# Relative Sea-Level Changes During Roman Times in the Northwest Mediterranean: The 1st Century A.D. Fish Tank of Forum Julii, Fréjus, France

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*In memory of Jacques Laborel (1934–2011) for his exceptional contribution to the multidisciplinary study of relative sea-level changes*

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Fish tanks become fashionable throughout the Mediterranean area between the 1st century B.C. and the 1st century A.D. Because of this narrow chronological window, and their link to former sea level, they constitute precious archives to investigate relative sea level (RSL) since the Roman period, especially when combined with fossilized marine benthos found attached to the fish tank walls. Here, we present new results from an integrated analysis of a fish tank located in the Roman colony of Fréjus, Southeastern France. The well-preserved biological remains on the fish tank wall allow us to estimate an RSL rise of 40 ± 10 cm at Fréjus since Roman times, consistent with a recently published range of −32 to −58 ± 5 cm for the Northwestern Mediterranean for the same time. By contrast, the findings contradict the ∼150 cm of RSL change since Roman times reported for the Northwestern Mediterranean by some authors. © 2013 Wiley Periodicals, Inc.

## INTRODUCTION

Over the last 50 years, the remains of ancient Mediterranean fish tanks have been widely used to assess relative sea-level (RSL) positions during Roman times (Schmiedt, 1972). There are two reasons for this: (1) former sea level and fish tank architecture are closely correlated (Lambeck et al., 2004; Evelpidou et al., 2012); and (2) the chronology of these structures spans a short two-century period of construction and utilization between the ∼1st century B.C. and the 1st century A.D., which is concomitant with the well-documented expansion of *Villa Maritima* (Higginbotham, 1997; Lafon, 2001).

Nevertheless, recent research has suggested four structural limitations: (1) the external perimeter of fish tank walls cannot provide reliable data on former sea level; (2) walkways are narrow paths running along the inner basins that were originally used for maintenance purposes and are therefore considered to lie above mean sea level. In some cases, such as the Lucullus fish tank in the Circeo National Park, Italy, lower foot walks were built below the openings for water entry (Pirazzoli, 1976a). (3) Canals were used to refill and empty the basins with water. They can correspond to sea level but can also be below the water line as at Fréjus and therefore should be studied with great care. (4) *In situ* mid-tidal closing gates, which are precise indicators of relative sea-level change, are exceptionally rare due to their original location in the wave-breaking zone. The aim of this paper is to present recent multidisciplinary results of the analysis of both biological and archaeological proxies.

In Fréjus, located in Southeastern Provence, recent research undertaken by the local council's archaeological department has brought to light a large fish tank dating to the Roman period. The tank, discovered in 2008, is located on the Kipling excavation at the Northeastern corner of the former Roman harbor (Gébara & Morhange, 2010; Bony et al., 2011) and sheds new light on RSL in the Northwestern Mediterranean during the Roman period, complementing preliminary data obtained in the same area by Devillers et al. (2007) and Laborel et al. (1994). Using the palaeozonation of fossil marine organisms attached to the walls of the fish tank, we report new RSL index points.

## ROMAN FISH TANKS AS INDICATORS OF RSL CHANGES

Since the seminal work of Schmiedt (1972) investigating archaeological indicators of sea-level rise in the Northwestern Mediterranean, fish tanks have been extensively used to measure RSL variations since Roman times (Auriemma & Solinas, 2009). Pirazzoli and Thommeret (1973) were among the first to systematically correlate archaeological structures with fossil marine organisms to obtain RSL index points of centimeter precision. In the ancient harbor of Marseille (Lacydon), they measured a palaeobiological sea level (the upper limit of barnacle populations) to be −25 ± 5 cm *Nivellement Général de la France* (NGF; French datum) dated to the 5th century A.D. (Pirazzoli, 1976a, 1979–1980; Morhange, Laborel, & Hesnard, 2001).

Roman fish tanks with their tide-controlled features are potentially excellent archives to estimate the age and extent of sea-level variations (Schmiedt, 1972). An understanding of hydraulic effects on sea life inside the fish tank is required to reasonably correlate the fish tank to past sea level. Ancient Latin authors such as Varro (1st century B.C.) and Columella (1st century A.D.) state that fish tanks were often built in association with Roman villas, a trend that started around the 1st century B.C. Seawater piscinae were prized and considered to be luxury status symbols. The largest fish tanks consisted of several basins intended to separate the fish population by size. Columella stated that the fish tanks had to be frequently washed by waves. Supply channels were accordingly equipped with bronze grids with fine netting. The summits of the walls of the basin are above water at all times, even under rough sea conditions. Some of their architectural elements give a precise indication of former sea-level positions. For instance, (1) outer walls were built higher than inner walls in order to protect the tank from storms and to prevent fish from escaping; and (2) the channels open to the sea had to supply water at least during the high-tide cycle (Pirazzoli, 1988). Estimates of the lower limits of past sea level are based on the premise that at least 10 cm of high-tide water must have passed over the bottom of the supplying channel at the basin entrance in order to have viable conditions maintained inside the tank (Caputo & Pieri, 1976; Flemming & Webb, 1986; Leoni & Dai Pra, 1997; Evelpidou et al., 2012).

In this study, we present new results from an integrated analysis of a fish tank located at Fréjus in the coastal zone of the Roman colony of Forum Julii that challenges a previous reinterpretation by Lambeck et al. (2004) in the central Mediterranean. We focus on the well-preserved biological remains on the fish tank wall to provide a quantitative interpretation of RSL change during the last 2000 years in the Provence coastal area. All altitudes are reported relative to the national datum of France, the NGF.

## STUDY AREA

Fréjus is located in a Permian depression between the Maures range and the volcanic Esterel complex (Figure 1). The lower valley of the Argens River corresponds to a former Holocene ria that has prograded by around 11 km during the past 6000 years (Dubar, 2003; Devillers & Bonnet, 2006). The Roman port of Forum Julii is located east of the Saint-Antoine hill at the margin of the Argens delta. This sandstone promontory, peaking at 11 m above sea level, is a former marine cape that protected the site from Argens flooding (Devillers et al., 2007; Excoffon et al., 2010). The relative protection of this area, at the foot of the ancient city, explains its transformation into a port location. The fish tank lies at the base of the southeastern slope of Forum Julii (Figure 2).

It is generally accepted that during the late Holocene, coastal Provence has been tectonically stable (Bennett & Hreinsdóttir, 2007). Over a millennial timescale, biological sea-level data from Giens show the absence of any crustal mobility between the so-called "stable" region of Marseille and Fréjus (Laborel et al., 1994). At a centennial scale, Le Notre (1990) has shown that there has been no uplift.

## METHODS: PRINCIPLES OF BIOLOGICAL ZONATION OF BENTHOS ON ARCHAEOLOGICAL REMAINS

Archaeological indicators (e.g., piers, quays, slipways, fish tanks, etc.) are by no means independent sea-level proxies (Marriner & Morhange, 2007). In particular, few of these interface indicators are valuable without associated biological proxies. Traditionally, biological indicators provide dateable radiocarbon material from which to establish sea-level histories, but it is notably their precision as

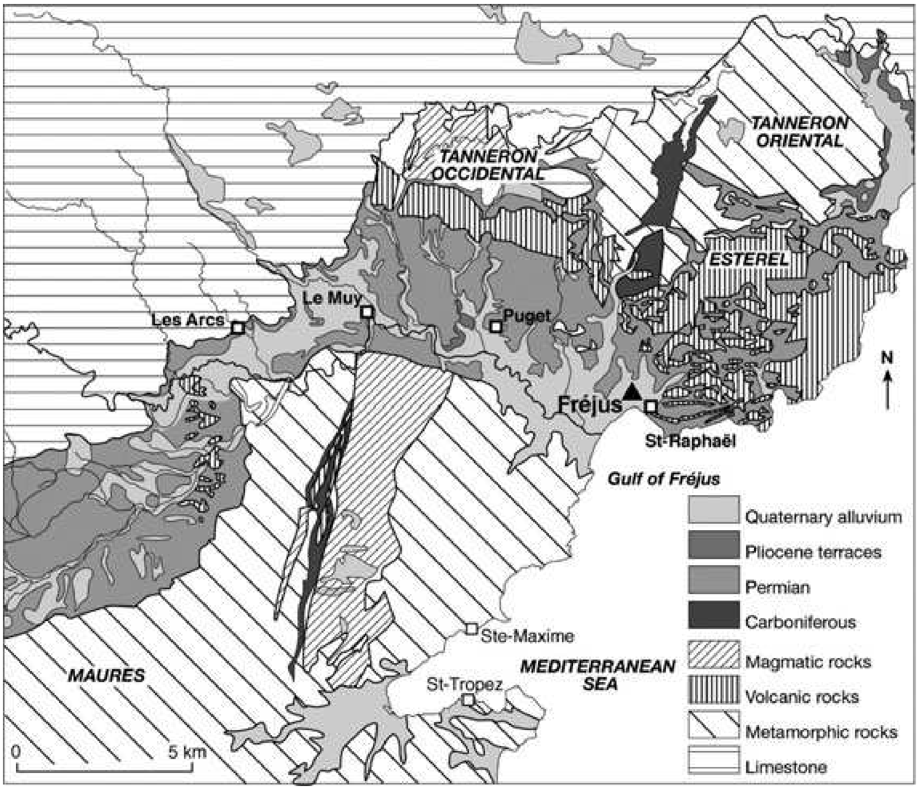

**Figure 1** The regional geomorphological context of the study site (from Georges et al., 2010).

reference markers for former sea levels that is of particular interest. Over the last two decades, the use of biological sea-level indicators in the study of Mediterranean sea-level changes in archaeological contexts has gradually evolved from a descriptive to a multidisciplinary approach based on the recognition that the vertical distribution of the fauna and flora of hard substrate shores shows a pattern of juxtaposed ecological belts, known as biological zonation (Stephenson & Stephenson, 1972; Péres, 1982; Kelletat, 1988; Laborel & Laborel-Deguen, 1994; Stewart & Morhange, 2009).

According to biological zonation, marine benthic animals and plants are finely adapted to very precise ecological conditions such as light intensity, turbidity, water salinity, temperature, and surf exposure. Consequently, changes in local ecological conditions such as relative sea-level change are followed by a concomitant quantitative and qualitative modification of the organisms with replacement by more tolerant forms. This zonation is particularly well-defined and precise in fish tank contexts, which are very well-protected from swell and storm activity.

The upper limit of the infra-tidal zone is marked by a sudden increase in biodiversity, defining a biological sea level. Aperiodic sea-level oscillations linked to atmospheric pressure or wind variations have little influence upon the marine zonation of living organisms with a lifespan of more than 1 year. The upper part of this infra-tidal zone is densely populated by fixed vermetid gastropod mollusks, and cirrhipeds, for example, *Balanus* spp.

Consequently, the upper limits of marine bioconstructions and bioerosive elements (marine burrows and perforations), and fixed invertebrates (oysters, barnacles, solitary vermetids) are useful biological sea-level indicators on archaeological structures. Bioindicators can be used to correct information from archaeological sea-level indicators, which are invariably imprecise due to the difficulties in establishing the former functional height.

All vertical measurements were undertaken using a DGPS (Differential Geographical Positioning System) relative to NGF. Radiocarbon data have been calibrated using Oxcal (Bronk Ramsey, 2000) with the Marine09 data sets (Reimer et al., 2009) and are quoted to two sigma.

## RESULTS

The Kipling fish tank shows two distinct phases of construction and utilization (Figure 3). (1) The initial

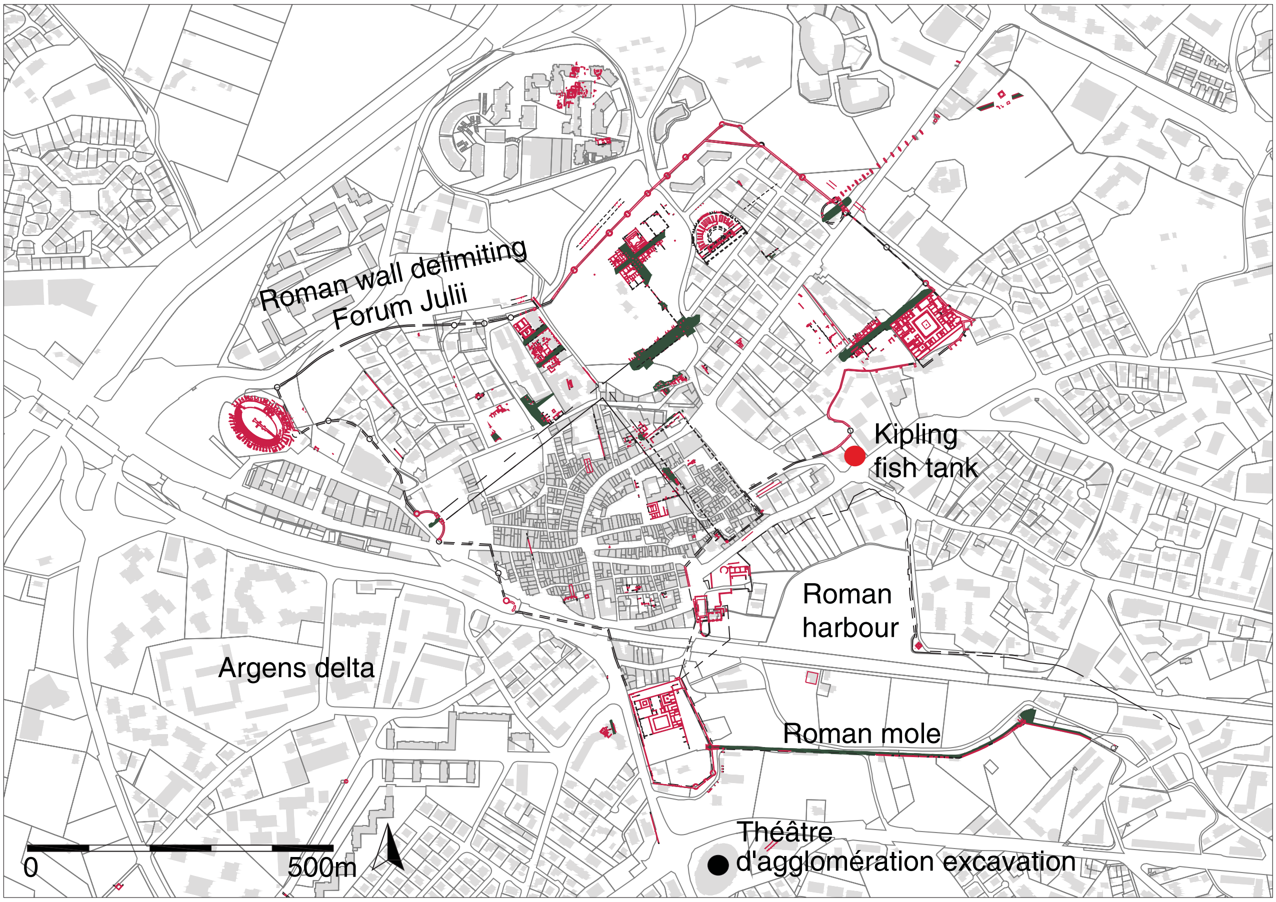

**Figure 2** Location map of the Roman fish tank at the Kipling excavation (Service du patrimoine/Fréjus Town Council). The excavation site is marked by the red circle.

structure was carved into a rocky promontory close to the sea. Later, during the first half of the 1st century A.D., this was extended and transformed into a fish tank connected to the sea. The basin measures 8.7 m by 8.3 m and is 5 m deep. On the landward side, artificial openings dug into the rock were used to tap the water table. (2) The transformation into a fish tank created a basin of 350 $m^3$ whose bottom presently lies 2.4 m below NGF. The basin was linked to the sea by three channels carved directly into the rock. They vary in width between 0.75 and 1 m. The depths of the channel outlets inside the basin are variable, −0.75 m NGF for channels 1 and 3, and −1.12 m NGF for channel 2 (Figure 4A and B). Seawater circulation was controlled via sluice gates identified on the basis of sliding vertical grooves cut into the rock. A wall was built on the southern corner of the fish tank in order to protect it from storm impacts. After a short period of use spanning just a few decades, a secondary decantation basin was delimited in the southeastern corner, comprising about a quarter of the entire volume. The new walls included six small permanently immersed gates that were equipped with closing lead plates at a depth between −1.3 and −1.66 m NGF (Figure 4B). These six openings allowed seawater to move between the small decantation basin and the rest of the fish tank. The archaeological excavation of the smaller basin uncovered sedimentary layers very rich in fine sediment and *Posidonia* fibers. We understand that this smaller basin was implemented to alleviate rapid silting of the main fish tank (Figure 5). In spite of these measurements, the whole fish tank was completely silted and abandoned around 60–70 A.D. in a context of high sediment supply and low-energy conditions (Bony et al., 2011).

The rapid silting had been particularly conducive to the preservation of the calcareous structures of an abundance of marine benthic organisms, which have remained attached to the walls of the fish tank (Figure 6A–D). This ancient fauna was studied *in situ* during the excavation

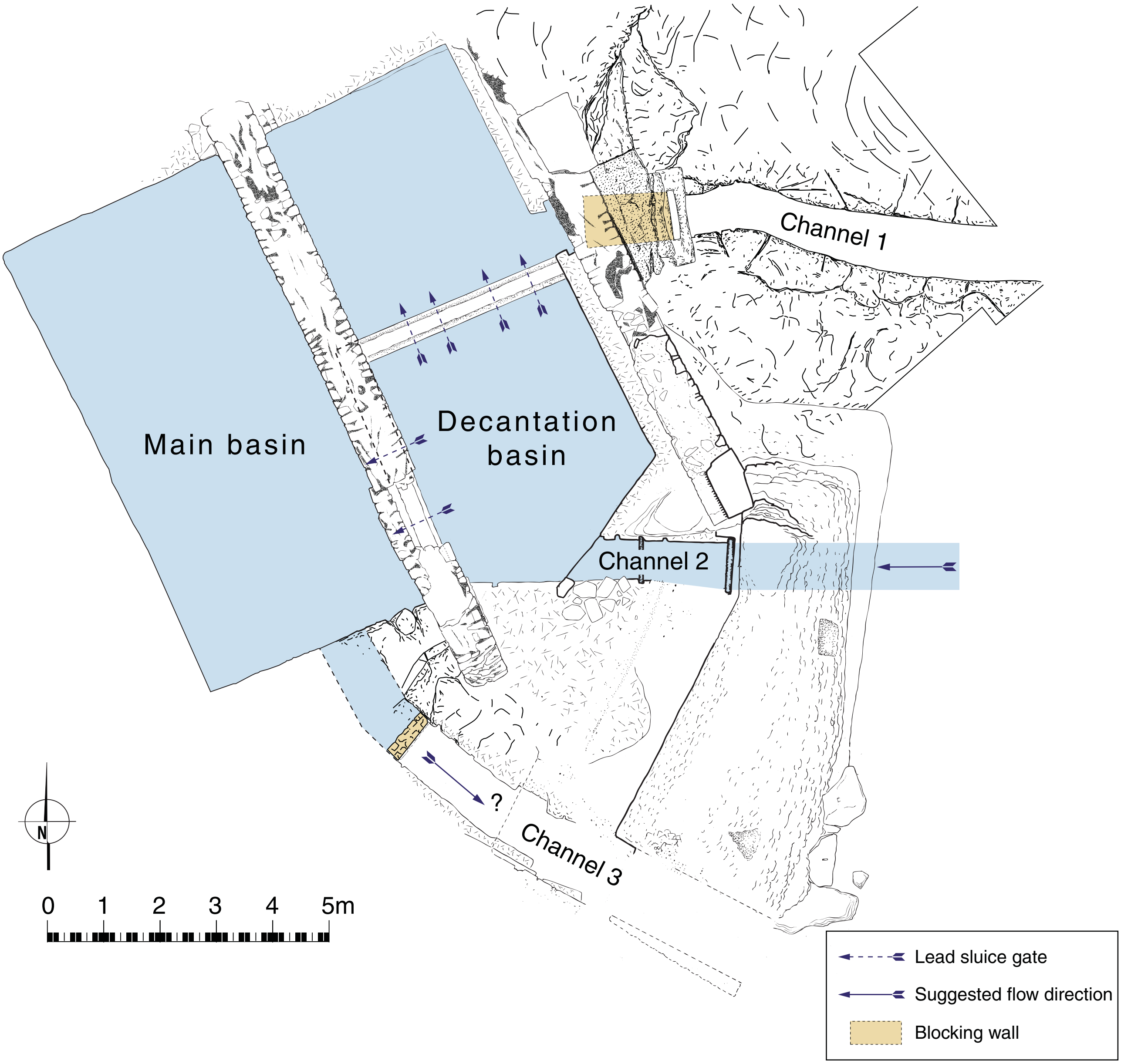

**Figure 3** Map of the Roman fish tank in its final stage dating to the 1st century A.D. (M. El Amouri/Fréjus Town Council).

and photographed. Identifications, most of them to the generic or even higher level only, resulted from the *in situ* study and subsequent analysis of the detailed photographic record.

Bivalve mollusks are represented by species having one valve cemented to the substrate, the other valve having fallen off and being lost: Ostreidae (oysters) and *Chama* sp. oyster shells are the most significant ones because of their larger size, but are difficult to identify to the species level due to the poor state of oyster taxonomy in general. Gastropod mollusks are represented by a rather common vermetid species (*Vermetus triqueter*) having its tube-like sinuous to coiled shell solidly fixed on the substrate. Fragile and mostly damaged encrusting bryozoan colonies belong to several species, one of which could be identified (*Cryptosulla palliasana*). Barnacles are represented only by perforate calcareous bases, all upper plates having fallen off. Thus "Balanus" is used as a general term in this context, even though this genus might have been present. Calcareous tube worms (Serpulidae and Spirorbidae) are

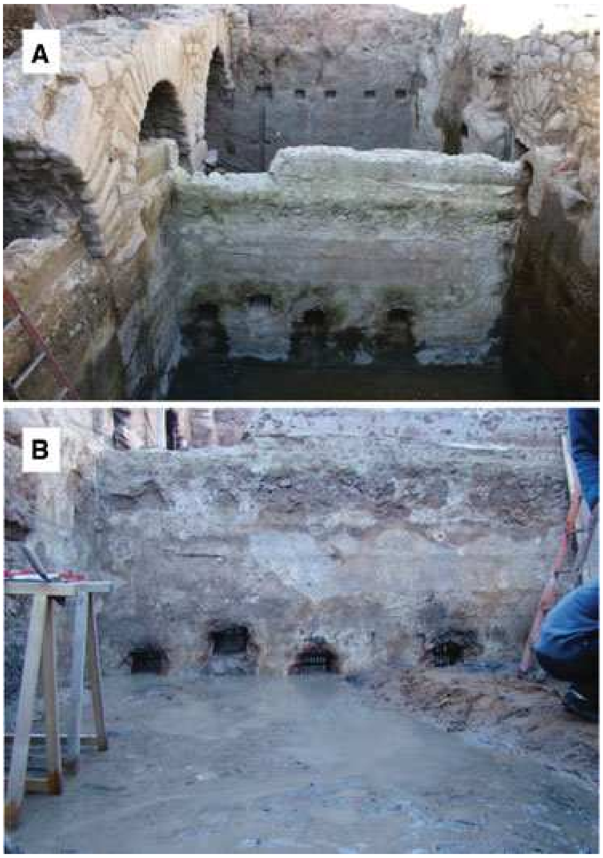

**Figure 4** (A–B) Infra-tidal gates equipped with lead gates at a depth between –1.3 and –1.66 m NGF (P. Excoffon/Ville de Fréjus). Detailed view of the northern wall of the decantation basin (C. Morhange).

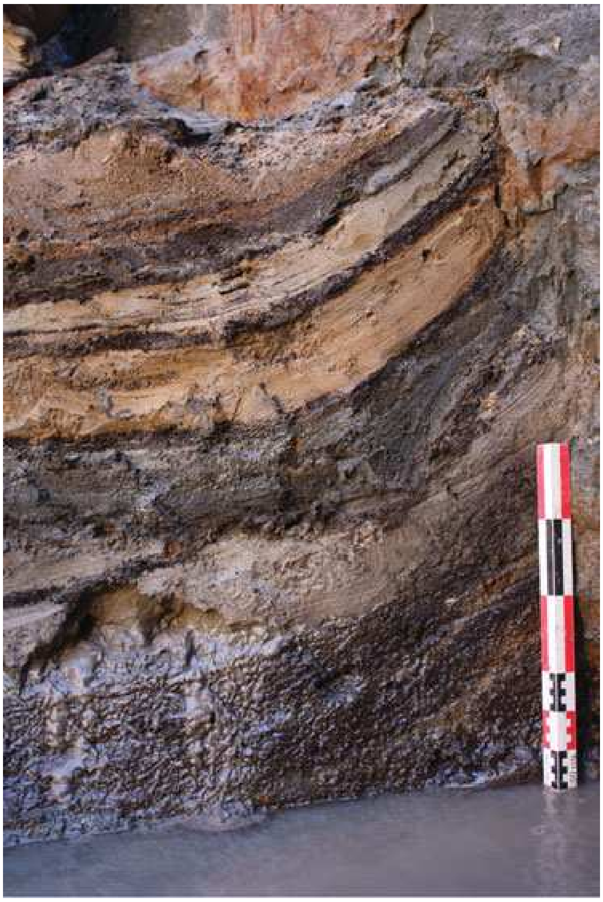

**Figure 5** Posidonia deposits inside the fish tank (P. Excoffon/Fréjus Town Council). The organic Posidonia beds alternate with brown silty clay suggesting a decantation process inside the tank.

the most diversified zoological group among the studied *in situ* remains. Better preserved serpulid tubes are represented by the genera *Hydroides*, *Pomatoceros*, *Protula*, *Serpula*, *Vermiliopsis* (it is possible that there were others). Some *Vermiliopsis* tubes are reminiscent of *V. striaticeps*. Of the at least two spirorbid species, the larger type seems to fit *Pileolaria militaris*.

The most remarkable find is a colony of the zooxanthellate colonial scleractinian coral *Cladocora caespitosa*, comprising many low corallites. The colony is about 8 cm wide, and attached to the face of the tank wall. Having photosynthecic symbiots, *C. caespitosa* needs a certain level of light to be viable. Its presence indicates that the fish tank was not covered, at least not in this part of the fish tank (Figure 6D).

Altogether the fauna observed on the tank walls, with a well-defined upper limit of preservation measured at −40 ± 10 cm NGF, corresponds to a community typical of infra-littoral rock in a sheltered subtidal environment, as presently found elsewhere on the coast of Provence (Laborel, 1987). Overall and macroscopically, it is in a good state of preservation.

The architecture and the biological indicators of the Kipling site show: (1) an RSL rise of 40 ± 10 cm during the past 2000 years; and (2) that the three connecting channels from the sea were always below mean Roman sea level by at least 30 cm. This suggests that the use of fish tank channels is imprecise and tends to overestimate RSL rise.

## DISCUSSION

A recent paper by Lambeck et al. (2004) reinterpreted the Tyrrhenian fish tanks of central Italy to propose a Roman sea level at 135 ± 7 cm below present mean sea level. This contrasts with the 50 cm reported by Pirazzoli (1976b). Subsequently, fish tanks have been widely used in the Mediterranean area to assess up to 150 cm of RSL rise in different crustal contexts (Antonioli et al.,

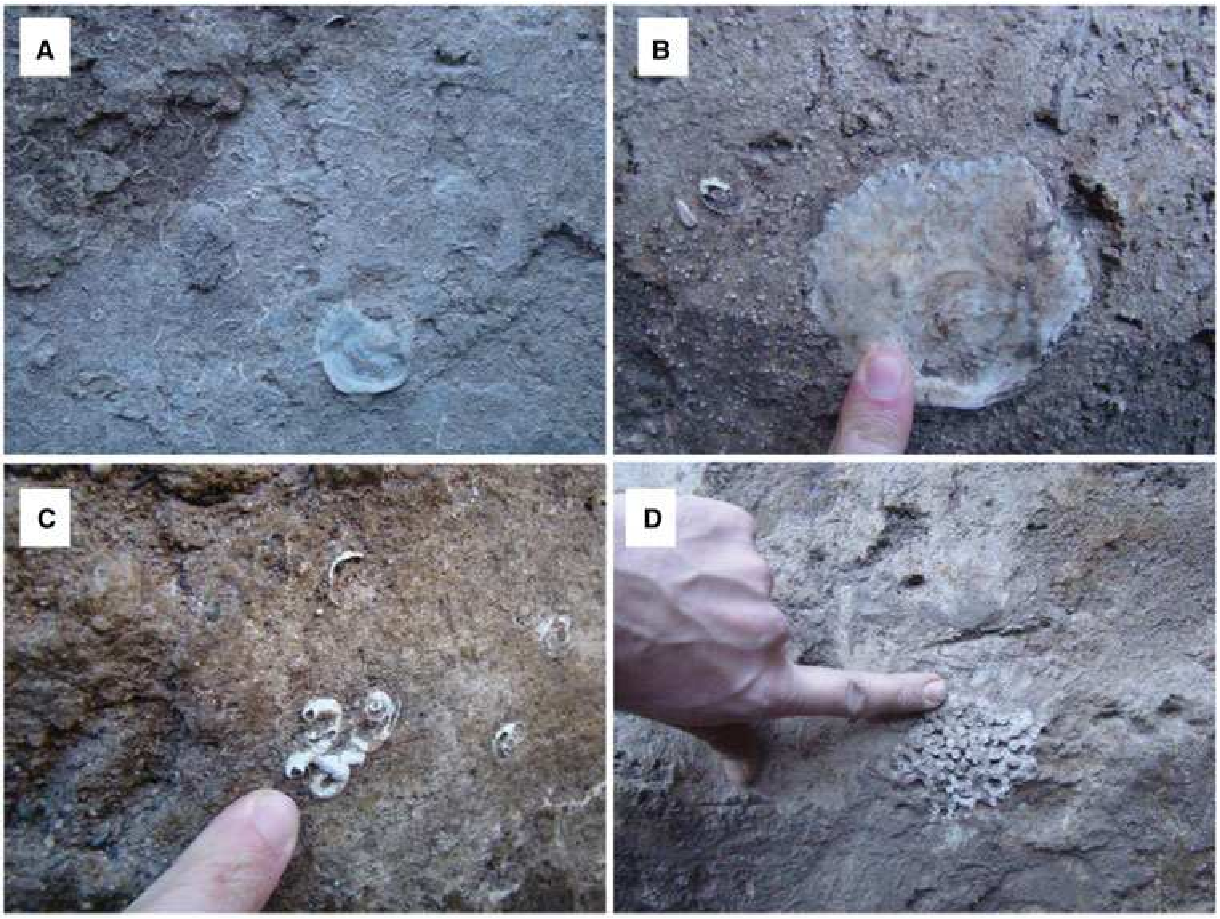

**Figure 6** Benthic marine organisms on the walls of the Kipling fish tank (C. Morhange). (A) General view of the marine benthos (Ostrea, Serpulids . . . ); (B) *Ostrea* sp.; (C) *Vermetus triqueter*; (D) *Cladocora caespitosa*.

2007; Auriemma & Solinas, 2009; Florido et al., 2011). We suggest that the discrepancies between data from the southern coast of France and Italy are essentially due to methodology. For example, Lambeck et al. (2004) used the top of the submerged sluice gates to define the upper limits of the reconstructed sea-level envelope. Based on work at various sites, Evelpidou et al. (2012) demonstrated that the sluice channels' sliding grooves are not a reliable archaeological indicator of former sea level because they can be located at any depth in the basin. Our data from Fréjus, using the palaeobiological zonation of marine benthos, appear to confirm this premise.

At a local geographical scale, the 40 ± 10 cm NGF of sea-level rise is in agreement with the 33 ± 6 cm NGF measured on the rocky coast of Fréjus (*Théâtre d'agglomération* excavation, Excoffon et al., 2006; Devillers et al., 2007; Figures 2 and 7). The small altitudinal difference is essentially explained by a contrast in the environmental context: an open sea coast in

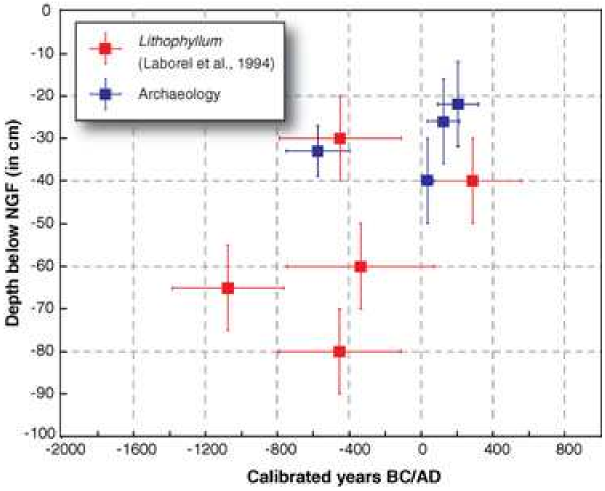

**Figure 7** Sea-level index points for the Fréjus area. For the raw data, see Table 1.

**Table 1** RSL index points from the Fréjus area. All radiocarbon dates were calibrated using Oxcal (Bronk Ramsey, 2000) with the Marine09 data sets (Reimer et al., 2009) and are quoted to two sigma.

| Laboratory Code | Material | Depth NGF (cm) | Age B.P. | Calibrated years B.C./A.D. | Authors |
|---|---|---|---|---|---|
| Poz-14371 | *Vermetus triqueter* | 33 ± 6 | 2420 ± 30 | 748 B.C. to 401 B.C. | Devillers et al. (2007) |
| Poz-14372 | *Vermetus triqueter* | 33 ± 6 | 2435 ± 30 | 751 B.C. to 405 B.C. | Devillers et al. (2007) |
| LGQ 703 | *Lithophyllum* | 30 ± 10 | 2330 ± 130 | 789 B.C. to 111 B.C. | Laborel et al. (1994) |
| LGQ 697 | *Lithophyllum* | 65 ± 10 | 2800 ± 130 | 1386 B.C. to 766 B.C. | Laborel et al. (1994) |
| LGQ 682 | *Lithophyllum* | 40 ± 10 | 1750 ± 120 | 18 A.D. to 555 A.D. | Laborel et al. (1994) |
| LGQ 683 | *Lithophyllum* | 60 ± 10 | 2200 ± 130 | 746 B.C. to 73 A.D. | Laborel et al. (1994) |
| LGQ 684 | *Lithophyllum* | 80 ± 10 | 2340 ± 130 | 794 B.C. to 114 B.C. | Laborel et al. (1994) |
| Poz-24339 | *Ostrea* sp. | 26 ± 10 | 1895 ± 30 | 33 A.D. to 215 A.D. | Georges et al. (2010) |
| Ly-9154 | *Ostrea* sp. | 22 ± 10 | 1820 ± 30 | 91 A.D. to 318 A.D. | Goiran (1998, personal communication) |
| NA | Archaeological and biological | 40 ± 10 | – | 0 A.D. to 70 A.D. | Morhange et al. (this study) |

the case of Devillers et al. (2007) and an artificially protected fish tank in the case of the present study. Goiran and Dufraigne (in Devillers et al., 2007) dated an upper limit of *Ostrea* sp. at –22 ± 10 cm NGF on the southern quay of the channel entrance to the Roman harbor to 1820 ± 30 B.P. (Ly-9154). Nearby, Georges et al. (2010) dated another sample of the same limit to 1895 ± 30 B.P. (Poz-24339) at 26 ± 10 cm. These two measurements are slightly above our data from the fish tank and appear to reflect hydrodynamic processes such as the channeling of the water by the narrow access channel. We recall that the biological mean sea level is a dynamic level that mimics the mean level of wave energy (Laborel & Laborel-Deguen, 1994).

Our field data are also supported by glacio-hydro-isostatic model predictions obtained by Lambeck and

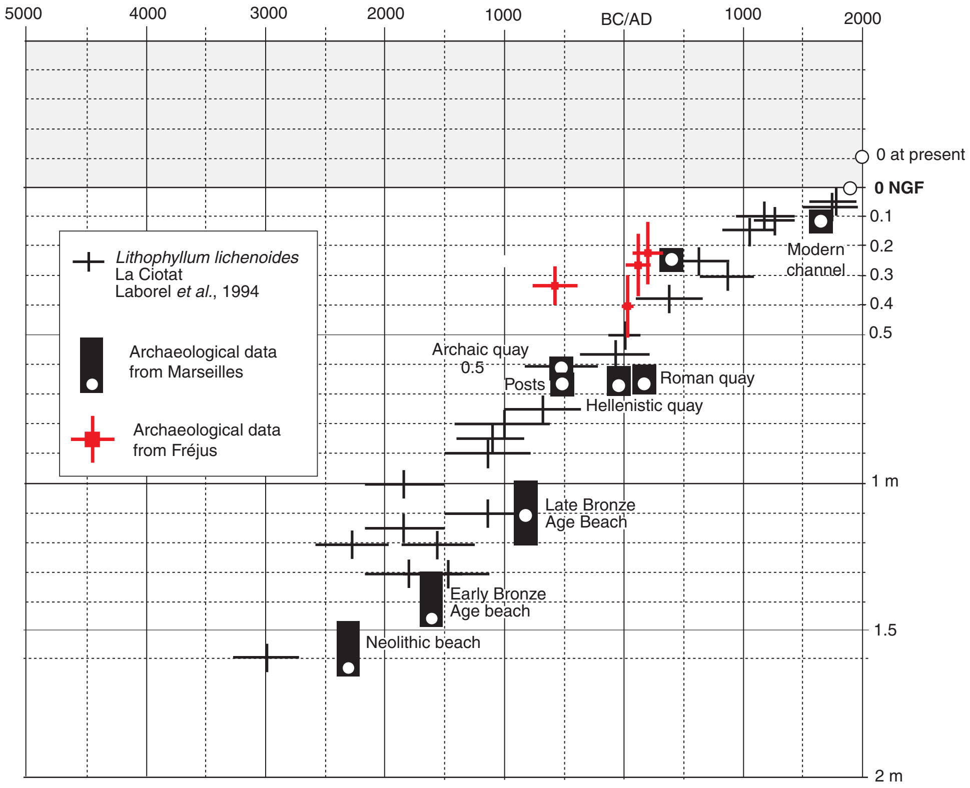

**Figure 8** Comparison of archaeological data from Fréjus with the sea-level data from Marseille. There is a notable juxtaposition of the data suggesting a slight tectonic uplift component linked to the orogensis of the nearby French Alps.

Bard (2000), who modeled sea-level change at Fréjus since 7000 years B.P. Our field data fit the predicted sea level of ~70 cm for 2000 years ago with a precision of 20 cm.

## CONCLUSIONS

Buried archaeological and biological features along the Fréjus Gulf in southern France have been examined in order to evaluate historical sea-level rise. We conclude that the sea level during the 1st century A.D. was slightly lower than at present. Referring to architectural structures and palaeozonation of marine benthos, we estimate an RSL rise of 40 ± 10 cm at Fréjus, a range in good correspondence with Evelpidou et al. (2012) who proposed a Roman sea level ranging −32 to −58 ± 5 cm on the Tyrrhenian coast of Italy. This range is considerably lower than that proposed by Lambeck et al. (2004); a discrepancy that we attribute to a different interpretation of the hydraulic position of fish tank structures relative to former sea level. Our measurements are consistent with regional archaeological evidence, historical records, and biological data (Laborel et al., 1994; Morhange et al., 2001; Figure 8). This underscores the importance of multidisciplinary research in improving our understanding of RSL changes in the Mediterranean since Roman times.

In conclusion, our new data confirm: (1) that no Holocene sea level occurs above the present sea level along the Provence coast, except in the direct vicinity of the maritime Alps near Nice (Dubar & Anthony, 1995); and (2) that RSL changes since Roman times have been very modest (of the order of a few decimeters). In Provence, the role of sea level in shaping coastal changes is therefore relatively minor in comparison to sediment inputs (Devillers & Bonnet, 2006; Devillers et al., 2007). (3) The most precise RSL results are achieved by marrying well-dated archaeological structures with biological zonation.

This paper is dedicated to the memory of Jacques Laborel (1934–2011) for his exceptional contribution to the multidisciplinary study of relative sea-level changes

The archaeological excavations (*Théâtre d'agglomération* and Kipling) were headed by M. Pasqualini and undertaken by the Town Council of Fréjus. We wish to thank P. M. Arnaud, J. G. Harmelin, and R. P. Carriol. Two anonymous reviewers and the editor Jamie Woodward are warmly thanked for their careful review and comments on an earlier version of this paper.

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