Holocene history of the River Seine, Paris, France: bio-chronostratigraphic and geomorphological evidence from the Quai-Branly

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Christine Chaussé[1,2], Chantal Leroyer[3], Olivier Girardclos[4], Gisèle Allenet[1,3], Patrick Pion[5] and Pascal Raymond[1]

[1] - INRAP, 7 rue de Madrid, 75008 Paris, France

[2] - Laboratoire CNRS de Géographie Physique, 1 pl. A. Briand 92195 Meudon, France; chausse@cnrs-bellevue.fr

[3] – Ministère de la Culture and UMR6566, Centre National de Préhistoire, 38 rue du 26e RI, 24000 Périgueux, France

[4] – Centre d'Etude en Dendrochronologie et de Recherche en Ecologie et Paléo-écologie, 12 av. de Chardonnet, 25000 Besançon, France

[5] – Maison de l'Archéologie et de l'Ethnologie/UMR7055, Université Paris X, 21 allée de l'Université, 92023 Nanterre cedex, France

Abstract

Bio-chronostratigraphic observations compiled from Quai-Branly in Paris (France) and their comparison with previous studies in the Paris Basin allow documentation of the morphodynamic evolution of the River Seine during the middle and late Holocene. This history begins in the Boreal (between 9500 and 8850 cal. BP), with the deposition of tufa, expressing a stabilized river bed. During the second part of the Subboreal the water table was low. At the beginning of the Subatlantic (towards 2800/2700 cal. BP), alluvial dynamics increase, as is recorded elsewhere throughout the Paris Basin. At the beginning of the second part of the Subatlantic (around 2000 cal. BP), flood dynamics persisted at a lower intensity. Human occupation occurred from the 5th century AD. Before or around the beginning of the 17th century AD, a natural levee was built, indicating the progressive attachment of the Quai-Branly area to the flood plain. The hydrodynamic evolution of the River Seine observed at the Quai-Branly site is similar to that recorded in other river valley floors of the Paris Basin. This evolution appears to be in response to global climatic changes rather than to variations induced by human activities.

Key words: River Seine, France, Holocene, hydrodynamic evolution, pollen data, dendrochronology,

1 Introduction

The construction of a new museum at the “Quai-Branly” site in Paris (France) has enabled the exploration of a part of the alluvial plain of the River Seine during an archaeological rescue operation (Figure 1).

This paper presents the history and human occupation of this riverside area. Our reconstruction makes use of a bio-chronostratigraphic approach based on pollen analyses, geochronological (radiocarbon dating and dendrochronology) and geomorphological analyses, while also taking into consideration the archaeological data. Using comparisons with previous work carried out both in Paris and in the nearby area, our observations can be placed in the context of the Holocene evolution of the River Seine within the Paris Basin.

2 Location and general context of the site

In Paris, the River Seine lies on an alluvial plain whose elevation ranges between 27 and 30 m above sea level (msl) (Figure 1). The entrenchment into the plateau above reaches ca. 100 m. The Quai-Branly site is situated at the apex of the convex left bank of the river meander that flows through Paris. The alluvial plain is made up of overwash deposits developed along an approximately 3-km-wide belt containing the current river bed. The deposits are 8 m thick, reaching 13 m along three palaeothalwegs cut down into the Eocene basement rocks. These deep longitudinal troughs follow isobathic contours situated 20 m msl. The current bed of the river is established within the southern one (Diffre, 1969; Mégnien, 1979) (Figure 1). Neither the age of their incision, nor the chronology of their infilling are known.

3 General Stratigraphy of zone A and trench B

Two archaeological excavation zones (A and B) allowed specific morphostratigraphic observation (Figure 1). In zone A and trench B, relevees were carried out along a profile following an overall N-S axis perpendicular to the current channel of the Seine. The various cross-sections obtained (north and south logs, 1003, 1004, 1007, 18, 10 and TR2) were assembled together and summarized as “cross-section 10” which extends over a length of about 50 m (Figure 2). It was completed by finer-scale stratigraphic observation (cross-sections 6, 8, 15, Figure 3) delivering more precise information on the sedimentary unit [3] containing preserved wood. The sequence is developed over 9-10 m, and displays several fluviatile sedimentary units. The deposits are overlain by 2 m of recent anthropic fill.

- At the base, unit [1] corresponds to a tufaceous deposit (Figure 2). It rests on coarse fluviatile pebbles [0] observed only locally at around 19 m msl. The base of the gravel layer was not reached. The tufaceous deposit is composed of carbonate concretions of metric to plurimetric size. The internal part of the structure contains cavities (from mm-scale to several cm in size), the smaller ones being filled by brown clay coatings 100 to 1000 µm thick. These argillans are weakly birefringent, showing a slight orientation. They enclose more or less altered carbonate particles (size ranging between 2 and 100 µm).

- The overlying unit [2] is composed of several sub-units (Figure 2). The lowermost sandy deposits [2a] cap a small scour-like structure, approximately 1.5 m deep and 5 m wide. This incision, located at the south of the profile, cuts down into the underlying tufa. The sediment fill has a concave structure and consists of coarse sands and occasionally oncolitic gravels. At the base, it encloses fragments of tufa resulting from the erosion of the underlying carbonate mass, as well as some clayey-organic balls. Locally, sub-unit [2a] is interstratified with organic-rich clays (C.174/1) (“C” stands for “clayey context”) and heterogeneous layers of gravel, sands and silts associated with fragments of tufa and clayey-organic balls (C.173/2 and 3). One of the layers (C.174/2) contains a dugout (W.175) (“W” stands for wooden object). The most recent sandy deposits of [2a] extend over the total width of the profile. Sub-unit [2a] is overlain by a gravel-sand layer [2b] with cross bedding, which caps the surface of the tufa [1] towards the north. This unit shows a progressive fining up texture with sedimentary aggradation. Wooden remains, including a fish-trap and posts (W.48), were found at its base. The overlying sub-unit [2c] is made up of heterogeneous material including gravel, clay gravels and balls enclosed in sands and silts mixed with fine-grained organic debris. The unit does not exhibit any internal structure. The uppermost sub-unit [2d] consists of sands with sub-horizontal gravel beds, containing two interstratified cm-scale organic clay lenses (C.136 and C.124).

- Unit [3] consists of gravely sand beds with a lenticular structure (sub-units [3a] to [3g]) filling several troughs. Their distribution can be traced along two courses (northern and southern: Figure 2) on either side of an alignment of piles (W.21) following an E-W axis. The northern course is filled by several layers of cross-stratified sand and gravel beds ([3a], [3d], [3g]). Their succession indicates a lateral displacement of the deposits northwards. They are interstratified with thin and discontinuous clayey-organic beds (5 cm) (C.43; C.154; C.35; C.26; C.23; C.24). The place of some so-called “floating” layers (I, C.2, C.15, C.17, C.41; C.69) in the stratigraphic succession is uncertain because of disturbance caused by an access road for excavation machines. Post-dating [3a-c] but older than [3g], these layers could belong to unit [3d] or to another unseen sedimentary unit. Along the southern course, the deposits [3e-f] are more homogeneous and consist of sands and gravels, containing argillaceous beds primarily along sections 6, 8 and 15 around the posts forming W.21 (Figure 3). These sandy deposits present an erosive contact with the underlying unit [2], cutting down to a depth of 1 m over an observed width of 8 m.

- Unit [4] is composed of sandy sediments becoming silty upwards. Three sub-units are distinguished. The oldest [4a] consists of medium to coarse loose bedded sands. Some beds contain pebbles or gravels. The overlying unit [4b] is made up of generally finer material with medium/fine sands at the base, grading into more or less sandy silts at the top; a progressive fining of textures is associated with sedimentary aggradation. This unit is interstratified with rather thin organic-clayey beds (between 5 and 10 cm), particularly in the lower half of the fill. The bedding of these units dips southwards. The top of [4b] is weathered by a soil horizon [H1] of dark beige colour, associated with a well-expressed microporosity and prismatic structure. It is overlain by more or less massive sandy silts [4c], which are themselves capped by a second soil horizon [H2] exhibiting the same overall characteristics as [H1].

4 Dendrochronological and radiocarbon data

One hundred and eleven wooden remains were extracted from the excavations in zone A, exposed in units [2] and [3] (Figures 2 and 3). In Table I, a first series of dendrochronological analyses is coupled with radiocarbon dating on the wooden remains, comprising sixteen objects of oak (English names with latin equivalents are given in Table II) and one of beech. These data contribute to the chronostratigraphic analysis of the Quai-Branly sequence. The first set corresponds to an alignment of vertical posts belonging to the archaeological context (wooden objects) W.21, which groups several sub-contexts: W.21, W.41, W.64, W.143 and W.146 (Figure 2). This alignment forms a structure built in the deposits of unit [3] that is contemporaneous with the accumulation of the sandy formations. The second set comprises posts in horizontal position, and objects included in the sedimentary deposits of unit [2] (W.164, W.48 and W.166).

All objects were cut from young trees exhibiting less than 50 rings. The short time-spans represented by the series of rings being difficult to match with the established dendrochronology master scale, dendrochronological analysis was associated with radiocarbon measurements (Baillie, 1995; Lambert, 1998). Using dendrochronological criteria, samples were assigned to growth groups (M1, M4 and M6), which then served as a basis for radiocarbon dating. The samples analysed by ^{14}C were cut out from segments crossing more than 10 rings.

The ^{14}C results generalized over the three growth groups are presented in years BP plus or minus one standard deviation (Table I). Ages were calibrated using the OxCal 3.8 program (Bronk Ramsey, 2001) based on the IntCal98 data (Stuiver et al., 1998). The limits selected correspond to the interception of the calibration curve with 95% i.e. two standard deviations of the radiometric age value measured. Ages are expressed in calibrated years on the historical scale (BC and AD) and in years before 1950, that is, cal. BP.

The M1 growth group is thus attributed to the period 4785-4423 cal. BP. It includes various objects belonging to the sets W.164, W.48 and W.166**.** ^{14}C dating of the W.164 object/12 yielded an age of 5025-4831 cal. BP.

The growth groups M4 and M6 are attributed respectively to the periods 1416-1298 and 1413-1300 cal. BP; M4 and M6 groups are thus contemporaneous. Statistical analysis demonstrates that M4 and M6 groups can be grouped (M13) and the calibration of the initial radiocarbon dates is combined using a procedure known as “wiggle-matching”. Ring ages 1-10 and 11-22 of M13 were thus determined, dating the trees felling between 1365 and 1265 cal. BP, corresponding to all of the oak objects. The reliability indicator for this result is significant, since its value is 116% for a threshold of 50% (Bronk Ramsey and Weninger, 2001). On the other hand, the ^{14}C measurement obtained on the beech pile yielded an older age, which shows that the foundation of W.21 is older by at least 100 to150 years.

5 Pollen data

Pollen analysis of 83 samples was carried out on zone A and trench B, throughout the sedimentary sequence from the tufa [1] to the sandy silts [4]. The samples were extracted from the various organic clay levels interstratified in the sandy units and the carbonate structures (Figures 2, 3, 4). Pollen preparation followed a procedure using separation by Thoulet heavy liquid (Girard and Renault-Miskovsky, 1969) but the pollen samples were then mounted in glycerol. Pollen preservation was very good in most of the levels, except in the unit [4]. An average of 370 pollen grains was counted in each sample and 109 taxa were identified (Table II). Their identification was based on literature reference (Faegri and Iversen, 1975; Reille, 1992, 1998) and pollen reference collections. The pollen diagram was calculated and drawn using GpalWin (Goeury, 1997). The percentages are based on a pollen sum that includes arboreal pollen (AP=trees and shrubs), herbs and ferns (*Sphagnum*, dinoflagellate cysts and unidentified grains were excluded). The pollen diagram presented here is a summary graph where taxa are grouped according to their ecological affinities (Figure 4, Table II).

The pollen diagram, divided into 9 local pollen assemblage zones (LPAZ), defined by a visual study of the diagram and mostly subdivided into subzones (Figure 4, Table III). Floristic features of the Quai-Branly pollen diagram are characteristic of the holocene vegetation history defined in the Paris Basin by 7 regional pollen assemblage zones (RPAZ) (Leroyer, 1997). These subdivisions used and there chronological implications are shown in Figure 5. According to the ^{14}C dating of the pollen diagrams of the Paris Basin, these correlations provide a biostratigraphical framework for the Quai-Branly sequence.

- The first local pollen zone (MBQ1) is characteristic of the second part of the RPAZ V (Boreal), defined by the prevalence of *Corylus* over *Quercus* and *Ulmus*. The Vb subzone begins towards 9500 cal. BP and ends towards 8850 cal. BP.

- The characteristics of MQB2 (appearance of *Tilia* and *Fraxinus*, rise in *Quercus* at the expense of *Corylus*, slight resumption of *Pinus*) show that it belongs to the RPAZ VI (early Atlantic phase). RPAZ VI begins towards 8850 cal. BP and ends towards 7500 cal. BP. However an attribution to the beginning of the late Atlantic (towards 7000 cal. BP) cannot be completely ruled out because *Cerealia* is present in MQB2b. Indeed, according to the cross-dating suggested by the pollen zonation, these traces of agro-pastoral activities appear to pre-date the establishment of Neolithic cultures. However, such early indications of cereal cultivation have already been pointed out (Richard ed., 2004.)

- From its characteristics (rise of *Tilia*, *Fraxinus* and *Alnus*), MQB3 can be attributed to the RPAZ VII (late Atlantic), beginning around 7500 cal. BP and ending between 5600/5450 cal. BP. Indication of human activities (presence of *Cerealia*, rise in ruderal assemblage, rise of hazel at expense of oak and alder) suggests an occupation of the area by early or middle Neolithic groups (Leroyer, 2004, 2006).
- MQB 4 can be attributed to the end of RPAZ VII or the beginning of RPAZ VIII (Subboreal) according to the increase of *Alnus* in the valley bottoms and the small rise of human pressure (Leroyer, 2003). This transition period is fixed between 5600 and 5450 cal. BP thus, MQB4 is situated at around 5500 cal. BP.
- The modifications observed in MQB5 (appearance of *Carpinus*, rather high frequencies of *Fagus* and increase of anthropogenic indicators), correspond to features characteristic of RPAZ IX (lower part of the Subatlantic phase), which covers the two Iron Ages (Leroyer and Allenet, 2006). RPAZ IX begins at around 2800/2700 cal. BP and ends towards 2100/2000 cal. BP.
- MQB6 can be linked to the RPAZ IX because of the relative abundance of *Fagus*. However, it appears to be related to RPAZ X because of the appearance of *Juglans* in MQB6b. Thus, we assume that MQB6 is situated at around 2000 cal. BP.
- The presence of *Castanea* and *Juglans* along with *Fagus* and *Carpinus* allows the attribution of MQB7 to the PRAZ X (later part of the Subatlantic), starting at around 2000 cal. BP, after the Roman conquest.
- Being still correlated with the RPAZ X (upper part of Subatlantic), the MQB8 assemblages could date from the 9^{th} to 10^{th} centuries AD (towards 1100-1000 cal. BP), a period when *Castanea* and *Juglans* are observed more regularly in the Paris Basin (Leroyer, 1996, 1997).
- MQB9 is still linked to RPAZ X but not precisely dated (possibly 730-560 cal. BP by correlation with the Bercy sequence). However, there are some problems of pollen preservation that limit the representativity of the observed assemblage.

6 Stages in the evolution of the fluvial and vegetation landscape

6.1 Formation of tufa: from the Boreal to the beginning of the Subboreal

The earliest stages of morphogenesis observed at Quai-Branly begin with the accumulation of tufa [1], which is deposited on top of a sheet of coarse fluviatile pebbles [0].

In Paris, the development of tufas in the bed of the Seine occurs downstream from two knick-points which are located on both sides of the confluence with the River Marne (Descombes, 1982). Tufas are found at Bercy (Roblin-Jouve, 1991), at “Quai-des-Célestins” (Chaussé, 1995) and finally at Quai-Branly (Figure 1).

From the stratigraphic and bio-stratigraphic observations, it appears that the Quai-Branly tufa started to develop on the right bank at least during the late Boreal (9500-8850 cal. BP), migrating northwards i.e. towards the central part of the flow channel of the Seine. Conditions favourable for tufa formation were maintained until the end-Atlantic/early-Subboreal (~5500 cal. BP). During this period, the Quai-Branly formed a bank submerged by calm waters traversed by weak currents, with the top of the stromatolite construction emerging during low-stage flow. According to the evolution of the pollen data (MQB1 to MQB4), this bank was gradually affected by a lowering of the water table. Behind the bank, the surrounding terrestrial environment was dominated by an increasingly dense tree cover. During the early stages of tufa construction, hazel forests developed with oaks and elms (MQB1). These forests evolved into open oak woodland with many hazels and elms (MQB2), followed by oak-lime woodland incorporating some ash and many shrubs (MQB3). While some willows and alders were always growing on the banks of the Seine, alder woodland was gradually established over the bottom of valley at the end of the phase of tufa formation (MQB4). Despite the wooded character of the environment, meadows of clearly humid character developed near the river and contributed to the landscape. The oak woodland was exploited at an early stage and agro-pastoral activities were practiced in the immediate vicinity (MQB2). A few centuries later (MQB3), early or middle Neolithic groups returned to the site. They cleared the alder and oak woods in order practice animal husbandry and crop cultivation. Later on (MQB4), the area was frequented by a middle to recent Neolithic groups, who exploited the oak woods.

6.2 Emergence: from the Subboreal to the beginning of the Subatlantic

At Quai-Branly, the pore-space of the tufa is invaded by brown-grey clayey coatings. The argillans are emplaced in conditions that require the emergence of the tufa. Indeed, their formation is brought about by decarbonatation in a necessarily subaerial context allowing argillogenesis. These features indicate that the banks of the channel dried out. This evolution does not appear to be limited to the Quai-Branly area, as argillans have also been found at Bercy (Lanchon et al., 1997). The similarity of the observation both sites supports the hypothesis of a general drop in the low-stage water level. The pollen assemblage (MQB5a) collected in the illuviation cutans is correlated with the beginning of RPAZ IX around 2800/2700 cal. BP. Subaerial emergence, weathering of carbonates in tufas and illuviation could have taken place during whole or part of the Subboreal, thus explaining why no fluviatile sedimentary record of this period is found at Quai-Branly.

6.3 Renewal of alluvial dynamics and emplacement of a secondary channel: the early part of the Subatlantic

The contact of the tufas with the overlying deposits [2] is sharp, well expressed by an erosion surface [S1]. This phase is associated with the establishment of a thalweg that cuts down approximately 2 m into the underlying carbonate constructions [1] at the southern end of cross-section 10 (Figure 2). According to the LPAZ MQB5b, this erosion renewal occurs during the first part of the Subatlantic (RPAZ IX; 2800/2700-2100/2000 cal. BP) (Leroyer, 1997; Leroyer and Allenet, 2006). It marks the emergence of new morphosedimentary conditions at Quai-Branly.

Increased hydrodynamic activity is responsible for the vertical accumulation of planar beds ([2b] to [2d]) with oblique ([2b]) or horizontal ([2d]) internal bedding, the coarseness of the sediments, and the alternation of definitely more gravely or even pebbly beds within the sandy sub-units. The change in flow conditions is accompanied by erosion of part of the nearby banks, implying the occurrence of lateral currents. This is illustrated by layer [2c], which contains poorly sorted clastic material with a broad grain-size distribution. However, this activity sometimes exhibits intensity contrasts. Indeed, the intercalation of clayey-organic beds in [2a] (C.174/1 and C.173/2 and 3) and [2d] (C.136) shows the temporary occurrence of calmer flow conditions allowing the deposition of clay particles. The rise of water level is recorded in the pollen assemblages, with an increase and a diversification of water plants. The presence of taxa such as *Nuphar*, *Nymphaea* and *Myriophyllum* suggests that water depths may have reached 3 m.

During this period, the landscape remains rather wooded, with alder established in the valley bottom and oak-beech woodland on the hill slopes. Meanwhile, the river bank vegetation appears clearly marked by human influence shown by plants accompanying pastoral activities and crop cultivation. In addition, subzone MQB5b provides evidence for human pressure on the forest cover. The alder woods are cleared, allowing the development of a water meadow while the oak-beech woodland is also affected. Although *Fagus*, *Ulmus* and *Tilia* seem to be more heavily exploited than *Quercus*, in a context involving the opening up of the environment, the record reflects the over-representation of *Quercus* producing more abundant pollen (Heim, 1970; Barthélemy, 1976).

At Quai-Branly, sub-units [2a] and [2b] yielded preserved wooden objects including fragments of a fish-trap, piles (W.48 and W.164), as well as a dugout (W.175; not dated). The dendrochronological and ^{14}C dating results of the artefacts W.48 and W.164 yielded ages ranging between 5025-4831 and 4785-4423 cal. BP (Table I). The felling of these trees thus took place at the beginning of the Subboreal (~5500 cal. BP) i.e. during the final phases of tufa construction in this sector. However, these data are contradictory with the pollen analysis results (subzone MQB5), which place the deposit around 2800/2700 cal. BP. Hence, the artefacts are reworked remains coming from a late to end-Neolithic settlement located upstream.

6.4 Channelling of flow in the secondary arm of the Seine at the beginning of the second part of the Subatlantic

The third morphosedimentary unit consists of a set of gravels and dominant sands making up more or less thick layers (from several metres to dm scale), with oblique to concave beds showing cross-stratification or oblique structure (unit [3]). This unit, formed by the fill of two distinctive courses, is also characterized by clayey-organic layers. The base of unit [3] erodes the top of the preceding one [2]. Both scours express two distinct axes of flow, one in the north and the other in the south (northern and southern courses; Figure 2), which are sub-contemporaneous. Indeed, pollen analyses on clayey beds interstratified in [3a], [3c] and [3d] assign both fills to a single pollen zone (MQB6), corresponding to the end of RPAZ IX or beginning of RPAZ X. The deposits of unit [3a-c-d] are thus placed at the boundary between the first and second parts of the Subatlantic (~2100/2000 cal. BP), generally corresponding to the time of the Roman conquest (Leroyer, 1997; Leroyer and Allenet, 2006).

The accumulation of the sandy deposits [3a-b-c-d] was controlled by a watercourse alternating between both courses. Along the northern course, the deposits [3a] with cross-bedded structure and clayey-organic layers form a sandbank (Allen, 1965) deposited during weakening hydrodynamic activity. They mark the progressive attachment of the sector to the main low-flow channel of the Seine. Along the southern course, the coeval sandy to gravely-sand bedded deposits [3b] are clearly channelized. Compared to the regime associated with lateral filling [3a], they were emplaced under more continuous and sustained hydrodynamic conditions. These deposits [3b] correspond to the continued filling of the secondary bed of the river, a process that began during the preceding phase. During this period, renewed expansion of forest cover both in the valley bottom and on the hillslopes starts with the development of recolonizing species (*Betula*, *Ulmus* and shrubs), followed by the establishment of forest taxa (*Fagus* and *Carpinus*). Nevertheless, the landscape is still marked by human activities. Although crop cultivation is practiced near the site, the decline of the ruderal assemblage seems to indicate a slight decrease in frequency of occupation of the area.

6.5 Development of the river bank in human-transformed landscape: from the fifth century AD onwards

The overlying deposits [3e-f] fill a narrower trough [S2.4] recorded in the southern course (Figure 2). The gravel-sand filling is interstratified with numerous clay-organic beds (C.99, C.70a, C.22, C.98, C.97, C.96, C.9, C.129) located primarily in the south of the site area along sections 6, 8 and 15 (Figure 3). They are mainly encountered in the immediate vicinity of the posts forming the W.21 alignment (Pion et al., 2005). According to the LPAZ MQB7, the clayey deposits accumulated during the second part of the Subatlantic (RPAZ X), after the Roman conquest. The three organic layers C.99/1, C.70a and C.22 (crossed by the posts or capping them; Figure 3) have floristic assemblages belonging to the same LPAZ MQB7a, which implies that part of the W.21 structure was emplaced during this palynozone (Figure 4, Table III). Radiocarbon measurements on one of the posts (W.21/40) yielded an age of 1538-1353 cal. BP (Table I). Hence, the emplacement of the posts can be dated between the 5th and 6th century AD i.e. between the fall of the Roman Empire (476 AD) and the establishment of Paris as the capital of the Merovingian King Clovis in 508 AD. By extension, this date also applies to the accumulation of the deposit [3e-f].

Arranged according to an overall E-W axis parallel to the river bank, the W.21 posts alignment is possibly a groyne (Coll. title, 1761). This structure aimed either to limit the impact of flooding or to stabilize the topography of the secondary arm along the southern course by enclosing it within a longitudinal line of driven posts (Bravard and Petts, 1993). Such an arrangement could also have been intended to fix and concentrate the water flow along the southern course. This development could be associated with a millrace or fisheries (Pion et al., 2005). During this period, the pollen analyses (MQB7a and 7b) stress the importance of human impact over the catchment area. The clearing of woodland affects just as much the alder trees established on the site as the forest cover of the slopes. The environment is open enough to allow a better representation of *Pinus* in the record, since the efficient spread of this pollen is favoured in lightly wooded terrain (Barthélémy, 1976). The environment was dominated by meadows - probably grazed -, evidently displaying a rather marshy character in places close to the River Seine. There were probably many cultivated fields in the surrounding area, but the high frequencies of cereal pollen may also reflect activities associated with winnowing, storage, flour-milling, etc. rather than dispersion related to crop farming (Heim, 1970; Richard, 1985). This hypothesis is probably valid for some of the “floating” levels that are sub-contemporaneous with unit [3e] (undifferentiated MQB7). The intensity of occupation of the site decreases at the end of [3e]. Indeed, MQB7c provides evidence for a decline in agro-pastoral activity indicators, correlated with a slight recovery of *Alnus*.

The overlying deposits [3g] are laid down on top of a new erosional contact [S2.5] located in the northern part of the excavation site. They record the continuing progradation building the sand bank in the main low-water channel of the River Seine. These deposits contain organic interbeds (C.26 and C.23; MQB8) yielding pollen assemblages, showing a marshy bank environment in this area. Between each flood peak, marshes remained by a shallow water depth, and colonized by amphibious herbs. The human pressure starting at the top of unit [3e] continues to decrease during the accumulation of unit [3g]. Forest cover shows a renewed expansion in the valley bottom as well as on the slopes, with a large proportion of recolonisation species (*Betula*, *Corylus* and shrubs). In MQB8b, we also observe a renewed increase of *Fagus*. This new forest cover dynamics is accompanied by a contraction of meadows and cultivated fields.

6.6 From the seventeenth (or possibly earlier) to nineteenth century: attachment of the sector to the floodplain

The fourth morphosedimentary unit corresponds to bedded sands exhibiting a uniform southerly dip [4a]. The massive convexo-concave morphology of the deposit in the N-S axis and its almost exclusively coarse sandy nature indicate a rising of the bank developed over a thickness of 3 m. The construction of the levee is due to the deposition of suspended matter during floods exceeding the bankfull discharge (Bravard and Petit, 1997). According to present-day data collected in the Loire Valley, levees are built in a context of lowering of the alluvial floor and contraction of the active river course (Gautier et al., 2001). At Quai-Branly, the construction of a thick levee on the northern bank of the river reflects the progressive attachment of this sector to the flood plain. No chronological data are available for dating the beginning of this modification in the river morphology. According to engravings, the alluvial ridge became apparent at least at the start of the 17th century, when several small sandy islands formed (Pion et al., 2005). Their accretion was completed towards the end of the 17th century with the appearance of a long and narrow island (“Ile-aux-Cygnes”). The final stages in the sedimentary filling of the channel led to the levelling of the sector, while the relative distance from the mean water channel or a fall of low-stage level contributed to the accretion of alluvial deposits. This ended with the development of a soil horizon marked by slight brunification [H1]. However, this phase of stabilization was temporary since the unit is again covered by overbank silts [4c]. These latter deposits are overlain by another slightly brunified horizon [H2], indicating that the sector is definitively sheltered from mean floods.

7 Quai-Branly in the context of middle- to late-Holocene evolution of the Seine basin

In spite of some chronosedimentary breaks, the reconstruction of the riverside environment of the Seine at Quai-Branly covers the middle to late Holocene. This permits chrono-morphostratigraphic comparisons with other data collected upstream in the Seine basin, particularly in Paris at the “Ile-de-la-Cité” and Bercy, but also in the Oise, Marne and Aube valleys, as well as the tributaries (Beuvronne) draining the northern and eastern part of the catchment. Moreover, using correlations with global climatic records, represented by variations in peri-alpine lake levels dependant on atmospheric circulation and fluctuations in solar activity (Magny, 1999, 2004) as formalized by the curve of residual $\Delta^{14}C$ (Stuiver et al., 1998), we can monitor the hydrosystem reactivity to the environmental changes that have taken place during the late Holocene (Figure 5).

Both at Quai-Branly and Bercy, as well as along the major and minor tributaries, the second half of the Boreal and the Atlantic is characterized by the accumulation of tufas framing the banks of the mean water channel. Tufa construction gives way to the emplacement of barriers, which isolate confined environments from current activity and favour the development of peat bogs. This phase begins in the Oise and Marne valleys and its tributary the Beuvronne as early as the Preboreal (~11200 cal. BP) and ends at Bercy and Branly at the beginning of the Subboreal (~5500 cal. BP). It marks a period of stability of fluvial environments, which is interrupted by a hydro-erosive episode around 8800 cal. BP. This could represent a delayed response to the cooling of the early Boreal, as inferred from the Joux 2 lake transgression (Pastre et al., 2002).

During the Subboreal, the valley bottoms are marked by the renewed activity of hydro-erosive processes at 5400 cal. BP. This rejuvenation is expressed by the reactivation of old channels or the formation of new erosive features, together with a generalized aggradation of the alluvial plains due to silty inputs that become increasingly regular from the latter part of the Subboreal on (Pastre et al., 1997, 2002, 2006; Gaillard, 1999; Orth et al., 2004; Le Jeune et al., 2005). This instability which follows the emergence of wetter global conditions is expressed in the Jura by the Chalain lake transgression (Magny, 1999, 2004), and occurs in a context of generalization of agro-pastoral activities (Leroyer, 1997; Leroyer and Allenet, 2006; Pastre et al., 2006). Although such an event is not observed at Quai-Branly, it is plausible that renewed downcutting occurred in the Seine valley bottom in Paris, since a phase of entrenchment is recorded on the "Ile-de-la-Cité" and at Bercy, which took place between the end of the Atlantic and the beginning of the Subboreal (Gaillard et al., 1997; Roblin-Jouve, 1991; Leroyer, 1997). However, even if this downcutting occurred at Quai-Branly, it is not accompanied by an increase of detrital sediment supply as seen in the upstream catchment in a sector nevertheless bordering the mean water channel of the river. The observation of argillans in the Quai-Branly tufa suggests that the formation of these features required an initial emergence of the tufa, followed by weathering of the surface of the tufaceous masses which then emerged as banks. Also recognized in the tufa of the third channel at Bercy (Lanchon et al., 1997), these features indicate an overall drop of the low-stage water level in the Paris area following either the entrenchment of the main low-flow channel or a phase of prolonged dewatering. According to the pollen analyses, the occurrence of these illuviation features (i.e. the weathering of the carbonates of unit [1]) at Quai-Branly can be attributed to the earliest Subatlantic. Since the water lowering pre-dates the illuviation processes, dewatering can be assigned to the Subboreal. This hypothesis agrees with observation at the "Ile-de-la-Cité" (Gaillard et al., 1997), which shows a first progressive reduction in hydrodynamic activity followed by stabilization accompanied by soil development. At first sight, this scenario disagrees with the general morphosedimentary model adopted for the Subboreal of the Paris Basin. However, the local renewal of peat-bog formation during the second part of the Subboreal, as noted by Pastre et al., (2002, 2006) and Orth (2003), reflects successive lulls in the functioning of hydrosystems within the Seine catchment. According to the chronological markers, this set of lulls corresponds to the phase of draining and stability recognized at Quai-Branly, and also agrees with the climatic improvement indicated by the general regression of lake levels in the Jura between 4800 and 3500 cal. BP. Thus, the instability of the hydrosystems recorded in the upstream part of the basin could be considered as a secondary process, while the general trend in the main valley is characterized by a prevailing stability of the fluvial environment.

The renewal of hydrodynamic activity recorded during the older part of the Subatlantic at Quai-Branly is expressed by the cutting down and emplacement of a lateral channel filled by sands (units [2]). It is also observed at Bercy, where a 5th channel is established. This event is well recognized, not only over the whole of the catchment area of the Seine (Pastre et al., 1997, 2002, 2006; Chaussé, 1997; Gaillard, 1999; Orth et al., 2004; Le Jeune et al., 2005; Chaussé et al., 2006) but also in the Loire Valley (Carcaud et al., 2002) and the Rhône basin (Salvador, 1991; Bravard et al., 1992; Arnaud et al., 2005). In Europe, it has been recognized in the Netherlands (Van Geel et al., 1996), United Kingdom (Lewin et al., 2005; Charman et al., 2006), Spain (Thorndycraft and Benito, 2006) and Poland (Macklin et al., 2006). The synchronous reactivation of hydrosystems argues in favour of a predominantly climatic control. This degradation of climatic conditions is recorded in the lakes of the Jura by the transgressive phase at Le Bourget (Magny, 2004), as well as in the residual $\Delta^{14}C$ curve accounting for the variations in solar activity (Stuiver et al., 1998). For certain authors (Orth et al., 2004; Pastre et al., 2002; Lewin et al., 2005), the impact of this climatic deterioration on morphogenesis appears to be amplified by the intensification of forest clearing initiated by the communities of the Late Bronze Age (between 3300 and 2800 cal. BP), which is well recorded in the pollen assemblages of the Paris Basin (Leroyer, 1997).

The accumulation of fluvial fill at Quai-Branly (unit [3]) continues unabated and remains generally compatible with the data collected over the upstream basin, which show continuity in the detrital sediment supply. However, it also expresses a progressive reduction of the hydrodynamic activity in the lateral channel, while the principal mean water channel of the river cuts gradually into its northern bank. This evolution takes place in two stages; the first extends at least until the 6th century AD, while the second is spread out between the 6th and the 17th century. Between the 5th and the end of the 6th

century AD, a longitudinal groyne made with wooden posts was established. So far, this period is only sparsely documented in the upstream parts of the Seine basin. However, the available data indicate an overall reduction in the hydrodynamic activity towards 1800-1700 cal. BP, which is sometimes accompanied by the temporary return of peat-bog formation in the valley bottoms of minor tributaries (Leroyer, 1996, 1997). This evolution is recorded in the valleys of the major tributaries of the Seine up until the 14th century (Pastre, pers. comm.).

The accumulation of coarse sands [4a-b] forming the levee at Quai-Branly is not precisely tied in with the chronology. However, its construction, which is accompanied by an entrenchment of the main low-water channel, could be tentatively correlated with the downcutting of the 6th channel at Bercy dated ca 730-560 cal. BP, i.e. 13th to 14th century AD (Leroyer, 1997). This hypothesis also agrees with the observation compiled from the “Ile-de-la-Cité”, which record a return to conditions of high-energy sedimentation at least from the 13th or 14th centuries on (Gaillard et al., 1997). We cannot rule out the contribution due to river-bank urban developments during the medieval period in Paris. By raising and stabilizing the banks, these works may have favoured the cutting down of the bed of the Seine (Gaillard et al., 1997). However, we should note that, if our cross-datings are confirmed, these morphosedimentary events, particularly at Bercy which is located upstream from the urban area at that time, coincide with the climatic deterioration of the Little Ice Age.

8 Conclusion

The observations compiled from Quai-Branly document the morphodynamic evolution of the Seine River from the late Boreal (9500 cal. BP) onwards. Firstly, it shows the presence of a laterally stable channel up until the beginning of the Subboreal (5500 cal. BP). From this period onwards, sedimentation is not recorded at Quai-Branly, this absence could correspond to a peak in erosive activity that occurred during the earlier part of the chronozone. At the end of the Subboreal (towards 3000/2700 cal. BP), the environment appears to become subaerial, probably because of a general lowering of the water level according to weathering features attributed to the earliest Subatlantic. The early Subatlantic (2800/2700-2100/2000 cal. BP) is marked by a renewed increase of fluvial dynamics, responsible for the cutting down and subsequent filling of a secondary channel. At the beginning of the later part of the Subatlantic, there is a decrease in hydrodynamic activity, which is then accompanied by the building of a groyne between the 5th and the end of the 6th century AD. The construction of a thick sandy levee, which may have started in the 13th century, marks the beginning of the integration of the Quai-Branly area into the flood plain.

The data collected at Quai-Branly is broadly compatible with records acquired at Bercy and the "Ile-de-la-Cité". Three hydro-erosive episodes are recognized since the end of the Atlantic. The first is dated at around 5700-5300 cal. BP, the second towards 3000-2700 cal. BP and the last around 600 cal. BP. The timing of these events coincides with the lake transgressions in the Jura at Chalain, Le Bourget and Petit-Clairvaux 1, which are themselves dependent on the variations of solar activity (Magny, 2004). These periods of renewed hydrodynamic activity of the Seine during the middle to late Holocene thus appear to respond to global climatic changes rather than to variations induced by human activities modifying the environment. Since the initial clearing of the forests, humans have had an undeniable impact on their environment. Nevertheless, this impact is not apparent on the scale of a hydrosystem such as the River Seine. It is probable that human impact generated an accentuation of hydrodynamic processes which seem to have been triggered first by changes in the climatic components of the system.

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Figure 1 : Location map of the Quai-Branly site in Paris (France)

Figure 2 : Synthetic cross-section of the Quai-Branly stratigraphical sequence

Figure 3 : Detailed cross-section

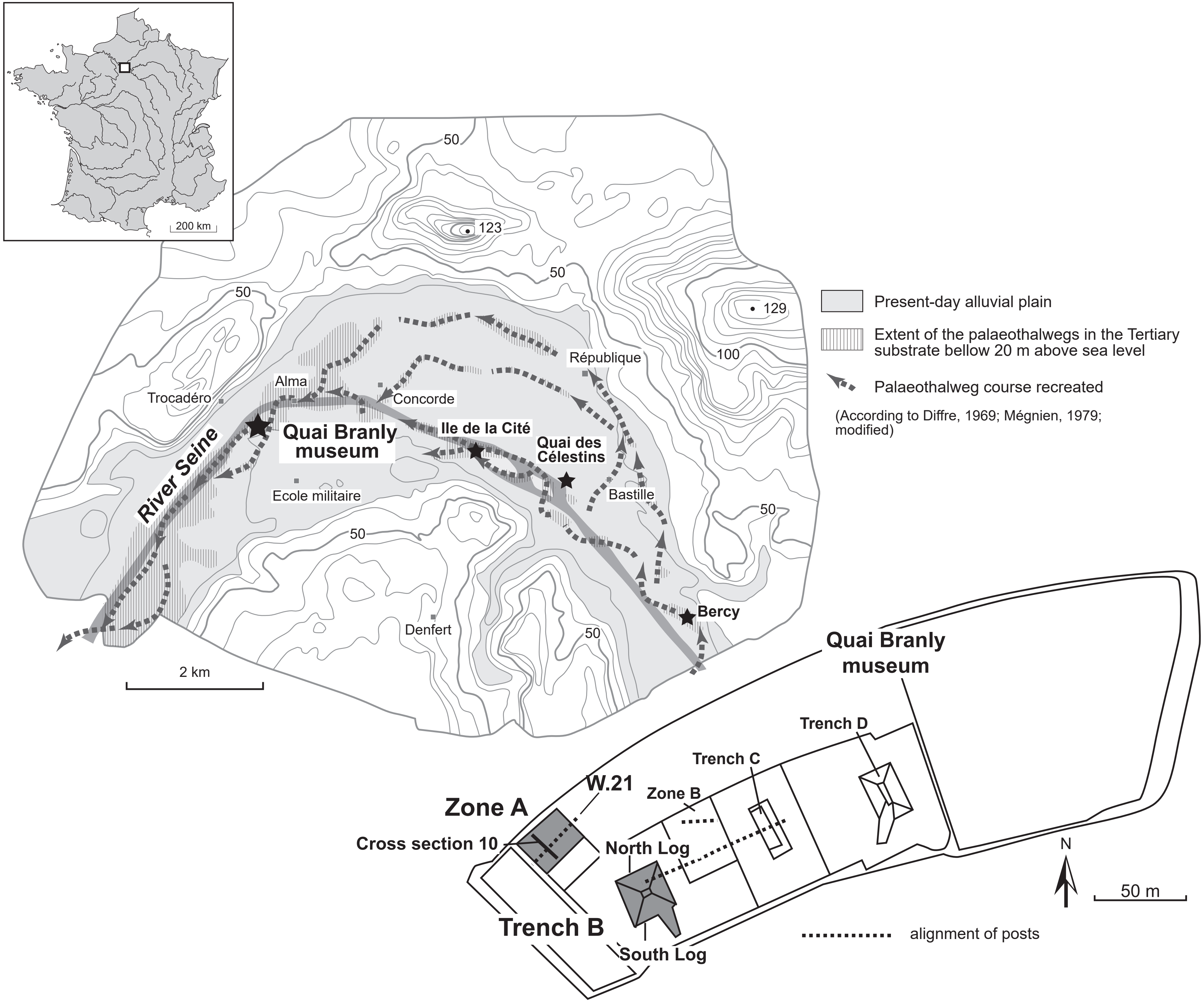
Figure 4 : Simplified pollen percentage diagram of Quai-Branly with taxa grouped according to their ecological affinities (see Table 2). The pollen sum includes arboreal pollen (AP = trees and shrubs), herbs and ferns (*Spagnum*, dinoflagellate cystes and unidentified grains are excluded)

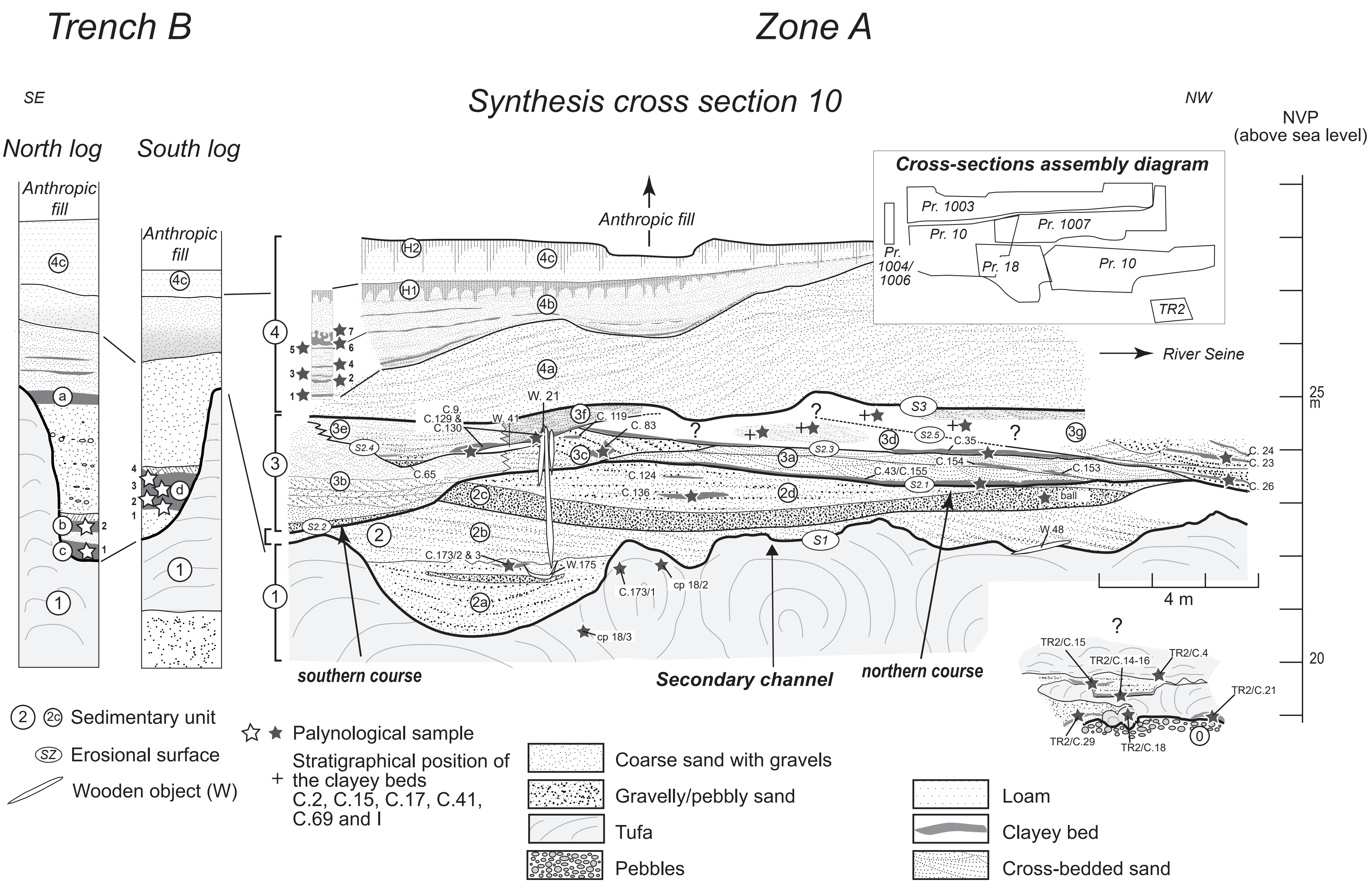
Figure 5 : Synthesis of Holocene morphosedimentary events in the Paris Basin floodplains

Table 1 : Dendrochronological results obtained for some wooden artefacts discovered in the Quai-Branly excavation

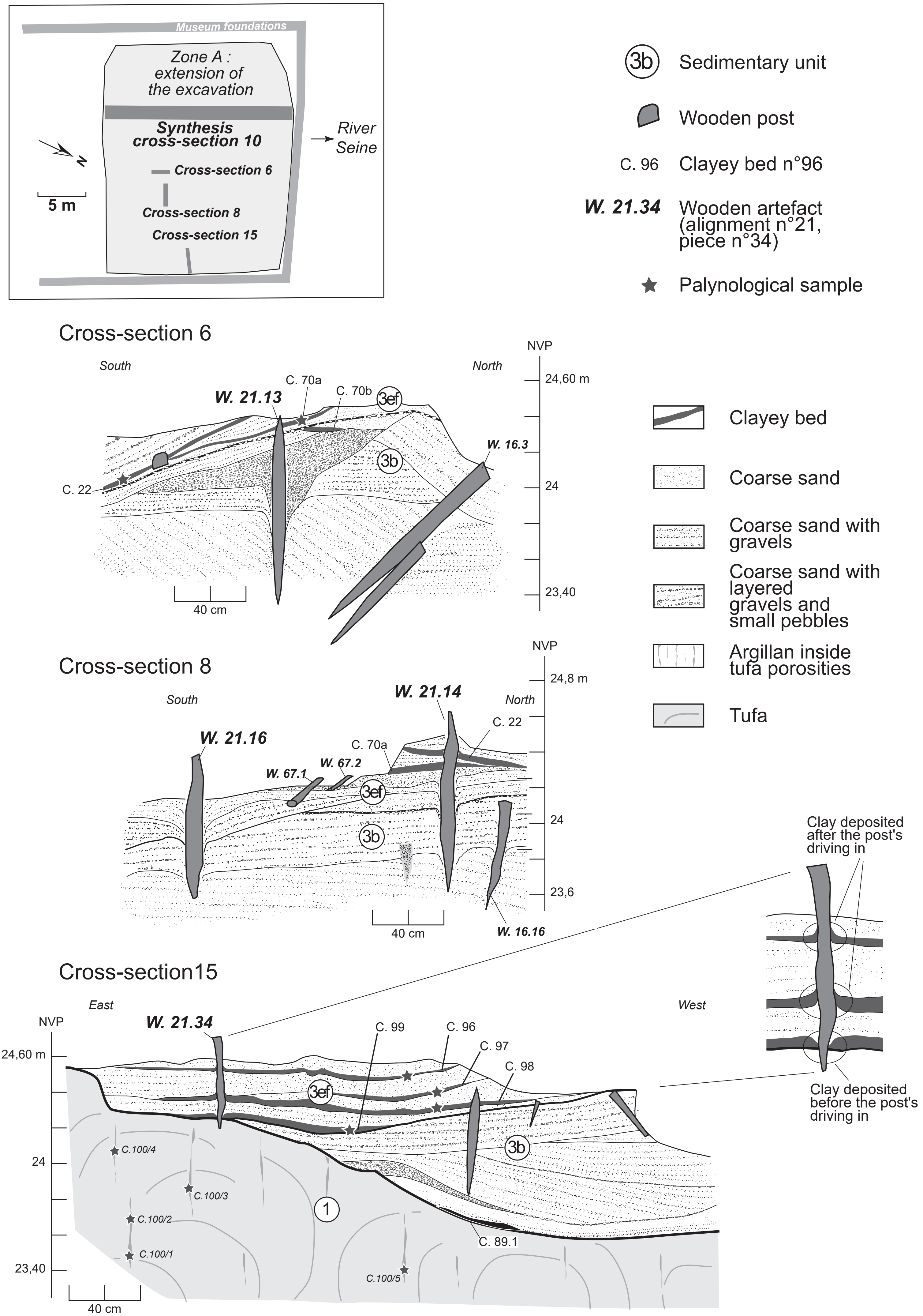
Table 2 : Floristic list recognized at the Quai-Branly site and ecological groups proposed in Figure 4

Table 3 : Description of the local pollen assemblage zones (LPAZ) of Quai-Branly, environnemental interpretation and correlations with regional pollen assemblage zones of the Paris Basin (RPAZ)

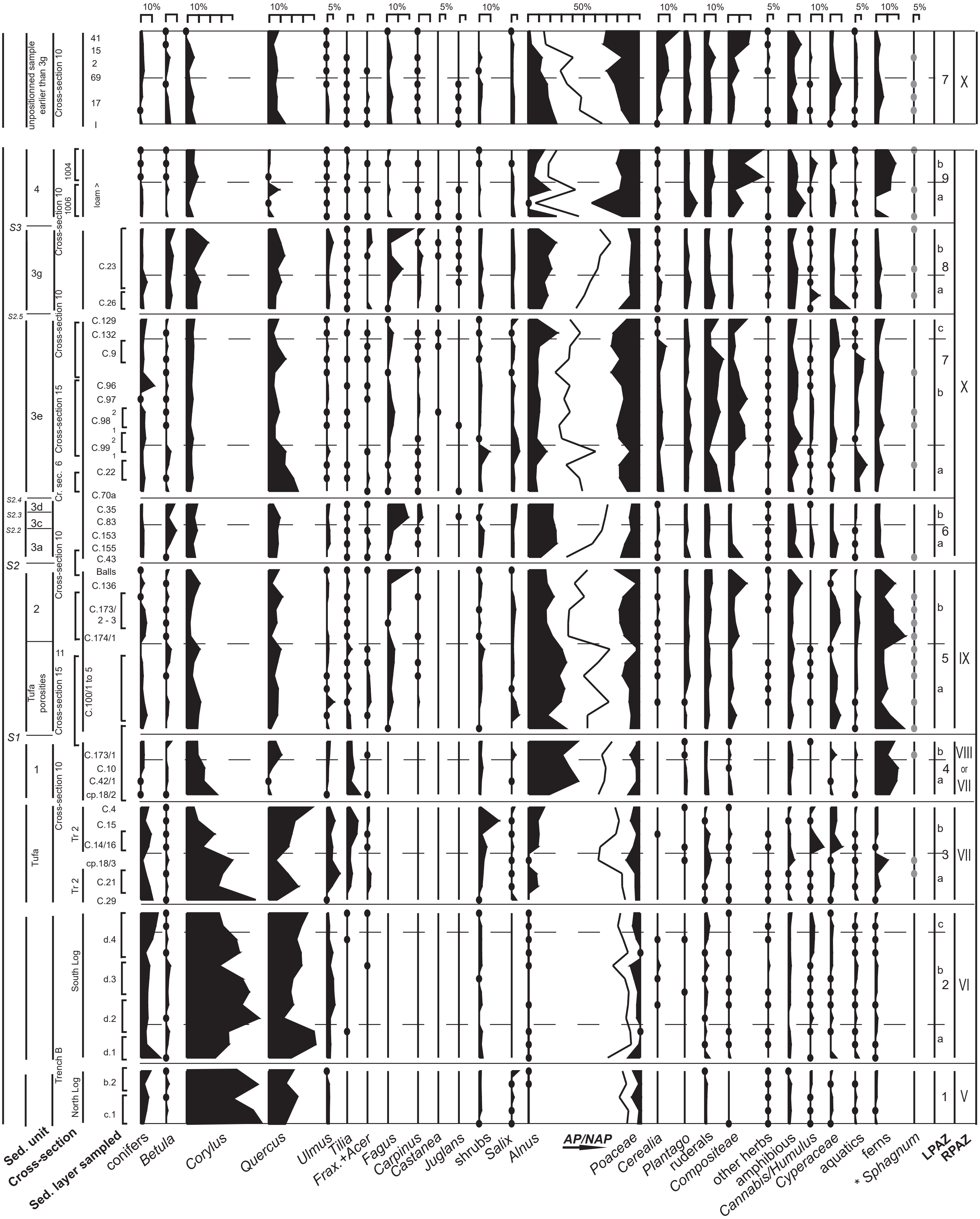

200 km
50
123
50
50
129
100
Present-day alluvial plain
Extent of the palaeothalwegs in the Tertiary substrate bellow 20 m above sea level
Palaeothalweg course recreated
(According to Diffre, 1969; Mégnien, 1979; modified)
République
Alma
Trocadéro
Concorde
Quai Branly museum
Ile de la Cité
Quai des Célestins
River Seine
Ecole militaire
Bastille
50
50
Bercy
Denfert
50
2 km
Quai Branly museum
Trench D
Trench C
W.21
Zone B
Zone A
Cross section 10
North Log
N
50 m
Trench B
South Log
alignment of posts



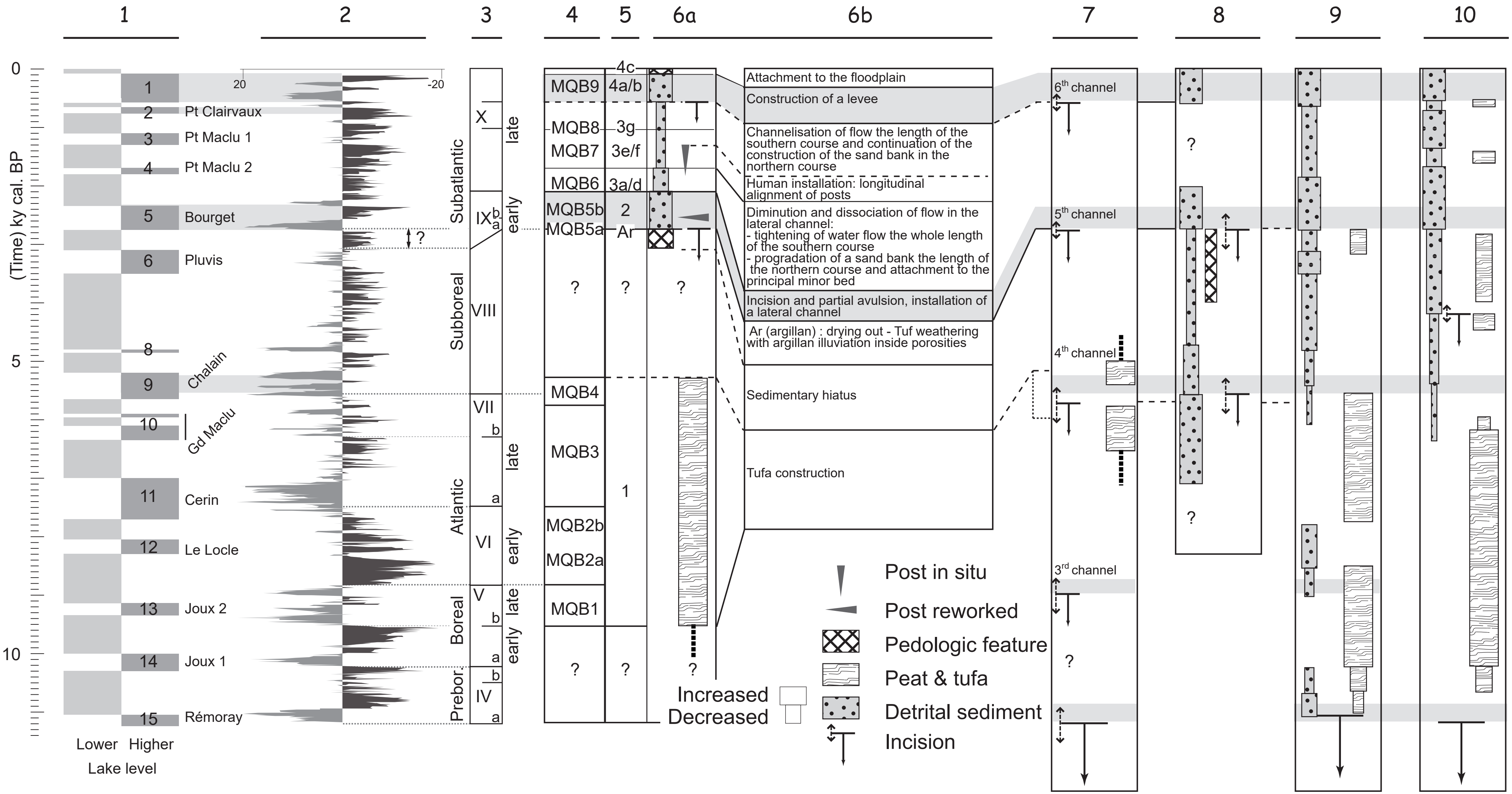
Trench B
Zone A
SE
Synthesis cross section 10
NW
NVP
(above sea level)
North log
South log
Anthropic fill
Anthropic fill
Anthropic fill
Cross-sections assembly diagram
Pr. 1003
Pr. 1007
Pr. 10
Pr. 1004/1006
Pr. 18
Pr. 10
TR2
River Seine
25 m
20
4 m
4c
4b
4a
H1
H2
3a
3b
3c
3d
3e
3f
3g
2a
2b
2c
2d
S1
S2.1
S2.2
S2.3
S2.4
S2.5
S3
W. 21
W. 41
W.175
W.48
C.9
C.129 &
C.130
C. 119
C. 83
C.65
C.35
C.154
C.153
C.43/C.155
C.124
C.136
C. 24
C. 23
C. 26
ball
C.173/2 & 3
C.173/1
cp 18/2
cp 18/3
TR2/C.15
TR2/C.14-16
TR2/C.4
TR2/C.21
TR2/C.29
TR2/C.18
southern course
Secondary channel
northern course
Sedimentary unit
Erosional surface
Wooden object (W)
Palynological sample
Stratigraphical position of the clayey beds C.2, C.15, C.17, C.41, C.69 and I
Coarse sand with gravels
Gravelly/pebbly sand
Tufa
Pebbles
Loam
Clayey bed
Cross-bedded sand



Museum foundations
Zone A : extension of the excavation
Synthesis cross-section 10
River Seine
N
Cross-section 6
5 m
Cross-section 8
Cross-section 15
3b
Sedimentary unit
Wooden post
C. 96
Clayey bed n°96
W. 21.34
Wooden artefact (alignment n°21, piece n°34)
Palynological sample
Cross-section 6
South
North
NVP
24,60 m
24
23,40
W. 21.13
C. 70a
C. 70b
3ef
3b
W. 16.3
C. 22
40 cm
Clayey bed
Coarse sand
Coarse sand with gravels
Coarse sand with layered gravels and small pebbles
Argillan inside tufa porosities
Tufa
Cross-section 8
NVP
24,8 m
24
23,6
South
North
W. 21.14
C. 22
W. 21.16
C. 70a
W. 67.2
W. 67.1
3ef
3b
40 cm
W. 16.16
Clay deposited after the post's driving in
Cross-section15
East
West
NVP
24,60 m
24
23,40
W. 21.34
C. 99
C. 96
C. 97
C. 98
3ef
3b
C.100/4
C.100/3
C.100/2
C.100/1
1
C. 89.1
C.100/5
40 cm
Clay deposited before the post's driving in



10%
10%
10%
5%
10%
5%
10%
50%
10%
10%
5%
10%
5%
10%
5%
unpositionned sample earlier than 3g
Cross-section 10
41
15
2
69
17
I
7
X
4
1004
1006
loam >
b
9
a
S3
3g
C.23
C.26
8
S2.5
3e
Cross-section 15
Cr. sec. 6
C.129
C.132
C.9
C.96
C.97
C.98
C.99
C.22
C.70a
c
7
b
a
S2.4
S2.3
S2.2
3d
3c
3a
C.35
C.83
C.153
C.155
C.43
6
S2
2
Balls
C.136
C.173/ 2 - 3
C.174/1
11
C.100/1 to 5
Tufa porosities
5
IX
S1
1
C.173/1
C.10
C.42/1
cp.18/2
4
VIII or VII
Tufa
Tr 2
C.4
C.15
C.14/16
cp.18/3
C.21
C.29
3
VII
South Log
Trench B
d.4
d.3
d.2
d.1
2
VI
North Log
b.2
c.1
1
V
Sed. unit
Cross-section
Sed. layer sampled
conifers
Betula
Corylus
Quercus
Ulmus
Tilia
Frax.+Acer
Fagus
Carpinus
Castanea
Juglans
shrubs
Salix
Alnus
AP/NAP
Poaceae
Cerealia
Plantago
ruderals
Compositeae
other herbs
amphibious
Cannabis/Humulus
Cyperaceae
aquatics
ferns
* Sphagnum
LPAZ
RPAZ



1 - Jura lake level (Magny et al., 2004)

2 - Residual $\delta^{14}C$ variations (Stuiver et al. 1998)

3 - Regional pollen zones of the Paris Basin (RPAZ) (Leroyer, 1997)

4 - Local pollen zone (LPAZ) - Quai Branly (Paris)

5 - Morphosedimentary unit - Quai Branly (Paris)

6a and 6b - Morphosedimentary events - Quai Branly (Paris)

7 - Morphosedimentary events - Bercy (Paris) (Roblin-Jouve, 1991 and Leroyer, 1997)

8 - Morphosedimentary events - Ile-de-la-Cité - Harley (Paris) (Gaillard et al., 1997)

9 - Morphosedimentary events - Marne and Oise valleys (Pastre et al., 2002, 2006)

10 - Morphosedimentary events - Beuvronne valley (Orth, 2003)

« Quai Branly » museum – Zone A (Paris, France)								
Objet ref.		**Sed. unit**	**Dendro. growth groups**		**^{14}C** Laboratory ref.	**^{14}C** Radiocarbon date BP	**^{14}C** Calibration	**Remarks**
W.21 (alignment of post)	W.41.4	3	M4/M13	One chronological phase	^{14}C Ly-12375	1480 ± 40 BP	[534 - 652] AD [1416 - 1298] cal. BP	After wiggle-matching: [585-686] AD |1365 –1265] cal. BP
	W.41.2 W.41.31 W.41.13 W.143.1							
	W.64.3 W.64.2 W.146.2		M6 / M13		^{14}C Ly-12374	1475 ± 35 BP	[537 - 650] AD [1413 - 1300] cal. BP	
	W.21.40		*Fagus* not in dendro group		^{14}C Ly-12376	1570 ± 40 BP		
Various objects	W.164.1 W.164.2 W.164.3 W.164.5 W.164.8 W.48.1 W.166.1	2	M1	One chronological phase	^{14}C Ly-12377	4055 ± 35 BP	[2835 - 2473] BC [4785 - 4423] cal. BP	
	W.164.12				^{14}C Ly-12378	4315 ± 40 BP	[3075 - 2881] BC [5025 - 4831] cal. BP	

Table I: Dendrochronological results obtained for some wooden artefacts discovered in the Quai-Branly excavation

	Pinus (pine)		*Poaceae*		*Apiaceae*
1	*Abies*				*Fabaceae*
	Picea		*Cerealia*		*Lamiaceae*
	Cupress./Taxaceae				*Scrophularaiceae*
		4	*Plantago sp.*	**8**	*Ranunculaceae*
	Betula (birch)		*Plantago lanceolata*		*Liliaceae*
					Rosaceae
	Corylus (hazel)		*Rumex*		*Filipendula*
			Artemisia		*Sanguisorba minor*
	Quercus (oak)		*Polygonum*		*Rumex palustris type*
			Convolvulus		
	Ulmus (elm)	**5**	*Urticaceae*		*Cannabis/Humulus*
			Chenopodiaceae		
	Tilia (lime)		*Rubiaceae*		*Cyperaceae*
			Brassicaceae		
2	*Fraxinus* (ash)		*Caryophyllaceae*		*Polygala*
	Acer		*Boraginaceae*		*Spergularia*
					Alisma
	Fagus (beech)		*Cichorioideae*		*Sagittaria*
		6	*Asteraceae*		*Koenigia*
	Carpinus (hornbeam)		*Carduaceae*		*Thalictrum*
			Centaurea		*Lythrum*
	Castanea (chestnut)			**9**	*Polygonum persicaria*
			Echium		*Zannichellia*
	Juglans (walnut)		*Sedum*		*Typha*
			Crassulaceae		*Potamogeton*
	Buxus		*Malvaceae*		*Sparganium*
	Rosaceae		*Verbena*		*Nuphar*
	Ericaceae		*Dipsacaceae*		*Nymphaea*
	Ephedra		*Scabiosa*		*Myriophyllum*
	Rhamnaceae	**7**	*Knautia*		*Equisetum*
	Rhamnus		*Calystegia*		
3	*Evonymus*		*Primulaceae*		monoletes
	Cornus sanguinea		*Campanulaceae*		monoletes orn.
	Sambucus		*Valerianaceae*	**10**	*Polypodium*
	Viburnum		*Gentianaceae*		triletes
	Ligustrum		*Geraniaceae*		triletes orn.
	Hedera		*Euphorbia*		
	Viscum				*Sphagnum*
	Vitis				
	Salix (willow)				
	Alnus (alder)				

1 = conifers
2 = *Frax./Acer*
3 = shrubs
4 = *Plantago*
5 = ruderals
6 = *Compositeae*
7 = other herbs
8 = amphibious
9 = aquatics
10 = ferns

Table II: Floristic list recognized at the Quai-Branly site and ecological groups proposed in Figure 4

Age (cal BP)	PAZ R.	PAZ L	Stratig.	Characters of the pollen assemblage	paleoecological interpretation
730-560 ?	X	9	sub-unit 4b sandy silts	Decrease in ligneous plants to the advantage of *Poaceae, Asteraceae* and ferns. Anthropogenic indicators remain well developed. MQB 9b = increase of *Asteraceae* and ferns at the expense of *Poaceae, Plantago* and amphibious plants. Slight enhancement of *Corylus* while *Quercus* decreases. MQB 9a = rise of *Poaceae, Asteraceae* and *Plantago.* Slight development of amphibious plants.	Open landscape marked by human activities 9b = the poor conservation of pollen grains skews the paleoecological interpretation of the data.
around 1000	X	8	sub-unit 3g organic beds	Re-expansion of ligneous at the expense of herbs. More regular record of *Juglans* and *Castanea.* MQB 8b = progression of *Fagus, Corylus, Ulmus* and *Fraxinus* in parallel with a reduction of anthopogenic indicators. MQB 8a = rise of certain ligneous (*Betula, Ulmus, Carpinus*, shrubs) while *Cerealia, Plantago* and others ruderal plants remain abundant.	Decrease of human pressure. Re-expansion of forest cover both in the valley bottom and on the slopes at the expense of meadows and cultivated fields.
1353-1538	X	7	sub-unit 3e/f (organic beds) + unpositionned samples	Appearance of *Castanea.* The decline of some ligneous (*Alnus, Betula, Ulmus, Fagus, Carpinus)* benefits herbs. *Cerealia*, *Plantago* and other ruderal plants attain their maximum frequencies. MQB 7c = fall of *Cerealia* but minor recovery of *Alnus.* Small rise of *Cyperaceae* while water plants decrease and *Cannabis/Humulus* disappears. MQB 7b = *Fagus* increases at the expense of *Quercus, Betula, Salix* and shrubs. Major rise in ruderal plants and the *Asteraceae* jointly with a more discrete enhancement of *Cerealia.* Water plants decrease slightly whereas amphibious and *Cannabis/Humulus* develop. MQB 7a = increase of *Quercus, Salix* and shrubs. Rise of water plants.	Peak of human influence (forest clearing and agro-pastoral activity) 7c = decline in agro-pastoral activity and slight recovery of alder woods. 7b = open landscape dominated by grazed meadow and cultivated fields. 7a = alder woods more cleared than oak.
1700 around 2000	X	6	base of unit 3 organic beds	Appearance of *Juglans.* Small rise of *Betula.* Regressive tendency of the herbaceous vegetation apart from *Cerealia.* Decline of ferns MQB 6b = increase of *Fagus* and *Carpinus* at the expense of *Betula, Fraxinus* and shrubs. MQB 6a = slight enhancement of *Ulmus, Fraxinus, Carpinus* and shrubs. Small renewal of *Cannabis/Humulus* and *Cyperaceae.*	Re-expansion of forest cover both in the valley and on the slopes. Small decrease of human influence.
2100	IX	5	Tufa poros. + unit 2 balls and organic layers	*Fagus* and *Carpinus* are present. Decrease of *Tilia.* Joint rise of *Poaceae, Asteraceae, Plantago* and other ruderal species. Sub-continuous curve of *Cerealia.* The hygrophylous assemblage increases and becomes more diversified. MQB 5b = the decrease of several ligneous (*Alnus, Betula, Ulmus, Fraxinus, Tilia*, shrubs) benefits *Asteraceae,* amphibious herbs, certain water plants (*Sparganium, Potamogeton*) and ferns. *Cannabis/Humulus* disappears. MQB 5a = *Salix, Betula* and *Fraxinus* increase but *Alnus* always the main taxon.	Alder remains established in the valley bottom and oak-beech woodland on the hillslopes. Development of a water meadow near the river. Landscape clearly marked by human influence (crop cultivation, animal husbandry). 5b = woodland clearance
2800 around 5500	VII/VIII	4	top of unit 1 Tufa	*Alnus* extends and supplants *Corylus.* Disappearance of *Cerealia.* Decrease of *Cyperaceae* and *Cannabis/Humulus*. Increase of ferns. MQB 4b = renewed expansion of *Quercus.* Retreat of *Plantago.* Small enhancement of *Rosaceae* and *Ranunculaceae* (amphibious assemblage). MQB 4a = retreat of *Quercus, Ulmus, Fraxinus* and shrubs. Slight development of *Plantago,* other ruderals and *Asteraceae.*	Alder woodland established in the valley botom and mixed oak woods on the slopes. 4a =opening of the oak woodland by middle to recent Neolithic groups.
5500	VII	3	base of unit 1 Tufa and organic levels	Rise of *Alnus* and of the oack woodland components (*Ulmus, Tilia, Fraxinus*, shrubs). Development of the hygrophylous assemblage. Rise of the ruderals. MQB 3b = increase of *Quercus* at the expense of *Corylus. Tilia* supplants *Ulmus.* Rise of *Cyperaceae* and *Cannabis/Humulus* while water plants become sparser. Ferns decrease. MQB 3a = *Corylus* remains predominant. *Tilia* is less abundant than *Ulmus.* Small rise of *Urticaceae* (ruderals). First increase of ferns.	Real development of the mixed oak woodland. Some alders are growing on the banks of the Seine. Humid meadows near the river. Slight human activity (early or middle Neolithic groups)
7500	VI	2	Tr.B (south log.) organic layers	Rise of *Ulmus.* First appearance of *Tilia* and *Fraxinus. Alnus* becomes sub-continuous. *Salix* disappears. Slight development of *Asteraceae.* Appearance of *Cerealia* and *Plantago*. Diversification towards water plants. MQB2c = retreat of *Corylus* and *Ulmus*, light renewal of *Quercus* and *Pinus.* Small rise of ruderals and *Cannabis/Humulus.* MQB2b = decline of *Quercus* and *Alnus* benefits *Corylus* and *Ulmus* while *Cerealia* and *Plantago* appear. MQB2a = rise of *Quercus* at the expense of *Corylus.*	Open oak woodland with many hazels and elms. 2b = woodland clearance for agro-pastoral purpose
8950 9500	V	1	Tr.B (north log.) organ. clays	Predominance of *Corylus* over *Quercus. Pinus, Ulmus, Salix, Betula* and various shrubs are present. Herbs sparsely developed with *Poaceae* preponderant aver ruderals. Hygrophylous assemblage diversified but weakly developed.	Open woodland dominated by hazel and oak. Meadows near the river.

Table III: Description of the local pollen assemblage zones (LPAZ) of Quai-Branly site. Environnemental interpretation and correlations with regional pollen assemblage zones of the Paris Basin (RPAZ)