Seismic Uplift of the Harbour of Ancient Aigeira, Central Greece

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Seismic uplift of the harbour of ancient Aigeira, Central Greece

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The Mavra Litharia cove, between Akrata and Derveni, in the North Peloponnesian coast (Central Greece), has been identified as the site of the harbour of the Hellenistic Aigeira, one of the very few natural harbours along the uplifting, fault-controlled North Peloponnesian coast.

Geomorphological, marine biological and archaeological data as well as radiocarbon dating of marine fossils testify to a 2 m relative land uplift since Hellenistic times (around 2000 years BP), part of which (1 m at least) was probably seismic, dated to the Byzantine period (AD 900–1200). This palaeoseismic event, as well as others deduced from archaeological data, are not included in the historical seismology records, but had probably dramatic impacts on the economic and cultural history of ancient Aigeira.

The amplitude of uplift at Mavra Litharia is of the same order of magnitude as submersion dominating the Aegean and, with the exception of the arc, the higher Holocene uplift rate recorded in this area and the surrounding regions. This result is consistent with the Quaternary uplift history of North Peloponnesus.

Introduction

Very few harbours existed in ancient times along the North Peloponnesian coast; it is sandy, fault-controlled and rather linear, with harder rocks that could form closed bays outcropping in only a few sites along this more than 100 km long south coast. In a few large ancient towns (Corinth, Sikyon, Patrai) artificial harbours have been excavated, and possibly only in the vicinity of Aigeira (Fig. 1) circumstances were somewhat favourable for the construction of a natural harbour. Very little is known about this site, but a combination of geomorphological, marine biological, archaeological and historical data may shed some light on the archaeology, history, palaeogeography and tectonics of the area.

History of the town of Aigeira

The ancient town of Aigeira is referred to both by Pausanias (VII, 26: 1–9) and Polybius (IV, 57). The town, known as Hyperisie to Homer (B, 573; o, 254) belonged to the kingdom of Agamemnon and participated in the Trojan war. Later, its name changed to Aigeira, according to a myth conveyed to us by Pausanias (VII, 26: 2–4), it flourished in Hellenistic times, and played a major role in the disputes between the Achaean and Aetolian Leagues, some time before the complete conquest of Greece by the Romans.

Important remains of the ancient town were first identified by some 19th-century travellers (Boblaye, 1835: 27; Curtius, 1851: 474; Bursian, 1862–72: 338) on the steep hill of Palaeokastro, a

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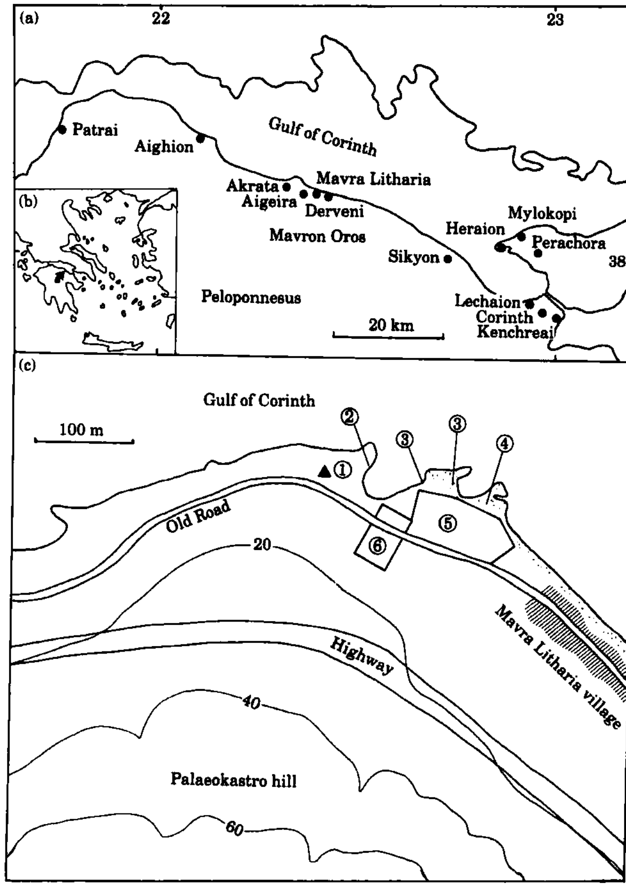

Figure 1. Location maps (c) 1; trigonometric pillar (solid triangle), area with marine Quaternary fauna; 2; fault-controlled vertical cliff with empty *Lithophaga* holes; 3; ancient hewn blocks, cemented sherds; 4; exposed vermetids, location of sample 90SS2; 5; area distributed by two villa complexes; 6; area with hewn blocks disturbed by a bulldozer in 1992. Height contours in metres. Based on the 6331–6, 1:5000 scale map of the HMGS and filed observations.

Late Pleistocene marine terrace, at the east end of the small plain of Akrata. During extensive excavations by the Austrian Archaeological Institute in 1916, 1925 and 1971–89 (Walter, 1919; 1932; Alzinger & Mitsopoulou-Leon, 1973; Alzinger, 1974; 1976), considerable remains of large buildings (theatre, defensive wall, temple of Zeus and of ?Artemis) and other findings (pottery sherds, a head of Zeus, a marble statue, votive inscriptions) mainly of the Hellenistic and Roman periods, but also the Mycenean period, such as graves, pottery sherds (Verdelis, 1958) were brought to light.

The harbour

The harbour which, according to Pausanias and Polybius, Aigeira possessed was first identified by Leake (1836: 386–387) with ancient ruins at the small cove of Mavra Litharia, at the foot of the hill of the ancient town (Figs 1 and 2). After Leake, the site was practically ignored, and only passing references (Wyse, 1865: 290; Miliarakis, 1886: 131; Papachatzis, 1980: 158; Stiros, 1988; Stiros & Papageorgiou, 1988) to it have been made.

Today, the area is drastically altered by the construction of two villa complexes and only

Figure 2. The cove of Mavra Litharia. View looking east from point 1 in Fig. 1(c).

some rectangular blocks, poor remains of various harbour constructions and pottery sherds of undetermined, possibly Hellenistic, age and abraded by the sea can be observed at points 3, 5 and 6 in Fig. 1(c).

Geological background

North Peloponnesus is an area of impressive Quaternary uplift: marine terraces 450,000 years old reach a height of 820 m (Dufaure & Zamanis, 1980; Keraudren & Sorel, 1987), and it is in one of the younger terraces that the anceint town of Aigeira is located. From the geological point of view, the area is built of Pliocene and Pleistocene marls overlain by conglomerates. In the vicinity of Aigeira, at Mavron Oros, deltaic type facies, indicative of near-coastal environment are found to the height of 900–1600 m or even more. The region is cut by numerous normal faults (mainly with E–W and NE–SW trends) which, to a large degree, control the geomorphology and the rather linear coast (Koutsouveli *et al.*, 1989; Ori, 1989).

The Gulf of Corinth is one of the most seismically active regions in the world, and this is why in early days of plate tectonics it was regarded as a plate boundary (McKenzie, 1972).

Observations of sea-level change

Dufaure & Zamanis (1980) mapped a number of marine terraces in the wider area, some of them attributed to the Pleistocene, while at Mavra Litharia, at a height of 1–8 m (Fig. 1c, point 1) Georgiades-Dikeoulia & Marcopoulou-Diakantoni (1976) identified a rich Quaternary fauna which they dated to the last interglacial (Eutyrrhenian) period. However, *Strombus bubonius*, the characteristic fossil of this period, was not found.

Figure 3. Hellenistic (?) pottery fragments cemented in exposed marine conglomerates. For location see Fig. 1(c). (Coin scale.)

What is, however, interesting is that at the site of the ancient harbour marine conglomerates containing pottery fragments are found up to a height of 2 m above the water (Fig. 3). Undoubtedly, these conglomerates were formed at the bottom of the harbour, during or even

Figure 4. Exposed fossil vermets, testifying to an episodic (seismic) uplift of the area. For location see Fig. 1(c).

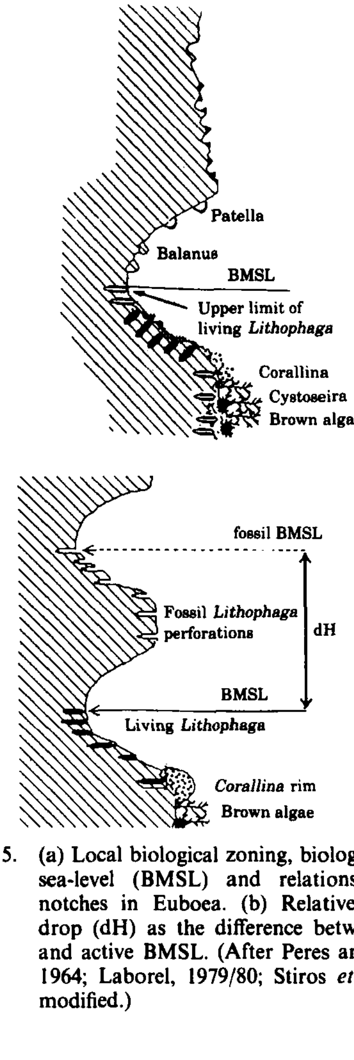

Figure 5. (a) Local biological zoning, biological mean sea-level (BMSL) and relationship with notches in Euboea. (b) Relative sea-level drop (dH) as the difference between fossil and active BMSL. (After Peres and Picard, 1964; Laborel, 1979/80; Stiros *et al.* 1992, modified.)

after its period of use, and have subsequently been uplifted to their present elevation.

Evidence of an undatable uplift is provided by empty holes of *Lithophaga* at the cliffs of the rocks (Fig. 1c, point 2) as well as by traces of monostromatic vermetid gastropods (*Dendropoma petraeum*, among others) that have been found exposed up to the height of 1 m (Fig. 4). These last species are an excellent indicator of relative sea-level change, for the upper limit of living specimens usually defines a sharp line that can be regarded as the present-day *biological mean sea-level* (BMSL) (Fig. 5). This line depends on local conditions, such as tide range or surf height, but is independent of short wavelength (usually seasonal) variations of sea-level and may not coincide with the mean sea-level deduced from tide-gauge measurements (Laborel, 1979/80).

Similarly, the upper limit of exposed fossil *Dendropoma* defines a fossil–biological mean sea-level. Since no important changes in the littoral flora and fauna of Greece, either in specific composition of habitat (Laborel and Laborel, in prep.), or dramatic changes in the coastal morphology of the area have taken place in the last millenium, the differences between fossil and present-day (biological) mean sea-level are a reliable and precise (up to 10 cm accuracy) indicator of the local relative sea-level change (Fig. 5; Laborel, 1979/80).

A seismic uplift?

As is been analysed elsewhere (Laborel, 1979/80; Laborel and Laborel, in prep.), the BMSL corresponds to the limit between the infra-littoral and mid-littoral zones. These two zones are characterized by different flora and fauna associations and bio-erosion patterns. As a consequence, a relative change of the sea-level, even of small amplitude, may have an important effect on certain littoral species. For example, in the case of a small relative sea-level drop, *Lithophaga* and monostromatic vermets will be found in the mid-littoral zone and will be quickly destroyed by bio-erosion in this zone.

In the case of Mavra Litharia, the exposed *Dendropoma* and *Lithophaga* fossils apparently indicate a quick, episodic relative sea-level change with an amplitude larger than that of the mid-littoral zone (a fraction of a metre in most

Hellenic seas, where the tidal rage is small). This apparently permitted the fossils to escape erosion.

Such motions are usually associated with earthquakes, but may be observed in volcanic areas as well. The Serapeion Temple at Pozzuoli (south Italy), near the Phleagrean Fields Caldera, with its pillars drilled by *Lithophaga* up to a height of 8 m, is the best known example.

For these reasons we suggest that the uplifted monostromatic vermets at Mavra Litharia indicate at least a 1 m episodic, probably seismic, land emergence.

Radiometric data

One sample of *Dendropoma petraeum* collected from the ancient harbour at a height of 1 m above the sea (sample 90SS2; Fig. 1c) was dated with the AMS technique at Gif-sur-Yvette (France), with the procedure described in detail in Stiros *et al.* (1992) and Arnold *et al.* (in press). An apparent radiocarbon age of 1420 ± 60 years (without reservoir correction) was obtained, which (as will be analysed elsewhere) yields a calibrated age of 770–1040 BP. This date corresponds with the presumed seismic uplift that killed the vermets.

Seismic history of the area

A 1 m seismic uplift, as deduced from coastal data, requires a destructive earthquake in the 10th–12th centuries with important economic and social impacts, for which no historical evidence exists. The seismic catalogue of Papazachos & Papazachou (1989) suggests that the area has probably been seriously affected by earthquakes in 1402, 1742, 1753 and 1887(?) (Papazachos & Papazachou, 1989). However, there is no reason to try to correlate any of these events with the palaeoseismic event presented here, for the available historical seismic record seems to be more than incomplete, as the following lines of evidence indicate:

(i) The seismic catalogue of Papazachos & Papazachou (1989) contains four events in about 500 years, but in the decade 1970–1980 alone the area has been affected by at least five earthquakes of magnitude 5·0–6·2 (Papazachos & Comninakis, 1982).
(ii) During the last two millennia the area of Aigeira was devoid of important habitation centres and thus not included in historical seismicity records which are a function of the density of population and importance of towns.
(iii) The archaeoseismic research provides information on previously unnoticed palaeoseismic events: during the 5th century BC a large-scale destruction led priests to deposit precious objects of destroyed temples in a kind of underground safe, where they have remained until their excavation (Koutivas, 1966: 305), while a sudden interruption of large-scale repairs in the theatre of Aigeira may be assigned to a destructive earthquake of the 3rd century AD (S. Gogos, pers. comm.).

Tectonic implications

Apart from the area of Aigeira, seismic uplifts with an amplitude of 1 m have been observed in Lechaion, the western harbour of ancient Corinth (Stiros *et al.*, in prep.) and the sacred harbour of Heraion and Mylokopi in the Perachora peninsula (Pirazzoli *et al.* (in press); Fig. 1a). These uplifts were not coeval, as radiometric dates indicate, but contributed to a certain degree to the evolution of the landscape of North Peloponnesus and Perachora.

What is interesting, however, is that in addition to seismic, a-seismic motions have been observed in North Peloponnesus. Stiros (1988) reported repeated levelling data corresponding to three surveys showing that in the last fifty years an approximate 20–30 cm uplift of the area of Aigeira, relative to the east and west parts of the Gulf of Corinth, has been recorded. Since there is no evidence of seismic motions during this period, this peculiar combination of seismic and a-seismic uplift is unexplained.

Data from Mavra Litharia indicate that this area experiences the highest rate of Holocene uplift, about 1 mm/year, among all other known sites in the Aegean back-arc basin. This rate is consistent with mareographic data (Flemming & Woodworth, 1988) and the long-term average rate of uplift in the area, 1·8 mm/year minimum, according to the data of Keraudren & Sorel (1987).

Towards a reconstruction of the ancient site

Our observations of land uplift indicate that the coastline about 2000 years BP was at a height of at least 2 m above present-day sea-level.

Consequently the small cove between points 1 and 3 in Fig. 1(c) was much larger and probably extended up to the old road.

It is also likely that east of the cove, the ancient shoreline (and the ancient harbour constructions, if any such still survive) are buried beneath the artificial terrace deposits of the two villas (Fig. 1c, site 5), where a few hewn blocks, fewer every year, can be observed.

Implications for the palaeogeography of ancient sites

While tectonic motions in the Gulf of Corinth and other parts of the Aegean (Stiros *et al.*, 1992; Stiros & Papageorgiou, 1988); are much smaller than along the arc where seismic uplifts of up to 8 m have been observed (Pirazzoli *et al.*, 1982; 1989), their amplitude is large enough to be ignored, both as far as their impacts on the ancient economy, and the palaeogeographic reconstructions of various areas are concerned.

It can therefore be concluded that in tectonically active areas coastal landscape does not change smoothly and gradually with time and space. Episodic uplifts with an amplitude not very different from the average total relative sea-level change (absolute values) in a few millennia, for instance, 1–2 m (Flemming, 1978) are not unusual, while submerged and uplifted ancient neighbouring coastal sites have, in several cases, been identified, for example, the two ancient harbours of Corinth, Kenchreai and Lechaion (Stiros, 1988; Stiros & Papageorgiou, 1988).

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