

# Biological Indicators of Relative Sea-Level Variations and of Co-Seismic Displacements in the Mediterranean Region

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## ABSTRACT

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During a study of more than ten years in tectonically active regions of the eastern Mediterranean coast notably in Greece, Turkey and Syria as well as in so-called "stable" areas of the western Mediterranean area, we have made a wide use of biological sea-level indicators (BioS.L.I.) as markers of past sea-levels. These are mainly coralline algae and invertebrates whose skeletons are well preserved as in the case of a rapid uplift of the coast, but much less so in the case of slow elevation or of submersion, whatever the velocity of the displacement. BioS.L.I. include reef-building species as well as solitary forms and boring species. Some BioS.L.I. are best adapted to the detection of slow relative movements (tectonic or eustatic) whereas others allow an accurate reconstitution of very rapid, co-seismic elevations or (more rarely) submergences. Examples put into evidence the ability of BioS.L.I. for the reconstitution of rapid and complex vertical relative movements as well as for simple monitoring of sea-level on coasts subjected to severe seismic hazard. A specific approach allows a comparative study of the possibilities offered by the principal species which may be used as BioS.L.I. in the Mediterranean area.

ADDITIONAL INDEX WORDS: *Sea-level, biological indicators, neotectonics, seismicity, Holocene, Mediterranean.*

## INTRODUCTION

This paper is an attempt to review and refine the methods of estimation in the field of relative sea-level variations with the help of biological sea-level indicators (BioS.L.I.), notably for putting into evidence slow and rapid vertical movements (linked with earthquakes or co-seismic movements) (PIRAZZOLI, 1976). The methods we describe have been used since 1979 on the coasts of eastern Mediterranean (LABOREL *et al.*, 1979; THOMMERET *et al.*, 1981; PIRAZZOLI *et al.*, 1982; LABOREL, 1986; PIRAZZOLI *et al.*, 1991; STIROS *et al.*, 1992) as well as on those of the northwestern Mediterranean basin (LABOREL *et al.*, 1983).

The use of BioS.L.I. is not new (DONNER, 1959, 1963; VAN ANDEL and LABOREL, 1964; FEVRET and SANLAVILLE, 1966) but has gained impetus as the study of sea-level variations gradually evolved from a descriptive to a multidisciplinary approach taking into account morphological, sedimentary, archeological, petrographic and biological criteria (THOMMERET *et al.*, 1981; KIDSON, 1986). In some cases, BioS.L.I. may provide an inexpensive mon-

itoring of sea level variation on coasts exposed to seismic hazard.

## RECALLING PRINCIPLES

### Mediterranean Biological Zonation on Rocky Shores

The spacial distribution of the littoral fauna and flora of rocky Mediterranean shores shows a pattern of superimposed parallel belts. A number of biological zones may be recognized in which either bioerosive or bioconstructive forces (or both) are in action (Figure 1). For a description of these zones, the reader should refer to the international scheme of PERES and PICARD (1964), (see also PERES, 1982) used in French-speaking countries and around the Mediterranean basin and the broadly similar one of STEPHENSON and STEPHENSON (1949), mainly used by English-speaking authors. (For a detailed discussion of these problems and their implication in measuring past sea-levels, see LABOREL, 1986.) These zones are:

(1) A *littoral fringe* (STEPHENSON and STEPHENSON, 1949) or *supralittoral zone* (PERES and PICARD, 1964) never submerged but wetted by surf in which the biomass is very low and mainly

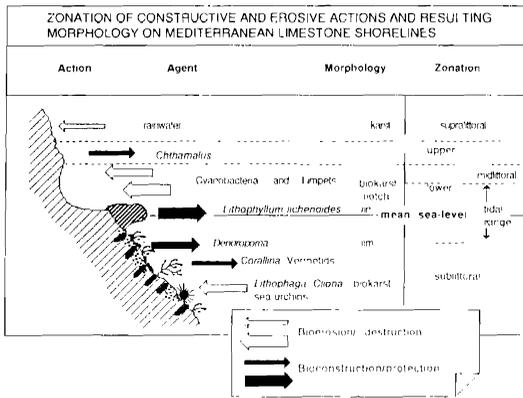


Figure 1. Repartition of erosion and construction on a vertical littoral profile in the Mediterranean.

represented by endolithic Cyanobacteria. Bioconstruction does not occur in this zone, but bioerosion is active (LE CAMPION-ALSUMARD, 1970, 1979b).

(2) A *midlittoral* zone submerged at close intervals by waves (and to a lower degree by tides) and displaying a pattern of parallel algal belts, with biomass and species diversity increasing downward. Erosive agents are important: Cyanobacteria in the upper part of the zone, limpets (*Patella* spp.) and chitons in the lower part, help shaping the intertidal erosion bench and tidal notch. Constructional elements such as the rim-building coralline rhodophyte *Lithophyllum lichenoides* may also exist (northwestern Mediterranean basin).

(3) An *Infralittoral* (*sublittoral*) zone ranging from MSL down to a depth of 25–35 m, whose upper part is densely populated by brown algae (*Cystoseira* and *Sargassum*), coralline rhodophytes, fixed vermetid gastropod mollusks (*Dendropoma petraeum*, *Vermetus triqueter*, *Serpulorbis arenarius*) cirripeds like *Balanus* sp., and also by active erosive agents such as Clionid boring sponges, sea-urchins and the rock-boring pelecypod *Lithophaga lithophaga*.

### Littoral Morphology

On limestone coasts, the local balance of bioerosion versus bioconstruction leads to the development of several types of vertical profiles (GUILCHER, 1953; DALONGEVILLE, 1977) which may be preserved for a long time when dried up by land uplift or resist underwater erosion when sub-

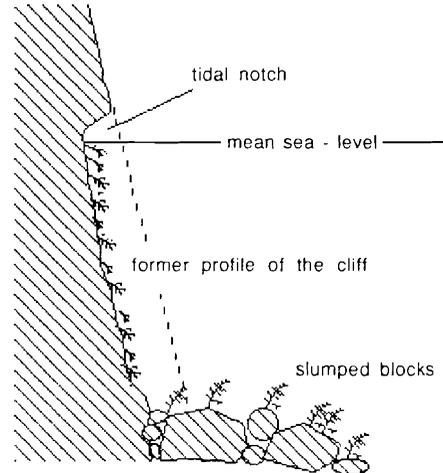


Figure 2. Tidal notch on a slowly subsiding limestone coast, Makris Gyalos, Zante. Gradual erosion gives the cliff a characteristic offset profile; slumped rocks tend to accumulate on the bottom.

merged. A *midlittoral* tidal notch (Figure 2) is carved by limpets (*Patella rustica*, *P. aspera* and *P. ulysiponensis*) and endolithic cyanophytes (LE CAMPION ALSUMARD, 1979a,b). Horizontal benches or tidal platforms also develop on soft rocks such as sandstones or marly limestones (GUILCHER, 1953, 1979; DALONGEVILLE, 1977). In the *infralittoral* zone, boring sponges of the genus *Cliona* as well as the sea-urchin *Paracentrotus lividus* and the rock-boring mussel *Lithophaga lithophaga* are responsible for a rapid erosion of the underwater limestones (SPENCER, 1992; TORUNSKI, 1979; BROMLEY *et al.*, 1990).

Various types of incurring organisms may build reef-like bioconstructions or develop a protective cover on the outer edge of the latter platforms and on vertical cliffs (PERES and PICARD, 1952) (Figure 3).

### Definition of a Biological Mean Sea-Level

The limit between *midlittoral* and *infralittoral* zones, *sensu* (PERES and PICARD, 1964) may be defined as a "biological mean sea-level" marked by a sudden increase in species diversity. Fixed species with a narrow depth range located just over or just under the latter limit are of special importance as sea-level indicators. This biological sea-level corresponds closely with distinctive features such as the vertex of the tidal notch (PIRAZZOLI, 1986) or with the tidal flat of the ero-

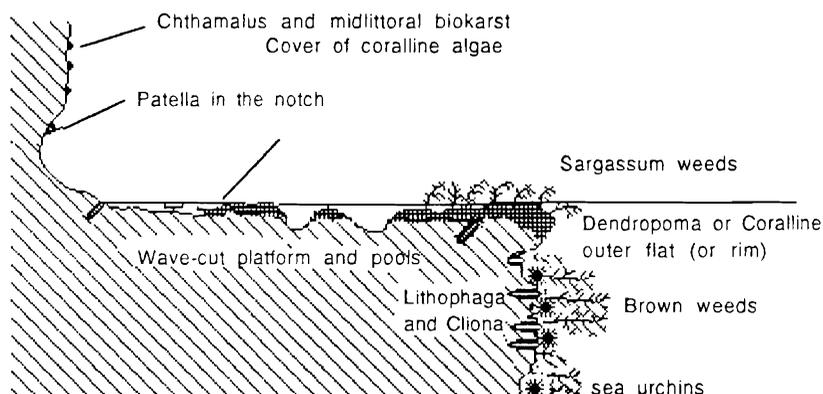


Figure 3. Wave cut platform and notch, Assos, Cephalonia island, Greece. Biological mean sea-level is a few cm above the surface of the platform. An outer rim attaining biological sea level is often formed by algae and invertebrates growing at the outer edge.

sion platform. Seasonal or aperiodic sea-level changes are slight in the Mediterranean and have little or no influence upon marine biological and geomorphological zonation so that they may be neglected for all living forms with a lifespan of more than one year such as vermetids, clionid sponges, barnacles and *Lithophaga* which integrate sea-level variations on a yearly scale and the upper limit of their populations is well delineated.

The reality and fine resolution of such a biological sea-level is easily demonstrated when a rock block is removed from a pier or jetty after a few years sojourn in sea water around m.s.l. After a few weeks in the sun, all the organic matter is removed and a fine microzonation may be observed: the biological sea-level appears as a slightly undulated line between the lower cupulae of limpet erosion and the highest perforations of *Cliona* and *Lithophaga* (Pl. 1).

Bioerosive morphological elements, bioconstructions (algal and vermetid rims) and the upper limits of elevated remains of non-building fixed plants and invertebrates (oysters, barnacles, solitary vermetids, *Lithophaga* shells) are commonly used as *biological sea-level indicators* (BioS.L.I.) now considered to be among the most reliable sea-level indicators (KIDSON, 1986).

#### FIELD USE OF FOSSIL BIOLOGICAL SEA-LEVEL INDICATORS

What May Be Demanded of Fossil BioS.L.I. in Field Conditions?

(1) Fossil BioS.L.I. must provide reliable information upon the general direction of the rel-

ative displacement of sea-level, and give hints about simple or complex up and down episodes.

(2) They must allow an accurate and reproducible measurement of the displacement.

(3) They must provide biological material datable by radiochronology.

(4) They must provide valuable data about the direction of sea-level change, from very slow (tectonic, eustatic, isostatic) to near-instantaneous (cosmic).

(5) Results obtained should be coherent with those obtained by converging multidisciplinary approaches (morphology, archaeology, geology and so on). For all these questions, correct answers may be supplied by fossil BioS.L.I. provided that: a suitable indicator is available, an accurate study of local conditions of preservation and sedimentation is done, and a correlation with other types of S.L.I. is possible.

#### Determination of Attitude

This problem has been extensively developed elsewhere (JARDINE, 1986; LABOREL, 1979, 1986) and we shall limit ourselves to a brief recall of the principle. The altitude of elevated or depressed shorelines is best estimated by direct measurement of the altitudinal difference between the upper limit of the elevated (or submerged) remains and the corresponding upper limit of its present homologue, taken as the local datum level. This can easily be done with species like *Dendropoma* or *Lithophyllum lichenoides* whose populations have a very narrow vertical range closely associated to MSL (see below). For species

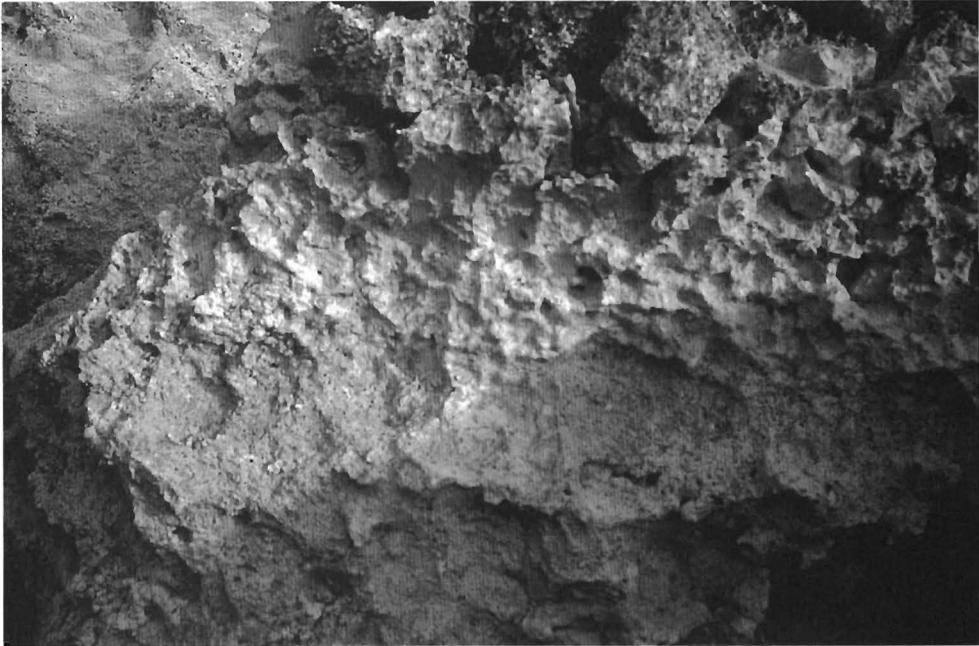


Plate 1. A "man made" elevated sea-level on a block of limestone breccia taken out of a harbour pier after a few years of submersion. Upper part of block has a ragged surface since *sublittoral* erosion dissolved the cement of the breccia. Middle part has a smooth cupulate surface due to the *midlittoral* action of limpets. Lower part has a smooth finely perforated surface shaped by Clionid sponges with greater cupula made by sea urchins. Biological sea-level runs horizontally at the limit between limpet cupulae and Clionid perforations. Photograph by J. Laborel.

with a wide vertical range like *Lithophaga*, *Balanus* or solitary vermetids, good results are obtained only when the uppermost limits of both fossil and living populations are well delineated or if the fossil remains are correlated with a morphological sea-level indicator such as a tidal notch (Figure 4). Such a method makes any direct reference to the actual water level, whether observed or calculated from the tide tables, unnecessary.

When a series of measurements is to be made in a limited area, one must keep in mind that biological sea-level marks are not perfect horizontal lines but are naturally warped, even on short distances, by local variations of hydrodynamism. Each individual measurement must be done on a vertical profile of its own including both the fossil specimen and its present equivalent. Selecting a unique temporary bench mark for several measurements (JARDINE, 1986), even at a horizontal distance of a few meters is, therefore, not recommended.

The accuracy which can be obtained is variable depending on the preservation of the limits of

fossil populations as well as of local ecological conditions: an accuracy of about  $\pm 5$  cm was obtained in Crete (THOMMERET *et al.*, 1981) for a series of remarkably well preserved vermetid rims or in Euboea Island for elevated populations of *Lithophaga* burrows (STIROS *et al.*, 1992). In the western Mediterranean region, a vertical accuracy of about  $\pm 10$  to 20 cm is common on submerged and eroded lines of *Lithophyllum lichenoides* (LABOREL *et al.*, 1983). The lowest accuracy observed (around  $\pm 50$  to  $\pm 100$  cm) was found in relation to *Chthamalus* populations in rock crevices exposed to surf.

#### Problems Associated with Radiocarbon Dating

It is generally considered that aragonitic material of shells living in agitated sea-water near the surface is well suited for radiocarbon analysis (THOMMERET and THOMMERET, 1965). Calcareous algae such as *Lithophyllum lichenoides* have also proved easy to date notwithstanding the presence of inner deposited matrix and micritic cements (LABOREL *et al.*, 1983).

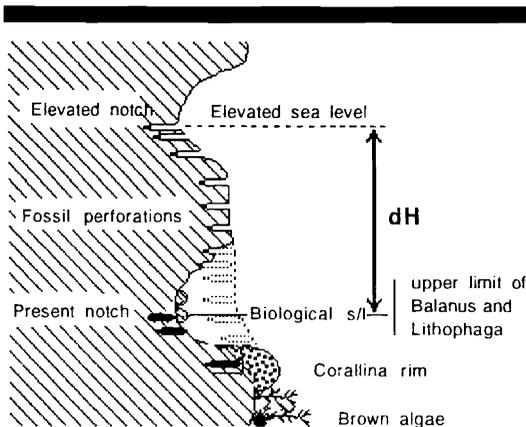


Figure 4. Principle of measuring elevated sea levels using both biological and morphological indicators, redrawn from STIROS *et al.* (1992). A direct measurement is taken inside a vertical plane joining elevated elements and their present homologue.

Recent development of direct counting methods (Tandetron) which allow the dating of small shell fragments made practical dating possible in places where no reef-building species occur (STIROS *et al.*, 1992), but accessory problems arose linked to the representativity of very small specimens and to possible contaminations by allogeous carbon sources (M. ARNOLD, *personal communication*). In any case, a careful selection of samples in the field is compulsory as well as a thorough removal of every kind of secondary deposits, either external or internal.

#### IDENTIFICATION OF CO-SEISMIC DISPLACEMENTS

##### Emergence

When emergence, whether eustatic, isostatic or tectonic, is slow (with an order of magnitude from less than one millimetre to a few millimetres per year), biological indicators living in the sublittoral are killed by emersion and their remains are slowly carried up through the midlittoral zone, where they are subject for many years to the attack of patellacean mollusks and rock boring cyanophytes. Such small elements as vermetid tubes, corals or bryozoan colonies are smothered and disappear in a matter of a few years to a few decades. Reef structures (algal rims, vermetid and coral reefs) on the contrary are more or less deeply etched but not destroyed, and their eroded remains may still be used as sea-level markers as was done in many parts of the world for elevated

reefs or algal constructions. In case of a *very rapid uplift* (generally linked to a seismic event), the preservation of elevated remains depends both upon the rapidity and upon the vertical amplitude  $D$  of the displacement (Figure 5). If  $D$  is smaller than or equal to the amplitude  $H$  of the midlittoral zone (particularly in strongly exposed situations), exposed remains are carried up into the new midlittoral erosion zone and rapidly destroyed, as in the preceding case.

When  $D$  is greater than  $H$  (as in a calm environment with a narrow midlittoral zone), fragile shells are carried up directly into the upper midlittoral or supralittoral zone where the erosion rate is much slower, and so may be preserved for long periods, especially in dry regions like southern Greece or when they are sheltered from direct impact of rainwater in a cavity or under an overhanging surface. Accurate criteria of co-seismic uplift are difficult to draw: preservation of fine details is generally the best proof of a rapid uplift. But some important exceptions occur:

##### (1) Case of Upper Midlittoral Species

In case of an upward movement, fixed species which live in the midlittoral zone are killed exactly as sublittoral species are, but their remains have a smaller distance to travel before entering the supralittoral zone than those of species living in the sublittoral and, hence, they are subject to midlittoral erosion for a shorter time. This also means that they can be preserved in case of a slower movement. This is especially true for the few forms which, like chthamalid barnacles, develop high in the upper midlittoral zone. For the latter species, even a very small uplift will bring their remains out of reach of midlittoral erosion, and it does not need to be a rapid one. In fact, chthamalids may be preserved in all cases of upwards displacement of the shore and are never a good proof of co-seismic movement unless other types of indicators point to the same conclusion.

##### (2) Case of Sheltered and Sedimented Area

The vertical extension of the midlittoral zone is much restricted in relation to exposed areas, and the action of midlittoral erosion is weak. Elevated remains may be remarkably preserved and allow very accurate measurements provided that erosion by rain and wind has not destroyed them. The co-seismic nature of the uplift must be looked for in the absence of intermediary benchmarks, biological attack on oyster shells and so on. In

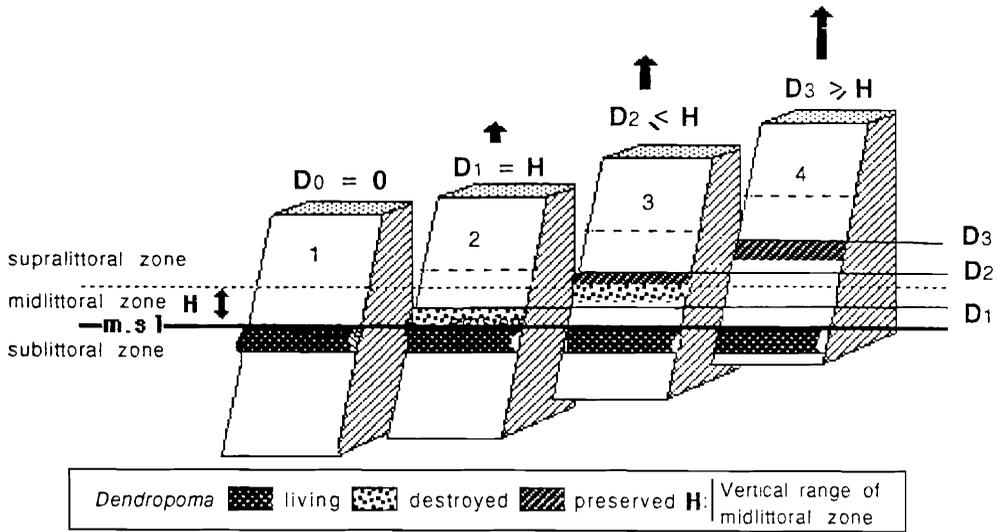


Figure 5. Diagram showing tectonic uplift of a coastal block with subsequent erosion of a vermetid rim elevated by vertical upward movements of increasing amplitude: if the jerk is a small one (block 2) *Dendropoma* are elevated into the midlittoral erosion zone and are destroyed in a few years. In case of a stronger jerk (blocks 3 and 4) part or all *Dendropoma* tubes are brought upwards into the supralittoral zone and are preserved for long.

places subject to sedimentation, like harbours or lagoons, either natural or artificial, preservation of fragile organisms may occur not only through seismic uplift but also when the latter have been killed and covered by natural sedimentation or by man-made earthworks. On a slowly rising coast, subsequent washing off of sediment by rainwater may uncover fine biological sea-level marks, whose perfect preservation may lead to a false interpretation of co-seismic movement. The true situation can generally be established by a sedimentological study of the environment.

### (3) Case of Endobiotic Fauna

Animals living in crevices or cavities of the rock are naturally protected against midlittoral erosion since they live in a dark environment where eroding Cyanobacteria cannot develop and to which rasping mollusks have little access, and no food to find. So it is not rare that breaking elevated coastal rock (or harbour masonry) may bring to light perfectly preserved remains of small endobiotic vermetids, balanids and serpulid worms in places where any other types of biological remains have been completely removed long ago. Such a problem was met several times during our Greek surveys, notably in the Gulf of Corinth and

on the western coast of the Euboean gulf. In such a situation, altitudinal reference with the corresponding sea-level is generally difficult to establish unless an upper limit of the endobiotic populations can be traced.

Two questions remain: What is the minimum speed of a co-seismic movement, and where can we place the limit between "rapid neotectonic" and "co-seismic"? Such a problem may be academic in most cases, but it is sometimes possible to get interesting results from biological observations. Working in the seismically active eastern Mediterranean basin confronted us with a number of such cases of near instantaneous uplift under the action of earthquakes (THOMMERET *et al.*, 1981; PIRAZZOLI *et al.*, 1982; PIRAZZOLI *et al.*, 1991; STIROS *et al.*, 1992). On a rocky, exposed coast such as that of western Crete, preservation of fragile species such as bryozoa or small corals with all their details is so perfect that these remains cannot have been exposed in the midlittoral zone for more than a few hours or even less if the water was rough at the moment of the quake. Conversely, well preserved oysters or *Lithophaga* shells associated with a disrupted morphological profile are excellent indicators of tectonic movement, but the uplift may as well have been a matter of a few

hours, weeks, or months. A moderate degree of erosion on a disrupt profile is suggestive of a rapid movement, geologically speaking, although it may be have appeared slow (or even have not been perceived) to the contemporary observer. In some cases, written historic records like those existing for the harbour of Seleucia Pieria (EROL and PIRAZZOLI, 1992) may provide important indications which reinforce the biological evidence.

Finally, the evidence for the co-seismic instantaneity of the uplift of a shoreline may be summarized as follows:

**Very Strong Evidence.** Elevated infralittoral features are perfectly preserved, including the smaller details of skeletons on the littoral rock of a rocky coast open to the surf. Examples: western coast of Crete (THOMMERET *et al.*, 1981); Rhodes (PIRAZZOLI *et al.*, 1982), or southern Cephalonia (PIRAZZOLI *et al.*, *in preparation*). Lines marking the upper boundary of elevated *Lithophaga* boreholes preserved with the shell inside are a very good proof provided that the shells did not develop into an endobiotic environment or were not preserved by sedimentation (STIROS *et al.*, 1992).

**Weak Evidence.** Places where well preserved elevated remains are those of midlittoral or endobiotic species. Additional evidence such as the vertical discontinuity of elevated populations or of morphological indicators such as notches must then be looked for (PIRAZZOLI, 1979, 1986).

**No Evidence At All.** Places where, for example, elevated *Chthamalus* are the one and only indicator of uplift.

**Evidence of a Slow Uplift.** We have no personal experience of such a case which seems to be rare in the Mediterranean area. It might be deduced from the complete destruction of all kinds of unprotected fragile remains such as solitary vermetids during the slow crossing of the midlittoral zone and from the erosion of bioconstructed features such as algal or vermetid rims which would present a continuous, non disrupted, profile.

Very few regional studies have taken this problem into account. A most interesting case is that of coasts which are thought to have been submitted to hydro-isostatic compensatory movements. What was the true velocity of the vertical sea-level variations? We are particularly concerned with the problem of such tropical coasts as these of north eastern Brazil, where we observed important elevated vermetid and coral formations (DELIBRIAS and LABOREL, 1971; LABOREL,

1979), some of them strongly eroded, others showing surprisingly little erosion.

### Submergence

Determination of the velocity of a submergence movement is much more difficult than for emergence since many biological sea-level indicators are either rapidly destroyed by sublittoral erosion or cannot be of any use if preserved unless carried down to a depth greater than the lower limit of the vertical range of the considered species. So only littoral bioconstructing species with a very narrow vertical range, such as *Lithophyllum lichenoides* or *Dendropoma petraeum* may be of some use. For such rims it is often possible to obtain information from the distribution of their drowned remains underwater: continuous or near continuous drowned remains under the present feature are generally found in case of a slow submergence. This is the case of drowned *Lithophyllum* rims in western Mediterranean (LABOREL *et al.*, 1983). A more rapid variation would not provide sufficient time for the development of a bioconstructed rim at intermediate depth and drowned rims would thus appear clearly separated one from the other.

Unfortunately, the limit between "rapid" and "co-seismic" velocity is extremely difficult to trace. Elevated vermetid rims of western Crete have been interpreted by us (THOMMERET *et al.*, 1981) as having been subjected to a series of vertical downward movements prior to their final (and undoubtedly co-seismic) uplift. The co-seismic nature of these downward movements was recently questioned by ADEY (1986) on the basis of a comparison with our preliminary results on drowned *Lithophyllum* rims in western Mediterranean.

ADEY's objection is interesting: the submerged and elevated formations of western Crete are separated from one another by definite vertical steps and thus appear to have been drowned in a series of rapid downward movements alternating with standstills (or slower submergence), and several distinct shorelines may be recognized (THOMMERET *et al.*, 1981; Figures 2 and 4), but evidence for an instantaneous co-seismic downward displacement is not as compelling as it is for the final upward jerk. Conversely, our latest studies on several drowned *Lithophyllum* rims in the western Mediterranean (*in preparation*) have failed to put into evidence any such succession of rim and steps, which our first, and limited, studies had suggested (LABOREL *et al.*, 1983).

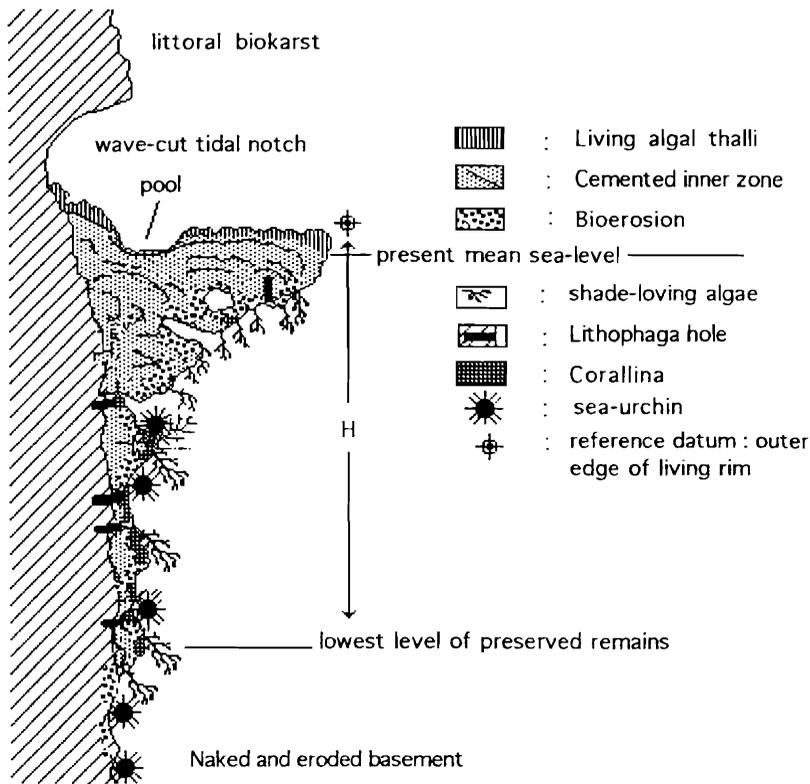


Figure 6. A typical profile on limestone cliffs in the region of Marseilles showing the disposition of the *Lithophyllum lichenoides* rim, developing in the lower part of the wave cut notch, the vertical range of living thalli, the offset profile of the underwater cliff and gradual disappearance of algal submersed remains under the influence of present sublittoral bioerosion.

### CASE STUDIES

#### Slow Submergence: The *Lithophyllum* Rim in the Western Mediterranean Basin

Well developed *Lithophyllum*-built formations are preserved underwater after submergence (LABOREL *et al.*, 1983). Bioerosion (mainly by sea-urchin *Paracentrotus lividus*, boring sponges such as *Cliona* spp. and the boring date-mussel *Lithophaga lithophaga*) is very strong and limits conservation to a few millenia. Sites for a good conservation are generally narrow and dark canyons with vertical slopes affording good conditions for *Lithophyllum* development and conservation through the development of a protective cover of shade-loving calcareous algae such as *Corallina elongata* or *Lithophyllum incrustans* (Figure 6). The best conservation was found in western Corsica, on the island of Port Cros and Ile du Levant and on the cliffs of La Ciotat (Southern France).

In the latter stations, a near continuous cover of submerged algal remains was found down to a maximum depth of 1.6 m, with an oldest date of  $4350 \pm 130$  BP (LGQ 762, R. LAFONT). In spite of former presumption (LABOREL *et al.*, 1983), no convincing proof was found of any type of discontinuity which would have been created by the alternance of periods of more or less rapid movement, either tectonic or eustatic (see above).

#### Cases of Rapid Co-Seismic Uplift

##### Datable Material and Morphological Indicators: Euboea Island (Greece)

A fossil tidal notch with a set of *Lithophaga* perforations is elevated just over the present one without intermediary traces (Plate 3). A good agreement between the upper limit of perforations and the vertex of the notch exists in both present and elevated features. Several measure-

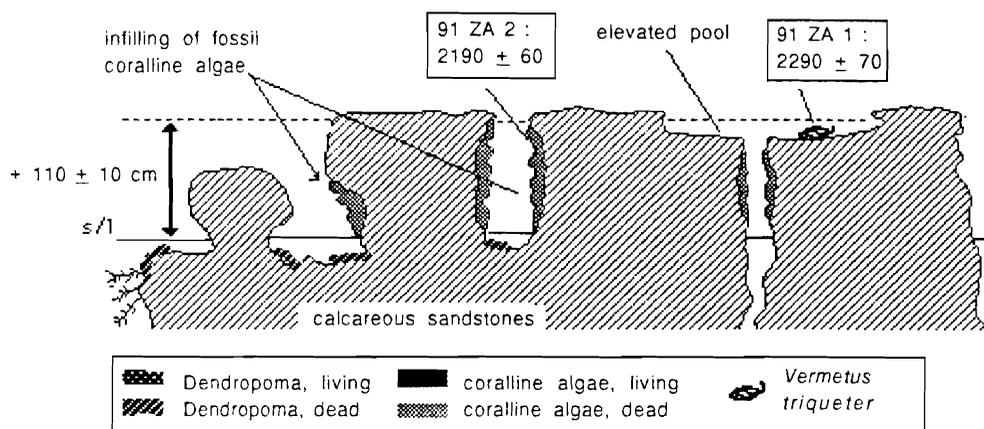


Figure 7. Dafni beach, Skopos peninsula, Zante, Greece. Bedrock shows traces of littoral erosion (littoral pans) with perfectly preserved *Vermetus triqueter* *in situ* and thick algal constructions on vertical surfaces.

ments were taken on different faces of rocks where the upper limit of perforations is intact in order to compensate for differences due to exposure and local profile. In such conditions, a maximum accuracy of  $\pm 5$  cm was estimated for this co-seismic uplift of 70 cm which occurred between 510 and 380 BC (STIROS *et al.*, 1992).

#### Datable BioS.L.I. with Minor Morphological Indicator: Dafni Beach, Zante

A rock promontory, slightly east of the beach shows well preserved incrustations of coralline algae on vertical surfaces and abundant vermetid remains in elevated tide-pools (Figure 7). A positive sea-level difference of  $110 \pm 10$  cm was estimated by direct altitudinal measurement of dead features (*Dendropoma* and rim of solution pools) taking as a reference datum the corresponding living features on the same portion of coast. The very rapid, co-seismic, nature of the upheaval was indicated by the perfect preservation of short lived specimens such as *V. triqueter* whose thin shells showed no trace of midlittoral bioerosion. This uplift probably occurred between 200 and 500 AD (PIRAZZOLI *et al.*, in preparation).

#### Uplift Without Morphological Indicators: Myrtos Gulf, Cephalonia (Greece)

On cliffs of hard limestone without any tidal notch, a direct measurement was done between the upper limit of dead elevated *Dendropoma* veneer and the upper limit of the living populations

of the same species. Remains being thin and patchy and marine erosion strong, observation was difficult and vertical accuracy was only  $\pm 10$  cm for an uplift of + 50 cm. This uplift movement occurred at the time of the AD 1953 earthquakes (STIROS *et al.*, in preparation).

#### Examples of Complex Movements

##### Cephalonia

The eastern coast of Cephalonia island near the village of Karavomylos bears elevated vermetids which, at first glance, seem to be correlated with an elevated notch. A closer observation shows, however, that the upper limit of the dead vermetids is 15 to 25 cm higher than the vertex of the elevated tidal notch instead of being at or very near the latter, as is the case for living populations on a stable coast. *Dendropoma* tubes found over the vertex are one-layered and seem to belong to the same generation (Figure 8).

This apparent anomaly may be interpreted according to the following sequence of events:

(1) A tectonically calm period (a few centuries?) allowed the excavation of a notch. *Dendropoma* developed at their normal level; *i.e.*, with their upper limit at the vertex of the notch.

(2) A slight rise of relative sea-level ( $-15$ – $20$  cm) allowed *Dendropoma* to colonize the upper part of the notch or, when no notch was developed, to fill up the supralittoral biokarst excavations (Plates 2 and 3). The time scale for this movement must have been short (a few years to a few decades) since there had been time for col-

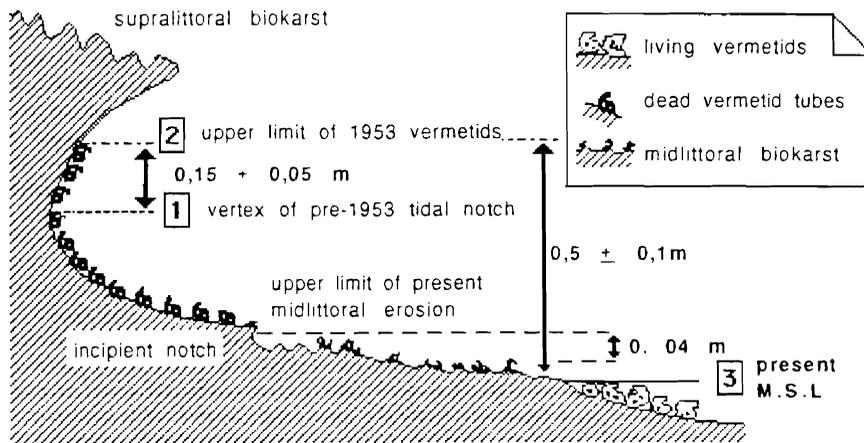


Figure 8. Karavomylos, Cephalonia island, Greece. Present sea-level is about 35 cm below the vertex of the elevated notch. Dead, elevated and well preserved Vermetids (*Dendropoma petraeum*) veneer the inside of the notch up to 0.15 m over the vertex. *Interpretation:* after a period (1) of relative stability leading to the excavation of the notch, a (slow) negative movement of the substratum (2) about  $-0.15$  m allows Vermetids to colonize the upper part of the notch for a few years. Then a final upward jerk (3) about  $+0.5$  m, corresponding to the earthquakes of 1953 brings the shoreline very rapidly to its present position. An incipient notch (about 0.04 m deep in 40 years) is developing at present sea-level.

onization by *Dendropoma* and young *Lithophaga* (burrows not exceeding 2 to 2.5 cm in diameter) but not for the corresponding upwards development of the tidal notch itself, since notch excavation is a much slower process than the installation of a population of *Dendropoma*.

(3) A very rapid (co-seismic) uplift of 0.5 m, corresponding to the 1953 earthquakes and leading to the present level (level 3). The rapidity of the movement is illustrated by the perfect state of preservation of the dead vermetid tubes which did not reside in the midlittoral zone.

(4) The present period of relative sea-level stability corresponds to the excavation of an incipient tidal notch of about 3 to 5 cm in 40 years; *i.e.*, about 1 mm per year, a rate which matches the results of previous authors quite well, notably TORUNSKI (1979) in the northern Adriatic and KELLETAT (1991) in Crete.

In a number of places in the island of Cephalonia (Argostoli, Poros, Karavomylos), it appears that the 1953 quakes occurred after a period of slow sea-level rise apparently linked to a downward movement of the island basement. Should this movement be proved to be pre-seismic and linked to the preparation of the major earthquake, then a periodical (an relatively inexpensive) biological monitoring of the shoreline animal pop-

ulations might be very useful as a preventive source of information.

#### Problems Linked to the Study of Ancient Harbours and Nearshore Constructions

At Lecheo and Mavra Litharia, ancient harbours on the Gulf of Corinth (Greece), some difficulties were experienced when attempting to select datable material on the elevated ruins.

Stones bearing many perforations and incrustations occurred locally in the walls, but it soon appeared that some of them were clearly out of context. For example, a stone with rounded angles and *Lithophaga* perforations all around was included in a row of intact stones; it had probably been collected on the shore or in shallow water by the harbour builders in order to be included in the masonry. The marine organisms borne by such a type of block should not be used as sea-level indicators; if dated, they would date the building (or repair) of the wall and not the period during which the latter was submerged. In the same way, the perfect preservation in the sediment of a well defined line of *Balanus* shells, oysters or *Lithophaga* burrows on a quay wall, as was the case in Marseilles (PIRAZZOLI and THOMMERET, 1973) will provide a date and a sea-level datum corresponding to the filling-up by sedimentation



Plate 2. Example of a co-seismically elevated shoreline outside the Mediterranean region. In the Gulf of Tadjurah near Djibouti (Republic of Afars and Issas). A quay built around 1960 was uplifted about one metre in 1984 by one or several earthquakes generated by a nearby volcanic eruption. Uplifted biological sea-level is indicated by the uppermost limit of dead oysters. Level of living oysters is shown by the tool at lower left. Photograph by J. Laborel.

of the harbour basin; *i.e.* to its latest period of use which may be several centuries younger than the building of the quay. In case of complete destruction of the incrusting animals growing on walls or quays by weathering after emersion, many endolithic (cavity-dwelling) fixed invertebrates such as serpulids, barnacles and non-building vermetids may still be available for study inside the slits and cracks of the masonry and may be used for dating past sea-levels (and even for levelling, provided their upper limit is still to be seen).

The best suited BioS.L.I. for archaeological study are: either a clear-cut uppermost limit of perforations, set across a whole architectural element (such as a wall or quay), or lines of incrusting invertebrates such as *Vermetus triquetter*, the latter species being also an excellent indicator of co-seismicity.

#### SPECIFIC APPROACH

*Lithophyllum lichenoides* Philippi, *Rhodophyta*, *Corallinacea*

This midlittoral plant builds rims (DELA-MARE-DEBOUDEVILLE and BOUGIS, 1951; PICARD,

1954; BLANC and MOLINIER, 1955; BOUDOURESQUE *et al.*, 1972) which are diversely referred to as "trottoir à *Tenarea*", "trottoir à *Lithothamnion*", or "trottoir à *Lithophyllum tortuosum*". The rim develops in shady coves of cliffs exposed to surf and its inner structure (BLANC and MOLINIER, 1955) consists of an outer layer of living thalli, a few centimetres deep, a hardened zone resulting from diagenesis and cementation processes and a lower eroded surface covered by shade loving algae and invertebrates. *Lithophyllum* rims are limited to the western Mediterranean basin, but the plant has a much wider repartition.

**Vertical Range.** *Lithophyllum lichenoides* is one of the Mediterranean littoral species with the narrowest vertical biological range (30–50 cm) and the rim is the highest biogenic building in the Mediterranean, slightly over MSL (lower midlittoral). Rims over 1 metre wide may occur in places exposed to strong wave action.

**Linkage with Erosion Patterns.** On limestone coasts, the *Lithophyllum* rim develops at the base of the midlittoral tidal notch and may even tend to fill it up (MORHANGE *et al.*, 1992).

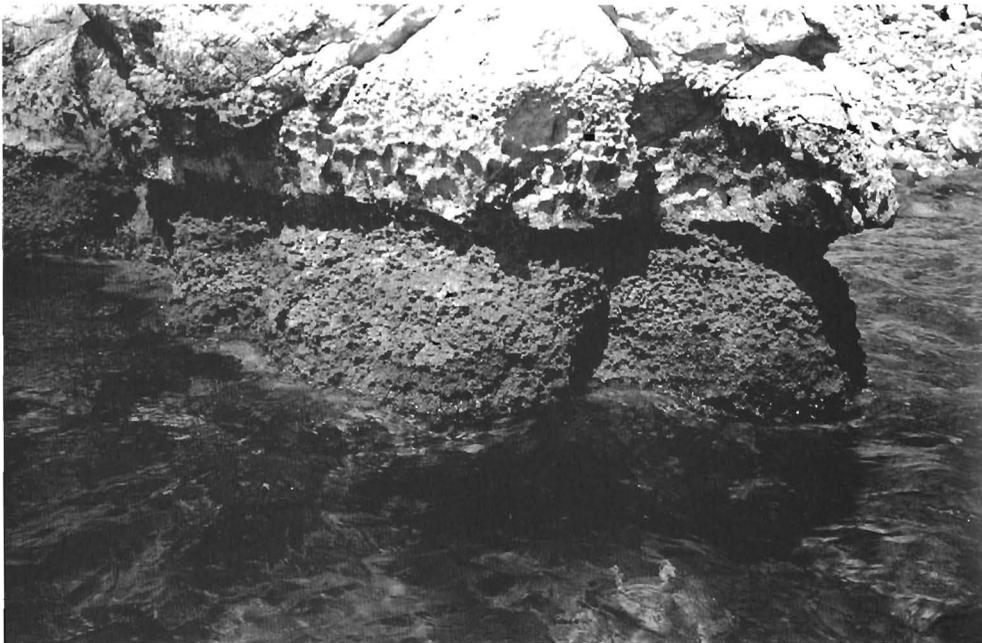


Plate 3. Detail of an uplifted shoreline along the south coast in the central part of Euboea island. The co-seismic nature of the uplift is indicated by the near perfect preservation of the notch at  $+1.15 \pm 0.2$ . *Lithophaga* shells preserved inside their burrows have been dated by Tandetron at  $3130 \pm 120$  radiocarbon years BP (STIROS *et al.*, 1992). Photograph by J. Laborel.

**Resistance to Erosion.** Living or unconsolidated thalli are easy to erode but the rim itself has an extremely good resistance to erosion due to its hardened core.

**Altitudinal Accuracy.** Fair to excellent following the preservation of eroded remains. Accuracy is generally about  $\pm 10$  cm in good conditions, rarely over  $\pm 20$  cm.

**Radiocarbon Dating.** Dating is generally easy, provided samples have been correctly sampled (possibility of confusing with other types of algal constructions) and cleaned of any kind of secondary, possibly younger, incrustations. *Cliona* perforations filled up by younger cements are the commonest case of error. Several recent control datations of living or recently dead thalli done by Dr. R. LAFONT at the Laboratoire de Geologie du Quaternaire in Marseilles yielded "modern" ages and not values around 400 years like marine shells (STIROS *et al.*, 1992), so it seems probable that *Lithophyllum lichenoides* directly assimilates atmospheric carbon dioxide with no indication of "reservoir effect" due to the uptake of marine carbon dioxide (STUIVER *et al.*, 1986).

**Uplift.** No example of slow uplift of *Litho-*

*phyllum* rims is known in the Mediterranean. An isolated case of localized tectonic uplift about 5 m was described on the flanks of the Etna volcano near Taormina (OTTOMAN and PICARD, 1954).

**Submergence.** *Lithophyllum* rims are the commonest markers of (slow) submergence in western Mediterranean (LABOREL *et al.*, 1983, *unpublished data*); no case of co-seismic submergence has been described up to now in the Mediterranean region although the *Lithophyllum* rim should be a perfect indicator of such a phenomenon.

*Dendropoma (Novastoa) petraeum* Monterosato,  
*Mollusca, Gastropoda, Prosobranchiata,*  
*Vermetidae*

This fixed Mediterranean species is often found as thin incrustations; but in the warmer parts of the Mediterranean basin, it may develop in association with the coralline rhodophyte *Neogoniolithon notarisii* and give reef-like structures of variable form and size; *i.e.*, rim, (MOLINIER, 1955), "trottoir" or atoll-shaped (SAFRIEL, 1974; KELLETAT, 1979). *Dendropoma petraeum* lives in the warmer regions of the Mediterranean only; sizeable "reefs" are limited to the central and ori-

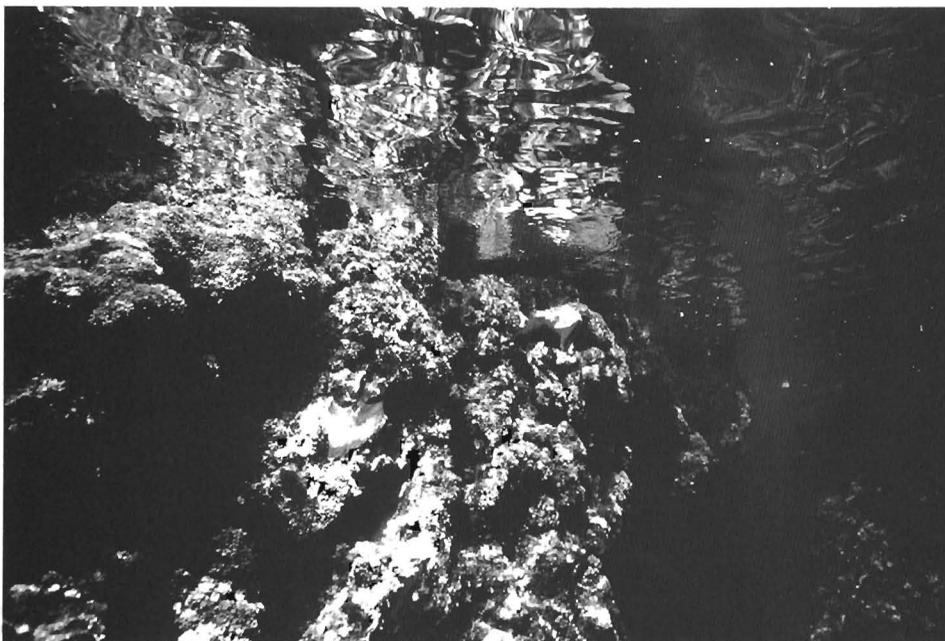


Plate 4. Underwater photograph of a submerged algal rim built by *Lithophyllum lichenoides* in western Corsica (Marine Reserve of Scandola, regional Park of Corsica). White scars of sampled submersed remains are visible in two places. Vertical repartition of drowned remains is nearly homogeneous, indicating a slow submergence under the influence either of eustatic movement of sea-level, or crustal subsidence (or a combination of both phenomena). Radiocarbon dates increase regularly downwards from modern at present level to more than 3000 BP at a depth of 1.6 metre (LABOREL *et al.*, in preparation). Photograph by J. Laborel.

ental parts of the basin, excluding the north-western region and the colder parts of Adriatic and Aegean basins. At the borders of these zones, thin non-building populations may occur. The reader should report to LABOREL (1979, 1986) for a detailed study of the use of vermetids as BioS.L.I. on rocky coasts in tropical and subtropical areas.

**Vertical Range.** The upper limit is fixed with great accuracy at MLWS (upper limit of infralittoral zone) but the lower limit is much less constant and may vary from 0.30 m to 1 m under mean sea-level and even more in exceptional cases (South eastern Spain, *unpublished data*). In places of strong surf, the algal-vermetid reef may develop a little higher (about 10 cm) than in calmer places.

**Linkage with Erosion Patterns.** *Dendropoma* is strongly linked to the outer edge of littoral erosion platforms but may develop also on shallow horizontal submerged surfaces.

**Resistance to Erosion.** Thick and cemented reef-rock is very resistant to biological erosion in the midlittoral as well as in the sublittoral zone, but

monostromatic populations especially when they develop without any cementing coralline algae are rapidly eliminated.

**Altitudinal Accuracy.** Excellent (about  $\pm 5$  cm) for seismically elevated remains (THOMMERET *et al.*, 1981), but not so good ( $\pm 20$  cm and more) in case of submersion due to the relatively great vertical range of the species.

**Radiocarbon Dating.** No special problems were met on well preserved and cleaned material.

**Slow Uplift.** Although no case is known in the Mediterranean basin, thick vermetid formations may resist for several millenia to the intense erosion prevailing in the midlittoral zone and are among the best known BioS.L.I. in warm waters: Brazil (DELIBRIAS and LABOREL, 1971), West Africa (LABOREL and DELIBRIAS, 1976), Madagascar (BATTISTINI *et al.*, 1976).

**Rapid (Co-Seismic) Uplift.** Excellent in all cases: Crete (THOMMERET *et al.*, 1981), Rhodes (PIRAZZOLI *et al.*, 1982).

**Submergence.** Thick vermetid constructions may potentially resist sublittoral erosive forces for long

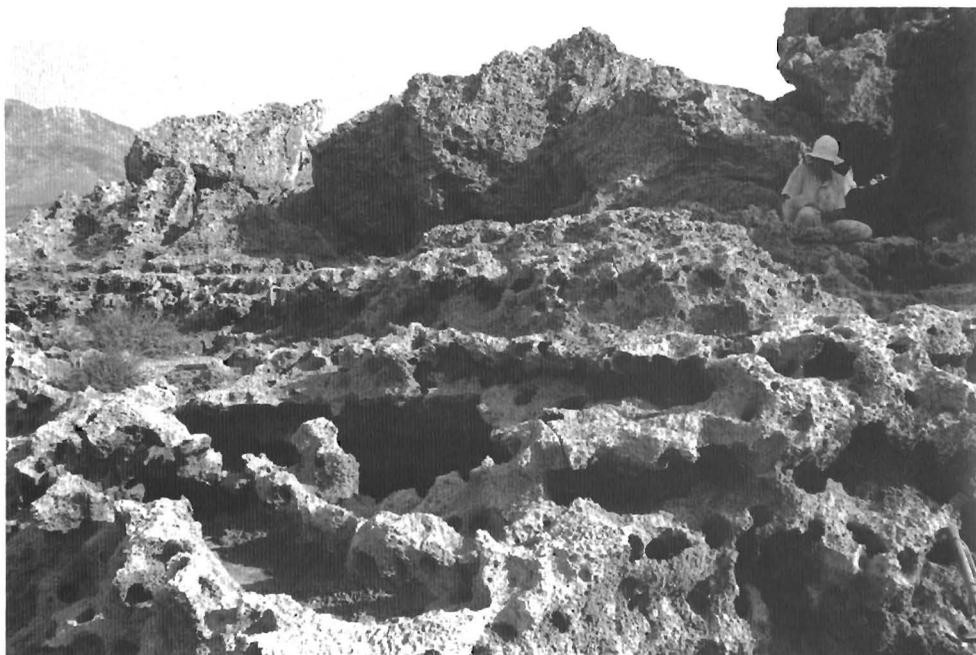


Plate 5. An example of complex co-seismic movements may be seen on the Western coast of Crete. Several separate shorelines marked by vermetid (*Dendropoma*) rims may be seen on this photograph, the highest being the more recent and dated about 1500 BP (LABOREL *et al.*, 1979; THOMMERET *et al.*, 1981). The co-seismic nature of the vertical displacements (several downward movements followed by a violet upward jerk) is indicated by the clearly disrupt profile and the clustering of the dates of lower levels. Photograph by J. Laborel.

periods. Unfortunately, since live *Dendropoma* may sometimes thrive at depths of  $-1$  metre or more, there is no practical way to decide whether a reef at that depth was actually drowned by submergence or developed *in situ*.

The mere presence of vermetid rock underwater at shallow depth is not a proof in itself of submersion unless: (1) all vermetids are dead and (2) the lower limit of living vermetids is shallower than the depth of the sample. Even in the most favourable case, the vertical accuracy would be much lower than for elevated vermetids (about plus or minus one metre) so a local survey of the living vermetid populations of the area is always necessary. During our recent survey on the Spanish coasts north of Barcelona, several dead and apparently submerged rims of vermetid rock yielded radiocarbon ages obviously too young to correlate with the evidence obtained by other indicators.

*Dendropoma* rock was nevertheless successfully used in Crete (THOMMERET *et al.*, 1981) on shorelines which had experienced a series of com-

plex seismic movements, being submerged first, then elevated. The same was done also with thin layered populations (Cephalonia, *in preparation*), (Plates 6 and 7). In both latter cases, the use of *Dendropoma* was possible only because the downward movement had been followed by an upward jerk which allowed the upper limit of the vermetids to be preserved. Recently, dead *Dendropoma*, apparently *in situ* were dredged by an Italian group at a depth of about 120 m on the western coast of Sardinia (Dr. Salvatore CARBONI, *personal communication*). At the latter depth, a vertical accuracy of plus or minus one metre is excellent and makes *Dendropoma* a promising potential indicator of low (intraglacial) sea-level stands.

*Vermetus triqueter* Gmel. and *Serpulorbis arenarius* (L.), *Mollusca*, *Gastropoda*, *Prosobranchiata*, *Vermetidae*

These two species of large solitary vermetids have related ecologies and their isolated or loosely agglomerated tubes form a thin layer on shallow



Plate 6. A complex movement of co-seismic origin in Cephalonia (PIRAZZOLI *et al.*, *in preparation*) may be deduced from biological observation. The lower part of the present supralittoral zone as well as the whole of the present midlittoral zone are covered with dead tubes of *Dendropoma*, indicating a gradual depression of about  $-40$  to  $-50$  cm followed by an upward jerk of subequal value. Morphological criteria are of little use for such a rapid succession of small scale movements. Photograph by J. Laborel.

littoral rock. *Vermetus triqueter* is more frequent than *Serpulorbis* and may sometimes build small nodules in association with crustose coralline algae.

**Vertical Range.** From upper limit of sublittoral zone (sublittoral ponds) down to 20–30 metres in the Mediterranean. In Indo-Pacific tropical areas however, *Serpulorbis annulatus* is limited to depths less than 3 m (RICHARD, 1982; PIRAZZOLI and MONTAGGIONI, 1988).

**Linkage with Erosion Patterns.** Frequent links with sublittoral pools and erosion bench.

**Resistance to Erosion.** Dead tubes of *Vermetus* and *Serpulorbis* are destroyed in a matter of a few years when submitted to midlittoral or sublittoral erosion.

**Altitudinal Accuracy.** Since solitary vermetids have a large vertical range, they may be used only when their upper limit may be traced and related to littoral morphology.

**Radiocarbon Dating.** Big tubes of solitary vermetids are easy to clean and to date by classical or AMS methods (M. ARNOLD, *personal communication*).

**Uplift—Slow/Rapid (Co-Seismic).** The rapid erosion of vermetid tubes in the midlittoral zone makes them impossible to use as BioS.L.I. in case of slow emergence. Conversely, they are among the best indicators along with small marine invertebrates such as serpulids, Bryozoa and solitary corals (THOMMERET *et al.*, 1981) for co-seismic upheaval.

**Submergence—Slow/Rapid (Co-Seismic).** Since their living range is large, solitary vermetids cannot be used as indicators in case of subsidence, either slow or rapid.

*Lithophaga lithophaga* (L.), *Mollusca*,  
*Lamellibranchiata*, *Mytilidae*

*Lithophaga* (date-mussels or boring mussels) are more or less ubiquitous limestone-boring lamellibranches. The Mediterranean species is *Lithophaga lithophaga* (L.). Colonization of substratum is slow and delayed (KLEEMAN, 1973a, b, c) but homogeneous and abundant not only on outer surfaces but also inside narrow crevices and cave environments.

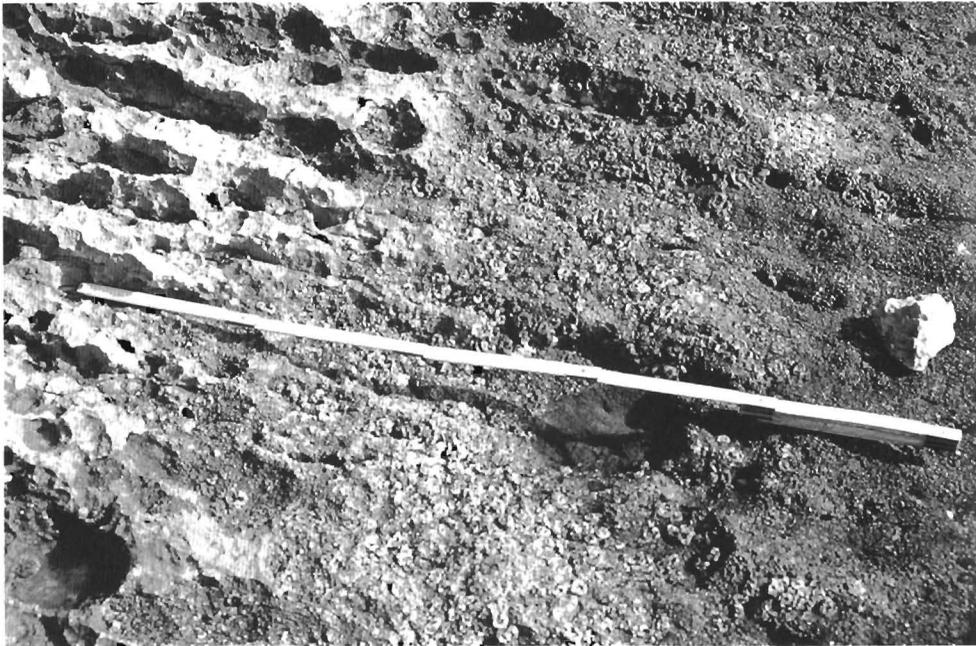


Plate 7. A detail of photograph n° 6 showing the dead elevated tubes of *Dendropoma* filling-up the depressions of the pre existing sublittoral biokarst. Photograph by J. Laborel.

**Vertical Range.** The shells may be found in limestones and calcareous sandstones, from the upper limit of the sublittoral zone down to deeper than 30 meters.

**Linkage with Erosion Patterns.** The upper limit of date mussels generally corresponds to the shoulder of the littoral notch or to the outer flat of the littoral erosion bench. In the sublittoral zone *Lithophaga* are associated with echinoderms to destroy the outer rock layer.

**Resistance to Erosion.** *Lithophaga* shells are, as a rule, rapidly destroyed after the death of the mollusk. Nevertheless, dead shells may sometimes be preserved underwater without being elevated, whether through inner sedimentation and consolidation of a marine sandy or muddy matrix inside the burrow or through the choking of the burrow aperture by encrusting organisms, resulting in the death of the mollusk and preservation of its shell, a common case in crevices and small cavities (RIEDL, 1966).

**Altitudinal Accuracy.** As is the common case among ubiquitous organisms, preservation of scarce isolated burrows cannot be correlated with a precise water level. Conversely, the preservation

of great surfaces of burrowed rock with a distinct linear upper limit is a very accurate indicator (HOPLEY, 1986). It is, nevertheless, necessary to make sure that the upper limit is not an artifact due to erosion or to the opening of a crevice by the tumbling of a rock.

**Radiocarbon Dating.** Due to the small weight of the shells and to the difficulty of their preservation, it is generally not possible to collect a homogeneous sample of 30 grams necessary for radiocarbon dating. Nevertheless, a good dating through AMS (STIROS *et al.*, 1992) is possible. Diverging dates have sometimes been obtained from samples which, when collected, seemed to belong to the same generation. A closer survey of the collecting site has showed that such difficulties may arise in sites where cracks and cavities in the rock have been populated separately and at different times by date mussels and have been closed at different periods by the development of encrusting endolithic organisms or by sediment deposition. In that latter case, shells of different ages will be perfectly preserved in case of emersion and will not be visible unless the cracks are secondarily opened by erosion or rock tumbling



Plate 8. Intact shells of *Lithophaga* are sometimes preserved *in situ* inside cracks of the rock which were filled-up and choked when still underwater by the development of endobiotic organisms. In such cases, paradoxically, frail *Lithophaga* shells may be the only proof of elevation remaining when all other types of indicators have been eroded. Such shells cannot however, in that particular case, be interpreted as a proof of co-seismic elevation. Greece, Western shore of the Gulf of Euboea. Photograph by J. Laborel.

(Plate 8). Such phenomena may be important in places where frequent earthquakes result in periodical fissuration of the rock, creating new biota for date mussel settlement. Dating problems may also arise from freshwater resurgences of karstic origin, changing the isotopic ratio of the shells (ARNOLD, *personal communication*).

**Uplift—Slow/Rapid (Co-Seismic).** *Lithophaga* shells can be excellent indicators of upwards co-seismic movements, notably in places where no vermetids or calcareous algae are available as indicators. They may also be quite useful for the reconstruction of complex movements (STIROS *et al.*, 1992).

**Submergence—Slow/Rapid (Co-Seismic).** Since *Lithophaga* can live down to important depths, submergence does not affect living populations and any use of these shells as an indicator of submergence is normally impossible. An important exception is that of temporary submergence followed by co-seismic emersion. In that latter case of sequence of movements, the study of elevated *Lithophaga* burrows can afford precious data

about the length of the submergence episode, especially if the latter has been short. KLEEMAN (1973a, b, 1976) states that *Lithophaga* larvae settle on newly submerged rock with a delay of a few years and that shells grow quite slowly, attaining their maximum size in about 80 years. So a possibility exists of estimating the duration of a short submergence (10–100 years) thanks to the statistical study of the corresponding population of *Lithophaga* burrows.

**Recommendations for Selecting *Lithophaga* shells.** (1) Preference should be given to *Lithophaga* populations with a clear-cut horizontal upper limit (or linked with a fossil erosion notch), (2) holes selected should be dug into the bedrock far from sources of fine sediment such as a beach or a river mouth. Preference should be given to shell remains not included into a sedimentary matrix, (3) holes near karstic freshwater sources must be avoided (ARNOLD, *personal communication*), and (4) elevated bedrock surface must not be covered by a layer of dead endobiotic invertebrates (foraminifers, serpulids and barnacles) indicating

that *Lithophaga* did not develop on a cliff surface but in a cryptic environment such as a crevice which was later opened by erosion.

Provided these recommendations are followed, *Lithophaga* shells preserved inside their burrow may be used successfully as indicators of rapid sea-level variations and be considered as good indicators of co-seismic movements.

#### Oysters, *Mollusca*, *Lamellibranchiata*, *Ostracidae*

With the exception of the remarkable case of a mixed construction of oysters (*Hyotissa*) and *Dendropoma* on the coasts of Turkey (PIRAZZOLI *et al.*, 1991), Mediterranean oysters are not important builders and live from surface down to 30–50 metres deep. Like *Balanus* they can be used in brackish areas and harbours as well as in open environments.

**Vertical Range.** Like *Balanus*, but with an upper limit slightly (20–30 cm) lower.

**Linkage with Erosion Patterns.** None

**Resistance to Erosion.** Excellent.

**Altitudinal Accuracy.** Like balanids.

**Radiocarbon Dating.** Oysters are generally not much appreciated (THOMMERET and THOMMERET, 1965).

**Uplift.** Like *Balanus*. Outside the Mediterranean area, a good, unpublished example was found a few years ago in the Gulf of Tajdurah where oyster reefs and oyster populations on quays were elevated about 1 metre by an earthquake, with the lower part of the reef staying alive (photo 2)

**Submergence—Slow/Rapid (Co-Seismic).** No known example of use.

#### *Chthamalus* sp. *Arthropodia*, *Crustacea*, *Cirripedia*

*Chthamalus* barnacles (especially *Chthamalus stellatus* and *C. depressus*) are common on Mediterranean rocky shores where they live scattered in the splash zone (upper midlittoral and lower supralittoral zones). Local cases of minor bioconstructions have been described (ZIMMERMAN, 1983). Although sometimes used (PIRAZZOLI *et al.*, 1985), *Chthamalus* are poor sea-level markers.

**Vertical Range.** The upper limit of *Chthamalus* is variable following local conditions of tidal amplitude, surf and topography. Range may vary from a few centimetres on a flat vertical rock surface in calm waters to several metres in a vertical crevice on a nearby, more exposed, profile.

**Linkage with Erosion Patterns.** None.

**Resistance to Erosion.** Empty shells are easily destroyed by bioerosion when submerged.

**Altitudinal Accuracy.** The vertical range of the species is so irregular that it is quite difficult to compare the upper limit of fossil *Chthamalus* to that of the corresponding living population and no accuracy better than  $\pm 0.25$  or even  $\pm 0.5$  m is to be expected. To make things worse, former periods of storminess may have led to the development of “energy elevated” fossil populations which may be erroneously interpreted as elevated sea-levels.

**Radiocarbon Dating.** The small size of the shells rarely allows datation; *i.e.*, dating by AMS method is possible but special care must be taken in cleaning the remains because deposition of calcareous material inside the shells is frequent. *Chthamalid* barnacles may (and must) be used as “last chance indicators” for dating when no other material may be found or when they can be correlated with a notch.

**Uplift—Slow/Rapid (Co-Seismic).** Since *chthamalids* live at the upper limit of the midlittoral erosion zone, they are little affected by it and dead remains may be preserved whatever the rapidity of the uplift, so that they are poor indicators of co-seismic movements.

**Submergence—Slow/Rapid (Co-Seismic).** Near immediate destruction of *chthamalid* shells by underwater erosion makes them unsuitable whatever the rate of submergence may be.

#### *Balanus* spp., *Arthropoda*, *Crustacea*, *Cirripedia*

The upper limit of *Balanus* populations has been used as sea-level indicator for a long time (DONNER, 1959; PIRAZZOLI and THOMMERET, 1973). It is situated a little over MSL in the lower midlittoral zone by French authors. Species of the genus *Balanus* are difficult to identify at the species level, especially on dead material (PIRAZZOLI and THOMMERET, 1973) and are often grouped under the designation of *Balanus* sp.

Balanids, like oysters, develop in single-layered populations or congregate in nodules or small rims. They are among the very few bioconstructors able to develop in brackish environments, hence the interest in them for the study of ancient harbours.

**Vertical Range.** Important, like *Vermetus* or *Lithophaga*, beginning at MSL.

**Linkage with Erosion Patterns.** None.

**Resistance to Erosion.** Good when emerged. Acid soils may separate barnacles from their substrate, especially on wood pilings.

**Altitudinal Accuracy.** Excellent (centimetric) provided a linear upper limit may be drawn on a certain distance on a flat vertical, open surface.

**Radiocarbon Dating.** Variations of isotopic ratio in brackish waters may cause problems.

**Uplift—Slow/Rapid (Co-Seismic).** Like solitary vermetids, balanids are excellent indicators for co-seismically elevated shorelines in brackish or harbour areas. In places where continental erosion was active after the uplift of the shoreline and no biological remains are to be found on the outer face of the rock, abundant balanids may still be preserved inside joints and crevices of harbour walls, along with serpulid tubes and other cryptic species.

**Submergence.** Balanids are not convenient for the study of submerged areas with the important exception of sedimented or filled-up harbours where the upper limit of balanid populations may have been preserved inside the sediment.

**Recommendations.** When a line of dead Balanids is found on an elevated quay or man-made structure, special attention must be paid to the sedimentary environment. If fossils are free of sediment (a frequent case in seismically elevated harbours), then the datation of the shells will give the date of the uplift. Conversely, if unearthed from a sedimented area, as in the old harbour of Marseilles (PIRAZZOLI and THOMMERET, 1973), the shells will date the last period when the harbour was filled with seawater; *i.e.*, the date of abandoning an oversedimented harbour or of its filling-up by man for urban development.

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□ RÉSUMÉ □

Au cours d'une étude de plus de dix ans des variations récentes du niveau marin dans des régions tectoniquement actives de Méditerranée orientale (Grèce, Turquie et Syrie notamment) et dans les régions plus "stables" de Méditerranée occidentale nous avons fait un usage constant d'indicateurs biologiques de niveau marin (BioS.L.I.). Ce sont surtout des Algues calcaires et des invertébrés, constructeurs ou foreurs, dont les parties squelettiques peuvent se conserver en cas de soulèvement et parfois d'enfoncement relatif du littoral. Certains BioS.L.I. sont particulièrement adaptés à l'étude de mouvements lents alors que d'autres permettent de reconstituer des mouvements rapides (notamment co-sismiques) et complexes, voire de pratiquer un suivi facile de secteurs de côtes soumis à des risques tectoniques. Une comparaison espèce par espèce complète cette étude.