EARTHQUAKE ARCHAEOLOLOGY

INQUA PALEOSEISMOLOGY AND ACTIVE TECTONICS

Sedimentary burial of ancient Olympia (Peloponnese, Greece) by high-energy flood deposits – *the Olympia Tsunami Hypothesis*

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Abstract: *Detailed geo-scientific studies were carried out in the Kladeos and lower Alpheios River valleys in order to clarify the mystery of the rapid burial of Olympia under 4-6 m of sediments after the 6th cent. AD and subsequent erosion of the Kladeos River by 8-10 m down to the ancient flow level. Sedimentological, geophysical, geochemical and microfaunal analyses were conducted along the Olympia terrace by means of 22 vibracores and 70 resistivity tomography transects. Geomorphological studies revealed strong discrepancies between the present hydraulic potential of the Kladeos River and the dimension and structure of the Olympia terrace. Our results show that the Kladeos River valley and Olympia experienced at least four distinct phases of catastrophic high-energy flood events. Sedimentary, geochemical and faunal traces found in the adjacent Basin of Flokas-Pelopio clearly document multiple tsunami impact. Identical fingerprints and strong stratigraphical correlations were also detected along the Kladeos River beyond the Ridge of Flokas-Platanos. We thus set up and discuss the* Olympia Tsunami Hypothesis *saying that the shallow saddles of the ridge were repeatedly overflowed by tsunami waters and the cult site Olympia was rather destroyed by tsunami than by fluvial processes related to the Kladeos River.*

Key words*: Olympia, high-energy deposits, tsunami, geoarchaeology*

Introduction

Olympia, used as famous cult site for Panhellenic games between Archaic times and the 4th cent. AD, is located at the confluence of the Kladeos and Alpheios Rivers in the western Peloponnese (Greece). The sedimentary burial of ancient Olympia is one of the most interesting geoarchaeological mysteries in the Mediterranean world. The sedimentological evolution since early medieval times shows two different steps. After the 6th cent. AD, the site was covered by 4-6 m of sediments; subsequently, the nearby Kladeos River eroded its bed by 8-10 m approximately reaching the level existing during antiquity.

Previous studies presented different explanations for this setting. Büdel (1981), together with Dufaure & Fouache 1988, Fouache & Pavlopoulos 2011, are in favour of anthropogenically induced soil erosion as main factor for enhanced sediment accumulation at the mouth of the Kladeos River during phases of uncontrolled landuse, especially after the Slavic invasion in early medieval times. On the contrary, Fountoulis & Mavroulis (2008) hold distinct periods of wet climate responsible for accelerated sediment accumulation. However, both scenarios do not give explanations for the change from accumulation to subsequent erosion dynamics within the past 1500 or so years.
Before systematic excavation of the site by the German Archaeological Institute started in 1875, the archaeological remains of Olympia were integrated into a wide terrace, the so called Olympia terrace. From a geomorphological point of view, this terrace can be traced both downstream the Alpheios River towards the present coast of the Gulf of Kyparissia and upstream all along the lower and middle Kladeos River valley. In the Kladeos area (Fig. 1), the Olympia terrace is up to 300-500 m wide. It is present on both sides of the Kladeos River with a distance of up to 200 m between the opposite terrace faces. Considering that the Kladeos River is rather a creek than a river with a perennial runoff concentrated within a maximum 5-8 m-wide secondary river channel and maximum water flow depths of 2-3 m during winter and heavy rain events, there is a considerable discrepancy between the dimension and the hydraulic potential of the Kladeos River on the one hand, and the local geomorphology of the Olympia terrace on the other hand.

The objectives of our investigations thus were (i) to establish a well-based stratigraphy of the Olympia terrace along the Kladeos River by detailed geomorphological and sedimentological studies, (ii) to compare these results with stratigraphies found along the Alpheios River, especially in the adjacent Basin of Flokas-Pelopio, and (iii) to find a geomorphological model which best explains the hydro-dynamic fingerprint and distribution pattern of the encountered sediments.

Methods

We carried out geomorphological mapping of the Olympia terrace using topographical and geological maps and remote sensing data. Stratigraphical studies are based on 22 vibracores, 16 of which were drilled in the Kladeos River valley and 6 in the Alpheios River valley by means of a handheld Cobra mk1 vibracorer (Atlas Copco) and a Nordmeyer drill rig (type RS 0/2.3). We used core diameters of 6 and 5 cm. Maximum coring depth was 17 m below ground surface (m b.s.). Earth resistivity tomography (ERT) was conducted to study subsurface structures and stratigraphies along 70 transects using a multi-electrode geo-electrical Iris instrument (type Syscal Junior Switch 48). Selected sediment samples were analysed by their microfossil content. Key cores were additionally cored with an inliner system and analysed using the X-ray fluorescence technique (XRF). We also conducted grain size analyses for selected samples. Vibracoring sites and ERT transects were measured by means of a differential GPS (type Topcon HiPer Pro) with an accuracy of 2 cm or better. A local geochronostratigraphical framework was established using age estimations of diagnostic ceramic fragments, radiocarbon dating and Optically Stimulated Luminescence (OSL) approaches.

Results

Vibracores ALP 3, 4, 5 and 8, drilled in the environs of ancient Olympia, especially on top of the Olympia terrace towards the south of the southeastern Roman baths and on top of the Olympia terrace to the west of the Kladeos, revealed characteristic sequences of light brown, silt- and clay-dominated alluvial or colluvial deposits with remains of freshwater fauna which are repeatedly interrupted by up to four sections out of light brown sand and gravel. These coarse-grained deposits were found in comparable stratigraphic positions in every core and thus indicate synchronous flooding of wide areas related to high flow velocities. Associated to these deposits, we found sedimentary structures such as basal erosional unconformities in underlying silt deposits, fining upward sequences with mud caps and abundant marine shell debris and marine microfauna. XRF analyses revealed clear maximum peaks of the Ca/Ti ratio for the coarse-grained sections. The calcium content documents the input of calcium carbonate from biogenic and bedrock sources, the titan content reflects terrigenous input by subaerial weathering into the sedimentary system. Results were also tested for masking and matrix effects which can be excluded as major sources of bias. Apart from a distinct and ca. 1 m-thick palaeosol found on top of a coarse-grained section at ca. 4 m b.s. in core ALP 8 (Fig. 2), which includes Roman sherds, palaeosols are missing. A charcoal fragment from a fining upward sequence out of sand and gravel deposited under high-energy conditions at site ALP 5 was ^{14}C AMS radiocarbon dated to 585-647 cal AD (2σ interval, 3.74 m b.s.).

Vibracores ALP 12-15 and 19 were drilled in the middle Kladeos River valley around the villages of Mageiras and Kladeos on top of the Olympia terrace. Here, we also found predominating clayey to silty deposits accumulated under quiescent to moderate flow conditions. These deposits are grey in colour, partly include lots of plant material and freshwater shell and thus document a permanent water body of fluvio-limnic nature. Similar to the situation at Olympia, we found up to four intersecting layers of sand and gravel, partly grey (base and mid-section), partly light brown in colour (top), associated to high-energy sediment type structures such as basal unconformities, muddy intraclasts, fining upward sequences and including abundant faunal remains of marine origin. Based on XRF measurements, the Ca/Ti ratio again shows clear maximum peaks stratigraphically corresponding to the intersecting coarse-grained layers. Thus, all along the Kladeos River valley between Kladeos, Mageiras and Olympia, the Olympia terrace shows a similar inner structure with the individual coarse-grained high-energy layers lying in stratigraphically consistent positions. The same is true for both distal and proximal parts of each specific terrace section as documented by ERT transects.

We thus conclude, in a first step, that the Olympia terrace between Kladeos and Olympia documents at least four phases of high-energy flood events that obviously affected the whole valley bottom to an extent far beyond the dimensions of the present Kladeos river channel.

Vibracores 9-11 were drilled at the eastern fringe of the Basin of Flokas-Pelopio at a distance of 1 to 2 km to the west of the Kladeos River valley across the Flokas-Platanos Ridge. Vibracore ALP 10 lies around 2.2 km distant from the Alpheios River at a right angle opposite to its seaward flow direction. Despite the vicinity to the Alpheios River, vibracore ALP 9 does not include any pieces of gravel; it consists of homogeneously light brown (top) to grey (base), clayey to silty deposits accumulated in a low-energy freshwater lake environment. Associated to basal unconformities, we found several intersecting layers of sand with fining upward sequences and mud caps and marine faunal remains which clearly document episodic high-energy interruption of the allochthonous environment. Vibracore ALP 10, drilled at the western hill slope of the Flokas-Platanos Ridge, revealed a similar stratigraphic pattern with distinct interruptions of limnic (base and mid-section) and colluvial (top) deposits by predominantly sandy to gravelly high-energy deposits reaching up to 20 m above present sea level (m a.s.l.). In each case, at least the upper part of the intersecting layer consists of brown sediments of mostly terrestrial origin. The Ca/Ti ratios for both cores show distinct maximum peaks for the intersecting coarse-grained allochthonous material (Fig. 3).

Fig. 1: View of the middle Kladeos River valley (foreground) towards the west. The valley is separated from the adjacent Basin of Flokas-Pelopio (middleground) by the homonymous ridge. The Alpheios River valley connects the basin and the Gulf of Kyparissia (left background) in a direct line. Photo taken by A. Vött, 2011.

In the more seaward vibracore ALP 7, drilled some 8 km inland in the midst of the Alpheios River valley halfway between ALP 9 and the present coast, we found autochthonous marine sand at approx. 2.50 m below present sea level (m b.s.l.). Covered by a 10 m-thick layer of sandy gravel, this unit documents that the Gulf of Kyparissia extended far into today's Alpheios valley during the Holocene.

Discussion

Sedimentary structures, geochemical fingerprints and faunal remains encountered at the western fringe of the Basin of Flokas-Platanos indicate episodic high-energy marine flooding from the sea side. Stratigraphies of cores ALP 9 and 10 clearly show tsunami-type marine incursions into a shallow lake and runup-backflow sequences at the adjacent hillside, respectively. Considering that at least parts of the lower Alpheios River valley were flooded by the sea during the Holocene and manifold traces of palaeotsunami are known from the present coast (Vött et al. 2011), these findings are plausible.

Considering, however, that both the geochemical and the overall stratigraphic patterns of the cores from the west of the ridge and from the Kladeos River valley itself are principally identical – documenting episodic high-energy input of coarse-grained marine sediments into prevailing quiescent environments – we hypothesize that marine flooding also affected the Kladeos River valley and Olympia. Our main arguments thus are of sedimentological and geochemical nature and based on consistent stratigraphies on either side of the Flokas-Platanos Ridge. We call this scenario the *"Olympia Tsunami Hypothesis"*.

As a major argument against our hypothesis one may bring forward the fact that Neogene bedrock units in the catchment area of the Kladeos River also include conglomerate and sand units, the latter being characterized by abundant remains of a Plio-Pleistocene marine fauna (IGME 1982). However, especially around Olympia and in most parts of the middle Kladeos River valley, Plio-Pleistocene marl and not sand is the predominant bedrock material provoking many landslides (IGME 1982, Christaras et al. 2002). Moreover, microfaunal analyses of selected core sections revealed freshwater ostracods in fine-grained silt-dominated deposits but exclusively marine species in high-energy flood sediments. In case, these were transported by a mega-Kladeos River with a width of several hundreds of meters – dimensions which are necessary to explain the consistent lateral distribution of this facies across the entire Olympia terrace – one would have to expect admixed freshwater or even river-borne species. This was not the case in the samples which we analysed. However, further attempts are needed to fully understand the fossil record of the high-energy flood deposits in the environs of Olympia.

Geomorphological studies carried out within our project revealed erosion as well as scouring features across the lower saddles of the Flokas-Platanos Ridge lying at about 60 m a.s.l. which indicate possible flow paths across the ridge.

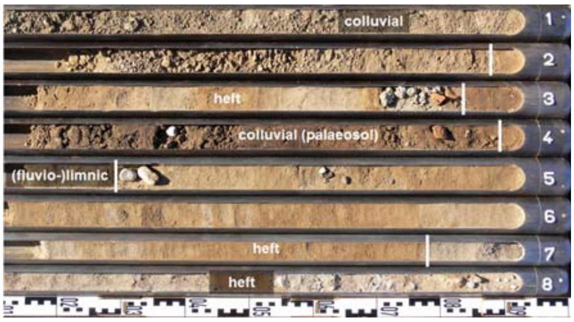

Fig. 2: Facies distribution pattern of vibracore ALP 8 (38.37 m a.s.l.) drilled on top of the Olympia terrace to the west of the Kladoes River some 250 m to the west of the Kronos hill. Several sandy to gravelly high-energy flood type (heft) deposits can be seen alternating with fine-grained colluvial or (fluvio-)limnic deposits. The mid-core palaeosol dates to Roman times. Please note the three fining upward sequences encountered in the uppermost heft unit. Photo taken by T. Willershäuser, 2010.

Concerning the elevation which, at a first glance, seems to be too high for tsunami flooding, one has to consider (i) channelling and accelerating effects of the tube-like and ca. 8 km-long lower Alpheios River valley during inflow, (ii) backwatering and boosting of inundating marine water masses because of blocked backflow in the Alpheios River valley itself and at the breakthrough through Drouva Ridge, where the modern Alpheios dam is located, (iii) the arrival of subsequent waves of a longer wave train before backflow was completely accomplished, as well as (iv) potential interim changes in the topography due to landslides of the predominating Tertiary marls typical for the ridge. From the nearby coast, there is evidence of multiple tsunami landfall since the mid-Holocene and for tsunami run-up up to 18 m a.s.l. around the ancient site Pheia, one of the harbours of Olympia (Vött et al. 2011).

By the *Olympia Tsunami Hypothesis*, we suggest that tsunami waters repeatedly overflowed the lower saddles between Flokas and Platanos and then partly flowed upstream and partly downstream the Kladeos River valley, hereby creating a vast terrace structure way above the flow level of the Kladeos at that time. Subsequently, tsunami backflow concentrated along the Kladeos creek eroding an up to 200 m-wide gap into the terrace. Tsunami backflow through the breakthrough of the Alpheios across the Drouva Ridge was hindered and possibly blocked, at least during tsunami inundation of the Basin of Flokas-Pelopio. One of the high-energy flood deposits encountered near Olympia was dated to 585-647 cal AD which fits well with the earthquake in 551 AD during which Olympia is reported to have been destroyed. However, there are no historic accounts on catastrophic flooding of Olympia.

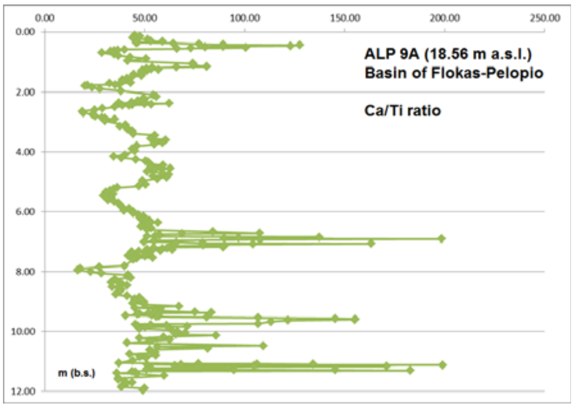

Fig. 3: Ca/Ti ratios for vibracore ALP 9A drilled at the western fringe of the Basin of Flokas-Pelopio at the foot of the homonymous ridge nearby Olympia. Allochthonous silt-dominated deposits of a quiescent limnic environment are characterized by a Ca/Ti base level around 50. Episodic interferences from the sea side by tsunami waves left behind marine sand deposits with Ca/Ti ratios up to 200. Similar Ca/Ti profiles and stratigraphies were found for vibracores in the Kladeos River valley and nearby Olympia.

Conclusions

Detailed geomorphological, sedimentological, geophysical, geochemical and microfaunal studies of the Olympia terrace in the Kladeos and the lower Alpheios River valleys allow to draw the following conclusions. (i) The Kladeos valley and the environs of Olympia were affected by at least four distinct phases of high-energy flood events by which the site was finally covered completely by sediments. (ii) Similar high-energy flood deposits were also encountered at the eastern fringe of the adjacent Basin of Flokas-Pelopio; due to their fossil content, their geochemical fingerprint, their geomorphological position and their stratigraphical pattern, they are interpreted as of tsunamigenic origin. (iii) In both areas, the high-energy facies is associated to sedimentary structures known from historic to recent tsunami events (basal unconformity, fining upward sequences, mud caps, ripped up intraclasts etc.) and is characterized by abundant fragments of a marine fauna. (iv) Geomorphological features such as marks of scouring and undercutting let us assume that tsunami overflow occurred across the comparatively shallow saddles between the villages of Flokas and Platanos wheras backflow was accomplished along the river valley as soon as blocking of the entrance of the Alpheios River into the Basin of Flokas-Pelopio by tsunami waters had ceased. We call this scenario "*The Olympia Tsunami Hypothesis*". (v) Our results, together with manifold geoarchaeological destruction patterns at Olympia, rather indicate catastrophic event-related flooding by tsunami than by the River Kladeos itself.

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