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Archaeological and geomorphological indicators of the historical sea level changes and the related palaeogeographical reconstruction of the ancient foreharbour of Lechaion, East Corinth Gulf (Greece)

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ABSTRACT

Study of the architectural, morphological and constructional features of the coastal harbour installations of the ancient foreharbour of Lechaion indicates that they were built or rebuilt during the period of the Roman domination of Corinth, and has facilitated the reconstruction of the vertical movements and the palaeogeography of the coast. On the basis of the current position of the sea level indicators including beachrocks, fossilized uplifted and submerged marine notches, and ancient coastal harbour installations, and the relationship between them, the sea level during the Roman operation of the harbour was determined to be 0.90 m lower than at present. Furthermore, the subsequent abandonment of the harbour and the siltation of its constructions were determined. During two successive tectonic subsidence co-seismic events, the sea level rose by 2.0 m in total, 1.60 m during the first event and 0.40 m during the second one. A strong uplift tectonic event followed and the sea level dropped by 1.10 m. This regression of the sea was responsible for the present shoreline morphology. Determination of the sea level fluctuation at the shore of the ancient harbour of Lechaion allowed the palaeogeographical reconstruction of the coast in different stages related to these changes.

1. Introduction

The Upper Holocene coastline of the Gulf of Lechaion is a highly dynamic zone in which the interaction of geography, geodynamics and human intervention has shaped, transformed and repeatedly overturned its balance and man's associated activities. Geography created the comparative advantage, ancient man exploited it and geodynamics reversed it.

Any attempt to decode the dynamics of the relationships between land and sea involves the articulation of sea level fluctuation with history. By detecting in space and time the relation between coastal geomorphological features and human constructions it is possible to understand the dynamics of the co-seismic vertical movements, their direction and magnitude, the palaeogeographical changes they caused to the coastline and the evolution of the natural and cultural environment they affected.

The ancient harbours of the Greek Mainland are a physical historical archive of Upper Holocene coastal changes, since they combine the possibility of understanding the palaeocoastal environment through the evolution of the coastal morphodynamic processes, the dating and the reconstruction of the harbour installations and their relation to the ancient city.

In the archipelago of the Cyclades, Negris (1904) and Cayeux (1907), in the early twentieth century, followed recently by Mourtzas et al. (2004), Desruelles et al. (2007) and Mourtzas (2012), reconstructed the palaeogeography of the submerged west coast of Delos and the shape of its ancient harbour. Mourtzas (2010) resynthesized the morphology of the submerged coastline and its relation to the ancient harbour installations in the bay of Classical Karthaia on the island of Kea (anc. Keos) in the western Cyclades. Further north, on the island of Andros and specifically the harbour of ancient Palaeopolis, the relation between sea level and the ancient harbour installations during the period of their use, points to one of the largest harbour works of Classical Antiquity, today submerged (Mourtzas, 2007). Scranton et al. (1978) mapped and studied the Roman harbour of Kenchreai on the west shore of the Saronic Gulf, and resynthesized and dated the phases of its submergence.

In the late 1960s Schlager et al. (1968) studied the ancient harbour installations of Anthedon in the Evoikos Gulf and

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Knoblauch (1969, 1972) the ancient port of Aegina in the Saronic Gulf.

The Classical–Hellenistic harbour of Phalasarna at the western tip of Crete, today elevated as a consequence of the earthquake in AD 365, has been studied by Hadjidaki (1988, 1996 and 2001) and Pirazzoli et al. (1992). On the south coast of central Crete, the reconstruction of the geomorphology of the coast of Minoan Kommos, when sea level was 3.90 m lower than at present, enhanced a now submerged shelter morphology which favoured the safe anchorage and beaching of ships (Mourtzas, 1988a; Shaw, 1990; Mourtzas and Marinos, 1994). On the south coast of central Crete, the now submerged harbour of ancient Lassaia has been studied by Mourtzas (1990), and Mourtzas and Marinos (1994).

Corinth played an important historical role throughout Greek Antiquity, mainly due to the Diolkos and to its two ports of Lechaion and Kenchreai. The entirely artificial harbour of Lechaion was in use continuously for 2655 years, from the seventh century BC until 1955, although its importance seems to have diminished after the Frankish period (AD 1500). It consisted of three inner harbour basins and one outer harbour with two curving harbour walls, along which piers, moles, breakwaters, a quay and a large number of warehouses and other installations were constructed.

Although the harbour of ancient Lechaion has never been excavated, it has been studied by numerous researchers since the early twentieth century. Georgiades (1907) and Paris (1915) give extensive descriptions of the ancient port, of its three inner basins, the entrance channel and the two breakwaters of the outer harbour. Pallas (1963, 1965), in the course of excavating the Early Christian basilica situated on the land barrier between the inner harbour and the coast, revealed important evidence on the early phases of its construction and its later development. Shaw (1969) described and dated the manmade islet in the middle of the west basin of the inner harbour, suggesting that it might have been the base of a lighthouse (pharos) or a statue. Rothaus (1995), in his thorough historical retrospection, describes the ancient harbour installations, emphasizing in particular the foreharbour, and tries to date them on the basis of their architectural and morphological features. Mourtzas and Marinos (1994), and Maroukian et al. (1994) were the first to refer to the elevation of the coastline of the outer harbour in historical times, while Stiros et al. (1996) attempted to date this tectonic rising event by the radiocarbon method and thus to estimate the date of construction of the ancient harbour. Theodoulou (2002) analysed the development of the ancient harbour on the grounds of historical data and literature, adding also new significant observations.

More recent stratigraphical investigations on the site of the ancient harbour identified two distinct tsunami layers (Hadler et al., 2011; Koster et al., 2011). Hadler et al. (2011) mention also a third violent flooding event, which was associated with earthquakes that struck in the first half of the sixth century AD. Morhange et al. (2012) estimated the sedimentation rates in the basins of the inner harbour and date by the radiocarbon method the tectonic event that elevated it.

2. Tectonic framework

The Gulf of Lechaion is a relatively shallow and asymmetrical trench structure trending NW–SE, located at the east end of the extensional sedimentary basin of the Corinthian Gulf, which is an active rift structure with very high deformation rates and seismicity (Fig. 1). It is about 17 km long and 10 km wide, with a maximum depth at its north end of 250 m. It is characterized by a steep fault margin in the north, smooth morphology at the bottom of the sea in the south and the east, and a layer of post-alpine sediments 2 km thick (Weiss et al., 2003; Sakellariou et al., 2004). The klippe of the Perachora peninsula, which comprises the northern emerged boundary of the trench, is formed between the north dipping Pisia and Skinos fault zone at the north and the south dipping Loutraki fault at the South. These are ENE–WSW to E–W normal faults, which have been active since the Pliocene and, according to palaeoseismic investigations, were reactivated in the periods AD 1295–1680, AD 670–1015 (Collier et al., 1998) and in the earthquake of 1981 with footwall uplift and hanging wall subsidence. During the 1981 earthquake the seismic surface ruptures displacements along the Pisia fault ranged between 0.50 m and 0.70 m, with a maximum value of 1.50 m, while the vertical displacement along the Schinos fault was almost 1.0 m (Jackson et al., 1982). At the same time, the co-seismic subsidence of the northern coast of the Perachora peninsula ranged between 0.60 m in its eastern section and 0.80 m in the western one (Andronopoulos et al., 1982; Jackson et al., 1982; Mariolakos et al., 1982; Hubert et al., 1996). The Loutraki fault, situated on the southern coast, was activated constantly during the late Quaternary, causing the elevation of the coast with an uplift rate of 0.29 mm/y–0.55 mm/y from W to E for the last 125,000 years (Cooper et al., 2007) and 0.75 mm/y for the last 6300 years (Pirazzoli et al., 1994). At the west entrance to the Isthmus Canal, in the area of Poseidonia, a reciprocating movement of the coast was determined with initial subsidence of 1.60 m and a following emergence of 0.70 m.

The basins of the Eastern and Western Corinthia grabens, on the northern shore of the Lechaion Gulf, which form the onshore prolongation of the present Gulf of Corinth, are undergoing lithospheric extension with active seismicity on both basin-bounding and intrabasinal normal faults (Jackson et al., 1982; Vita-Finzi and King, 1985; Davies et al., 1997; Hatzfeld et al., 2000). A complex history of extensional subsidence and deposition, periodically interrupted by intrabasinal tectonic uplift and erosion, is represented in the Lower Pliocene to Holocene sediments currently at outcrop levels (Freyberg, 1973; Collier and Dart, 1991). The high rates of the tectonic uplift, between 0.35 mm/y and 0.60 mm/y (Westaway, 1996), have dramatically changed its morphology raising marine deposits and terraces of 180–230 ka BP up to the elevation of 80 m (Vita-Finzi and King, 1985; Keraudren and Sorel, 1987; Collier et al., 1992; Westaway, 1996). The staircase Quaternary morphology is interrupted by the fault scarp of active normal fault zones. The whole area is characterized by the existence of large fault zones which separate it into blocks, forming large tectonic grabens and horsts (Papanikolaou et al., 1996; Kranis et al., 2004). The dominant neotectonic structure of the area is the active fault of the east margin of the Eastern Corinthian graben, known as the Corinthos–Dervenakia–Kaparelli fault zone, which separates it from the Western Corinthia graben, defining also the boundary between the marly marine sediments of the western basin and the lacustrine sediments of the eastern one. This is an oblique-dip slip, left-lateral, orientated NE–SW and 48 km in length. The Oneia fault zone, at the south of the basin, which demarcates the homonymous alpine mass at the north, and the Mavri Ora, Agios Dimitrios, and Agios Vasilios-Ryton fault zones parallel to it at the south, are actually normal faults trending E–W and dipping to the north, with their length varying from 7 km up to 24 km (Papanikolaou et al., 1996). The parallel fault of the Dervenakia–Kaparelli fault zone is the secondary neotectonic structure which forms the SE coast of the Gulf of Lechaion, passes through the city of Corinth, east of the Acrocorinth horst, and ends several kilometres to the south. Its length is about 20 km and it has a NE–SW direction. Some other faults, probably active, form also the north, west and south sides of the Acrocorinth horst. Parallel to the direction of the large oblique-slip, left-lateral structures of the east margin of the East Corinth basin, there are some smaller, secondarily activated normal faults of NE–SW direction which