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Caroline Schaal, Henri-Georges Naton. Contribution of archaeobotany to understand taphonomic phenomena. The case of a Preboreal palaeochannel of Autrecourt-et-Pourron (Ardennes, France). Bulletin de la Société Géologique de France, 2021, 192, pp.6. 10.1051/bsgf/2021003. hal-03168370

HAL Id: hal-03168370

<https://hal.science/hal-03168370>

Submitted on 29 Feb 2024

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Contribution of archaeobotany to understand taphonomic phenomena. The case of a Preboreal palaeochannel of Autrecourt-et-Pourron (Ardennes, France)

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Received: 16 November 2019 / Accepted: 18 January 2021

Abstract – Palaeoecology, through the analysis of the interactions between environmental factors and ecosystems, refines the knowledge of the structuring process of plant communities and helps to understand the complexity of past environments. However, it is necessary to analyse the taphonomic phenomena (deposition, conservation, degradation) affecting plant macrofossil assemblages in order to perform relevant palaeoecological analyses. Indeed, plant macrofossils may be under or over-represented in carpological assemblages, depending on the resistance of their cell membranes and the sedimentary condition deposits. For this reason, it is necessary to estimate the representative quality of the conserved part as a source of information. Like all archaeological documents, the plant archives are distorted by the processes of formation of the sedimentary levels and, ignore the diagenetic history of the sedimentary layers could lead to wrong palaeoecological interpretations. To this aim, we analysed plant macrofossils contained in the wet sediments of a Meuse palaeochannel (Autrecourt-et-Pourron, Ardennes, France). This archaeobotanical study of an oxbow lake dated to the Preboreal (11.7–10.7 ka cal. BP), provides a reference of a taphonomic referential according to a hierarchy of organic remain preservations. This framework successfully helped the palaeoecological interpretations of the Autrecourt-et-Pourron off-site, and it has brought robustness to environmental history reconstruction of the early Holocene in the Ardennes Meuse.

Keywords: Taphonomy / Conservation / ecofacts / oxbow lake / waterlogged sediment / archaeobotany / plant macrofossils

Résumé – Contribution de l'archéobotanique à la compréhension des phénomènes taphonomiques. Le cas d'un paléochenal Préboréal d'Autrecourt-et-Pourron (Ardennes, France). La paléoécologie, par l'analyse des interactions entre facteurs environnementaux et écosystèmes, affine la connaissance des mécanismes de structuration des communautés végétales et, aide à comprendre la complexité des environnements passés. Cependant afin d'entreprendre des analyses paléoécologiques pertinentes, il est nécessaire d'analyser en amont les phénomènes taphonomiques (dépôt, conservation, dégradation) affectant les assemblages macrofossiles de plantes. En effet, les macro-restes végétaux, en fonction de la résistance de leurs membranes cellulaires et des conditions sédimentaires de dépôts, peuvent se trouver sous- ou surreprésentés dans les ensembles carpologiques. C'est pourquoi, l'évaluation de la représentativité des restes permet d'estimer la qualité représentative de la part conservée en tant que source d'information. Comme tous documents archéologiques, les archives végétales nous arrivent déformées par les processus de formation des niveaux sédimentaires et ne pas prendre en considération l'histoire diagenétique des couches sédimentaires pourrait conduire à des interprétations paléoécologiques erronées. Pour entreprendre ce travail, nous nous sommes attachés à l'étude des macrofossiles végétaux contenus dans les sédiments humides d'un paléochenal de la Meuse (Autrecourt-et-Pourron, Ardennes, France). Cette étude archéobotanique d'un bras-mort de rivière daté de la période Préboréal (11,7–10,7 ka cal. BP), pose les

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premières bases d'un référentiel taphonomique selon une hiérarchisation de la préservation des restes organiques. L'utilisation de ce référentiel a orienté les interprétations paléocéologiques du contexte hors-site d'Autrecourt-et-Pourron et il a apporté de la robustesse à la reconstitution de l'histoire environnementale du début de l'Holocène en Meuse ardennaise.

Mots clés : Taphonomie / Conservation / écofactes / paléochenal / sédiment humide / archéobotanique / macrorestes végétaux

1 Introduction

Wetlands and lakeshores sites, is known to provide outstanding conservation. Organic archaeological material such as architectural wood elements, perishable artefacts and plant remains allow to reconstruct societal and environmental history (Pétrequin and Pétrequin, 1984; Bourquin-Mignot *et al.*, 1999; Lebreton *et al.*, 2017). These preservation conditions allowed developing scientific research programs based on materials and topics that cannot easily be addressed while studying sites on dry soils where organic remains have almost systematically disappeared (Schaal and Pétrequin, 2016). In wetland and anaerobic conditions, plant remains preservation is due to a process that stops or strongly slows down the activity of micro-organisms and physico-chemical reactions, and is called "waterlogging" (Rettallack, 1981; Bleicher and Schubert, 2015; Lebreton *et al.*, 2017; Bleicher *et al.*, 2018). Archaeobotanists consider waterlogged preservation to be exceptional, but they also point that robust interpretation of plant assemblages depends on the ability to reconstruct the history of their deposit (Lundström-Baudais *et al.*, 1983; Dietsch, 1997; Schaal, 2000). They are questioning the formation of sedimentary layer that can influence the taphonomic history (Marinval-Vigne *et al.*, 1989; Behre and Jacomet, 1991; Gee and Sander, 1997; Berger *et al.*, 2008; Birks, 2014; Bleicher and Schubert, 2015; Antolín *et al.*, 2017a; Steiner *et al.*, 2018). The characterisation of fossilisation indicators is complex, as they cover both sediment deposition circumstances or "biostratinomic" processes, and post-deposition circumstances or "diagenetic" processes (Holyoak, 1984; Martín-Closas and Gomez, 2004; Antolín *et al.*, 2017b). The preservation state of plant remains can be classified into two main indicators: (i) chemical indicator, when anaerobic and humid condition changes towards drying and oxidation, macrofossils are damaged or destructed due to resumption of chemical actions and/or micro-organisms that decompose organic matter; (ii) physical indicator, weathering and physical process generated by natural action of water and sediment transport and/or by human action which mainly causes fragmentation of remains, surfaces degradation and re-deposition of rests. It is therefore important to determine which factors or combination of factors are affecting the deposition of plant macrofossils and if some taxa are under- or over-represented in archaeological assemblages (Ferguson, 1995, 1996).

With this context in mind, the aim of this work is twofold, (1) to propose an adapted taphonomic approach for off-site sediment deposits based on grain-size, organic carbon content and degree of degradation of the macrofossils, and (2) to cross-check this information with past environmental settings in order to reconstruct the environmental history of Autrecourt-et-Pourron. To study the taphonomy of plant macro-remains, we selected the archaeological site of Autrecourt-et-Pourron, "Le Pré du Roi" (Ardennes, France). It intersects some

palaeochannels of the Meuse River, most of them dating back to the early Holocene (11.7–10.7 ka cal. BP). Based on questioning and assessing quality of conservation of plant macrofossils in a fluvial and marshy context, we present a statistical reference system for the conservation of waterlogged plant remains preserved in oxbow lake sediments.

2 Material and methods

2.1 Study area

The fluvio-palustrine sequence of Autrecourt-et-Pourron "le Pré du Roi" (49°36'57, 391"N/5°2'53, 781"E/altitude ca. 155 m a.s.l.) is located in the Meuse Valley (Fig. 1). The Meuse River flows in a northwesterly direction through Jurassic (Late-Lias) marly bedrock, following the Jurassic cuesta scarp of the Eastern Parisian Basin. Airborne imagery and LIDAR-DEM resources (Institut Géographique National, IGN) provide a comprehensive overview of the present-day alluvial landscape, which includes a low sinuosity channel (*Canal de l'Est*), partly-located on the northwestern border of the valley floor and a 2 km-wide floodplain. This floodplain was shaped by both recent meandering planforms and older irregular palaeochannels with narrowing expansion. Such palaeochannels of the PalaeoMeuse river system were incised by a 4 m-thick layer composed of fluvial gravels corresponding to the Pleniglacial valley infilling of Weichselian age (Lefèvre *et al.*, 1993). The study carried out here was undertaken at the same time archaeological excavations of 2008 and 2012 (O. Brun, unpublished). Both field surveys highlighted several palaeochannels of the PalaeoMeuse River, including a well-preserved palaeochannel sequence (Fig. 2). Several stratigraphical units (SU) were defined according to a continuous vertical succession (Section 3–6) exposed from the bottom of Trench N°6 which was also continuously sampled for the palaeoecological reconstruction (Tab. 1).

2.2 Radiocarbon dating

Samples were directly collected from a 160 cm thick section including a fluvio-palustrine deposit with organic horizons. Based on the different lithostratigraphic units and organic material availability, 10 samples of wood and terrestrial plants were dated by the AMS radiocarbon method (^{14}C) in the Beta-Analytic (US) and Poznan-Radiocarbon (Poland) laboratories (Tab. 2). Oxcal 4.3 (Ramsey, 2017) was used to calibrate the AMS ^{14}C ages based on the Northern Hemisphere terrestrial IntCal13 calibration curve (Reimer *et al.*, 2013). Calibrated radiocarbon ages are expressed as ka cal yr BP, while the absolute chronology based on an age-depth model was constructed with a 2σ confidence envelope using

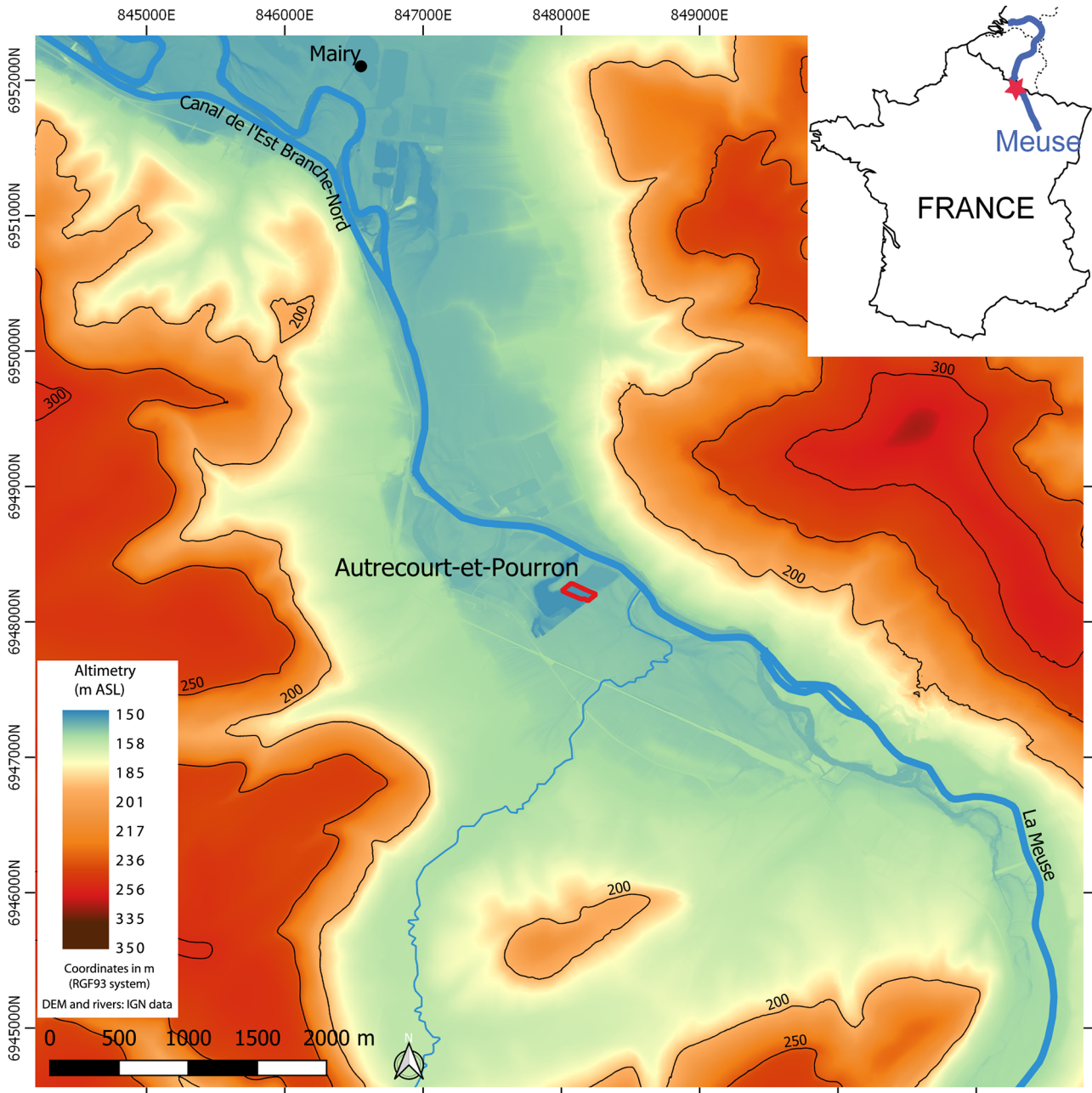


Fig. 1. Location of Autrecourt-et-Pourron sites (red rectangle), IGN-France map with altitude.

R-studio and CLAM package (Blaauw, 2010) and linear interpolation between the dated intervals was applied (Fig. 3).

2.3 Geochemical analyses

For each sediment sample, the grain-size range was assessed with a laser granularity analyser (Coulter LS 230). Samples were prepared by decarbonation (10% H₂O₂) and dissolution of the organic matter (HCl). They were sieved using a 2-mm mesh and then deflocculated with a few millilitres of sodium hexametaphosphate (Na₆O₁₈P₆). After homogenisation, the samples were introduced gradually using an eyedropper, and the concentration values were checked. The

different granulometric fractions of the sample were measured by laser sensor. The analyser measured the relative proportions of clay (0.04–2 μm), silt (2–50 μm) and sand (50–2000 μm) with an accuracy of < 1%.

Dry sediment samples (ca. 100 mg) were analysed for Total Organic Carbon (TOC) with a CNS analyser. The TOC content was measured by thermocatalytic oxidation (Elementar, Vario TOC cube analyser).

2.4 Analysis of plant macrofossils

The 29 carpological samples with a thickness of 5 centimetres and a volume of 10 to 20 litres were extracted

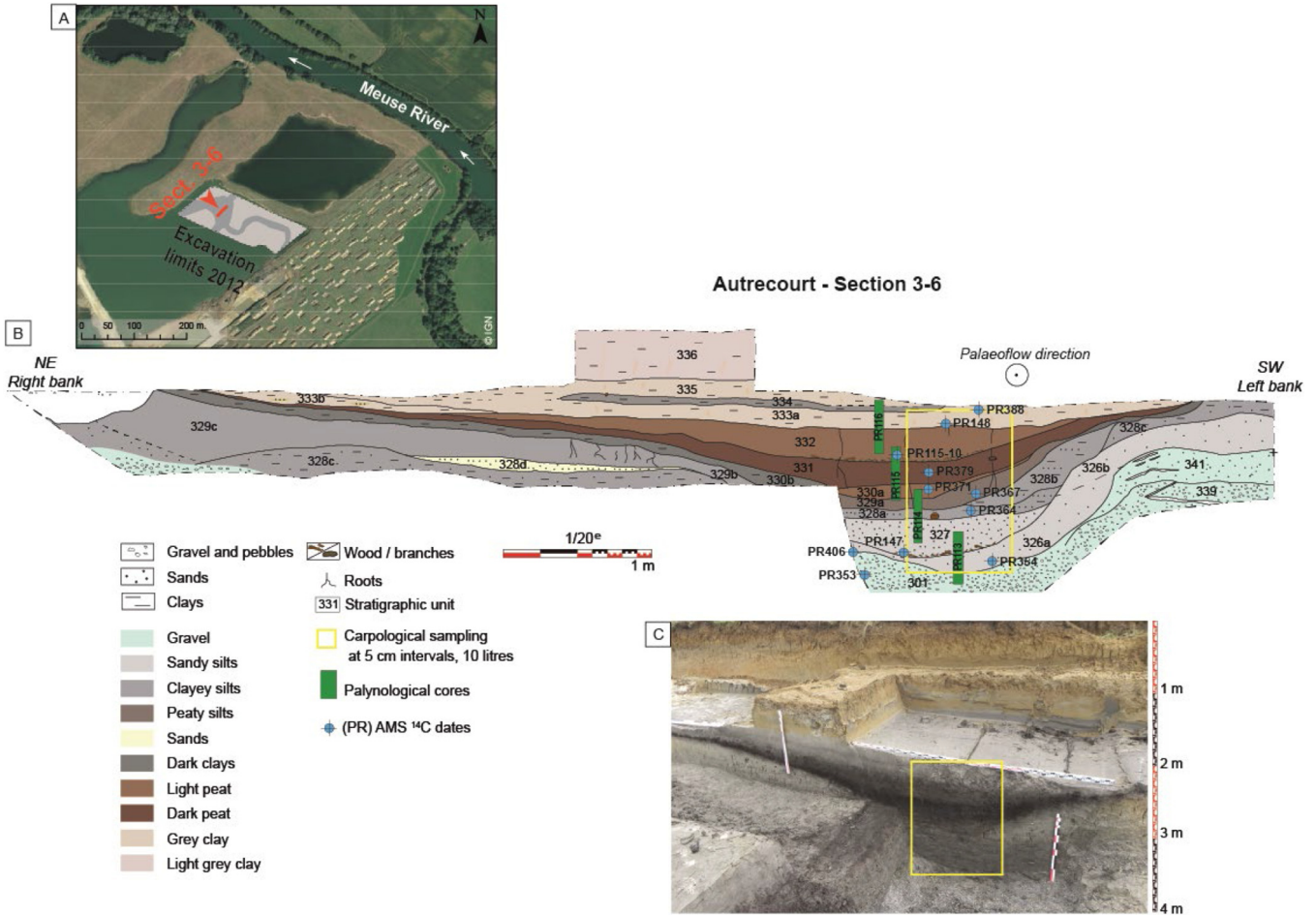


Fig. 2. Section 3–6 stratigraphy based on 2012 excavations at Autrecourt-et-Pourron. A. Location of 3-6 profile on the Meuse River valley. B. Detailed Cross-section 3–6 of Autrecourt-et-Pourron. 301: Alluvial plain with overbank fines deposits and pedogenesis, 339: Sandy gravels, 341: Gravelly sands with calcareous granules, 326a: Homogeneous grey sandy silts, 326b: Grey Sandy silts, 327: Grey sandy silts and with wood debris, 328a&b: Light grey clayey silts with sandy beds, 328c: Light grey clayey silts, slightly sandy, 328d: Homogeneous yellowish sands, 329a: Brown silts, slightly organic and bioturbated, 329b: Grey clayey silts, 329c: Mottled clayey silts with root traces, 330a: Light-brown peat, 330b: Grey clayey silts, 331: Dark-brown peat, 332: Light-brown peat affected by desiccation cracks topward, 333a: Grey to greenish-grey clay, 333b: Mottled light clay with sandy beds, 334: Dark-grey humic horizon, 335: Gray clay, 336: Light-grey clay with hydromorphic features. C. Section’s picture, yellow rectangle = sediment sampling area.

continuously on a stratigraphic column 85-cm wide. After sampling, sediments were water-sieved with several meshes (2, 1, 0.5, and 0.25 mm). Sieved macrofossils were fully sorted under a stereomicroscope with a magnification of 2x to 60x. Extracted elements were seeds, bryophytes, buds, vegetative parts (internodes, leaf abscission scars), twigs larger than 2 mm in diameter, whole leaves, needles, and charcoal over 1 mm in diameter. Plant macrofossils were identified using standard specialised literature (Berggren, 1969; Beijerinck, 1976; Tomlinson, 1985; Cappes *et al.*, 2006) and the reference collections from the Chrono-environnement Laboratory and GéoArchÉon company. The count is based on the fact that each whole macrofossil consists of one specimen. The fragments were also counted and then converted into an estimated integer (minimum number of individuals) using the “*méthode au jugé*” (Pradat, 2015). All data were recorded in the AGAM database (Schaal, 2019a). To measure functional diversity, the ecological requirements (Ellenberg, 1992; Julve, 1998) of species were averaged and weighted by the abundance of fossil remains.

2.5 Taphonomic criteria

We considered five descriptors, defined according to qualitative and quantitative parameters. The letters in parentheses correspond to abbreviations of the different conservation status.

- Sclerification rate of cell walls of plant macrofossil: sclerified (S), not sclerified (N), mixed-intermediate sclerification, (M).
- Fragmentation rate: whole (W) or fragmented (F).
- Degradation rate of external tissues: intact (I) or degraded (D)

We tested the influence of these descriptors on macrofossils’ potential preservation using a Principal Component Analysis (PCA) based on plant macrofossil concentrations, except for “algae oogons” and “charred remains” as they result from different taphonomic processes. PCA was done with R and the *vegan* package (Oksanen *et al.*, 2019). Thus, samples

Table 1. AMS radiocarbon dates, depth and dated material of Autrecourt-et-Pourron section 3–6 as indicated in Figure 2. The shaded line was not considered in the age model.

Autrecourt sample	Depth cm	Laboratory N°	Dated material	$\delta^{13}\text{C}$ (‰)	Age ^{14}C yr B.P. without $\text{d}13\text{C}$ correction	Conventional Age ^{14}C yr B.P. with $\text{d}13\text{C}$ correction	Calibrated age (cal yr B.P. 2σ) INTCAL13 (95.4%)	Calibrated age (cal yr B.P. 2σ) INTCAL13 (68.2%)	Calibrated age (cal yr B.C. 2σ) INTCAL 13 (95.4%)
2018-PR388-US333	210	Poz-106329	Waterlogged <i>Eupatorium cannabinum</i> seeds (174 fgt)		9090 \pm 50	10 396–10 182	10 271–10 200	8447–8233	
2012-PR148-US333a	215	Beta-326918	Waterlogged root	-29.3	4750 \pm 40	5577–5315	5467–5323	3628–3366	
2018-PR115-10-US332	240	Poz-10386	Waterlogged <i>Hippuris vulgaris</i> (4) + <i>Carex</i> (1) seeds		10 160 \pm 50	12 053–11 511	11 974–11 750	10 104–9562	
2018-PR379-US331	255	Poz-106360	Waterlogged <i>Thalictrum flavum</i> seeds (20)		9890 \pm 50	11 597–11 202	11 336–11 230	9648–9253	
2018-PR371-US330a	270	Poz-106318	Waterlogged <i>Thalictrum flavum</i> seeds (20)		9900 \pm 50	11 600–11 208	11 385–11 236	9651–9259	
2018-PR367-US329	290	Poz-106317	Waterlogged <i>Carex rostrata</i> seeds (30)		9900 \pm 50	11 600–11 208	11 385–11 236	9651–9259	
2018-PR364-US328	305	Poz-106387	Waterlogged <i>Carex</i> seeds (20)		9990 \pm 50	11 705–11 263	11 603–11 322	9756–9314	
2012-PR147-US327	330	Beta-326917	Charred wooden twigs	-28.2	10 030 \pm 40	11 620–11 264	11 620–11 398	9671–9315	
2017-PR354-US326	355	Beta-469433	Waterlogged <i>Linum alpinum</i> seeds (3)	-26.0	9810 \pm 50	11 287–11 126	11 242–11 191	9338–9177	
2012-PR406-US326a	360	Beta-460229	Waterlogged wooden twigs	-27.6	10 140 \pm 30	11 998–11 626	11 941–11 715	10 049–9977	
2012-PR353-US303	400	Beta-460231	Waterlogged wooden twigs	-27.9	10 310 \pm 30	12 377–11 962	12 156–12 011	10 428–10 013	

Table 2. Stratigraphy of the channel-fill sequence of Autrecourt (Section 3–6).

Stratigraphic units (SU)	Description (field and grain-size)	Thickness (in m.)	Sedimentary interpretation (depositional setting)
336	Light-grey clay with hydromorphic features		
335	Grey clay		
334	Dark-grey humic horizon	0.85	Alluvial plain with overbank fines deposits and pedogenesis (humic horizon and redoxic soil) (FF: floodplain fines sensu Miall, 1996)
333 a	Grey to greenish-grey clay		
333 b	Mottled light clay with sandy beds		
332	Light-brown peat affected by desiccation cracks topward	0.3	
331	Dark-brown peat (reworked to the North-East direction)	0.22	Vegetated swamp deposits with Histosol development (3 soils) (CH-FF sensu Miall, 1996)
330 a	Light-brown peat	0.12	
330 b	Dark-grey clay (progressive transition with 330a)		
329 a	Brown silts, slightly organic (peat) and bioturbated		Vegetated swam a) with overbank
329 b	Grey clayey silts	0.2	fines (b) and incipient soil
329 c	Mottled clayey silts with root traces		(c) (CH-FF sensu Miall, 1996)
328 a&b	Light grey clayey silts with sandy beds		
328 c	Light grey clayey silts, slightly sandy		
328 d	Homogeneous yellowish sands	0.5	Backswamp to overbank deposits in a channelized area (CH-FF sensu Miall, 1996)
327	Grey sandy silts and with wood debris		
326 a	Homogeneous grey sandy silts		
326 b	Grey Sandy silts		
341	Gravelly sands with calcareous granules		
339	Sandy gravels		Lateral accretion macroform and cross-bedded silty sands (Lateral accretion: LA; Sandy bedforms: SB sensu Miall, 1996)
301	Cross-bedded polygenic gravels with silty sand beds organized in fining upwards (Clast size: 2–50 mm, sub-rounded clasts, moderately sorted, openwork texture and normal grading)	1 min	

of Autrecourt-et-Pourron were classified qualitatively, and a reference system was created for the site.

3 Environmental history of Autrecourt-et-Pourron

3.1 cold steppic environment

Sandy and clayey silts (SU326, SU327 and SU328) deposited in low sedimentation dynamics, while herbaceous plants and taxa from basophilic grassland vegetation such as *Linum alpinum*, *Scabiosa columbaria* and *Knautia arvensis* are dominants (Fig. 4). The record of *Linum alpinum* in SU326 is meaningful in terms of paleoclimate, as this species only grows today in subalpine areas, above 1500 m a.s.l. (Julve, 1998). *Salix* is the dominant tree, as it grew directly near palaeochannel. In addition, plants typical of eroded sandy and stony soils, such as *Arenaria serpyllifolia* and *Linaria supina*, together with the recorded fungal species *Cenococcum geophilum*, indicative of short environmental stress (Kroll, 1988; van Geel *et al.*, 1989; Walker *et al.*, 2003; Eide *et al.*, 2006), suggest most certainly an erosion of soil and organic matter in the floodplain. Sporadic fluvial inputs observed as overflow facies in SU327 and SU328 are in agreement with such biological features. The notable abundances of *Urtica dioica*, *Chenopodium rubrum*, *Ranunculus repens* and *Prunella vulgaris* might suggest the presence of large herbivores (Bos *et al.*, 2006) since coprophilous fungi (Sordariaceae and *Sporormiella*), which could be indicators of grazing pressure (van Geel and Aptroot, 2006; Gauthier *et al.*, 2010), have been observed in

the pollen samples (E. Gauthier, personal communication, Apr. 2020).

3.2 Channel infilling

During SU329 phase, a decline of *Betula* sp. was observed, suggesting a greater distance from wooded areas in the valley (Fig. 4). A decrease in *Salix* sp. was also detected in the floodplain, while Poaceae steppe, *Thalictrum* and *Filipendula* wet meadows were significantly well-represented. Plant macrofossils assemblages were strongly dominated by *Chara* oogonia and *Carex rostrata*, indicative of aquatic environments. This sudden change in the vegetation composition together with the development of organic mud in SU329 suggest that channel abandonment occurred away from the active river system. Furthermore, the presence of aquatic and helophytic plants, such as *Myriophyllum spicatum* and *Carex rostrata*, indicate slightly colder average temperatures than before.

3.3 Development of riparian environment

In the silts, the moisture content was rather stable and provided a suitable environment for the preservation of organic material, the plant macrofossils in the peat layers (SU330 to SU332) were more deteriorated. This taphonomic bias, even if low, should be carefully considered in palaeoecological interpretations. In the diagram (Fig. 4), aquatic plants virtually disappeared and were replaced by marsh plants, especially *Carex elata*, *Filipendula ulmaria* and *Thalictrum flavum*.

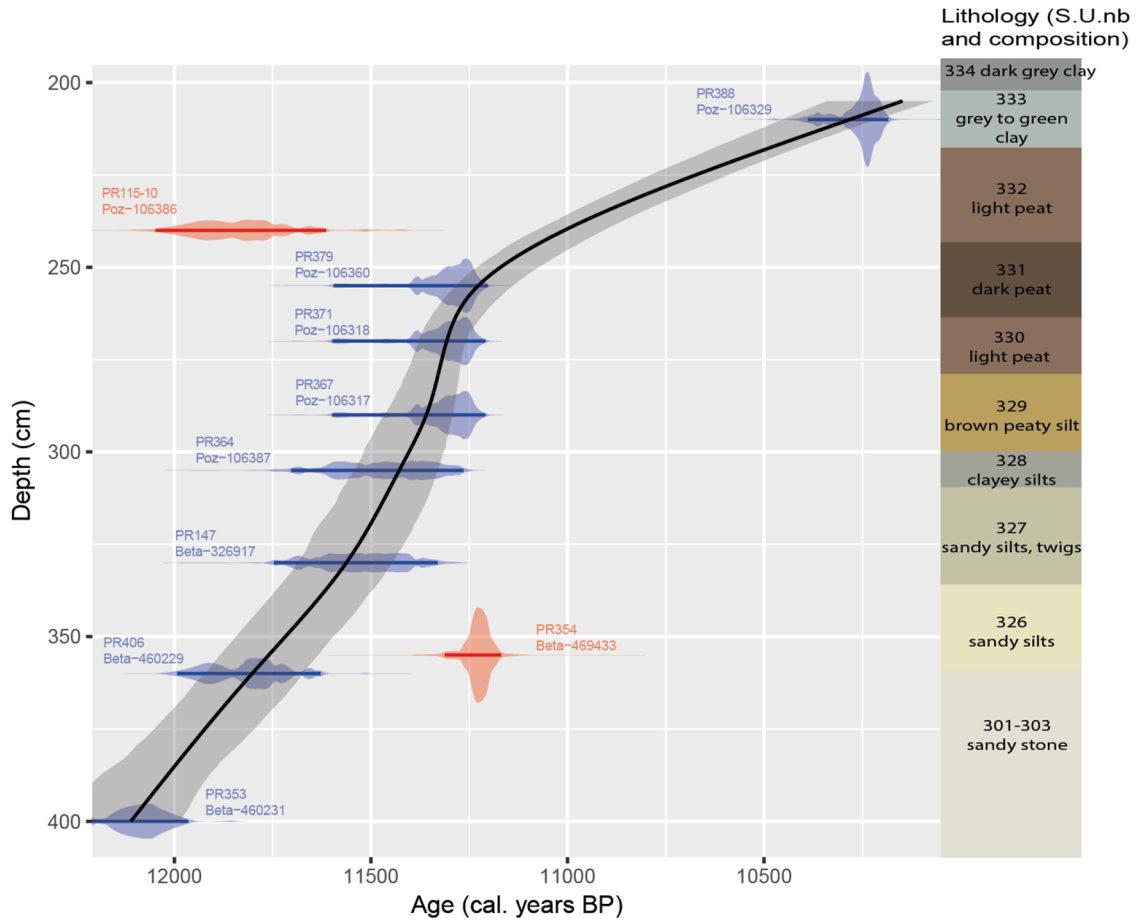


Fig. 3. Age-depth model in calibrated yr BP and lithology of the Autrecourt-et-Pourron, section 3–6 sequence. Radiocarbon dates (Tab. 1) were calibrated using Oxcal 4.3 (©Christopher Bronk Ramsey 2018) based on the Northern Hemisphere terrestrial IntCal13 calibration curve (Reimer *et al.*, 2013). The absolute chronology based on an age-depth model was produced with a 2σ confidence envelope using the CLAM package (Blaauw, 2010). The age-depth model is presented with its median (middle grey line) and its associated 95% confidence interval (grey area). The calibrated age range of dated samples is indicated in blue and the dates excluded from model in red (outlying). Two dates were rejected after age-depth modelling and outlier analysis, primarily because of age reversals.

In addition, the biodiversity of terrestrial grasses sharply decreased. Then in SU331 (dark peat), the specific composition of marshland plants changed: *C. elata* and *T. flavum* were replaced by *Sparganium erectum* and *Filipendula ulmaria* as the principal species. Large helophytic plants with rhizomes, such as *Typha* and *Sparganium*, developed in connection with the nutrient-rich peat. Based on their ecological requirements, appearances of the tree species *Prunus spinosa* and *Rhamnus cathartica*, and the herbaceous forest plants *Stachys sylvatica* and *Luzula* sp. were favoured by the soil texture and its organic-rich content (Ellenberg, 1992; Julve, 1998). The abandoned channel was colonised by trees and grasses that composed the riparian vegetation.

3.4 An abandoned channel

In SU332, *Betula* sp. was noticeable, while a high density of *Salix* sp. macro-remains was observed together with the first occurrence of *Populus* (Fig. 4). The results reveal that an alluvial forest developed in the floodplain. Changes in the

composition of the aquatic community (*Ranunculus aquatilis* and *Hippuris vulgaris* as the main species) provide evidence of hydrodynamic fluctuations. These wetter and more anoxic conditions favoured the conservation of the organic remains. The alluvial sedimentation also changed with massive clay deposition as observed previously in SU333. These facies settled out from suspension in a backwater area of the floodplain, thus in the distal part of the fluvial distributary system. This upper layer of grey clay was strongly subjected to erosional factors, resulting in the carpological material being most likely moved and reworked, causing fragmentation and even destruction. Given the absence of fossil remains of aquatic plants, it can be assumed that the channel was definitely abandoned.

4 Adapted taphonomic approach

4.1 General description of the PCA results

In total, 18 065 plant macro-remains from 88 taxa were isolated and PCA results highlight a clear structuring of



Fig. 4. Combined analysis diagram. From left to right: the age chronology calibrated before the present, lithostratigraphy, the sediment accumulation rate (year/cm), the organic carbon content (%), coals larger than 1 mm, carbonized seeds, microfossils, malacofauna and forest plants, aquatic and terrestrial, sclerotia of *Cenococcum*, remains of algae oogons, seeds of wetland plants, macro-remains of trees and forest plants, grasslands and wastelands, herbaceous plants not associated with a group. At the end of the diagram, the palynological data are summarized by the percentage of trees and herbaceous plants.

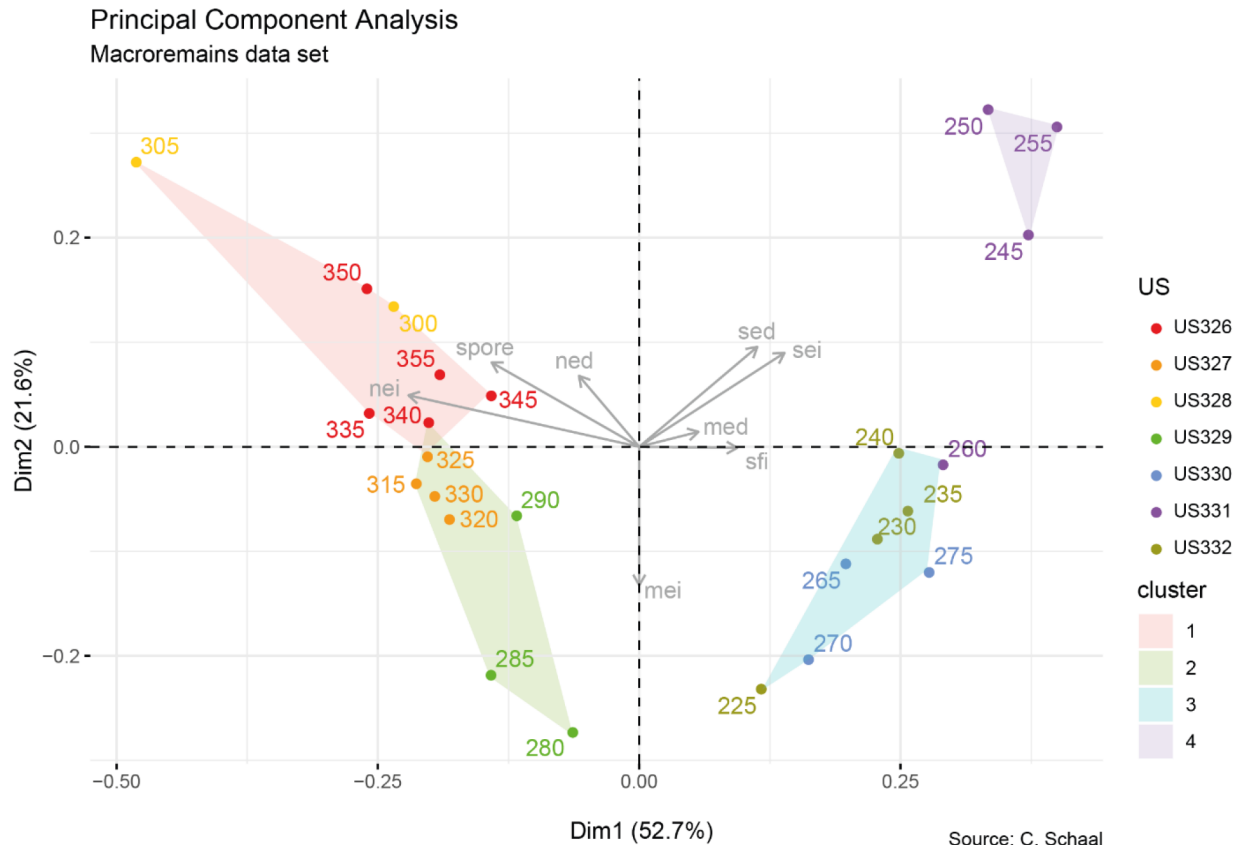


Fig. 5. PCA on taphonomic variables. The colours of the points correspond to the stratigraphic units. The labels correspond to the depths of the samples. The colour polygons correspond to the cluster of the correspondence analysis. The arrows correspond to the variables defining the state of conservation of the macro-remains (NWI: non-sclerified whole intact; NWD: non-sclerified whole degraded; MWI: mixed whole intact; MWD: mixed whole degraded; SWI: sclerified whole intact; SWD: sclerified whole degraded; SFI: sclerified fragmented intact).

variables (Fig. 5). Axis 1 retains 52.7% of inertia. Axis 2 also retains 21.6% of inertia. We see clear trends in the distribution of groups according to their conservation. The samples found on the negative side of axis 1 come from the deepest SUs characterised by whole and intact non-classified macro-remains (NWI) and whole but degraded non-classified remains (NWD) associated with fungi *sclerotia*. The intermediate depth samples are located on the positive side of axis 1, associated with intact whole sclerified remains (SWI) and whole but degraded sclerified remains (SWD). Axis 2 is strongly influenced by the mixed nature of sclerification; the intact whole mixed whole plant macro-remains (IPM) are mostly distributed on the negative side of the axis. Archaeobotanical variables of the PCA are distributed according to conservation status of plants, ranging from “good” in negative part of axis to “bad” in the positive part. On one hand, this distribution correlates with grain-size and organic chemistry, pointing out that samples with the best-preserved remains have a high sand content and C/N ratio. On the other hand, the least well-preserved remains belong to samples with low sand content and C/N ratio. Intermediate samples show a wide range of variations in particle size and chemical factors in increasing or decreasing order.

4.2 Good conservation in lower units of sequence

Silt-sand, silt-clay or silt-muddy contexts (SU326 to 329), located more than 280 cm below current ground unit and constantly bathed in the water table, are favourable for conservation of plant remains (Fig. 6). The unsclerified remains, with fragile cellular tissues, are mainly present as whole elements that do not present any morphological degradation. Bryophyte stems, Cyperaceae achenes still enclosed in their utricles, *Linaria supina*, *Rorippa palustris*, or *Linum alpinum* seeds are typical examples of these fragile macrofossils (Fig. 7A). Thus, the remains embedded in lower stratigraphic units are only slightly eroded or corroded. The confidence in fossil assemblages is robust and assemblages could be considered as representative of the ecosystems existing at the time of the unit formation.

4.3 Differential conservation in peat units

4.3.1 Light peat unit

The light brown peaty marshlands contexts, SU330 and SU332, located between 275–255 cm and 245–225 cm deep and still below the maximum unit of current groundwater

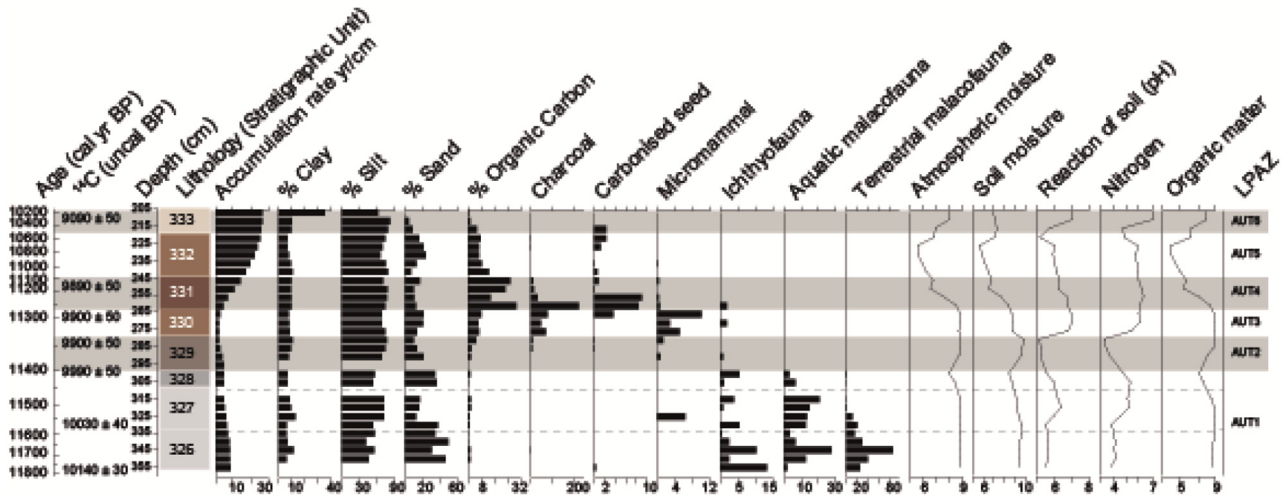


Fig. 6. Diagram with Lithostratigraphy, grain-size (%), organic carbon (%), charcoal (number/litre), carbonized seed (number/litre) and aquatic and terrestrial fauna (number/litre) data. Ecological values (moisture, reaction, nitrogen and organic matter), of the identified plant taxa at the species level, were averaged and weighted by the abundance of plant fossil remains. Depth below ground level. LPAZ: Local Pollen Assemblage Zone.

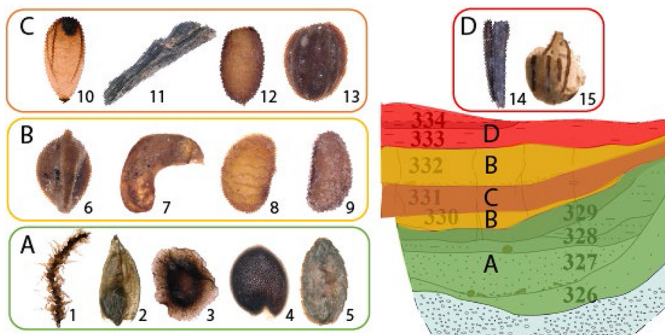


Fig. 7. Stratigraphic distribution of examples of plant macrofossil types and conservation morphological differences. 1. Bryophyte twigs; 2. Cyperaceae achenes still enclosed in their utricles; 3. *Linaria supina* seed; 4. *Rorippa palustris* seed; 5. *Linum alpinum* seed; 6. *Carex* sp fruit; 7. *Filipendula ulmaria* seed; 8. *Ranunculus aquatilis* seed; 9. *Myriophyllum spicatum* seed; 10. *Sparganium erectum* seeds; 11. *Salix* sp. buds; 12. *Hippuris vulgaris* seed; 13. *Thalictrum flavum* seed; 14. *Eupatorium cannabinum* fruit; 15. Apiaceae mericarpe.

table, were positive to preservation of organic plant material (Fig. 6). However, these peat units constitute a context of poorer conservation. The carbon to nitrogen ratio, value below 20, indicates a progressive resumption of macroremains deterioration. The fragile plant macrofossils (bryophyte leaves, Cyperaceae utricles) are absent or degraded. The proportion of remains with more resistant walls (called mixed or intermediate between unsclerified and sclerified) increases proportionally, such as fruits of *Carex* sp., *Filipendula ulmaria*, *Ranunculus aquatilis* or *Myriophyllum spicatum* (Fig. 7B). These peat units are characterised by a slowdown in water circulation, notable by an increase in proportion of silt, accompanied by a development of swampy vegetation on the edges. The most fragile remains, which do

not settle quickly in the water, are degraded in an aerobic environment. A swamp zone is developing, limiting runoff inputs. Nevertheless, soil and atmosphere remain sufficiently moist, slowing down the significant degradation of organic matter. Robustness of fossil assemblages is reduced but still reliable. Taphonomic bias, although low but noticeable, should be carefully considered in palaeoecological interpretations.

4.3.2 Dark peat unit

The SU 331 (dark brown peat horizon) is interbedded between the two units of light. It is located between 255 and 245-cm depth in the current groundwater table (Fig. 6). The concentration in remains drops from 2385 to 886 per litre of sediment. On the other hand, the average number of taxa raised from 35 to 28. A C/N ratio of 17 suggests an acceleration of decomposition of organic matter. This dark brown peat sedimentary horizon is mostly composed of intact or degraded whole sclerified plant remains, such as *Sparganium erectum* seeds, *Salix* sp. buds, *Hippuris vulgaris* or *Thalictrum flavum* seeds (Fig. 7C). Non-sclerified elements are absent or rare and highly degraded. The environment is subject to start of an infilling of the channel. Nevertheless, floristic composition is not a major factor causing the aggravation of organic material decomposition. Hydrological and climatic condition changes towards drying and/or warming are more likely. This environmental evolution is confirmed by abundance of carbonized plant macrofossils (wood and seeds) whose climatic and/or anthropogenic origin remains to be discussed (Schaal, 2019b; Schaal et al., 2020). These major changes in soil and hydrological conditions cause important taphonomic variations that lead to increased decomposition. Palaeoecological interpretations of this sedimentary unit will have to take into consideration the poor robustness of assemblages due to degraded conditions; many taxa are disappearing because of repeated drying. These drying phases could be at the origin of the desiccation, differential conservation and disappearance of

the most fragile macrofossils, such as fruit envelopes and capsules with thin and soft outer walls.

4.4 Degraded units

The upper unit of the stratigraphic section, SU333, located below the current groundwater table, consists of grey to green clay (Fig. 6). The granulometric analyses highlight strong increase in clayey deposits. The C/N ratio is the lowest found in the entire sequence/trench (14), and suggests the acceleration of organic matter alteration. The average concentration and taxonomic diversity of plant remains are at their lowest with 392 remains per litre, for 15 taxa. A majority of fragmented and/or degraded remains such as *Eupatorium cannabinum* and Apiaceae are characterising the macrofossil assemblages (Fig. 7D). Weathering and physical erosion are potentially the main factors responsible for high degradation, or even the total destruction of a large part of assemblage and therefore impossible to recover. Palaeoecological interpretation must be extremely careful considering this major taphonomic bias. Thus, low number of taxa, with differential conservation, could be an indicator of a water level decline.

5 Conclusion

Wetlands (lakeshores, peat bogs, rivers) are ideal contexts for archaeobotanical research, indeed, the quantity of organic material preserved is often much higher than that observed in terrestrial environments. While it is certain that absence of wet conditions leads to destruction of non-fossilised plant macrofossils, the current presence of groundwater does not presume an exceptional conservation of waterlogged subfossil material.

Up to now, for off-site, a comprehensive framework for assessing the conservation status of plant macrofossils in a wet context does not exist. Based on the various studies done in this field, we have set up a specific methodology for the analysis of the Autrecourt-et-Pourron palaeochannel. This method is based on granulometric and physico-chemical measurements of sediment to which we associate histological and morphological parameters of plant macrofossils. From the combination of these parameters, we created a taphonomic scale to assess the conservation status of archaeobotanical material. This scale makes it possible to estimate the level of confidence that we can bring to palaeobotanical assemblages.

- 1 Deep units of silty sediment provide an excellent preservation of plant macrofossil assemblages that will make possible to reconstruct past environments in details.
- 2 The unit of light peat, whose moisture content has remained sufficiently constant, is also a suitable environment for the proper conservation of organic material.
- 3 The unit of dark peat is strongly impacted by the degradation of plant remains and caution must be taken for the interpretation of incomplete carpological assemblages.
- 4 Unit of grey clay is very strongly subject to erosion factors, material is most likely moved and reworked, leading to its fragmentation and even destruction, interpretations must be considered with care.

Taphonomic phenomena do not affect the organic material in the same way given the histological differences of the remains. During sampling and analysis, it is therefore important to consider, independently, preservation status of each vegetation marker. The perceptible changes in taphonomy of plant macrofossils suggest that the landscape structure is changing with hydrological and climatic changes. In addition, anthropogenic causes such as the exploitation of the palaeochannel or the nearby land are possible hypothesis. However, the absence of archaeological data acquired to Autrecourt-et-Pourron for the Preboreal, do not allow for confirm or infirm a potential human impact.

In conclusion, it seems that taphonomic approach contributes significantly to the understanding and interpretations of plant macrofossil assemblages. For future palaeoecological studies, it will be important to strengthen our knowledge through multidisciplinary approaches, in order to build solid taphonomic references adapted to river and off-site sites. The framework will have to be applied to other sites of the same type to confirm the conclusions obtained at Autrecourt-et-Pourron.

Acknowledgements. Financial support for this study was provided by a CIFRE ANRT and by the Conseil Départemental of the Ardennes (France). The authors express their sincere thanks to Christophe Loup for CNS analyses, Marguerite Perrey for grain-size analyses, Mathieu Lejay for data mapping, and to Benjamin Dietre for his help with age-depth model drawing and linguistic editing. We are also grateful to the anonymous reviewers for their help in improving the quality of the manuscript.

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Cite this article as: Schaal C, Naton H-G. 2021. Contribution of archaeobotany to understand taphonomic phenomena. The case of a Preboreal palaeochannel of Autrecourt-et-Pourron (Ardennes, France), *BSGF - Earth Sciences Bulletin* 192: 6.