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Lateglacial and Holocene climate and soil erosion in southeastern France: a case study from Etang du Pourra, Provence

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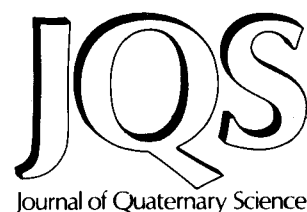
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ABSTRACT: A synthesis of pollen evidence from Etang du Pourra, a small pond in Rhodanian Provence, France, complemented by new sedimentological, mineralogical and palynological data allow a reassessment of the Lateglacial–Holocene vegetation and climatic history of the area. The Etang du Pourra succession is shown to consist of two parts; the lower part dates from the Lateglacial and the upper reveals the Holocene pollen-stratigraphic succession typical of the region. In the Lateglacial, a humid and cooler phase is recorded before the Younger Dryas conditions progressively set in. In the Holocene succession, the consequences of human modifications on the environment are clearly visible in changes in mineralogy and pollen stratigraphy.



KEYWORDS: Pollen analyses, sedimentology, mineralogy, lacustrine sediments.

Introduction

In prospecting for a site suitable for the study of Quaternary vegetation history, the Provence region did not initially appear promising because the prevailing climate does not favour the accumulation of continuous continental sediments (Triat-Laval, 1979). However, recent pollen analysis of Late Quaternary sediments from Beauchamp Panières, Etang de Berre (Laval et al. 1991a, b) and the small Pourra pond (Fig. 1) demonstrate that fairly continuous sedimentary sequences do exist at a few locations. These provide valuable records of the environmental history of Provence during the last 13 000 yr. The 'classic' palaeoenvironmental sequence established for the area extending from south of Orange to the Mediterranean borders is briefly outlined, before we present the results obtained from the Etang du Pourra. This pond preserves an apparently continuous lacustrine succession from the Lateglacial to late Holocene. The unusual accumulation of Late Glacial sediments in this pond may be explained by a karstic downward migration of the basin floor (Mars, 1966). Comparison of sedimentological, mineralogical and palynological evidence from this site provides comprehensive information for piecing together the regional effects of Late Quaternary climatic changes.

The regional context

Evidence for precise climatic changes in the French Mediterranean region during the Upper Pleistocene are scarce (Eicher, 1987; Laval et al., 1991a). It is evident, of course, that temperatures had risen sharply by about 9000 yr BP following the cold Younger Dryas. Subsequently, only very minor climatic fluctuations occurred, as, for example, a humid phase (Table 1) that characterised the littoral zone from about 5000 to 3000 yr BP (Planchais and Parra Vergara, 1984; Laval and Médus, 1989). This phase is reflected in an extension of *Abies*, which is thought to have required a more oceanic rainfall regime.

The Lateglacial, including the Younger Dryas, is as evident at the various sites of Lower Provence (for example Courthézon, Beauchamp, Les Baux and Les Frignants (see Triat-Laval, 1979) as it is in many other regions.

The Preboreal period for the entire French Mediterranean region is essentially characterised by a short extension of pine before the development of *Quercus pubescens* woodland.

This is followed in the Boreal (ca. 8400 yr BP), by a strong but brief extension of *Corylus* accompanied by an expansion of *Quercus pubescens*. At Courthézon, Beauchamp, Mollèges and Meyranne, however, at ca. 8000 yr BP, *Pinus* percentages decline markedly. At the same time an increase in such taxa as *Plantago* and *Ericaceae* (Beauchamp), *Cyperaceae*

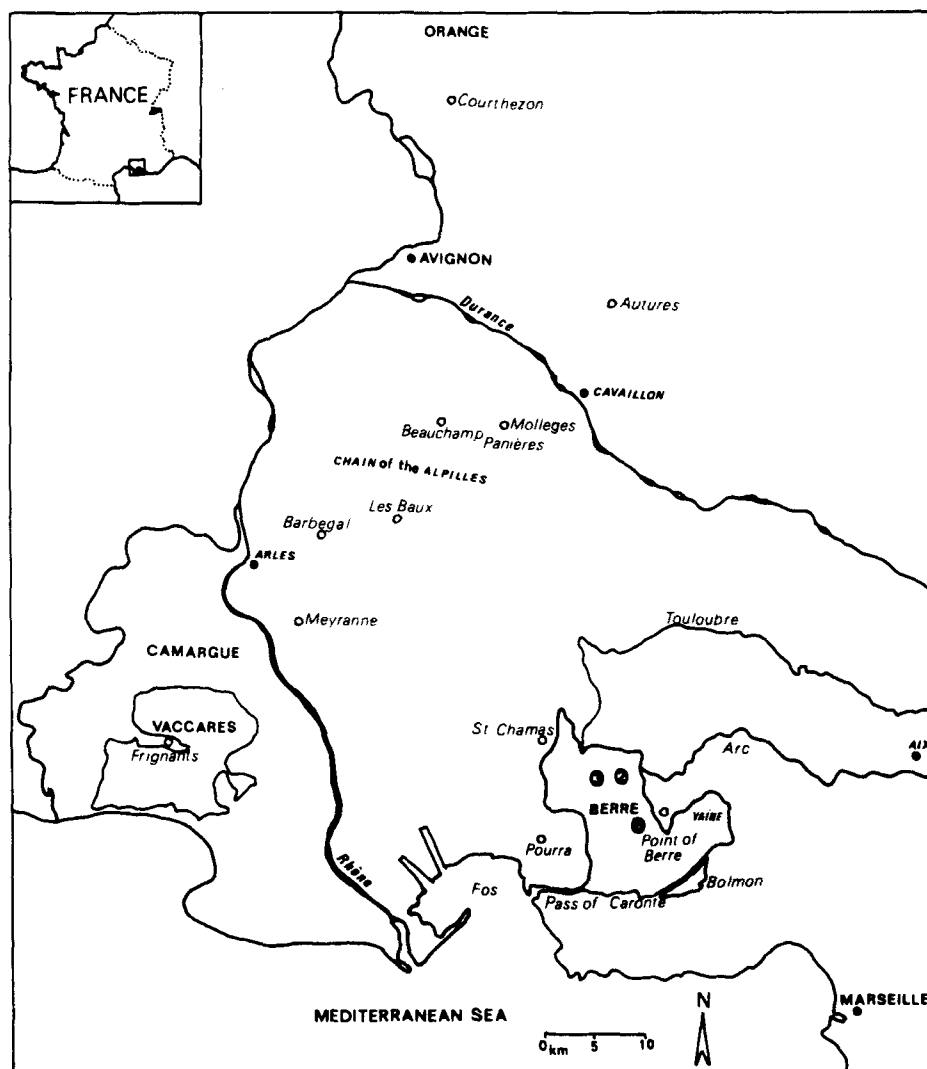


Figure 1 Location map of the study area showing a number of pollen sites referred to in text.

(Meyranne, Courthézon) and *Juniperus*, *Quercus ilex*, and *Corylus* can be observed.

The decrease in percentages of *Pinus*, and the increase of heliophytes and Cyperaceae pollen (Autures, Barbegal, Beauchamp) persist into the Atlantic period. Evidence in the diagrams of human action is inferred from clear indications of deforestation and agriculture, which suggest widespread human action by ca. 7000 yr BP. At Courthézon, high percentages of *Melampyrum* found in a second diagram (Triat-Laval, 1979, Fig. D1) distinctly show clearing of the forest, and use of fire is revealed by a level of charred remains encountered above a date of 7350 ± 170 yr BP. Chicoraceae, Papilionaceae, Labiatae, *Plantago* (and *Odontites* in the diagram of Courthézon) have developed at numerous sites, suggesting the local application of agricultural methods. Moreover the cereals curve distinctly increases during this part of the succession.

In the Sub-boreal–Subatlantic the percentages of *Quercus ilex* type clearly replace those of *Quercus pubescens* along a N–S gradient in the Lower Rhône Valley. Depending on locality, these phenomena occur simultaneously (Barbegal, Les Baux), or successively (Beauchamp, Courthézon, Meyranne); that is to say, the rise of *Quercus ilex* type pollen occurs both before and after a steep decrease of *Pinus* pollen.

Site description

The Etang du Pourra (140 ha) is a shallow, seasonal sheet of water that occupies a trough which is only open to the north, and which lies within the hills bordering the Etang de Berre. Its bottom is at -6 m below sea-level in Begudian (Maastrichtian continental facies) sequence of impermeable marls and clays. Above this is the transgressive Miocene made up of alternating shelly calcarenites and sandy marls. The altitude of the surrounding plateaux (142 m), which seems to have ruled out any link with the sea during the Quaternary, and the imperviousness of the substratum, lead us to assume that the water regime of this lake is related only to the local hydroclimatic record.

The vegetation of the surrounding calcareous hills, outside the cultivated areas, where there are olive plantations on plots of *Brachypodium phoenicoides*, consists of garrigue (with *Quercus coccifera*, *Ulex parviflorus* and *Rosmarinus officinalis*), groups of *Quercus ilex* and thickets of *Pinus halepensis* in the valleys.

Table 1 Post-glacial and Holocene vegetation sequence

| ¹⁴ C scale in years BP | Firbas zonation | Chronozones | | West European vegetational history | Vegetational history in Provence (H. Triat-Laval, 1979) |
|-----------------------------------|-----------------|---------------|--------------------------|--|---|
| 0 | X | Subatlanticum | Post-glacial or Holocene | Anthropic action dominant | <i>Quercus</i> , <i>Ulmus</i> , <i>Alnus</i> , <i>Betula</i> , <i>Fagus</i> , <i>Abies</i> <i>Carpinus</i> decline almost completely |
| 1000 | | | | | |
| 2000 | IX | | | <i>Juglans</i> line (2000 yr BP) <i>Fagus</i> , <i>Carpinus</i> | <i>Olea</i> (ca. 2000 yr BP) Anthropogenic action dominant <i>Pinus</i> , <i>Quercetum</i> sclerophyllous, anthropic grasses <i>Juglans</i> (ca. 3400 yr BP) <i>Quercetum</i> mixtum decline Human activity, forest clearing, erosion <i>Fagus</i> , <i>Betula</i> (North Provence) |
| 3000 | VIII | Sub-boreal | | <i>Alnus</i> Coniferous woodland | |
| 4000 | | | | <i>Quercus</i> , <i>Fagus</i> | |
| 5000 | | | | <i>Fagus</i> | |
| 6000 | VII | Atlanticum | | <i>Ulmus</i> decline <i>Quercetum</i> mixtum | <i>Quercetum</i> sclerophyllous (<i>Quercus</i> , <i>Erica</i> , <i>Pistacia</i> , <i>Phyllirea</i>) <i>Abies</i> regional Indications of human activity <i>Quercetum</i> mixtum (with <i>Quercus</i> deciduous dominant) |
| 7000 | VI | | | <i>Quercus</i> , <i>Ulmus</i> , <i>Tilia</i> <i>Fraxinus</i> | |
| 8000 | Vb | Boreal | | <i>Corylus</i> dominant, <i>Pinus</i> | <i>Quercetum</i> mixtum <i>Corylus</i> (North Provence) |
| 9000 | Va | | | <i>Betula</i> decline | |
| 10000 | IV | Preboreal | | <i>Betula</i> , <i>Pinus</i> | Anthropogenic action (?). <i>Quercus</i> deciduous <i>Abies</i> , <i>Fagus</i> , <i>Corylus</i> (South France) <i>Ephedra</i> , <i>Betula</i> , <i>Juniperus</i> and steppe decline, short expansion of <i>Pinus</i> , <i>Artemisia</i> decline |
| 11000 | III | Younger Dryas | Late glacial | Tundra (<i>Artemisia</i> , Poaceae) with low shrubs | Steppe, light wood |
| 12000 | II | Allerød | | <i>Betula</i> , <i>Pinus</i> | <i>Pinus</i> + few <i>Quercus</i> , <i>Corylus</i> , <i>Alnus</i> , <i>Salix</i> |
| 13000 | Ic | Older Dryas | | Steppe | ? |
| | Ib | Bølling | | Tundra with low shrubs | <i>Pinus</i> , <i>Betula</i> , <i>Ephedra</i> , <i>Artemisia</i> <i>Juniperus</i> slight decline |
| | Ia | Pleniglacial | | Steppe | Steppe (<i>Artemisia</i> , Chenopodiaceae) <i>Juniperus</i> , <i>Pinus</i> |

Samples and methods

A hole was made with an auger to a depth of 2.80 m, and below this to 5.03 m by a piston corer. For pollen analysis, 66 samples were taken at spacings of about 5 cm from the

base to 2.80 m (samples 24) then at about every 12 cm. From 4.84 to 5.03 m, 10 of the samples proved to be non-polliniferous. The total number of palynomorphs counted for each level is variable (minimum 97, mean 136, maximum 216). This might result from poor preservation of pollen in some horizons.

Mineralogical analysis was carried out on 15 of these

samples distributed over the length of the core. The mineralogical composition of the bulk rock and the < 2 µm clay fraction was determined by X-ray diffraction, using a Philips 1729 diffractometer with a Co anticathode, operating at 40 mA and 50 Kv. In order to distinguish the different clay minerals, the orientated clay specimens were analysed in four different forms (see e.g. Holtzapf, 1985): natural sample, treated with ethylene glycol, treated with hydrazine hydrate, and heated at 490°C for 4 h. Semi-quantitative estimates of the relative proportions of the minerals detected were calculated from measurements of the areas of selected diffraction peaks. Furthermore, two parameters were calculated from the diffraction spectrum of the clay minerals after treatment with ethylene glycol: the smectite : illite ratio and the crystallinity index (Vp) of smectite measured using Biscaye's method (1965).

A granulometric analysis was carried out on 35 samples taken every 10–12 cm using a laser diffractometer for the fraction below 80 µm; sand particles with a diameter greater than 80 µm, which were in any case absent or present in negligible amounts in all samples, could not be measured by the instrument.

Proportions of organic matter (OM) were determined using Walkley's method (in Brunel, 1948), and two ¹⁴C measurements were obtained from 10-cm-thick samples of the lower part (from 4.70 to 4.80 m and 3.42 to 3.55 m) where the OM curve peaked.

Statistical associations between the palynological taxa and organic matter content and different size grades were investigated, with a program of the AS (1986) software package, using factor analysis optimised by means of varimax rotation.

Pollen zonation

Two pollen assemblage zones (PAZ) have been distinguished on the basis of the major pollen percentage variations (Fig. 2): zone A from level 62 (480 cm) to 27 (296 cm), and zone B, from level 26 upwards.

Zone A

In this zone, the pollen from trees (AP) such as *Pinus*, *Quercus* (essentially *Q. t. pubescens*) and *Corylus* predominate. Herbaceous pollen types (NAP), which are few in number, are predominantly represented by Poaceae, Chenopodiaceae and *Artemisia*. This zone, which is characterised by high percentages of *Corylus* and *Q. t. pubescens* together with records for Cupressaceae, *Betula*, and other trees of Quercetum mixtum (deciduous oak) groves (e.g. *Ulmus*, *Tilia*, *Fraxinus*, *Ligustrum*, *Vitis* and *Acer*) suggests a vegetation cover typical of a humid climate. The zone is relatively homogeneous, although three subzones can be differentiated.

- A1 From sample 62 (480 cm) to sample 53 (423–426 cm), corresponding to the immigration of the above-mentioned vegetation. It is characterised by a definite decrease in *Pinus* and an increase in *Corylus*.
- A2 From sample 52 (417–419 cm) to sample 34 (324–326 cm), with rather high percentages of *Q. t. pubescens* and records of *Carpinus*, Oleaceae, *Pistacia* and Ericaceae. It reveals a diversification of the her-

baceous component (e.g. Ranunculaceae, *Sanguisorba*, Fabaceae), which suggests a change to a milder and more humid climate. However, the rise in the number of holm-oak (*Quercus t. ilex*) indicates a slight drying, favouring a more typical Mediterranean flora (Molinier and Molinier, 1956; Wijmstra et al., 1990);

- A3 From sample 33 (319–321 cm) to sample 27 (298 cm), recording the presence of *Olea*, the beginning of a slow decrease in *Q. t. pubescens*, *Ulmus* and *Chara*, oscillations in the curve for *Corylus*, the rarity of the Cupressaceae, the disappearance of *Betula* and the nearly complete absence of *Carpinus*, which taken together indicates a drier and probably cooler deforested period.

Zone B

This zone, from level 26 (287–289 cm) to the surface, is marked by a decrease in *Corylus*, oscillations in the curve for *Q. t. pubescens*, the appearance of *Abies* followed by *Fagus* and an increase of *Q. t. ilex*. In this upper part of the sequence, before the change in humidity reflected by the *Abies* curve, the increase of Chenopodiaceae marks dry local conditions. Three subzones can be differentiated.

- B1 From sample 26 to 16, shows a fall in *Corylus* and a subsequent increase in Chenopodiaceae, which coincides with a decline in *Q. t. pubescens* and *Ulmus* pollen. These changes are considered to indicate significant environmental changes. *Erica* appears to have gained from these changes while *Tilia* disappears from level 15 onwards.
- B2 From sample 15 to 6, shows a recovery of *Q. t. pubescens* while *Abies* slowly declines from level 18 onwards and eventually disappears in the upper part of the subzone. A second decline in *Abies* occurs after level 14. Next occur increases in *Q. t. ilex*, *Fagus* and *Alnus*. Chenopodiaceae pollen decrease, while *Artemisia* increase. The fact that *Fagus* and *Q. t. ilex* both appear at the same time from level 13 onwards, whereas in other diagrams from this region they are normally out of phase, may indicate a hiatus at this level.
- B3 This subzone is characterised by a sharp rise in *Olea* accompanied by Chenopodiaceae, and a drop in *Artemisia* against a background of a general reduction of pollen of trees other than *Pinus* signals the establishment of a historical culture in a deforested landscape.

Sedimentological and mineralogical results

On the basis of macroscopic petrological characteristics (grain-size, colour) the core can be subdivided into four lithological units (Fig. 3A). From bottom to top we can distinguish 2.20 m of grey, fine-grained stratified sands with silty clay interlayers. 1.30 m of sandy silts where the colouring (grey, pink, greenish) is similar to that of the surrounding Begudian rocks, 0.50 m of dark grey silts with fine-grained sands with some charcoal at the bottom, then 1.00 m of beige grey silty clays. The last two facies are mottled with friable, knobbly limestone and reddish traces of oxidation.

The granulometric analysis (Fig. 3B) shows:

Figure 1 displays stratigraphic pollen diagrams from the A1 to B3 zones of the Tula section. The diagrams show the relative abundance of various pollen taxa across different stratigraphic zones. The taxa listed on the right include: Reworked pollen, Hystrichosphaerae, Chara, Pedicularis, Vicia, Liliaceae, Alisma, Hypericum, Urtica, Dipsacus, Geranium, Spores, Valerianella, Linum, Sanguisorba, Convolvulaceae, Galium, Cruciferae, Rumex, Ranunculaceae, Plantago, Fabaceae, Apiaceae, Labiatae, Helianthemum, Malva, Chenopodiaceae, Caryophyllaceae, Centaurea, Asteraceae, Cichoriodeae, Artemisia, Cyperaceae, Typhaceae, Cerealia, Poaceae, NAP, A.P., Euonymus, Hedera, Rhamnus, Cistus, Sambucus, Platanus, Viburnum, Acer, Salix, Vitis, Ericaceae, Olea, Pistacia, Ligustrum, Oleaceae, Tilia, Carpinus, Ulmus, Fagus, Juglans, Alnus, Corylus, Betula, Juniperus, Qu. ilex, Qu. pubescens, Autres Quercus, Abies, Pinus, and Foraminiferae. The x-axis at the bottom represents the age in years, with a scale from 0 to 61,000 years BP, and a specific date of 13,180 ± 260 years BP marked.

Figure 2 Pollen diagram. All percentages are calculated on the basis of the continental flora. Foraminifera, Hystrichosphaerae, reworked pollens, *Chara* and *Pediastrum* are excluded from the pollen sum and their percentages based on the overall palynomorphs counted.

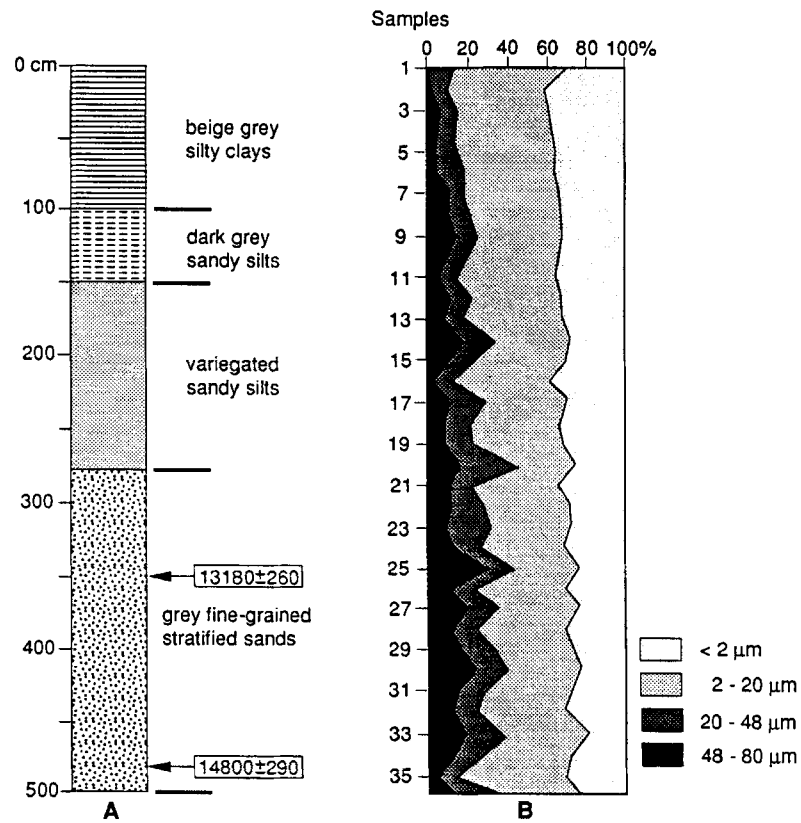


Figure 3 Lithological units (A) and grain-size distribution (B) in the Pourra core. Sample number references are particular to the grain-size study.

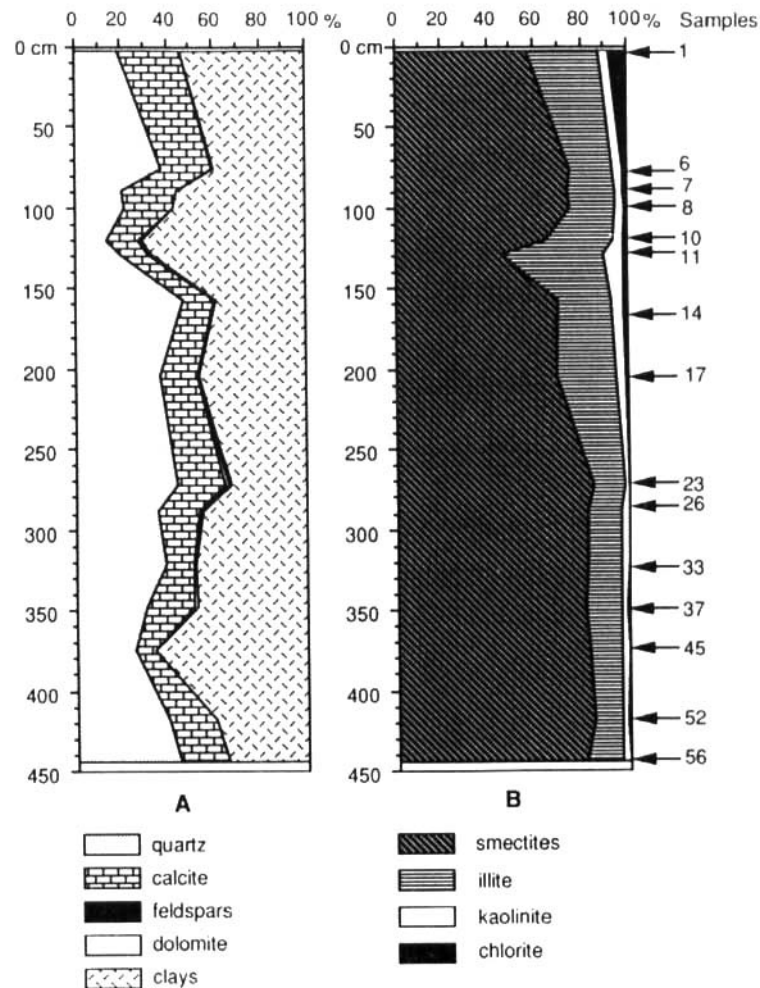


Figure 4 Mineralogical composition of the bulk rock (A), and of the clay-size fraction (B) in the Pourra core.

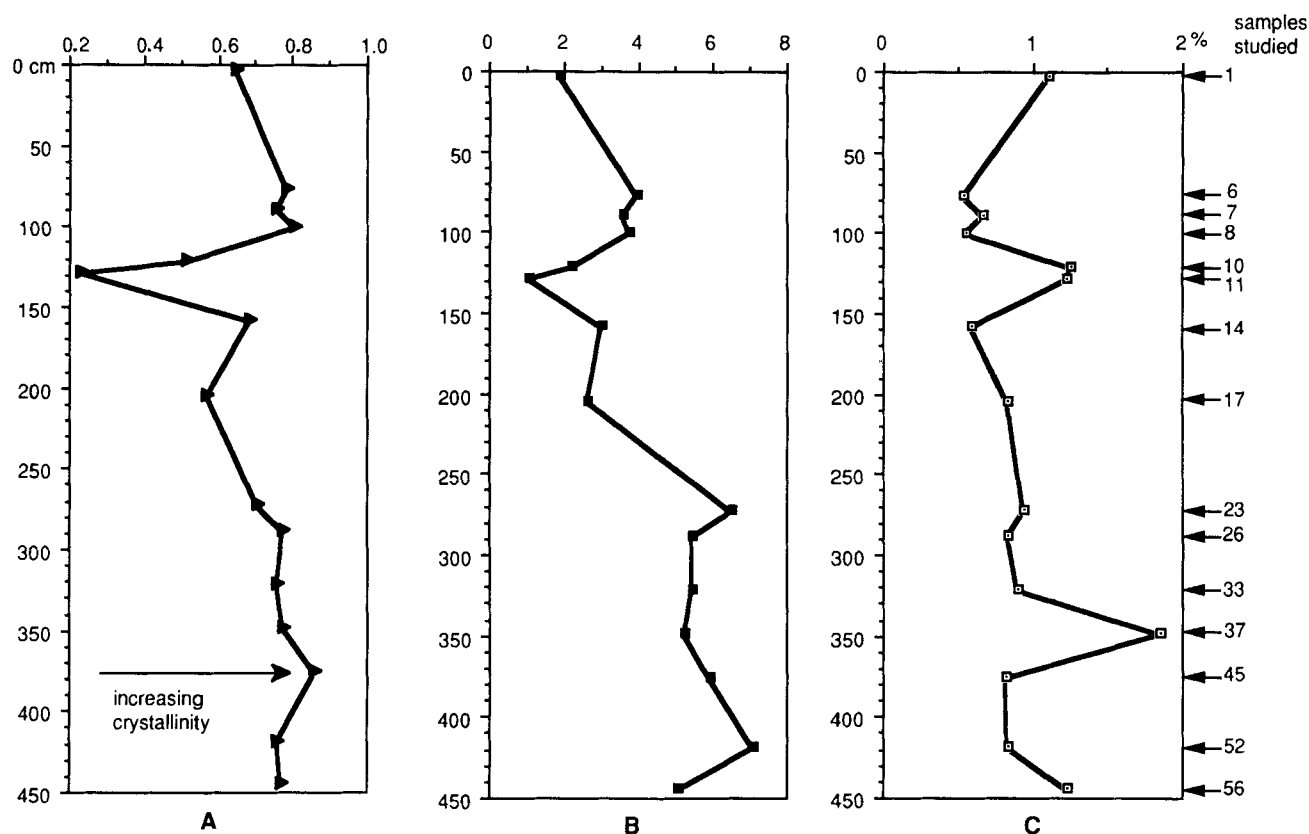


Figure 5 Variation in (A) crystallinity index of smectite, (B) smectite : illite ratio and (C) organic matter (OM) content in the Pourra core.

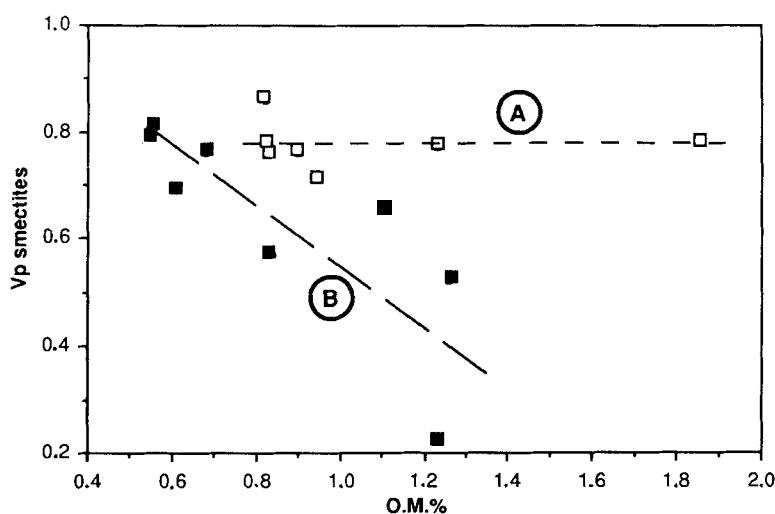


Figure 6 Relationship between the crystallinity index (V_p) of smectite and the organic matter (OM) content in the lower (A) and upper (B) parts of the Pourra core. Dashed lines correspond to calculated regression lines. Correlation coefficient is -0.05 for A and -0.81 (level of significance = 0.005) for B.

1. the importance of silts ($2-20\ \mu\text{m}$) which make up more than 40% of each sample;
2. that grain size decreases with height. In the lower half of the core, fine-grained sands ($48-80\ \mu\text{m}$) then coarse silts ($20-48\ \mu\text{m}$) make up 25–40% of each sample. They are progressively replaced, in the upper half, by silts, then clays ($<2\ \mu\text{m}$).
3. A significant granulometric variability in the lower two-thirds, characterised by more sandy peaks (samples 33, 30, 27, 25), then coarse silts (samples 20, 17, 14), in

contrast to the regularity of the granulometric composition in the upper part.

X-ray diffraction studies of the bulk rock (Fig. 4A) reveal that quartz, calcite and clay minerals are predominant; dolomite and feldspars are found intermittently in trace amounts ($\leq 1.5\%$). There is an up-profile decrease of quartz percentages and a concomitant increase of calcite and clay minerals. This trend is interrupted twice: in the lower part, between 370 and 380 cm (level 45) and in the upper part at 120 cm (level 10), by significant declines in the amount of quartz and increases in clay minerals.

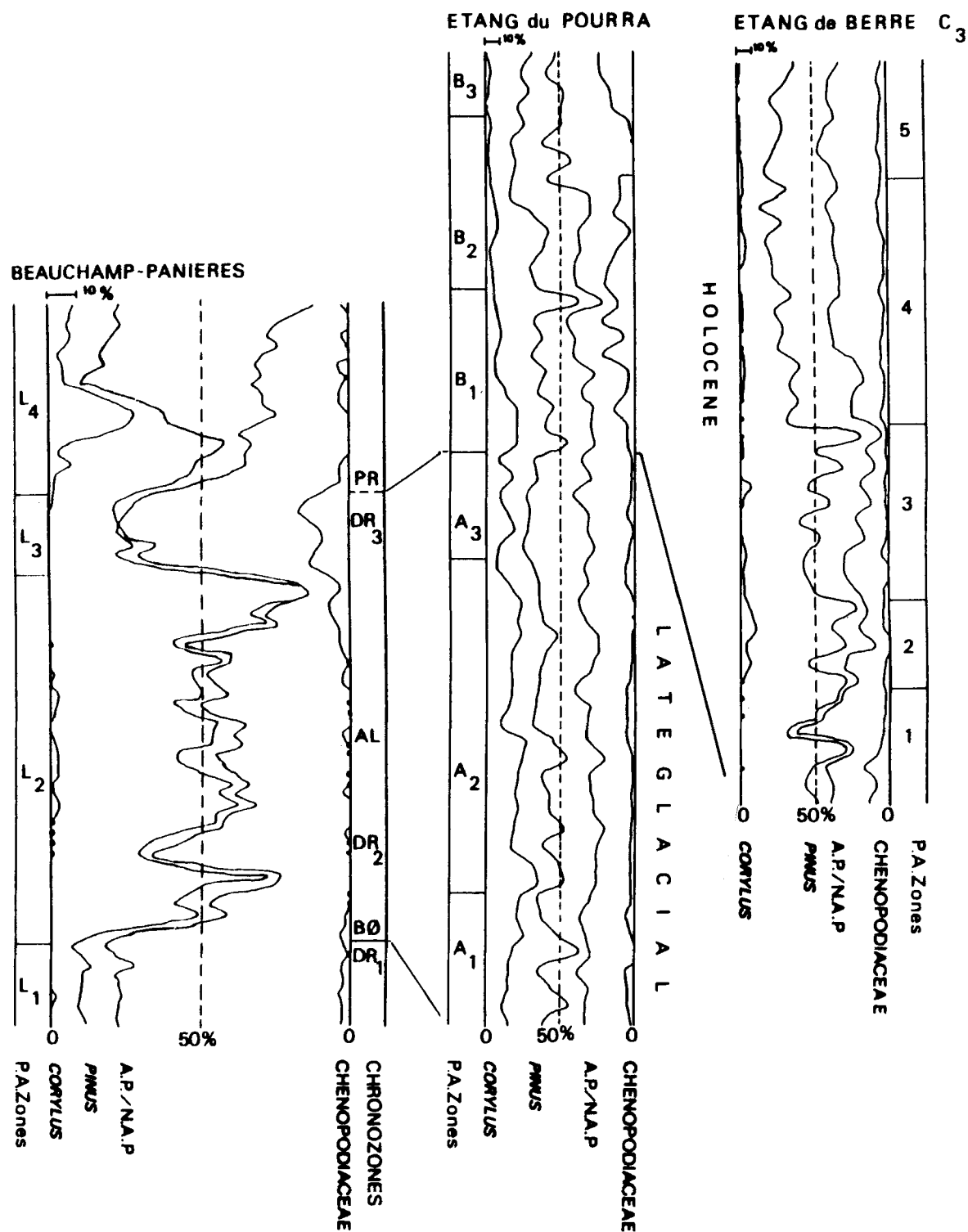


Figure 7 Simplified AP/NAP pollen diagrams of Etang de Berre core C3, Etang du Pourra and Beauchamp-Panières. All curves represent the relative percentages based on the overall continental flora. The chronozone of the Beauchamp-Panières diagram was inferred from the $\delta^{18}\text{O}$ curve (Laval et al., 1991a). PR = Preboreal, DR = Dryas, AL = Allerød, Bø = Bølling.

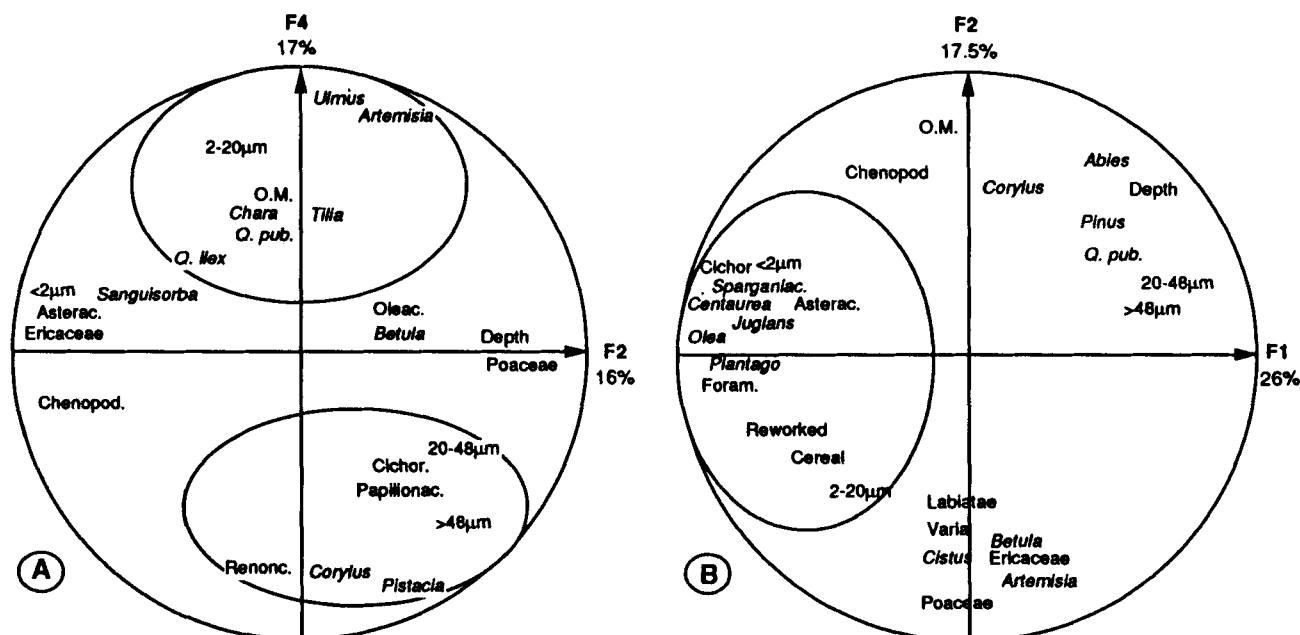


Figure 8 Results from the factor analysis for (A) the lower part and (B) the upper part of the Pourra core. Four factors account, in the two parts of the sequence, for 65 and 70%, respectively, of the variance of the system. Only the two major factors in each part of the sequence are represented. For the sake of clarity, factor loadings < 0.4 were omitted.

The clay fraction (Fig. 4B) is composed of smectite (always the major component) and illite; the amount of kaolinite and chlorite is significantly lower. The variations in clay composition fall into two parts, which correspond to the two pollen zones (A and B). In the lower part of the core (up to level 23 (272 cm); PAZ A) smectite is largely predominant and its proportion is relatively constant (80% on average, smectite : illite ratio = 5–7). Its crystallinity index (Fig. 5A) remains practically constant and high ($V_p = 0.77$ on average), indicating well-crystallised minerals. Kaolinite is present in small proportions, while chlorite is not detected. In the upper part of the core (above level 23; PAZ B) the variations are more irregular. On the whole, the percentage of smectite decreases up the profile while illite becomes more important and chlorite values are more significant. In detail (Fig. 5), starting from level 23, the percentage of smectite, the smectite : illite ratio and the crystallinity index of smectite decrease, reaching a minimum at level 11 (128 cm); above that, between levels 11 and 6 (76 cm), an inverse trend is observed. Finally, at the top of the core, between levels 6 and 1 (3 cm), there is a further decrease in the percentage and the crystallinity of smectite.

The organic (OM) content of the sediments shows two peaks at levels 37 and 10–11 (Fig. 5C). While the lower OM peak is not marked by any quantitative or qualitative change in clay minerals, the upper peak is found precisely at the level where smectite is less abundant and less crystallised, and where illite is most abundant. The same relationship is detected at the very top of the core (level 1). Overall, the crystallinity index of smectite and the OM content show a significant negative correlation in the upper part of the sequence (PAZ B) but no obvious relationship in the lower part (PAZ A) (Fig. 6).

Discussion

Pollen-stratigraphic correlations

We can correlate the Pourra sequence by reference to the biostratigraphic table suggested for Provence (Table 1).

Zone B shows a succession that clearly corresponds with the general Holocene history of vegetation established for Provence (Triat-Laval, 1979). The increase in *Pinus* and the occurrence of *Corylus* observed at the base are comparable with the forest recolonisation sequence typical of the region at ca. 10 000 yr BP. The increase of *Abies*, followed by rises in *Alnus*, *Fagus* and *Juglans*, have already been dated for this region (Triat-Laval, 1982), which allows subzones B3 and B2 to be ascribed to the Subatlantic and Sub-boreal and the upper part of B1 to the Atlantic. The lower parts of the succession (pre-*Abies*) are therefore of Preboreal and Boreal age.

Comparison of summary pollen diagrams from Berre (core C3), Beauchamp-Panières and Pourra (Fig. 7) reveals a number of similarities. First, the decline of *Corylus* and the long decrease of Arboreal Pollen (partly due to *Pinus*) which commence at the 3/4 Berre (core C3) boundary and the B1/B2 Pourra boundary, are similar to features dated to ca. 4200 yr BP in the Etang de Berre profile (Laval et al., 1991b). The presence in both diagrams of a Chenopodiaceae phase pre-dating the rise of *Abies* is also consistent. Further, although there are differences in detail, the decline in *Pinus* and in *Corylus* pollen in the Pourra PAZ A3 is comparable to that observed in Beauchamp and ascribed to the Younger Dryas (L3). However, the lower and middle part of zone A (PAZ A1 and A2) does not show the classic features of a Bølling/Allerød subdivision. The ^{14}C determinations from the lower part of the Pourra sequence indicate ages of 14800 ± 290 yr BP (Ly5254) and 13180 ± 260 yr BP (Ly5263) respectively. They are older than the accepted date for the opening of the Lateglacial (13 000 yr BP). Since the

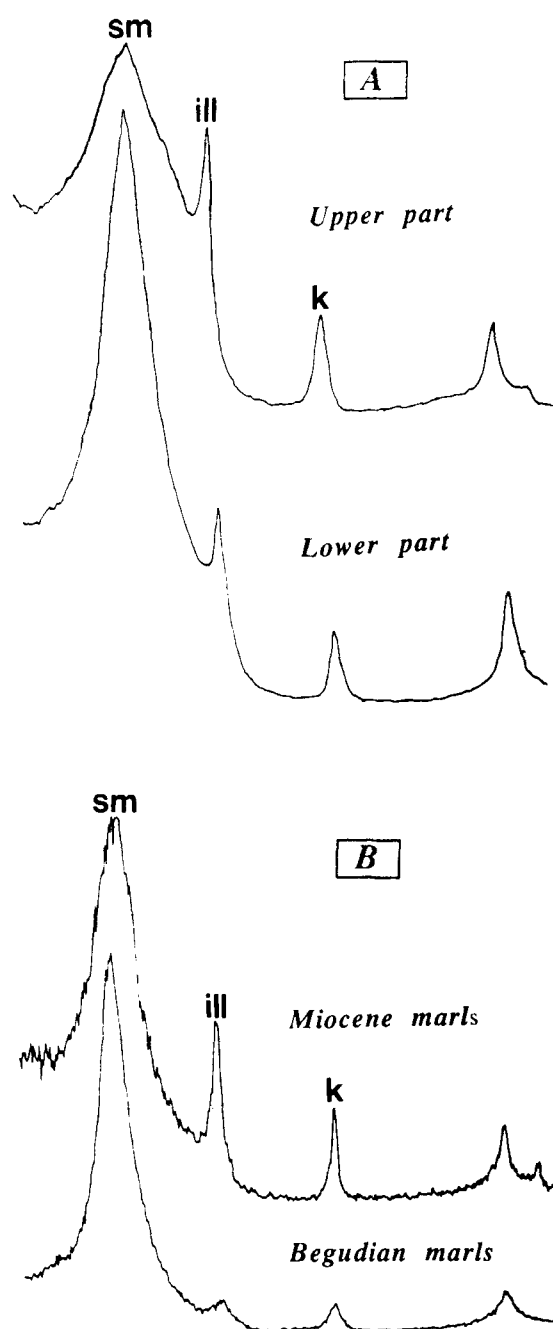


Figure 9 Typical X-ray patterns of the clay-size fraction from: (A) the upper and lower parts of the Etang du Pourra (samples 10 and 23, cf. Fig. 4); (B) representative samples of the bedrock (Begudian and Miocene) surrounding the Etang du Pourra. sm = smectite, ill = illite, k = kaolinite.

site lies in an area of calcareous bedrock these Lateglacial samples, obtained from predominantly inorganic carbonates, are likely to have been affected by hard-water error.

Environmental history

The lower part of the Pourra profile (PAZ A), as indicated by the pollen evidence, suggests a forested vegetation cover indicative of a humid climate. This zone is differentiated by a relatively coarse granulometry, fluctuations in the

granulometric parameters and a relatively homogeneous clay fraction, dominated by extremely well-crystallised smectite.

The coarse granulometric fractions ($\geq 20 \mu\text{m}$) are statistically related, using factor analysis (Fig. 8A), to the presence of *Pistacia*, characteristic of poor soil areas in the Mediterranean, and to hazel-wood (*Corylus*), usually found on the banks of streams feeding ponds. In contrast, the fine-grained fraction ($2\text{--}20 \mu\text{m}$) and the OM content are statistically associated with plants more clearly linked to enriched humic soils (*Ulmus*, *Tilia*, *Q. pubescens*) and to a high water table (*Chara*).

In order to elucidate the source of clay minerals in this lower part of the Pourra sequence, a comparative examination of X-ray diagrams of the clay-size fraction of typical samples of the surrounding geological substratum (Begudian and Miocene) was undertaken (Fig. 9). It reveals, through the predominant content and high crystallinity of smectite, a high degree of similarity between the clay fraction of the bedrock and the lower part of the Pourra sequence. Therefore, the palynological, sedimentological and mineralogical characteristics of PAZ A are consistent in suggesting a relatively humid climate during this period. This may have induced a relatively aggressive run-off which delivered material to the basin from freshly exposed bedrock.

The upper part of the profile (PAZ B) is characterised by an increase in fine granulometric fractions ($< 20 \mu\text{m}$) and by quantitative and qualitative variations of clay minerals in the $< 2 \mu\text{m}$ fraction: that is to say a decrease in the smectite content and a definite degradation of the crystallinity of this clay mineral, which is significantly correlated with increases in the OM content. Thus, clay mineral associations appear to be clearly different from those characterising the lower part of the sequence and the geological substratum (Fig. 9). We conclude that the finest granulometric fractions of the Pourra PAZ B did not simply originate from the direct erosion of the surrounding geological substratum, as suggested for PAZ A. Statistical analysis (Fig. 8B) suggests an association of the finest granulometric fractions ($< 20 \mu\text{m}$) with cultivated vegetal species (*Olea*, *Juglans*, cereal), associated 'weeds' (*Centaurea*) and with water-margin species (*Sparganiaceae*). Palynological, sedimentological and mineralogical characteristics of PAZ B are therefore consistent with the hypothesis that sediments accumulating during PAZ B were derived from disturbed soils on adjacent slopes, following extension of cultivated areas in forested lands. However, the effects of human activities, which are clearly obvious in this part of the sequence, appear to be complex. Thus, following the evidence for strong soil erosion (strongly degraded smectite correlated with high amounts of OM, which are at their highest at level 11), there is a progressive change in the granulometric and mineralogical parameters and the OM percentages up to level 6. These show characteristics closely similar to those of the lower part of the profile, which suggests renewed exposure of local bedrock following widespread removal of soils. This interpretation is supported by the increased percentages of reworked Cretaceous and Tertiary pollens, particularly in zone B3 (Fig. 2).

Conclusion

Sedimentological and mineralogical data in association with pollen-stratigraphic information has proved useful for reconstructing environmental changes, in particular hydrological

fluctuations, deforestation events and related soil erosion phases during the Late Quaternary.

The Holocene bioclimatic sequence formerly proposed for Provence has been confirmed. In particular, the Holocene is characterised by repeated impacts of anthropogenic activity on the landscape: it appears that Mediterranean vegetation provided but a weak protection against surface erosion.

The palynological succession shown in the Lateglacial of the Pourra pond and, particularly, the surprising weakness of the Younger Dryas signature help to illuminate previous research results in relation to the survival of mesothermic trees (e.g. *Corylus* and *Quercus*) and the rapid Preboreal forest recolonisation recognised in sites nearest the littoral zones (see Triat-Laval, 1979). For the Pourra site it is our opinion that the weakness of the changes recorded in the lower half of the pollen stratigraphic sequence is related to the exceptional geographical situation of the site and its geomorphological position in the small basin, but above all to less arid edaphic conditions. Certainly these conditions enabled the local vegetation to partly absorb regional climatic variations. Nevertheless, the climatic succession inferred for the lower part of the Pourra sequence is similar to the sequence observed in glacial–interglacial successions in Greece (Wijmstra et al., 1990), and emphasises, as we have already suggested from a study of the Beauchamp Panières sequence (Laval et al. 1991a), that there were diverse reactions of vegetation to the Younger Dryas event in Mediterranean regions.

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