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Evidence for an early land use in the Rhône delta (Mediterranean France) as recorded by late Holocene fluvial paleoenvironments (1640–100 BC)

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Abstract – The overall objective of this paper is to describe the late Holocene (1640–100 BC) sedimentary and biological evolution of the Rhône–delta–plain, to interpret the sedimentary facies and palynofacies as the result of the effects of fluvial dynamic fluctuations and relative sea level change and to evaluate the paleohydrological constraints in the development of the land use and settlements of the Camargue. Focus is made on the upper part of V_{III} core drilled on NE of the Vaccarès lagoon. By combining sedimentology, palynology, magnetic susceptibility and archeological data, this study allowed to identify the superposition of three types of paleo-environments (marsh, fluvial floodplain, levee/crevasse splay). This sequence indicates a gradual extension of fluvial environments between the end of the second millennium BC and the 1st century BC. The variability of fluvial dynamic is evident during this period with important flood events which contrast with periods of low flow. Pollen record can be a good marker of the fluvial dynamic variability. The expression of the riparian tree pollen grains in the coarser floodplain deposits could correspond to increased fluvial influence and probably to erosion of riverbank during flood events. The local plants are associated to the low energy sedimentary environments. Focuses are made on the relations between the evolution of the environment and land use. The development of the cereal culture in the floodplain of the Rhône delta has been demonstrated between 1640–1410 and 100 BC. The last alluviation of the Rhône perturbs the research of the archaeological sites in the central part of the delta but the existence of the rural villages from

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the first part of the first millennium BC is highly possible.

fluvial dynamic / land use / late Holocene / Rhône delta / France

Résumé – Preuves d'une mise en culture précoce de la plaine deltaïque du Rhône (France méditerranéenne) enregistrées par les séquences fluviales de l'Holocène récent (1640–100 av. J.-C.). L'objectif de cet article est (1) de préciser l'évolution sédimentaire et biologique de la plaine deltaïque du Rhône au cours de l'Holocène récent (1640–100 av. J.-C.), (2) de proposer une lecture des unités sédimentaires et des palynofaciès qui rende compte des effets des fluctuations de la dynamique fluviale et du niveau moyen relatif de la mer et (3) d'évaluer les contraintes paléohydrologiques et sédimentaires exercées par le Rhône sur l'utilisation du sol et le développement des habitats en Camargue. Par la sédimentologie, la palynologie, la susceptibilité magnétique et l'archéologie, cette étude montre la succession de trois types de paléoenvironnements (marécage, plaine d'inondation, berge/delta de rupture de levée). Cette série indique une extension graduelle des environnements fluviaux entre la fin du second millénaire et le I^er^ siècle av. J.-C. La variabilité de la dynamique fluviale est évidente durant cette période marquée par l'occurrence de grosses crues alternant avec des phases de bas régime hydrologique. L'enregistrement pollinique peut être considéré comme un bon marqueur de cette variabilité hydrodynamique. La présence de grains de pollens de la ripisilve du Rhône dans les dépôts grossiers de la plaine d'inondation traduit le renforcement de l'énergie fluviale dans le delta et probablement l'érosion des levées de berge durant les épisodes de crue. Les pollens de plantes locales restent le plus souvent associés aux milieux fluviaux de basse énergie. La palynologie des dépôts permet également de s'intérroger sur les relations entre l'évolution de l'environnement et l'utilisation agricole du delta. Le développement de la céréaliculture dans la plaine d'inondation du Rhône d'Ulmet est démontrée entre 1640–1410 et 100 av. J.-C. Les dernières phases d'alluvionnement du Rhône perturbent la recherche des sites archéologiques dans la partie centrale du delta mais l'existence de villages ruraux mis en place dès la première partie du premier millénaire av. J.-C. est hautement envisagée.

dynamique fluviale / mise en valeur agricole / Holocène récent / delta du Rhône / France

1. Introduction

The Rhône delta was built in a context of highstand transgressive system [1]. Holocene deposits overlaid Pleistocene fluvial formations (isotopic stages 2–4) whose top is reached by coring at –24 m on the north side of Vaccarès lagoon [2–6]. The Holocene sequence is characterized by the superposition and interstratifications of four paleo-environmental types of sediments: (1) downstream and at the base, marine deposits form the major part of the deposits, with maximum 'on-lap', dated 6500 BC and located at around –12 m NGF on the north of Vaccarès lagoon [7]. They are overlain by (2) brackish deposits, which occupied the present location of Vaccarès during the second part of the Holocene, (3) freshwater swamp deposits, mostly located in the north part of the plain and (4) fluvial deposits, corresponding to several ancient channels, which overlie most of the previous formations. The geometry and the location of each paleoenvironmental unit depend on the sediment supply of the Rhône, which explain the displacement of the coastline and the halomorphic environments to the South.

This present paper aims (1) to describe the late Holocene (1640–100 BC) sedimentary and the biological evolution of the Rhône deltaic plain, (2) to interpret the sedimentary facies and palynofacies as the result of the effects of fluvial dynamic fluctuations and relative sea level change and (3) to evaluate the paleohydrological constraints in the development of the land use and settlements.

1.1. General setting

The study area is located between two paleochannels of the Rhône river (Saint-Ferréol and Ulmet channels) (*figure 1*). The avulsion of the Rhône channels and their chronology are described by Duboul-Razavet [3] and L'Homer et al. [8]. The Saint-Ferréol channel constitutes one of the main outlets during the early Holocene. Towards 4000 BC, the Ulmet channel is active; nowadays, it forms the eastern bank of the Vaccarès lagoon. These two channels were active until the 14th to 15th centuries [9, 10]. They correspond to sand–silt ridges, sinuous and slightly raised, which change laterally to fine grained floodplain sediment. Their sedimentology, analysed at several archaeological sites recently investigated [11–13], indicates a pluri-millenary hydrological and sedimentological variability, according to the history of the climate and anthropization of the Rhône drainage basin [14–17].

The history of the vegetation has been described by Triat-Laval [18], who analysed pollen content from several boreholes. The most important changes which occurred since the Atlantic period are mainly linked to anthropic action (reduction of the deciduous oak forest, enlargement of shrub lands (with *Quercus coccifera*) and open landscapes, including cultivations).

1.2. Sampling and methods

In the framework of the Programme National d'Océanographie Côtière (PNOC), two cores, of about 20 m depth, were taken with a stationary piston core sampler on either side of Vaccarès lagoon; the cores meet marine, brackish and alluvial series (*figure 1*). The V_{III} core was drilled on the Pont Noir site at 0.40 m NGF, at about 3 km further south from the Saint-Ferréol channel. It is collected at the foot of a micro-cliff located on NE of the Vaccarès lagoon, which cuts the alluvial ridge of the Rhône d'Ulmet culminating at 0.65 m NGF. In this paper, focus is made on the upper part (2.8 m) of V_{III} core (*figure 2*). The method used was based on different topics, associating palynologists, sedimentologists, geomorphologists and historians. It allows a description of the last fluvial episodes and the biological context where they have been acting.

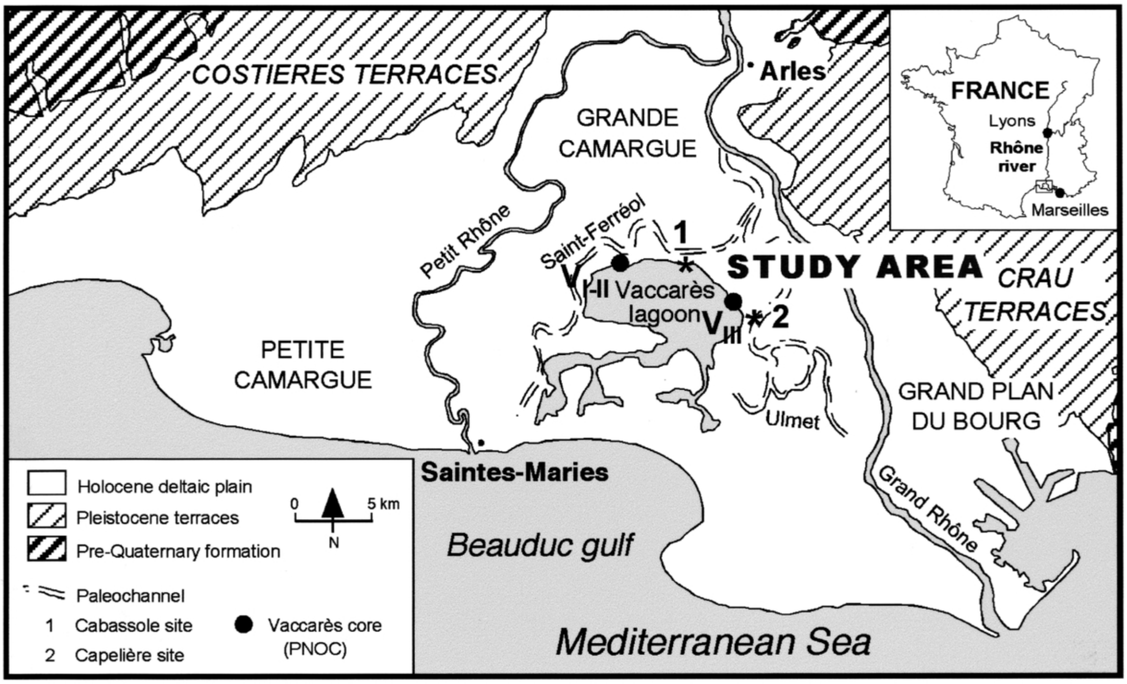

Figure 1. Location map of the Rhône deltaic plain and the paleochannels near the study area.

The 2.8 m section of studied sediments is characterized by fine, mainly silty, deposits, except between 129–163 cm and between 38–116 cm, related to two sandy layers. The distinction of the sedimentary units is based on variations in colour, fauna and structure (massive/bedded). Sedimentological and palynological analysis were carried out on sampling collected every 5 to 10 cm, or according to the variation of the facies. In addition, near-continuous measurements of the low-field volume magnetic susceptibility (κ) were performed on U-channel subsamples at 2 cm depth-interval.

The base of the studied section (around 273 cm) is dated by radiocarbon on organic matter mainly composed of *Ruppia* macro-remains, 3245 ± 60 BP, cal. BC 1640–1410 [Lyon–248 (OxA)]. On the top of the section (at 0.25 m NGF), an archeologic site dated to the 1st century BC, corresponding to the sedimentary unit 5 of the core (cf. infra), gives a 'terminus' of the chronology [19].

2. Results

2.1. Sedimentology and magnetic susceptibility

Sedimentological analysis of the V_{III} core allows to identify five sedimentary units that will be characterized in the upcore order (*figure 2*).

Sedimentary unit 1 – Between 278–253 cm, a sandy-clayey silt layer with centimetric subhorizontal laminae, dark to light brown (7.5 YR 4/2 to 6/4), is characterized by an abundant shell debris [*Cardium* (*Cerastoderma glaucum*)]. The sandy, fine grained, fraction decreases progressively towards the top. Three laminae are characterized by a negative asymmetry concerning the grain size distribution. The deposit is rich in carbonates (38–40 %) and organic carbon (1.7–1.9 %).

This sedimentary unit corresponds to an environment of low energy sedimentation (palustrine). The fine particles (silts and clays) have been deposited by decantation processes. The sandy fraction of the laminae probably corresponds to episodic coarser influxes of fluvial and/or marine origin and explains the negative asymmetry. The high organic content is explained by a confined environment with abundant organic debris. The carbonates have a biogenic origin, in relation with the presence of *Cardium* (*Cerastoderma glaucum*) which indicates an oligohaline environment but does not necessarily induce a relationship with an open marine environment [20]. The base of this sedimentary unit is dated 3245 ± 60 BP, cal. BC 1640–1410 [Lyon–248 (OxA)].

Sedimentary unit 2 – Between 253–163 cm, sandy silts, dark grey (2.5 Y 4/0), light grey (2.5 Y 7/0) or whitish (5 Y 8/1), are characterized by rhythmic subhorizontal centimetric laminae (0.5–5 cm). The percentage of organic matter and carbonates contained in the sediment is less important than in the underlying unit and decreases toward the top of

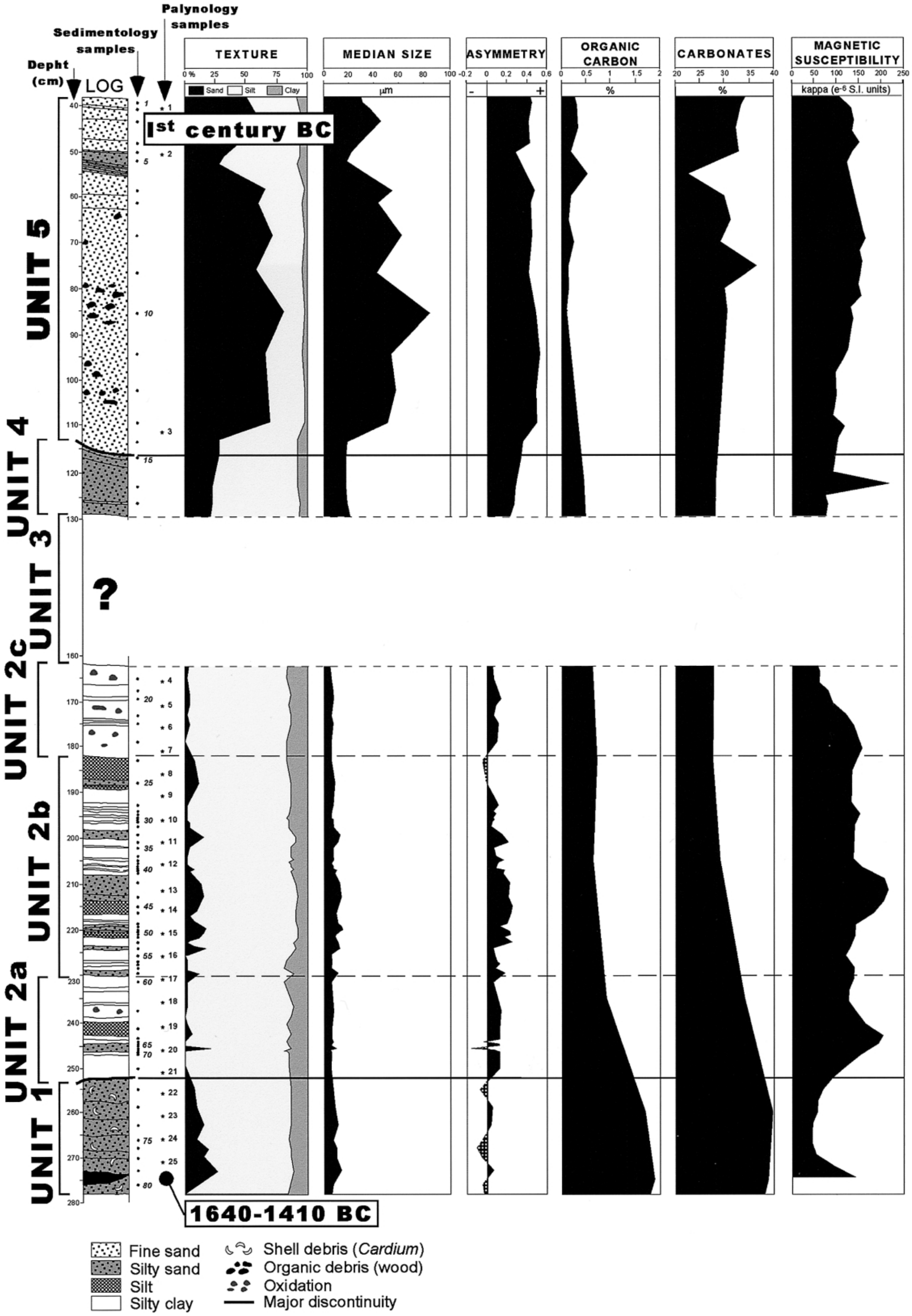

Figure 2. Sedimentological and magnetic susceptibility analysis of the V_{III} core.

the unit (organic matter: 0.9–0.5 %, carbonates: 34–28 %). A general positive asymmetry shows an increase of clay, which indicates a low energetic environment (distal floodplain). Moreover, the variations in sand content allow to distinguish: (1) facies 2a (253–230 cm) – very fine silty-clay deposit, where rare sandy peaks (243–246 cm) induce a negative asymmetry and indicate the temporary arrival of coarser material; (2) facies 2b (230–182 cm) – coarser, i. e. silty sand, deposit with thinner, more numerous and frequently dark laminae. The positive asymmetry indicates an increase of clay, except in the top-layer, characterized by an influx of coarser silt; (3) facies 2c (182–163 cm) – silty clay deposit is characterized by a positive asymmetry and oxido-reduction traces (pseudo-gley).

This sedimentary unit shows the drying up of a palustrine environment, characterized by the disappearance of *Cardium* and the decrease in organic carbon and carbonates. It corresponds to sedimentary functioning of the floodplain, where textural variations indicate variability of hydric fluxes and/or the shifting of the river branch away from the site. Facies 2a represents distal floodplain deposits: large amounts of silt and clays indicate very low energy, interrupted by rare more energetic episodes. Facies 2b represents a slight increase in hydrodynamics (flood frequency), demonstrated by the increase in the number of laminae. Nevertheless, their smaller thickness indicates a decrease in sediment volume accumulated during each flood. Facies 2c indicates a low energy condition in a hydromorphic environment linked to recurrent fluctuations in the water table (pseudogleyification).

Sedimentary unit 3 – Between 163 and 129 cm, a 34 cm sediment hiatus is due to coarse sand layer, not preserved in the core tube. It reflects probably the increase of the fluvial dynamics or an important flood event.

Sedimentary unit 4 – Between 129–116 cm, dark sandy silts (2.5 Y 4/0) correspond to a coarse detritic unit. Moreover, the positive asymmetry indicates a relative increase in fine silts and clays; the amount of organic carbon is very low (0.5 %).

This sedimentary unit shows a proximal floodplain deposit, with relatively high energy flow, related to the nearby river channel. The decrease of the organic carbon can be associated with a proximal environment without seasonal swamp flooding. The positive asymmetry corresponds to the fine fraction accumulated at the end of the floods.

Sedimentary unit 5 – Between 116–38 cm, a massive sand silt deposit, pale brown (10 YR 6/3), is characterized by an abundant and coarse sandy fraction. Nevertheless the positive asymmetry reflects an increase of fine particles (silts and clays). The deposit is characterized by a high percentage of carbonates (23–33 %) and a low organic carbon content (0.1–0.5 %). The content of carbonates decreases toward the top of the unit. Plant debris (wood) is present at 106–96 cm, 88–78 cm, and 70–64 cm. At 52–55 cm, sandy–silt laminites correspond to finer grained deposits, with higher content of organic carbon and lower percentage of carbonates.

This sedimentary unit indicates a global change in dynamics. The large sand fraction and the increase of grain size indicate an energetic hydrodynamic environment. Numerous sandy peaks result from a temporary increase of river discharge, concerning the layers located in the median part of this unit. Moreover, a positive asymmetry shows the presence of a fine fraction linked to the end of the event. The low content of organic carbon corresponds to an emerged environment or an abiotic detritism. The increase of the content in the fine laminated layers could indicate the episodic events of submersion. The variations of the percentage of carbonates are not related to the grain size variations; the fine or coarse carbonated particles have a detritic origin. In fact, this sedimentary unit corresponds to the build-up of the Rhône river bank. Compared to previous phases, it represents a drastic change of the environment, characterized by a shifting of the river branch close to the site and an increase of the river water discharges. This shifting is anterior or contemporaneous to the archeological site of the Capelière dated to the 1st century BC.

Concerning the magnetic susceptibility analysis, the κ profile of V_{III} core shows two zones of maximum values (up to $150 \cdot 10^{-6}$ S.I.) corresponding to the fluvial silt and clays from sedimentary units 2a–b and 5, respectively. This observation is consistent with former magnetic studies from the Vaccarès pond, which indicated relatively high κ values in silty and clayey materials from the Rhône river [21]. Such behaviour likely results from (1) the dilution effect by weakly paramagnetic sands as enriched in diamagnetic marine or continental minerals, such as quartz or calcium–carbonate (shells, limestone) debris, and (2) the enhancement effect by allochthonous or autochthonous pedogenic iron oxides in the silty and clayey fraction.

In addition, the pseudo-gley from zone 2c presents low κ values, similar to the sands from sedimentary unit 1 or 3. This is not surprising, as gleying processes usually result in a near-complete dissolution of iron oxides like magnetite and maghemite in reducing conditions [22]. Thus, the κ record of V_{III} core likely depends on two main processes: the energy of deposition, and pedogenic processes.

To conclude, the sedimentological analysis shows the succession of three types of paleoenvironments: (1) at the base, a swamp, episodically supplied by fluvial and/or marine deposits; (2) a fluvial floodplain, at varying distances to the river channel, whose low-dynamic sedimentation is interrupted, near the top, by the influx of coarse sandy deposits (rupture of a bank?); (3) a bank deposit, indicating the shifting of the river branch very close to the site. The CM pattern of Passega [23] reflects these contrasting environments (*figure 3*).

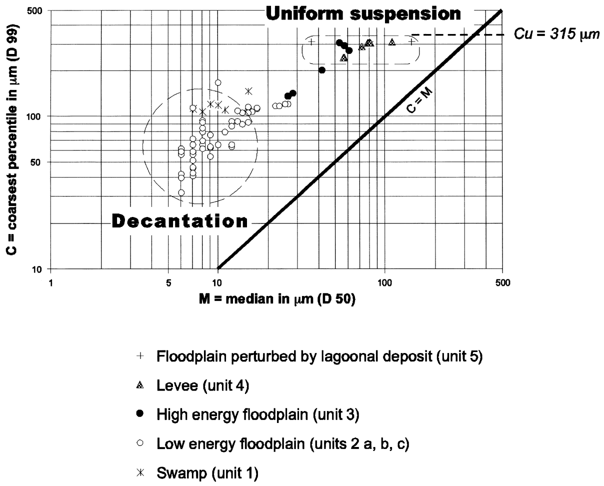

Figure 3. CM pattern of the sedimentary environments.

The variability of fluvial dynamics is evident between the end of the second millennium BC and the 1st century BC, with important flood events. This trend can be interpreted as an hydrologic variability effect, with an increase of the river discharge, or a shifting of the river branch close to the site.

2.2. Palynology

The pollen flora is composed of 129 taxa (Arboreal Pollen: 45; Non Arboreal Pollen: 84) and yields a reliable illustration of the southern France vegetation (*figure 4*). The riparian trees of the Rhône valley (*Alnus*, *Salix*, *Populus*, *Fraxinus*) are represented by low amounts of pollen grains. *Alnus* is the most frequent element, mainly between 240.5–170.5 cm depth. The Mediterranean xerophytes (*Pistacia*, *Olea*, *Phillyrea*, *Quercus ilex* type, *Cistus*, etc.) have been regularly recorded. The mesophilous elements (deciduous *Quercus*, *Castanea*, *Juglans*, *Buxus*, *Celtis*, *Ulmus*, *Carpinus*, *Ostrya*, *Tilia*, *Acer*, *Corylus*, etc.) are abundant, especially in the lower part of the pollen diagram (from 270.7–175.5 cm depth). The mountain vegetation belt is expressed by low percentages of *Betula*, *Fagus*, *Picea* and *Abies*. *Pinus* shows frequencies reaching sometimes 20 % and should illustrate various environments from the seashore to the mountainous belt. As demonstrated in a recent study of modern pollen spectra in Camargue [24], Cupressaceae are significantly under-represented and probably constituted by two genera, *Cupressus* and *Juniperus*, of different ecological sense. Non arboreal pollen grains are predominant with large amounts of Poaceae, Asteraceae, *Plantago*, Polygonaceae and *Hippophae rhamnoides*. Halophytes (Amaranthaceae–Chenopodiaceae, Caryophyllaceae *p.p.*, Plumbaginaceae, *Tamarix*) are important in the lowermost samples (25–22) and compose the largest part of the pollen flora in the uppermost samples (2 and 1). Ericaceae (including *Calluna*) are common and exhibit two maxima in samples 15 and 13. Water plants (*Myriophyllum*, *Potamogeton*, *Sparganium*, *Typha*, *Ruppia*) and plants which can be considered as partly associated with freshwater marshes (Cyperaceae, Ranunculaceae) are very frequent in the lowermost part of the section (samples 25–20) and show a second optimum in samples 7 and 5. Cultivation is illustrated by the almost continuous record of *Olea*, *Vitis*, Cerealia (maximum between samples 16–12) and by some occasional records (*Castanea*, *Linum usitatissimum*, *Cannabis*, *Rheum officinale*). Man's influence is characterized by the continuous presence of *Juglans* and some sporadic documents as *Platanus*. Fern spores are frequent within the lower half of the diagram. Dinocysts have been scarcely found in the lowermost samples. Pollen concentration is very high (from 16 000 to more than 32 000 pollen grains/g of sediment) in the lowermost samples (25 to 22) and relatively low (from about 30 to ca. 7 000 pollen grains/g) in the overlying samples. Some reworked palynomorphs (pollen grains, spores and dinocysts) have been recorded along the section. They exclusively concern elements from Mesozoic to Neogene deposits which regularly exposed along the Rhône valley. They are especially frequent from samples 20 to 4.

In addition, the composition of the pollen flora is in agreement with the ^{14}C age of the base of the studied section (3245 ± 60 BP, cal. 1640–1410 BC) and the overlying development of cereal cultivation, but the continuous presence of *Juglans* might suggest that the ^{14}C dating is too old. According to Beug [25], *Juglans* cultivation has been extended in the western Mediterranean countries thanks to the Roman expansion at the turn of the era. But unpublished data from the Old Port of Marseilles suggests that *Juglans* was present in Provence at the time of the Greek settlements, that is supported by the continuous presence of *Juglans* since ca. 3500 BP in two pollen diagrams from Greece [26, 27]. Thus the timing of the *Juglans* arrival may have occurred earlier (ca. 3200 BP) than the Roman expansion. This pollen succession provides an original focus of the southern France vegetation over the last 3 000 years which was missing in the previously studied along the Camargue core from Les Frignants [5, 18].

A synthetic pollen diagram contributes also to evidence local and regional vegetation changes which are concurrent with the sedimentological subdivisions of the section (*figure 5*). Pollen diagrams represent the local environment changes, of the anthropic action and of the climate evolution. Four pollen assemblages have been distinguished.

Pollen assemblage 1 – From sample 23 to sample 21, between 270.5–248 cm, successively, halophytes (Amaranthaceae–Chenopodiaceae) and freshwater plants (mainly *Myriophyllum*, *Typha* and *Ruppia*) are abundant. Pollen concentrations are the greatest ones recorded in the section (from 16 000–32 000 pollen grains/g of sediment) and denote the predominance of the local environment. Such an environment, associating nearby salted water lagoons and

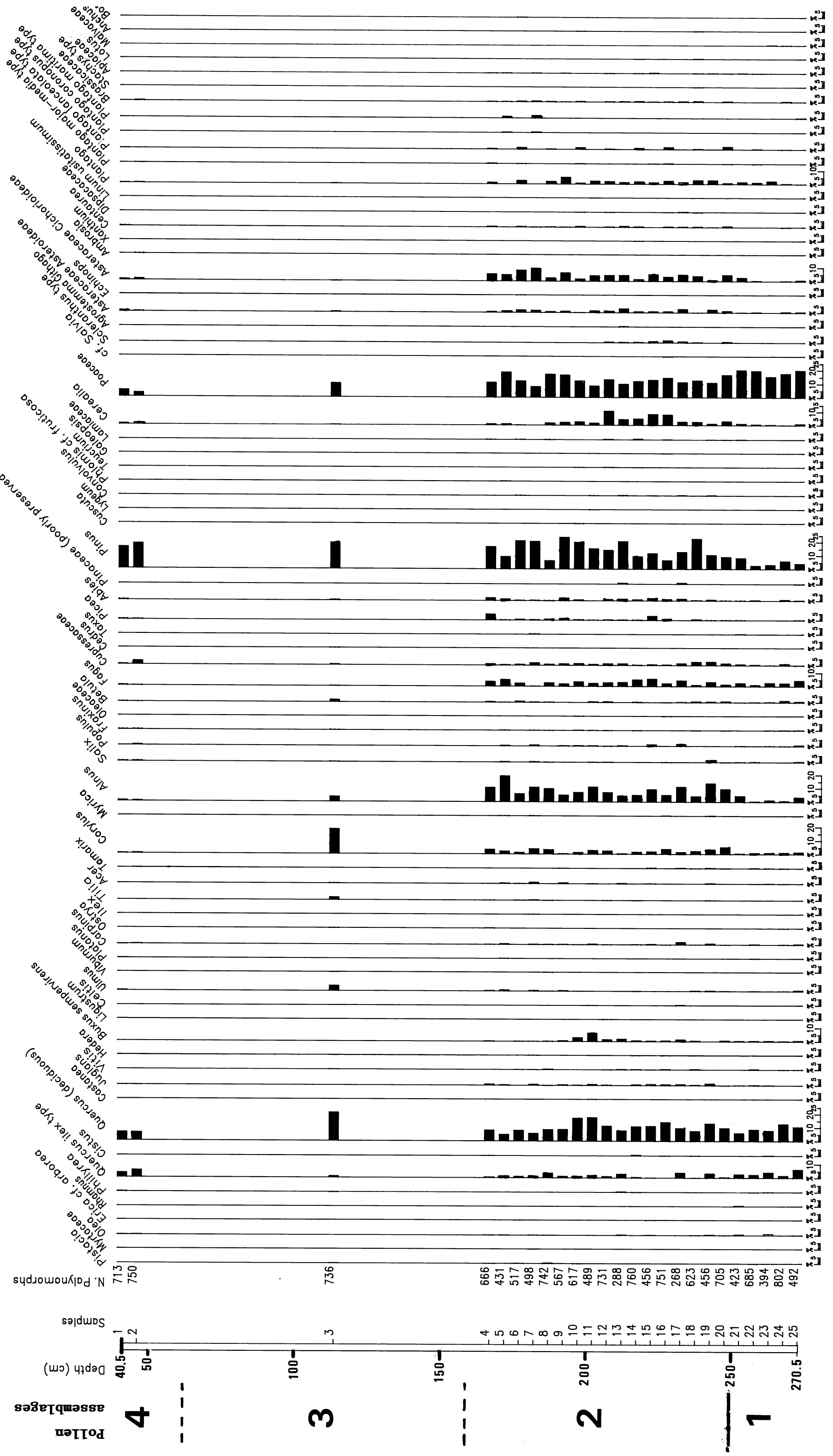

Figure 4. Pollen diagram.

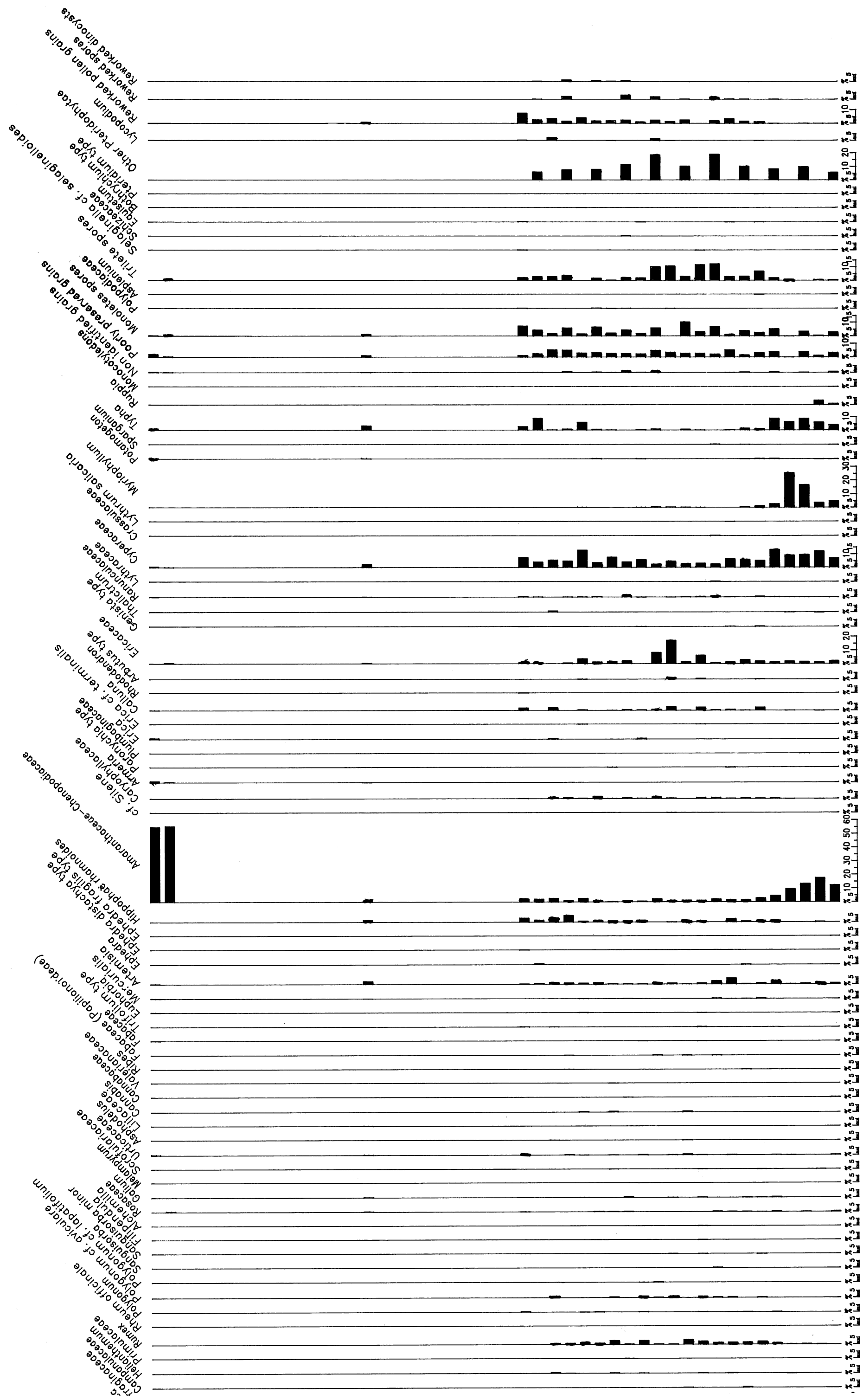

Figure 4 (suite).

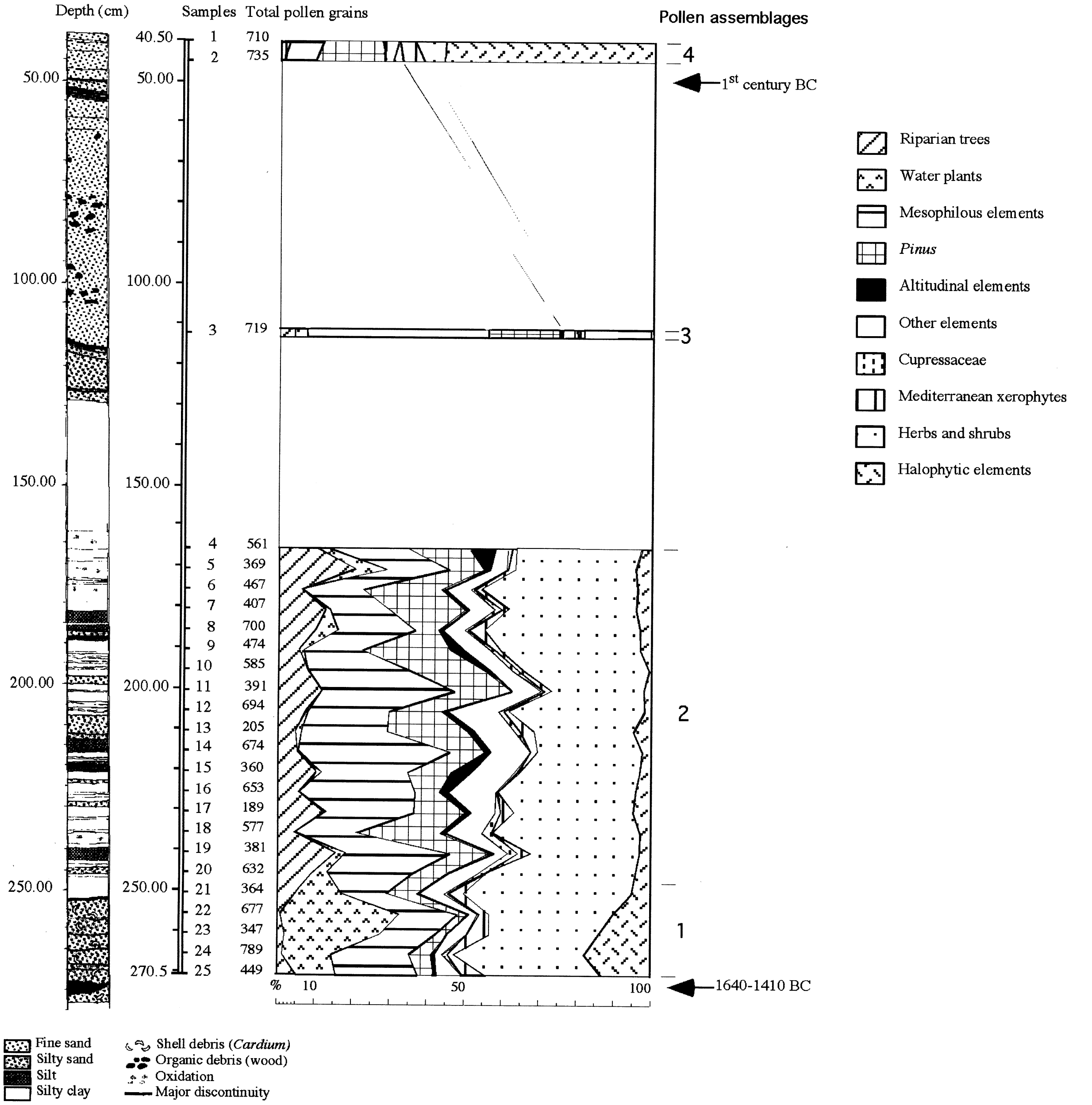

Figure 5. Synthetic pollen diagram (taxa are grouped according to their ecological significance).

freshwater ponds, is similar to the modern ones in Camargue and, in addition, the variations in the pollen sedimentation response are well known [18, 24]. The brackish conditions of the base of the sequence are supported by the presence of *Cerastoderma glaucum* and of some dinocysts. The overlying increasing freshwater environment is also indicated by the richness in *Ruppia* macro-debris. Such a change in environment suggests fast variations in water salinity.

Pollen assemblage 2 – From sample 20 to sample 4, between 248–163 cm, this assemblage is characterized on the one hand by a strong decrease in water and halophilous plants, on the second hand by an increase in *Alnus* (riparian tree) and *Pinus*. This indicates the importance of the fluvial action over transport and sedimentation of the pollen material as deduced from the positive comparison with the modern pollen records in the Grand Rhône prodeltaic sediments

[28]. Indeed, the later are rich both in riparian element and in *Pinus*, the pollen of which is highly advantaged in transport. The clear influence of the river is also supported by the presence of reworked palynomorphs. Such reworked palynomorphs are very scarce in the modern Grand Rhône prodeltaic deposits. Increases of reworked palynomorphs are recorded during phases of lowering relative sea-level [29]. We must notice that this assemblage includes the maximum record of cerealia that could appear prior to the generally accepted period of beginning of cultivation in the area (100 BC–100 AD) which corresponds to the Roman occupation [19, 30].

Pollen assemblage 3 – At 112.5 cm depth, the sample 3 appears to be less reliable as the underlying samples because of the lower number of recorded taxa. This probably indicates low conditions in preservation that could also support the relatively high percentages of taxa whose pollen grains have a thick exine (*Quercus*, *Corylus*). Sample 3 is the only one to have provided pollen material within the sandy sediments from the sedimentary unit 5.

Pollen assemblage 4 – From the samples 2 and 1, between 45.5 and 40.5 cm, the poor pollen flora (about 30 taxa only) shows the same representation of the modern rain in Camargue (pollen traps) as also recognized in the surface sediments of the Vaccarès lagoon [24]. Amaranthaceae–Chenopodiaceae pollen grains highly predominate, which indicates the development of the brackish marshes. The intensive modern cultivations in Camargue (rice, corn) is only illustrated by some pollen grains [24] that could be an argument for estimating the development of cultivation during the phase located between 1640–1410 and 100 BC (pollen assemblage 2).

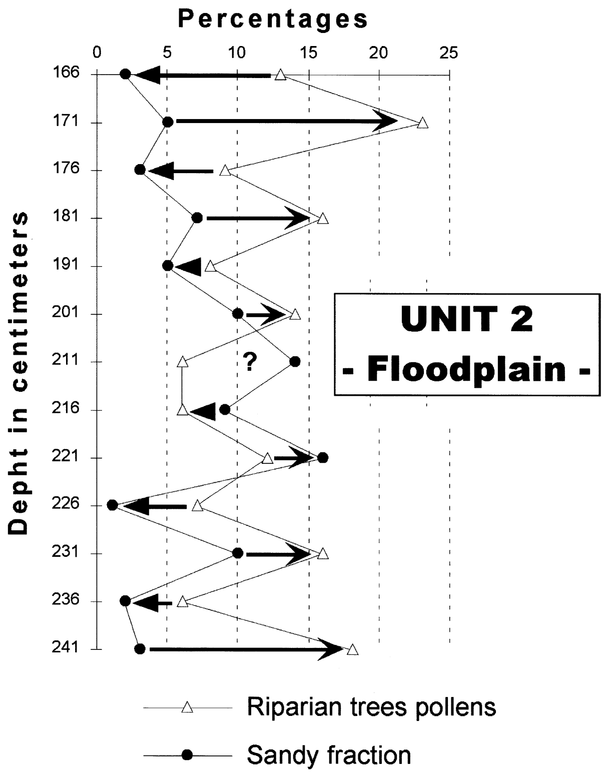

Figure 6. Relations between riparian tree pollen grains and sand fraction deposited in the floodplain.

3. Discussion

3.1. Pollen assemblage and fluvial dynamic variability

The succession of sedimentary facies, revealing the fluvial dynamic variations, is in agreement with the pollen analysis. In the floodplain deposits, no statistic correlation exists between riparian trees pollens and the sand fraction ($r^2 = 0,19$). But it seems that riparian tree pollen grains grow when sand fraction grows too. Abundance of the riparian tree pollen grains seems to be associated to the high energy facies. Today, the Grand Rhône prodeltaic sediments are rich in riparian tree pollen grains (20 % on an average) [24, 28]. So, the increase of these elements, often in association with growing of mesophilous elements can be considered as the consequence of a closer influence of the Rhône d'Ulmet over the studied locality. In addition, erosion of riverbanks and the riparian soils during the important flood events could also contribute to explain the migration of the riparian tree pollen grains in the floodplain (*figure 6*). The representation of the herbs of the floodplain is associated to the low energy sedimentary environments (sedimentary units 2a and 2c). The presence of the hydrophytes, at the top of the sedimentary unit 2b and in the sedimentary unit 2c, in association with peaks of riparian trees, could express the incursion of Rhône waters into marshy environments.

But the correlation between sedimentological and palynological data is less evident at the top of the core (sedimentary unit 5) because several samples are either pollenless or characterized by a low taxonomic diversity.

The correlation between the results of this study and the paleohydrological activity described for some other sites of the delta is not evident. It shows that the hydrological history of the Rhône delta is complex. The alluviation on the deltaic plain is not uniform; it depends on several factors such as fluvial dynamics or relative sea-level variations. Between 3700–1500 BC [31], a phase of stability of the relative sea-level rise, associated with an hydrosedimentary change in the Rhodanian catchment basin [16, 32], produce a rapid progradation of the coastal fringe to the South. Several archaeological sites, located on the side of the Rhône de Saint-Ferréol and Ulmet, allowed a description of the paleohydrologic activity in the Rhône deltaïc plain during the Protohistoric and the Roman times [11]. The brackish and freshwater deposits have overlain the marine and lagoon sedimentary environments at the Carrelet site, the Mornès site and the Capelière site. Then a phase of flooding is observed between 5th–4th to 1st century BC. On the Cabassole site (*figure 1*), the heterogeneous deposits (silts alternating with fine sands) reflect an irregular hydrologic flow. Moreover, between 1st century BC and 1st century AD, homogeneous and coarse deposits (sandy silts essentially) indicate a high and regular dynamic in the floodplain; it can be considered like a hydrological change which affects the streams of the Rhodanian catchment basin [14, 15, 17].

3.2. Reworked pollen grains as an evidence of riverbank's erosion in the watershed

The pollen analysis highlights the presence of low quantities of 'reworked pollen grains' in the sedimentary unit 2, deposited after 1640 BC. This period corresponds to the fluvial change in the Rhodanian watershed, in the context of climatic degradation of the Sub-Boreal [11, 15, 33, 34]. Consequently, the presence of 'reworked pollen grains' could indicate the erosion of the riverbank in the Rhône valley, in relation to the channel infilling and/or a lateral channel instability during periods of major flooding. In comparison, the absence of 'reworked pollen grains' in the recent prodelta deposits of the Grand Rhône could indicate that the recent incision phenomenon and/or the lateral channel instability in the Rhône valley is less important than at the Sub-Boreal period.

3.3. An early cereal cultivation in Camargue

This study shows that the extension of cereal cultivation, associated with the drying of the wetland, begins around the Bronze Age in Camargue, earlier than it was suspected until now. The cereal culture, developed in the distal floodplain, persists without major discontinuity during several centuries: the increase of the energy conditions, induced by the shifting of the river branch close to the site or an increase of the river liquid discharge, has not changed the practice of the soil. The abandon of the cereal culture is linked to the extension of hydromorphic environments which do not allow the drainage of the lands; then a fluvial change, in relation to a channel's defluviation, stopped the agricultural activities around the 1st century BC.

The observed situation in the Rhône delta is quite similar to that described by Triat-Laval [18] and Andrieu-Ponel et al. [35] in the Baux valley and the western part of the Arles plain. These works show a remarkable presence of cerealia which was radiocarbon dated to the Bronze Age. The early part of this evolution is accompanied by the maximum occurrence of *Fagus*, dated to 3160 ± 45 BP [35, 36]. According to this date, the Calade site in the Arles plain reveals a cereal curve (*Cerealia* sp. and *Secale*) that is very prominent during the Roman period [37].

We know the existence of late Neolithic to Bronze Age tombs nearby at Fontvielle, despite this, the region was considered to be paludual during this period. Both pre- and protohistorians have excluded the possibility of permanent settlements in this area and attributed these structures to exterior populations. Environmental research of Bruneton [38] on water-level fluctuations invalidates this. Prior to the Iron Age and the Roman period, the zones above –0.7 m NGF remain drained. The rescue excavation necessitated by the laying down of a gas pipeline allowed the discovery of a Bronze Age site at Barbegal at 2 m NGF. This discovery is part of a series that allows us to partly explain the dearth of low lying sites during this period by the fact that they are covered by deep alluvial deposits. In the paludal areas of the Rhône valley, the excavations necessitated by the construction of the TGV allowed the discovery of a number of buried sites attributed to this period. On the Gard side of the Rhône at Roquemaure, large-scale hydraulic structures have been found in a depression [39]. On the other side of the river, upstream on the Orange plain, Neolithic levels have been found at depths of 5 or 6 m, whilst the roman levels are at 3.5 m [40]. Prior to the execution of rescue excavations of sites with deep stratigraphy, the number of Bronze Age sites was limited. On the eastern edge of the Rhône delta around the Saint-Blaise lagoon, Trément [41] observed a contrast between the reduced Bronze Age settlement and the preceding dense level of settlement during the late Neolithic. However, he also noticed a change during the late Bronze Age when there was a movement of settlement down towards paludal environments. To the west of the Rhône delta, the coastal lagoons in the Languedoc have been subject to underwater survey and sites dating to this period have also been found.

The geomorphic characteristics of the Rhône delta restrict the discovery of Bronze Age sites. The fact that the slope descends from north to south means that the Roman levels at the head of the delta are not very deep, at about 0 m NGF at Cabassole site, at –0.3 m at Carrelet site and at –0.5 m at Capelière site [19, 42, 43] (*figure 1*). As for the 5th century BC levels, these are located at between –0.5 m (Cabassole site) and –1.5 m (Capelière site) [42, 44]. Taking these characteristics into account, it is really not that surprising that so little is known about the prehistory of this area.

4. Conclusion

By combining sedimentology, palynology, magnetic susceptibility and archeological data, we have highlighted the late Holocene sedimentary and biological evolution of the Rhône deltaic plain. This study allowed to identify the superposition of three types of paleo-environments (marsh, floodplain, levee) which indicate a gradual extension of fluvial environments between the end of the second millennium BC and the 1st century BC. The variability of fluvial dynamics is evident during this period with important flood events which contrast with periods of low flow.

This work illustrates a relative correlation between the palynological and sedimentological data in deltaic floodplain. Pollen record can be a good marker of the fluvial dynamic variability. The expression of the riparian tree pollen grains in the coarser floodplain deposits could correspond to increased fluvial influence and probably to erosion of riverbank during flood events. The local plants (herbs and halophytes) are associated to the low energy sedimentary environments.

Focuses are made on the relations between the evolution of the environment and land use. Between 1640–1410 and 100 BC, the development of the cereal culture in the floodplain of the Rhône river is associated to the late Holocene construction of the fluvial sedimentary environments in the deltaic plain. The last alluviation of the Rhône perturbs the research of the archaelogical sites, but the existence of the rural villages, from the first part of the first millennium BC, is highly possible.

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