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LECHAION, THE ANCIENT HARBOUR OF CORINTH (PELOPONNESE, GREECE) DESTROYED BY TSUNAMIGENIC IMPACT

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Abstract: *Lechaion, the harbour of ancient Corinth, is situated at the south-eastern extension of the Gulf of Corinth (Peloponnese, Greece). Due to extensive fault systems dominating the gulf, seismic activity is frequent and often related to landslides or submarine mass movements. Thus, the study area is highly exposed to tsunami hazard. By means of geo-scientific studies comprising geomorphological, sedimentological and geophysical methods, evidence of multiple palaeotsunami impact was encountered at the Lechaion harbour site and the surrounding coastal area. The detected tsunami signatures include allochthonous marine sediments intersecting quiescent harbour deposits, extensive units of tsunamigenic beachrock and geo-archaeological destruction layers. Our results suggest that the harbour at Lechaion was finally destroyed in the 6th century AD by strong tsunami impact.*

Key words: *Palaeotsunami, beachrock, ancient harbours, Lechaion*

INTRODUCTION

Situated in the eastern Mediterranean, the Gulf of Corinth belongs to one of the seismically most active regions in the world. Due to ongoing continental rifting with high extension rates up to 16 mm/yr, this half-graben structure is surrounded by active on-shore and submarine faults (Papazachos & Dimitriu 1991; Sachpazi et al., 2003; Avallone et al., 2004). Strong earthquakes, often accompanied by coseismic displacement of the seafloor and/or inducing submarine slides are therefore common throughout the gulf. Water depths of maximum 900 m, steep submarine slopes and a narrow shelf additionally enhance the potential of strong tsunamis (Hasiotis et al., 2002; Stefatos et al., 2006). Accordingly, numerous tsunami catalogues for the Mediterranean and especially for Greece report on historical tsunami events that occurred within the Gulf of Corinth (Soloviev et al., 2000; Papadopoulos, 2003; Ambrasey & Synolakis, 2010). Solely for the 20th century, six tsunamis have been recorded; the most destructive occurred near Aeghio in 1963 (Papadopoulos, 2003).

The main objectives of our study were to (i) detect allochthonous high-energy event layers within the sedimentary record of the harbour basin at Lechaion and (ii) to reconstruct the late-Holocene coastal evolution of the study area.

LECHAION – THE ANCIENT HARBOUR OF CORINTH

Lechaion, the western harbour of ancient Corinth, is situated at the Isthmus of Corinth, which connects the Peloponnese with mainland Greece. The harbour was most probably founded around 600 BC when the Corinthians expanded their military and trading activities (Stiros et al., 1996). According to ancient sources, Lechaion served as a naval base from the 4th century BC and was connected to the city of Corinth by a harbour road protected by strong walls (Xen. Hell. 4.4.6-8 after Brownson, 1918). With the devastation of Corinth in 146 BC, Lechaion was abandoned but re-activated under Roman supremacy in 44 BC. In Roman times, the harbour underwent different phases of reconstruction and mainly served as trading base (Strab. Geogr. 8.6.20-23 after Hamilton & Falconer, 1903). The final abandonment of Roman Lechaion is reported to be associated with the destruction of ancient Corinth by a series of strong earthquakes in 521 or 551 AD. Though occasionally re-used in medieval times, the harbour never regained its former importance (Rothaus, 1995).

Today, certain harbour installations are still visible, including two outer moles, an entrance channel leading to an elongated inner harbour basin and the remains of an ancient quay wall (Paris, 1915). The present day topography is dominated by large mounds of sediments dredged from the harbour basin (Fig. 1). Between the inner harbour basin and the present beach the remains of an early Christian basilica, dating to the late 5th century AD, were excavated. The basilica, 186 m long, represents the largest from this period and was completely destroyed by the 521 or 551 AD earthquake series (Krautheimer, 1989; Rothaus, 1995).

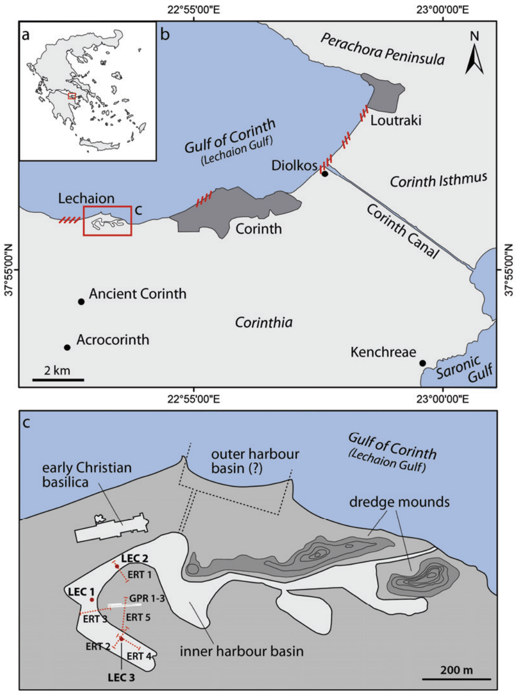

Fig. 1: (a) Location of study area in Greece. (b) Overview of the Corinthia. Red box indicates harbour site of Lechaion, red dashes indicate beachrock. (c) Map of the Lechaion harbour basin and adjacent area. Vibracores LEC 1-3 are indicated by red dots, ERT-measurements by red dashed lines and GRP-measurements by white lines (maps modified after Google Earth images, 2009).

TSUNAMI IMPACT AT THE LECHAION HARBOUR SITE

Sedimentary evidence from the harbour basin

As previous studies show, tsunami impact may be documented by layers of allochthonous coarse-grained sediment intersecting quiescent near-shore deposits (Vött et al. 2009). Low-energy environments such as harbour basins therefore represent excellent geological archives for palaeotsunami research.

Sedimentological, geochemical and micropalaeontological studies were carried out at the Lechaion harbour site (see Fig. 1 for location of vibracores). The local stratigraphy comprises shallow marine (pre-harbour) deposits overlain by harbour-related, quiescent lagoonal sediments followed by limnic to terrestrial deposits accumulated when the harbour was already out of use (Fig. 2). The stratigraphical record of all vibracores is repeatedly interrupted by layers of allochthonous coarse-grained sediment and shell debris, partly characterized by fining upward sequences. These ex situ-layers extend up to 450 m inland. Erosional unconformities at the base (Fig. 2b) and immediately re-established quiescent conditions on top of the event layers indicate short term high-energy interference of the Lechaion harbour site.

*Fig. 2: (a) Vibracore LEC 2 (N 37° 55' 58.6 E 22° 53' 03.5", -0.04 m a.s.l.) was drilled in the central Lechaion harbour basin. Here, two coarse-grained tsunami layers were found, intersecting the autochthonous, predominantly shallow-marine to lagoonal facies. Youngest tsunami deposit as encountered in core LEC 3 and covering early Christian basilica is dredged at site LEC 2 (see Δ). ^{14}C-samples are marked by *. (b) Detailed view of the younger event layer. The quiescent harbour environment was abruptly covered by allochthonous high-energy deposits (Photo by T. Willershäuser, 2010).*

The event-stratigraphical correlation of all vibracore profiles reveals three distinct tsunami layers. The geochronological framework is based on radiocarbon dating and age determination of diagnostic ceramic fragments. Tsunamigenic impact could be time-bracketed by radiocarbon dating to around 760 cal BC and 50 cal AD and to the 6th century AD by geoarchaeological findings. The youngest event correlates to the geoarchaeological destruction layer presented below.

Geoarchaeological destruction layers

Large sediment mounds adjacent to the inner harbour basin are generally referred to as natural dunes or sediments obtained from dredging activity (Frazer, 1965; Rothaus, 1995; Stiros, 1996). They consist of sand and gravel, intermingled with numerous ceramic fragments and marine macrofossils. The sediment composition and grain size distribution thus exclude natural dune formation. However, gravel is also completely atypical for the siltation of a quiescent harbour basin environment (Marriner & Morhange 2007). According to their grain size, the sediments provide evidence of high-energy influence. Incorporating marine as well as terrigeneous material, they indicate strong tsunamigenic inundation and backflow affecting the coastal plain at Lechaion. Since associated to dredging activities, the mounds therefore document tsunami influence burying the Lechaion harbour basin.

Widespread burial of the harbour site by high-energy influence must also be assumed regarding the ruins of the 5th century AD Christian basilica. The entire foundation like the adjacent area is completely covered by an up to 2 m thick sediment layer. The surrounding topography as well as the sediment composition, however, exclude a colluvial, fluvial or mass denudative burial of the site. The deposits are also not related to the archaeological excavation of the site. A former door lintel used as a threshold after the destruction of the church attests that the entrance level was already elevated during historic times. Made up of a sandy matrix incorporating abundant gravel, numerous ceramic fragments and marine macrofossils, the high-energy sediment layer again reflects tsunami backflow.

Fig. 3: (a) Excavated remains of the 5th century AD Christian basilica erected to the north of the former harbour basin. (b) The present day ground surface overtops the basilica's original ground level by up to 2 m (in photo: ca. 1.2 m). (c) The sedimentary cover consists of sand and gravel with abundant ceramic fragments and marine shell debris.

Several earth resistivity transects were carried out around the ancient harbour basin (Fig. 1c). They revealed a sharp boundary between the allochthonous high-energy deposits and the underlying autochthonous fine-grained harbour sediments as well as a clear thinning landward of the event layer up to 450 m inland. Furthermore, ground penetrating radar profiles (Fig. 1c) revealed channel-like structures at their base. Orientated perpendicular towards the coastline, these incised channels indicate strong linear erosion in land-/seaward direction. Similar structures, created by strong backflow processes, were observed along the Chilean coast after the February 2010 Chile tsunami (Bahlburg & Spiske 2010).

In a summary view, our results give evidence for the influence of tsunami impact on the Lechaion harbour. According to Rothaus (1995), only few ceramic fragments younger than late Roman to early Byzantine times were found in the vicinity of the harbour basin and basilica. Thus, we consider tsunami landfall in the 6th century AD as the most probable cause for the final destruction and abandonment of the harbour.

Beachrock as indicator for tsunami impact

Along the Corinthian coastline, extensive beachrock formations dominate the present coastal geomorphology. As recently described by Vött et al. (2010), beachrock deposits may be of tsunamigenic origin. At the Corinth Canal at a distance of 7 km from Lechaion, the beachrock complex extends up to 300 m inland (Fig. 4a), while the maximum extension of the recent beach is less than 25 m. The deposits show a clearly laminated structure with multiple fining upward sequences reaching from gravel to fine sand. The inner structure reveals a landward orientated imbrication of the gravel components (Fig. 4b) documenting landward flow dynamics as may be induced during tsunami inundation. According to their sedimentary structure, these beachrock deposits must not automatically be regarded as lithified beach but may rather represent calcified tsunamigenic deposits (for further discussion see Vött et al. 2010). The "diolkos", an ancient slipway across the Isthmus of Corinth, is partly covered by beachrock; used until the early 1st century AD, the diolkos represents a *terminus post quem* for the tsunamigenic impact.

Fig. 4: (a) Extensive beachrock deposits at the Corinth Canal. (b) The internal structure shows a fining upward sequence as well as imbricated pieces of gravel.

CONCLUSION

Based on our studies, multiple tsunami impact was determined for the Lechaion harbour site and adjacent coastal areas. At least three distinct event layers were identified, the youngest and obviously most destructive event dating to the 6th century AD.

The spatial distribution and geomorphological variability of the encountered tsunami deposits require an event-stratigraphical approach to understand and reconstruct the chronology of events. Based on the combination of historical accounts with geomorphological, sedimentological, geophysical and geoarchaeological data we conclude that the ancient harbour of Lechaion, though influenced by tsunamis before, was finally destroyed by tsunami impact, most probably triggered during the 521 or 551 AD earthquake series. The present day topography of the harbour site is due to a latter re-activation of the harbour in medieval or pre-modern times and thus only partly represents the ancient Corinthian harbour.

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