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Die holozän Transgression im Golf von Lion, süd-west Frankreich

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Aller au sommaire du numéro

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Résumé de l'article

Les auteurs font la synthèse de résultats ponctuels pluridisciplinaires (analyse lithosismique, sédimentologie palynologie, radiométrie ^{14}C) obtenus en mer et sur la bordure du golfe du Lion. Le nombre d'échantillons datés (plus de 120) et la diversité des sites étudiés permettent une approche méthodologique. Une courbe de la remontée de la mer holocène est proposée qui tient compte de deux facteurs essentiels : la position géomorphologique du site et les caractères du milieu de sédimentation (faciès sédimentaire et environnement paléobotanique). On note : 1) une rapidité générale de la transgression depuis 14 000 ans BP, accélérée de 8000 à 6000 BP; 2) l'existence de courtes périodes de relative stabilité à 12 000 et à 8000 BP; 3) l'existence d'un haut niveau marin à environ +2 m vers 4500 BP.

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THE HOLOCENE TRANSGRESSION IN THE GOLFE DU LION, SOUTHWESTERN FRANCE: PALEOGEOGRAPHIC AND PALEOBOTANICAL EVOLUTION*

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ABSTRACT Starting from multidisciplinary punctual results, the authors offer a synthesis of lithologic seismic analysis, sedimentology, palynology and radiometrical measurements from sites in sea and at the border of the Golfe du Lion. The dated samples (more than 120) and the variety of the studied sites has permitted a true methodological approach. The authors also propose a curve of the rising of the Holocene sea that takes into account two major facts: the geomorphologic localisation of the site and the characteristics of the sedimentary environment (sedimentary facies and paleobotanic environment). They conclude to: 1) a generalised rapid rise of the transgression since 14,000 years BP, with an acceleration from 8000 to 6000 years BP; 2) intervals of relative stability from 12 000 to 8 000 years BP; 3) a high sea-level at +2 m at around 4500 years BP.

RÉSUMÉ *La transgression holocène dans le golfe du Lion, Sud-Ouest de la France.* Les auteurs font la synthèse de résultats ponctuels pluridisciplinaires (analyse lithosismique, sédimentologie palynologie, radiométrie ^{14}C) obtenus en mer et sur la bordure du golfe du Lion. Le nombre d'échantillons datés (plus de 120) et la diversité des sites étudiés permettent une approche méthodologique. Une courbe de la remontée de la mer holocène est proposée qui tient compte de deux facteurs essentiels: la position géomorphologique du site et les caractères du milieu de sédimentation (faciès sédimentaire et environnement paléobotanique). On note: 1) une rapidité générale de la transgression depuis 14 000 ans BP, accélérée de 8000 à 6000 BP; 2) l'existence de courtes périodes de relative stabilité à 12 000 et à 8000 BP; 3) l'existence d'un haut niveau marin à environ +2 m vers 4500 BP.

ZUSAMMENFASSUNG *Die holozän Transgression im Golf von Lion, süd-west Frankreich.* Die Autoren machen die Synthese pluridisciplinärer Resultate (lithosismische Analyse, Sedimentologie, Palynologie und Radiometrie), erhalten durch Proben, die im Meer und an der Küste des Golfes von Lion genommen wurden. Die datierten Proben (mehr als 120) und die Verschiedenheit der studierten Plätze erlauben eine methodische Annäherung. Eine Kurve der Erhebung des Meeresspiegels im Holozän ist vorgeschlagen, die zwei Hauptfaktoren in Betracht nimmt: die geomorphologische Lage des Platzes und den Karakter des Sedimentationsmilieus (Fazies und paleobotanische Umgebung). Man bemerkt: 1) eine allgemeine Schnelligkeit der Übertretung seit 14 000 Jahren BP, beschleunigt von 8000-6000 BP; 2) das Vorhandensein von kurzen Zeiträumen relativer Stabilität um 12000 und 8000 BP; 3) das Vorhandensein eines hohen Meeresspiegels bei ungefähr 2m gegen 4500 BP.

* English translation by Judith Read (université Paul-Valéry, Montpellier) and Nadine Planchais

From a multidisciplinary study of the continental shelf of the Golfe du Lion, the main features of the Late-Quaternay paleogeographic evolution of the region were traced (ALOÏSI *et al.*, 1975). The results of each aspect are remarkably consistent for the different areas of Languedoc and Roussillon despite the statistical characters inherent to the radiometrical measurements performed on the molluscan fauna of the submerged layers. If the correlations with other underwater sites in the Mediterranean (underwater caves) are rendered uncertain by tectonism, they are more difficult when one compares the marine and margino-coastal areas.

A more fundamental approach to the Late-Holocene paleogeography has involved multidisciplinary research conducted since 1974 on two types of sites: coastal lagoons and off-shore bars (Fig. 1) at five localities on the coast of Languedoc: Port-la-Nouvelle, Agde, Sète, Palavas and Mauguio. The studies concern sedimentology, palynology and ^{14}C age determinations on samples from outcropping layers or borings, as well as complementary data from continuous seismic survey on the continental shelf which made the amount of punctual results easily reliable.

It is important to state the necessity of carrying out morphological and faciological analysis of the dated sites in order to avoid erroneous reconstruction and spurious correlations.

At the same time a methodological and critical approach to the dating of the carbonates was attempted by multiplying the number of radiocarbon measurements: a) on several species of molluscs from a given level; b) on several individuals of the same species in different degrees of preservation; c) on the fauna collected from the modern sand-bar of Languedoc.

Altogether, the data leads to more general considerations concerning: a) limitations on the use of radiometric ^{14}C dating of shells, b) sedimentary mechanisms such as sedimentation rate, reworking etc. c) the patterns of Holocene sea-level change.

I. METHODOLOGY OF THE RADIOCARBON MEASUREMENTS

Dating of the shells is based on the assumption that during the life of the mollusc all the carbonates composing the tests (without distinction of types) had the same carbon isotopic composition and that the latter began to change only after the death of the animal by radioactive decay of the ^{14}C isotope. In fact, this is not always so, mainly because of ecological factors that are recognized as the principal reasons for the non-uniformity of the isotopic composition of the shells of living organisms, and post-depositional conditions changing the isotopic relationships in the shells, thus invalidating the ideal radioactive decay relation.

The change of isotopic ^{14}C ratio in the fossil shells can be quantified by a measurement of the ^{13}C isotope concentration, but in this study, the ^{13}C correction for age has not been done because it was judged negligible (at the most some few decades) when compared with the other causes of error. According to a study (NYDAL *et al.*, 1972) and to some previous measurements (THOMMERET, unpubl.) the ^{14}C activity of known aged marine shells (pre-1950) do not significantly differ from the 95% NBS standard activity.

A certain number of shells dated during this study gives conflicting ages which one can only attempt to rationalize in terms of ecological factors or by implicating contamination due to exchange of carbon by fresh water from continental origin, or by reworking of the sedimentary deposit.

Exchange of carbon isotopes has been the object of numerous studies (KEITH and ANDERSON, 1963; CHAPEL and POLACH, 1972; GRANT-TAYLOR, 1972; MANGERUD, 1972; MANGERUD and GULLIKSEN, 1975; THOM, 1972; THOMMERET, 1976; HILLAIRE-MARCEL and OCCHIETTI, 1977) and constitute an important source of error in shell age determination; the true age is increased if the exchange involves fresh water from calcareous springs or decreased — and this is the more frequent case — by the action of running water containing carbonic acid from the air. It has also been shown that the contaminations by isotopic exchanges are enhanced by the crystal structure: aragonite being far less susceptible to ionic substitution than calcite; in fact an X-Ray diffractogram is sufficient to be able to reveal tests containing recrystallized or foreign calcite. This verification is important and we have come to it during a study of parallel chronology of the lagoonal-marine formations in the Petite-Camargue; the X-Ray analyses were done on both *Cardium* and *Pectunculus* (coming from the same deposit) and no other type of recrystallisation except that of aragonite was found, although large differences were noted between the age of each species. The main reason for error is probably sedimentary reworking during interpenetration of successive groups of coastal bars that presents complex problems of reconstruction to the geomorphologist (BAZILE and THOMMERET, unpubl.).

In constrast the marine environment does not present many opportunities for exchanges of carbon isotopes in the calcium carbonate. The shells of marine faunas which are still *in situ* and non-estuarine can, from the strict point of view of isotopic contamination,

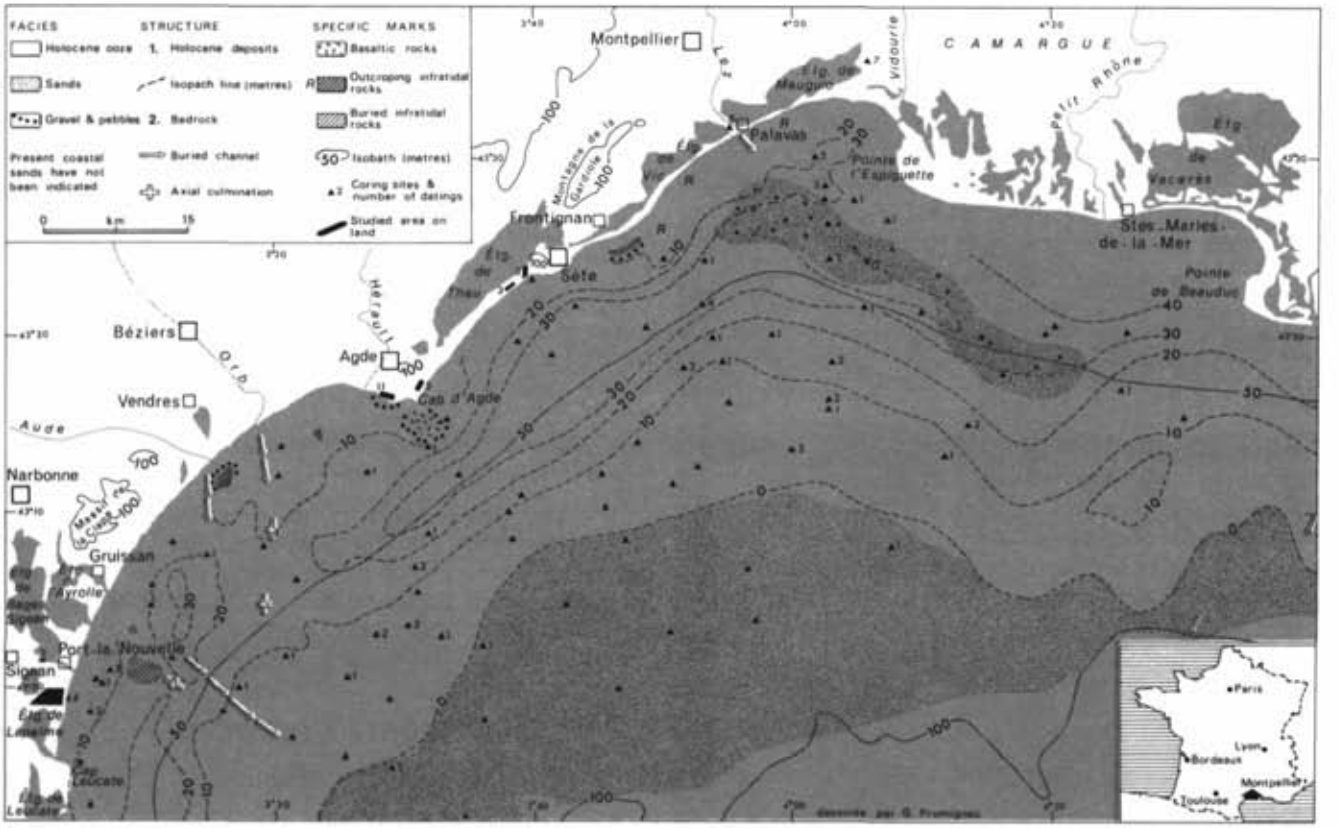

FIGURE 1. Schematic distribution of the facies of surficial deposits, and rate of Holocene infilling. Coring sites and studied areas.

Répartition schématique des faciès de la couverture sédimentaire superficielle et puissance du remplissage holocène. Sites des sondages et secteurs d'étude.

be dated with confidence whatever the crystalline nature of their carbonate. However, one must not forget that in the marine sedimentary environment the fossil shells can come from various bathymetric levels (MARS, 1973) and do not necessarily provide good chronological markers unless they are found *in situ* (this relatively rare case being only valid for littoral strata). For example, there are several occurences of species said to belong to the marine coastal level (*Cerithium*) that were found mixed with much older layers of sedimentation (at least one thousand years older).

To conclude, for neritic or lagoonal sediment, chronology based on ^{14}C analysis becomes a reliable method, thanks to a knowledge of various disturbing factors and providing there are enough analyses for cross-checking. A representative age being based if possible on an average of several ^{14}C measurements of different molluscan faunas it appears useless to take into account an inexplicably discordant result when obtained in a coherent sedimentological complex. Nevertheless dubious age results have been mentioned in the present work.

II. THE CONTINENTAL SHELF IN THE GOLFE DU LION

About forty ^{14}C assays obtained recently on various samples (Fig. 1) afford a detailed chronology of post-glacial deposits. They corroborate published accounts of a series of five lithosequences *a*, *b*, *c*, *d*, and *e* (Fig. 2) belonging respectively to the Late-Glacial (*a* and *b*), to the Preboreal (*c*), to the Boreal-Atlantic (*d*), and to the Subboreal-Subatlantic (*e*). This succession is therefore based not only on the absolute ages of the sequences but also on the facies of the sediment and its seismic signature. Moreover, analysis of the continuous seismic reflection profiling has allowed the recognition of various sections whose particular morphological features have guided recent paleogeographical evolutions; thus in the Agde-Petit Rhône area, the lower levels *a* and *b* pinch out themselves and disappear in the shallow areas of Agde to the west and Beauduc to the east (Fig. 1).

The paleogeographical diagram is complicated by rocky knolls that form promontories or paleothalwegs in the Würmian alluvium: the paleothalwegs of the

FIGURE 2. Submarine formations of the Languedocian coast. a) Rocky knolls made of sandstone (probably Tyrrhenian) off Palavas that outcrop from a depth of 15 m; b) gravel sand with shells and encrusted pebbles part of Holocene shore formations (< 8000 years BP). They arise from the reworking of Würmian alluvian sheets and often brace to rocky knolls as shown in a).

Formations sous-marines au large de la côte languedocienne. a) bancs rocheux formés de grès probablement tyrrhéniens, affleurant par 15 m de profondeur, au large de Palavas; b) Sables graveleux coquilliers et galets encroûtés représentant des formations littorales holocènes (< 8000 ans BP). Ils résultent du remaniement de nappes d'alluvions würmiennes et s'ancrent fréquemment sur les témoins rocheux illustrés en a).

Agly, the Sude and the Hérault and the fluviatile network in front of the basin of Thau (CHASSEFIÈRE *et al.*, 1970).

New data include age determination on molluscs, depositional conditions and analysis as background for the derived Holocene sea-level curve.

- The sea-level history confirms preliminary indications, particularly for the interval between the Late-Glacial and the Atlantic periods,
- Dates on coeval facies of various Holocene sequences yield a consistent reconstruction of depositional environments and a good understanding of the role of morphology. For example, the near-shore muds of the gulf of Agde-Petit Rhône and the sandy near-shore bars of the Petit Rhône formed simultaneously,
- Collectively data reveal an important deltaic complex, deposited by the Rhône diverted westward of its present course.

The construction of this complex over the ages, between 10,000 BP and around 6000 years BP is shown by a (1) a system of bars at −60 m to −25 m anchored to the rocky knolls at Palavas to the west (Fig. 2) and the the alluvial terraces of Beauduc Point to the east (ALOÏSI *et al.*, 1975), and (2) dated silts interbedded Holocene muds on the shelf (Fig. 3).

This complex is partly buried under the more recent sediments which accumulated after 5000 years BP as pro-deltas of the Lez and Petit Rhône, and the Vidourle in the Golfe of Aigues-Mortes (ALOÏSI and MONACO, 1975; MONACO, 1975; ALOÏSI, 1973).

III. PORT-LA-NOUVELLE

(X, 76 to 78; Y,657 to 658)

Nearly thirty borings were made near the eastern end of the Corbières spur, between Port-la-Nouvelle and Cap Leucate, in the plain which extends seaward from cliffs cut into calcareous Mesozoic rocks. These form the capes named du Roc (50 m) and Romarin (100 m); their abrupt decline under the Quaternary cover probably marks a fault. A sandy shore isolates the lagoon of Lapalme from the sea.

The borings penetrate mainly Holocene sand to an average depth of 20 m, whereas the calcareous basement is at about −50 m. These were the basis for the study of coastal formations built between Cap Leucate and Cap du Roc.

The series is characterized by decrease in grain size upward. The basal strata are predominantly gravelly sand, rich in well-shaped quartz pebbles reflecting the proximity of Cap du Roc which probably forms the foundation of the first coastal constructions. The upper 15 m consist mainly of well-sorted fine to medium sand, and locally shell-bearing, in which thin layers of muddy silt rich in organic debris occur at −5 to −6 m.

Forty-four ^{14}C age determinations were made largely on the macrofauna, at various levels, with a few, on vegetal debris (Table 1). They also deal with the fauna associated with sandy formations situated at an elevation of 1.5 to 2 m at the foot of the calcereous cliffs at

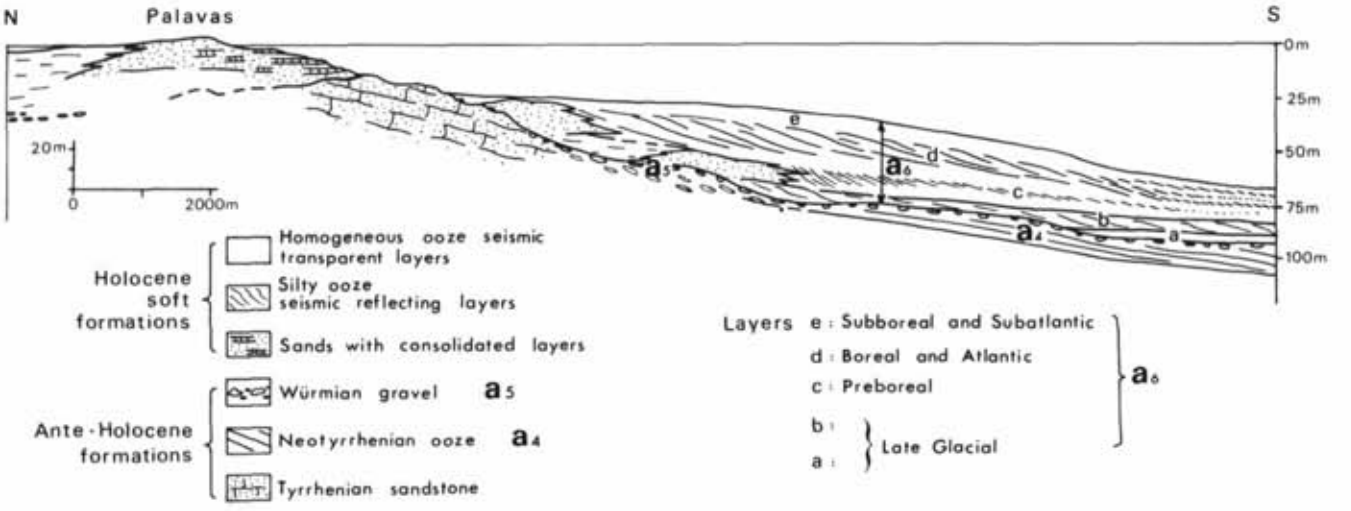

FIGURE 3. Holocene lithologic sequences: the continental shelf off Palavas.

Lithoséquences de l'Holocène. Exemple du plateau continental face à Palavas.

Cap Romarin (Fig. 4a) (FIEUZAL, 1972). The dates range from 6300 to 390 years BP. Notwithstanding certain discrepancies, to be discussed later, the correlation of dates and facies allow a tentative reconstruction of the dynamics of infilling (Fig. 5): a) a general transgression until about 4000 years BP, when the positive level was reached (around 2 m at Cap Romarin); b) a subsequent regression marked, from 2000 years BP onwards, by thin silt and muddy layers at progressively later time toward the east.

The paleogeographic reconstruction of land and sea level changes takes into account the morphological situation. Indeed, the granulometric gradient on the steep shores as those flanking Cap Romarin during Late-Holocene (Fig. 4a) contrasts with the gradients noted on the flat shores. It would be difficult to fix the exact level of the sea corresponding to each stage. In Figure 5, the various stages of infilling have been represented and their dynamics is interpreted in terms of the results obtained at other sites.

Nevertheless, the sedimentary changes reflect a progressive construction of the lagoon. Initially, the shore was open and received (around 6000 BP) detrital material (gravel and stones). The Cap Romarin anchors the Holocene bar which formed a tombolo between this promontory and that of Leucate to the south. Euxinic facies represented by coastal sands in the lagoons do exist, however, at Cabanes des Angles (near Port-la-Nouvelle) where the ages are invariably 1200 years BP.

Concerning the absolute ages, the multiplication of the radiometric measurements revealed discrepancies between the ages at one same level. Dates on *Cardium* are often more than one or two thousand years greater than dates on other genera (*Venus, Pectunculus, Merethrix*) at the same level. Moreover, the discrepancy increases in the lower gravelly layers. On the other hand, dates on *Pectunculus* and *Cardium* in the sandy stratum at the foot of the cliff at Cap Romarin which represents the main Holocene transgression, agree satisfactorily (from 4100 to 4450 years BP ± 100). Age discrepancies on the younger sediments are minimal and decrease upwards with the precision of the measurements. Examination of this data and of the facies suggests that reworking is responsible.

IV. THE COAST FROM CAP D'AGDE TO SÈTE

Two sites were studied: one near Cap d'Agde which includes the beach of La Roquille to the east and the beach of Rochelongue to the west (Fig. 4b); the other on the sandy coast 2 km west of the hill at Sète (Fig. 1).

The main characteristics of the first area lies in the abundance of large shells (*Cardium, Pectunculus* = *Glycimeris, Merethrix, Cerithium*) which contrasts with a relative paucity observed on the coast of the Golfe du Lion. The size of these accumulations, several metres thick, can be more than 100 m long (Fig. 4b).

About twenty samples (Table II) taken from various levels in the beach have been dated, the measurements having been carried out on various individuals of different species and in different states of preservation. The ages obtained usually range from the Present to 4800 BP in the same level. In such mixtures as at Port-la-Nouvelle, the age of *Pectunculus* is never less than 2000 years BP (Fig. 2 and 4). The biological sampling

TABLE I

Core No.	Lab. No.	Present height above/under sea level (m)	Material	^{14}C age* yr BP
PN 221-1 (N1)	MC-881	− 6.10 to 6.20	*Pectunculus*	390 ± 70
221-4	MC-882	− 12.45 to 12.65	*Pectunculus*	2180 ± 100
221-5	MC-883	− 15.50 to 15.60	*Pectunculus*	3600 ± 120
PN 01 (N2)	MC-866		*Cardium*	140 ± 70
PN 201-4	MC-867	− 4.10 to 5.10	*Venus*	600 ± 70
201-8	MC-868	− 6.70 to 6.80	*Pectunculus*	840 ± 70
201-8	MC-930		*Venus*	720 ± 70
201-9	MC-869	− 9.80	*Pectunculus*	880 ± 70
201-10	MC-870	− 12.60 to 12.75	*Pectunculus*	2200 ± 90
201-10	MC-934		*Venus*	2530 ± 70
201-11	MC-871	− 18.75 to 19.10	*Cardium*	5520 ± 100
201-11	MC-931		*Pectunculus*	3700 ± 90
PN 251-3 a) (N3)	MC-960	− 15.57 to 15.76	*Pectunculus*	2890 ± 100
b)	MC-961		*Merethrix*	3500 ± 100
c)	MC-962		*Cardium*	3330 ± 100
e,d,f)	MC-963		Mixed shells	3440 ± 100
PN 213-2 (N4)	MC-872	− 6.40 to 6.60	*Pectunculus*	1900 ± 90
213-2	MC-932		*Mactra*	2000 ± 90
213-5	MC-873	− 12.05 to 12.15	*Pectunculus*	3200 ± 90
213-6	MC-874	− 16.60	*Cardium*	3650 ± 90
213-6	MC-933		*Mactra*	3450 ± 90
PN 212-5 a) (N5)	MC-949	− 14.60	*Cardium*	3970 ± 90
b)	MC-950		*Pectunculus*	3945 ± 90
c)	MC-951		*Pectunculus*	3390 ± 90
PN 212-6	MC-952	− 17.65 to 18.00	*Cardium*	3910 ± 80
	MC-953		*Merethrix*	3725 ± 100
PN 211-3 a) (N6)	MC-954	− 6.50 to 6.70	*Cardium*	1630 ± 90
b)	MC-955		*Venus*	1850 ± 90
c)	MC-956		*Pectunculus*	1595 ± 90
PN 211-6 a)	MC-957	− 14.30 to 14.50	*Cardium*	4940 ± 100
a)	MC-984		*Cardium*	4660 ± 200
b)	MC-958		*Merethrix*	3560 ± 90
c)	MC-959		*Pectunculus*	3330 ± 90
PN 214-1 (N7)	MC-875	− 3.55 to 3.60	*Posidonia* (Alg.)	2080 ± 60
214-3	MC-876	− 6.50	*Pectunculus*	2040 ± 70
PN 214-6	MC-878	− 11.60	Brok. shells	2870 ± 80
214-7 + 8	MC-879	− 14.00 to 15.50	*Cardium*	4670 ± 130
214-9	MC-880	− 17.00 to 17.25	*Venus*	6300 ± 160
Cabanes des Angles	MC-1178	+ 0.50	*Cardium*	1200 ± 50
Cap Romarin 1 CR1	MC-1123	+ 2.50	*Pectunculus*	4100 ± 100
Cap Romarin 2 CR2	MC-1124	+ 2.00	*Cardium*	4190 ± 100
Cap Romarin 2 CR2	MC-1125	+ 2.00	*Pectunculus*	4150 ± 100
Cap Romarin 4 CR4	MC-1126	+ 1.50	*Pectunculus*	4430 ± 100
Cap Romarin 4 CR4	MC-1127	+ 1.50	*Cardium*	4450 ± 100

* The radiocarbon age was calculated with a ^{14}C half-life of 5570 years and a contemporary value equal to 0.95 times the activity of the NBS oxalic acid standard (A.D. 1950). The standard error is based on counting statistics only.

of different species of *Glycimeris* has been done but we are expecting the results.

The off-shore bars were constructed partly of recycled relict material from deposits formed during the Holocene sea-level maximum (around 4000 years BP) where the knolls can be preserved locally. This is the case of the sites at Rochelongue (RL 1) and Sète (75 Se) sheltered from the east-west currents by the rocky promontories of the capes at Agde and at Sète.

The structural conditions of the coastal bars are thus comparable with those of Port-la-Nouvelle (Cap Romarin) at one stage in its evolution, namely construction at the foot of rocky outcrops in an open coastal environment of reworking. Nevertheless, at Port-la-Nouvelle, the relict knoll of the sea-level maximum has been isolated since 4500 years BP by a recent propagation. At Agde and Sète, the fossil beaches are still being eroded and redeposited.

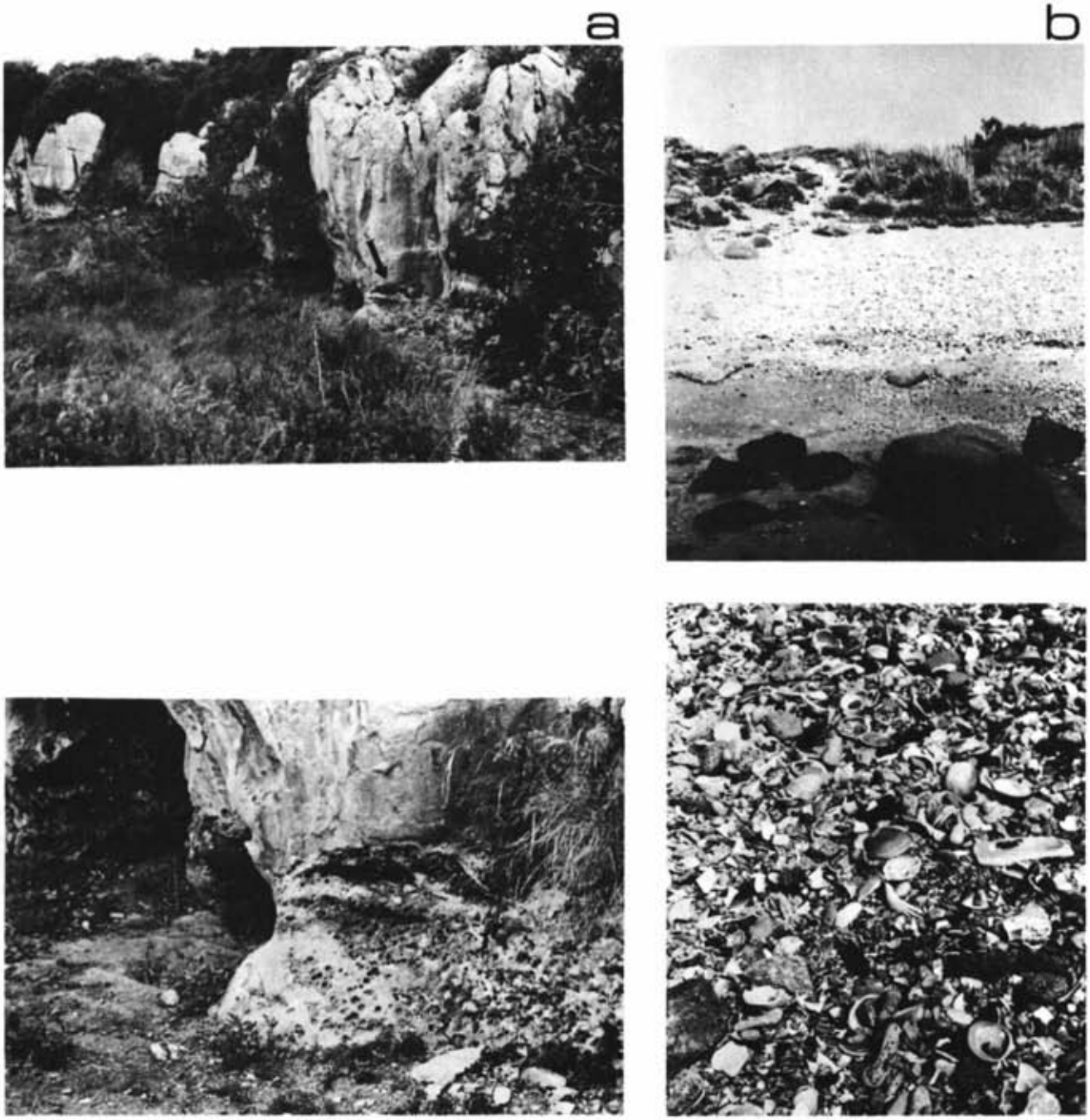

FIGURE 4. Recent indicators of Holocene transgression on the Mediterranean coast. A) Calcareous cliff (Mesozoic) of Cap Romarin showing a littoral facies and holes caused by shells and molluscs due to a positive level (+2m) of the Holocene sea. At the foot of the cliff (detailed photo) the sandbar dated 4100 to 4500 years BP resulting from sedimentary infilling of the plain. B) Shell accumulations on Rochelongue Beach (Cap d'Agde). The upper photo offers a general view of the formation and basaltic blocks outflow of the Quaternary volcano of Agde on the shore. Lower photo shows the abundance and variety of the shells mixed with pebbles and sands different in nature and origin. Dates on this material range from the Present to 4700 y BP.

Témoins récents de la transgression holocène sur la côte méditerranéenne. a) Falaise calcaire (mésozoïque) du cap Romarin montrant un façonnement littoral (encorbellement) et des perforations de lithophages attribuables à un niveau positif (+2m) de la mer holocène. On note au pied de la falaise (photo de détail) le cordon sableux daté de 4100 à 4500 ans BP et appartenant au remplissage sédimentaire de la plaine. b) Accumulations coquillières de la plage de Rochelongue (cap d'Agde). La photo du haut montre l'ensemble de la formation avec, sur le rivage, les blocs basaltiques provenant des coulées du volcan quaternaire d'Agde. La photo de détail illustre l'abondance et la variété des coquilles mêlées à des galets et sables de nature et d'origine diverses. Les datations de ce matériel fournissent des âges allant de l'actuel à 4700 ans BP.

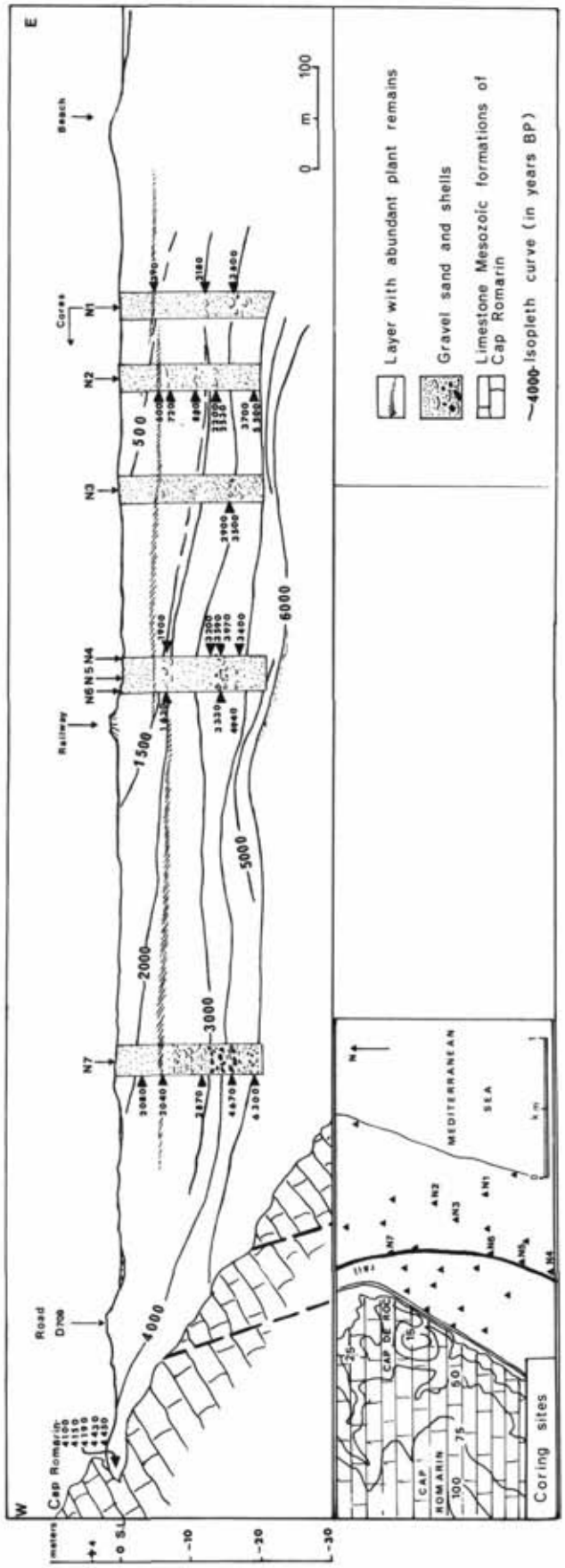

FIGURE 5. Synthetic and interpretative cross-section of Holocene infilling showing progradation of the shore in Port-la-Nouvelle area.

Coupe synthétique et interprétative du remplissage holocène dans la région de Port-la-Nouvelle, montrant la progradation du littoral.

V. PALYNOGICAL CONTRIBUTION TO THE PALEOGEOGRAPHICAL RECONSTRUCTION OF SOME MEDITERRANEAN LITTORAL SITES

1. THE FILLING OF THE PALEOCHANNEL OF THE LEZ RIVER

(Coordinates: X,728, 32; Y,138, 05) (Fig. 1 and 4)

Pollen analysis of the marine lagoonal sediments provides biostratigraphic results which can be compared with the chronostratigraphic data given by the radiocarbon measurements. This type of investigations could be made on eight sites in the Languedoc, but only three sites are reported here: Palavas, being the reference site for the palynology and dating in lagoonal systems, Sète (the Canal des Quilles) and Marsillargues (Étang de Mauguio).

Concerning the first published diagram at Palavas (PLANCHAIS *et al.*, 1977a) the pollen zonation A, B, C, D, E, and F had been established in relation to eight ^{14}C dates, and the first biostratigraphic scale has been described for the last ten millenia in the Languedoc. Further details are given on the complete tree-pollen diagram (Fig. 6) where the total amount of herbaceous pollen percentages is shown in the middle of the figure. To the left of the A.P./N.A.P. ratios the curve of the variations in total content of pollen grains and spores counted is drawn.

In the zone A, the curves of the *Quercus* ilex type and *Fagus* indicate a period lasting from the Subatlantic until the Late-Atlantic in the paleo-environment of south western France. The upper layers were not analysed because the sands were not consolidated and might have been disturbed.

Of significance to pollen sources is the fact that the main distributary channel of the Rhône was initially on the western side of its delta, whereas it is now on the east. Hence, the pollen influx to the Languedocian coast was very large and consisted mainly of grains transported by floods from the Vosges and the Jura, from the Alpes and the Massif Central as well as secondary component brought by water or wind from the Mediterranean plains or hills with local, mainly herbaceous, pollen grains (Graminae, Cyperaceae, Chenopodiaceae, Compositae, etc.). This latter frequently amounted to 50% of the total. The differentiation of components has been made from the various

TABLE II

Core No.	Lab. No.	Present height above/below sea level (m)	Material	^{14}C age yr BP
Plages de Rochelongue (Cap d'Agde)				
RL2	MC-1216	+ 1	*Cardium*	modern
RL2	MC-1217	+ 1	*Pectunculus*	2680 ± 90
RL1	MC-1212	+ 0,80	*Cardium*	4775 ± 100
	MC-1213		*Cerithium*	4400 ± 100
	MC-1214		*Pectunculus*	2350 ± 75
	MC-1215		*Merethrix*	450 ± 80
RL3	MC-1218	0	*Cardium*	140 ± 75
	MC-1219		*Merethrix*	1860 ± 75
	MC-1220		*Pectunculus*	3700 ± 75
	MC-1221		*Mactra*	1050 ± 80
	MC-1222		*Venus*	modern
Plage de la Roquille (Agde)				
75 Ca 1	MC-969	lower beach	*Cardium*	3135 ± 100
	MC-970		*Pectunculus*	3575 ± 100
	MC-971		*Merethrix*	2600 ± 90
75 Ca 2	MC-972	top of beach	*Cardium*	3675 ± 100
	MC-973		*Pectunculus*	2325 ± 90
Plage de la Corniche (Sète)				
75 Se	MC-966	lower beach	*Cardium*	4865 ± 100
	MC-967	~0	*Pectunculus*	2640 ± 90
	MC-968		*Merethrix*	2630 ± 90
Canal des Quilles (Sète)				
Sète D	MC-762	− 1.30	*Peat*	5410 ± 100
Sète A 2	MC-760	− 3.50	*Cardium*	27,000 ± 1000
Sète B	MC-761	− 3.00	*Cardium*	5650 ± 200

aeropalynological data now observed at Montpellier (five years of air investigations) and in other sites in the French plains and mountains.

The pollen zonation can be compared in this way to the mountain zonation (WOILLARD, 1975: MATTHEY, 1971; WEGMÜLLER, 1966, 1977; BEAULIEU, 1977) because of the significant content of long-distance transport of mountain tree-pollen genera, as well as to the local zonation (PLANCHAIS, 1973, 1976, 1977; PLANCHAIS *et al.*, 1977a et b; TRIAT, 1973, 1975; VERNET, 1973, 1976).

In zone B, *Abies* and *Tilia* correspond with the Atlantic pollen zonation and partly with the Godwin's or Firbas' zonation systems.

In zone C, *Pinus, Ulmus, Corylus* and Cypressaceae (probably *Juniperus*) are taxa which signify the Boreal.

Zone D is the Preboreal, whereas zone E is more likely the Late Dryas period because of the importance of the herbaceous vegetation. From the strict palynological point of view, these two zones are probably somewhat older because it is unrealistic to imply steppe-like vegetation in the Mediterranean French lowlands at about 10,000 years BP when in fact the south-alpine French glaciers probably melted as early as 14,000 years BP (BEAULIEU and EVIN, 1977). The hypothesis of a greater age than 10,200 BP also allows for the possibility that dated material (humified and calcareous) may have been deposited under very shallow water and could have dried up. On the other hand, this type of sediment may be too old because of the possibility of redeposited organic material, as described by DONNER and JUNGNER (1974). The latter hypothesis is preferred because of the great difference of levels between the ancient continental shelf and the lagoonal-lacustrine deposit in question. The presence of Chenopodiaceae pollen grains (more than 10%) in zone E and that of the *Hemicystodinium zoharvi* indicate at least a slight brackish tendency (ROSSIGNOL, 1969) which could be due either to a sudden transgression after a period of stable level or to a slight regression which probably caused local incision to about 20 m deep. A rapid oscillation may also have occured about then because of the occurence of the fresh water bed sited above (9800 BP), and because of the pattern of the smoothed Holocene transgression curve showing a very rapid increase with inflections. Thus, we have to accept the recently available results for the Languedocian lagoons area.

Zone F belongs to Würm times.

Following the rapid saline incursion the brackish influence recurs, as evidenced by *Hemicystodinium*

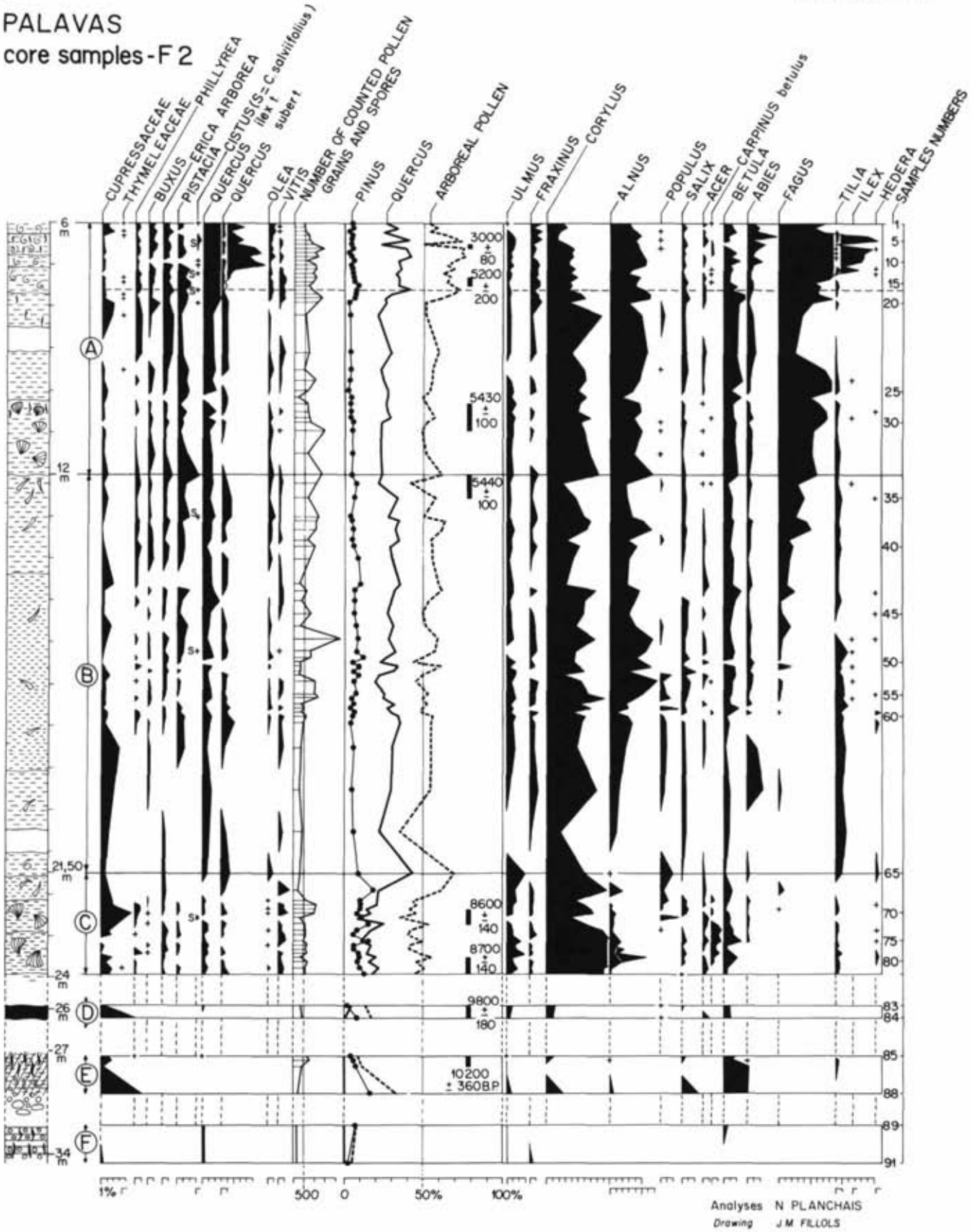

FIGURE 6. Pollen diagram of Palavas. All percentages were calculated on the total number of pollen and spore samples counted.

Diagramme pollinique de Palavas. Tous les pourcentages ont été établis sur l'ensemble des grains de pollen et des spores comptés.

zoharyi, with few Chenopodiaceae, in sixteen consecutive samples from — 24 m to 21.5 m. Radiocarbon dates of 8600 ± 140 and 8700 ± 140 years BP support the palynological assignment to the Boreal. True lagoonal sedimentation appears clearly at −20 to −21 m as shown by a rapid increase of Chenopodiaceae and abundant Hystrichosphaerids, including mainly *Lingulodinium machaerophorum* with *Spiniferites bentori, Spiniferites ramosus* and *Operculodinium centrocarpum*. Fine muddy sedimentation almost without shell prevails over increasingly larger areas during the Atlantic, as after inferred from palynological data. This agrees with the marine level of that period when offshore from Palavas at 8230 ± 180 years BP a large offshore bar, now at −30 m, existed (ALOÏSI *et al.*, 1975).

Greatest rate of infilling at Palavas seems to have occured from −12 m to −8 m during the five centuries between 5440 ± 100, 5430 ± 100 to 5200 ± 200 years BP. Those relatively consistent dates correspond to an average of 10% of *Fagus* pollen and could reflect a different locus of rapid fluvial sedimentation that may have borne locally derived materials with shell and pollen.

The onset of the Subatlantic is recorded at around −6.5 m by a maximum of *Fagus* to 15% with a date of 3000 ± 180 years BP. This fact corresponds to an expansion of Beech-forest in the mountain hinterland, but a marine fluctuation may also be inferred (see 3).

2. SÈTE (THE CANAL DES QUILLES)

A trench opened during the building of the Canal des Quilles (marinas) to the west of the town of Sète (Fig. 1) revealed the following lithological sequence (Fig. 7): a) at the bottom, around −3.5 m: coquina and sand-stone-like nodules (1st level); b) at around

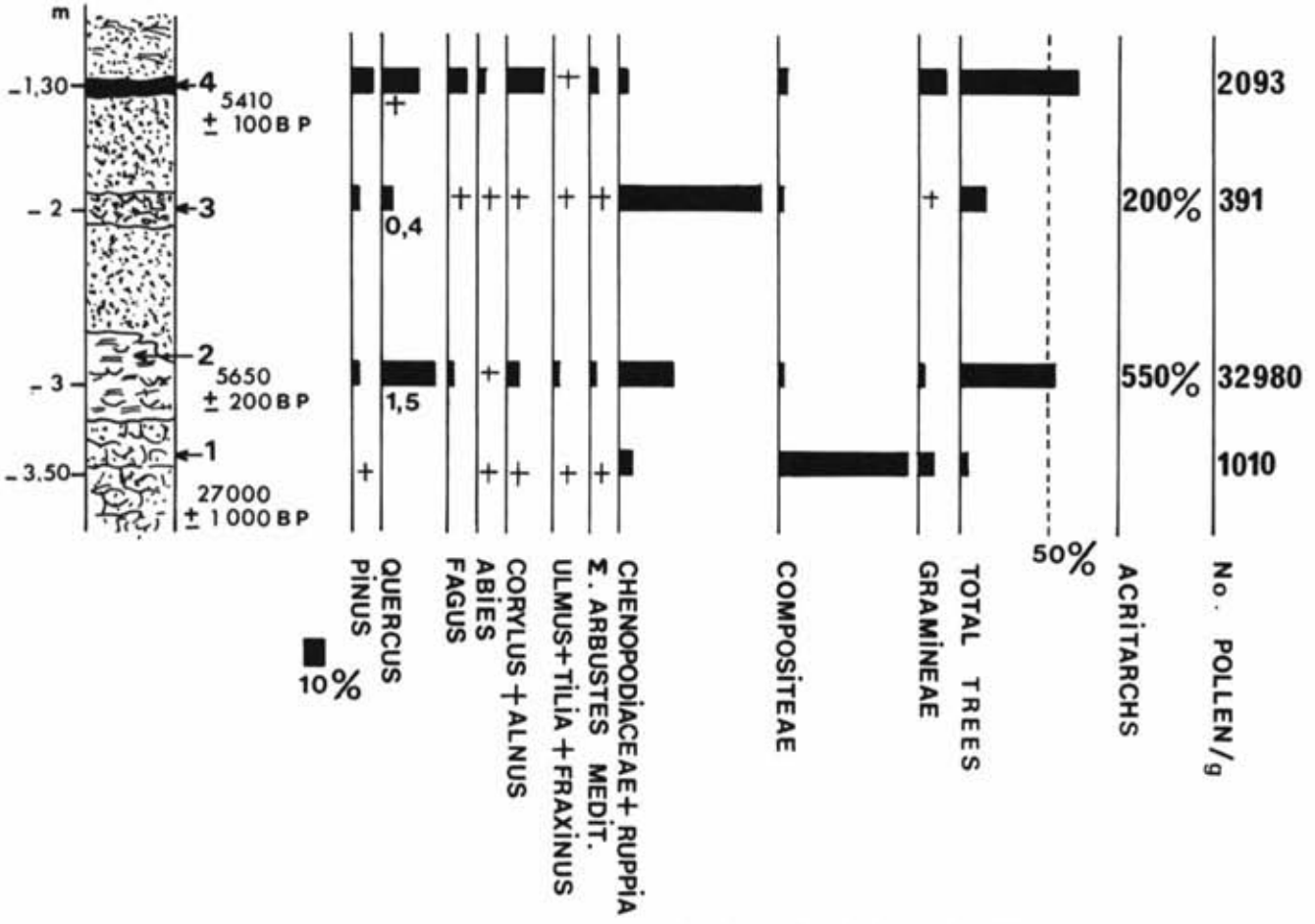

FIGURE 7. Simplified palynological results obtained on dated samples (not taken on the same level) of a section in the area of Canal des Quilles near Sète.

Résultats palynologiques simplifiés obtenus dans les échantillons datés (mais non pris sur la même verticale) d'une coupe relevée dans la zone du canal des Quilles, à Sète.

−3 m: grey mud, plastic, with shells (2nd level); c) from −2.5 to 1.3 m: fine grey sand with gravelly lenses (3rd level; d) at −1.3 m: an organic layer (4th level); e) at the top: grey sand with clay lenses.

Cardium sp. in the coquina (1st level) gave an age of 27,000 ± 1000 years BP. However, because of the much younger dates in all other comparable sequences and the distinct possibility of contamination, we are rather reluctant to assign a Würm age, even if the biostratigraphic pollen data strongly suggests it.

The second level dated from 5650 ± 200 years BP undoubtedly has the most palynological significance (Fig. 7). A deciduous *Quercus*-forest is strongly indicated although pollen of *Quercus* ilex type amounts to only 1.5% and that of *Quercus* suber type to 1.8% while *Fagus* reaches 2%. The indicators of halophytic biotopes (Chenopodiaceae, 30% and "Acritarchs" *cf.* Michrystridium, 50%) probably represent a regressive lagoonal facies. Pollen analysis of the upper level (3) confirms this influence because of the association of 47% Chenopodiaceae pollen with 33% *Ruppia* pollen, signifying hypersaline water in a lagoonal environment.

The sample (4) dated from 5410 ± 100 years BP contains about 10% of *Fagus* pollen, as do the muds at Palavas of the same average age.

3. MARSILLARGUES (ÉTANG DE MAUGUIO)

(Coordinates: X, 742,67; Y, 145,35; Z, 0,5 m)

At the edge of the slight-brackish lagoon near Mauguio cores at Marsillargues penetrate six levels much richer in shells than the other muddy deposits (Table III). Man's presence is indicated near the base of the boring, as early as 4760 ± 100 years BP. Here, the maximum of *Quercus* ilex type occurs between 4760 ± 100 years BP which agrees with all other data on the French Mediterranean plains and hills (Bibliography in PLANCHAIS *et al.*, 1977b). The maximum of *Fagus* takes place at 3200 ± 100 years BP during the Late-Subboreal as at Palavas. A marine influence, dated around 4000 to 3000 BP, is shown by a relative increase in the Hystrichosphaerids at −5, −5.5 and also at −3.5 m which corresponds to a location about 4 km beyond the present shore. Core-samples from −5.5 to −3.5 m also show an increase of the total amount of the tree-pollen content as at Palavas (from −7.5 to −6.5 m and between 5 200 ± 200 years BP and 3 000 ± 80 years BP). For the moment, these seem to be palynological criteria to characterise a transgressive oscillation by means of an increase in tree-pollen coupled with a decrease in sea-shore vegetational pollen. In such a case, pollen assemblages of Chenopodiaceae + Compositae + Graminae + Cyperaceae, signifying a flooded environment, can tolerate only very low levels of salt.

4. RECAPITULATION AND CONCLUSIONS

Comparision of four published palynological sites in Languedoc enables us to identify the following pollen-assemblage zones from our study of lagoonal deposits:

a) Graminae + Compositae (Liguliflorae) + *Ephedra* (*E.* distachya type present) + a little amount of *Pinus*, in two sites: Sète (core-samples 1F; PLANCHAIS,

TABLE III

Core No.	Lab. No.	Present height below sea level (m)	Material	^{14}C age yr BP
PALAVAS				
6 — 7	MC-1311	− 6.60 — 6.70	Shell remains	3000 ± 80
14 — 15	MC-1312	− 7.38 — 7.55	" "	5200 ± 200
27 — 31	MC- 978	− 10.30 — 10.90	Cardium	5430 ± 100
33 — 35	MC-1175	− 12.00 — 12.55	Shell remains	5440 ± 100
69 — 72	MC-1176	− 22.35 — 22.70	" "	8600 ± 140
79 — 82	MC-1177	− 23.50 — 23.90	" "	8700 ± 140
84	MC- 979	− 26.00 — 26.20	Peat fragments	9800 ± 180
85 — 87	MC- 980	− 26.90 — 27.30	Vegetal remains	10,200 ± 360
MAUGUIO				
12 — 13	MC-1404	− 2.35 — 2.55	Cardium and shell remains	1300 ± 60
16 — 17	MC-1405	− 3.10 — 3.30	" "	2270 ± 70
20 — 21	MC-1406	− 3.90 — 4.10	" "	2800 ± 90
26 — 27	MC-1407	− 5.10 — 5.30	Cardium	3200 ± 100
31 — 32	MC-1408	− 6.10 — 6.25	"	4460 ± 100
38 — 39	MC-1314	− 7.50 — 7.75	Mixed shells	4720 ± 100
" "	MC-1315	− " "	Cardium	4760 ± 100

1973) at around −7 m of freshwater character and Palavas at around −27 m, of slightly brackish character; the time probably corresponds to the Preboreal or the Late-Dryas period, but possibly the Late-Glacial.

b) *Pinus* + *Ulmus* + *Corylus* + Cupressaceae + *Carpinus betulus*, at Palavas, at around −24 m to −21.5 m, marking the onset of distinct but very slightly brackish; the radiocarbon measurements fix the zones as Boreal.

c) *Quercus* + *Ulmus* + *Tilia* + *Abies* + *Corylus* + *Alnus* + Chenopodiaceae, at Palavas (and partly near Sète) at around −21.5 to −12, now quite brackish and open to the sea; the biostratigraphical correlation and dates on the top layers give ages spanning much of the Atlantic.

d) *Quercus* pubescens and ilex types + *Fagus* + indicators of Man's activity + Chenopodiaceae, at Palavas, Sète and Marsillargues, at around −12 m to − 6 m (the top layers were not analysed), −1.3 m to the top and −7.5 m to the top respectively in the three sites, indicating a brackish, somewhat closed environment; the radiocarbon measurements indicate an age ranging from the Late-Atlantic to the Subboreal and from the Subatlantic until the early Middle-Ages.

Pollen analysis of the lagoonal deposits corroborate the radiometric dates on shells which indicate the ancient biocoenoses of muddy layers between the towns of Sète and La Grande Motte along the Languedocian coast. These facts are particularly consistent for the last five millenia for which numerous paleobotanical reference data substantiate the validity of radiocarbon measurements in euryhaline environments. In all, biostratigraphical as well as radiometric results give consistent indications of the character of the Early and Middle-Holocene, owing to the interpretative limits and the probability range.

VI. SYNTHESIS AND DISCUSSION OF THE RESULTS

1. ESTABLISHMENT OF A CURVE PLOTTING THE RISE OF THE HOLOCENE SEA

This construction takes into account several factors (Fig. 8): a) the location (letters P, N, A, Q, etc); b) the geomorphic setting (signs **O**, △); c) the environmental conditions: the lenght of the dashed-line above each point, corresponding to one or more radiocarbon measurements, depends on the theoretical depth of sedimentation, this latter being inferred from the facies.

In the Mediterranean, the sedimentary facies which form the recent epicontinental prism are disposed according to a clear zonality (ALOÏSI *et al.*, 1972; ALOÏSI, 1973) which can be superposed with a fair amount of precision to the bathymetric stages defines by the biologists (PÉRÈS and PICARD, 1964). The constant characteristics of this zonality recognised throughout the whole Golfe du Lion and the northern spanish precontinent greatly facilitates our reconstruction.

The curve, traced between the various points, although smoothed, does not obscure the role of certain factors. For example, the points for Port-la-Nouvelle (N) remain apart from the curve. This effect can be ascribed to a change in the mean value of the grain size distribution (displacement of finest sand deposits offshore) due to the sheer limestone cliffs bordering the former shore of Cap du Roc and Cap Romarin.

For the points Palavas (P) and Mauguio (M) which have been the object of detailed pollen analysis (PLANCHAIS *et al.*, 1977a) no inference to former sea-level position has been made, because the majority of the samples are sediment deposited in lagoonal environment. In particular, in the euxinic environments the lagoonal deposits occur in shallow water; the depth of the studied levels deduced by their position in relation to the curve (2 to 10 m) is completely in agreement with the actual bathymetric conditions in the lagoons along the Languedocian coast and the palynological facies. However, the work is not yet advanced enough to permit recognition of small fluctuations that probably interrupted the general transgression. For this reason only the general features may be compared with other studies. TERS (1973), for example, on the basis of palynological and pre-historical criteria recognised seven sea-level maxima since 8200 years BP, with a periodicity of about 1000 years. If similar fluctuations occured in the Golfe du Lion they would explain the scatter of indicators presented here.

Apart from this possibility, it can be noted that there are some discrepancies attributable to methodology, and certain others which are best explained by reworking that occurs during construction of off-shore bars like that of Port-la-Nouvelle and those at Agde and Sète. These moreover often implie a certain period of stable sea-level.

The correlation between our data and that of other authors (BONIFAY, 1971, 1973; de LUMLEY, 1976; VIGNEAUX, 1973) for Mediterranean and Atlantic coast sites is more or less satisfactory depending on whether or not they have considered faciologic and morphologic factors,

Lastly, other sources of scatter include isostatic movements as yet unsubstantiated in the Languedocian area. For the related period, diastrophism does not appear to be the cause of the possible lack of correlation. When considered on the full plio-Quaternary time scale, the bottom subsidence of the whole region of

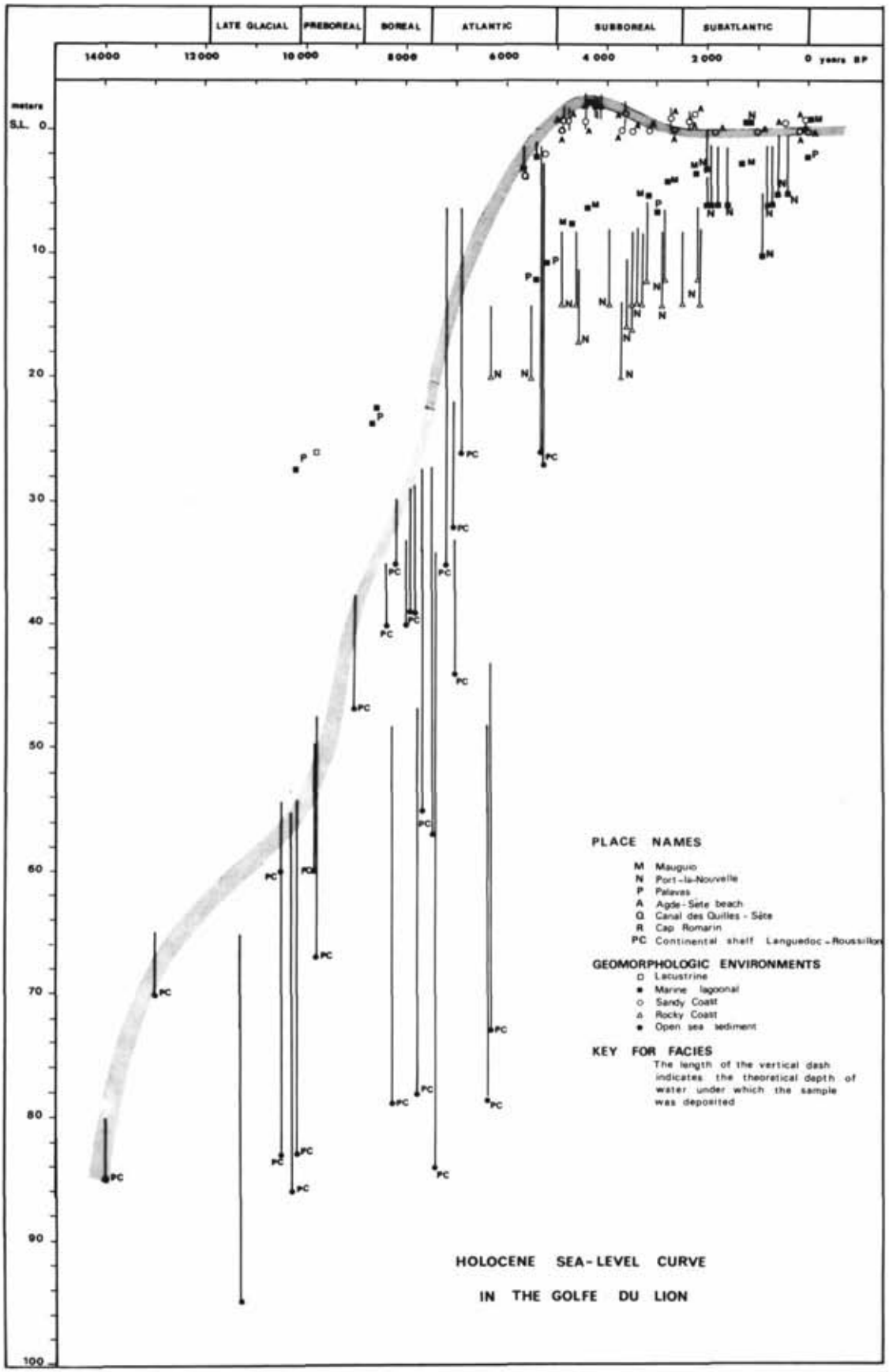

FIGURE 8. Holocene sea-level curve in the Golfe du Lion. *Courbe de remontée de la mer holocène dans le golfe du Lion.*

the Golfe du Lion may have been appreciable, but it may be neglected in relation to subsiding movements of the littoral zone during the last few millenia.

2. CAUSES OF THE HOLOCENE TRANSGRESSION AND ITS SEDIMENTARY CONSEQUENCES

The configuration of the curve, as given by marine and subaerial features reveals several aspects of the Holocene transgression.

- The average rate, beginning at 80 cm/100 y after 14,000 BP, accelerated between 8000 and 6000 BP to 140 cm/100 y.
- Two marked inflections between 12,000 and 8000 BP correlated with the formation of the nearshore bars submerged deltas of the ancestral Rhône on the continental shelf.
- Sea-level position changed relatively little since 4000 BP except for slight variations, until recent historical times (VERDEIL, 1970; PIRAZZOLI, 1976).
- A higher than present sea-level stand at approximately 2 m *ca.* 4000 to 5000 BP in the western Mediterranean is almost proved. The palynological results are in agreement with the average age of 5200 and 3000 BP for the maximum when considerable tree-pollen entered the marginal coastal area.

An high-standing sea-level, though, in relatively inactive margins remains questionable. In the Atlantic coastal area, TERS (1973) and VIGNEAUX (1973) do not recognise a stand above the present level. On the basis of many such occurences, FAIRBRIDGE (1976) fixes two levels at around 5000 and 4000 BP with an intervening regression at 4500 years BP. Recently, ÉLOUARD *et al.* (1977) presented results from the Senegal coast which compare with ours and those in the Camargue (BAZILE, 1976).

Palaeoclimatic inferences based on $^{18}O/^{16}O$ ratios corroborate the eustatic behaviour; a rapid rise in the isotopic temperature between 10,000 years varies with the rate of Holocene transgression. The aggradation of up 20-40 m is comprised of a series of sedimentary prisms on lapping towards the coast (ALOÏSI *et al.*, 1977a). These structures suggest that the transgression was an episodic series of sudden positive changes followed by intervals of relative stability accompanied by coastal progradation. This evolution explains the sequence of lithozones.

Additional factors intervene to modulate these events. The relative rate of the eustatic rise influences the preservation of the strata. It was during warm and humid periods, such as the Atlantic, that the greatest embankment is recorded. Sedimentation is, of course, dependent on sediment influx and on hydrodynamic vigor. In the Golfe du Lion, areas proximal to the Rhône debouchment record up to 45 m of Holocene deposits, Roussillon, fed by the coastal river is covered by 10 to 20 m of post-glacial mud. In all cases, maximum sedimentation in infra-coastal areas results from decreasing turbulence and attendant floculation (ALOÏSI and MONACO, 1975).

Lastly, morphology inherited from the regressive phases had an equally important role and conditions the paleogeographic features of the Holocene evolution (ALOÏSI *et al.*, 1975). Thus, in essence, marine incursion began in the Atlantic period (MONACO, 1971, 1976; PLANCHAIS *et al.*, 1977a) first on the rias cut by the coastal rivers (Lez, Aude, Agly, etc.) during regressive periods. After the filling of the lagoons and the slight regression following the maximum at 4500 BP (subject to the usual statistical uncertainty) there was a shift to the epicontinental sedimentary prism toward the sea.

We have been able to note during this study, the interaction of various environmental factors such as sediment type rate of sedimentation, granulometric gradients and local geomorphologic setting. The latter continues to determine the ongoing construction of the modern off-shore bar.

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