

Variation of Relative Mean Sea Level During the Last 4000 Years on the Northern Shores of Lacydon, the Ancient Harbour of Marseilles (Chantier J. Verne)

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ABSTRACT

MORHANGE, C.; LABOREL, J.; HESNARD, A., and PRONE, A., 1996. Variation of relative mean sea level during the last 4000 years on the northern shores of Lacydon, the ancient harbour of Marseilles (Chantier J. Verne). *Journal of Coastal Research*, 12(4), 841-849. Fort Lauderdale (Florida), ISSN 0749-0208.

Sediments, archaeological structures and marine paleo-environments unearthed from the northern shore of Lacydon, the ancient harbour of Marseilles, reflect a steady rise of relative sea level (RSL) during the last 4000 years, gradually slowing down to a nearly stable level from about 500 AD on to the last century. This evolution is similar in direction to that previously found along rocky coasts of the same region, but the rise appears to have been more rapid due to local neotectonic action and sediment compaction. No traces of a sea level stand above present datum have been found. The 0.10 m rise of MSL, recorded by tide gauges from the end of the 19th century to present times, appears to be a recent acceleration rather than the continuation of a trend.

ADDITIONAL INDEX WORDS: sea level, geo-archaeology, harbours, Marseilles, France.



INTRODUCTION

The Lacydon, the ancient harbour of Marseilles, is a deep and narrow natural embayment or creek, running east to west and dug into heterogeneous sediments of Oligocene age (conglomerates and sandy marls). It also acts as an estuary for a few coastal rivers and rivulets. The creek is surrounded inland by several steep hills (Figure 1, 2).

Archaeological excavations undertaken on the northern shore of Lacydon (Place Jules Verne), during the years 1993-1994 under the direction of one of us (HESNARD, *in press*) produced a series of new paleo-bathymetrical data which we compared with dates previously obtained from submerged algal constructions of *Lithophyllum lichenoides* developed on the rocky coasts of the same region (LABOREL *et al.*, 1994; MORHANGE, 1994). Such a comparison allowed us to separate, at least from a qualitative point of view, some of the various factors (eustasy, geodynamics, sedimentology and human action) which resulted in the rise of relative sea level in that place during the last 4000 years.

METHODOLOGY

For the present study we took into account three types of relative sea level (RSL) indicators: archaeological, biological and sedimentological (Figure 3).

95050 received and accepted in revision 30 May 1995.

Archaeological Indicators

Several types of archaeological structures are known to be linked to the immediate vicinity of sea level so they can be used as RSL and shoreline indicators, provided they can be dated and placed in their original context (FLEMMING, 1969, 1979, 1992; PIRAZZOLI, 1976). Such structures fall into three main categories, depending on the place where they were originally constructed (FLEMMING, 1979): (1) on dry land (emergent structures), like drains, room floors, quay and road surfaces; (2) at the land-water interface, like quay walls, sewer outlets, fish ponds, slipways and wharf pilings; and (3) underwater, like quay basements or sunken wrecks.

These three types of structures may be used, provided their significance is accurately known; they may then be compared with corresponding present day equivalents. They allow in many cases a fair reconstruction.

Biological Indicators

Among the various types of biological indicators used in the Mediterranean area (LABOREL and LABOREL, 1994), *Balanus* cf. *amphitrite* (Darwin), the common Mediterranean barnacle is best adapted for use in semi-closed or harbour areas (DONNER, 1959; SPECCHI, *et al.*, 1976; MORHANGE, 1994) and indeed was used for previous archaeological studies in Marseilles (PIRAZZOLI and THOMMERET, 1973). Recent investi-



Figure 1. Aerial photograph of the center of Marseille, the Greek and Roman cities developed on the hill north of Lacydon creek, now the "Vieux Port". Cross indicates the site of excavations at Place Jules Verne. Photograph: Centre Camille Jullian.

gations (MORHANGE, 1994) on modern quays and wooden pilings still existing in the Provence region confirm that the upper limit of *Balanus* in natural populations can be used as RSL indicators with an accuracy of ± 0.05 cm.

For periods before the foundation of the city we relied mainly upon biological indicators such as "maërl" which is a bio-accumulation of rhodoliths on the sea bottom. They are made of small branching thalli of two coralline Rhodophytes: *Mesophyllum coralloides* and *Phymatolithon calcareum* (M. VERLAQUE pers. comm.). These algae reach the low tide level in calm and narrow creeks (BOURCIER, 1980; GAILLANDE, 1968) so that the upper limit of their natural populations can be taken as a good RSL indicator with an accuracy of about 1 metre.

Sedimentary Indicators

These are mainly beaches, deposited along natural shorelines or archaeological structures (jetties and quay walls). After identification of the various types of sedimentary layers, it was necessary to determine their exact relationship with the corresponding paleo-water levels. Since no outer slope was present, confusion was possible between beaches at or near RSL, mixed (mud and sand) sublittoral bottoms, and pre-existing Oligocene sand bedrock. We used two main types of indicators in order to separate these three types of sediments.

Sediment Composition and Texture

Beaches at close proximity of the mean relative sea level are characterized by an abundance of coarse sediment and a large amount (one fifth of total weight or more) of anthropogenic elements, such as driftwood fragments, broken shells, potsherds and fragments of amphorae. Well preserved beaches allow the reconstruction of the former sea level with an accuracy of ± 0.30 m.

Muddy sublittoral grounds are poorer in coarse elements and ballast (less than 5 % in weight), with the exception of places

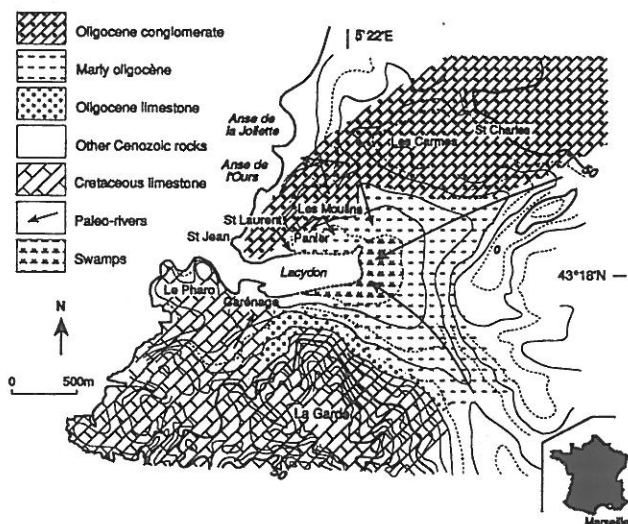


Figure 2. Present time topographic and geological features of Lacydon creek, from GUERY (1992). The details of the coastline are not accurately defined.

near or under wharves or piling structures, from which rubbish or artefacts were lost or jettisoned. Their use as RSL markers depends upon the good preservation of their upper limit.

Undisturbed Oligocene sands are sometimes difficult to separate from recent sediments. They are extremely variable, because they were deposited in various types of environments (NURY, 1977) and are, of course, devoid of anthropic material

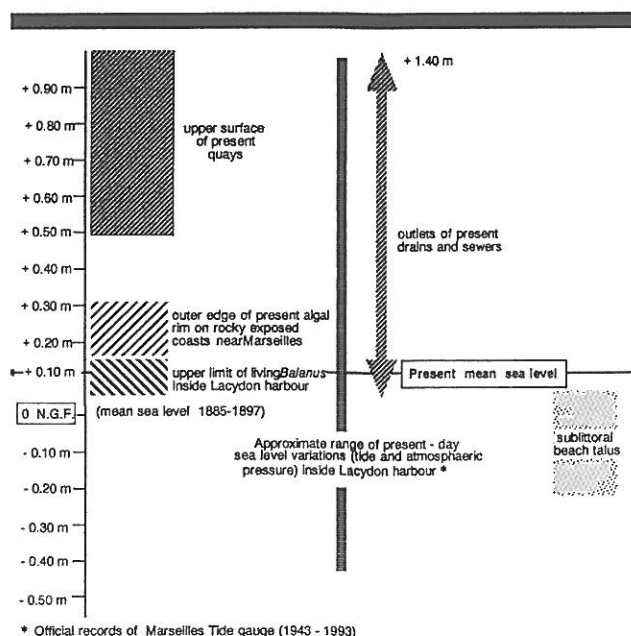


Figure 3. Altitudinal setting with reference to present mean sea level of main types of RSL indicators in the region of Marseille.

of any kind. Their importance is nevertheless great; they are a major source of gravel, sand grains and fine material. A certain amount of confusion was possible so morphological analysis of sand grains with Scanning Electron Microscope (SEM) was often necessary.

SEM Examination of Subtidal and Oligocene Sands

Microscopic surface features of quartz grains are determined by a number of factors of physical, chemical, mechanical or biological nature. Transformations and superposition of these features are indicative of the relative chronology of forces and events to which the grains were submitted during the course of their sedimentary history (PRONE, 1980; LEGIGAN and LE RIBAUT, 1987).

Subtidal sands are characterized by the presence of pyritospheres, typical of confined marine environments. The faces of most quartz grains may present some degree of solution etching, sometimes along preferential directions.

Oligocene sands contain raw or imperfectly polished grains, with edges generally less blunted than in marine quartz. Siliceous deposits and gypsum microcrystals may be seen under higher magnification. Secondary deposits appear inside depressions of grains and may eventually be polished by subsequent scouring. Such polished deposits are indicative of periodical emersion and flooding, typical of Oligocene fluvio-lacustrine environments.

Beach sands display typical traces of a marine environment of medium energy in very shallow water; grain ridges are smooth and the faces display cupular and crescent-shaped depressions with small coalescing globules of silica inside them. Traces of impact, abrasion and dissolution are indicative of wave action in an intertidal environment. Traces of a former eolian evolution on dry land may also be seen but they have been in part polished out by ulterior underwater stirring.

Levelling

Levelling measurements performed during the excavations at Place Jules Verne were related to a temporary bench mark (TBM *sensu* JARDINE, 1986), painted on the casing wall of the excavations, at the elevation of the French geodetic datum (zero NGF). However, on rocky coasts where no accurate levelling bench mark is commonly available, sea-level indicators were levelled by differential height measurement between the fossil indicator and its present-day corresponding equivalent at the same location (LABOREL, 1986).

It was recently proved (GUERY *et al.*, 1981) that in Marseilles, the zero NGF datum (originally defined as the average value of mean sea level from 1885 to 1897), now lies 0.11 m below present mean sea level, a consequence of the rise in sea level during the last century observed by tide gauges in many parts of the world (PIRAZZOLI, 1986; BLANC and FAURE, 1990). This was confirmed when we measured with a surveyor's level the height of the upper limit of barnacles (*Balanus amphitrite*) which occurs at mean sea level on vertical hard substrates in the Lacydon area and found it to be 0.10 m above NGF.

One of our problems was to compare results from Place

Jules Verne with those obtained on rocky coasts where an excellent biological MSL indicator was used, the *Lithophyllum lichenoides* algal rim (LABOREL *et al.*, 1994). For the latter study, our levelling was done by taking the outer edge of the present day rim as a reference datum. In most cases, however, the upper limit of the living algal populations was found to be about 10 cm or more above the outer edge, a fact coherent with the recent rise of RSL quoted above. We decided, nevertheless, not to include this correction into our data, since the secular rise could not be checked by radiocarbon dating and was difficult to measure with sufficient accuracy with our methods (MORHANGE, 1994).

Thus, a direct comparison with little risk of error may be carried out between differential height measurements of algal rims on rocky coasts and uncorrected measurements based on NGF in harbour areas.

Dating

Several types of chronological indications were found during the excavations. Archaeological dates obtained from the analysis of man-made objects and structures were indicated in centuries relative to the Christian Era, i.e. BC (Before Christ) and AD (*Anno Domini*) with an accuracy of about ± 50 years. Radiocarbon dates from faunistic elements were given uncorrected in the BP (Before Present) notation with indication of their value of confidence, by the radiocarbon laboratory (Laboratoire de Géochronologie, Laboratoire de Géologie du Quaternaire, CNRS, Marseilles). A calibration was done following STUIVER and BRAZILUNAS (1993) for biological samples, including those from *Lithophyllum* rims used for comparison (Table 1).

RESULTS

Late Neolithic to Early Bronze Age

No artefacts of human origin were found, but a 0.70 m thick layer of algal thalli (maërl) was discovered (Figure 5), with an upper limit at -2.44 m NGF. Radiocarbon dating of the top of the deposit yielded an age of 3860 ± 130 BP (LGQ 977) or 2080–1820 cal BC. Sea level was then about 2 m ± 0.5 m below NGF (MORHANGE, 1994). This layer of calcareous algae was killed by siltation and an anthropogenic deposit of oyster shells, indicative of a pre-Greek occupation (WEYDERT, 1994).

Greek Archaic and Classic Periods

A Greek quay wall, made of lined up stones of metric size and dated 500 BC was unearthed on the northeastern corner of the excavation zone. Its basement had been dug into the contemporary beach at about -1.20 m NGF and it is backed up to the north by an earth platform at an altitude of about -1.00 m NGF which was used as a transit area. The upper surface of the quay and platform had been elevated by deposition of several layers of compacted earth between 500 and 400 BC, a possible indication of a contemporary RSL rise. No *Balanus* has been found on this quay.

The beach sediment contains 90% marine sands, contrasting with the submerged subtidal muddy bottom. The sorting

Table 1. Heights below present MSL and Radiocarbon dates obtained from *Lithophyllum* rims on rocky cliffs at La Ciotat, near Marseilles. (LABOREL et al., 1994 and unpublished dates). Calibration according to STUIVER and BRAZUNAS, 1993. Datations by Laboratoire de Géologie du Quaternaire, C.N.R.S., Marseille, R. LAFONT.

Lab. Id No. of Sample	Height (m)	Error (m ±)	¹⁴ C Age (years BP)	Error (±)	Cal. Age Years BC/AD
LGQ 804	0.05	0.1	140	110	present
LGQ 803	0.08	0.1	150	120	present
LGQ 773	0.1	0.1	810	120	1380–1620 AD
LGQ 802	0.11	0.1	670	120	1560–1800 AD
LGQ 801	0.15	0.1	960	120	1290–1530 AD
LGQ 800	0.25	0.1	1,360	120	940–1180 AD
LGQ 798	0.3	0.1	1,200	120	1120–1360 AD
LGQ 769	0.38	0.1	1,590	130	690–940 AD
LGQ 1080	0.54	0.1	2,100	130	140–400 AD
LGQ 1081	0.57	0.1	2,020	130	270–530 AD
LGQ 1082	0.6	0.1	2,460	130	10–270 BC
LGQ 768	0.75	0.1	2,530	120	90–330 BC
LGQ 1083	0.8	0.1	3,560	140	1340–1620 BC
LGQ 764	0.85	0.1	2,850	130	590–850 BC
LGQ 770	0.9	0.1	2,900	130	620–880 BC
LGQ 760	1	0.1	3,420	130	1330–1590 BC
LGQ 1084	1.1	0.1	2,890	130	620–880 BC
LGQ 763	1.15	0.1	3,420	130	1330–1590 BC
LGQ 761	1.2	0.1	3,200	130	1050–1310 BC
LGQ 765	1.2	0.1	3,750	130	1590–1850 BC
LGQ 766	1.2	0.1	3,160	130	840–1100 BC
LGQ 767	1.3	0.1	3,370	140	1120–1400 BC
LGQ 762	1.6	0.1	4,350	130	2390–2650 BC

index of the sandy fraction is poor (1.6) and skewness is highly negative (−0.45) (FOLK and WARD, 1957) indicating an enrichment in fine sands. Such a composition is typical of the surf zone of beaches developing at the bottom of a bay (DEGIOVANNI, 1972; MORHANGE, 1994), and we interpret it as having been deposited close to sea level about −1.10 m NGF around 500 BC.

Hellenistic Period

Two main architectural structures were unearthed (Figure 4).

Shipyards zone (300–100 BC): two shipping docks had been established upon the northern part of the excavations. Slipways were used for hauling up ships onto the emerged beach for maintenance and preservation during winter. They were made of wooden beams, lying flat or partially buried into shallow trenches parallel to the beach shoreline (oriented from east to west).

The present altitude of the slipways is between −0.30 m NGF upstream and −0.85 m NGF downstream. Unfortunately, we have no trace of their lower limit since it was cut out by Roman dredging operations during the first century AD. We can deduce that mean RSL was situated roughly at the lower extremity of the ramps, i.e., about −0.85 m NGF during the third and second centuries BC.

Hellenistic quay (around 50 BC): it was made of rock boulders and wooden posts driven into Oligocene sediments and covered with barnacles. Measurements of the upper horizontal limit of the barnacles vary from −0.68 m to −0.76 m NGF, with a mean value of $-0.72 \text{ m} \pm 0.05 \text{ m NGF}$ ($0.82 \text{ m} \pm 0.05 \text{ m}$ below the upper limit of present barnacle populations).

Roman Period

An important change in landscape occurred at the end of the Hellenistic period (Figure 5). Two promontories were gained on the sea by filling up, east and west of the Hellenistic shipyards, with a small embayment between them. These promontories were fitted with warehouses and present a number of well preserved Roman structures (Figure 6).

Three drain lines, with their outlets well preserved, have been dated from the first century AD for the central one and from the second century AD for eastern and western drains.

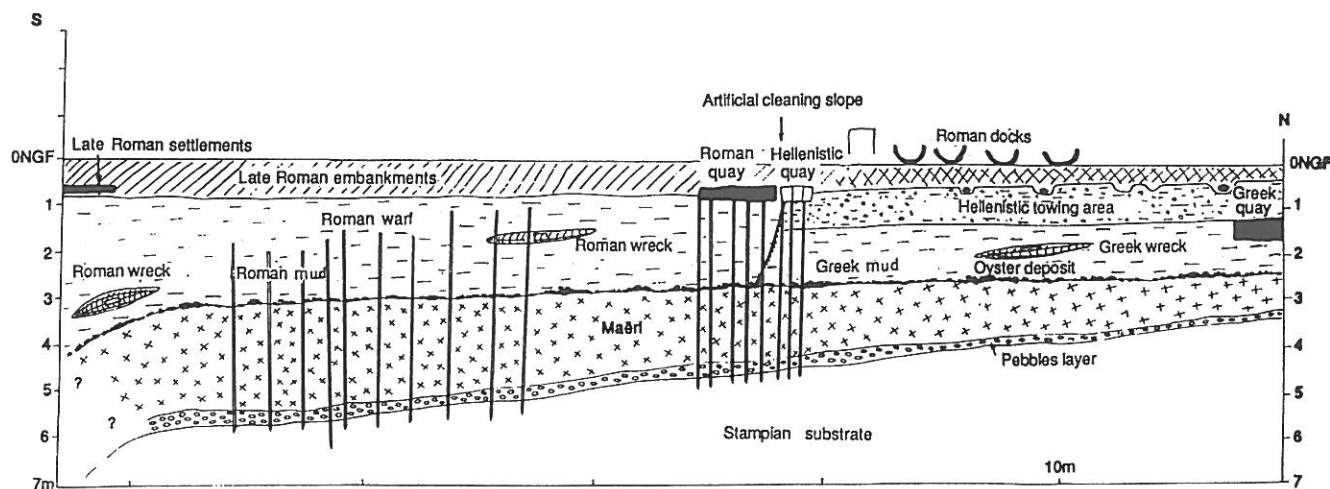


Figure 4. Stratigraphic section of the North shore of Lacydon, Marseilles.

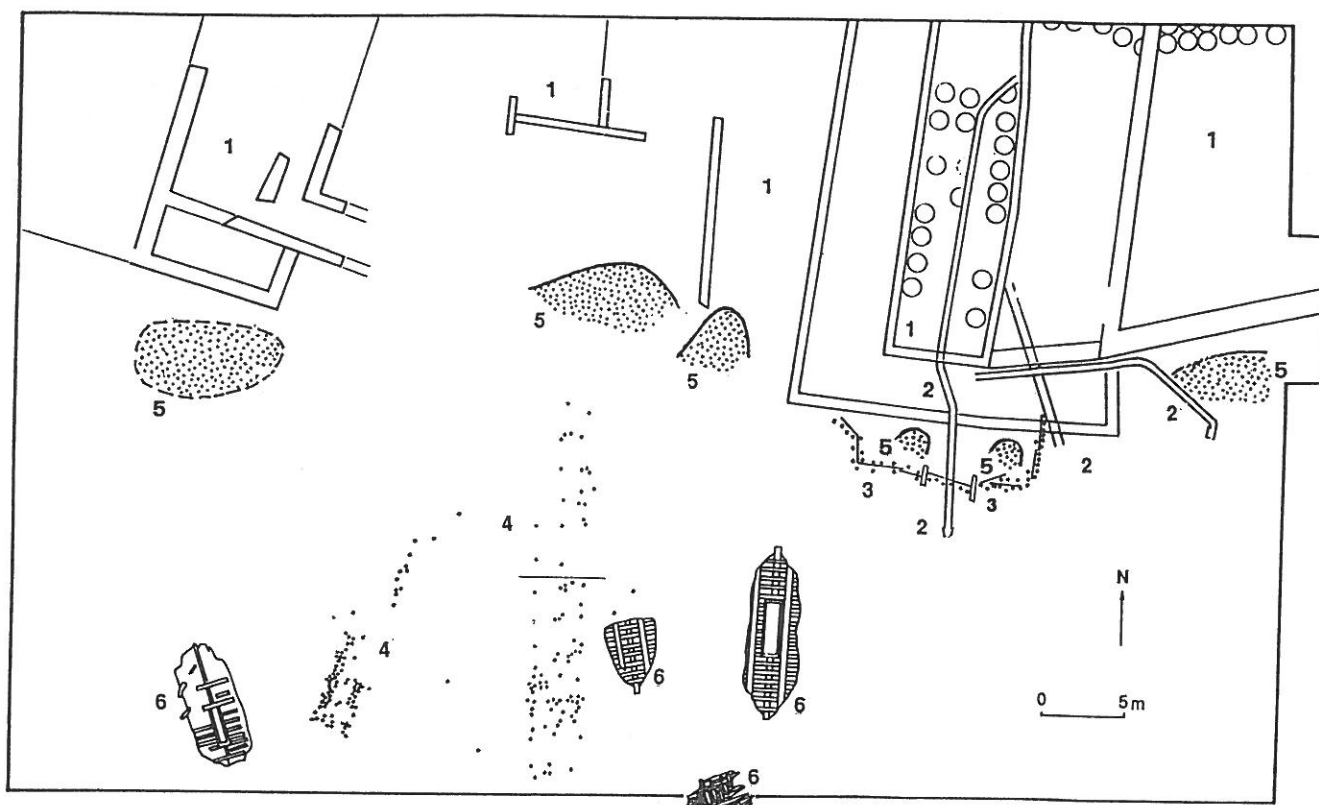


Figure 5. Roman archeological and sedimentological structures (from HESNARD, 1993). Dry land structures: (1) warehouse, (2) drain outlet. Land-sea interface structures: (3) quay, (4) wooden wharf, (5) beach. Sublittoral zone: (6) sunken shipwreck.

Present altitude of the outlets are -0.34 m NGF (east drain), -0.67 m NGF (west drain) and -0.85 m NGF (center drain).

To allow a permanent flow, as a rule drain and sewer outlets are built at or just above mean sea level, but the exact altitude of the outlet depends upon local conditions (e.g., slope, nature of substrate, wave energy). For these reasons, the 0.33 m difference between the altitudes of the two outlets attributed to the second century AD is within the interval of accuracy of the indicator. The fact that the lowest outlet is also the oldest is nevertheless consistent with the general trend of RSL rise obtained with other indicators.

A quay (1–50 AD) was unearthed at the southern limit of the eastern promontory. It was made of planks, wooden posts and rock boulders driven into the Oligocene substratum. The posts are well preserved, although slightly slanting to the south and bear a dense cover of barnacles (Figure 7) and sometimes oysters. The upper limit of *Balanus* populations varies from -0.65 m NGF to -0.71 m N.G.F (mean value -0.68 ± 0.05 m NGF). A discrepancy exists, however, between the latter result and that obtained from the center drain outlet of the warehouse which is of the same age but a little deeper (-0.85 m NGF). Cross checking of a number of other structures of the same layer and age (wharves and beaches) suggests that our estimations based on *Balanus* are representative of the contemporary sea level. The outlet of

the center drain is the only indicator lower than -0.71 m NGF and thus should have been built 0.15 – 0.20 m below contemporary mean RSL. We infer that sea level was between -0.65 m NGF and -0.71 m NGF (mean value -0.68 m NGF) in the middle of the first century AD.

Wooden pilings of a nearby Roman wharf of the same period present a dense cover of *Balanus amphitrite* which were killed when the wharf was abandoned and covered with earth (Figure 8). Radiocarbon dating gave an uncorrected age of 1760 ± 150 BP (LGQ 905), or 510–810 cal AD. These dates are coherent with the abandonment of the wharf at the end of late antiquity as derived from the study of associated ceramics (A. HESNARD, unpublished data).

Marine beaches in close association with archaeological structures are scarce, small and not fully developed, since they are located at the foot of quays or walls abutting the shoreline. The lack of an emergent beach limits the action of water movements (swash and backwash) responsible for the forming of the beach talus (DEGIOVANNI, 1972). Corresponding sands are thus poorly sorted with negative skewness (enrichment in fine material). At the same time (and rather paradoxically), sands display a high percentage of coarse material (more than one fifth of sample weight) including fixed fauna (fallen from hard structures) and anthropogenic arte-

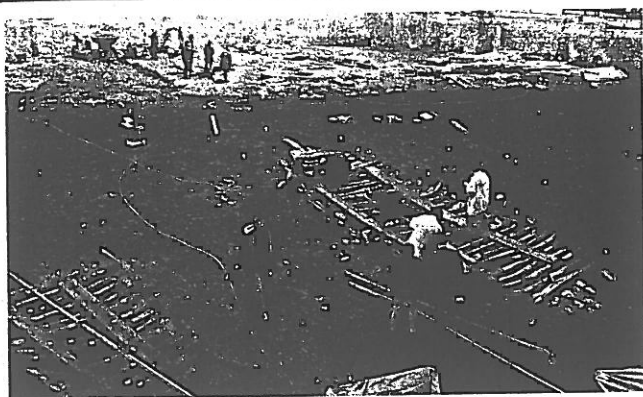


Figure 6. A partial view of the excavations at Place Jules Verne, showing the Roman harbour. On the foreground the marine sublittoral sediments (dark area) with two shipwrecks, in the background the Roman docks (light area), lying upon the Roman beach and embankments. (Photograph: C. Morhange).

facts. Such mixed characteristics are indicative of a water circulation strongly affected by man.

We consider the upper part of these Roman beaches a good RSL indicator, with a vertical accuracy of ± 0.30 m. Sea level was between 0.25 m and 0.85 m below NGF during the second century after Christ and between -0.04 m and 0.64 m NGF during the third century after Christ.

During late Roman times (fifth century after Christ) the whole zone of present Place Jules Verne was filled up, as RSL progressively reached its present value (HESNARD, *in press*), a result in coherence with previous estimates (GUERY, 1992).

DISCUSSION AND CONCLUSIONS

The general age/depth diagram (Figure 9) summarizes the data obtained during the present study. Relative MSL rises from a minimum of -2 m up to present datum in about 4000 years. However, since our oldest date based on the pre-greek maërl layer was not accurate enough, we decided not to take it into account for our statistical analysis and to limit our processing of data to the last 2500 years only.

During the latter period, the rise of RSL was not uniform. Between fifth century BC and fifth century AD, the rise of relative MSL was rapid. A comparison with our previous data from rocky coasts near Marseilles (LABOREL *et al.*, 1994) shows a higher amount of sea-level rise for the Lacydon area than for the rocky coasts. From fifth century AD on to present times, relative MSL has been stable close to its present altitude.

A linear regression age/depth approach applied to our data shows ($r^2 = 0.88$ %) that the mean velocity of MSL rise was 1.3 mm per year between the fifth century BC and the fifth century AD, a value much higher than that the one we had previously found on rocky coasts (0.49 mm per year between 4500 BP and 1500 BP, declining to 0.24 mm per year from 1500 BP to present). A second linear regression (computed velocity versus age) indicated ($r^2 = 0.08$) that sea level rise decelerated at a rate of 4.8×10^{-4} mm/year², so that stabi-

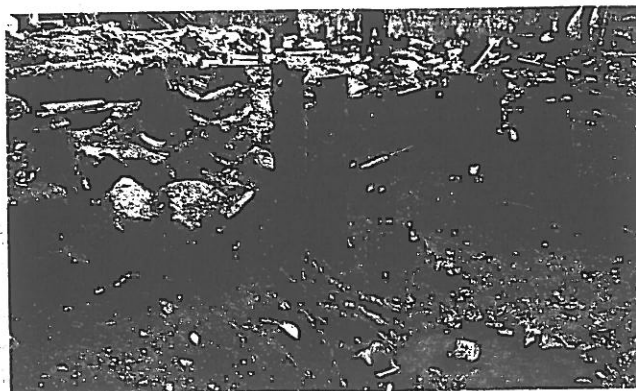


Figure 7. A well preserved Roman quay, with contemporary sea bottom and derelict artefacts in place (rope and broken amphorae). (Photograph: C. Morhange).

lization of RSL around present datum was probably gradual in the Lacydon area like on the rocky coasts of the same region.

Three factors may be responsible for such a high rate of SL rise. The first is the relative lack of accuracy of sedimentary data which conveys the impression that present MSL was reached as early as the fifth century AD (for comparison, it was about 0.30 ± 0.10 m below present MSL on rocky coasts around 1500 BP).

The second is a local subsidence of the basement, already shown by previous authors (BONIFAY, 1980; BONIFAY and COURTIN, 1980; COLLINA-GIRARD, 1992; GUEU, 1977) and generally interpreted as a geological tilting of the Marseilles geological basin from East to West. A recent review by LENOIRE (1990) of old levelling surveys demonstrates an active depression of the Marseilles basin, a general feature for Southwestern France. The Marseilles basin would be the most depressed part of the littoral of Provence, at least on the time scale of the present century.

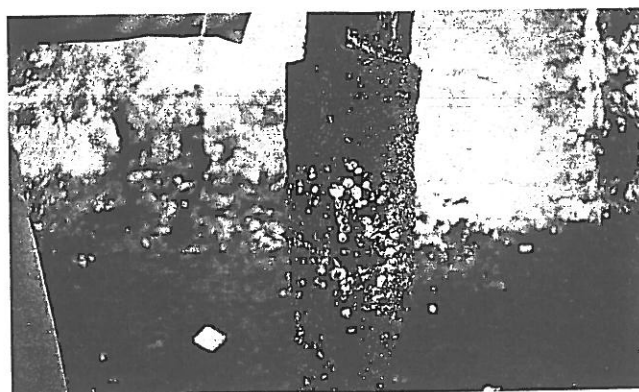


Figure 8. A broken Roman wharf piling, extracted from the bottom mud and presenting an intact upper limit of its cover of barnacles (not in place). (Photograph: C. Morhange).

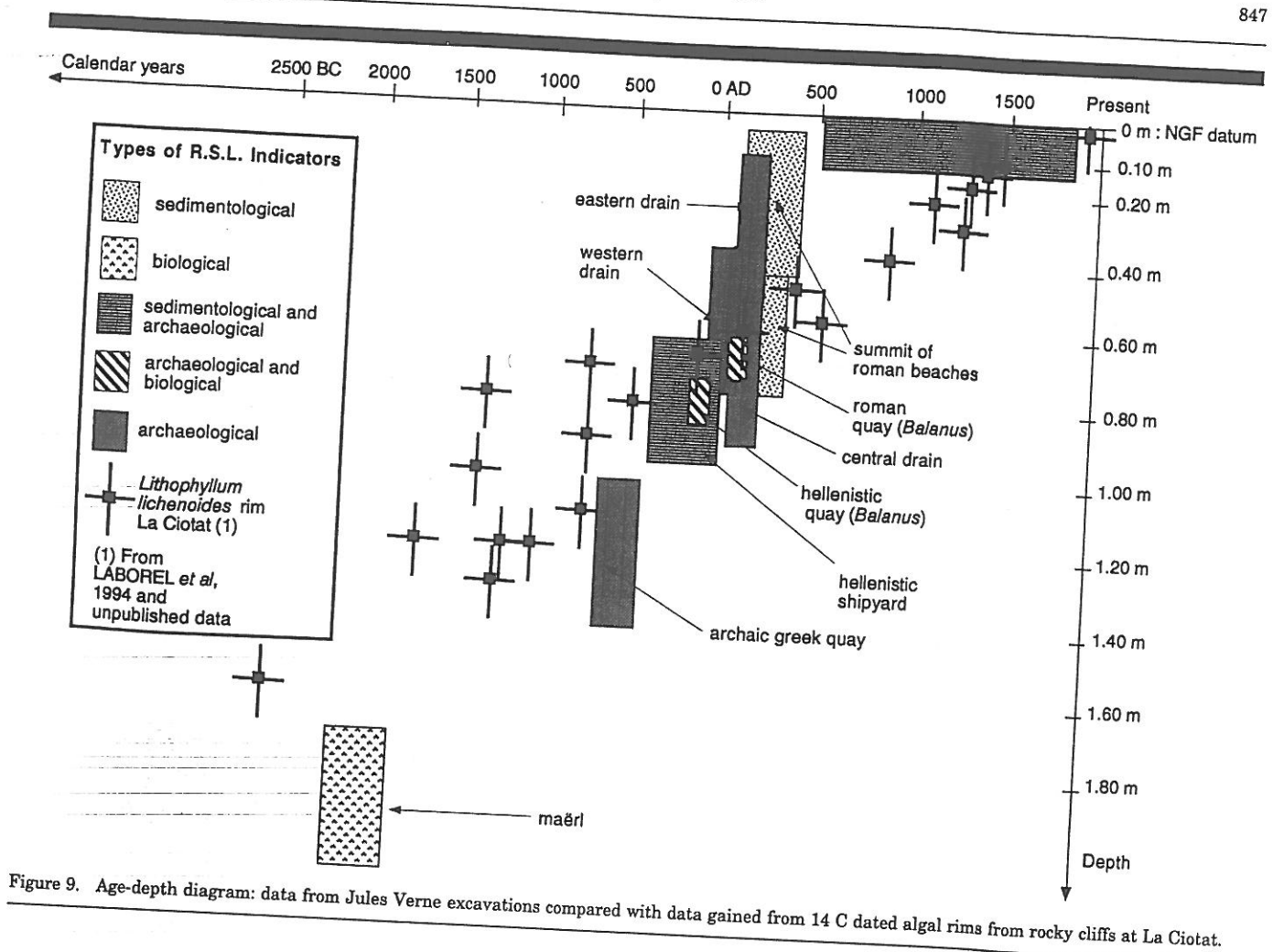


Figure 9. Age-depth diagram: data from Jules Verne excavations compared with data gained from 14 C dated algal rims from rocky cliffs at La Ciotat.

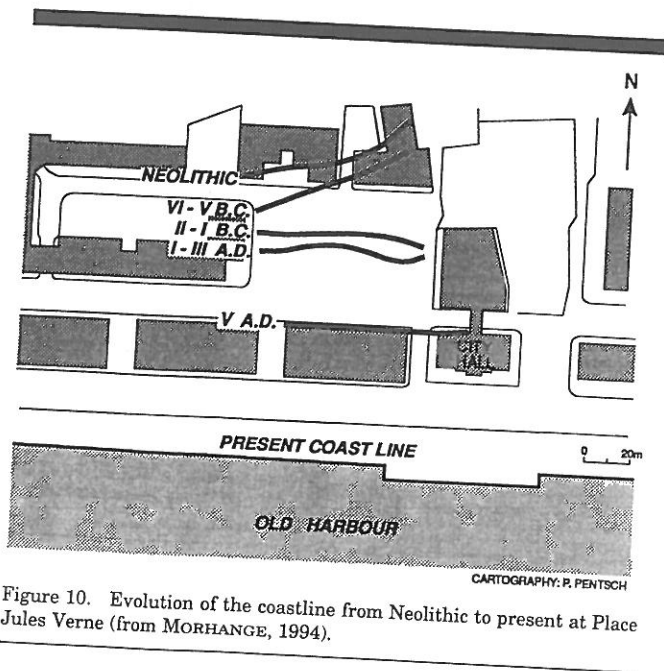


Figure 10. Evolution of the coastline from Neolithic to present at Place Jules Verne (from MORHANGE, 1994).

The third contributing factor is local compaction and deformation of marine sediments, especially where they are overlain by roads, houses and quays built during the many centuries of city development.

No traces of vertical oscillation or of any kind of transgressive movement above present sea level were found in the Marseilles area, neither in the Lacydon nor on the rocky coasts. In Marseilles, the end of the Holocene transgression seems to have been progressive and completed around 500 BC or thereafter (PIRAZZOLI, 1991; MORHANGE *et al.*, 1993). The recent rise of MSL of about 0.10 m, beginning at the end of the 19th century AD (BLANC and FAURE, 1990; PIRAZZOLI, 1986; BLANC, 1993) should accordingly be perceived as a new phenomenon and not as the continuation of an old trend.

A long and steady rise of MSL should, at first sight, have resulted in an enlargement of the water surface of the Lacydon. Eventually, it was the contrary that happened and the shoreline underwent a progradation of about 120 m to the south in 4000 years (and mostly during the last 2500 years), at least on the site of the excavations (Figure 10).

Such an effect may be explained by a strongly positive sedimentary budget, mainly under human influence. Lacydon was gradually filled in, either directly by artificial enbank-

ments or indirectly by sedimentary outflow from rivulets and runoff waters whose sediment load was enhanced by city development and soil erosion (MORHANGE, 1994; MORHANGE, et al., in press).

ACKNOWLEDGEMENTS

This study was done during archaeological excavations at Place Jules Verne, in Marseilles, a project of the Regional Service of Archaeology, under the direction of one of us (A. H.) assisted by M. Pasqualini. Funds for the excavations were partly provided by the City of Marseilles and also by a complementary fund from French CNRS and the universities of Aix-Marseilles I and II. Radiocarbon analyses were performed by the Laboratoire de Géologie du Quaternaire (M. Lafont) and funded by the excavations project. Laboratories involved were URA CNRS 141, URA CNRS 903 and L.B.M.E.B. (EP 75 CNRS). We thank Drs. M. Bourcier (Station Marine d'Endoume, Centre d'Océanologie de Marseille) and M. Verlaque (L.B.M.E.B) for their help in the determination of marine paleo-communities and the late P. Weydert (Laboratoire de Géologie du Centre d'Océanologie de Marseille) for his help in the interpretation of sedimentary sequences. Thanks are also due to Dr. M. Frajut for his critical revision of the English manuscript.

This research is a contribution to CEE Program, "The impacts of climate change and relative sea-level rise on the environmental resources of European coasts", (R. Devoy coordinator) and to IGCP 367 (Late Quaternary coastal records of rapid change).

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□ RÉSUMÉ □

Les fouilles archéologiques, récemment entreprises Place Jules Verne à Marseille (Bouches du Rhône, France), sur la rive Nord du Lacydon (Vieux Port) ont mis en évidence des formations sédimentaires, biologiques et archéologiques qui ont pu être datées et rapportées au niveau marin contemporain par l'intermédiaire de leur nivellement NGF. Depuis 4000 ans, le niveau relatif moyen de la mer s'est élevé d'environ 2 mètres sur le site du Lacydon. Une comparaison avec les résultats précédemment obtenus sur côte rocheuse dans la région marseillaise (La Ciotat) montre des tendances identiques, notamment pour ce qui a trait au ralentissement de la vitesse de montée du plan d'eau à partir de 500 ans A.D. Cependant, des facteurs locaux (subsidence ou tassement des sédiments) ont pu jouer au niveau du Lacydon. La montée générale du niveau de plus de 10 cm, enregistrée par les marégraphes depuis la fin du XIX^e siècle représente donc une accélération récente et non la poursuite d'une tendance ancienne.