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Modern pollen deposition in the Rhone delta area (Lagoonal and marine sediments), France

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Modern pollen deposition in the Rhône delta area (lagoonal and marine sediments), France

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The investigation identifies the two main types of pollen sedimentation in the Rhône delta, and presents synthetic pollen spectra in terms of ecological groups in order to predict the pollen source areas. Two different domains are studied: the lagoonal zone occupied by the Vaccarès where atmospheric pollen input predominates and the Rhône mouth area (river delta and prodelta) where fluvial pollen influx prevails. The reflection of local and regional vegetation in the surface sediment pollen spectra is carefully discussed with reference to atmospheric pollen records and to water sample analyses. This work is designed to help the interpretation of past pollen spectra and paleovegetation and through them also paleoclimate reconstructions.

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The importance of understanding the processes of pollen transport, from production site to sedimentary deposit, has been recognized for several decades (Cross *et al.* 1966, Groot & Groot 1966, Solomon & Harrington 1979). Accurate reconstructions of past vegetation based on pollen spectra from deltaic sediments require reliable data on the respective contributions of fluvial and atmospheric components, as shown recently by Bernard & Pons 1985, Chmura 1990, Brush & Brush 1994, Chmura & Eisma 1995. The important role of fluvial transport in marine coastal environments adjacent to the river mouth has been demonstrated for both recent (Muller 1959, Heusser & Balsam 1977, Heusser 1988, Streel & Richelot 1994, Traverse 1994) and ancient (Suc & Drivaliari 1991) sediments. On the other hand, some marine areas, such as the Baltic sea, near the Swedish coast (Praglowksi 1977) or the Atlantic Ocean adjacent to the coast of West Africa, (Hooghiemstra 1988, Calleja *et al.* 1993) show the primary importance of airborne pollen. Here we present the results of an investigation of pollen deposition in the Rhône delta system (Fig. 1), a remarkable modern experimental domain.

The two primary objectives are: (1) to identify the respective significance of lagoonal (Vaccarès) and fluvial (Rhône delta and prodelta) pollen floras in terms of local, regional and distant vegetation sources; and (2) to discriminate qualitatively and quantitatively the relative influence of aerial and fluvial modes of pollen transport.

METHODS

Four kinds of samples are considered. 1) Atmospheric samples collected with horizontal pollen traps (Cour 1974). Two stations were set up, one near the Vaccarès lagoon, at La Tour du Valat

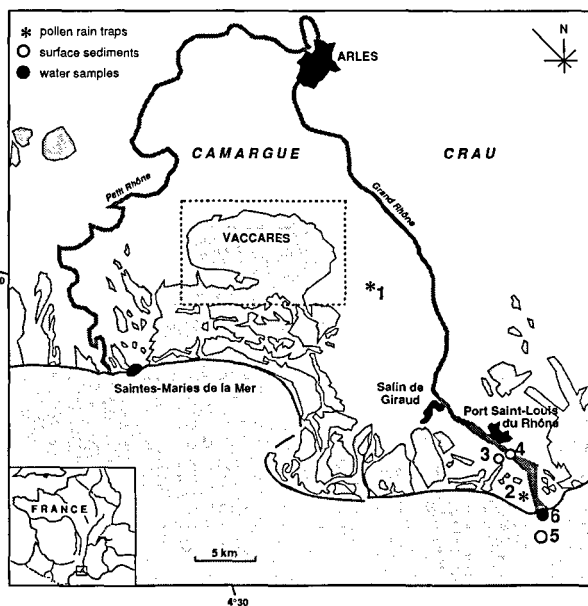


Fig. 1. The Rhône delta: sampling stations. Rose compass from Istres indicating the main wind direction. 1. La Tour du Valat, 2. La Palissade, 3. La Palissade sediment, 4. Port Saint-Louis du Rhône, 5. KTR05 core, 6. Grand Rhône plume area. Samples from the Vaccarès lagoon are located on Fig. 2.

(43°30'00" N, 4°39'34" E), the second near the Rhône mouth at La Palissade (43°21'00" N, 4°51'17" E) (Fig. 1). At both of these, horizontal filters were removed every fortnight for one year (from the first week of May 1992 to the first week of May 1993) thus providing 26 pollen records. 2) Lagoonal surface sediments collected from 13 localities: 12 scattered throughout the Vaccarès (Fig. 2 and

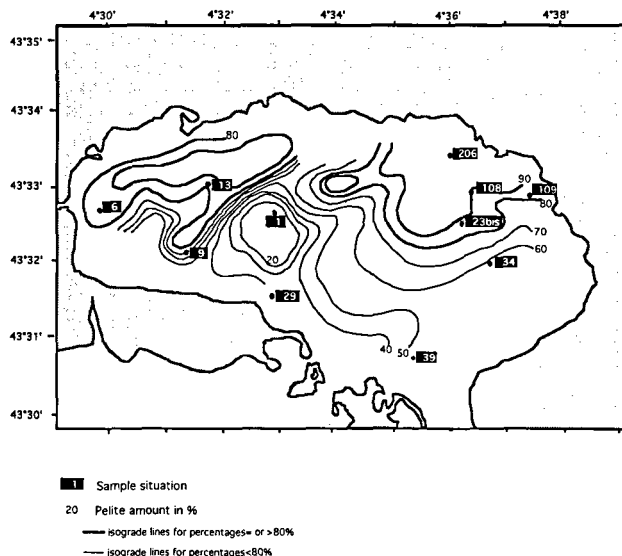


Fig. 2. Sample situation and granulometry distribution in Vaccarès lagoon. (isograds lines for percentages of pelite amount).

Table 1), and one in a salt marsh near La Palissade (43°24'31" N, 4°49'25" E) (Fig. 1). 3) Surface sediment collected from the Rhône river itself near Port Saint-Louis du Rhône (43°22'57" N, 4°48'30" E) (Fig. 1). Additional sediment was collected from the top (uppermost 8 cm) of an off-shore core, KTR05, belonging to the Rhône prodelta (43°18'28" N, 4°51'01" E) (Fig. 1). 4) Two marine water samples taken from the Grand Rhône plume area (near the surface and near the bottom = 29 m deep) (43°18'37" N, 4°50'34" E) (Fig. 1).

Surface sediments provide almost modern pollen records in two different sedimentary environments, lagoonal and deltaic which can be estimated by comparison with present day water and atmospheric pollen data.

Pollen was extracted from the surface sediments by standard sediment chemical processing (Planchais & Guillet 1969)

Atmospheric pollen samples were collected every fortnight, processed and analysed according to Cour's method (Cour 1974, Cambon 1981). The total of the 26 fortnightly data gives the annual atmospheric pollen record.

50 liter water samples were first filtered on nitrate cellulose filters (5 µm pore) and the residue was then processed in the standard way used for the sediments.

VEGETATION

Molinier & Tallon (1970) provide a general map of the vegetation of the Camargue (Fig. 3). The southern part of the delta is occupied

Table I. Geographical setting of the Vaccarès samples.

Core name	N. Latitude	E. Longitude
Vaccarès 1	43°32'40"	4°32'55"
Vaccarès 6	43°32'41"	4°29'47"
Vaccarès 9	43°32'08"	4°31'13"
Vaccarès 13	43°33'04"	4°31'33"
Vaccarès 23 bis	43°32'34"	4°36'08"
Vaccarès 29	43°31'30"	4°32'48"
Vaccarès 34	43°30'42"	4°35'32"
Vaccarès 39	43°30'41"	4°35'31"
Vaccarès 108	43°33'00"	4°36'16"
Vaccarès 109	43°33'00"	4°37'20"
Vaccarès 206	43°33'29"	4°35'57"

by equal areas of freshwater and halophytic associations. Halophytic elements are important in a large area around the Vaccarès lagoon. Rice fields exist on both sides of the delta. Within the delta, halophytic associations decrease northward being replaced by freshwater associations and areas of cultivation (rice, corn, vineyard). In addition, the delta includes some woodlands with *Pinus pinea*, *Juniperus phoenicea* on dunes and some open vegetation with *Asphodelus lavalis*. The two arms of Rhône are discontinuously bordered by riparian woodland (*Alnus glutinosa*, *Fraxinus excelsior*, *Populus alba*, *Salix alba*, *Ulmus campestris*). Agriculture (vineyard, cereals, fodder, fruit trees) is important out of the delta area and, to the east, competes with steppe associations on the Crau gravels which are mainly devoted to pasture.

At the regional scale, high mountains (Alps and Central Massif) constitute the eastern and western borders of the Rhône valley (Fig. 4), each with a regular altitudinal zonation of vegetation. The altitudinal limits vary according to latitude. The ranges indicated concern the area considered here. (Fig. 4 and Braun-Blanquet 1923, Ozenda 1966, 1975; Ozenda & Wagner 1975, Quézel 1979). The montane or beech zone (Ozenda 1975), from 600–900 m to 1 400–1 700 m, includes, in addition to *Fagus sylvatica*, *Abies alba*, *Pinus sylvestris*, *Populus tremula*, *Betula alba*, and, according to location, altitude, exposure and occasionally degradation, *Buxus sempervirens*, *Taxus baccata*, *Genista cinerea*, *Juniperus sabina*, *Lavandula vera*.

Above this are subalpine and alpine belts, which go up to 2,100–2,400 m and 2,800–3,100 m respectively. They consist firstly in *Picea excelsa*, *Larix decidua*, *Pinus uncinata*, *Pinus cembra* and higher of herbaceous alpine associations (Rosaceae, Ericaceae, Asteraceae, etc.). In southeastern France (Fig. 4), the herbaceous alpine associations are only represented on the Alps. The subalpine belt is often degenerated, consisting of heaths with *Rhododendron ferrugineum*, *Vaccinium uliginosum*, *Juniperus nana* and *Alnus viridis*. Adjacent to the alluvial plain, at low and mid altitudes the Rhône valley and its tributaries are occupied by two successive vegetational latitudinal zones (Fig. 4 and Bagnouls & Gaussen 1968), the meso-mediterranean belt and the supramediterranean belt (corresponding to hill vegetation out of the Mediterranean climatic domain). The mesomediterranean evergreen vegetation is characterized by a *Quercus ilex* woodland (with *Pinus halepensis*) and its deteriorated form, the garrigue, with *Quercus coccifera*. This zone, which corresponds to the cultivation area of *Olea europea*, is a zone of intensive agriculture (olives, vineyard, cereals, fruit trees, etc.). The supramediterranean belt (hill belt) is occupied by deciduous trees (mainly *Quercus pubescens*, *Tilia*, *Carpinus betulus*, *Corylus avellana*, etc...); *Buxus sempervirens* is also present in this belt. This is also an important agricultural zone (vineyards, cereals, *Juglans regia*, *Castanea sativa*, etc...).

POLLEN DATA IN THE CONTEXT OF VEGETATION AND SEDIMENTOLOGY

The results are presented in a synthetic pollen diagram (Fig. 5) from which *Pinus* has been excluded because it is a greatly over-represented taxon, as it can be observed from Fig. 6. The grouping of pollen taxa into ecological categories has been made to provide a reasonable assessment of the respective vegetation sources, as follows:

(1) *Alnus*, *Fraxinus*, *Populus*, *Salix* will be considered as indicators of the riparian woodland which is especially well developed along the lowland Rhône margins. *Ulmus campestris*, another element of the delta riparian woodland, is not so significant in this pollen group because of its scarcity in the pollen records. The cause is probably the elm disease (Férel 1983), the effect of which has been obvious in the atmospheric pollen records of Montpellier since 1988 (Cambon 1992), although the incidence of the disease began

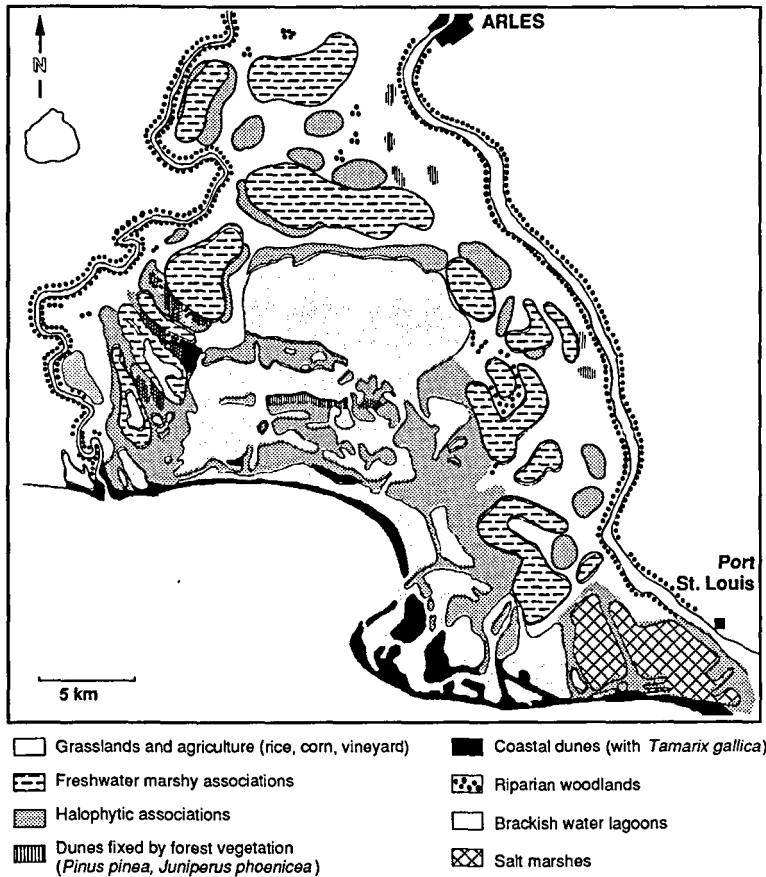


Fig. 3. Simplified vegetation map of the Camargue (after Triat-Laval 1978) including Grasslands, cultivation (rice, corn, vineyard), Freshwater marshy associations, Halophytic associations, Dunes fixed by forest vegetation (*Pinus pinea*, *Juniperus phoenicea*), Coastal dunes (with *Tamarix gallica*), Riparian woodland, Brackish water lagoons, Salt marshes.

much earlier (1970) in the Northern part of France (Férel 1983).

(2) Water plants (*Potamogeton*, *Ruppia*, *Typha*, *Sparganium*, *Myriophyllum*, Cyperaceae) reflect the freshwater associations which are greatly expanded in Camargue.

(3) Mesophilous elements (deciduous *Quercus*, *Carpinus*, *Corylus*, *Tilia*, *Ulmus*, *Hedera*, *Buxus sempervirens*, Ericaceae, *Acer*, *Sambucus*, *Viburnum*, *Castanea*, ...) are considered as mostly characteristic of the supramediterranean (i.e. hill vegetation to the north) belt.

(4) Altitudinal trees (*Betula*, *Fagus*, *Abies* and *Picea*) will represent the mountainous and subalpine combined belts.

(5) Most of the so called 'other elements' group, are considered in this work as not significant, since it includes taxa which either have an anthropogenic origin (*Platanus*, *Juglans*, *Vitis*, *Cedrus*, *Aesculus*, *Liquidambar*, Cerealia, Rosaceae) or may grow in a variety of environments (Ranunculaceae), plus taxa with non-identified and poorly preserved pollen grains.

(6) Cupressaceae pollen grains may originate from the Camargue (*Juniperus phoenicea*), from the mesomediterranean associations s.l. (*Cupressus sempervirens*, *J. oxycedrus*) from the successive altitudinal belts (*J. communis*, *J. thurifera*, *J. nana* and *J. sabina*), or even from gardens.

(7) Mediterranean xerophytes (*Olea*, *Pistacia*, *Quercus ilex*,

an evergreen species, *Cistus*, *Rhamnus*, ...) represent the mesomediterranean belt.

(8) Herbs and shrubs (Asteraceae, Poaceae, Brassicaceae, Papaveraceae, Urticaceae, *Helianthemum*, *Hippophae rhamnoides*, *Plantago*, *Rumex*, *Polygonum*, *Sanguisorba*, *Filipendula*, *Galium*, *Mercurialis*, ... For most of these, identification at the specific level is questionable and the irgeo-graphical distribution area may consequently be very large. This means that many of the corresponding plants may live from the Mediterranean shoreline up to the alpine belt.

(9) Halophytic plants (Amaranthaceae/Chenopodiaceae, Caryophyllaceae, Plumbaginaceae, *Ephedra*, *Tamarix*). The pollen grains of these families are mostly indicative of the Camargue halophytic vegetation (brackish and salted lagoons, coastline).

It is difficult to characterize the relationship between pollen assemblages from modern deltaic sediments and vegetation (Clark & Patterson 1985, Campbell & Chmura 1994). This problem is particularly acute in the Rhône delta because of the difficulty of identifying the source area of the pollen of some ecologically important taxa: (1) *Pinus*, *Tilia*, Cupressaceae and many herbs (Fig. 4) due to the inadequate level of their identification; and (2) *Buxus sempervirens* and *Carpinus betulus* which, among others, have a widespread distribution outside the area (Fig. 4).

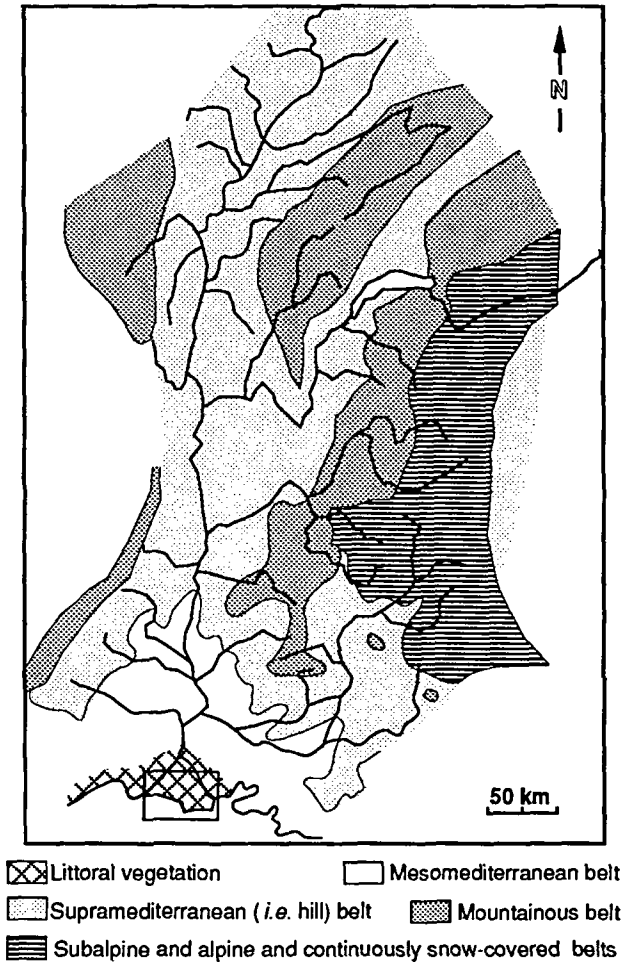


Fig. 4. Simplified vegetation map of the Rhône basin (after Bagnouls & Gaussen 1968) including Littoral vegetation, Mesomediterranean belt, Supramediterranean (i.e. Northward hill) belt, Mountainous belt, & Subalpine, alpine and continuously snow-covered belts. The box marked in the littoral vegetation corresponds to Fig. 3.

It is known that *Pinus* pollen is subject to extreme long-distance transport. Furthermore the different pine species, often from significantly different vegetation types, cannot be identified palynologically.

Modern pollen rain

La Tour du Valat and La Palissade atmospheric stations were working simultaneously and their annual spectra are presented with same legend as for the sediment and water diagrams (Fig. 5).

For quantitative point of view a mean annual number of pollen grains, (pg)/m²/day, has been calculated: this was 303,648 pg/m²/day at La Tour du Valat and 12,665 pg/m²/day at La Palissade. The large difference in pollen influx between the two sites can easily be explained by the location of the La Palissade trap, in close proximity to the sea, where the terrestrial, vegetated surface source is of minor importance (Fig. 1). The situation is similar for other airborne particles. Thus, Guieu *et al.* (1991a, 1993) have noted large quantity of metal elements at the La Tour du Valat site, with values of at least 15,107 g/km²/year i.e., 4.13·10⁻⁵ g/m²/day.

Qualitatively the two atmospheric spectra indicate a very similar source landscape in their general features. Nevertheless the La Tour du Valat spectrum shows more swamp plant pollen grains and a stronger manifestation of mediterranean xerophytic elements and relatively less herbaceous and halophytic vegetation. In accordance with the local environment (near the mouth of the Grand Rhône arm), riparian and mesophilous communities seem to play a more important part at La Palissade. At this station, altitudinal tree pollen percentage reaches 2% (mainly *Fagus*), whereas at La Tour du Valat this frequency is much lower (0.40%). High percentages of Cupressaceae are common in Mediterranean atmospheric pollen spectra (Cambon 1982); this is also observed at our two stations: 35.84% at La Tour du Valat and around 20% at La Palissade: such high values

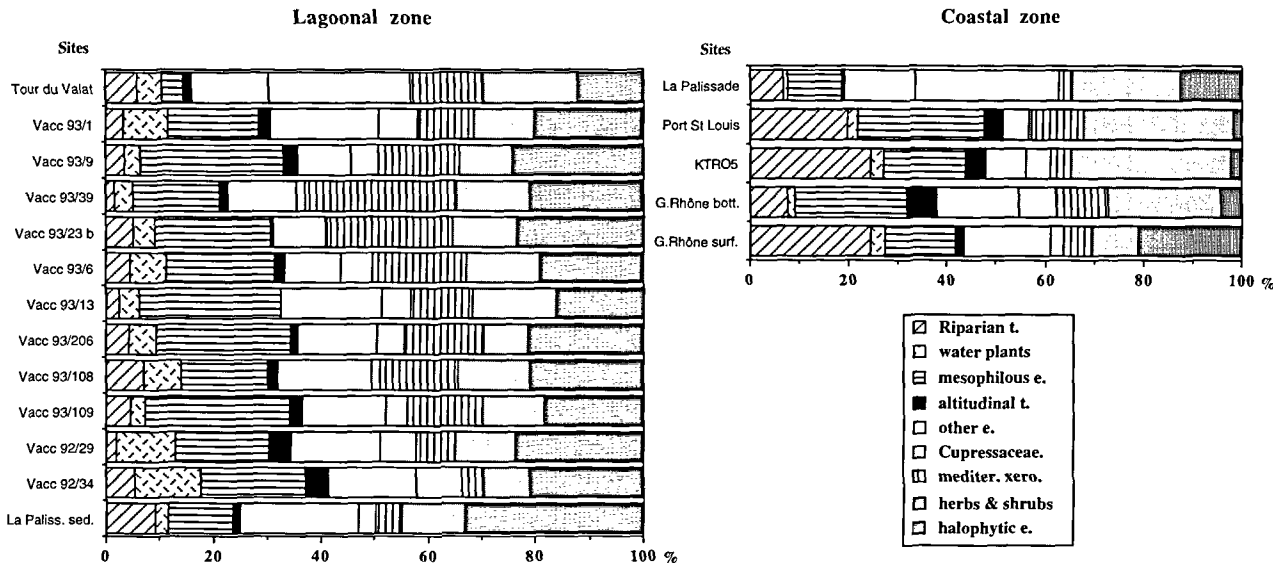


Fig. 5. Pollen diagram. Percentages are calculated on the total pollen sum, excluding *Pinus*.

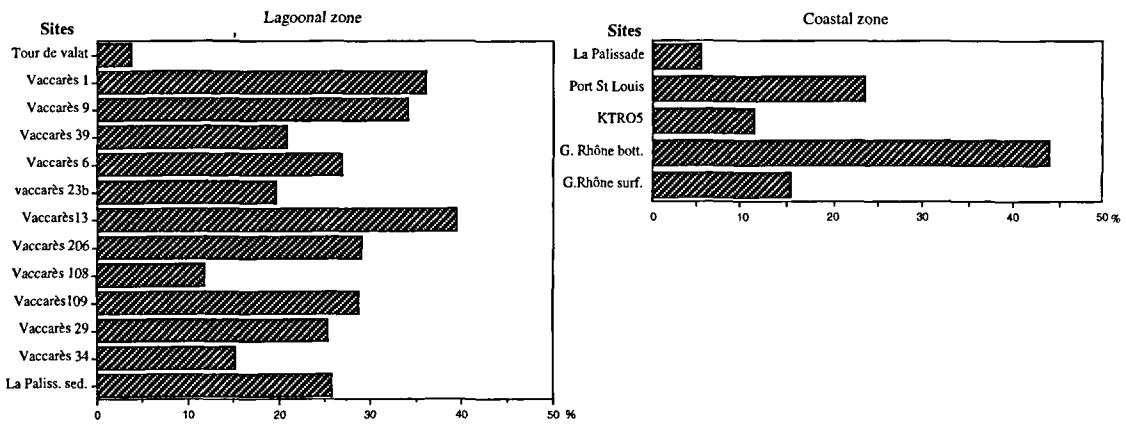


Fig. 6. *Pinus* pollen diagram. Percentages are calculated on the total pollen sum.

are never recorded in sediment pollen spectra from the same climatic area because pollen grains of this family are badly preserved (Cambon 1981, 1982). At La Tour du Valat, the high frequency of Cupressaceae fits well with the importance of the mediterranean xerophytic group and thus gives a stronger representation of the mediterranean associations.

Lagoonal records

The Vaccarès surface samples (the uppermost 5 cm) were collected in 1993 and 1994. The pollen concentrations of the individual samples differ as can be seen from Table II. These variations seem to be well correlated with granulometry distribution. In Table II., bold characters are used to show samples with high pollen concentrations located in areas where the amount of pelite (pelite: <40 µm fraction) is important. These areas are located in the northern part of the Vaccarès (Fig. 2). As commonly observed at other sites, these sediments with fine particles have provide high pollen concentrations.

The modern sedimentation in the Vaccarès lagoon is mostly controlled by winds (NW wind frequency = 54–57% according to Pauc 1970), but can be sporadically influenced by minor fluvial inputs. In addition, winds cause strong deflation over the southern part of the lagoon where sands of the old deltas are exposed. So, samples Vaccarès 6, 9, 23bis, 108 109 and 206 can be considered as representative

of the present-day pollen deposition in the lagoon, probably slightly exceeding one year according to the sedimentation rate which can be estimated at about 3cm/year in the Frignants borehole (Triat-Laval 1978).

The salt marsh sediment from La Palissade (collected in early 1993) shows a concentration of 151,854 pollen grains (pg)/gram of sediment (g).

The two more important groups are those of halophytic plants and mesophilous trees or shrubs. The halophytic group is well represented with percentages between 18 and 27%. In La Palissade sediment a remarkable maximum frequency of 33.13% is recorded; such high percentages generally characterize salt-marshes in the area (Poumot 1982). The mesophilous group is represented everywhere by more than 16% except in La Palissade where it is much lower.

Although most Mediterranean taxa have a low pollen productivity, it is noteworthy that this group is well represented in the lagoon samples (maximum 28.20% in sample 39 from Vaccarès), but, as for the other taxa, the values in the sediment from La Palissade are lower, with a minimal value of 4.81%.

The riparian community is represented in every sample: the maximum being at La Palissade (9.21%) and the minimum from the box core 39 from Vaccarès (1.56%).

The aquatic group is always present but never reaches high percentages: exceptional maximum frequencies are observed in box cores 1 and 34 from Vaccarès (over 10 and 12% respectively).

Table II. Pollen concentrations in the Vaccarès samples.

Core	Pollen concentration pg/g
Vaccarès 1	4,336
Vaccarès 6	43,932
Vaccarès 9	33,013
Vaccarès 13	13,565
Vaccarès 23 bis	20,984
Vaccarès 29	8,845
Vaccarès 34	27,495
Vaccarès 39	11,438
Vaccarès 108	21,066
Vaccarès 109	2,888
Vaccarès 206	29,166

Rhône records

Port Saint-Louis du Rhône

The Port Saint-Louis du Rhône surface sample was collected in March 1991 from the bed of the river. The uppermost 10 cm are on the whole made of dark grey to black fine-grained muddy material evolving from silty mud to a very fine muddy sand.

The pollen concentration of the uppermost 5 cm is about 41,100 pg/g. The synthetic pollen spectrum (Fig. 5) shows the importance of riparian and mesophilous communities. Herbaceous pollen grains are very numerous (32.29%), and the frequencies of the halophytic group is weak (1.38%). It

is not possible to estimate the time span covered by such a sample, especially if one takes into account the high variation in the flow of the Rhône and the potentiality for posited material. However, the presence of all the taxa generally recorded during one year in the La Palissade atmospheric pollen trap suggests that the pollen spectrum covers at least one year. The quasi absence of Cupressaceae (0.75%) could be explained by very poor preservation in such a tumultuous deposition environment.

KTR05 core

The KTR05 core, in the prodelta was sampled in early January 1992. These marine prodeltaic sediments are well known (Pauc 1970, Aloisi & Monaco 1980, Aloisi 1986, Calmet & Fernandez 1990, Got & Aloisi 1990). They are representative of variations both in fluvial and marine dynamics such that millimetre to centimetre thick black silty layers alternating with pluricentimetre thick medium to dark grey muddy layers, correspond to relative active and calmer phases of the river respectively. The uppermost 50 cm of the core is a dark grey to black homogenous mud (sands: <15%; CaCO₃: 20–27%; organic Carbon: 1.0–1.5%). Slightly increasing concentrations of precipitated carbonates (22–25 cm, 5–10 cm depth) afford the most important fluctuations. The sandy fraction is rich in vegetable fibres, reworked calcite and gypsum and fecal pellets. The oligospecific microfauna (*Elphidium crispum* and *Ammonia beccarii*) has developed mostly during moderate sedimentation phases (i.e. the last 10 cm). Concentrations in phosphorus vary between 0.012 and 0.016% i.e. close to those of the sandy deposits in the South Vaccarès lagoon. In this prodeltaic domain, the sedimentation rate ranges between 30 and 40 cm/year (Aloisi 1986, Calmet & Fernandez 1990, S. Charmasson in litteris 1996). The palynological and sedimentological analysis of the core suggests that the uppermost 35 cm represent the year 1990¹ with a well-marked seasonality (Suc et al. 1996). Consequently top 8 samples have been considered in this study.

The concentrations of the eight uppermost samples range from 9,671 to 47,497 pg/g (average: 24,672 pg/g). Riparian and mesophilous communities are well represented in the mean pollen spectrum (Fig. 5) while the pollen frequencies for xerophytic mediterranean vegetation are very weak, as are those of halophytic plants. The herbaceous part of the landscape is represented by about 32.59% of pollen.

Water samples

Two sea water samples from the Grand Rhône plume, were collected in August 1994: 50 l near the surface and 50 l near the bottom (i.e., 29 m depth). The pollen concentrations were 49 pg/l and 21 pg/l respectively; these values are coarse and very difficult to relate to the sediment pollen concentrations. Nevertheless the qualitative data are comparable (Fig. 5): riparian, mesophilous and halophytic plants are

well represented, with herbaceous pollen percentages up to 32.40%. The xerophytic mediterranean community is less important (6 to 10%).

DISCUSSION

Pollen transport

It was clear from a preliminary inspection of the data that a comparative quantitative analysis of pollen accumulation rates between samples would not be feasible because it is impossible to evaluate with sufficient accuracy the time period that each sample may represent (one to several years).

A possible exception is the set of lagoonal samples, derived from locations with very similar sedimentary histories. On the other hand, a comparison of the frequencies of the pollen groups from all sites reveals useful information (Fig. 5). It is possible to identify a first group of diagrams in which halophytic and mesophytic communities are represented by percentages near 20%, xerophytic mediterranean elements have some importance, and riparian and water plants show relatively low pollen frequencies; all these pollen spectra are from the Vaccarès lagoon.

The spectrum from the La Palissade surface sample shows a higher proportion of halophytic plants, a lower representation of mesophilous, and a minor value for the xerophytic Mediterranean component.

If we compare these data with those of the two atmospheric stations many characters are similar. Some of lagoonal samples more closely resemble the atmospheric pollen spectrum of La Tour du Valat but with less or more xerophytic elements, and with altitudinal tree and hydrophyte components importance being small, i.e. cores 1, 9, 39, 23b, 6, 13, 206, 108, 109, 29, 34, while La Palissade sediment is nearer to the La Palissade atmospheric pollen spectrum.

The importance of Cupressaceae pollen in the atmospheric samples has been yet explained and does not hide similarities between atmospheric and sediment spectra.

The results from the sites in the coastal zone which consist of a group of samples collected in a fluvial environment (sediment from the river bed and prodelta, and sea water in the river plume) are also shown in Figure 5. The KTR05 core has high frequencies of the riparian woodland element (maximum almost 30%, average 24.36%). All the sites show intermediate frequencies for the mesophilous elements, very low frequencies of aquatics, a low but consistent presence of altitudinal trees, and low percentages of halophytes except in the Grand Rhône plume surface sample. The importance of Amaranthaceae/Chenopodiaceae pollen (the mainly constituent of the halophytic group) in this spectrum can be explained by the fact that the sample was collected during the fall which is a flowering season for plants of this family. The same is true for the higher value of the fresh water plant group (Typhaceae and Cyperaceae are blooming at the end of June and in July). However it is impossible to explain the importance of the riparian tree pollen in the surface sample in this way: perhaps it is difference of buoyancy of the pollen types.

We conclude that the pollen deposition in the Vaccarès sites and in the adjacent salt marsh, is mainly of atmospheric

¹ The sediments deposited in 1991 would not be collected because material was missing at the topmost of the core (P. Cochonat in litteris 1993).

origin, and that the low frequencies of Cupressaceae are the result of poor preservation in these saline sediments.

A recent study of anthropogenic and natural lead in various sediments from the Gulf of Lions area, including the Vaccarès lagoon, considers the latter as mainly fed today by atmospheric fallout (Ferrand 1996).

In contrast, the similarities between the 4 spectra from the coastal sediments indicate that the main source is fluvial, shown by the predominance of riparian trees, slightly lower values of mesophilous elements, low values of halophytes, and relatively low frequencies of Mediterranean xerophytes. Altitudinal tree pollen grains are present in the four spectra, probably transported from the Alps and the Central Massif toward the sea by running water in larger quantities than they could be transported by air. Pollen of riparian vegetation falls directly into the river, so larger quantities, found in the path of the river, are not surprising.

Therefore the riparian group is considered as helpful for detecting an indication of occasional fluvial fluxes in the Northeast of the Vaccarès lagoon during Rhône flooding periods (1992 for instance). We compared the data of the lagoon (in northeastern Vaccarès and in the other parts) and the atmospheric record of La Tour du Valat (situated near the Vaccarès). The results are given in Table III.

Vaccarès cores 108 and 34 (North-East part) show the highest frequencies of riparian elements in the lagoon. The atmospheric input, recorded at La Tour du Valat, is weaker, so that it is possible to consider that temporary Rhône flooding has brought the observed quantity of pollen grains from the riparian woodland in the northeastern part of the Vaccarès, particularly in cores 34 and 108. Furthermore we know that floodings of the Rhône cannot overprint the modern sedimentary process very much, because the flow of the Rhône is now restricted by dams.

Therefore, modern pollen sedimentation in the Vaccarès lagoon is almost exclusively forced by air transport, in spite of some occasional Rhône influxes. Pollen sedimentation in the Rhône prodelta is mainly controlled by fluvial transport but it is impossible to say precisely what the continuous contribution of pollen rain along the length of the Rhône is. A rough calculation tends to indicate that the atmospheric pollen input at the Rhône mouth is about 400 times lower than the fluvial input. The estimation has been made by

comparing the annual atmospheric pollen input at La Palissade (values extended to the Rhône mouth length) and the annual content pollen of the fluvial waters (according to the Rhône flow, Savey & Deléglise 1967). However, we must assume that an indeterminable component of oxidized or deposited pollen has been removed from the total fluvial input. These two different origins for the sedimentation were also observed with the modern fallout of metal particles both over the Vaccarès area and over the Rhône prodelta (Guieu et al. 1991). These authors have shown a significant shift from fluvial sources to atmospheric with increasing distance from the deltaic zone. Their estimate, that the fluvial input of metal particles is approximately X10 the atmospheric input, is significantly different from our estimates for pollen. The estimations made by Ferrand (1996) of the amount of lead show a similar ratio (about 16) between the two ways of transport in the same prodelta zone.

Camargue sediment pollen spectra and local-regional vegetation

A brief comparison is made between the 10–20 most important taxa from each sediment type (Vaccarès lagoon, La Palissade salt marsh, KTR05 core in the Rhône prodelta) and the local-regional vegetation (Fig. 3 and 4).

Everywhere in the Camargue, the pollen spectra are dominated by Amaranthaceae/Chenopodiaceae, if *Pinus* is excepted. *Quercus* (deciduous and evergreen species), *Typha* (everywhere more than 1%) and Cyperaceae are regularly present as well as *Alnus* and *Olea*; *Fraxinus*, *Corylus* and Ericaceae present significant percentage values in pollen spectra from the Northeastern Vaccarès. Poaceae constitutes a continuous background with pollen frequencies between 3 and 7%.

This means that all the Camargue vegetation types (Fig. 3) are well represented, the marshy environments being particularly emphasized (Amaranthaceae/Chenopodiaceae, *Typha*, Cyperaceae). Riparian woodland is regularly present in the spectra at pollen frequencies of about 6% (from 2.3% at core 13 to 9.21% at La Palissade). The mesomediterranean belt (Fig. 4) is obviously expressed by *Quercus ilex*-type, *Olea* and *Pinus* p.p. Finally, of the other vegetation communities,

Table III. Pollen representation of the riparian tree group in the Vaccarès sediment samples and in the atmospheric samples.

Northeastern lagoonal samples		Other lagoonal samples		Atmospheric sample	
Core	Riparian tree %	Core	Riparian tree %	Site	Riparian tree %
Vaccarès 34	8.94				
Vaccarès 108	6.93				
				La Tour du Valat	5.82
Vaccarès 23	5.1				
		Vaccarès 29	4.93		
Vaccarès 109	4.51				
		Vaccarès 6	4.44		
Vaccarès 206	4.4				
		Vaccarès 9	3.45		
		Vaccarès 1	3.1		
		Vaccarès 13	2.32		

only the supramediterranean is well represented, mainly by deciduous *Quercus*.

At La Palissade (salt marsh), the dominant taxa are, (with the exception of *Pinus*), decreasing frequency:

– *Amaranthaceae/Chenopodiaceae* dominant, *Poaceae* (7%), *Quercus* (deciduous), *Quercus ilex*-type (evergreen), *Populus*, *Ulmus* (relatively high percentage of 1.93%), *Fraxinus*, *Salix*, *Alnus* and *Cupressaceae*;

– with lower percentages of *Ericaceae*, *Cerealia*, *Plantago*, *Betula* and *Olea*.

This pollen spectrum in particular provides an image of the immediate vegetation (brakish water marshes and riparian woodland).

All the modern samples taken from the Vaccarès area have pollen spectra of the same kind (the same 10 most important taxa) with slight variations in the frequencies according to differences in depth, distances from the shore, granulometry and position with respect to the dominant wind direction.

At KTR05, the dominant taxa can be classified into three groups (decreasing percentages):

– *Alnus*, *Cupressaceae*, *Poaceae*, *Pinus*;
– *Populus*, *Fraxinus*, deciduous *Quercus*, *Quercus ilex*-type;
– *Salix*, *Cyperaceae*, *Potamogeton*, *Carpinus*, *Corylus*, *Ericaceae*, *Betula*, *Fagus*, *Picea*, *Platanus*, *Rosaceae*, *Ambrosia*, *Cerealia*, *Artemisia*, *Asteraceae-Asteroidae*, *Asteraceae-Cichorioidae*, *Brassicaceae*, *Mercurialis*, *Cannabaceae*, *Rumex*, *Plantago* and *Amaranthaceae/Chenopodiaceae*.

It is obvious that the riparian woodland (*Alnus*, *Populus*, *Fraxinus*, *Salix*) is greatly dominant and its pollen representation probably corresponds to a short distance of transport. Many taxa can represent the entire region under consideration (*Cupressaceae*, *Pinus*, *Platanus*, *Rosaceae*, and particularly the herbs such as *Poaceae*, *Asteraceae* including *Ambrosia* and *Artemisia*, *Rumex*, *Cannabaceae*, *Plantago*, *Mercurialis*, and *Brassicaceae*). The mesomediterranean belt is poorly represented by *Quercus ilex*-type. The supramediterranean (i.e. hill) belt is better represented by deciduous *Quercus*, *Corylus*, *Carpinus* and *Ericaceae* p.p. Mountainous and subalpine belts are also moderately represented by *Betula*, *Fagus* and *Picea*. Local marshy vegetation is poorly represented (*Amaranthaceae/Chenopodiaceae* on the one hand for brackish or salted water environments, *Cyperaceae* and *Potamogeton* on the other hand for freshwater environments) as are the cultivated areas (*Cerealia* only).

On the whole, the local vegetation (freshwater plants and halophytes for lagoonal sediments, riparian trees for fluvial samples) are predominantly represented within the two kinds of spectra (Fig. 3). Lagoonal and fluvial (including prodeltaic) sediments provide a similar image of the mid to high altitude vegetation belts (regional vegetation). Differences concern the percentages of herbs and shrubs which are higher in the deltaic zone sediments (Port Saint Louis du Rhône and KTR05 cores). It seems that this group takes the place of *Chenopodiaceae/Amaranthaceae* in the spectra, as well as in the surrounding landscape (cf atmospheric sample of La Palissade).

CONCLUSIONS

In general, our data of pollen spectra of atmospheric origin are consistent with the results of Pons et al. (1979), although

their analyses were based on moss polster samples and our investigations provide information that is more relevant to the interpretation of pollen assemblages from deltaic sediments. Nevertheless, although the Rhône delta is less complex in its fluvial dynamics than some others (e.g. the Mississippi), it remains difficult to elucidate the role of all factors that control the modern deposition of pollen in this ecosystem.

However, using appropriate ecological groupings of pollen taxa, and relating them to the local and regional vegetation, we have been able to demonstrate the following two major modes of deposition:

– one where atmospheric pollen transport, i.e. pollen rain, is the main pollen influx for surface sediments. The Vaccarès lagoon landscape and its immediate surroundings are well represented by halophytic, fresh-water and mediterranean-xerophyte pollen assemblages;

– the other, immediately in the Rhône mouth area, where fluvial pollen influx illustrated by riparian communities and altitudinal trees is dominant.

So we have evidenced that at least two kinds of pollen spectra may express the same local and regional vegetation (according to the prevailing sediment influx). We think that, in the light of this information, accompanied by well documented sedimentological work, a more reliable interpretation of fossil pollen spectra will be possible for such areas.

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REFERENCES

- Aloïsi, J.-C. 1986. Sur un modèle de sédimentation deltaïque. Contribution à la connaissance des marges passives. – Thesis Univ., Perpignan.
- Aloïsi, J.-C. & Monaco, A. 1980. Etude des structures sédimentaires dans les milieux deltaïques (Rhône). Apport à la connaissance des conditions de sédimentation et de diagenèse. – Comptes Rendus de l'Académie des Sciences de Paris 290: 159–162.
- Bagnouls, F. & Gaussen, H. 1968. Vegetation map of the Mediterranean region (1/5,000,000) – Western part.
- Bernard, J. & Pons, A. 1985. Contribution à la connaissance de la dispersion pollinique en mer: une étude au large du delta du Rhône. – Sciences Géologiques 38: 91–98.
- Braun-Blanquet, J. 1923. L'origine et le développement des flores dans le Massif Central de France. – L'Homme, Paris & Beer, Zürich.
- Brush, G.S. & Brush, L.M. 1994. Transport and deposition of pollen in an estuary: signature of landscape. – In: Sedimentation of organic particles, (ed. A. Traverse), pp. 33–46. – Cambridge Univ. Press, London–Cambridge.
- Calleja, M., Rossignol-Strick, M. & Duzer, D. 1993. Atmospheric pollen content off West Africa. – Review of Palaeobotany and Palynology 79: 335–368.

- Calmet, D. & Fernandez, J.-M. 1990. Caesium distribution in Northwest Mediterranean seawater, suspended particles and sediments. – *Continental Shelf Research* 10: 895–913.
- Cambon, G. 1981. Relations entre le contenu pollinique de l'atmosphère et le couvert végétal en Méditerranée occidentale à Montpellier (France), Valencia (Espagne) et Oran (Algérie). – Thesis, Univ., Montpellier 2.
- Cambon, G. 1982. Atmospheric pollen spectra in the western Mediterranean area: characteristic taxa. – 2nd Int. Conf. Aerobiology, Seattle 1982, Abstracts (ed. R.L. Edmonds p. 15. – Coll. Forest Res. Div. Cont. Educ. Univ. Washington, Seattle, WA.
- Cambon, G. 1992. Contenu pollinique de l'atmosphère de quatre stations du sud de l'Ontario, Canada (années 1983–85). Contribution à la biogéographie, à la bioclimatologie et à la phénologie. – Thesis, Univ. Montpellier 2.
- Campbell, I.D. & Chmura, G.L. 1994. Pollen distribution in the Atchafalaya River, U.S.A. – *Palynology* 18: 55–65.
- Chmura, G.L. 1990. Palynological and carbon-isotopic techniques for reconstruction of paleomarine salinity zones. – Thesis, Louisiana State Univ., Baton Rouge, LA.
- Chmura, G.L. & Eisma, D. 1995. A palynological study of surface and suspended sediments on a tidal flat: implications for pollen transport and deposition in coastal waters. – *Marine Geology* 128: 183–200.
- Clark, J.S. & Patterson, W.A., III 1985. The development of a tidal marsh: upland and oceanic influences. – *Ecological Monographs* 55: 189–217.
- Cour, P. 1974. Nouvelles techniques de détection des flux et des retombées polliniques: étude de la sédimentation des pollens et des spores à la surface du sol. – *Pollen et Spores* 16: 103–141.
- Cross, A.T., Thompson, G.G. & Zaitzeff, J.B. 1966. Source and distribution of palynomorphs in bottom sediments, southern part of Gulf of California. – *Marine Geology* 4: 467–524.
- Dérault, C. 1983. La graphiose de l'Orme. – *Horticulteurs et Maraîchers* 237: 25–29.
- Ferrand, J.-L. 1996. Etude isotopique du cycle géochimique du plomb anthropique et naturel en milieu marin et côtier. – Thesis, Univ. Marseille 3, Aix-en-Provence.
- Groot, H. & Aloisi, J.-C. 1990. The Holocene sedimentation on the Gulf of Lions margin: a quantitative approach. – *Continental Shelf Research* 10: 841–855.
- Groot, J.J. & Groot, C.R. 1966. Marine palynology possibilities, limitations, problems. – *Marine Geology* 4: 387–395.
- Guieu, C., Thomas, A.J., Martin, J.M. & Brun-Cottan, J.C. 1991. Multielemental characterization of the atmospheric input to the Gulf of Lions. Impact upon the upper layer water chemistry. – In: EROS 2000. 3rd Workshop on the North-West Mediterranean Sea (ed. J.M. Martin & H. Barth), pp.505–518. – Texel, Den Burg.
- Guieu, C., Martin, J.M., Thomas, A.J. & Elbaz-Poulichet, F. 1991. Atmospheric versus river inputs of metals to the Gulf of Lions. Total concentrations, partitioning and fluxes. – *Marine Pollution Bulletin* 22: 176–183.
- Guieu, C., Zhang, J., Thomas, A.J., Martin, J.M. & Brun-Cottan, J.C. 1993. Significance of atmospheric fallout on the upper layer water chemistry of the North-Western Mediterranean. – *Journal of Atmospheric Chemistry* 17: 45–60.
- Heusser, L. 1988. Pollen distribution in marine sediments on the continental margin off northern California. – *Marine Geology* 80: 131–147.
- Heusser, L.E. & Balsam, W.L. 1977. Pollen distribution in the Northeast Pacific Ocean. – *Quaternary Research* 7: 45–62.
- Hooghiemstra, H. 1988. Palynological records from northwest African marine sediments: a general outline of the interpretation of the pollen signal. – *Philosophical Transactions of the Royal Society of London*, B 318: 431–449.
- Molinier, R. & Tallon, G. 1970. Prodrôme des unités phytosociologiques observées en Camargue. – *Bulletin du Muséum d'Histoire Naturelle de Marseille* 30: 1–111.
- Muller, J. 1959. Palynology of recent Orinoco delta and shelf sediments, reports of the Orinoco shelf expedition. – *Micropaleontology* 5: 1–32.
- Ozenda, P. 1966. Perspectives nouvelles pour l'étude phytogéographique des Alpes du Sud. – *Documents de la Carte de Végétation des Alpes* 4: 1–198.
- Ozenda, P. 1975. Sur les étages de végétation dans les montagnes du bassin méditerranéen. – *Documents de Cartographie Ecologique* 16: 1–32.
- Ozenda, P. & Wagner, H. 1975. Les séries de végétation de la chaîne alpine et leurs équivalences dans les autres systèmes phytogéographiques. – *Documents de Cartographie Ecologique de Grenoble* 16: 49–64.
- Pauc, H. 1970. Contribution à l'étude dynamique et structurale des suspensions solides au large de l'embouchure du Grand Rhône (Gau de Roustan). – Thesis Univ., Perpignan.
- Planchais, N. & Guillet, B. 1969. Note sur une technique d'extraction des pollens des sols par une solution dense. – *Pollen et Spores*, 11: 141–145.
- Pons, A., Toni, C. & Triat H. 1979. Edification de la Camargue et histoire holocène de sa végétation. – *Terre Vie, Revue Ecologique*, Suppl. 2: 13–30.
- Poumot, C. 1982. Palynologie et palynofaciès des sédiments récents des marais salants de Salin-de-Giraud (sud de la France). – *Géologie Méditerranéenne* 9: 551–562.
- Pragowski, J. 1977. Pollen Deposition on and under the water surface. – *Grana* 16: 203–209.
- Quézel, P. 1979. La région méditerranéenne française et ses essences forestières. Signification écologique dans le contexte circum-méditerranéen. – *Forêt méditerranéenne* 1: 7–18.
- Savey, P. & Deléglise, R. 1967. Les incidences de l'aménagement du tiers central du Bas Rhône sur les transports solides en suspension. – *Association Internationale des Hydrologues Scientifiques Publ.* 75: 462–476.
- Solomon, A.M. & Harrington, J.B. 1979. Palynology models. – In: *Aerobiology. The ecological systems approach* (ed. R.L. Edmonds), pp.338–361. – Dowden, Hutchinson & Ross, Stroudsburg, PA.
- Streel, M. & Richelot, C. 1994. Wind and water transport and sedimentation of miospores along two rivers subject to major floods and entering the Mediterranean Sea at Calvi (Corsica, France). – (ed. A. Traverse), pp. 59–67. – Cambridge Univ. Press, London–Cambridge.
- Suc, J.-P., Cambon, G., Gadel, F., Giresse, P., Aloisi J. -C., Suballyova, D., Serve, L., Marsset, T., Touzani, A., Arnaud, M., Charmasson, S., Duzer, D. & Ferrier, J. 1996. Sédimentation rythmique au large de l'embouchure du Grand Rhône au cours de la dernière décennie (carotte KTR05). – Séance spécialisée Soc. Géol. France "Sédimentologie de la matière organique" abstracts, – C.N.R.S., Paris.
- Suc, J.-P. & Drivaliari, A. 1991. Transport of bisaccate coniferous fossil pollen grains to coastal sediments: an example from the earliest Pliocene Orbria (Languedoc, southern France). – *Review of Palaeobotany and Palynology* 70: 247–253.
- Traverse, A. 1994. – Sedimentation of land-derived palynomorphs in the Trinity-Galveston Bay area, Texas. – In: *Sedimentation of organic particles*, (ed. A. Traverse), pp. 69–102. – Cambridge Univ. Press, London–Cambridge.
- Triat-Laval, H. 1978. Contribution pollenanalytique à l'histoire tardive et postglaciaire de la végétation de la basse vallée du Rhône. – Thesis Univ. Marseille 3, Aix-en-Provence.