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Relative sea-level rise and neotectonic events during the last 6500 yr on the southern eastern Rhône delta, France

C. Vella*, M. Provansal

CEREGE, UMR 6635 CNRS, B.P. 80, F-13545 Aix en Provence cedex 4, France

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Abstract

The analysis of peat formations from the eastern limit of the Rhone delta allows us to follow relative sea-level changes over the last 6300 yr. The curve represents two periods of rapid relative sea-level rise (about 2 mm/yr), the first, between 6295 ± 50 and 4585 ± 45 BP, and then the second, between 2120 ± 55 and 1200 ± 55 BP. These two periods are separated by a period of stability between 4085 ± 60 and 3520 ± 55 BP. The comparison with data from the rocky coast to the east of Marseille indicates a negative difference of between 1.5 and 0.5 m, then rapid adjustment after 2120 ± 55 BP. The existence of an incompressible substrate, along with the thinning-out of the Holocene deposits along the limits of the deltas, restricted the effects of subsidence and compaction. We prefer the hypothesis that tecto-subsident movements account for these differences, as well as the rapid rise in relative sea-level during this second period. This is compatible with the network of post-miocene faults that account for the differences in altitude of the Roman quarries carved-out from the miocene layers.

Keywords: Neotectonic events; Sea level; Peat; Holocene deposits; Rhône Delta

1. Introduction

The presence of first century AD archaeological remains (buildings and warehouses) in the Fos Gulf (Rhône delta) beneath 1.5 m of water raises the question of the role of subsidence and tectonic processes in relative sea-level rise (Liou, 1977). The level of submersion is greater than for other sites of the same age, for example, 0.4 m at Marseille which is on stable, rocky substrate. L'Homer (1991, 1993) suggested that the presence of negative deformations to the east of the delta could explain the general characteristics of the sediments in this area. Using seismic shooting, Gensous and Tesson (1997) have revealed the presence of a pleistocene tectonic fault over the axial zone of the delta.

The aim of this work is to describe the forms and speed of relative sea-level rise to the east of the Rhône delta, based on stratigraphical analyses. A comparison with the speed of sea-level rise measured on the rocky substrate to the east of Marseille (at La Ciotat, Fig. 1) through the study of a bio-indicator (*Lithophyllum lichenoïdes*) should allow us to evaluate and date the distortions. Finally, the interpretation (subsidence or

* Corresponding author. Tel.: +33-4-42-97-15-77; fax: +33-4-42-97-15-49.
E-mail address: vella@cerege.fr (C. Vella).

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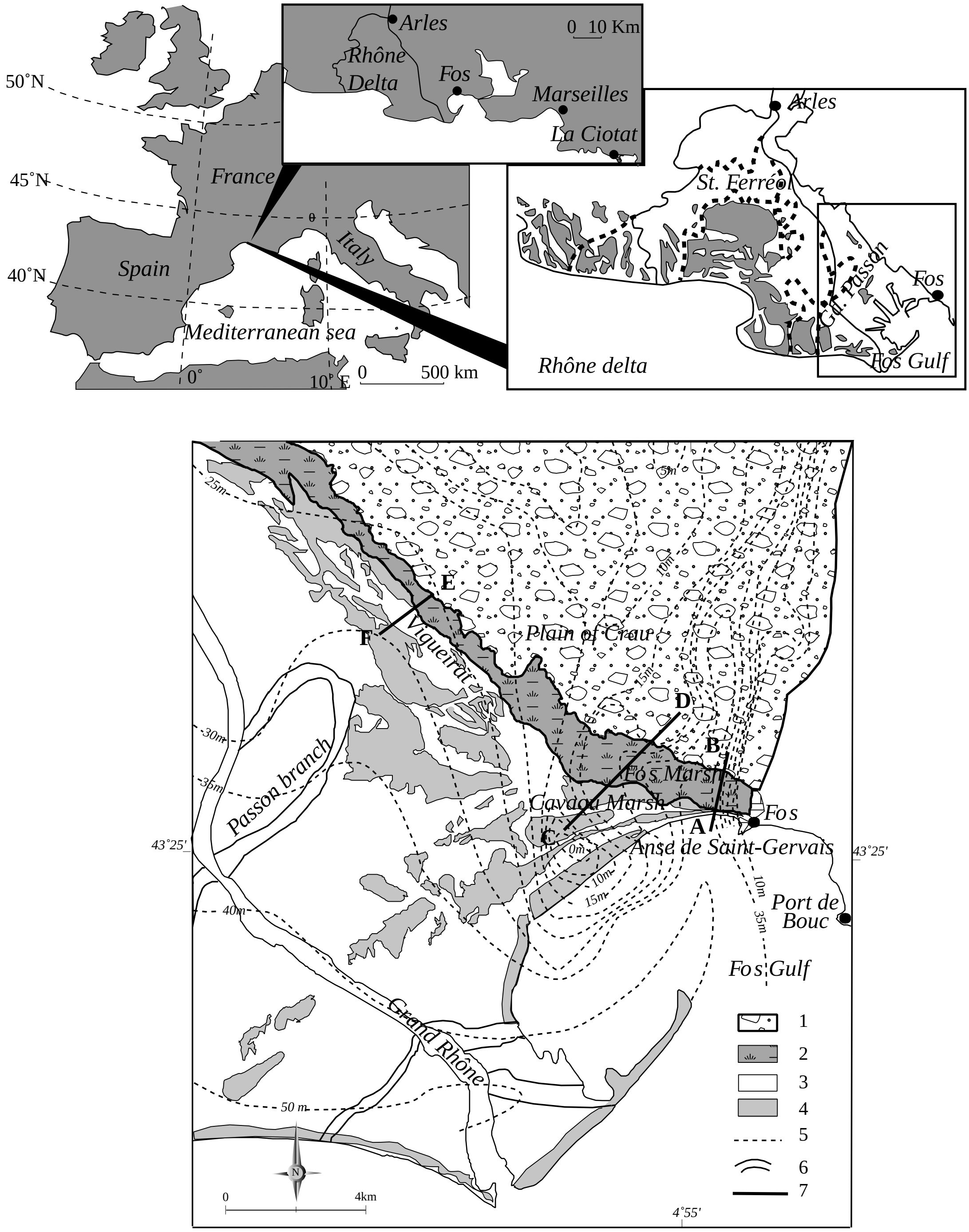


Fig. 1. Location maps of the study and cross-sections. 1: Pleistocene conglomerate; 2: fresh-water marsh and peat bog; 3: lagoonal and salt marsh zones; 4: actual and fossil beach bar; 5: thickness of pleistocene gravels; 6: actual and fossil alluvial channels; 7: cores cross-section.

fault reactivation) will rest on the analysis of the regional structure and the altimetry of the roman quarry levels.

2. The stratigraphy of the sedimentary bodies to the east of the Rhône delta

To the east of the Rhône delta, the holocene deltaic deposits, that thin-out towards the east, lie upon pleistocene conglomerates. The aquiferous stony layers that are in contact with the micro-porous sediments of the flood-plain allow the development of fresh-water marsh and peats (Fig. 1). From 1978, Triat-Laval proposed a link between the rise in the phreatic system, recorded in the holocene peats, and sea-level height.

The stratigraphy, based on 50 new cores that traversed fossilised near-shore peats (−10 m) and went as far as the littoral plain, is briefly described below (Figs. 1 and 2).

At the base of the stratigraphy, the summit of the stoney pleistocene conglomerate slopes towards the south-west at an angle of about 0.5%. It is transgressed to the south by lagoonal units and then by littoral formations (Fig. 2a) that are dated to between 6560 ± 85 (Ly-7021) and 5135 ± 75 BP (Ly-7018). At their summit and along the lateral plain, a first peaty unit developed between 6580 ± 50 BP (Ly-8681) at −6 m NGF and 4825 ± 45 BP (Ly-8150) at −3 m NGF (Fig. 2a–c). It forms a retrograding transgressive body that records the rise in the water-table in turn induced by the rise in sea-level. This layer usually sits upon the pleistocene conglommerate, or locally, on lacustrine low content carbonate, marls (0.1–0.2 m) with a fresh-water fauna (Triat-Laval, 1978). Marine and lagoonal-marine sands then covered this unit.

A second peat unit dated to between 4825 ± 45 and 3520 ± 55 BP (Ly-7862) of 10–20 cm, partially caps these earlier deposits and is interbedded within the alluvial formation. This layer progrades towards the south between −3 and −1.8 m NGF. Its development implies the presence of an offshore bar for which there is no sedimentary record. To the south-east, two sandy littoral formations (from near-shore to emerged beaches) transgress the upper level of these peats and have been dated to between 2110 ± 140 (LGQ-744) and 1530 ± 45 BP by radiocarbon dating, and archaeological remains: These units record the continuing rise in relative sea-level (Vella et al., 1998). These layers contain roman remains (walls and warehouses) at between −1.5 and −1 m (Fig. 2a). On the deltaic-plain to the north (Fig. 2c) lagoonal and the fluvial deposits that are associated with the Rhône floodplain's progradation top the peat levels.

3. Sea level rise and methodology of study

Fresh-water peat is often found in stratified deposits on coastal plains. Their development affects coastal bars and salt-water lagoons which is related to the rising of the groundwater level, a consequence of Holocene sea-level rise (Baeteman, 1991; de Groot and de Gans, 1996). In particular, they are related to the slowing down of this transgression from about 6000 BP onwards (van de Plassche et al., 1989; Stanley and Warne, 1994; Jelgersma, 1994). After having been characterised as fresh-water peats, thanks to the analysis of the plant-macrofossils and the pollen, we were able to follow the variations in relative sea-level and take into account the effect of compaction. (Jegerlsma, 1961; van de Plassche, 1982; van Dijk et al., 1991; Denys and Baeteman 1995; Törnqvist et al., 1998; Allen, 1999). Most of these other studies concern Atlantic macro-tidal coastal zones. More recent work has revealed the utility of these formations in the Mediterranean (Stanley and Warne, 1994; Dubar and Anthony, 1995; Bellotti et al., 1994), and likewise, sea-level rise related to rising of the water-table is reflected in the peats found on the eastern limit of the Rhone delta.

In the Fos Gulf, the variation in relative sea-level has been measured based on the dating of 23 samples taken from the basal layers of peat deposits that are generally sat upon the stony Pleistocene substrate. The stony substrate is considered as being incompressible (Colomb et al., 1975). The level of incertitude regarding these levels is considered through the study of modern peat surfaces.

3.1. Modern references: peat development and sea-levels

The surveys of modern flora carried out prior to the industrialisation of the 1970s shows that the area was

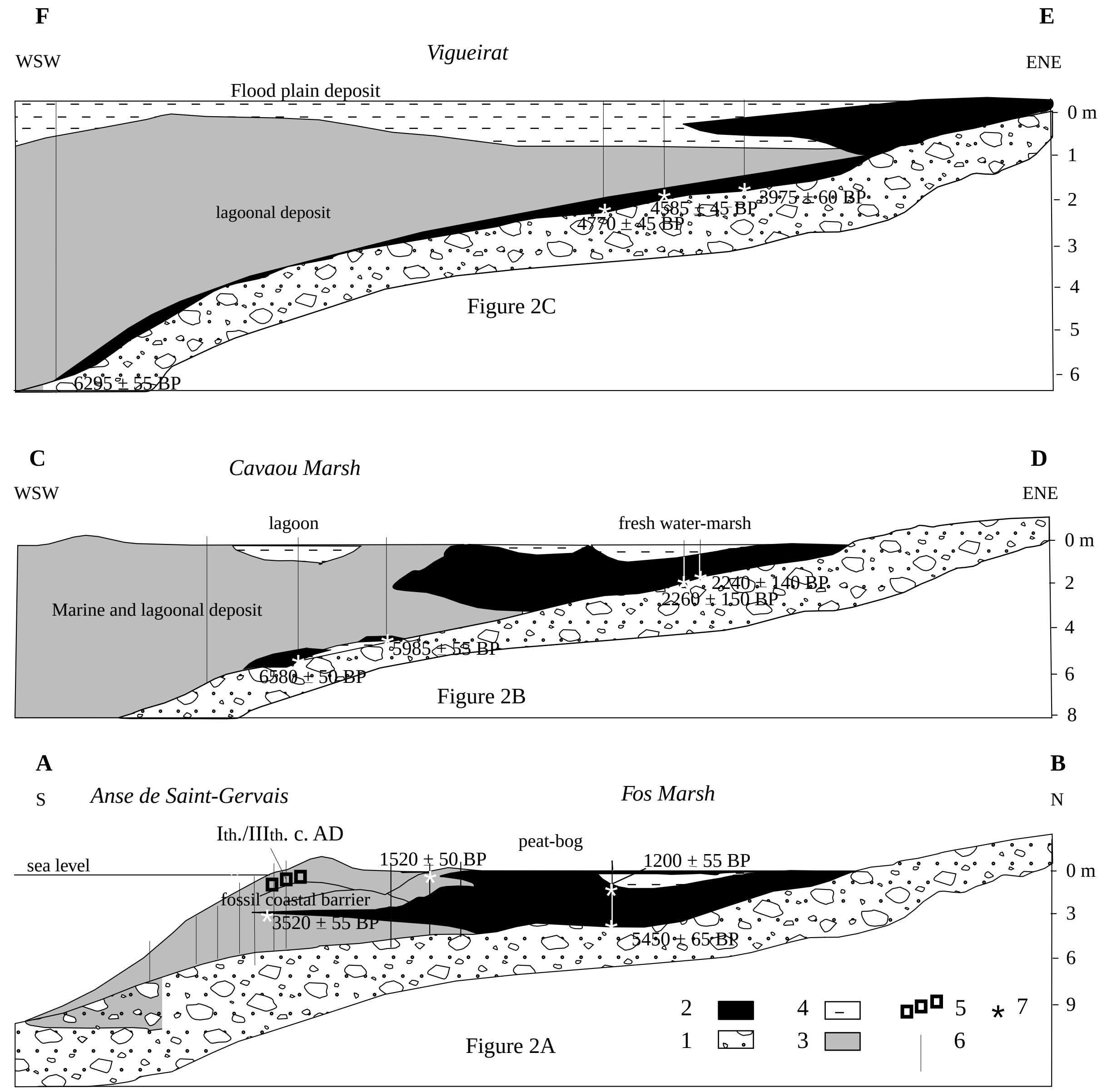


Fig. 2. Cross sections over the eastern part of the Rhone delta deposit lithostratigraphy after core-observations by the autors and the report of the Port Autonome de Marseille (1970). 1: Pleistocene conglomerate; 2: peat deposits; 3: sand; 4: clay and silt; 5: archeological structures; 6: cores; 7: position of ^{14}C date.

dominated by wet prairie herbaceous species (*Holoschoenus vulgaris, Molinia coerulea, Schoenus nigricans, Claudium mariscus*), with Phragmites communities around the etang's edges (*Phragmites communis*).

Palaeo-biological studies were undertaken by Triat-Laval (1978) and de Beaulieu (pers. com.). The abundance of Cyperacae pollen (10–30% of the herbaceous plants), associated with the low Chenopodacae values along with the macro remains (*Holoschoenus vulgaris, Mariscus serratus, Carex acutiformis*) found within these fossilised peats attests to the

Table 1
Peats radiocarbon datation on the eastern Rhône delta and limits of the sea-level in meters NGF. Datations by Centre de datation par le radiocarbone de Lyon, J. Evin and C. Oberlin. Calibrations according to Stuiver and Braziunas, 1993

Sample	^{14}C age	Years BC/AD	δ ^{13}C	Upper limit	Lower limit	Cross-sections	Latitude N	Longitude E
Ly-8447	1220 ± 55	700/965 AD	−28.44	0.73	0.03	A–B	43°26′300	4°56′400
Ly-7591	2100 ± 45	305 BC/2 AD	−27.3	−0.7	−1.4	A–B	43°26′180	4°56′500
Ly-7860	2120 ± 55	342 BC/0	−28.36	−0.9	−1.6	A–B	43°26′100	43°56′500
Ly-1493	2240 ± 140	733 BC/43 AD	Estimated −25	−1.35	−2.05	C–D	43°28′800	4°52′200
Ly-1494	2260 ± 150	747 BC/46 AD	estimated −25	−1.43	−2.13	C–D	43°28′800	4°52′200
Ly-7862	3520 ± 55	1964/1702 BC	−26.73	−1.8	−2.5	A–B	43°25′900	4°56′240
Ly-5249	3735 ± 75	2385/1928 BC	estimated −25	−2.5	−3.2	C–D	43°25′920	4°56′
LGQ-1059	3750 ± 190	2853/1674 BC	estimated −25	−2.15	−2.85	A–B	43°25′900	4°56′
LGQ-1055	3760 ± 170	2615/1689 BC	estimated −25	−2.13	−2.83	A–B	43°25′880	4°56′
LGQ-1057	3780 ± 180	2856/1689 BC	estimated −25	−2.24	−2.94	A–B	43°25′860	4°56′
Ly-8020	3975 ± 60	2617/2297 BC	27.57	−1.89	−2.59	E–F	43°30′500	4°48′400
LGQ-1064	3990 ± 210	3033/1891 BC	estimated −25	−2.13	−2.83	A–B	43°25′860	4°56′
Ly-7592	4085 ± 60	2858/2483 BC	−27.67	−1.8	−2.5	A–B	43°26′	4°56′
Ly-1496	4450 ± 300	3807/2294 BC	estimated −25	−2	−2.7	C–D	43°26′860	4°52′450
Ly-8731	4585 ± 45	3488/3112 BC	−27.73	−2.05	−2.75	E–F	43°28′650	4°52′200
Ly-8621	4755 ± 50	3635/3383 BC	−27.21	−2.3	−3	E–F	43°30′450	4°48′380
Ly-8670	4770 ± 45	3638/3388 BC	−26.71	−2.88	−3.58	E–F	43°31′	4°48′200
Ly-8150	4825 ± 45	3690/3414 BC	−27.6	−3	−3.7	A–B	43°25′900	4°56′300
Ly-7081	5135 ± 75	4138/3767 BC	−27.25	−3	−3.7	A–B	43°26′080	4°55′860
Ly-8446	5450 ± 65	4452/4106 BC	−27.42	−3.9	−4.6	A–B	43°26′300	4°54′
Ly-364	5600 ± 150	4774/4094 BC	estimated −25	−4.37	−5.07	C–D	26′800	4°52′450
Ly-8218	5986 ± 55	5005/4763 BC	−27.09	−4.76	−5.46	A–B	43°27′	4°54′300
Ly-8671	6295 ± 50	5315/5089 BC	−27.49	−5.68	−6.38	E–F	43°30′	4°47′800

non-halophytic nature of the vegetation. The soft-water fauna (*Lymnosa stagnatus, Pseudammicola similis, Galba sp., Succinea oblonga, Planorbis carinatus, Gyralus cf. laevis* and *radix (radix) limosa*) confirms the fresh-water characteristics of this environment. Since 6500 BP there has been a relatively small change in the composition of the vegetation.

The peat corresponds to a state of equilibrium between the water-table's output and the sea-level. Increase in the output of freshwater transforms this sedimentary-environment into a permanent lagoon with "chalky" facies. We can thus reduce the role attributed to the modifications caused by rapid climate change. The present top surface of these peats, employing the exact ecological criteria, is between 0.1 and 0.7 m NGF, this being between 0 and +0.6 m above the present sea-level (Guery et al., 1981). This margin of error was taken into account for the analysis of the fossil peats, whose ecosystem was identical to that of their modern counterparts. The fossilised peats are thus considered as reliable markers of successive sea-levels.

Engineering tests carried out on the site prior to industrialisation demonstrate the fact that both the modern and fossilised peats here posses low compaction potentials (36–45%, Port Autonome de Marseille, 1971) compared with those from along the french Atlantic coast (90%, Prigent, 1981). Our own compaction tests on the fossilised peats (250 g/cm^2) confirm their low compaction potential. The highest level of 45% will thus serve as a reference for our calculations of heights of samples that are not sat upon the stony pleistocene substrate.

3.2. Samples and dates

The whole of the chronostratigraphy relies on 48 radiocarbon dates: The 23 dates obtained from the peat are exploited here (Table 1). The remaining 25 come from the littoral formations (shells, marine phanerogams, wood) and confirm the overall organisation of the stratigraphy (Vella, 1999). Of the 23 dates taken from the peats (Triat-Laval, 1978; Vella et al., 1998), 14 new dates were obtained using the

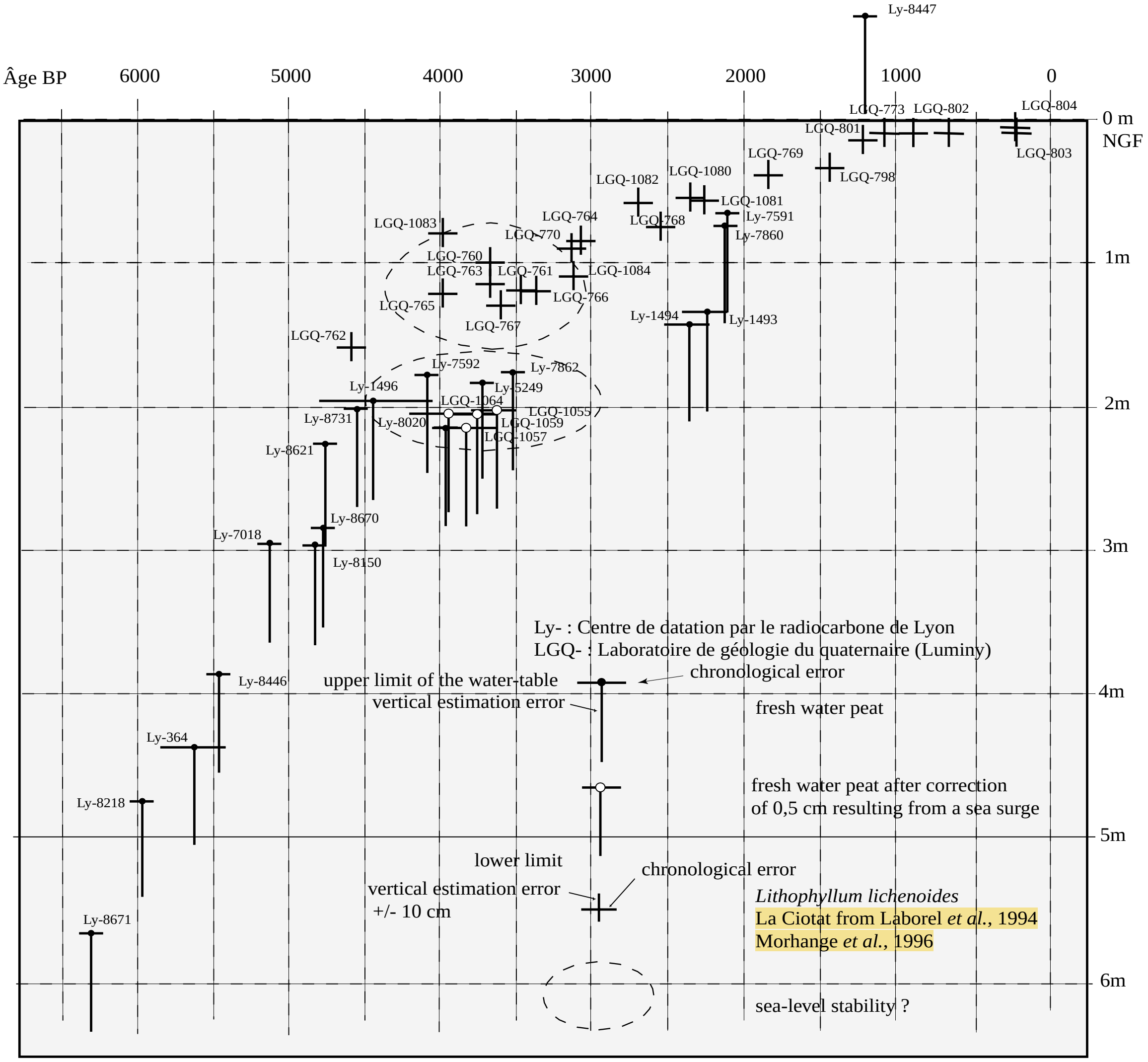


Fig. 3. Comparison age/altitude diagrams of the sea-level in the Rhône delta with biological data from La Ciotat.

conventional method at the *Centre de Datation Radiocarbone de Lyon* (code Ly-).

For the trenches excavated with the mechanical digger, a 1 cm thick sample was taken in order to limit dating errors caused by sampling, whilst between 2 and 4 cm worth of sediment were taken from the cores in order to obtain enough organic material. Vella (1999) has demonstrated that the rate of peat development is of the order of 0.1 cm/yr; therefore, a layer 4 cm thick represents about 60 yr.

The 23 samples of dated peat, with the sole exception of Ly-8447, come from the basal layers. The lie upon coarse detritus formations that are considered to be incompressible (20 samples on pleistocene stones, two on littoral sands of 2 m maximum).

The levels of $\delta^{13}C$ found in these samples were between 28.44% and 26.71%, which is characteristic of continental environments. Nine dates that have been published already in previous work (Triat-Laval, 1978) were re-used applying a correction based on a standard rate of 25%.

4. Results

4.1. Age/altimetry diagram

The curve is founded on 23 dates from the basal-peats (Table 1). The age/altimetry diagram based on the dated levels (Fig. 3) reflects the elevation of the water-table as related to sea-level. The margins of error for the dates, the altimetric measurements (0–0.6 m), are all integrated into the diagram. The compaction levels are also taken into account for the sample Ly-8447. Between 6295 and 4085 BP the water level rises from −6 to about −2 m NGF. The points line up on a uniform slope. Between 3990 and 3520 BP the water-level becomes stationary towards −2 m NGF (including the margins of error) for more than a millennia (calibrated data). The four dates obtained from cores taken at sea (represented by white circles on Fig. 3) come from the 0.5 m level in order to adjust for any sea-surge effect indicated in September 1992 by the tide-gauge. This correction is confirmed by the date obtained from the same altitude 10 km to the north. Between 2260 and 1200 BP, the level rises by about 1.5 m. The spacing between the points is greater, and their distribution is less uniform than in the lower part of the diagram, thus detracting from the resolution of the tendency.

4.2. The statistical analysis of the data

Two periods of rapid sea-level rise are thus separated by a period of stability. This general form of the distribution can be modelled by two linear regressions, excluding the period of stability, that allow us to estimate the theoretical speed of the rise in sea-level. A linear or non-linear regression over all or a portion of the curve would have disregarded the period of stability, which corresponds to a least one millennium (calibrated years) between 4085 and 3520 BP, and at least two millennium if the date of 2260 BP is retained as the upper limit for this period.

The linear regression analysis carried out on the data series fulfils the conditions for statistical validity (Fig. 4); a large part of the information bring accounted for by the model (expressed in the value of $R2$), which is greater than the correlation coefficient threshold (r) defined by Bravais and Pearson for an error of 2%. Taking this distribution of points, that is both linear and sloped, we propose to divide them into two groups: between 6295 and 4450 BP, and then, between 2260 and 1200 BP.

The first part of the curve between 6295 (Ly-8671) and 4450 BP (Ly-1496) is characterised by a strong slope and points that are regularly and perfectly aligned. For the 10 points that comprise this series, the determination coefficient value is very high ($R2 = 0.96$), whilst the correlation coefficient ($r = 0.98$) is quite clearly higher than the threshold of significance ($r > 0.71$). Based on the equation, the speed of sea-level rise is 2 mm/radiocarbon year. The slope of the curve measured to the east of the Rhone delta is comparable to those from other Mediterranean curves (Labeyrie et al., 1976; Aloisi et al., 1978; Dubar and Anthony, 1995) even if the others do not posses the same resolution and precision.

The second part of the curve, between 2260 and 1200 BP is calculated with only five points, but the statistical validity conditions are well respected, taking into account the high correlation coefficient of 0.96, whilst the correlation coefficient ($r = 0.98$) is higher than the significant threshold of ($r = 0.93$). The average rate of sea-level rise here is 1.9 mm/radiocarbon year.

4.3. Comparison with the Lion gulfs curves

The curves from the Golfe du Lion confirm the measured speeds up until 4440 BP (Labeyrie et al., 1976; Aloisi et al., 1978; Dubar and Anthony, 1995), but their chronological and altimetric resolution do not allow a comparison with the upper part of the curve. Only the curve produced by Laborel et al. (1994); Morhange (1994); Morhange et al. (1993, 1996) based on biological indicators on rocky substrate offer a satisfying chronological and altimetric resolution.

Fig. 3 deals with results from the eastern edge of the

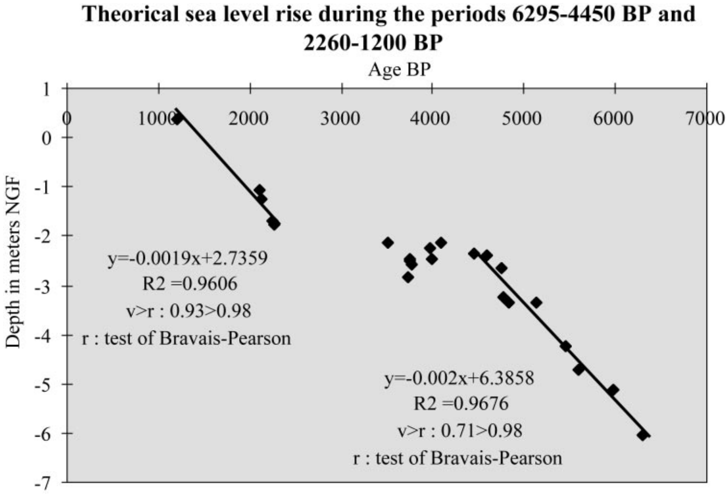


Fig. 4. Linear regression analysis on the peat deposit.

Rhone delta with points established from bio-indicators. The comparison of dates obtained from material from both continental and marine contexts requires that the level of isotopic fractionation be taken into account, which is measured by assessing the ratio of $^{12}C/^{13}C$. Continental vegetation possesses a level of $\delta^{13}C$ between 28.44 and 26.71%. The level of $\delta^{13}C$ was not automatically measured in the samples of *Lithophyllum lichenoides*, which is usually estimated at a level of 0% which obliges us to push-back the dates published by Morhange et al. (1996) by 400 yr. Between 4085 and 1200 BP, we observe a difference in the speeds of sea-level rise and a negative, vertical difference in the points from the Rhone delta of 0.5–1.5 m. The rise in sea-level along the rocky coast was subject to a constant slowing-down for about five millennia: the speed estimated at between 0.4 and 0.3 mm/yr for the period 4500–2500 BP and 0.3–0.15 mm/yr after 2500 BP (Morhange et al., 1993). At Fos, the speeds for sea-level rise are 2 mm/yr between 6300 and 4450 BP, and then 1.9 mm/yr between 2260 and 1200 BP. The speed calculated for the Rhône delta since 2000 BP is therefore superior to all of the other data currently published concerning the Golfe de Lion.

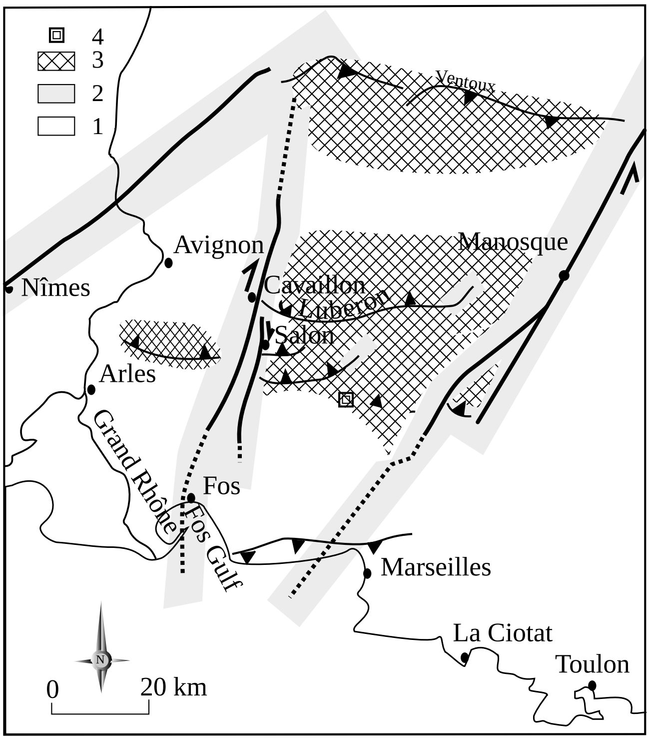
This rapid rise in relative sea-level allows us to reach the levels indicated on the curve produced by Laborel and Morhange. The vertical difference disappears between 2100 and 1200 BP if we take the error level of 0.6 m into account.

5. Discussion

5.1. The impossibility of compaction effects and stratigraphical evidence for a rapid change in relative sea-level in the Rhône delta

The soft nature of the lagoonal and lacustrine deposits along with the sampling methods employed do not allow us to reveal sedimentary indicators such as thixotropy, flow, … within the tectonic deformations.

All the dated levels (except 1) lie on uncompressible substratum (pleistocene stones; holocene littoral sands). Due to the marginality of the study area with regards to the Rhone delta, the holocene sediments are not very thick (1–6 m). The Pleistocene is represented by a coarse stoney layer within an interbedded sandy matrix between 3 and 30 m thick. The conglomerates lie on sandstone and neogene marls, the compaction of which can not explain the sudden reduction in the altitude of the peats after 2260 BP. However, within the study zone, a 30 m thick palaeochannel oriented north-south exists on the limits of the outcropping miocene layers. For the comparative period on the curve produced by Morhange et al. (1996) 9 of the 16 dated points are located on the AB transect vertical to this palaeotopography. The positions of the points need to be discussed. We propose to keep them for two reasons: (1) the reliability of this date is confirmed by its alignment with the other points that



(a)

Fig. 5. (a) Main seismo-tectonic features in the Basse Provence and position of the Fos Gulf from Combes (1984). 1: tectonic stability zone and no or very poor seismic activity; 2: linear transverse fault zone characterised by a rapid but moderate sismicity. The epicentres are localised on the faults; 3: compressive fault zone characterised by several seismic events only but stronger than thoses observed in second zone; 4: earthquake of Lambesc in 1909. (b) Lithostructural map of the eastern Rhône delta and location of archeological quarries. (c) Shematic transect across the Fos Gulf after cores of *BRGM*. 1: holocene deposits; 2: pleistocene deposits; 3: miocene substrate; 4: marine cretaceous substrate; 5: continental cretaceous substrate (*Begudien*); 6: faults; 7: probal faults; 8: cross-section A-B (figure 5c); 9: cores.

have varied geographic provenance (transects CD and EF located beyond the palaeochannel, cf. Table 1); (2) the points on transect AB do not all represent a lowered position.

Sample Ly-8447 is situated at 0.73/0.03 m, at the top of a 365 cm thick peat deposit that has potentially been compacted. But, the presence of a sand bar of the same age that cuts the southern limit of the peat allows us to locate the contemporary sea-level at between 0.75 and 0 m NGF. The marine fauna found within the sandy matrix is typical of a detritic environment where the mid-littoral species are dominant. Considering this level, we estimate the compaction in this sediment to be in the order of 25%. This very low value seems coherent with the vesicular nature of the peat.

5.2. The altimetric differences with the rocky substrates: evidence for the effect of local tectonics

The observed gap can only reveal differences in the visco-elastic response. But the two regions in question are very close to one another and are included in the same model (Lambeck and Johnston, 1995; Pirazzoli, 1997). The discrepancy with the peat from the Rhone delta reveals negative movement in the level of the land that has a local origin.

There are several factors that imply a probable local warping within the rigid substratum along the eastern limits of the Rhône delta (Fig. 5a).

Seismic surveys carried out in the Fos Gulf (Fig. 5b) reveal a steep sloping of the miocene layers as well as the top of the pleistocene stoney sediments towards the south-west, this being related to the

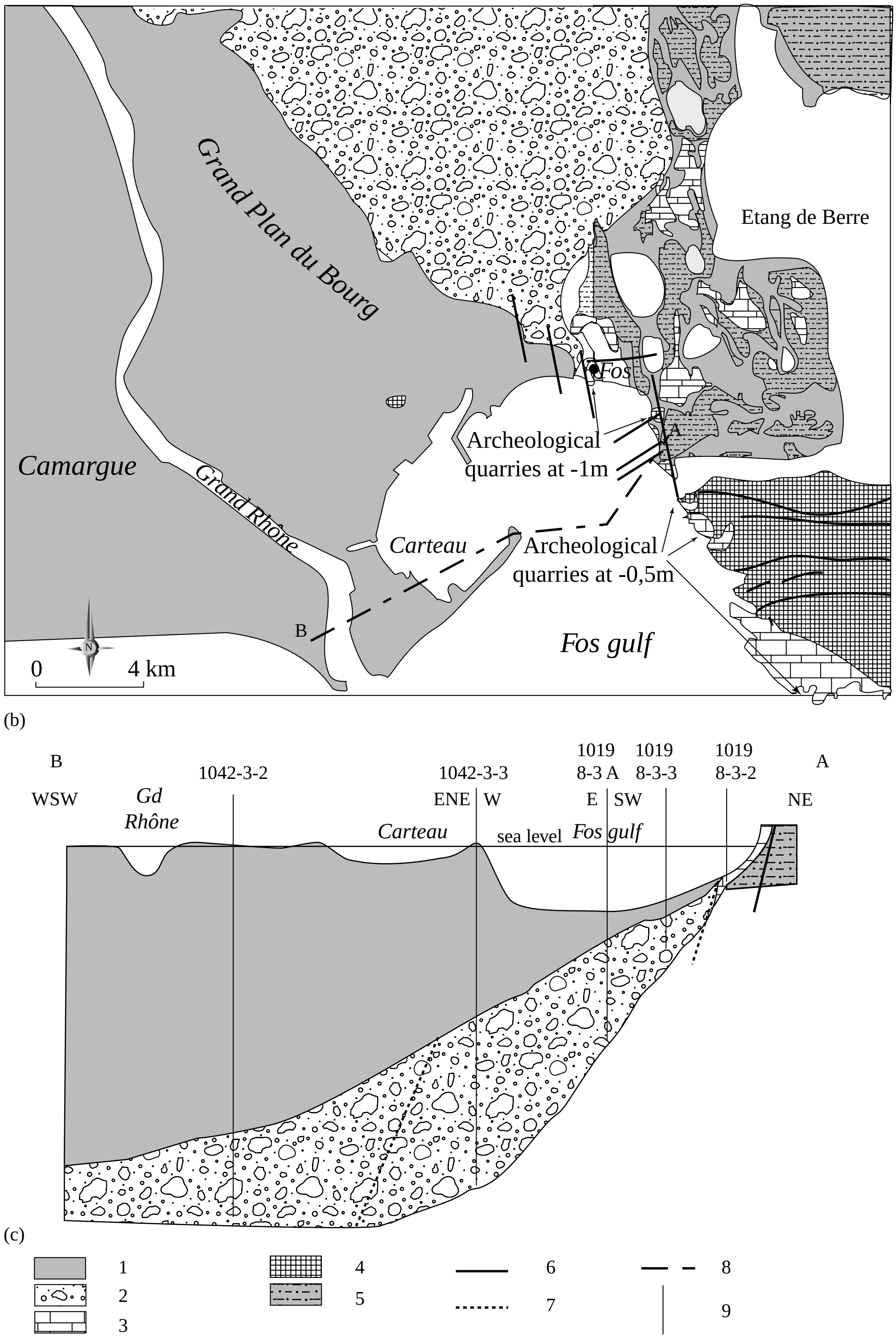


Fig. 5. (*continued*)

north-south faults. Cores show a rapid thickening in the holocene deposits that fill the space left as a result of the lowering of the pleistocene material (Fig.5c). These faults become extended towards the north within the continental area and can be related to the observations made by de Chorowicz and Paul (1974) who link the line of the coast and the Durance palaeotalweg with a group of tectonic faults N 160°.

The Fos Gulf is crossed by one or several major tectonic features (Fig. 5a–c), which are known to have been active during the Pleistocene. To the west, Tesson and Allen (1995), have employed seismic-shooting to demonstrate the presence of a north-south fault aligned with the present course of the Grand Rhône that was active during the Pleistocene. To the north of the Fos gulf, Colomb and Roux 1986 have shown that the pleistocene stoney layers have undergone a certain level of deformation that are related to north-south compressive stresses. These movements can be related to movements within the Salon-Cavaillon right-hand transverse-fault (N 10°); Terrier (1991); Combes (1984); and Peulvast et al. (1998) have revealed pleistocene and holocene activity within this fault using geomorphological indicators. The levels taken here reveal negative movements associated with this fault to the east of Avignon. The dated peat levels are aligned along the edge of the supposed line of this fault.

On the edge of the deltaic plain, the extraction-levels from Roman quarries, gouged out from incompressible Miocene limestone, are 1 m lower than the modern sea-level, whilst just slightly further to the east they are at about −0.5 m above sea-level (Guéry et al., 1981). Therefore, we presume that there is a deformation in the solid-geology along the eastern limit of the Rhone delta.

The acceleration of relative sea-level rise between 2260 and 1200 ± 55 BP would therefore be directly related to a local and rapid negative deformation of an amplitude of between 0.5 and 1.5 m. It is difficult to decide between the possibility of subsidence due to a sedimentary overload, or tectonic movements that were the result of fault reactivation on the edges of the delta. Given the restricted thickness of the holocene deposits and the incompressibility of the underlying sediments, we favour the tectonic hypothesis, especially as the movement is localised both in time and space.

Spatially, we can see the difference in altitude of the roman quarry levels over a distance of 2 km either side of the fault. Finally, this situation explains the abnormal depth of −1 and −0.5 m at which we find the first to third century AD Roman buildings, even though we normally find structures from this period on the French and Italian Mediterranean coasts at about −0.4 m below sea level (Pirazzoli, 1976; Morhange et al., 1993).

Temporally, the comparison of the curves obtained on the rocky coast (Morhange et al., 1996) allow the approximate dating of the “event” to between 2120 (the start of the acceleration of the sea-level in the Rhône delta) and 1200 BP (the end of the difference between the two curves).

The negative deformation in the Fos Gulf allows us to explain why the river branch (Passon branch) on the extreme east of the delta-plain moved towards the east during the fourth century AD (Fig. 1). Despite the increase in the quantity and the average grain-size of sedimentary inputs, the coastline retreated (>500 m) between 300 and 900 AD. The dramatic sea-level rise transformed the coastal peats into a fresh-water pond.

6. Conclusions

The distribution of points and the straight regression lines that represent the rise in relative sea-level, based on the analysis of fresh-water peats, are characterised by irregular speeds in the rise of the water-level: a slowing down between 4085 and 3520 BP, followed by a rapid rise between 2260 and 1200 BP.

When compared with the nearby provençal rocky coasts there is a −1.5 m difference prior to 2260 BP. Even if its dating is still imprecise, only a local and abrupt tectonic event could explain this difference as well as account for the rapid rise in sea-level and the historic palaeogeographical modification. This is consistent with the palaeogeographic evolution of the delta-plain coastline.

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