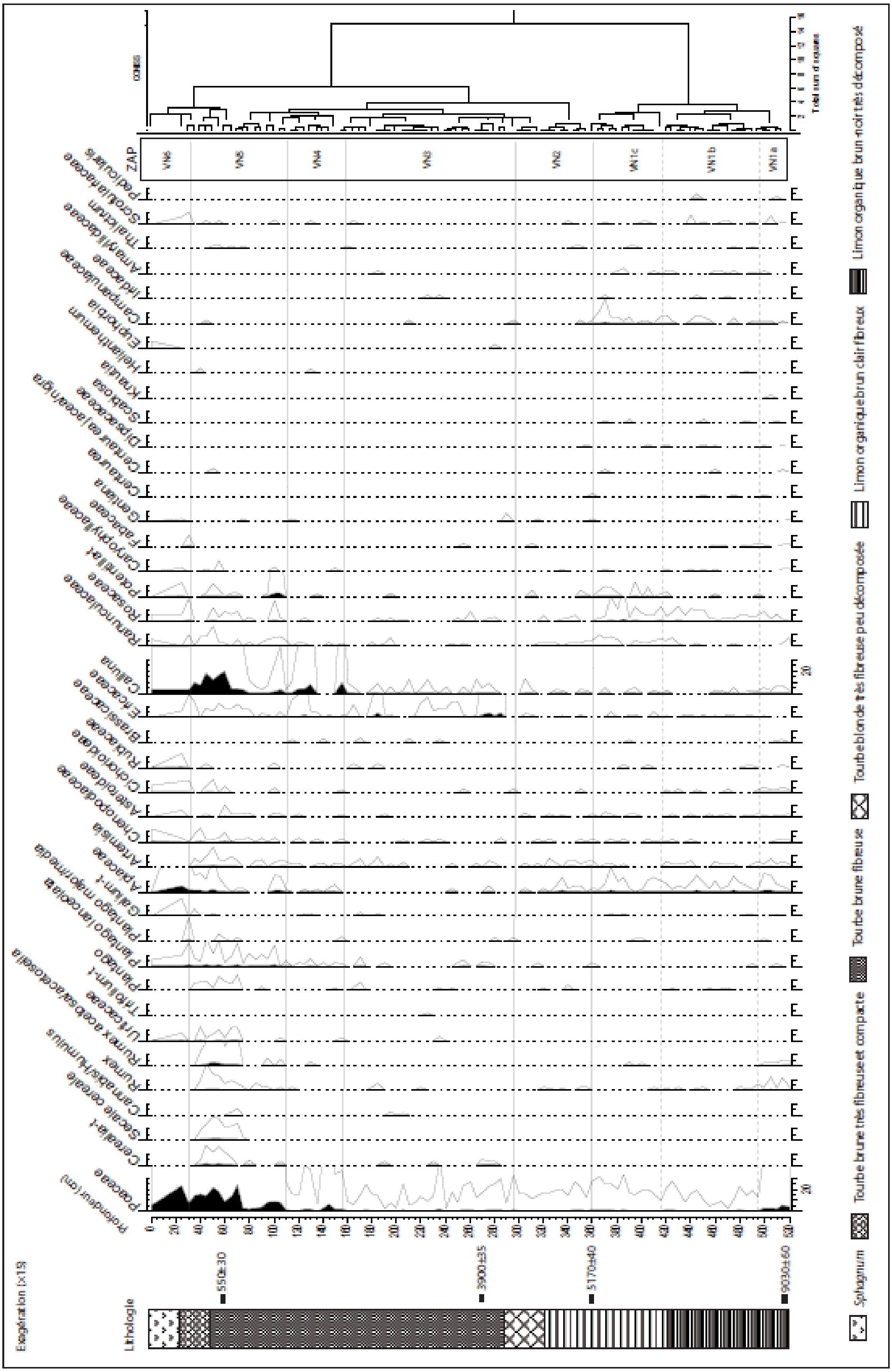

***Figure 5**: Palynological diagram (herb taxa) for the stratigraphy of the La Vergne Noire peatland (Faure 2012).*

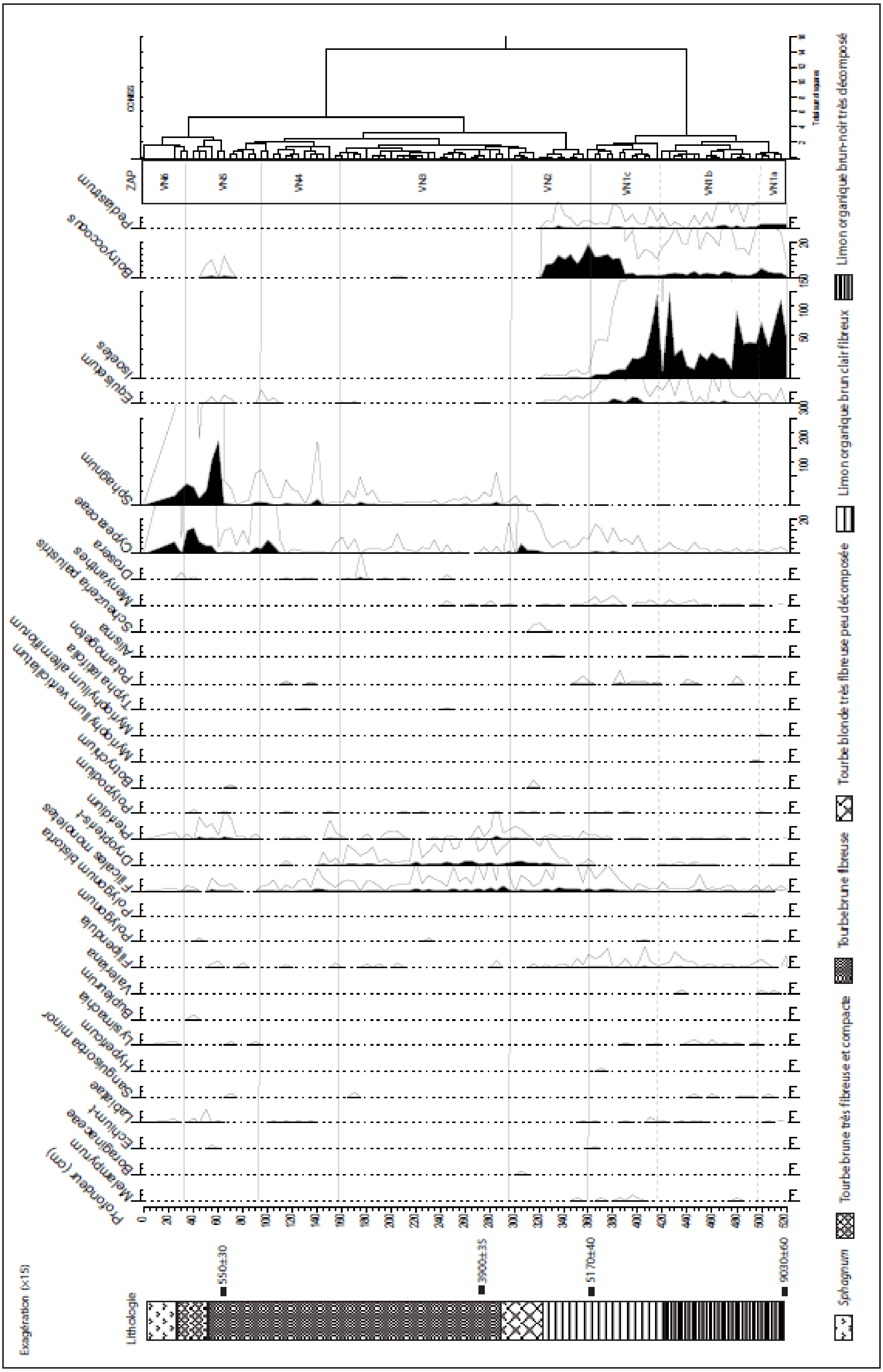

***Figure 6**: Palynological diagram (herb, hydrophyte and aquatic taxa) for the stratigraphy of the La Vergne Noire peatland (Faure 2012).*

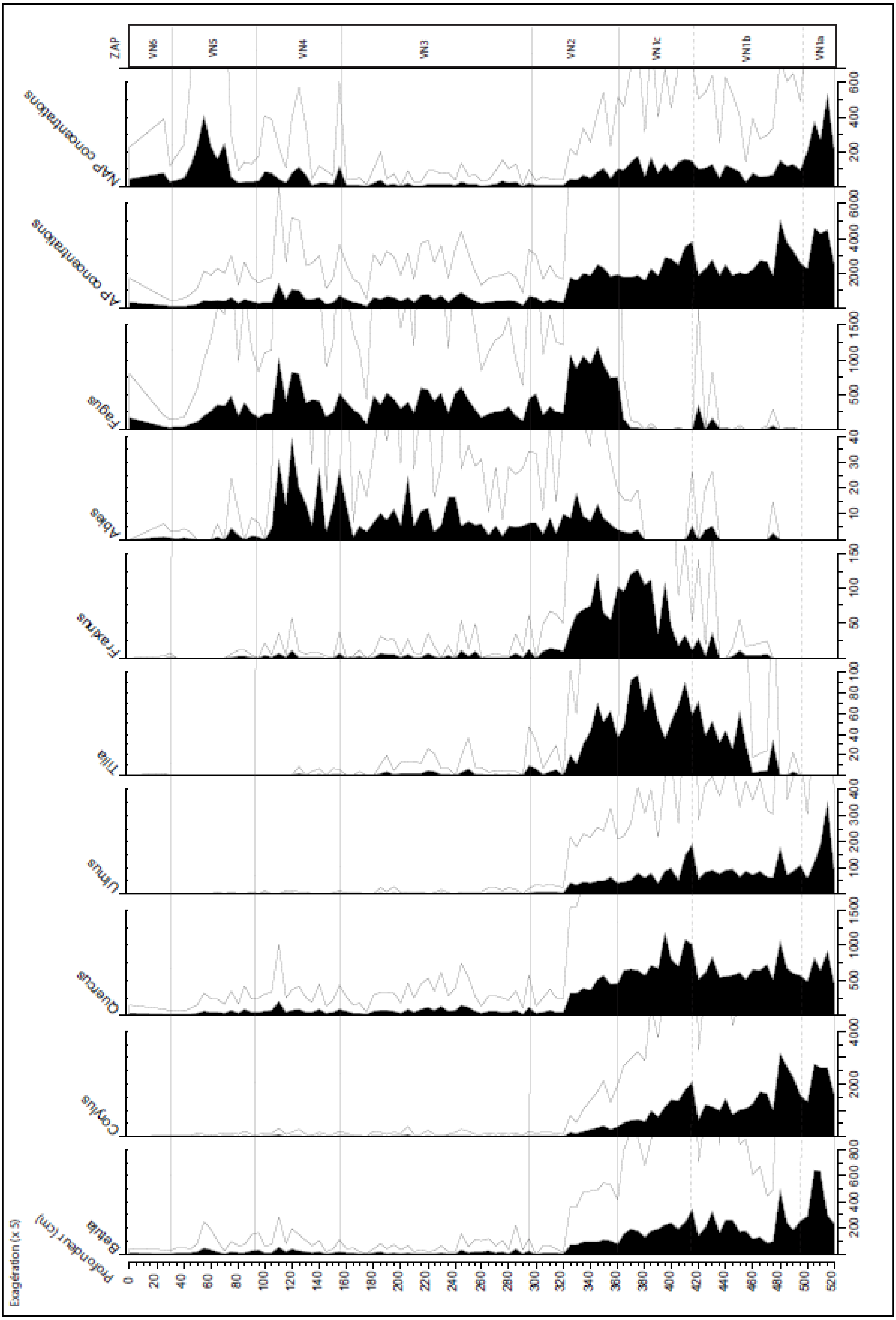

***Figure 7**: Palynological diagram for selected taxa presented as concentrations for the stratigraphy of the La Vergne Noire peatland (Faure 2012).*

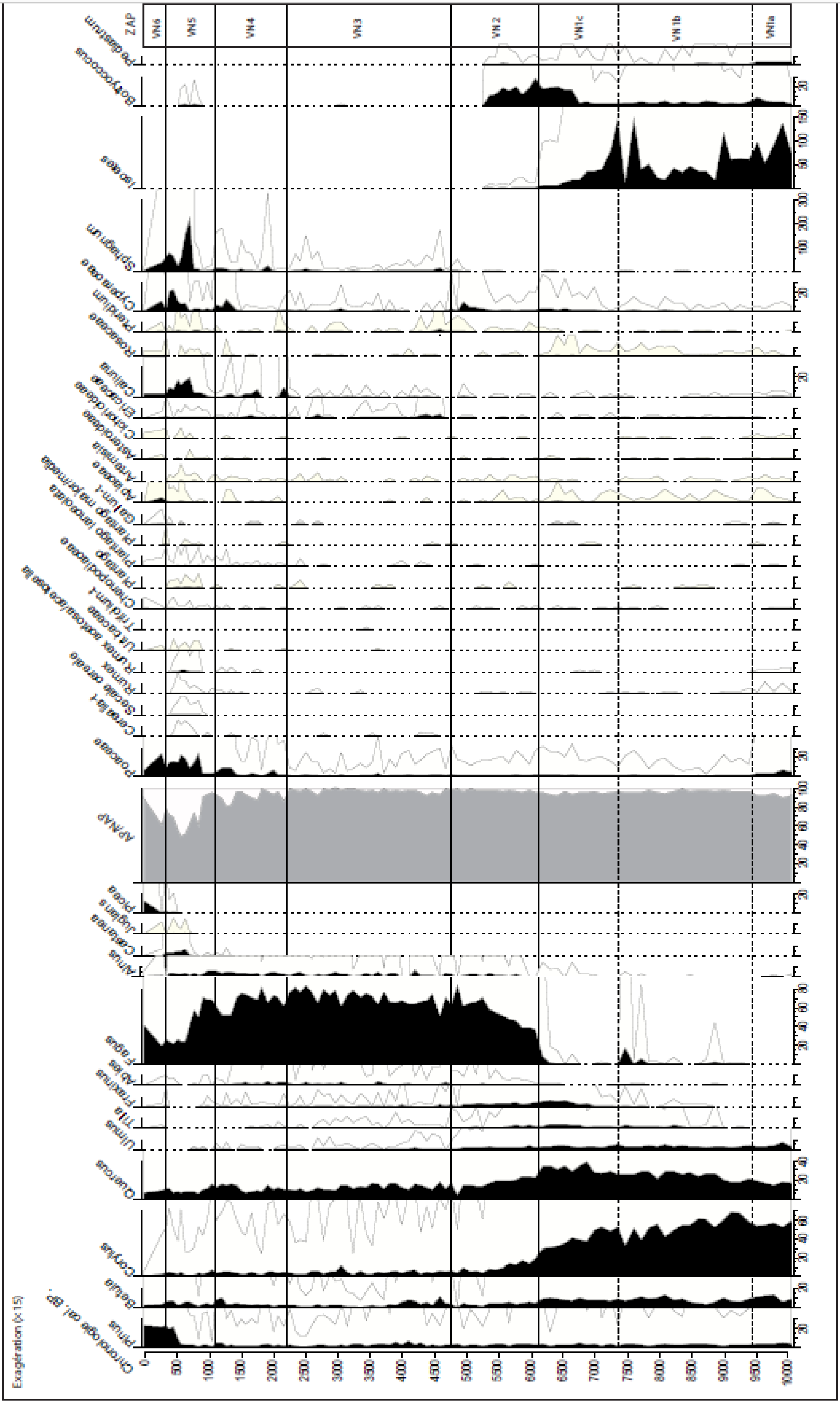

Figure 8*: Synthetic Palynological diagram for the stratigraphy of the La Vergne Noire peatland (Faure 2012).*

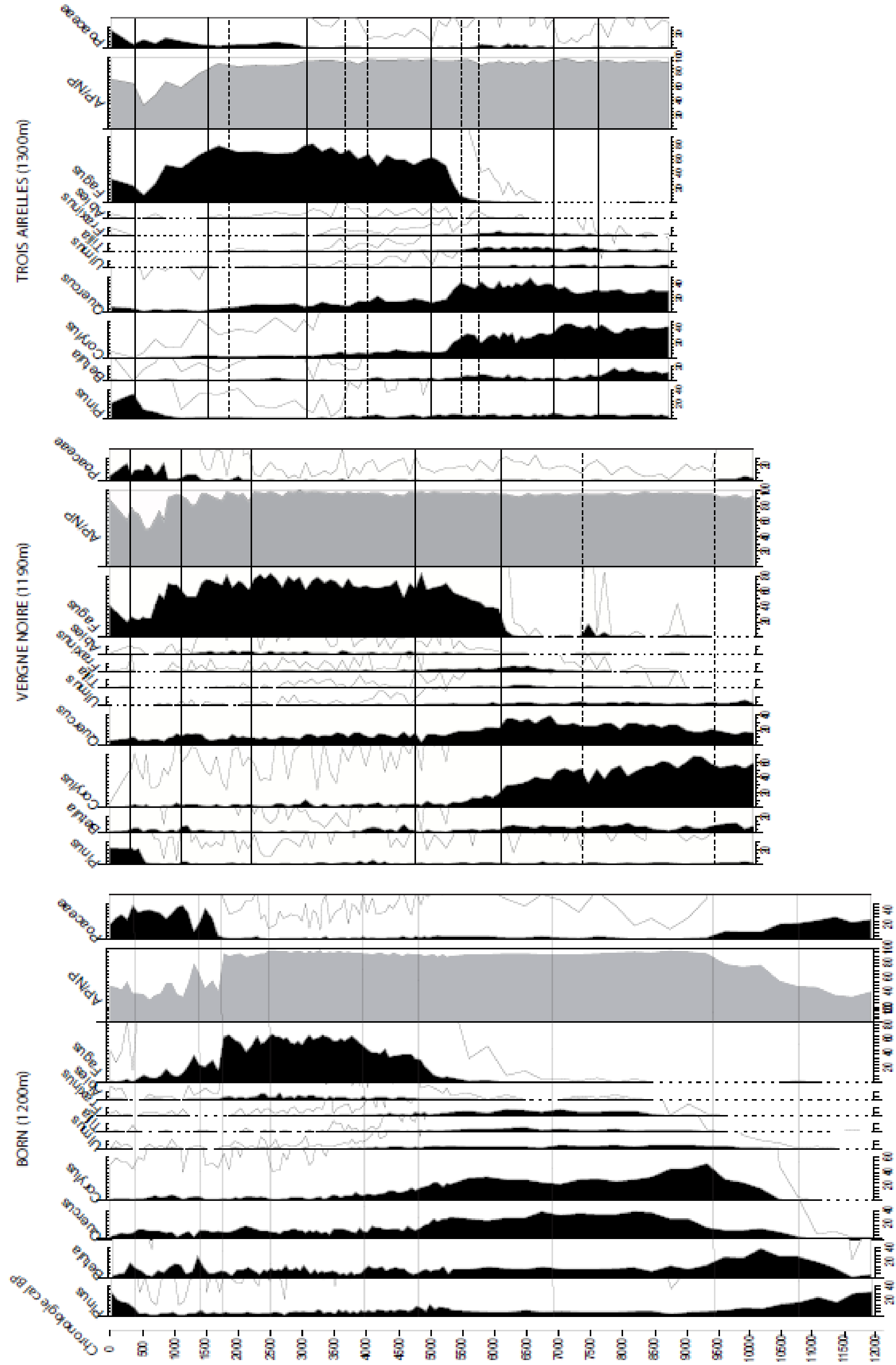

***Figure 9**: The dynamics of most prominent arboreal taxa comparing three different sites in the Aubrac Mountains (Massif Central, France; Faure 2012).*

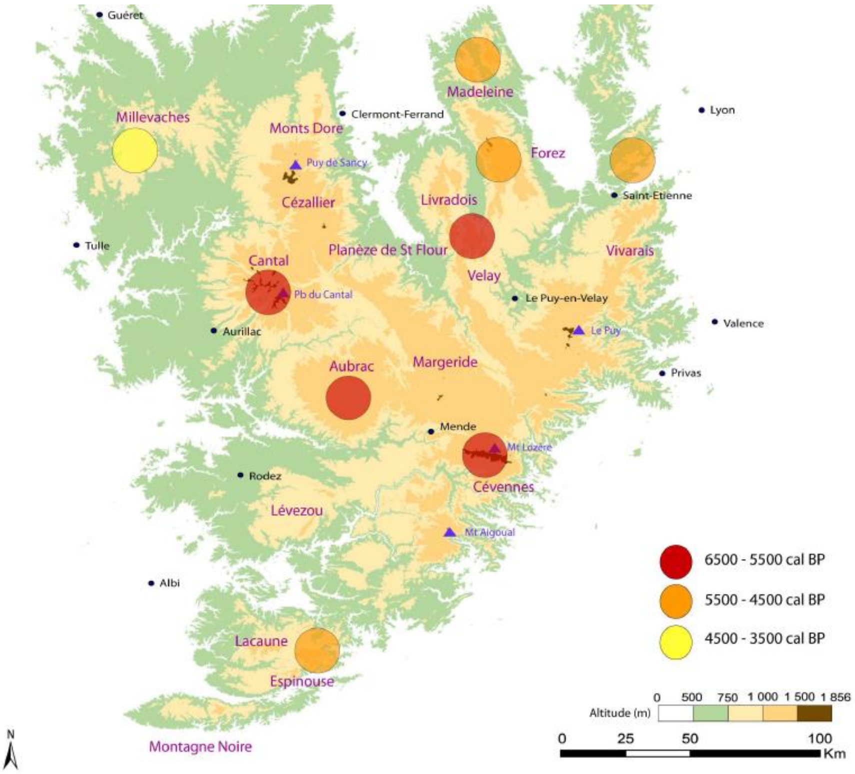

***Figure 10**: Chronology and spatial dynamics of Fagus sylvatica in the Massif Central, France (Faure 2012).*

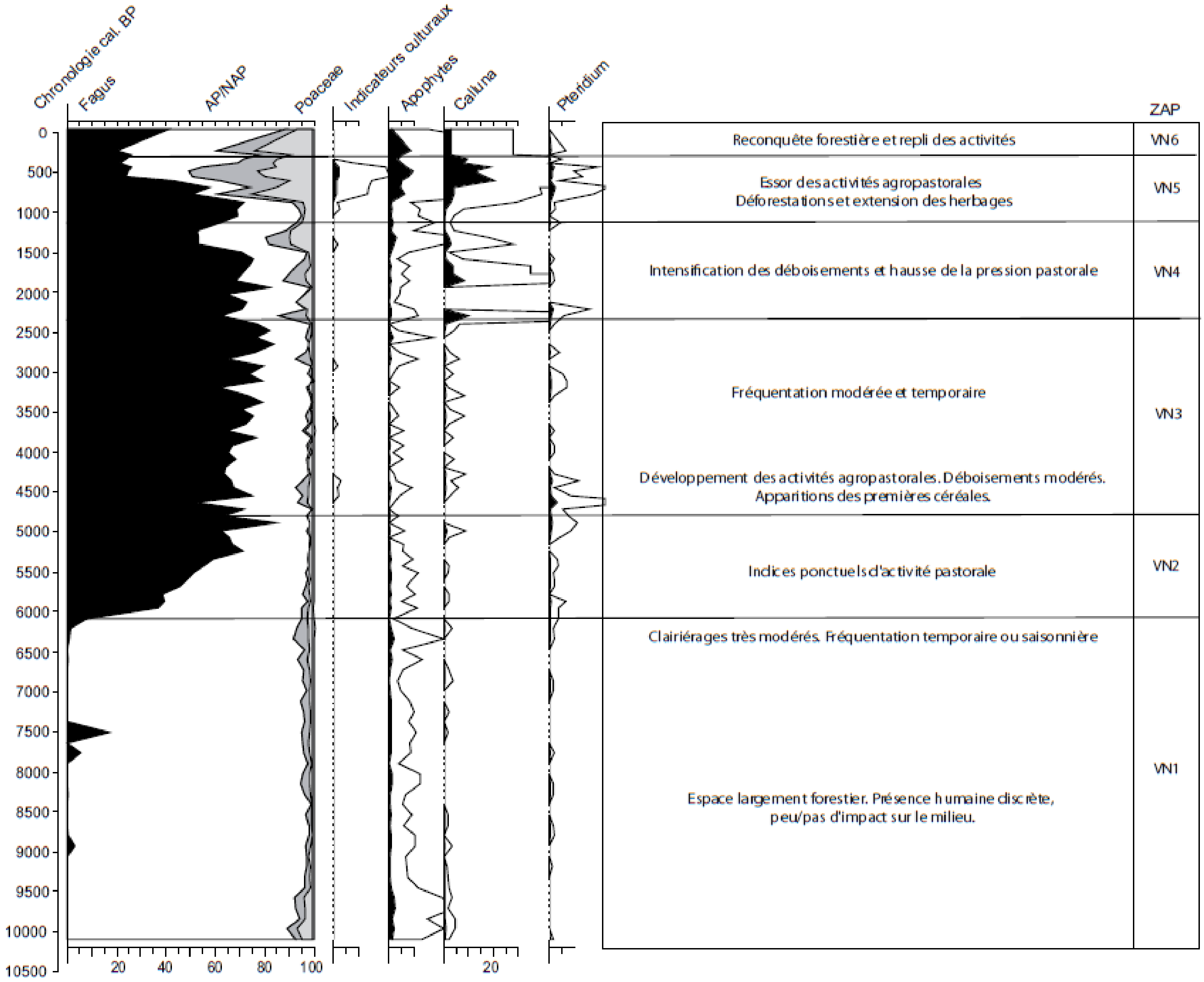

***Figure 11**: Anthropisation dynamics at the La Vergne Noire peatland according to API (Faure 2012).*

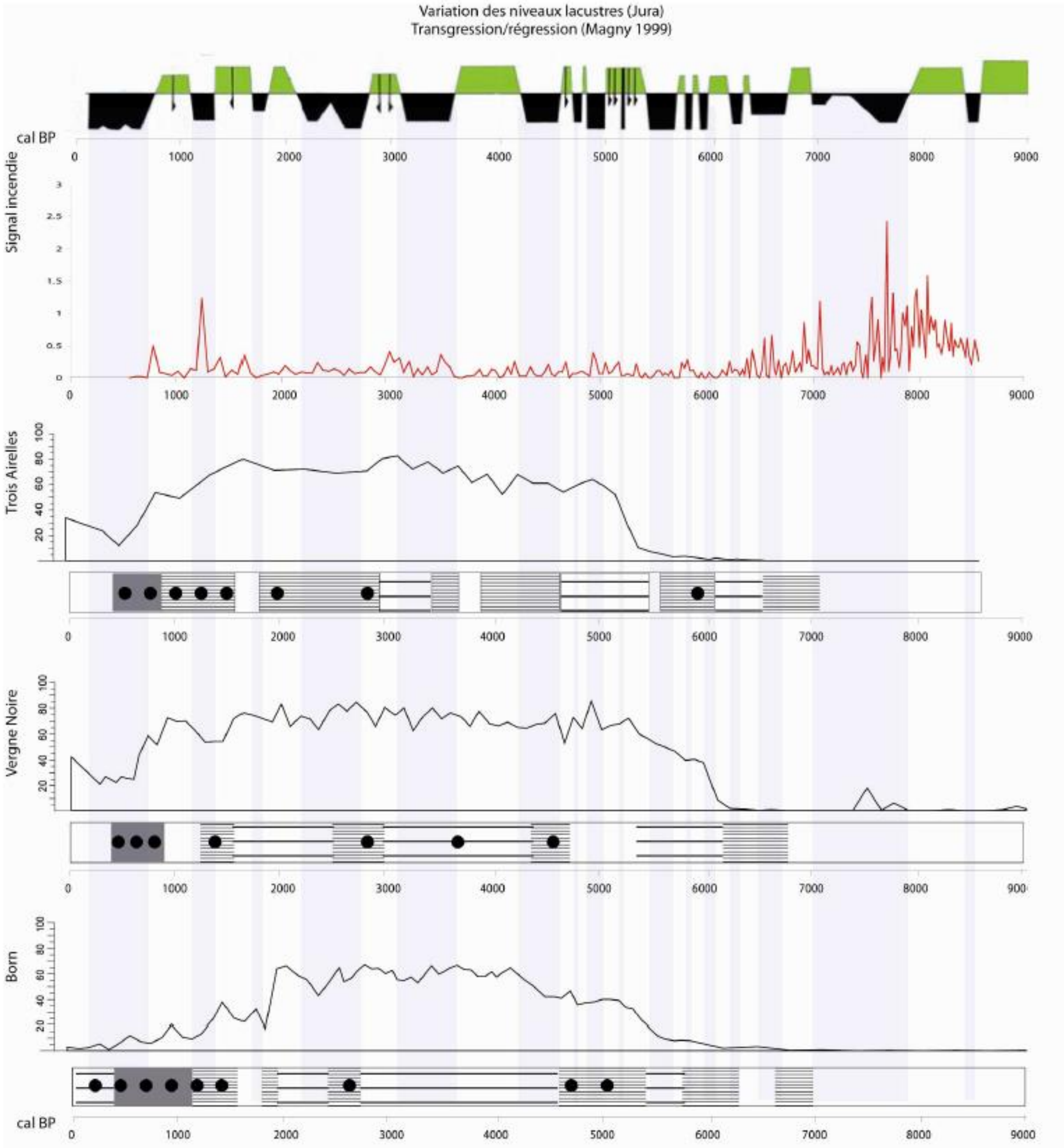

Figure 12*: The history of Fagus sylvatica in the Aubrac Mountains (Massif Central, France) compared to anthropisation dynamics and climatic change, i.e. changes in lake levels in the Jura Mountains (Faure 2012).*

ENVIRONMENTAL AND CLIMATE CHANGES AT THE « LES ROUSTIERES » PEAT-BOG (MASSIF CENTRAL, FRANCE) DURING THE LATEGLACIAL/HOLOCENE TRANSITION

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INTRODUCTION

Pollen analysis carried out in the 1980's on numerous sites of the Massif Central allowed to define a robust framework for the regional vegetation history (De Beaulieu *et al.*, 1988). In one of the most promising sites, the peat bog of "Brameloup" (named here "Les Roustières", **Figure 1**) provided a long sedimentary record marked by a high sedimentation rate for the Lateglacial section (De Beaulieu *et al.* 1985). Unfortunately, this pioneer work (focused on the Lateglacial / Holocene transition), suffered from insufficient radiocarbon chronological control and lack of multi-proxy analysis.

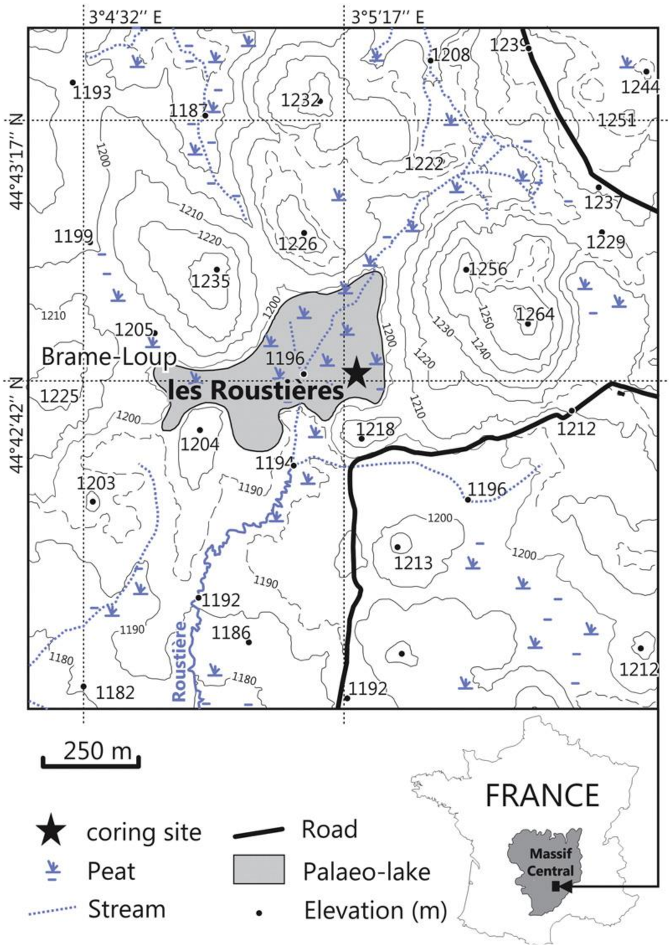

***Figure 1**: Location of the study area*

Hence, a new coring campaign has been done to reconstruct with accuracy the palaeoenvironmental dynamics during the Late Glacial/Holocene transition, with a particular attention on specific issues such as: (i) what was the past climate variability in the southern Massif Central? (ii) Can we estimate amplitude shifts in temperature? (iii) Can short minor cold oscillations be identified (such as "Intra Bolling Cold Period", "Intra Allerod Cold Period") (iv) With an impact on the ecosystems?

Several independent proxies have been used: diatoms and chironomids for the aquatic communities (Gandouin *et al.*, 2016) and pollen and Coleopteran (Ponel *et al.*, 2016) for the terrestrial ones. A well-constrained age-depth model has been performed (**Figure 2**) based on a set of 18 radiocarbon dates. We present here a short cross-comparison of the main results.

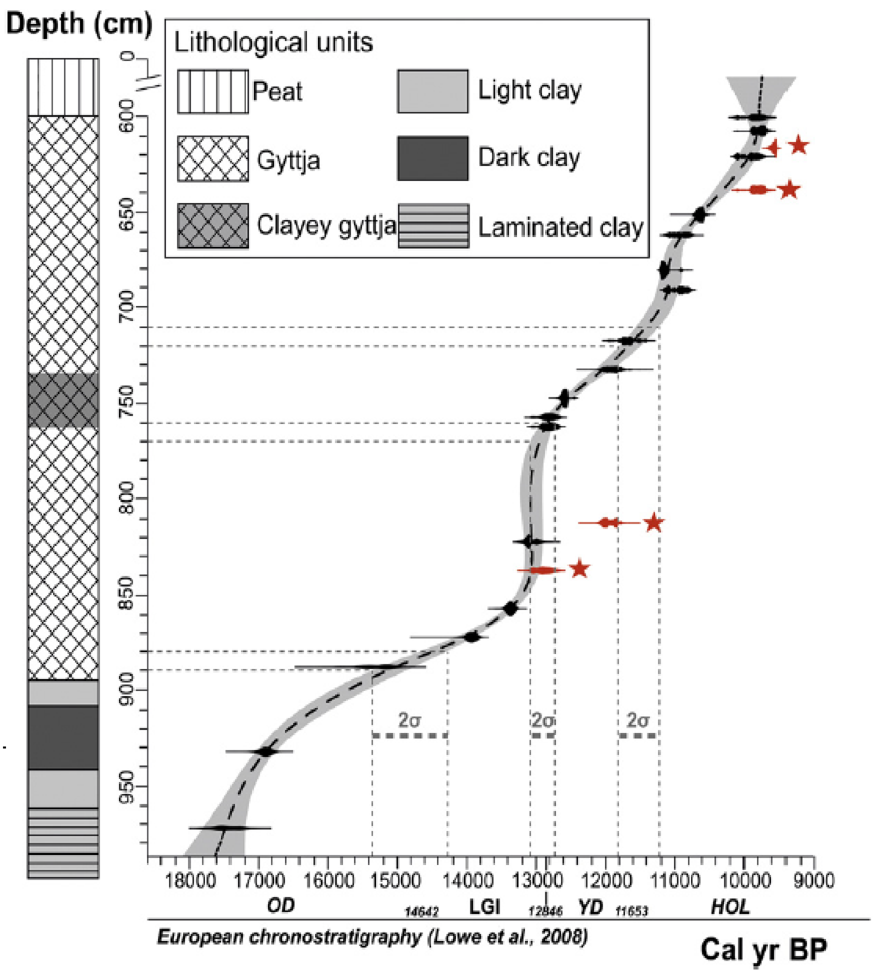

Figure 2*: 14C age-depth model developed with the CLAM software (Blaauw, 2010) using a smooth spline method with 10,000 iterations and the "IntCal13" C calibration curve. The dates marked by a star are considered as outliers. Boundaries between the Older Dryas (OD), Late-Glacial Interstadial (LGI), Younger Dryas (YD), and Holocene (HOL) are shown as dotted grey lines with 2 standard deviations (2σ).*

MAIN CHIRONOMID AND DIATOM RESULTS

Gandouin *et al.* (2016) provided a detailed environmental reconstruction of hydrological changes in the Les Roustières palaeolake from the Oldest Dryas to the Early Holocene. This environmental reconstruction has shown that environmental factors such as water-depth and macrophyte abundances, may have played a significant role in faunal and diatom assemblages in some parts of the Lateglacial-early Holocene transition. It provided an accurate quantitative reconstruction (Figure 3) of summer temperatures (C-IT: T July) inferred from subfossil chironomid data (Figure 3: C-IT, GOF and Modern Analogues).

Thus, CI-T are based on good correspondences between subfossil assemblages and modern analogue ones (except from the EH and in the first part of the OD). LGI, YD and EH temperatures have been validated by GOF results. Summer temperatures (T° july) during LGI and YD were not very different, and close to 11- 13° C (slightly lower, about 10°C, at the onset of the YD). During the EH, C-IT were close to 16°C. The main conclusion of this climate reconstruction is that a cold regional ambiance is maintained during the Lateglacial period and at the onset of the Early-Holocene.

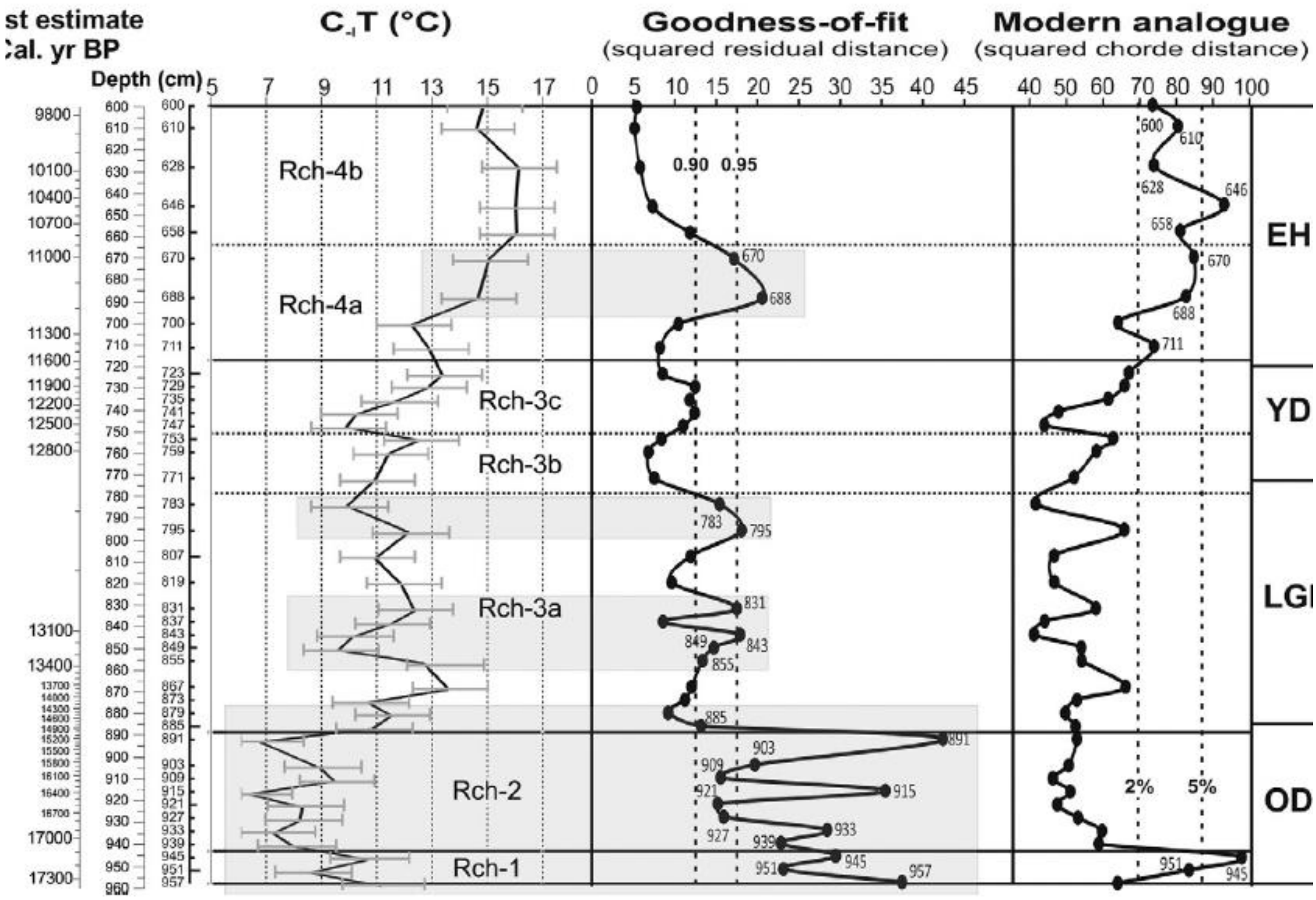

Figure 3: From left to right, chironomid-inferred temperature estimates (C-IT) with sample specific error bars; goodness-of-fit of the fossil assemblages to temperature, vertical dotted line indicates the 90th and 95th percentiles of squared residual distances of modern samples to the first axis in a CCA, samples to the right of the line have a poor or very poor fit-to-temperature respectively; nearest modern analogue analysis, vertical dotted line indicates the 2nd and 5th percentiles of squared chord distances of the fossil sample to samples in the modern calibration dataset, samples to right of line have no close and no good modern analogue respectively. The shaded areas correspond to samples that should be considered as tentative and interpreted with caution. OD: Oldest Dryas; LGI: Late-Glacial Interstadial; YD: Younger Dryas; EH: Early Holocene.

MAIN COLEOPTERAN AND POLLEN RESULTS

Beetle and pollen data analyzed by Ponel *et al.* (2016) at les Roustières, suggest that the harsh climatic conditions prevailing in the Aubrac mountains did not allow warm dependent fauna and trees to establish during the Lateglacial Interstadial, at least in the Roustières region, and that wide-open landscapes occupied the plateau at that time. The LGI-Holocene transition is marked by a complete replacement of the cold fauna by temperate elements, an event certainly induced by a rapid climate warming. This warming is associated with a strong increase in water flow and brook energy, as indicated by a sharp and brief peak of running water Coleoptera. This event could be correlated with a generalized snow patch melting in the area, in response to the rapid warming. During the Early Holocene, concordant beetles and pollen data enable to reconstruct the rapid recolonization of the plateau by mesophilous trees (*Ulmus, Quercus*), suggesting the possible presence of refugia to the southern slopes of the Aubrac plateau.

MULTIPROXY SYNTHESIS

At "Les Roustières", the LGI is marked by: (i) the persistence of herb dependent Coleoptera (**Figure 4**); (ii) cool summer temperatures (between 11-13°C) that probably explain the persistence in high abundance of *Corynocera ambigua*, a chironomid taxon, nowadays absent of France and localized at northern European latitudes; (iii) high abundance of *Staurosirella pinnata*, a diatom abundant in cold water lakes from northern Norway or in the tundra zone of Russia.

Due to the high altitude and the cold climate of the Aubrac plateau, it remains difficult to identify the impact of minor cold oscillations on such mountain ecosystems. Nevertheless, a cold episode seems to be briefly recorded around 13100 cal BP as suggested by peaks in Artemisia, *S. pinnata / S. venter* ratio and C-IT of about 11°C.

Simultaneously with the peak of running water Coleoptera, the plant microfossil record shows a strong peak of *Isoetes*. This strong rise in the *Isoetes* record suggests that ecological conditions are much more favorable to this taxon at the very beginning of the Holocene, and should be interpreted as a marked rise in the lake water level. Such a possible scenario does not imply necessarily an increase of rainfall at this period, but illustrates the rapid runoff generated by snow melting in the watershed. Chironomid clearly shown a contemporaneous rise of about 2-3° C at this period. Temperatures rise rapidly to 15-17 ° C during the early Holocene, which is favorable to the establishment of deciduous forest taxa such as oak and elm close to the site.

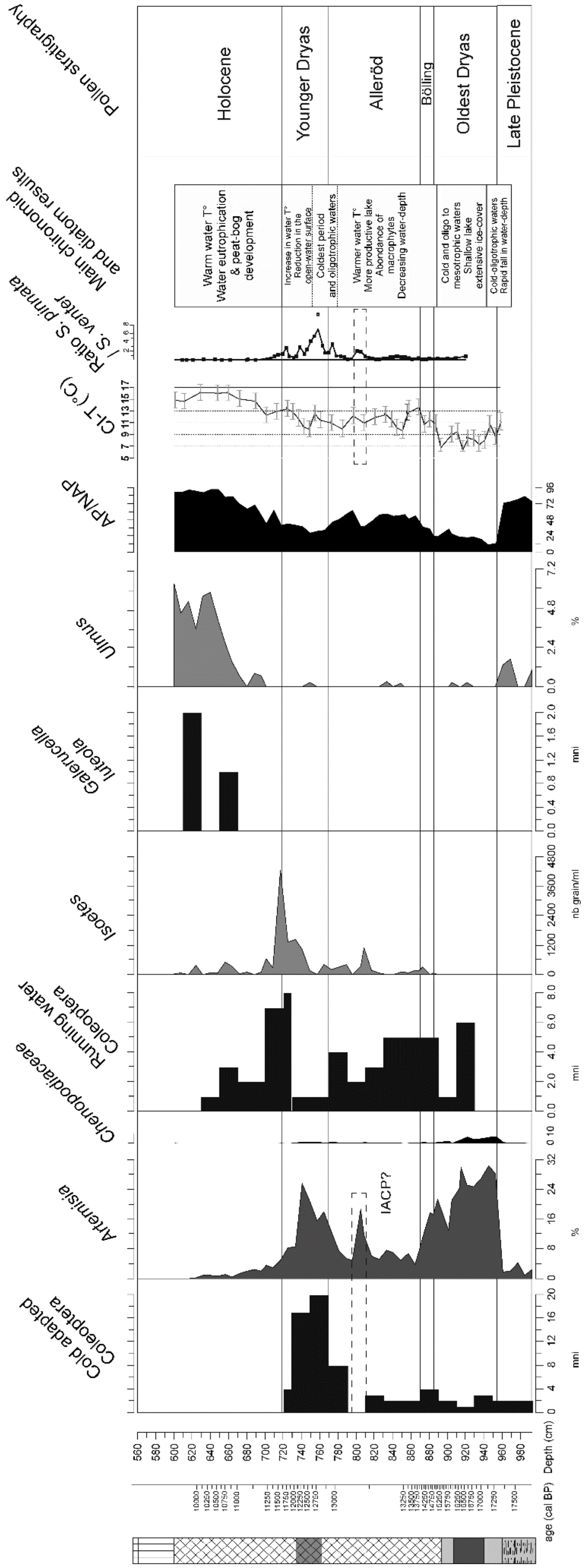

Figure 4: Comparison between the main results of pollen, coleopteran, chironomid and diatom analysis. AP/NAP: Arborean - Non Arborean pollen ratio.

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IME-Site 9a: Village of Lajo – Lozère Department

THE POLLARDING VILLAGE OF LAJO (MASSIF CENTRAL, LOZERE, FRANCE).

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Abstract

In Central Europe, one of the major agricultural challenges since Neolithic Times 6000 years ago has been for prehistorical farmers the ability and yearly planning in order to get enough fodder for the winter period in order to be able to have livestock survive harsh winters. This has especially been true for mountainous areas such as the Massif Central where cumulative winter snow amounts might reach values of up to 5 m, and preventing the harvest of winter-green plants such as blackberry (*Rubus fruticosus*), ivy (*Hedera helix*), or mistletoe (*Viscum album*) in huge amounts. Harvesting of leaf-bearing twigs of all major central European tree and shrub species during late summer/early autumn, and drying the according biomass in order to get valuable leaf-hay fodder has therefore been an invaluable agricultural method since the Neolithic in order to guarantee agricultural sustainability on a long-term perspective in remote mountain areas and elsewhere (Haas & Rasmussen 1993; Haas & Schweingruber 1993; Rasmussen 1993; Haas et al. 1998; Haas & Abrecht 2001; Haas 2002). Historical documents on pollarding, shredding and/or pruning of trees also exist as paintings from the Medieval Ages (**Figure 1**) and examples can still be seen in several valleys of the European Alps (such as in Southern Tyrol in Italy, the Lötschen and Tessin valleys in Switzerland, as well as in the southern French Alps), but also in Southern Norway, Spain, Turkey or Iran (**Figure 2**). However, more and more of the implied farmers are getting seniors and young farmers are not always taking over this old tradition very valuable for the health of livestock (sheep, goat, cows, pigs etc.) because of the high nutritional value of leaf and twig-fodder helping to produce excellent milk products (such as butter and cheese). One of the few exceptions, where nearly all trees of a whole village community are pollarded since decades or even centuries (millennia?) is the village of Lajo in the Central Massif Central, Lozère Department, France (**Figures 3 and 4**). Given several personal visits of the last 26

years it becomes clear, that in this village all existing broad-leafed trees such as European ash (*Fraxinus excelsior*) or Maple species (e.g. *Acer campestre*) are regularly pollarded and the harvested leaf-hay used as fodder. Most trees and shrubs can thereby only be pollarded and harvested at intervals of two to six years, as if the intervals are smaller, the trees won't survive. However, the exception related to these intervals is the European ash, which may be pollarded every year, and which explains its high abundance in the French Massif Central. All these pollarding aspects have also recurrent impact on landscape formation and the local biodiversity below pollards, with a rise in species numbers (e.g. plants, insects) due to regular canopy openings, as shown at different localities from Southern Norway, Sweden and up to Northern Italy or Iran (Austad 1988; Austad & Skogen 1990; Slotte 1997 & 2001). In addition, a considerable additional aspect lies in the touristic and aesthetic value of pollarded landscapes, so that subsidy strategies may have to be considered in areas of Central Europe where this old agricultural tradition is vanishing or where expensive grass fodder could easily be replaced on a short- to mid-term if forestry laws and agricultural principles may be adapted.

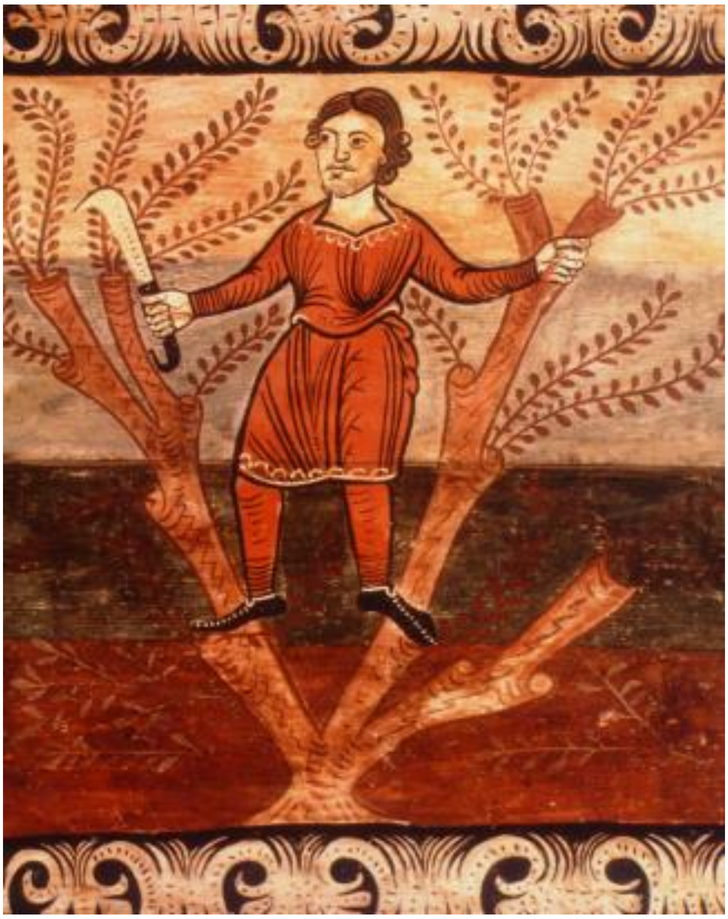

Figure 1. *Medieval ceiling fresco from the monastery church of Zillis, Switzerland (dated to the 12th century AD) with a lively scene of pollarding and leaf harvesting (probably of an ash tree) surely well known to the churchgoer of that epoch (Photo P. Heman).*

Figure 2. *Pollarding and harvesting of ash leaf-hay (Fraxinus excelsior) by the farmer Xaver Siegen near Ried (Blatten commune) in the Lötschen Valley, Switzerland in 1991. Leaf-hay is thereby cut with a specific, so-called "Gertel"-knife (Photo by J.N. Haas).*

Figure 3*. The village of Lajo (Massif Central, Lozère Department, France) surrounded by pollarded ash trees (Fraxinus excelsior) in March 2017 (Photo by J.N. Haas).*

Figure 4*. View on a row of pollarded trees within the village of Lajo (Massif Central, Lozère Department, France) in March 2017. Pollarded ash trees are notable alongside an agricultural field wall. Please note the twigs remains in the foregrounds, the result of leaf-hay harvesting, or of twigs having been collected after having been foddered to livestock in order to use them for other purposes such as for burning as firewood (Photo by J.N. Haas).*

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THE LAJO MIRES AND THEIR *BETULA NANA* STANDS

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Lajo is a small village (100 inhabitants) situated in the heart of the granitic Margeride region. In the Lajo mountain environment, a discovery path in 12 stops highlights landscapes and vegetation of several mires north to the village, from 1,290 to 1,400 m a.s.l. (**Figure 1**). We propose to discover the most important steps of this pathway during the IME-2017.

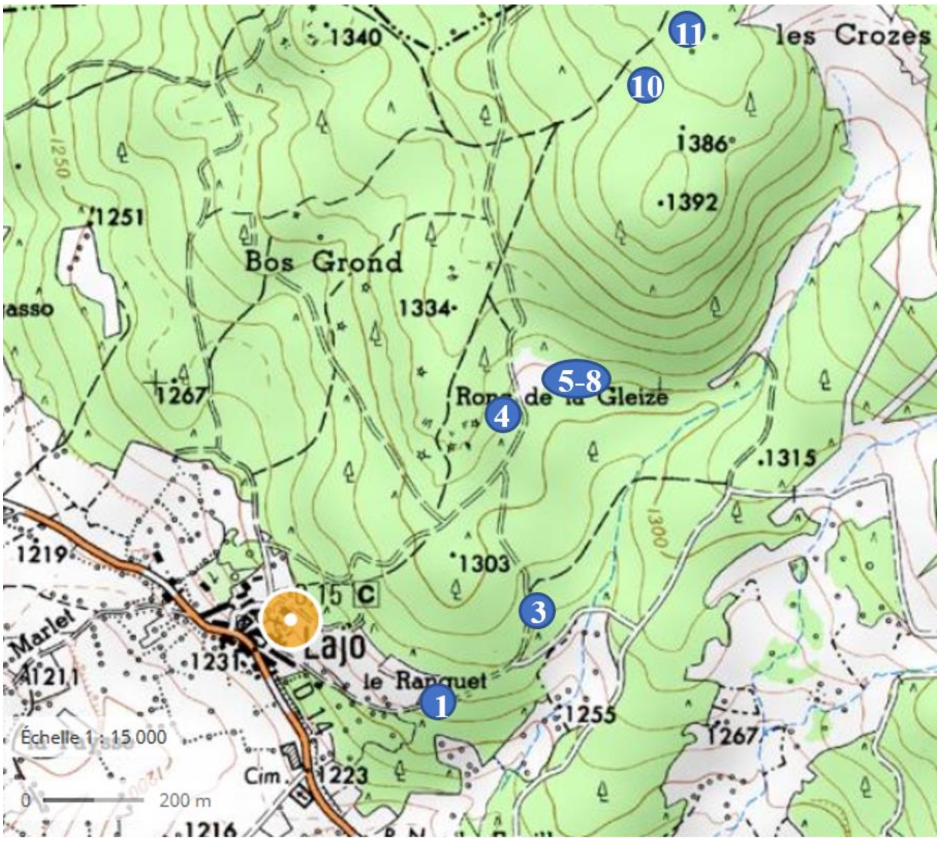

Figure 1: *Location of the Lajo village and the stops of the mire path. 1) Wall built in local porphyroid granite; 3) pastured mire with cotton grasses (Eriophorum vaginatum); 4) former mire colonised by shrubs; 5-8) Betula nana and Drosera stands;10) Salix lapponum stands; 11) granitic chaos.*

The first stop (**stop 1**), 400 m east to the Lajo village, is situated on the line between pastured meadows and forests. The stop is located in front of a retaining wall built in local porphyroid granite, called "granite with horse teeth" due to the presence of large feldspar crystals. This type of rock, constituted during the Hercynian orogeny (340 – 320 Myrs ago) forms the bedrock of the Margeride region. This stone has been used to build the houses of Lajo. Leaving this stop, the forest is dominated by conifer plantations, established on former grazing areas as indicated by several place names (such as "Issartous" meaning "cleared place"). The management of the forest domain – locally called "Montagne" – depends on the county.

The **stop 3** is situated in front of a pastured and forested mire (**Figure 2**). The mire vegetation is composed by hummocks of *Sphagnum* and Polytrics; rushs and cotton grasses are also found. Living pines are located on drier areas, in particular on peat bulges.

Figure 2: *Stop 3 – forested and grazed mire (photograph: Dendievel A.-M., June 2017).*

After a few hundred meters, a wooded deck leads to an elongated and convex mire, occupied by *Sphagnum* hummocks and shrubs (**stop 4**). Clearing restauration works have been conducted in the 2000's in order to promote the expansion of *Betula nana*. However, today the mire is buried by undergrowth with a low water table level as indicated by the presence of heather (*Calluna vulgaris*), cranberries, birches, junipers and willows.

From **stops 5 to 8,** slatted floors lead us to the middle of a mire which supports a large variety of wild life such as viviparous lizards (*Zootoca vivipara*), common on mountain areas, European brown frogs (*Rana temporaria*) and arachnids like *Dolomedes striatus*. Dwarf birches (*Betula nana*) are nestled among the pine trees (**Figure 3**). This glacial relict species, 30-40 cm high, presenting very small and rounded leaves, is protected at a national level. In France, this species can be found only on Jura mires (Mouthe, Frasne) and on some places in the Massif Central (on Margeride – from Lajo to Chanaleilles, on the Mézenc massif and maybe on the Forez mounts). This mire also hosts willows groves (*Salix repens* and *S. aurita*), small cranberries (*Vaccinium microcarpum*), marsh grass of Parnassius (*Parnassia palustris*) and carnivore common sundews (*Drosera rotundifolia*).

Figure 3: *Betula nana stand (photograph: Dendievel A.-M., June 2017).*

Stop 10 is a mountain peatbog (1390 m a.s.l.) which hosts blueberry shrubs. Populations of downy willows (*Salix lapponum*) are located on a projecting ledge, near cold sources (**Figure 4**). This small sized species (0.5 to 0.8 m high), presenting small elongated and hairy green leaves, is also considered as Late Glacial relict species.

Figure 4: *Salix lapponum stands (photograph: Dendievel A.-M., June 2017).*

Stop 11 is located on the top of the hill and presents a typical granitic chaos. These stacked blocks come from a granitic outcrop dismantled by cryoclastic processes.

IME-Site 10: Le Bouchet Lake (1210 m a.s.l.) – Bouchet-Saint-Nicolas – Haute-Loire Department

IME-Site 11: Ribains Maar (1070 m a.s.l.) – Landos – Haute-Loire Department

IME-Site 12: Praclaux Crater (1090 m a.s.l.) – Landos – Haute-Loire Department

IME-Site 13: Les Narces de la Sauvetat (1060 m a.s.l.) – Landos – Haute-Loire Department

LONG POLLEN SEQUENCES FROM THE DEVES MAARS

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LOCATION AND ORIGIN OF THE SITES

During the Tertiary, as a consequence of the Alpine uplift, the Hercinian granitic plateau of the Massif Central has been fractured, generating an intensive and generalized volcanic activity (Cantal, Chaine des Puys, Aubrac and Velay). In the Velay the initial eruptive center was to the North-East (Mézenc, Gerbier des Joncs) during the Miocene and, at the end of the Pliocene, moved toward the South-West of the Le Puy graben where, along a South-East/North-West fissure line numerous basaltic flows expanded on the Devès plateau (**Figure 1**, from Mergoil, 1987). The last early Mid-Pleistocene eruptions, around 800 ka ago determined numerous craters, rather fresh in the landscape, either cinder cones (sucs) or phreomagmatic explosion "maar" craters. Their lacustrine infilling, present mostly at Lac du Bouchet, Ribains and Praclaux craters, will be discussed here.

HISTORICAL OF RESEARCHES

During the nineteenth century, the sedimentary deposits associated to Plio-Pleistocene volcanic activity in the Velay attracted palaeontologists due to their rich mammal fauna. Thus, in the late fifties, a first 180m core was explored for the lacustrine infilling of the Seneze maar, already known by its "upper Villafranchian" fauna collected from top outcrops. Pollen and diatoms analyses were applied to this core (Elhaï, 1969). In 1973 P. Bout produced a synthesis on the Plio-Pleistocene for the Velay. Simultaneously, from 1965, E. and M.-F. Bonifay carried on systematic excavations on palaeontological sites inside lower and middle Pleistocene maars to the north of le Puy-en-Velay. The studies on these sites, which evidenced a controversial early human occupation, are still going on.

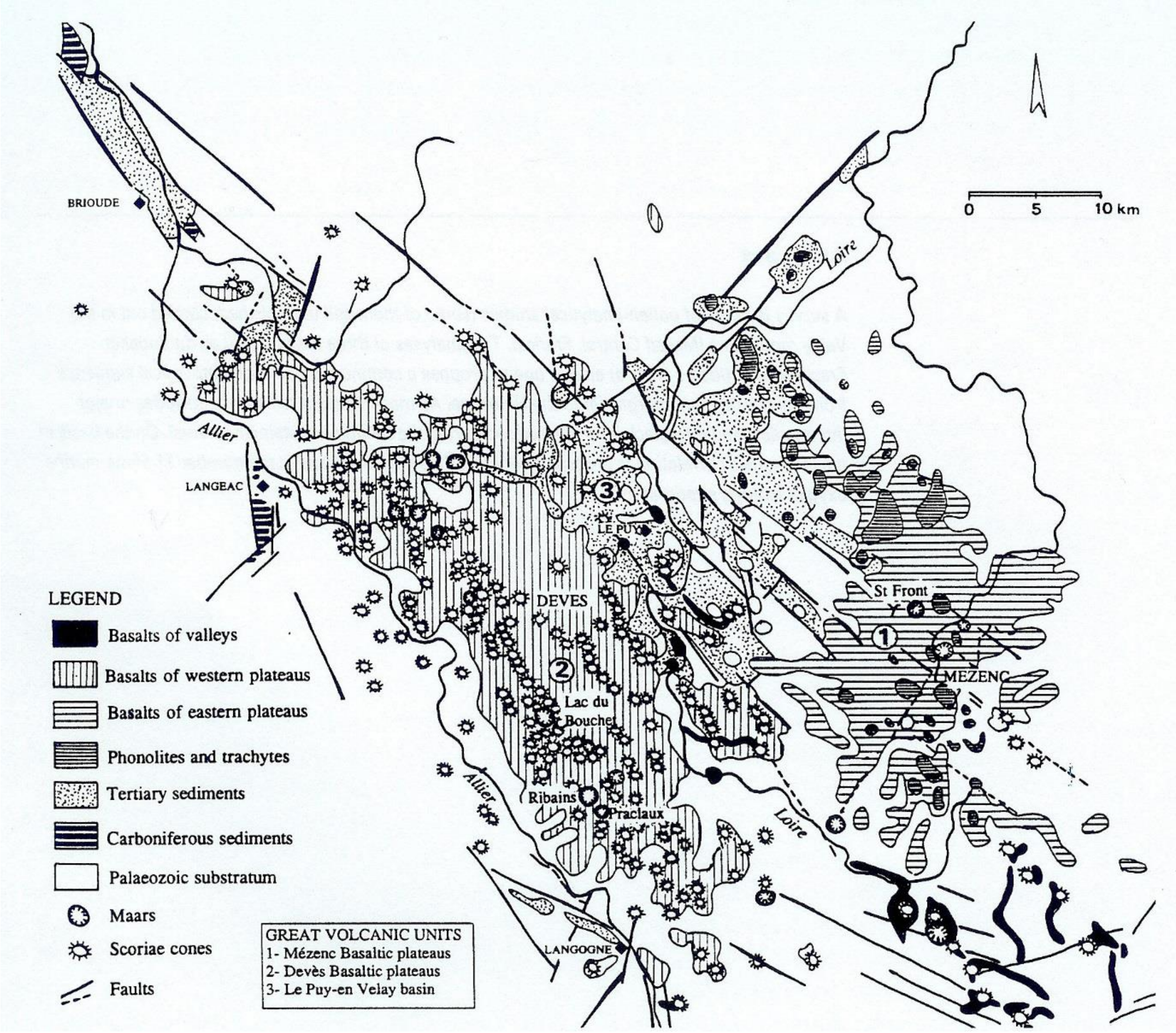

Figure 5: *Structural map of the Velay Volcanic Province (after Mergoil, 1987)*

For a while the "Plateau du Devès", younger and without lacustrine outcrops, did not attract Quaternary geologists. The development of new geophysical paradigms and techniques has been an unexpected trigger for their exploration. At the end of the seventies Ken M. Creer and his team (University of Edinburgh) started a large scale study of the secular variations of the terrestrial Magnetic field, exploring numerous lakes infillings scattered across Europe. They identified the Lac du Bouchet and Lac d'Issarlès deep crater lakes as a perfect target and they organized a collaboration with E. Bonifay and N. Thouveny (Quaternary Geology Laboratory, Marseilles University) in order to manage coring campaigns within the EU program Geomaar.

In the meantime, the IMEP team started in 1978 an extensive study of peat-bogs from different regions of the Massif Central (Cantal, Cezallier, Aubrac, Margeride, Velay) in order to improve the knowledge on their Late-Glacial and Holocene vegetation history (Beaulieu et al., 1988). They have been naturally included in the Geomaar project to perform the pollen analysis of the cores.

At that time palaeo-environmentalists were poorly trained to extract sediment cores from deep lakes. Fortunately the Edinburgh team was able to operate with a relatively light and efficient tool: the

Mackereth piston corer. Between 1981 and 1983 several campaigns allowed getting a good number of cores 2m to 12m long (below 48m water). Their pollen studies were published in 1984 (Beaulieu *et al.*) and 1988 (Reille & Beaulieu). The deepest cores reached the middle pleniglacial (ca 40 000 Yr BP). But this great success did not hide a great frustration: knowing the early Mid-Pleistocene age of the Devès craters, their lacustrine infillings certainly covers several climatic cycles. How to extract such archives? In 1986, J.F.W. Negendank (University of Trier) joined Geomaar and invited his partner from Kiel, H. Usinger to try a coring with his "home made" piston corer derived from the Livingstone corer. Five long cores were obtained two of them 20m long. Their studies (palaeomag: N. Thouveny, HDR; Sedimentology: E. Truse thesis, 1992; diatoms: C. Paillès, 1989; pollen: Beaulieu & Reille, 1991; Reille & Beaulieu, 1990) clearly showed that the longest cores cross at their basis two temperate interglacial episodes corresponding to Saint Germain 1 an 2 and stop at the very end of the last interglacial (ca 115 ka BP). These results invited again to get deeper. We must be grateful to A. Pons and E. Bonifay who decided to gather funds from two EU research projects (Euromaar, EPOCH) to buy a mid-size industrial coring machine (Sedidrill) and build a large platform able to sail on lakes with the corer and its tools. This investment was also justified by the evidence that many other key sites in the Velay (and elsewhere) could also be explored and that such a tool was needed for a larger community of Quaternary geologists. After training with the Sedidrill, a technically clever post-doc, Pascal Guenet was appointed for a while as an engineer responsible of this machine. A relatively easy to core site was selected for a first experiment: the totally infilled (meadows) maar of Praclaux, 7km distant from Lac du Bouchet. A 55m long sediment core was extracted in 1988 and the pollen record published by Reille & Beaulieu (1995). On this a triple-wall rotative corer (Mazier) was used. The year after we explored another crater, the Ribains maar; it is adjacent to Praclaux but difficult of access, as occupied by a peat-bog. The heavy Sedidrill machine was pulled to the center of the bog on a trail made of large planks. The upper part of the core was disturbed but between 22,8m and 31,9m, a splendid accumulation of diatomite was collected.

Finally our attempt on Lac du Bouchet from the above mentioned platform took place during autumn 1990 and we succeeded to extract three 65 m cores. It was an impressive success for a non professional team! In 1992 we cored another crater lake, Saint Front, to the north of Mont Mézenc.

SUMMARY OF THE RESULTS

When opening the cores, it is not easy to identify visually sediment changes due to a uniform blackish color as the clays accumulated during cold intervals are black due to the basaltic nature of the maars as the organic layers were linked with temperate episodes. Even diatomites are colored in black immediately after their extraction, but they quickly turn to white with the oxidation of their organic content. Fortunately geochemical analyses (Bertrand *et al.*, 1992) or magnetic susceptibility curves

(Thouveny *et al*, 1994, Williamson *et al*, 1998) constitute efficient stratigraphic tools. Moreover, when sub-sampling we evidenced a succession of deeply compressed organic mud layers which latter appeared as containing a temperate pollen floras. **Figure 2** summarizes the stratigraphies of the main cores obtained from the three sites. On this figure appears the evidence of a trachytic tephra layer observed both at Praclaux and Ribains, perfectly white and easy to observe. This tephra layer has been observed first at Praclaux at a time when it was difficult to give an age to this sequence. But when we have observed similar tephra in the deepest core from Lac du Bouchet a great enthusiasm rose: "if the two layers are contemporaneous, we shall be able to link the two sites and present a long continuous sequence". A series of AR/AR dates confirmed this hypothesis: in both sites the age of the tephra is around 375 Ka. The origin of the tephra is attributed to the Puy de Sancy region, 60km to the North-West, known to be active during the Mid-Pleistocene. It was certainly a major eruption as the thickness of the tephra is up to 60 cm at Lac du Bouchet with a complex stratigraphy (**Figure 3**, unpublished).

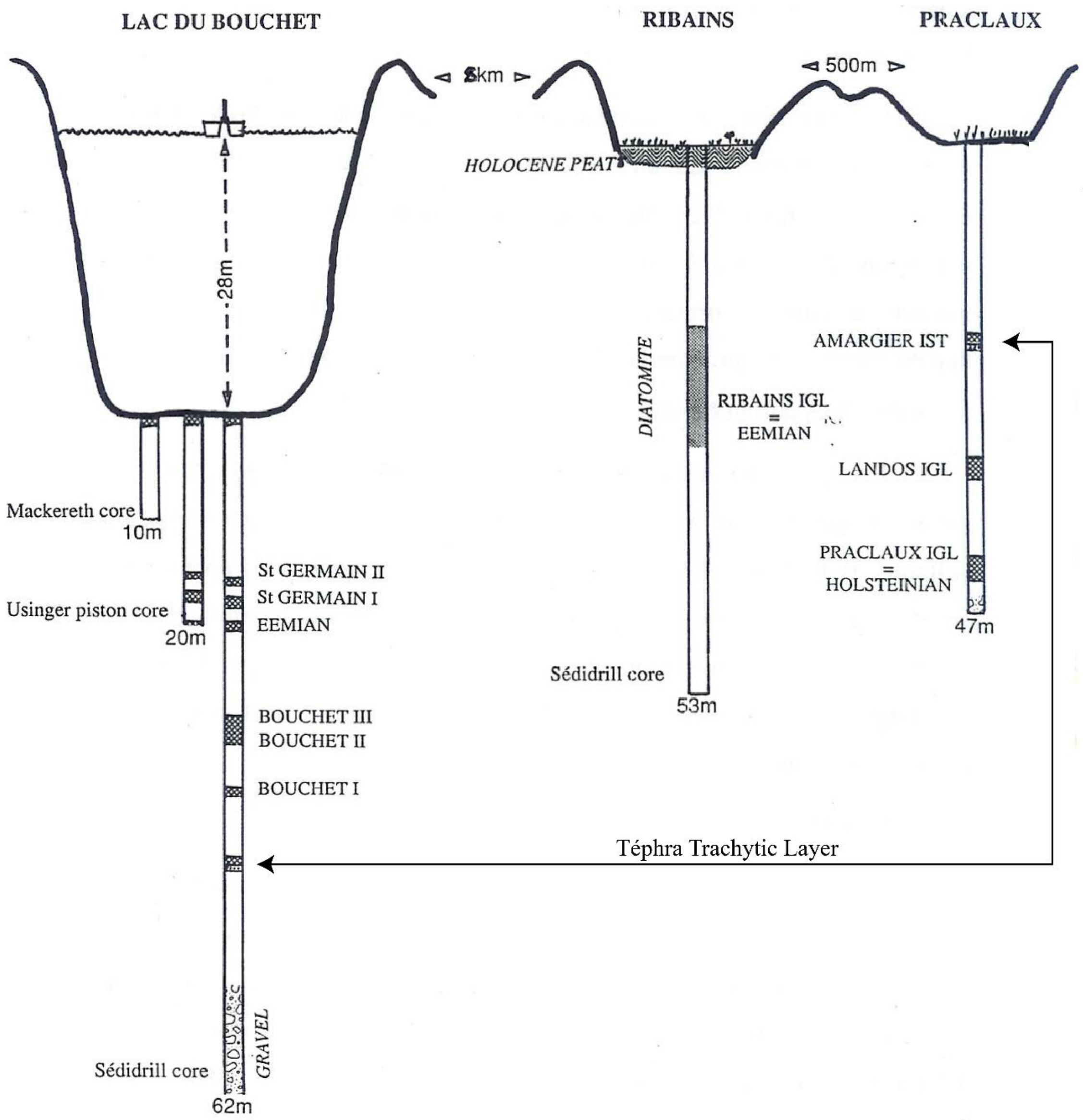

Figure 6: Comparison of the cores extracted from the maar craters of the Eastern Velay

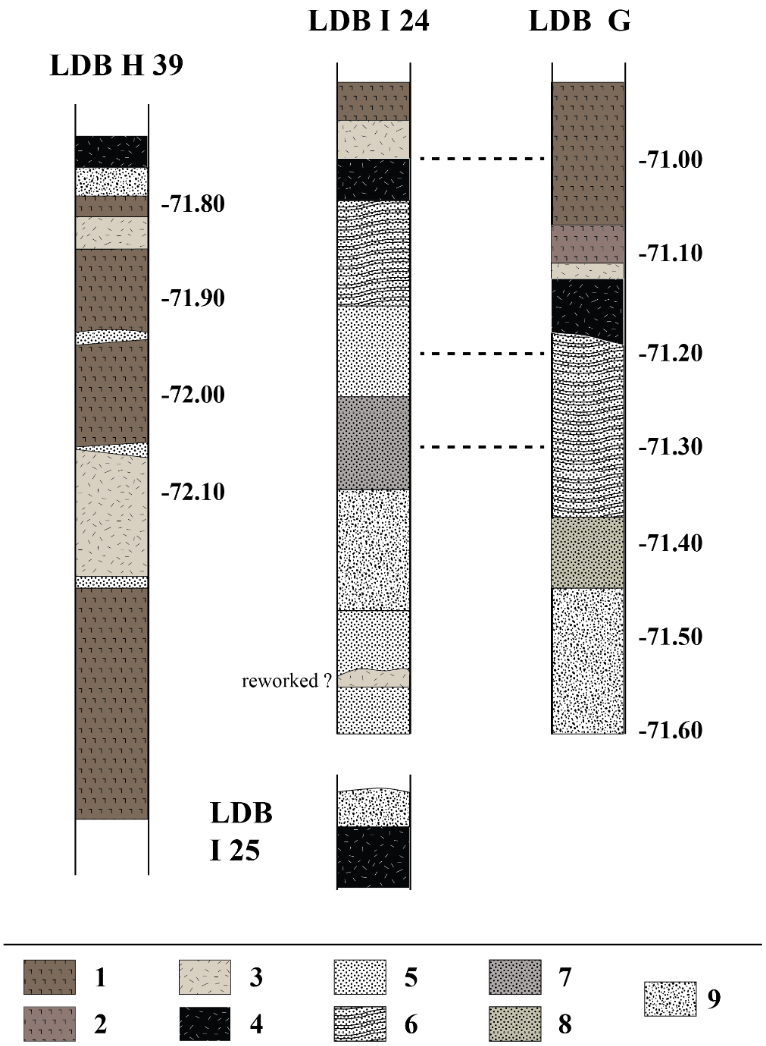

***Figure 7**: Tephro-stratigraphy of several cores from the Bouchet Lake. 1) Brownish clay, 2) Bister clay, 3) Dark brown clayey gyttja, 4) Blackish gytjja, 5) White fine ash, 6) Multicoloured ash, 7) Greyish ash, 8) Beige ash, 9) Coarse ash.*

This succession of coring campaigns was followed by intensive studies leading to numerous PhDs and publications. The pollen data were published in 5 publications on Lac du Bouchet, 1 on Ribains and two on Praclaux. At Lac du Bouchet the intervals corresponding to Interglacial episodes (Holocene, MIS 5, MIS 7) suffer of a rather low sedimentation rate (linked with oligotrophy) and do not allow a very high resolution. Fortunately at Ribains, the diatom blooms during MIS 5 allow a very detailed comparison between the local/regional vegetation dynamics and the diatoms population changes in the lake (Rioual *et al.*, 2001) suggesting millennial scale climate oscillations during the Interglacial.

We present in **Figure 4** a simplified synthetic pollen diagram which shows an impressive succession of 12 periods of when more or less temperate forest trees are dominant, alternating with periods when Poaceae and steppe elements are abundant. Among them, 5 periods present complex Interglacial dynamics easy to correlate with the stratigraphies from the long marine cores : 1/Holocene to the top, 2/Ribains Interglacial, the local equivalent of the Eemian (MIS 5e), 3/ Bouchet 1 Interglacial, corresponding to MIS 7e interglacial, 4/ Landos Interglacial = MIS 9e, 5/ Praclaux Interglacial = MIS

11e. We assume that the Praclaux Interglacial is contemporaneous with the Holsteinian Interglacial described in Northern Germany, due to the similarities in their vegetation dynamics: 1/ a long phase with *Abies* dominance, 2/ *Carpinus* almost absent, 3/ late expansion of *Fagus*, 4/ an episode with *Pterocarya* toward the end of the Interglacial. This proposal is generally accepted now.

When scanning the forest dynamics of these five major Interglacials, it appears that they present rather different successions (**Figure 5**).

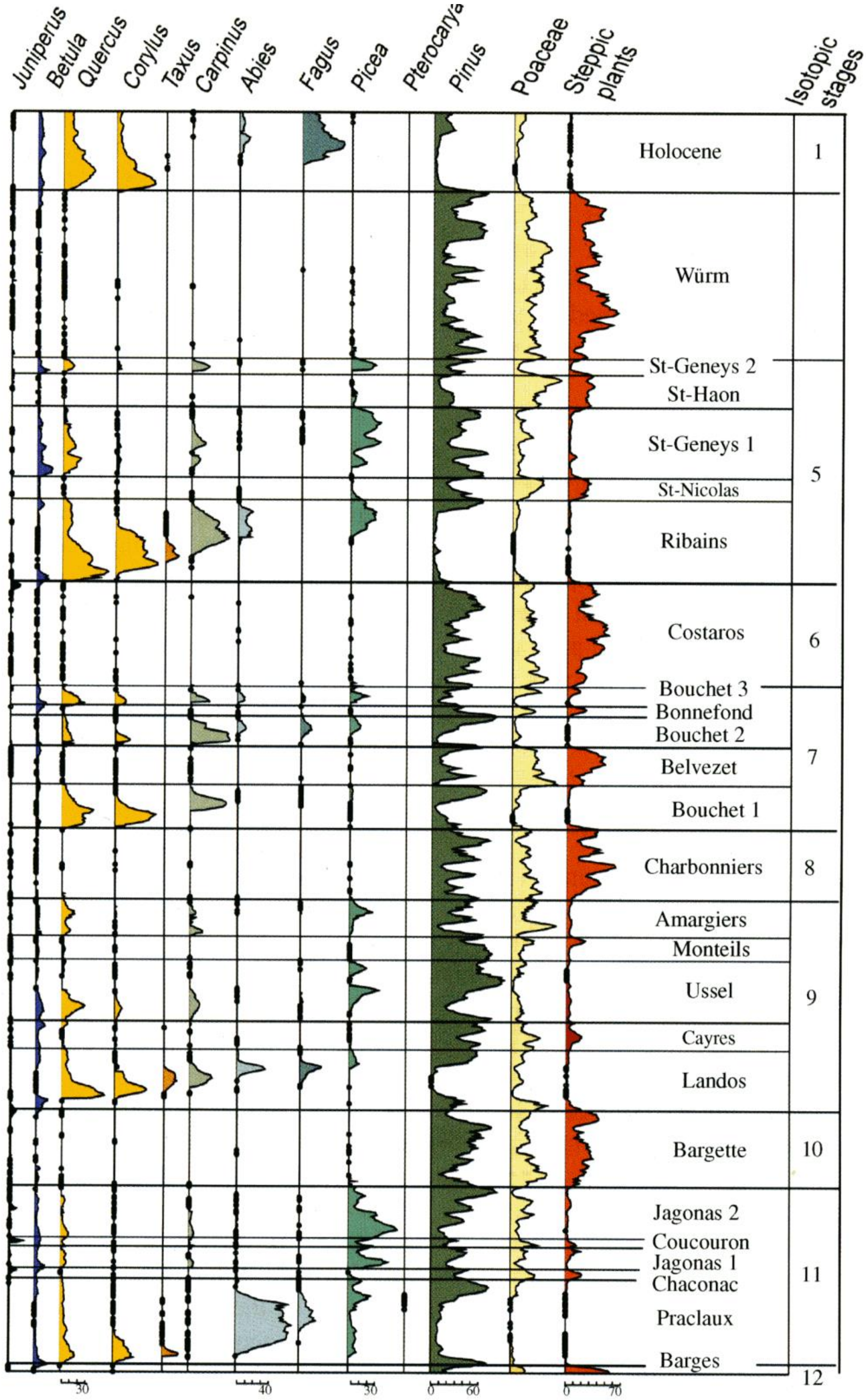

***Figure 8**: Late Pleistocene and Holocene Pollen Velay Sequence.*

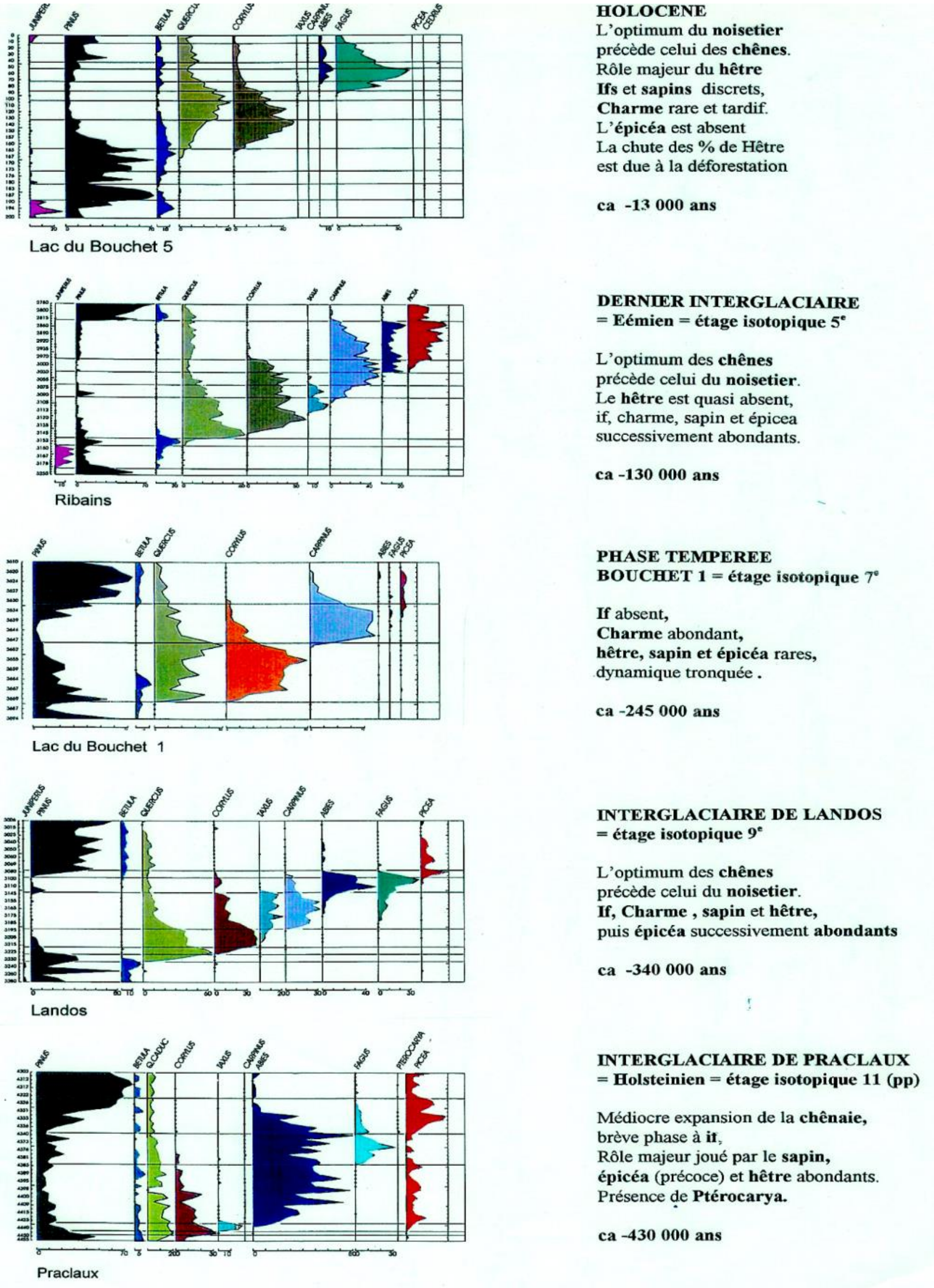

***Figure 9**: Detailed interglacial pollen sequences of the Eastern Velay (after de Beaulieu et al., 2006)*

As a matter of fact, it was the first time in Europe (except for the Mediterranean site of Tenaghi-Philippon) when such a succession was evidenced and we assumed that this reference site could be used to attribute an age to isolated discontinuous sequences and to propose correlations across Europe (Tzedakis *et al.*, 1997; Beaulieu *et al.*, 2001). Among numerous questions to be discussed on the field, we point three innovative (when published!) cases.

1/ The Velay sequence provides a rare example on a complete terrestrial equivalent of MIS 11 in which the Praclaux Interglacial is followed by a succession of stadial and more or less temperate Interstadial episodes, illustrating once more an oscillatory climate decline toward the next pleniglacial, a dynamic which seems classical since the mid-Pleistocene revolution.

2/ During the Bouchet 1 Interglacial, a *Quercus*/*Corylus* is followed by a *Carpinus* phase (as during the Eemian, but *Taxus* is absent) ending with an abrupt collapse toward a Boreal Pine forest, without any evidence of a late temperate coniferous phase with *Abies* and *Picea*. Initially, we balanced between two hypotheses: Either a sedimentary hiatus responsible of an incomplete record or a case of abrupt cooling. The new continental and marine long sequences published later lead to accept the second hypothesis, but the origin of this event is far to be explained. In any case the cold stadial following Bouchet 1 (**Figure 6**) seems to be particularly cold and is followed by the Bouchet 2 interstadial (?) which is particularly warm.

3/ Our record of MIS 5 represents vegetation dynamics very similar to those observed during the last Interglacial elsewhere in France (Les Echets, La Grande Pile) and central Europe. Nevertheless, when trying a detailed comparison between Ribains and Grande Pile, a double peak of *Taxus* appears in both sites and this structure suggests they are contemporaneous (**Figure 7**). But *Carpinus* starts its expansion during the first *Taxus* maximum at Ribains and during the second at Grande Pile. We deduced that this difference could be explained by a northward migration.

4/ Finally, as already mentioned, the Holocene vegetation dynamics are also very different, with a major role played by *Fagus*, *Carpinus* appearing during the late Holocene and *Picea* disappearing from the Massif Central during the upper Pleniglacial till its recent re-introduction by man.

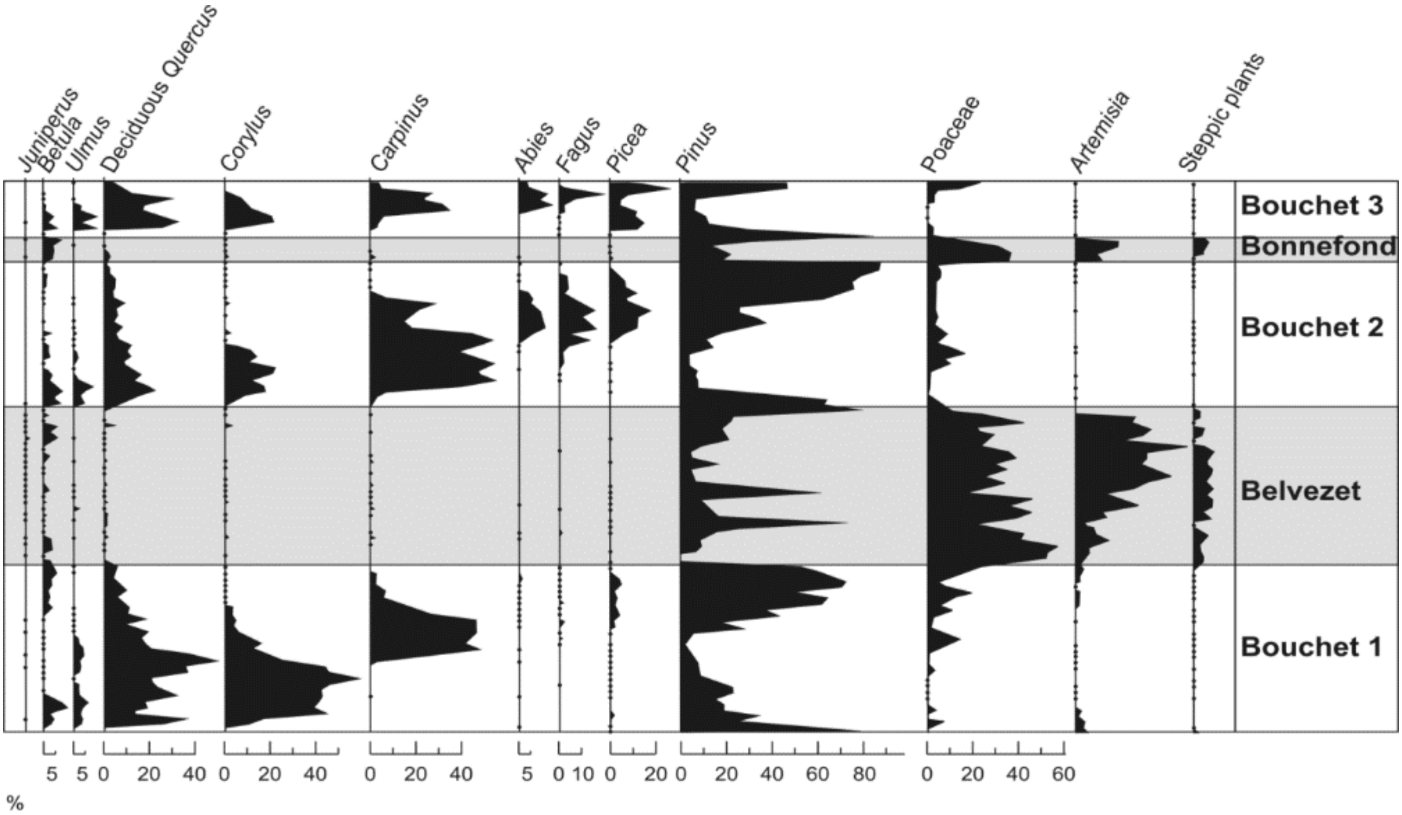

***Figure 10**: Focus on the OIS 7 Isotopic Stage from 245 (Bouchet 1) to 182 kyrs (Bouchet 3)*

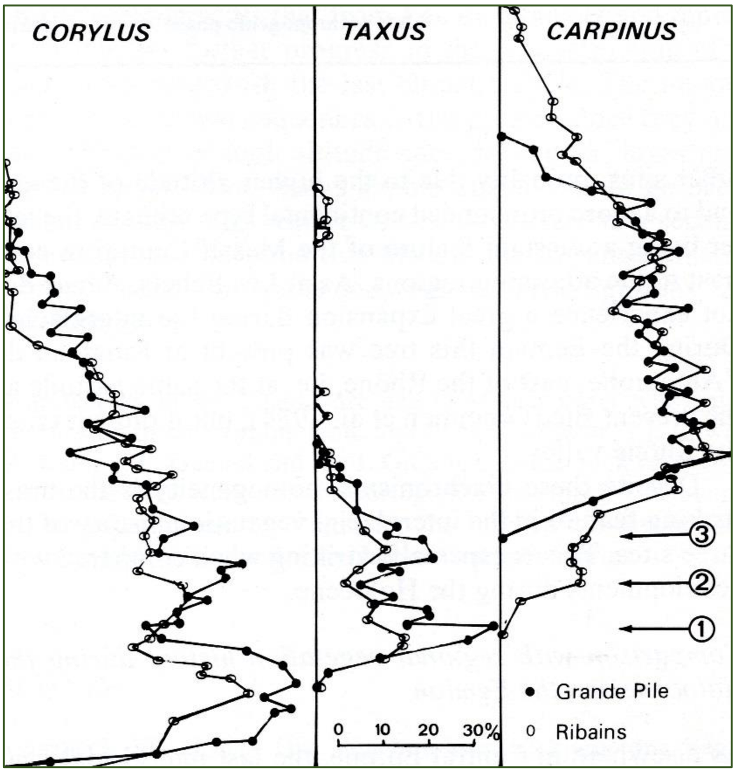

***Figure 11**: An attempt at correlation of three pollen curves (Corylus, Taxus and Carpinus) from the last interglacial at Ribains and Grande Pile. 1, First Taxus peak; 2, Taxus regression; 3, Second Taxus peak (De Beaulieu & Reille, 1992)*

FINAL CONSIDERATION

The results summarized here are already 25 years old. During the following years several new long sequences have been published, most of them confirming and completing the evidences we described (for instance the marine cores from the Iberian Margin: Desprat *et al.*, 2009) so that the Velay sequence remains a reference. We nevertheless regret that more intensive multidisciplinary studies, using new techniques developed during the two last decades were not applied to these fantastic archives.

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MEZENC MASSIF EXCURSION - FOREWORD

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The Mézenc volcanic Massif is located on the South-Eastern Massif Central edge, at the border between the Haute-Loire and Ardèche (**Figure 1**). The regional granitic substratum, *i.e.* Velay granites and migmatites, derives from the end of the Hercynian Mountain's orogenesis, around 320-300 Ma (Faure *et al.*, 2009). Coeval with the uplift of the Alps, between 11 and 5 Ma, multiple eruptions produced basaltic plateaus and trachy-phonolithic summits of the Mézenc highlands (Mergoil & Boivin, 1993; Defive & Poiraud, 2014). The most famous tops are Mount Mézenc (1,753 m a.s.l.) and Mount Gerbier de Jonc (1,551 m), where the river Loire begins. Finally, youngest volcanoes were formed during the last 220,000 years (Guérin & Gillot, 2007; Nomade *et al.*, 2014). This ultimate stage resulted in phreatomagmatic and Strombolian eruptions over the Eastern Velay and the Vivarais region. Some examples are the maars of Saint-Front or Chaudeyrolles, as well as the Issarlès/Cherchemus complex (**Figure 1**). The Mézenc Massif is characterized by an oceanic climate with a total rainfall around 1,000 mm/year and an annual average temperature close to 7 °C. Intense Mediterranean ("Cevenol") events occur in autumn and, between October and May, precipitations regularly consist of snow; the snow cover can reach 5 m/year in cumulative values (Defive & Vidal, 1997). Due to this circum-mediterrenean location, ombrotrophic bogs are really scarce in the Mézenc Massif (Cubizolle *et al.*, 2004). Slope mires are quite common but, the regional volcanic history provides an ideal geomorphological framework for limnogenous mires. Indeed, numerous lakes and fens are established in ancient maar craters as well as in small basins created by periglacial processes during the Late Pleistocene. These original terrain traps have stored more or less organic sediments and constitute interesting continuous "natural archives" for palaeoecologists.

The earliest palynological works on the Mézenc region were conducted by the botanist Georges Lemée, exploring mires on the whole Massif Central during the 40's and in the 50's (Lemée, 1941, 1942, 1943, 1945, 1955). G. Lemée presented a pollen synthesis about post-glacial forest evolutions and proposed a first bio-zonation of the Holocene from his study of Les Vastres peatland, Les Narces de Chaudeyrolles fen and Mount Mézenc peat layers next to the Peccata Cross (Lemée, 1946; **Figure**

1). Seven years later, based on current flora surveys, pollen rain transects and thanks to the count of non-arborean pollen, he proposed an updated reconstruction for the vegetation history since the oldest Dryas (Lemée, 1953). Despite the absence of radiocarbon dating, he remarkably proposed to place a long-term human impact during the Iron Age. He also defined a second major step of forest clearing and agro-pastoral management before the XVIth century AD, that is to say during the Middle Ages. Well known across the Massif Central, these pioneer works supported several discussions over the subsequent decades (Lang & Trautmann, 1961).

Scientific teams from the Laboratory of historical botany and palynology of Marseilles (today IMBE) began to work on the Mézenc massif since the late 1970's. At first, Michel Couteaux, working closely together with Jacques-Louis de Beaulieu, studied Boreal and Atlantic fossil peat layers from Mazan, Le Roux and Mézilhac – Areilladou/La Destourbe (Couteaux, 1976, 1978). He published a pollen study of the lacustrine sediments and the bank deposits of the Issarlès Lake (Couteaux, 1984). This work has been a support for the first palaeo-entomological analysis in the Velay, confirming the local presence of a *Corylus* forest during the Atlantic! (Ponel & Gadbin, 1988). Couteaux's results from Les Narces de Chaudeyrolles and, more importantly, on the Peyrebeille peat sequences (Boreal to Subatlantic) are still a work of reference today (Couteaux, 1978, 1984). After the research program Euromaar, a complete study of the Saint-Front Lake was undertaken (Lallier-Vergès *et al.*, 1993; Rhoujjati, 1995). These studies have provided fundamental knowledge about climatic changes during glacial-interglacial cycles of the Late Pleistocene, in particular concerning Eemian stadials (Thouveny *et al.*, 1994; Vlag *et al.*, 1997; Stockhausen & Thouveny, 1999). However, Holocene data have only been partially published (Andrieu-Ponel *et al.*, 1995; Sifeddine *et al.*, 1996) and this site still holds a high potential for further studies (see IME-Site 14).

The study of this region and its peatlands has recently been picked up again. This renewed attention is the fact of regional scientific teams from Clermont-Ferrand and Saint-Etienne. The PhD thesis of Alexandre Poiraud (2012) has highlighted the potential of small peatlands created after landslides, such as Montchamp and Le Lac mires at Lausonne (**Figure 1**). The WRACC program has also revealed the presence of organic layer interbedded in Late Holocene mountain alluvial deposits (La Valette and Champetienne), during the warm periods of the Middle Ages (Defive, 2013; Defive *et al.*, 2016). Finally, a study of the Béage plateau on Holocene sequences combining macrofossil analyses, palynology, sedimentology and archaeology was performed during the PhD thesis of André-Marie Dendievel (Dendievel *et al.*, 2015; Dendievel, 2017). Confirming human occupation since the 2nd Iron Age, this work also identified 3 phases of human impact (clearings and agro-pastoral activities) between the Early and the Late Neolithic. This work describes the evolution of local peatlands ecosystems since the Early Holocene. The study of the Late Glacial sequences of La Narce du Béage and Pré-du-Bois is still in progress (see IME-15 & 16).

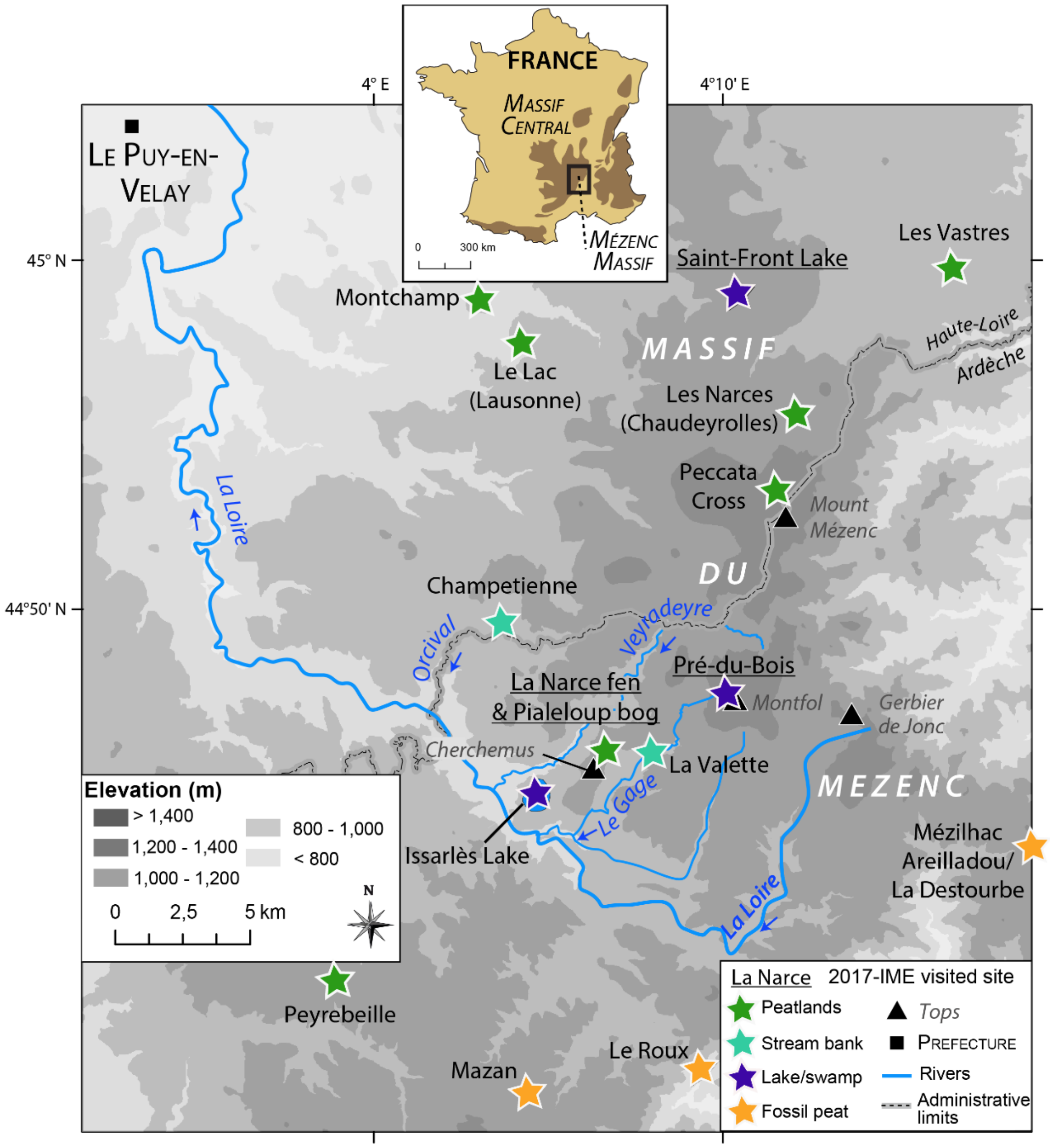

***Figure 1:** Palaeoecological studies over the Mézenc massif (after Dendievel, 2017). Sites mentioned with an underlined name will be visited during the 2017 International MoorExkursion.*

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THE VEGETATION OF THE LAST 140 000 YEARS AT THE LAKE OF ST FRONT, MASSIF CENTRAL, FRANCE

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In the Lake of St Front, three cores were extracted (A, B, C). The profile A (44.5 m depth) was analysed for 511 pollen spectra by V. Andrieu-Ponel and M. Reille. Sedimentological analyses, magnetic susceptibility and pigments were also carried out, but only the results of the palynological analyses are presented. These results are unpublished.
The history of the vegetation begins at the end of the glaciation and ends at the end of the Holocene.

THE END OF THE RISSIAN GLACIATION

The Rissian Tardiglacial is characterized by the development of a local steppe (*Artemisia* and Poaceae) and by the collapse of the pollen of *Pinus* of distant origin. This dynamic is the analogous of what is found at the end of the last glaciation.

THE EEMIAN (RIBAINS INTERGLACIAL)

The first forest vegetation begins with the classic pioneering trilogy *Juniperus-Betula-Pinus*. It is followed by the appearance of a mesophilous oak forest, with *Ulmus, Fraxinus* and *Acer*. This oak forest reaches its optimum before the appearance of *Corylus*. Such a dynamic is also encountered during the Holocene in the Piedmont sites of the French Pyrenees. A mixed oak forest rich in *Corylus* succeeds the oak forest. Later, *Taxus* enters this vegetation and reaches its maximum before the arrival of *Carpinus*. The development of the *Carpinus* forest marks the beginning of the catathermic phase of the Eemian Interglacial. It reaches its optimum of expansion whereas all the taxa of the mixed oak (*Quercus, Corylus, Taxus, Ulmus, Fraxinus*) decline continuously. The succession of *Abies, Picea, Pinus*, whose optimums appear in this order, marks the end of the Interglacial. The vegetation passes from a mountain *Abies* and *Picea* forest to a boreal forest with *Pinus* and *Picea*. As in all sites in Western Europe, Fagus is absent from the Eemian forest dynamic.

THE POST-EEMIAN FOREST INTERSTADES

* The Interstade of St Geneys 1 (= St Germain 1), whose base is probably reworked, begins with an impressive extension of *Betula*. A spectrum showing a strong decline of the forest could correspond to the cold episode of Montaigu, well represented in Les Échets and Lac du Bouchet. Because of a hiatus, the optimum of *Quercus* and the extension of *Carpinus* (well characterized at Lac du Bouchet) are lacking. Only the catathermal phase of this Interglacial is marked by the eradication of the *Carpinus* forest and its replacement by a spruce forest increasingly rich in *Pinus*, and finally a boreal forest of *Pinus*. In this dynamic, the role of *Abies* is very discreet whereas that of *Fagus* shows regular occurrences, attesting the presence of this tree.

* The Melisey 1, that part of the glacial that separates the two post-Eemian forested Interstades, is characterized first by a steppic vegetation within which some islets of *Picea* existed, and then a periglacial environment with a scattered and poor local vegetation.

* The St Geneys 2 (= St Germain 2) is reduced to 50 cm. Like at Lac du Bouchet, it bears witness to an elegant forest dynamic. The anathermic phase is marked by an oak tree forest surprisingly poor in *Corylus*. Then there is a good optimum of *Carpinus*. As for *Picea*, its frequencies indicate that it did not have much move away from the site during the Melisey 1 because it is present early from the end of the optimum of *Quercus*. *Abies* is almost absent from this Interstade, while Fagus plays the same role as during the former Interstade.

THE PLENIGLACIAL

The Würmien Pleniglacial is spread over 21 m thickness. In the lower part, it is characterised by the persistence of moderate rates of *Picea, Pinus*, deciduous *Quercus* and *Betula*, which could testify to the persistence of a local afforestation of these taxa at the beginning of the last glaciation. The temperate episode of OIS-3 is mainly represented by an increase of TOC (Total Organic Carbon) and a modest development of *Betula* and *Picea*.

At the top of this sequence, "the 15 000 BP event" is perceptible by the collapse of *Pinus* frequencies and the rise of *Artemisia*. All the rest of the Tardiglacial is absent due to a hiatus of unknown origin.

THE HOLOCENE

It occupies the first 11.7 m of the core and begins at the end of the Preboreal because of a hiatus. Fagus plays a major forest role at the end of the Holocene, whereas *Carpinus* and *Picea* are absent from the spectra except at the extreme end. Indices of human intervention on the forest ecosystems of the Velay appear clearly during the Subatlantic. The most relevant markers of human action are the decline of the tree pollen and the parallel progression of the Poaceae. The continuous pollen curve of *Secale* pollen from the beginning of the Subatlantic shows that this rustic cereal, particularly adapted to the middle altitude mountain, was cultivated in the Velay.

PRE-DU-BOIS SWAMP AND OPENFIELD BLOCKSTREAM FORMATIONS

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INTRODUCTION & STUDY AREA

The Béage basaltic plateau and its phonolitic summits constitute the southern part of the Mézenc massif (**Figure 1**). This volcanic landscape, built during the upper Miocene, is incised by the Loire River and its tributaries: Gage, Orcival and Veyradeyre rivers for example (Defive, 1996 ; Defive *et al.*, 2013). Periglacial geomorphological processes of the Late Pleistocene has been also involved in the erosion of basaltic and phonolitic formations, creating openfield blockstreams (Valadas, 1984 ; Etlicher, 2005 ; Defive *et al.*, 2013). New investigations have been initiated to characterise formation pathways and chronologies of these typical landforms (Peignelin, 2014 ; Peignelin *et al.*, 2014 ; Peignelin & Defive, 2015).

This paper focuses on the area of Pré-du-Bois (1,400 to 1,475 m a.s.l.) at the foot of the Montfol peak (**Figure 1**). Two phonolitic blockstreams are present: "Pré-du-Bois bas" and "Pré-du-Bois haut" formations. A small swamp, located at the contact with the "Pré-du-Bois haut" blockstream (1,460 m a.s.l,) has been also studied in order (i) to examine relationships between this wetland and the formation of blockstreams and (ii) to reconstruct past landscape changes (Peignelin, 2014 ; Dendievel, 2017). In the surroundings, the soil cover is thin and consists of a brown ochre soil (Dejou & Kessler, 2006). The vegetation is mainly composed of grasslands and moors with heather, dotted with dwarf juniper (*Juniperus communis* ssp. *nana*) and mountain pine (*Pinus uncinata*). Conifer plantations (*Abies alba*, *Pinus sylvestris*, *Pseudotsuga menziesii* and *Larix decidua*) are found at the foot of the phonolithic mounts.

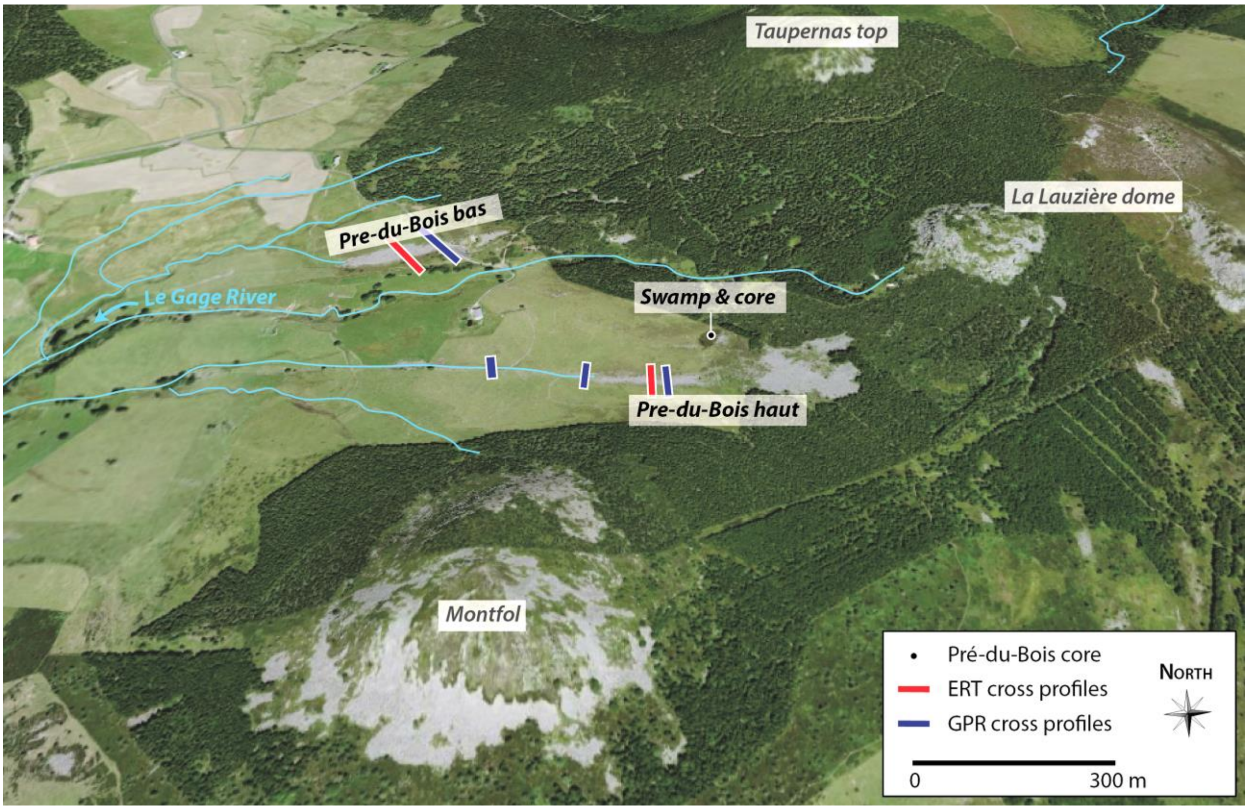

***Figure 1**: Location of the Pré-du-Bois operations at Le Béage in Ardèche (base map from Geoportail-3D ®)*

METHODS

GPR (georadar) and ERT (electrical resistivity tomography) cross profiles have been conducted to identify the extension and the depth of the Pré-du-Bois blockstreams*:* electrodes were placed with an interval of 1 to 2 meters and results were analysed with *Reflexw* and *Res2Dinv* programmes (Peignelin, 2014 ; Peignelin *et al.*, 2014). Orientations of blocks were measured on field by manual counting and by photo-interpretation. In the swamp of Pré-du-Bois, two cross profiles has been realised thanks to manual tests with graduated threaded rods (**Figure 2**).

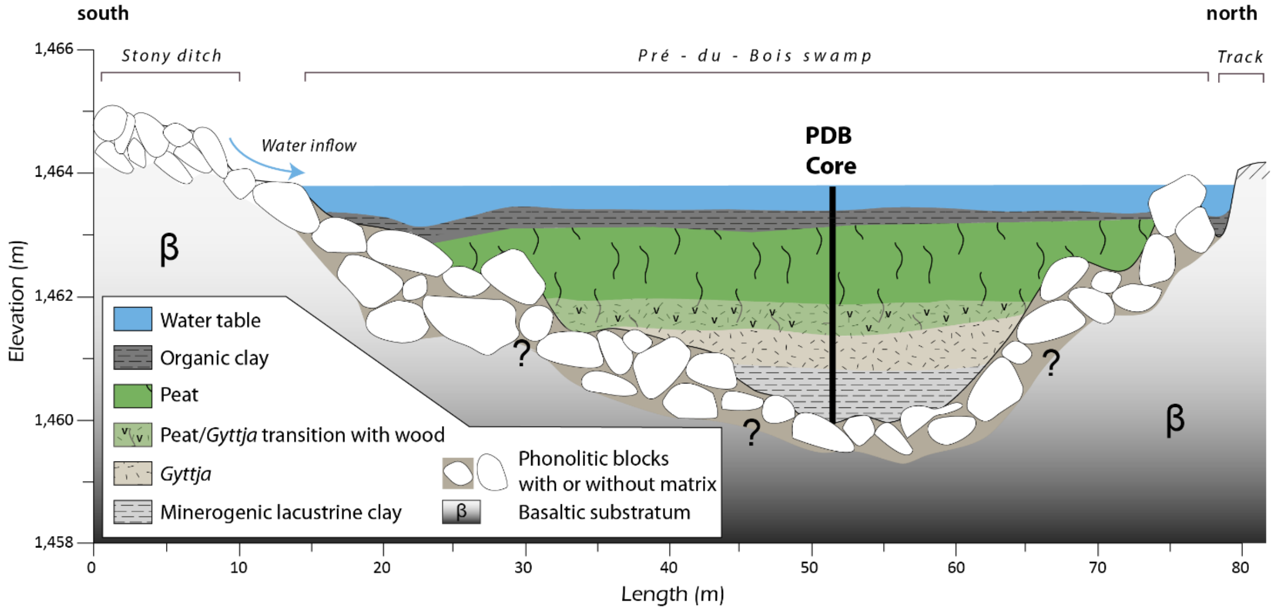

***Figure 2**: Cross section of the Pré-du-Bois with the location of the PDB Core (unpublished)*

Cores were extracted using a "Russian" manual peat corer (Peignelin, 2014 ; Dendievel, 2017). Magnetic susceptibility was measured in the laboratory using a *Bartington* device (resolution= 1cm) and, after sampling, organic matter content was computed by LOI (loss on ignition). Two AMS radiocarbon dates were obtained on bulk sediments and two others are in progress (**Table 1**).

Table 1*: Radiocarbon dates from the Pré-du-Bois sequence (after Peignelin, 2014 and Dendievel, 2017)*

Depth (cm)	Material	Lab code	Measured Age (1 σ; BP)	Calibrated Age (2 σ)		References
36 – 37	Peat	Lyon-12473 (SacA43637)	1,730 ± 30 BP	1,704 –1,562 cal. BP	246 – 388 cal. AD	Dendievel, 2017
162	Gyttja	Beta-369315	8,040 ± 40 BP	9,085 –8,728 cal. BP	7,135 – 6,778 cal. BC	Peignelin, 2014
209	*Wood*	*In progress: Center of Radiocarbon Dating of Lyon and Artemis program*				
289	*Bulk sediment*	*In progress: Center of Radiocarbon Dating of Lyon and Artemis program*				

RESULTS

3.1 Blockstream measurements

Measurements on "Pré-du-Bois bas" and "Pré-du-Bois haut" show a primary orientation of the blocks in the slope direction or in a field of less than 50 degrees with respect to the global block alignment (Peignelin, 2014). The block size progressively decreases in a downstream direction. Ripples and terminal bulges imply creep processes. These formations are prolonged by gullies which are starting points of several streams, including the Gage River (**Figure 1**).

According to GPR data, from 0 to 5 m deep, the signal is clear due to the presence of phonolitic blocks; beyond, the signal is scrambled suggesting hydromorphic or clayey levels (**Figure 3**). ERT data match well with these results (**Figure 3**): the blockstream surface is identify by a thin and resistive layer (3,000 to 10,000 $\Omega.m^{-1}$); up to 5 m in depth, a heterogeneous layer with resistive lens indicates the blockstream extend (200 to 2,000 $\Omega.m^{-1}$) and a very conductive layer (< 100 $\Omega.m^{-1}$) could be a humid and altered matrix at the basis of the blockstream.

3.2 Stratigraphy, age and analysis of the PDB core

In the Pré-du-Bois swamp, a 3 meter core – PDB core – was extracted (Dendievel, 2017). From the basal part to 2.5 m, the sediment is composed of minerogenic lacustrine clay (**Figure 4**). From 2.5 to 2 m, a *gyttja* layer reveal an organic enrichment and, after a wooded transition, several peat layers are recorded since 9,000 cal. BP. Finally, an organic clay layer is present just before the surface and linked to the current swamp function (**Figure 4**). Magnetic susceptibility values decrease from positive to negative values (from basal layers to the surface). However, positive values come back in the upper 20 cm, in the clay deposits of the swamp. LOI values also show a shift at this level characterised by a short decrease in the organic matter content (**Figure 4**).

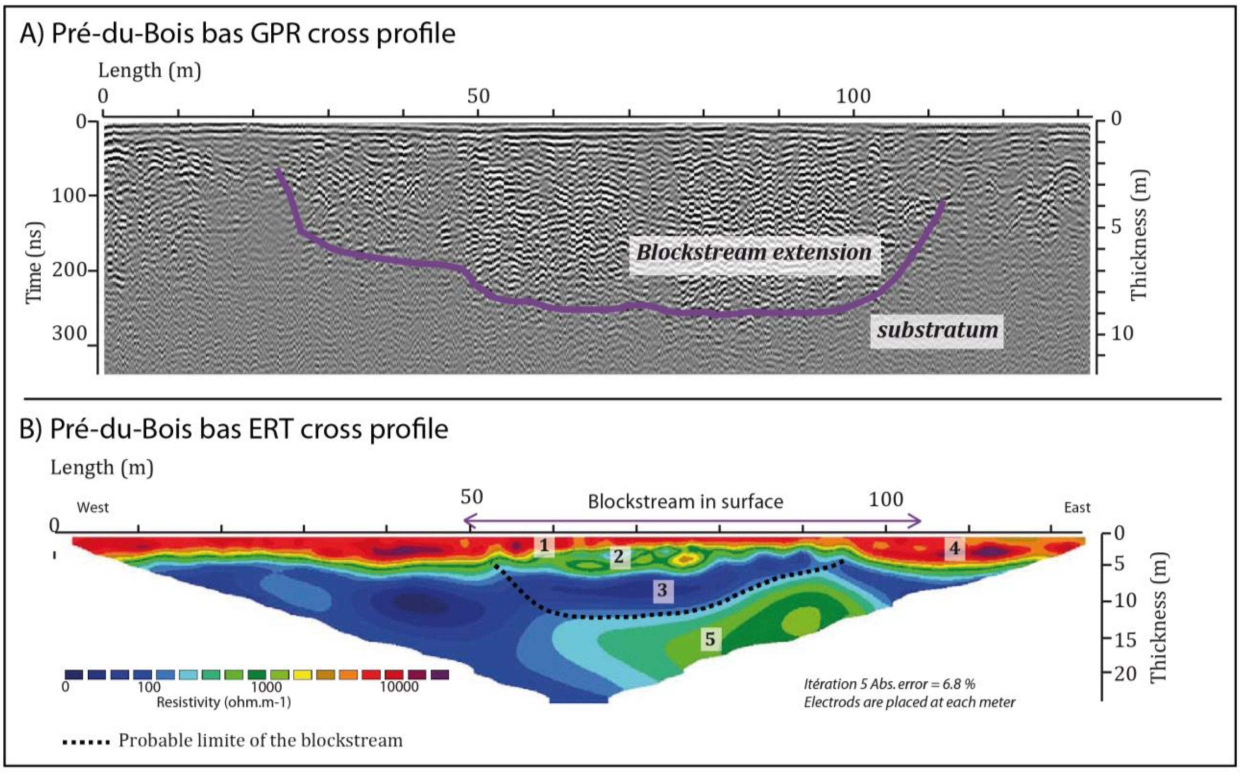

***Figure 3**: Geophysical cross-profiles from the Pré-du-Bois bas blockstream (after Peignelin et al., 2014)*

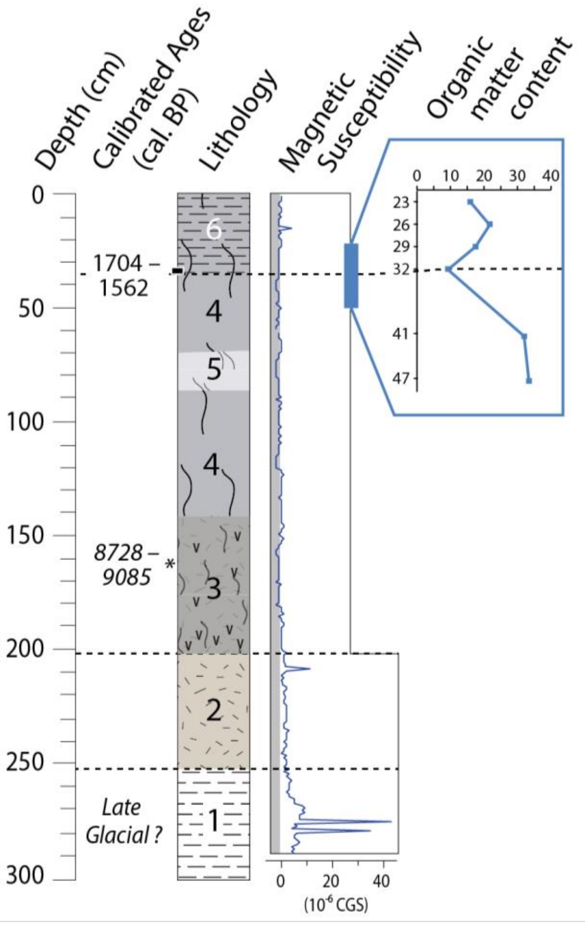

***Figure 4**: Chrono-stratigraphy, magnetic and organic data from the PDB core (after Dendievel, 2017)*

DISCUSSION

4.1 Blockstreams: formation

The vertical zonation of the geophysical signal (GRP and ERT) underlines the presence of an openwork blockstream formation, 5 to 10 m thick. Its basis is more conductive and could corresponds to humid and altered layers (clay?). Aerial photographs and measurements showed that creeping is involved in the blockstream formation, creating riddles and bulges. Creeping axes and block alignments/concentrations also suggest links with other geliflucted blocks formations in the surroundings. Thus, several hypotheses are considered (Peignelin, 2014): (i) blockstreams could be a part of wider formations, with a block enrichment partly due to a specific topography (micro-thalwegs and gullies). (ii) A leaching of clay and silts is also probable along these lines. (iii) The presence of an ice core between blocks could also have been at the origin of these formations. This hypothesis is also supported by resistivity values similar to values from rock glaciers, but there is still no evidence of a Late Pleistocene continental ice cover in this area (Etlicher, 2005 ; Defive *et al.*, 2013).

4.2 Blockstreams: age

According to literature, blockstreams of Pré-du-Bois could have been created in less than 5,000 years of creeping (Harris *et al.*, 1998 ; Bodin, 2011). This short duration must be tempered because we do not know how many steps were involved and if the blockstream formation was continuous in time.

The presence of a former lake at the location of the PDB core is established on the basis of deep minerogenic lacustrine clay and *gyttja*. According to low organic content and to high magnetic values, this lake could date back to the Late Glacial. Two radiocarbon dates are in progress to confirm this hypothesis (**Table 1**). After a progressive infilling, this lake became a fen around 9,000 years cal. BP (peat deposits). All of these sediments were deposited above a bed of blocks, indicating that local blockstreams are necessarily older than these deposits, *e.g.* probably older than the Late Glacial.

4.3 Recent changes: formation of a swamp at Pré-du-Bois

The top of the PDB stratigraphy shows a shift around 30 cm, with the replacement of peat by organic clay (**Figure 4**). This change, linked to the establishment of the current swamp, was achieved at the end of the Roman period (AD 246–388). An anthropogenic origin could be deduced from numerous drains and ditches, dug to bring water, and also by the arrangement of an outlet (**Figure 5**). The creation of this swamp is probably due to the need of a long-term source of water for the pastoralism.

IN THE NEAR FUTURE

To supplement our knowledge of these Late Pleistocene landforms and ecosystems, a complete study of the PDB stratigraphy will be completed. Holocene deposits are also very interesting in order to get an overview of climate changes and anthropogenic activities at such elevation (1,460 m a.s.l.).

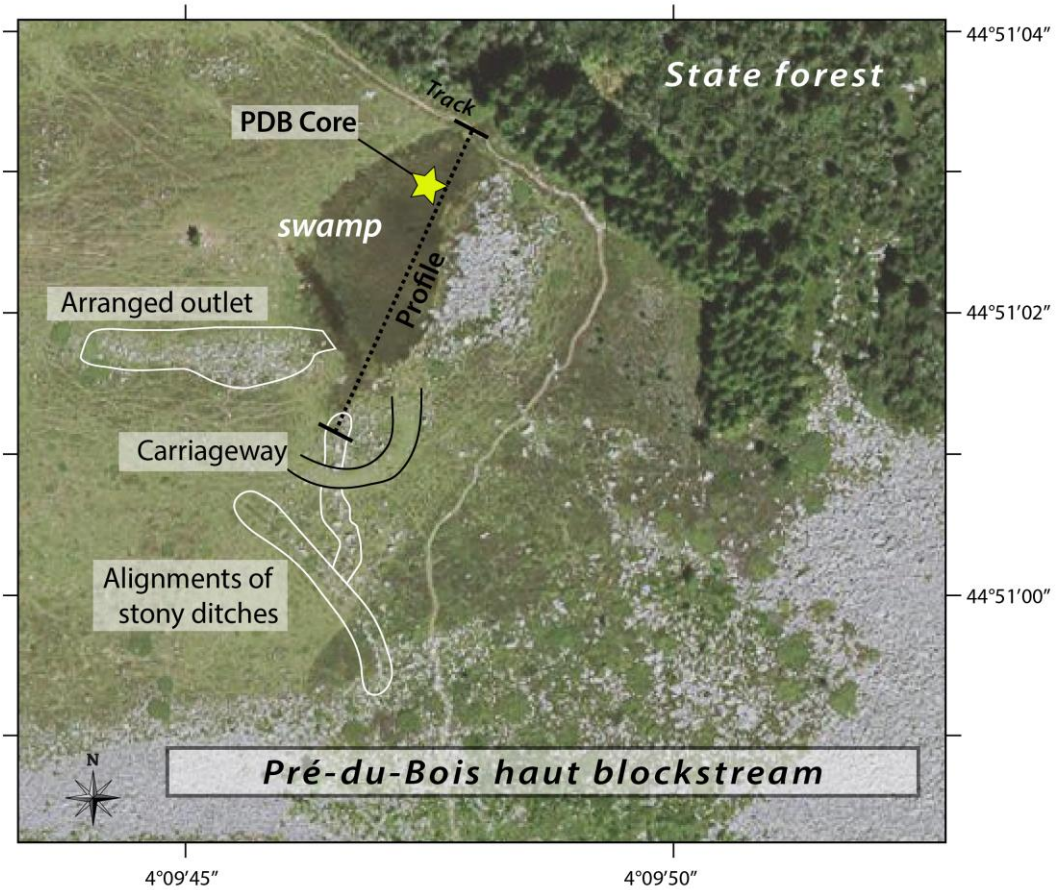

***Figure 5**: The Pré-du-Bois swamp and adjacent anthropogenic structures (after Dendievel, 2017)*

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INTRODUCTION TO IME-SITES ON THE BEAGE PLATEAU (EASTERN MASSIF CENTRAL)

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First palaeoecological studies for the south of the Mézenc Massif were published by Michel Couteaux (1984), as well as by P. Ponel and D. Gadbin (1988) studying Late Glacial and Holocene lacustrine and bank deposits from the Issarlès maar. But, in contrast with deposits filling other Velay maar craters (De Beaulieu *et al.*, 1984; Bonifay & Truze, 1987; Reille & De Beaulieu, 1988; Reille *et al.*, 2000; De Beaulieu *et al.*, 2006), the Issarlès stratigraphies were very difficult to interpret because of several slumps, inversions and overlaps, additionally emphasised by the absence of radiocarbon datings (Couteaux, 1984). Today, new investigations have been conducted in this area. This paper reviews the first results of an interdisciplinary approach combining palaeoecology, sedimentology and archaeology on the Béage Plateau, near the Issarlès-Cherchemus volcanic complex. We present a reconstruction of environmental changes since the Late Glacial. A specific focus was paid to the chronology and local consequences of climatic changes and human activities during the Holocene, as recorded on the La Narce du Béage and Pialeloup peat sequences (Dendievel *et al.*, 2014; Dendievel, 2017).

From The Late Glacial To The Mid-Holocene: The La Narce Du Beage Sequence

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STUDY AREA

La Narce du Béage is a fen (0.9 ha), located at 1,200 m a.s.l. on the Béage Plateau (**figure 1**). Its catchment is about 11 ha, from the top of the former Cherchemus volcano to two basaltic outcrops (**figure 2**). Two basaltic block streams are located around the peatland. According to Defive *et al.* (2013), the Velay granite is the local substratum. The vegetation of the fen is distributed in 3 areas: (1) a hygrophilous tall herbs fringe with belts of *Gentiana lutea*, *Narcissus pseudonarcissus* and *Caltha palustris*, (2) the middle of the fen is only occupied by *Molinia caerulea* and (3) the outlet presents more diversity with – among others – *Equisetum palustre*, *Comarum palustre*, *Carex vesicaria* and *Sphagnum* hammocks (for details see Dendievel *et al.*, 2015).

The Béage plateau presents several conifer plantations (mainly *Picea abies* and *Pinus sylvestris*) and beech stands (*Fagus sylvatica*). A major part of the landscape is devoted to livestock grazing with extensive pastures and anthropogenically accumulated soils attesting past farming practises.

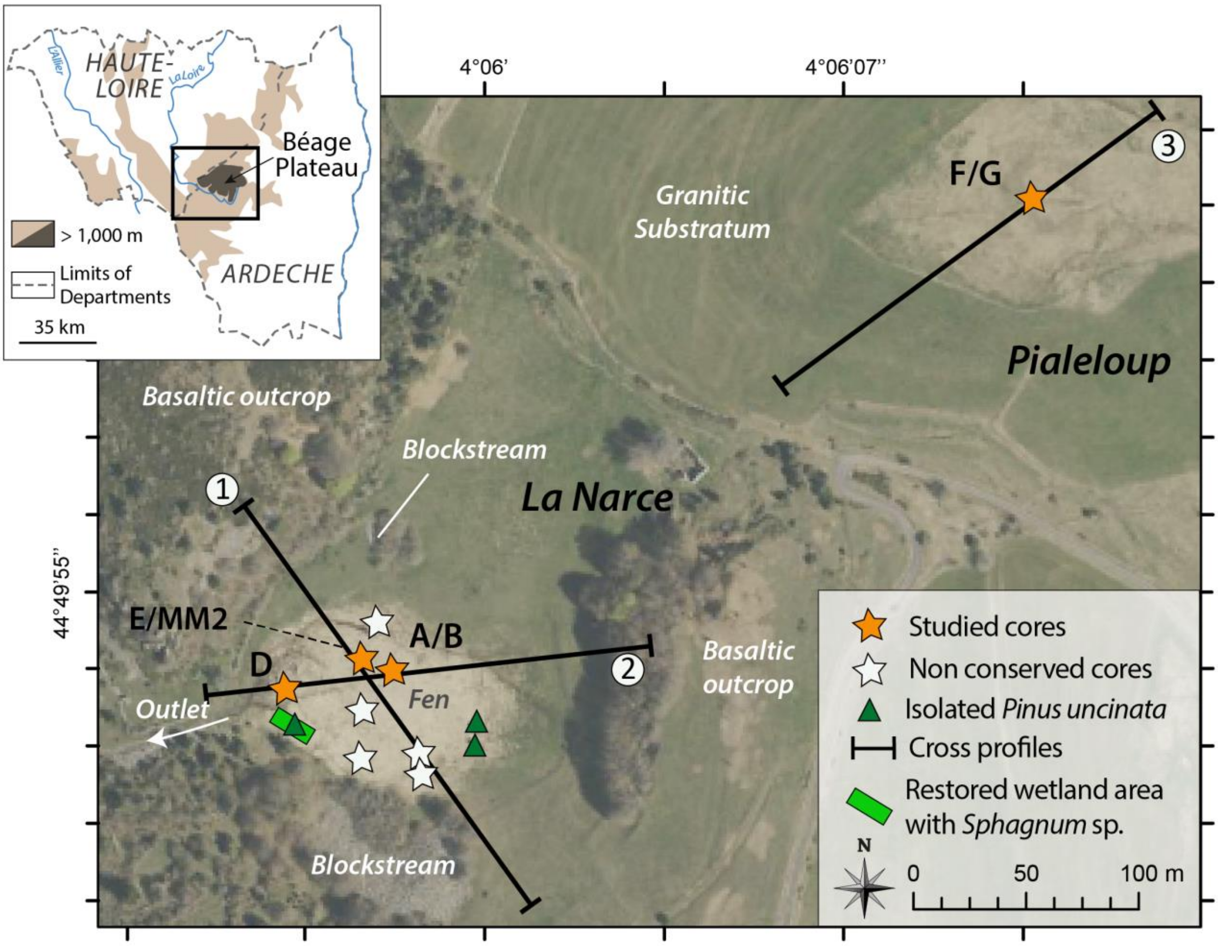

Figure 1*: Location of La Narce du Béage fen and Pialeloup peat stratigraphies with localisation of the field operations (after Dendievel, 2017). Cross profiles are numbered from 1 to 3.*

MATERIALS AND METHODS

Cross profiles (electrical tomography resistivity and tests with graduated rods) were conducted in order to understand the infilling of La Narce du Béage (**Figure 1**). After coring with a manual peat corer, sequences were described on the field using the *Munsell Soil Color Charts* and by means of the *Von Post estimation* for the degree of peat decomposition.

Magnetic susceptibility was measured in the laboratory (resolution= 1cm) using a *Bartington* device. Organic matter content (loss in ignition, 4h at 550°C), grain size (*Malvern Mastersizer 2000* laser granulometer) and geochemistry (ACP-AES accelerator) were acquired each 2 cm.

Main focus was put on palaeoecological analyses with a mean resolution of 2 cm. After sieving (2 mm, 1 mm, 500, 250 and 125 µm meshes), all organic and inorganic macrofossils > 250 µm were identified with a stereomicroscope and a light microscope, and by using seed/fruit collections (University of Innsbruck) and determination keys from the literature for the identification of plant remains (Dendievel, 2017).

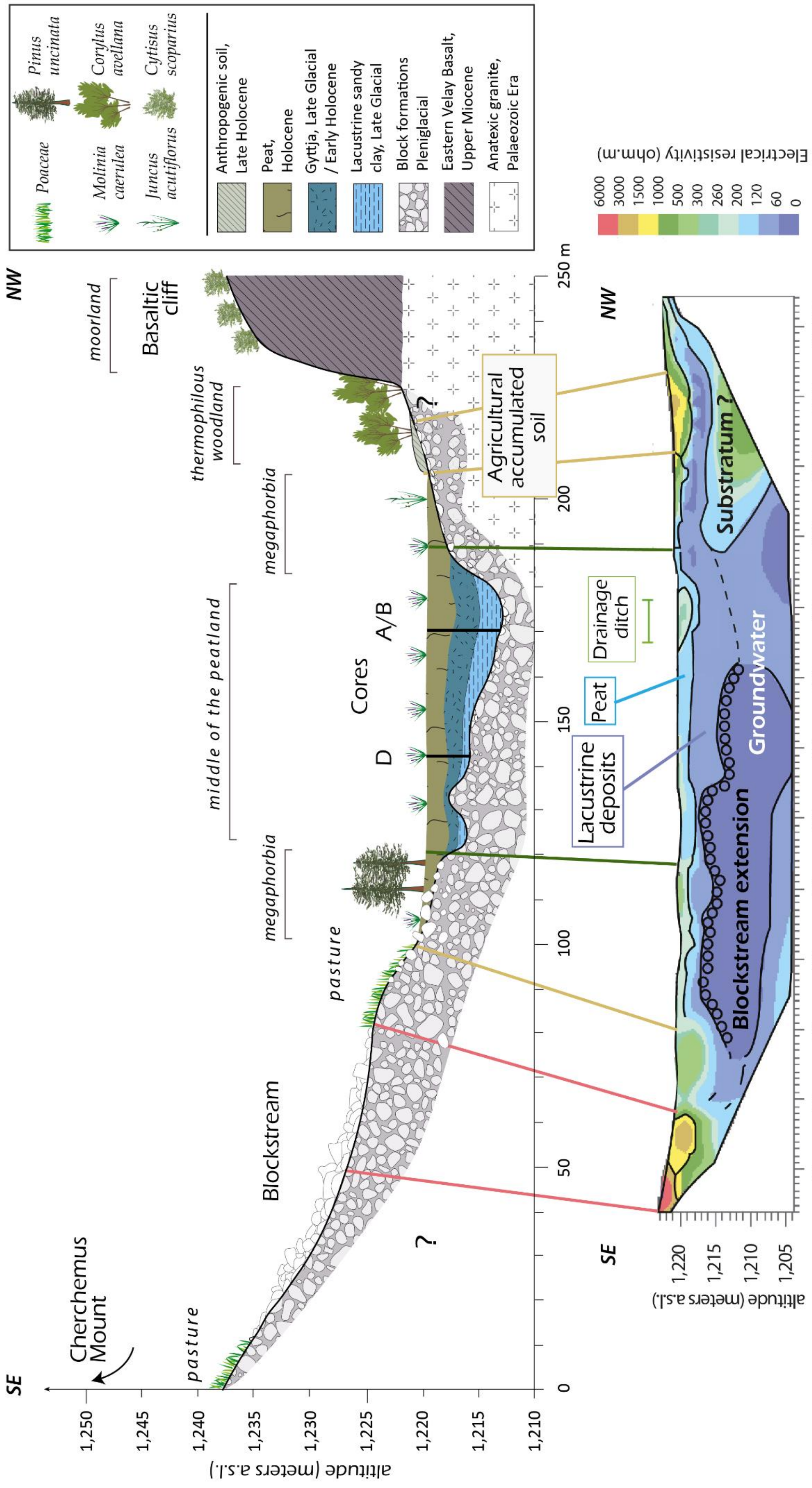

***Figure 2**: Topo-stratigraphical and Resistivity cross profile (#1) from the La Narce du Béage fen.*

After chemical treatment (see Moore *et al.*, 1991), pollen, spores and Non-Pollen Palynomorphs *(NPPs)* were studied from the same samples (1cm^3 each) with a light microscope. At least 500 arboreal pollen were counted for the Holocene and a total of 1,000 pollen for the Late Glacial. Diatoms were analysed after Serieyssol *et al.* (2010-2011) and counted using a Zeiss Axioskop.

Data were statistically sorted by the CONISS clustering method in *Psimpoll* for diatoms (Bennett 2002) and in *Tilia* for other palaeoecological data (Grimm, 1987; 2011). Ecological assemblages zones were defined according to the brocken stick model (Bennett, 1996).
Chronological control was obtained thanks to AMS-radiocarbon dates from macrofossils or, if not possible, from bulk sediment. After calibration with the "IntCal13" curve (Reimer *et al.*, 2013), linear age-depth models were drawn using the CLAM package in R (Blaauw, 2010).

LITHOLOGY AND CHRONOSTRATIGRAPHY
The infilling of the La Narce du Béage fen presents lacustrine deposits resting on a bed of blocks (deepest areas) and the last 2 meters are composed of peat. This layering is well documented in ERT and manual cross profiles (**Figure 1**). Three cores were extracted and conserved: cores A/B (5.5 m deep) and E/MM2 (6.45 m) from the deepest part of the fen and the core D (3.6 m) near the outlet. Chronologies of deposits are very similar: the succession of lacustrine sandy clays (unit 1a) and *gyttja* deposits (unit 1b), from the basal layers to 2.5 m, covers the entire Late Glacial Era since 18,000 years cal. BP (**Figure 3 & 4**). After a transition (unit 2), peat accumulation started during the Early Holocene between 10,800 and 9,200 cal. BP depending on the location of the cores (units 3 to 5). The upper part shows decomposed and mineralised peat layers (unit 6: **Figure 4**).

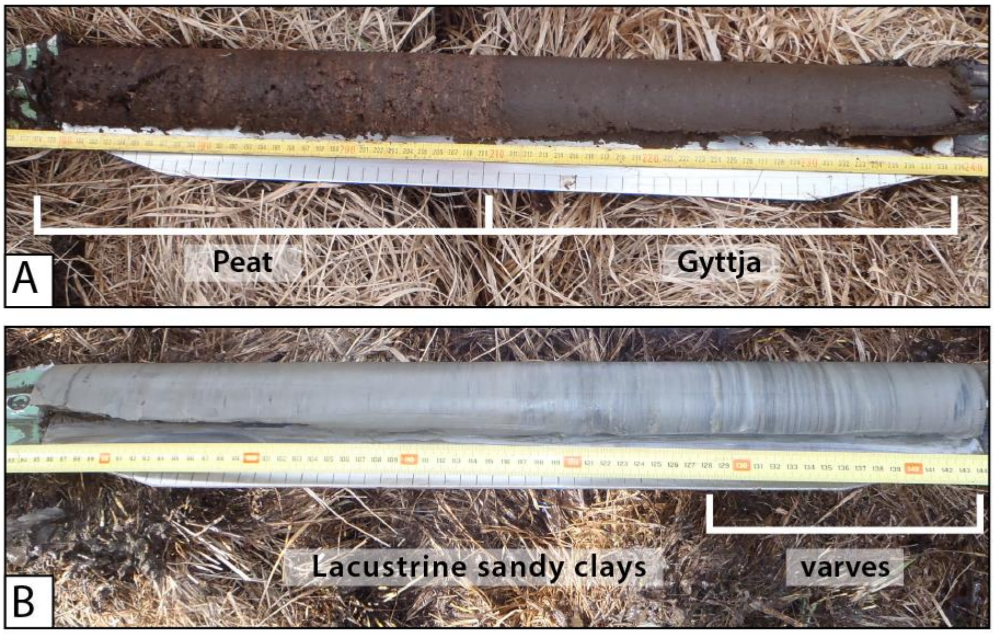

Figure 3*: Examples for the La Narce du Béage sediment cores. A) Peat/Gyttja transition at 180-240 cm on core MM2, B) Lacustrine deposits at 585-645 cm on core MM2.*

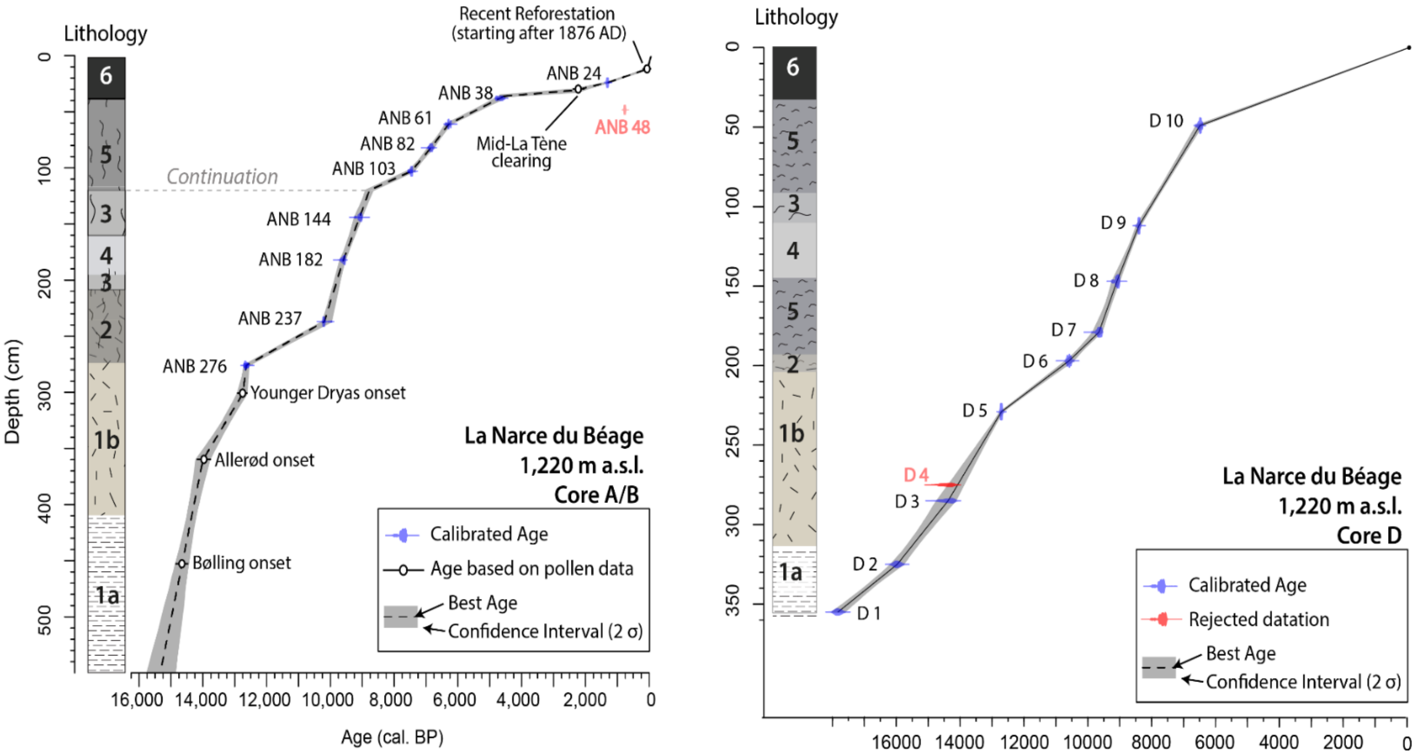

***Figure 4**: La Narce du Béage age-depth models on core A/B and D (after Dendievel et al., 2015; Dendievel, 2017). Lithology: 1a) Lacustrine sandy clay, 1b) gyttja, 2) transition gyttja-peat, 3) hemic peat, 4) fibric peat, 5) sapric peat, 6) mineralized peat.*

RESULTS

4.1 Late Glacial and Early Holocene environmental change

Since 18,000 years cal. BP, sedimentological data show a gradual silting of a Late Glacial lake (**Figure 5**). Magnetic and TiO_2 values rapidly dropped due to a diminution of erosion. SiO_2 decreased in a different way because SiO_2 also derives from biogenic silica (diatoms).

Indeed, short rises in SiO_2 could correlate with successive peaks of *Navicula*, Epiphytes or *Fragilaria* species. *Fragilaria* species, and in particular *F. pinnata,* are usually found at the cold end of the temperature gradient (Pienitz *et al.*, 1995) indicating long periods of ice cover (**Figure 6**).

Around 15,000 years cal. BP, a stabilisation in the diatom composition and an increase in biodiversity suggest a change from active erosion to a stable aquatic environment. This marks an ice free period. Organic matter increased in two steps (1) after 15,500 cal. BP (Bølling inset) and (2) between 13,700 and 12,700 cal. BP, during the Allerød. Pollen data show a change in steppic taxa (reduction of *Artemisia*, increase of *Campanula* and *Rumex acetosa*-type), whereas *Betula* and *Pinus* extended (**Figure 7**). This interval is also characterised by an enrichment in Al_2O_3 due to soil formation.

A sharp decrease in organic matter and a TiO_2 increase coincide with the Younger Dryas onset due to minerogenic inputs (**Figure 5**). *Fragilaria* increase whereas a drop in planktonic taxa (*Aulacoseira)* mark a local ice cover, as shown at other sites (Lotter & Bigler, 2000). *Artemisia* as well as Apiaceae or Ranunculaceae expand during this cold event (**Figure 7**).

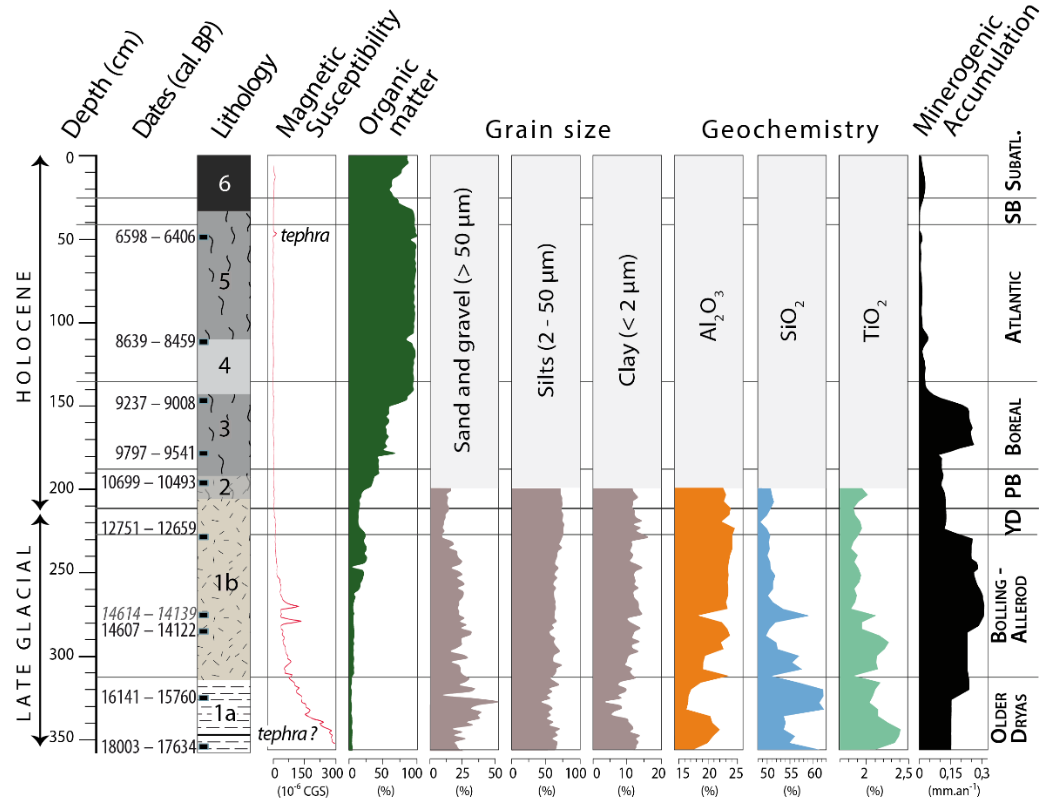

Figure 5*: Physicochemical measurements and radiocarbon dates performed on the La Narce du Béage core D (modified after Dendievel et al., 2015). Lithology: 1a) Lacustrine sandy clay, 1b) gyttja, 2) transition gyttja-peat, 3) hemic peat, 4) fibric peat, 5) sapric peat, 6) mineralized peat.*

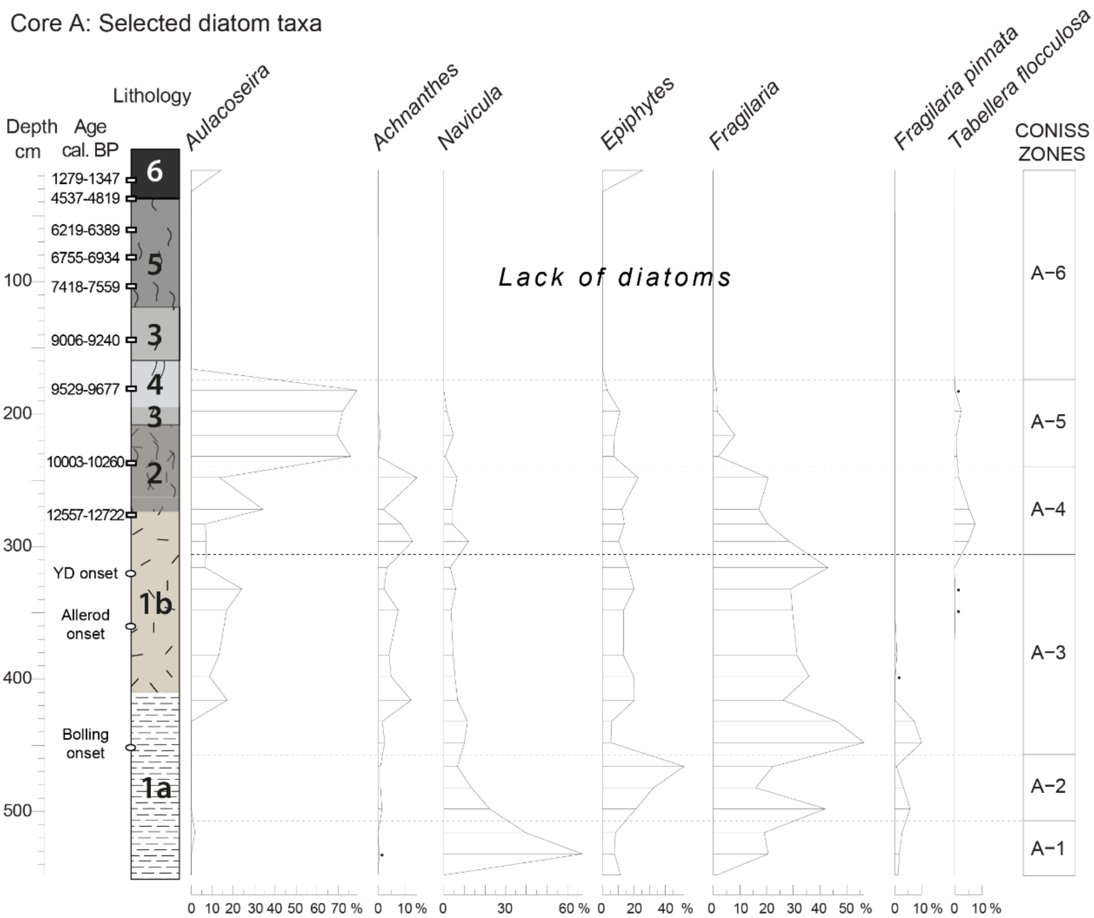

Figure 6*: Selected Diatom taxa from the La Narce du Béage core A (Sérieyssol). Lithology: 1a) sandy clay, 1b) gyttja, 2) transition gyttja-peat, 3) hemic peat, 4) fibric peat, 5) sapric peat, 6) mineralized peat.*

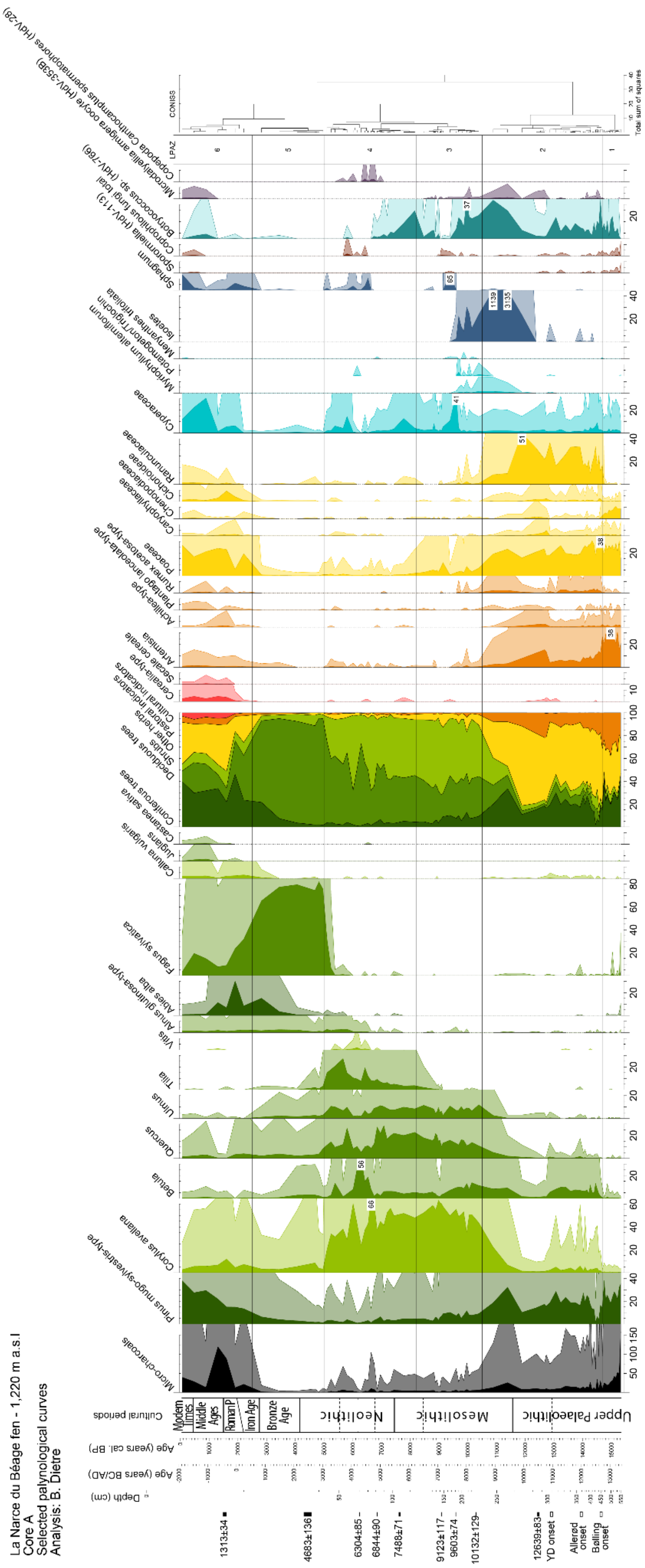

***Figure 7**: Selected Pollen, Spores and Non-Pollen Palynomorphs (NPPs) taxa from the La Narce du Béage core A (10 X exageration curves are plotted in semi-transparent colours).*

The establishment of a fen, implying a reduced depth of water and the terrestrialization of the lake, occurred during the Early Holocene. This change is observable in many proxies: organic matter exceeding 50% (**Figure 5**), expansion of *Aulacoseira* living in shallow water where wind activity keeps it in suspension (**Figure 6**) and disappearance of green algae (**Figure 7**). Macrofossil analyses showed a low water level and a eutrophication phase with rise in water temperature. Aquatic taxa dropped (*Isoëtes*, *Ranunculus* sect. *Batrachium*, *Daphnia*, *Sialis* and Trichoptera) and several plants invaded the water surface, such as *Potamogeton*, *Sparganium* and *Plantago alisma-aquatica* (**Figure 8**). *Menyanthes trifoliata*, *Comarum palustre* and *Sphagnum* remains revealed the formation of floating mats of peat where shrubs could grow (*Betula* and *Salix)*. We also highlighted the presence of today endangered species, such as *Isoëtes lacustris* (lake quillwort), *Betula nana* (dwarf birch) and Mesiaceae. The description of this type of environment could also give precise data for conservation and restauration of the currently endangered ecosystems in the Massif Central. Diatom are lacking in the upper part of the fen by increased acidity which dissolved their siliceous valves.

4.2 Early human impacts

Mid-Holocene human impact was defined according to the presence of macrofossils and palynological results. Agro-pastoral disturbances occurred between 4,950 and 4,500 cal. BC, at the end of the Early Neolithic. It consists in a short increase of charcoal particles and anthropogenic pollen indicators (API) such as Cerealia-type, *Artemisia* and *Plantago lanceolata* pollen (**figure 7 & 8**). Synchronous reductions in *Quercus* and *Corylus avellana* might highlight forest clearings. Macrofossils of soil fungi (*Coenococcum geophilum*) underlined erosion processes. This brief change is followed by the spreading of pioneering species (wood and pollen of *Betula*). It coincides with Early Neolithic frequentations of the Loire Valley and archaeological findings of stamped ware at Mount Mézenc (**figure 9**).

Another phase of human impact has been identified from 3,750 to 3,250 cal. BC. The body of evidence presents charcoal levels and API such as Cerealia-type and *Centaurea cyanus* pollen. Synchronous findings of *Molinia caerulea* and *Juncus effusus*-type seeds and spores from coprophilous fungi could be an evidence of livestock grazing (**figure 7 & 8**). This period coincides with the local formative phase of the Recent “Ferrières” Neolithic, represented by the Rond-du-Lévrier burial and by several sites at the confluence of the Baume and the Loire Rivers (**figure 9**).

Finally, the development of a degraded histosol and a decrease in the accumulation rate occurred between 2,850 and 2,150 cal. BC, during the Late Neolithic. This change, based on synchronous stratigraphic changes, could be anthropogenically and/or climatically driven. It could be related to the start of *Fagus sylvatica* (beech) and *Abies alba* (fir) continuous curves, respectively before (3,450 cal. BC) and just after (1,900 cal. BC) this change.

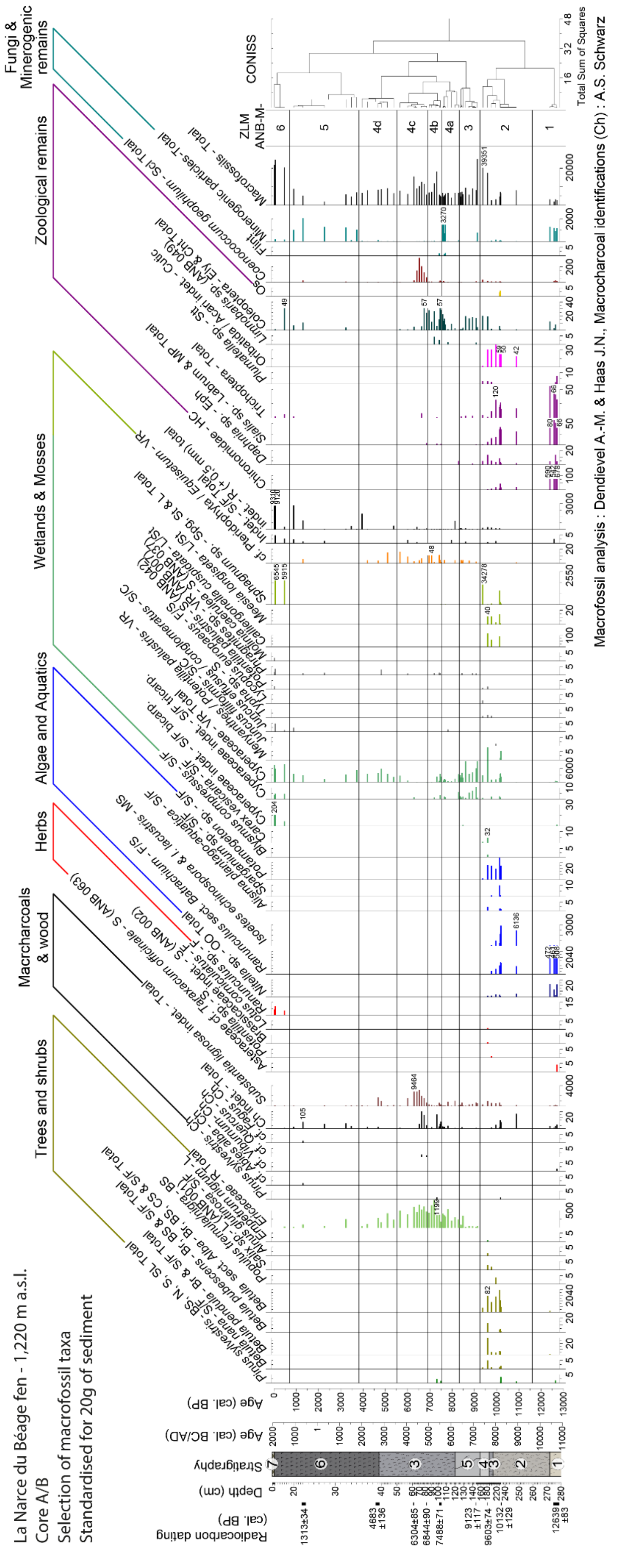

***Figure 8**: Selected Macrofossils taxa from the core A of the La Narce du Béage core A.*

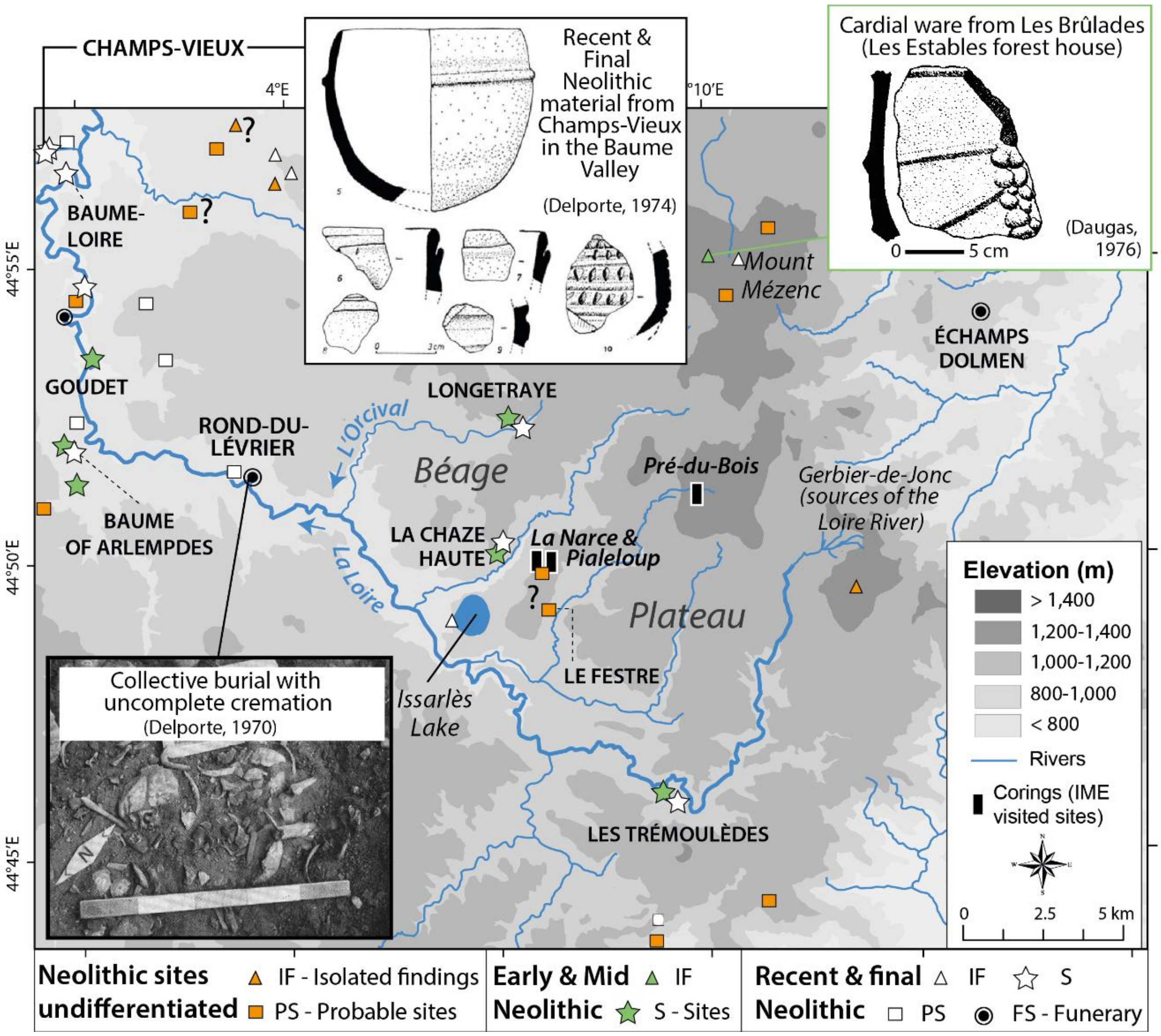

***Figure 9**: Archaeological map of Neolithic sites on the Béage Plateau (after Dendievel, 2017). Sites abbreviations: IF= isolated findings, FS= funerary sites, PS= probable sites, S= sites.*

4.3 A Mid-Holocene volcanic deposit

According to magnetic susceptibility variations, several samples were taken off from the sedimentary sequence. In the youngest one, located at 0.5 m deep, small **vesicular glass shards** are very **specific of volcanic deposits**. The chemical composition of these volcanic glass shards has not been analysed yet. Radiocarbon dating indicates a best age of **6,512 ± 106 cal. BP** (Dendievel *et al.*, 2015), an age contemporaneous with the activity of the Montchal, Montcineyre and Pavin volcanoes from the Chaîne des Puys volcanic field (Boivin *et al.*, 2009). Recently, an occurrence of an Atlantic Period eruption from the Chaîne des Puys has been also revealed in the Forez Moutains (NE Massif Central), around 6,339 ± 61 cal. BP (Jouannic *et al.*, 2014). A new Holocene tephrostratigraphic framework for the Eastern French Massif Central, Jura and the Alps suggest that the tephra layer (B1) from the Béage site could be correlated with MF-1 tephra layers (**Figure 10**). In this case, a widespread volcanic deposit extended to the east and to the south-east excludes a Lake Pavin origin (Boivin *et al.*, 2009).

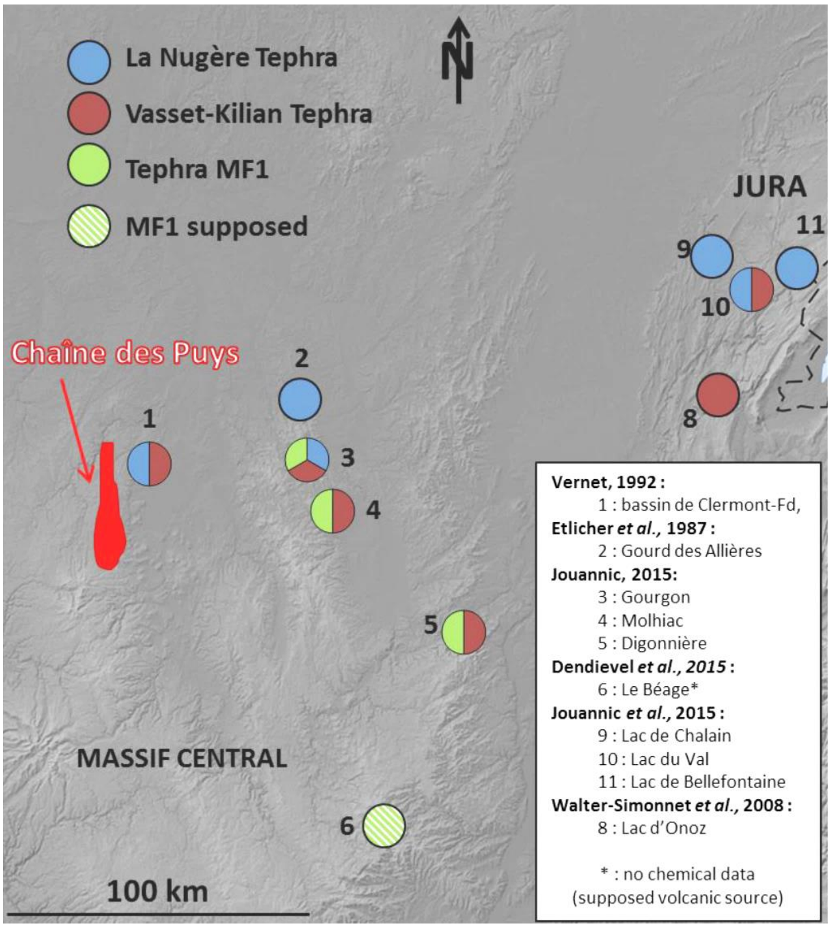

***Figure 10**: New Holocene tephrostratigraphic framework for the Eastern Massif Central and the Jura Mountains (Jouannic, unpublished).*

4.4 And more recently?

Palaeoecological data are also available for the Late Holocene. They indicate a rapid opening of the landscape during the last 2,400 years. However, the upper stratigraphy of the La Narce du Béage fen is very compressed and does not allow to define phases of changes during this timeframe. To supplement these data, other palaeoecological analyses were conducted on the Pialeloup peat sequence (see IME-Site 17).

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HOLOCENE ENVIRONMENTAL CHANGES REFLECTED IN THE PIALELOUP BOG CORE

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STUDY AREA

The Pialeloup bog is located at 1,220 m a.s.l., 400 m north-east of the La Narce du Béage fen. It's a small peat area (< 100 m²) nestled in a break in the slope, maybe a former nivation's alcove (**figure 1**). Its catchment area (9 ha) includes the top of the basaltic table of the Béage Plateau resting on granitic altered formations. Miocene fluvial deposits are found between the two (**figure 1**). The Pialeloup bog hosts *Juncus effusus* and hummocks of *Sphagnum, Menyanthes trifoliata* and *Comarum palustre*. *Molinia caerulea* occurs also in the remainder of the parcel (**figure 2**).

MATERIALS AND METHODS

Following cross profile measurements (manual tests with graduated rods) a core was taken off from the deepest part of the bog with a manual peat corer (**figure 1**). The lithology of the Pialeloup core was described on the field using the *Munsell Soil Color Charts* and by means of the *Von Post test* estimating the degree of peat decomposition.

In the laboratory, non-destructive measures were acquired at a 1 cm resolution: magnetic susceptibility using a *Bartington* MS2E device and X-fluorescence geochemistry with a handheld *Delta InnovX* device, used in "soil mode" (Dendievel, 2017). After a 2 cm resolution sampling, organic matter content (loss in ignition, 4h at 550°C) was also computed.

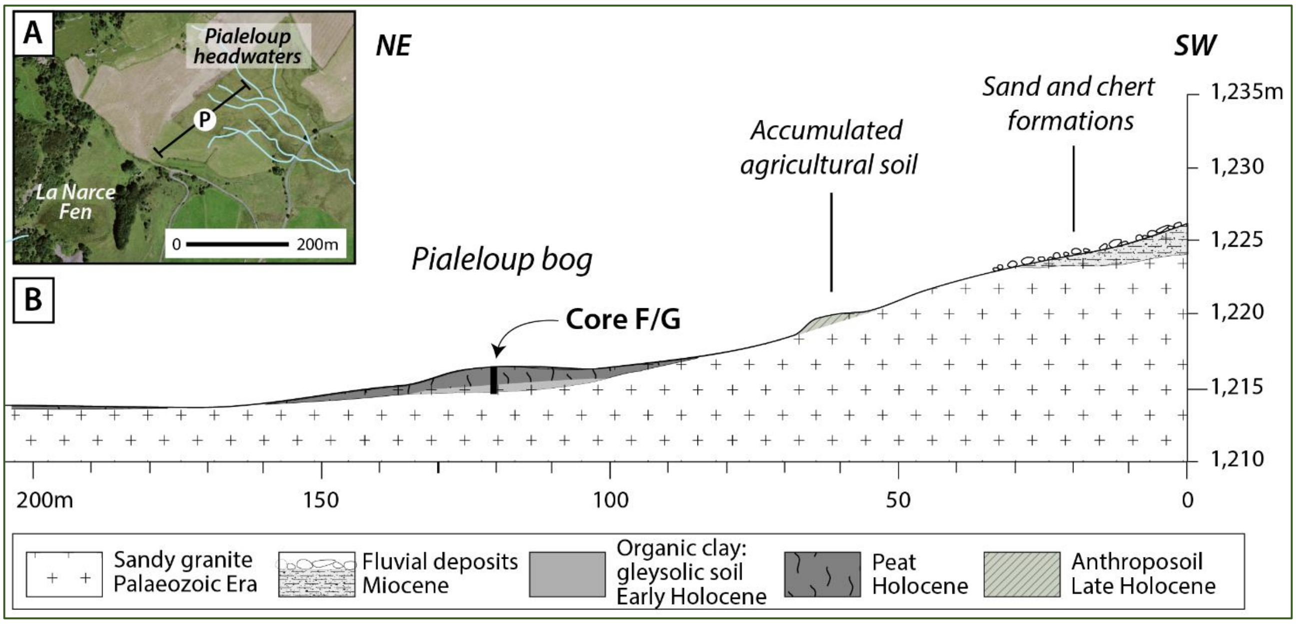

***Figure 1**: Physical context of the Pialeloup bog (Eastern Massif Central, France). A) Aerial photograph of Pialeloup and La Narce du Béage areas. The Pialeloup cross profile is designated by the letter P. B) Detailed cross profile of the Pialeloup Bog, from the north-east to the south-east (after Dendievel, 2017).*

***Figure 2**: The Pialeloup bog vegetation (Eastern Massif Central, France). 1) Juncus, Menyanthes trifoliata and Comarum palustre. 2) Sphagnum hummocks. 3) Juncus belt. 4) Large surface of Molinia caerulea.*

Sediment samples were sieved for macrofossils (1 to 3 cm resolution) using gently running tape water (2 mm, 1 mm, 500 and 200 µm meshes). Identifications were achieved with a stereomicroscope and a light microscope, using macrofossils collections (University of St Etienne & National Botanic Conservatory of the Massif Central - CBNMC) and literature references (Dendievel, 2017). Insect remains, sorted out simultaneously with plant remains, were identified by comparison with modern specimens from reference collections and by using specific keys. After chemical treatment (Argant, 1990), pollen and spores from the same samples (1 cm^3) were studied under a light microscope. A mean of 484 pollen grains were counted and identified by using ARPA's reference collections and Maurice Reille's atlas (Reille, 1999). Palaeoecological data were statistically sorted with the CONISS method in *Tilia* (Grimm, 1987; 2011). Zones were defined following the brocken stick model (Bennett, 1996). Chronological control was based on AMS-radiocarbon dates (**figure 3**). Calibration and age-depth modelling were achieved with the "IntCal13" curve (Reimer *et al.*, 2013) and the CLAM package in R (Blaauw, 2010).

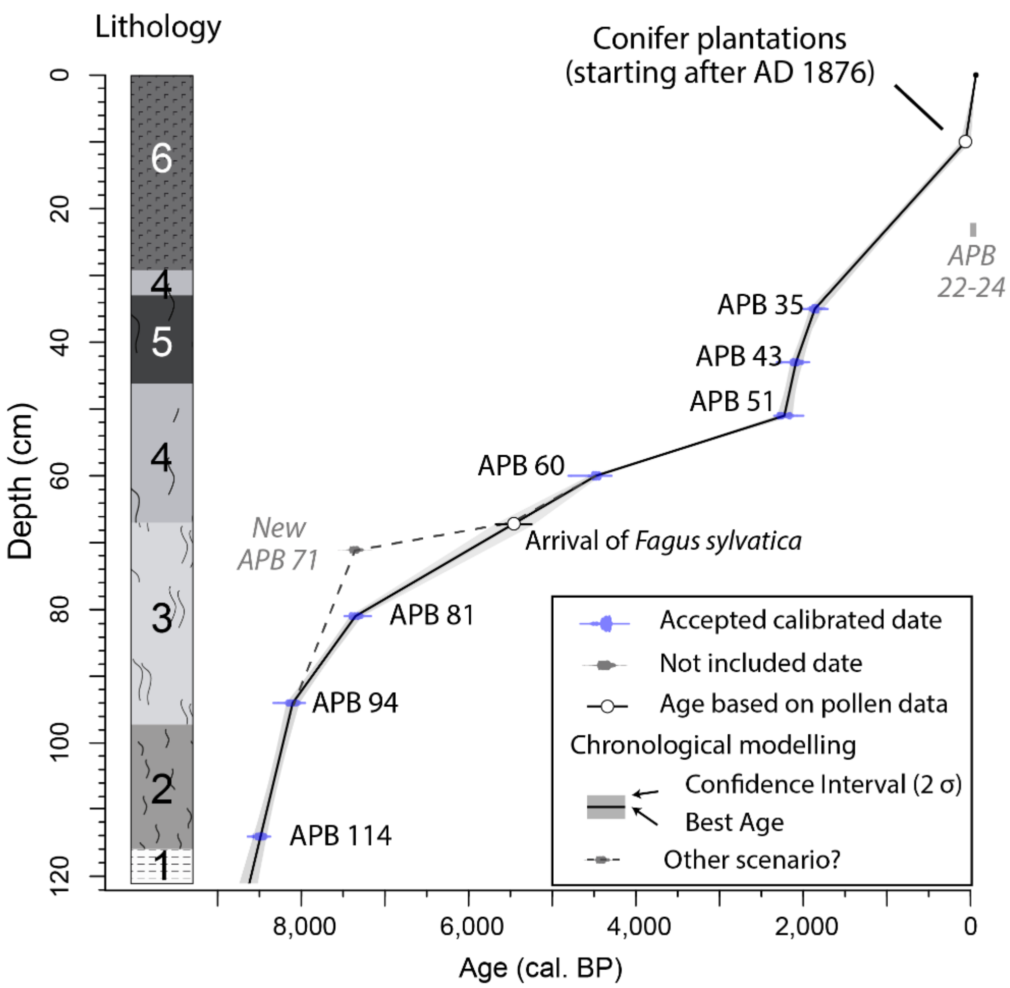

***Figure 3**: Age-depth model for the Pialeloup core (Eastern Massif Central, France; after Dendievel, 2017). Lithology: 1) Black organic clay, 2) Sapric peat, 3) Fibric peat, 4) Hemic peat, 5) Charcoal layer, 6) Mineralised peat. Radiocarbon dates in grey italics were not included in the depth-age modelling.*

CHRONO-STRATIGRAPHY

The Pialeloup core starts with a black clayey layer (**figure 3**: unit 1). Then, the peat accumulation covers 115 cm, starting 8.6 ky ago (**figure 3**: units 2 & 3). The middle of the core (63 to 46 cm) presents hemic peat which is highly mineralised and compressed (**figure 3**: unit 4). The top of the core is the more dilated and could supplement precise data for the last 2.4 ky (**figure 3**).

RESULTS AND DISCUSSION

4.1 Peat Inception phase

The Pialeloup sequence starts by a black clayey layer (unit 1), with a low organic content (11 to 28%), positive magnetic values and high elemental concentrations of Fe, K and Ti (**figure 4**). It reveals local hydromorphic conditions. Peat inception began 10 cm above around 8,500 cal. BP with a drop in magnetic values and by crossing the 30% of organic matter threshold (**figure 4**).

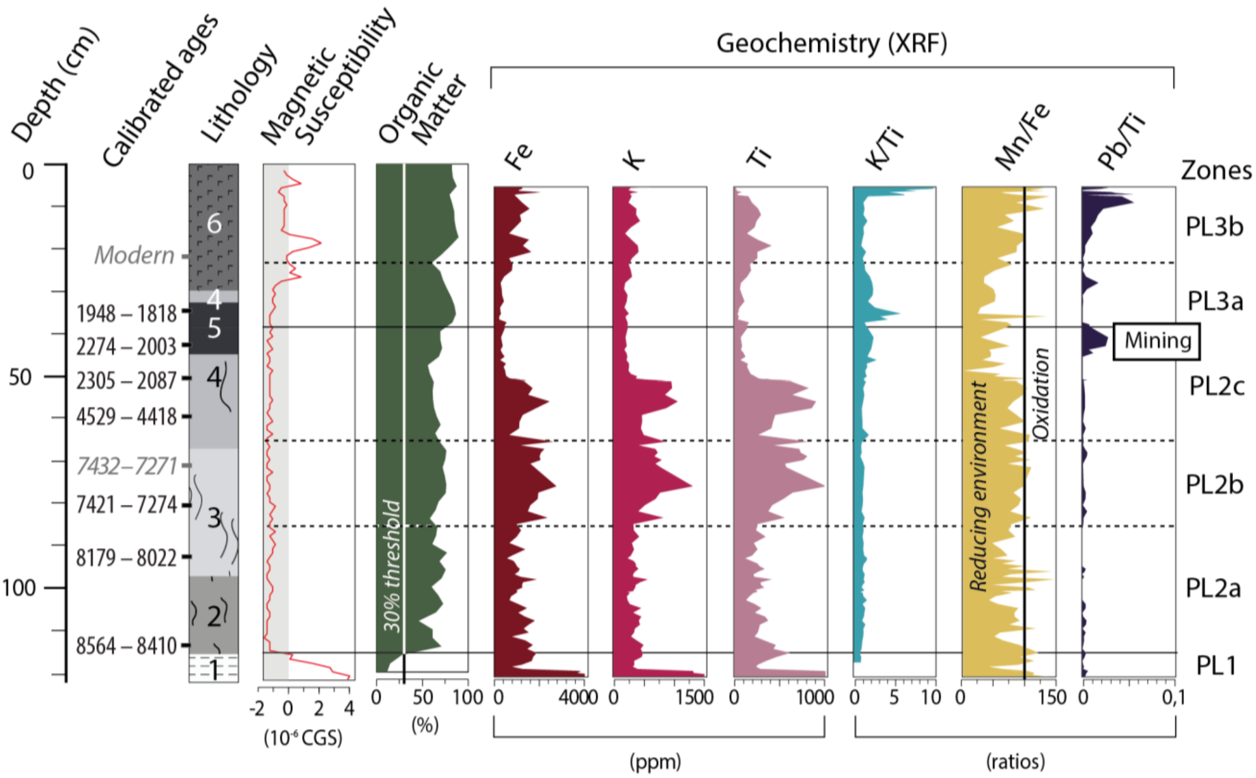

Figure 4*: Physico-chemical data obtained on the Pialeloup core (Eastern Massif Central, France; after Dendievel, 2017). Radiocarbon dates in grey italics were not included in the depth-age modelling. Lithology: 1) Basal organic clay, 2) Sapric peat, 3) Fibric peat, 4) Hemic peat, 5) Charcoal layer, 6) Mineralised peat. LMAZ means Local Macrofossils Assemblage Zones.*

This change is less clear-cut in the macrofossil data. *Betula*, *Alnus* and *Salix* wood fragments evocate a humid forest edge vegetation (**figure 5**). The shrub and herb layers are represented by heather roots (Ericaceae), *Fragaria* seeds (wild strawberry) and Cyperaceae remains (sedges). A damp wooded environment, such as forest swamps, is also stressed by the entomological record showing *Bembidion*

gilvipes, *Cercyon tristis* and taxa such as *Quedius* spp. and *Lathrobium* spp. (**figure 6**). *Coenococcum geophilum* soil fungi and the click beetle *Denticollis linearis* revealed the presence of decaying organic matter. *Cercyon tristis*, *C. haemorrhoidalis*, *Aphodius ater* and *Athous vittatus* found on dung from herbivore grassers indicate meadow, grassland or open woodland (**figure 6**).
At the regional scale, high percentages of *Quercus*, *Corylus avellana* and *Tilia* pollen revealed the presence of a thermophilous forest cover (**figure 7**). These taxa are replaced by *Fagus sylvatica* and *Abies alba*, showing continuous curves during the Subboreal (5,400 – 2,800 cal. BP).

Protohistoric and Gallo-Roman landscape

Then, ecological changes occurred only after 3,000 cal. BP with the appearance of *Equisetum* sp. (horsetail) and rush beds of *Juncus effusus/conglomeratus* type (**figure 5**). Swampy woods with leaf litter are indicated by several beetle species: *Trechus rivularius*, *Pterostichus diligens*, *Cercyon tristis*, *Acidota cruentata* and *Quedius* sp. (**figure 6**). The return of shrubs on or around the peatland is also revealed by wood fragments of *Alnus* or *Betula* and by seeds of *Rubus*. A phase of flooding and erosion is underlined by numerous minerogenic inputs (**figure 5**).
Anthropogenic changes caused major modifications between 2,400 and 1,650 cal. BP (IVth century BC to IIIrd century AD): for instance, clearings are suggested by a thick macro-charcoal layer, between 46 and 33 cm (**figure 3 & 5**). Caryophyllaceae, *Potentilla* sp., *Ranunculus* sp. (buttercups) and *Viola arvensis* (field pansy) seeds (**figure 5**) demonstrated an agro-pastoral landscape with meadows and fields around Pialeloup. Grazing is suggested by dung beetles of the *Aphodius* genus (**figure 6**).
This important shift is also highlighted in the pollen data by sharp decreases of the curves of *Fagus sylvatica* and *Abies alba*, whereas agricultural and pastoral indicators increased such as Cerealia-type, *Artemisia*, *Plantago* and *Rumex* pollen (**figure 7**). Finally, atmospheric lead deposits (Pb/Ti ratio on **figure 4**) coincide with a major regional phase of mining activities at Mount Lozère (Baron *et al.*, 2005; Servera Vives *et al.*, 2014).
Furthermore, local archaeological excavations revealed a Mid-La Tène site (IVth century BC), 300 m south of the Pialeloup bog (**figure 8-A & 8-B**). The most noteworthy domestic items include millstones illustrating grinding of cereals from the Béage Plateau (**figure 8-C**). Findings of local turned pottery ware confirm the early introduction of the potter's wheel on the Eastern Massif Central (Dendievel *et al.*, 2016).

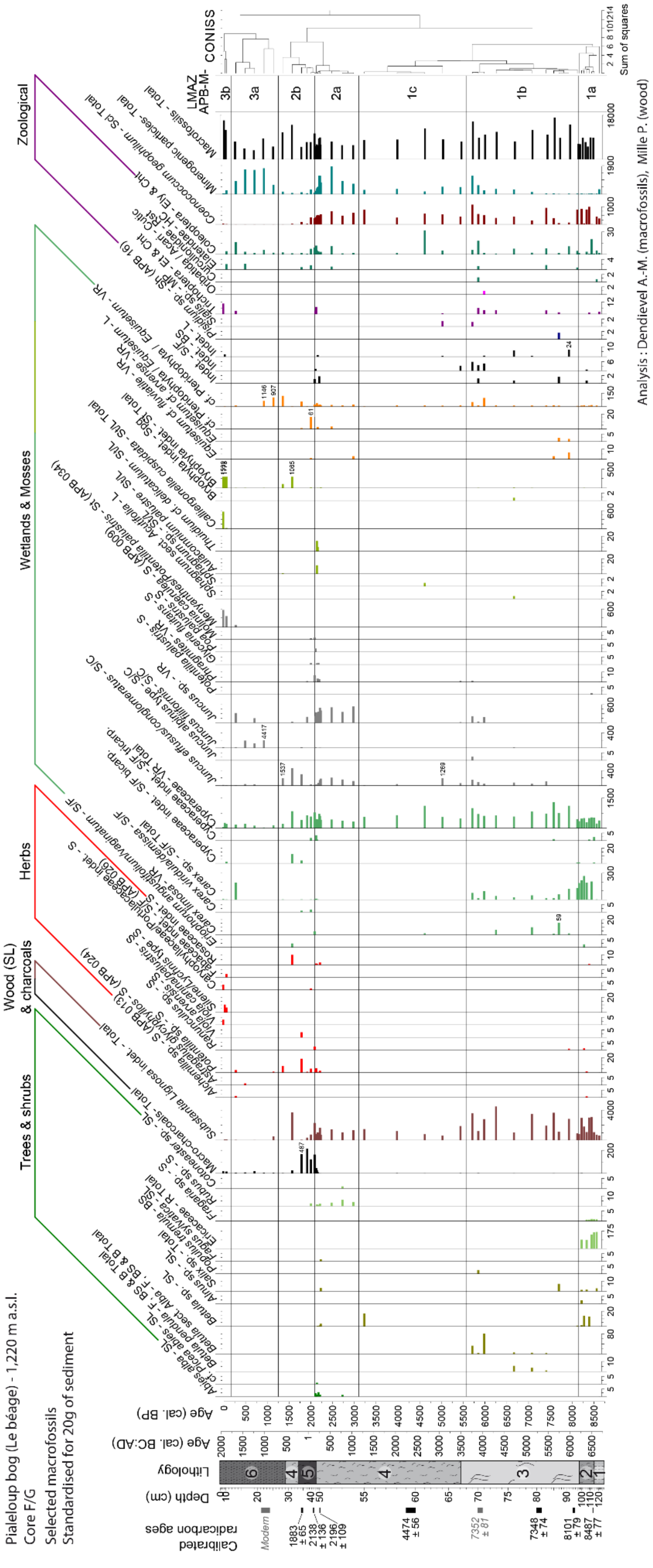

***Figure 5**: Selected macrofossil taxa from the Pialeloup core (Eastern Massif Central, France). <u>Lithology</u>: 1) Basal organic clay, 2) Sapric peat, 3) Fibric peat, 4) Hemic peat, 5) Charcoal layer, 6) Mineralised peat. LMAZ means Local Macrofossils Assemblage Zones.*

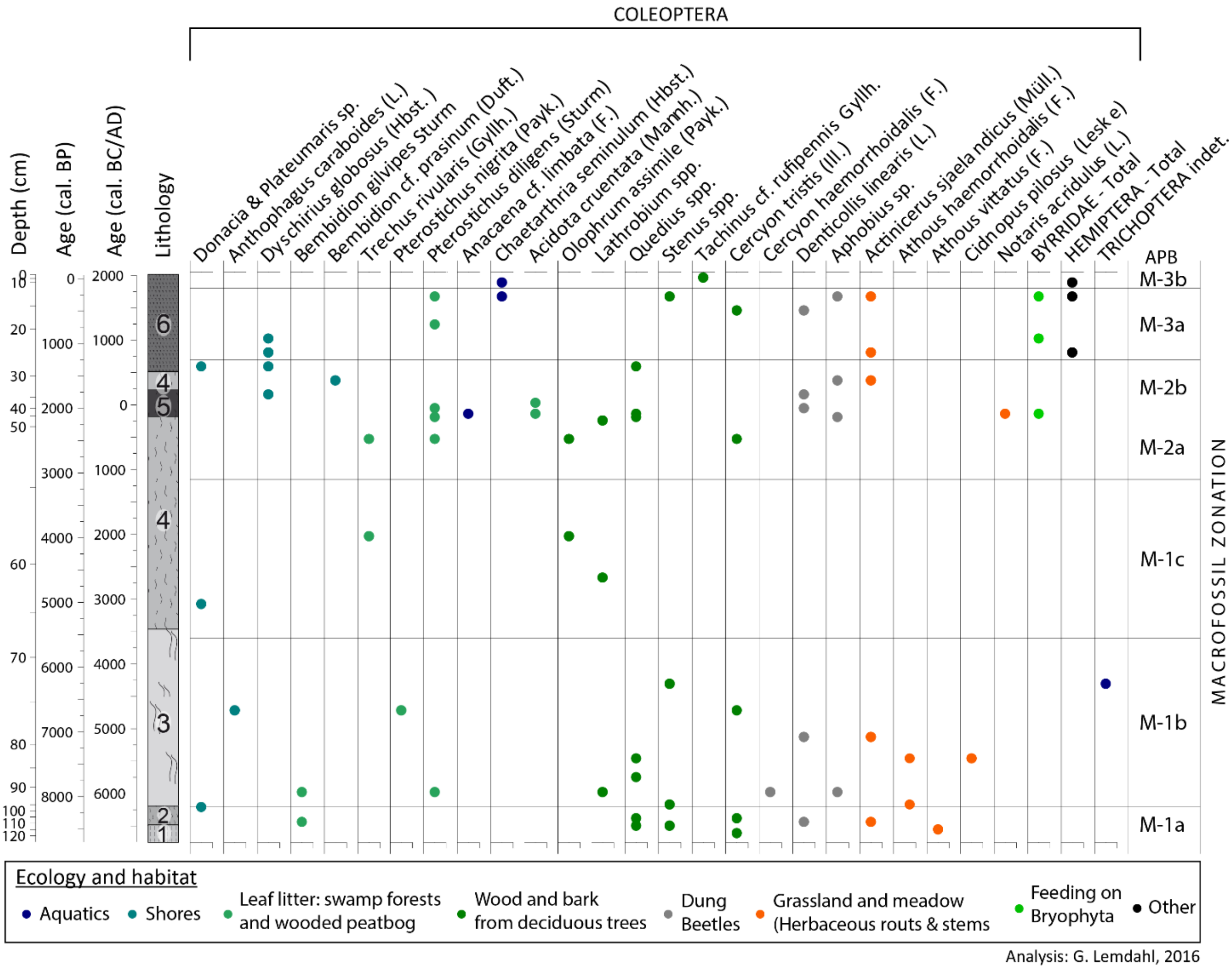

Figure 6: *Selected insect taxa from the Pialeloup core (Eastern Massif Central, France; G. Lemdahl, unpublished). Lithology: 1) Basal organic clay, 2) Sapric peat, 3) Fibric peat, 4) Hemic peat, 5) Charcoal layer, 6) Mineralised peat.*

Continuous presence during the Early Middle Ages?

Based on the Pialeloup record, we can assume continuous human presence on the Béage until the VI^th^ century AD. Indeed, at this time, non-arboreal pollen rate continued to progress (up to 35%) with notable increases of Cerealia-type and *Plantago*-type pollen (**Figure 7**). *Juncus effusus/conglomeratus* seeds and dung beetle remains (*Aphodius* sp.) emphases the presence of livestock (**Figure 5 & 6**).

These evidence of local human impact are confirmed by the recent discovery of pottery shards collected on the embankment of the Pialeloup creek. Among these findings, several neck fragment come from *Ollae* jars in grey ceramic, characteristic of the regional production at the end of the V^th^ and the first half of the VI^th^ centuries AD (Dendievel, 2017).

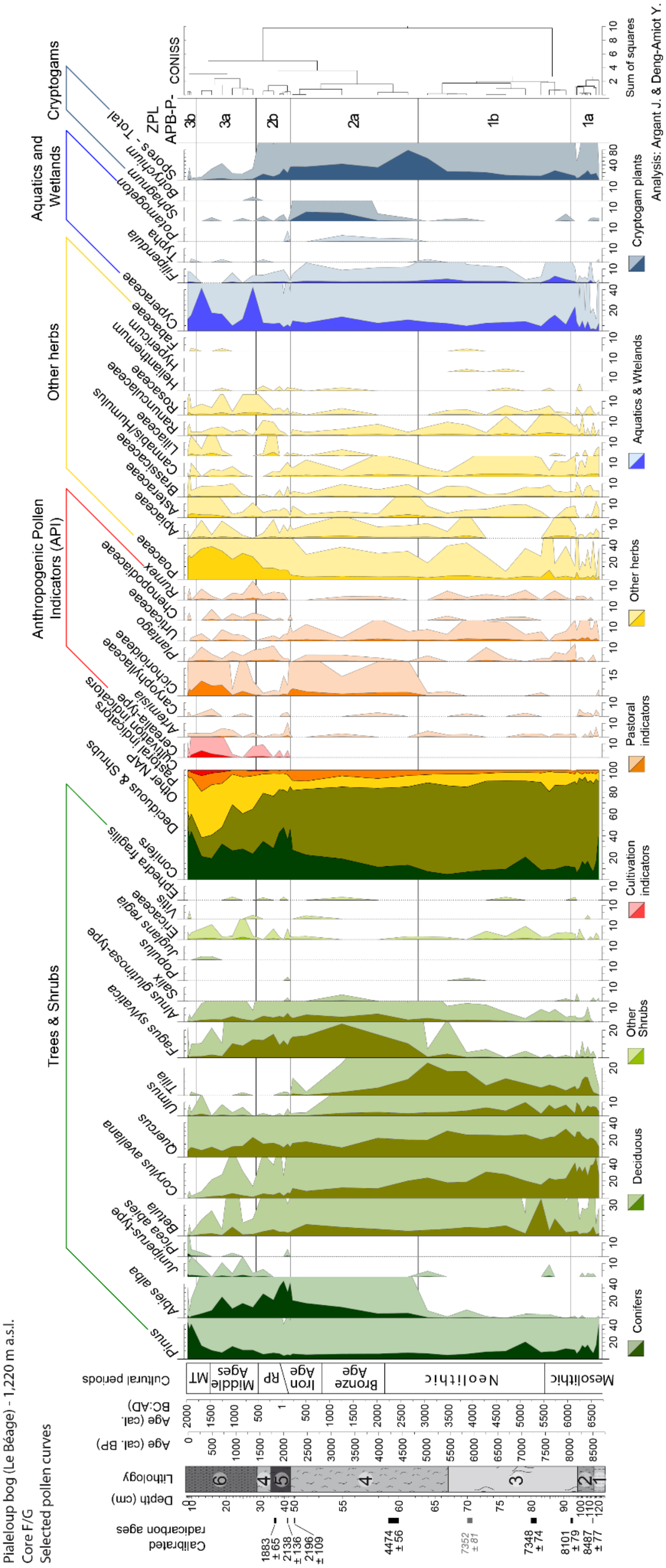

Figure 7: *Selected pollen taxa from the Pialeloup core (Eastern Massif Central, France). Lithology: 1) Basal organic clay, 2) Sapric peat, 3) Fibric peat, 4) Hemic peat, 5) Charcoal layer, 6) Mineralised peat. Abridged cultural periods: RP= Roman Period, MT= Modern Times.*

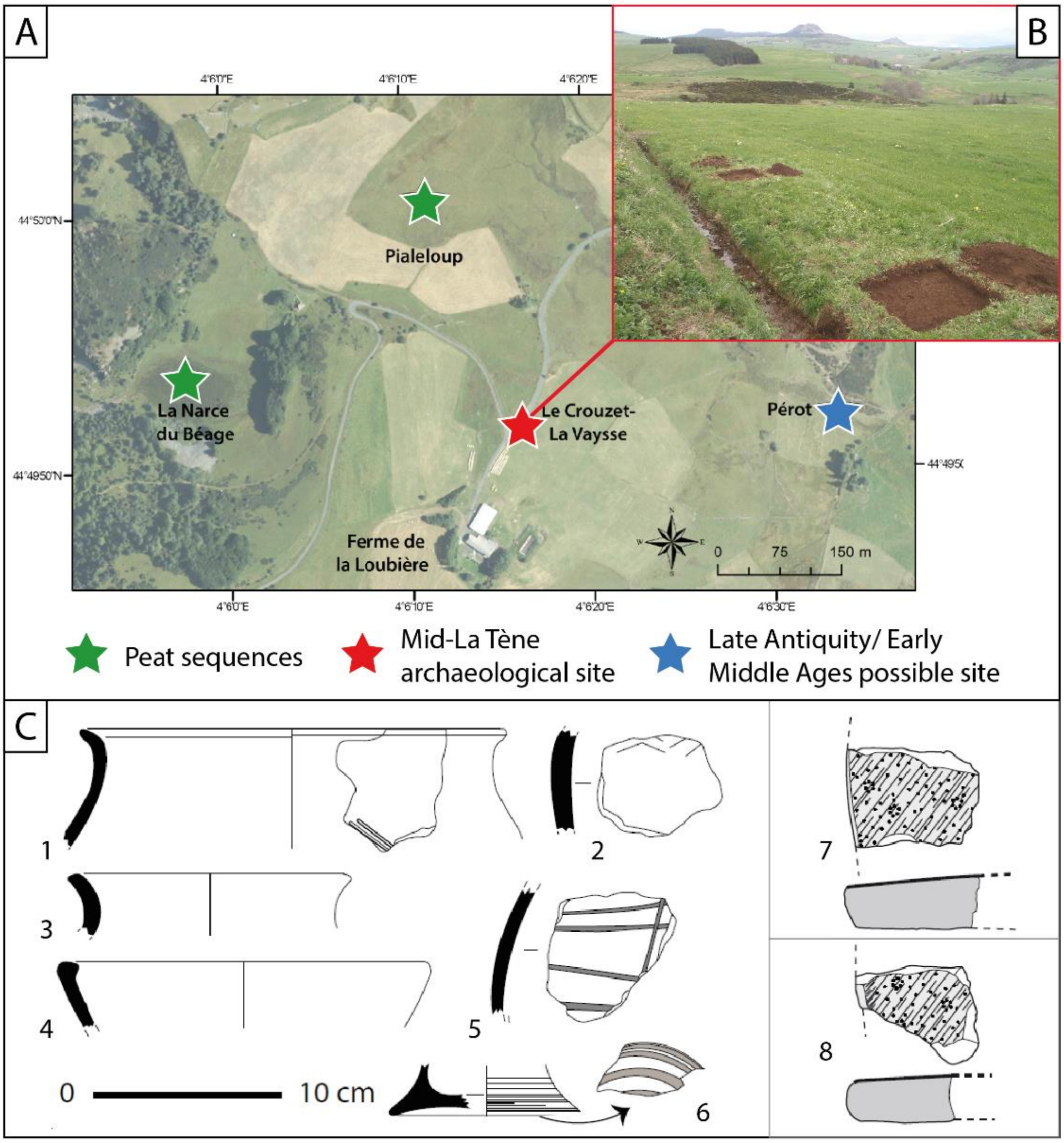

Figure 8: *Archaeological operations conducted on the Béage Plateau (Eastern Massif Central, France). A) Aerial photo of the study area. B) Archaeological surveys at Le Crouzet-La Veysse, SE of the Pialeloup bog. C) Examples of archaeological material excavated at Le Crouzet-La Veysse: 1-5) handmade pottery with typical decoration such as rafters and brownish bands, 6) wheel-turned ware with foot-ring detail, 7-8) basaltic millstone fragments (after Dendievel et al., 2016).*

After AD 1,000

After a slight reduction (AD 700 to 950), new increases in anthropogenic indicators are observable after the XIth century AD. Critical slope erosion and peat oxidation are indicated by high inputs of minerogenic particles together with an upsurge of the K/Ti ratio (**Figures 4 & 5**). This change is also supported by increasing magnetic values, turning positive (**Figure 4**). This change could be linked to intensive agricultural activities as indicated by increases of cereal-type pollen and and pollen from weeds (**Figure 7**). *Secale cereale* (rye) was not found at Pialeloup, but its local cultivation could be deduced after La Narce du Béage study (see IME-site 16) and also according to medieval mentions of fees payment in rye, salt and chestnut floor (Bréchon, 2000). Arboriculture (walnut) is established since the XIV[th] century AD according to the pollen data (**Figure 7**). Seeds of *Juncus* together with findings of *Aphodius subterraneus*, mainly found in dung from grazing domestic animals, and bugs of the Lygaeidae family, feeding on seeds of herbaceous vegetation, also evocate grassland and pastured meadows (**Figure 5 & 6**). The agro-pastoral purpose of the Béage Plateau is confirmed by written medieval transhumance agreements between monk communities since the XIII[th] century (Bréchon, 1998; Dendievel, 2017).

Today, farming has been abandoned for livestock breeding on the Béage Plateau and the Mézenc Massif. In our data, extensive livestock grazing is underlined by the insect *Chaetarthria seminulum,* found at the edges of stagnant and eutrophic water bodies (**Figure 6**). Macrofossils from pastured lands are common such as *Viola* sp., *Silene* and other Caryophyllaceae seeds (**Figure 5**).

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