Palaeogeographical aspects of tsunami impacts on the Lefkada coastal zone during the past millennia

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1. Introduction

The eastern Mediterranean is well known for its high seismo-tectonic activity. Earthquakes and plate movements are mostly bound to the Hellenic Arc between Cyprus, Crete and the Ionian Islands where the African Plate is being subducted and overridden by the Eurasian Plate. Tsunamis are high energy events mostly triggered by strong earthquakes. The area thus possesses a high tsunamigenic potential. Further triggers may be submarine landslides, volcanic eruptions or cosmic impacts. Tsunami events are characterized by a sequence of waves which, when hitting the continental shelf run up the coast to considerable elevations and may cause severe damage.

Numerous sites of tsunamigenic impact on coastal geomorphology have been discovered in the eastern Mediterranean. Gianfreda et al.[1] and Mastronuzzi and Sansò[2] describe tsunamigenically dislocated mega-blocks in southern Italy. Kelletat and Schellmann[3] and Whelan and Kelletat[4] (2002) found imbricated mega-blocks, bimodal sandy to gravelly sediment layers and fields of scattered stones on Cyprus. Fields of tsunamigenically scattered stones are also known from southern Turkey[5]. Tsunami research in Greece has mainly concentrated on the Aegean Sea[6]. Minoura et al.[7] (2000), for instance,

[1] Gianfreda et al.[1] 2001
[2] Mastronuzzi and Sansò[2] 2004
[3] Kelletat and Schellmann 2001, 2002
[4] Whelan and Kelletat 2002
[5] Kelletat 2005
[6] Dominey-Howes 2002

encountered thin tsunamigenic sand layers at Crete[8]. A powerful tsunamis hit the Island of Astypalaea in 1956 and reached a runup of 10 m above sea level (a.s.l.)[9]. Kortekaas et al.[10] report on thin-layered sandy tsunami deposits found near Aegio and Itea along the shores of the Gulf of Corinth.

This paper gives an overview of different types of Holocene tsunami deposits unique for the eastern Mediterranean which were found at the northeastern coast of Lefkada Island during field work in 2005 and 2006 and discusses the influence of tsunami impact on the palaeogeographical evolution of the Sound of Lefkada. It summarizes the most important statements given at the International Conference Honouring Wilhelm Dörpfeld on August 6-9, 2006 at Lefkada and is mainly based on Vött et al.[11].

2. Topographic and tectonic settings

Lefkada Island is located in northwestern Greece and belongs to the Ionian Islands. The Sound of Lefkada represents a shallow water lagoonal environment and separates the island from the Akarnanian Plaghia Peninsula in central Greece. Water depths of the lagoon hardly exceeds 0.5 m. The city of Lefkada lies at the shore of the lagoon at elevations of 1-5 m a.s.l. and is accessible via an artificial canal which connects the Bay of Drepano with the Bay of Lefkada.

North of Lefkada city a narrow beach ridge system closes off the Sound of Lefkada from the open Ionian Sea. The base of the beach ridges is characterized by a thick sequence of beachrock which, in the very north, at the Plaka, is completely disrobed from uncemented beach material[12]. The Plaka protects the Bay of Aghios Nikolaos from open waters and creates a favourable natural anchorage with water depths up to 8 m. The adjacent shallow Bay of Cheladivaron next to the village of Aghios Nikolaos lies behind a north-south trending rocky promontory. Aghios Nikolaos lies on top of a bedrock sill, 5-18 m high, which separates the marine embayment from the Lake Voulkaria to the east. There is an artificial canal across the sill – the so called Cleopatra’s canal – which was built in ancient times and induced brackish conditions to the former freshwater ecosystem of the Lake Voulkaria[13].

Lefkada Island is part of the Ionian Zone of the Western Hellenic Nappe which belongs to the outer Hellenides and represents the westernmost outpost of the Aegean microplate. Offshore the island, there is a multiple plate junction where Africa, the Adriatic and the Aegean form different types of plate boundaries by collision, subduction, transform faulting, and spreading[14]. The Cefalonia transform fault (CF) and subordinate faults lie around 25 km northwest of Lefkada Island and are responsible for the strong seismic activity of the area which is one of the highest in the eastern Mediterranean

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[7] Minoura et al. 2000
[8] see also Dominey-Howes et al. 2000a, McCoy and Heiken 2000
[9] Dominey-Howes et al. 2000b, Soloviev et al. 2000: 153ff.
[10] Kortekaas et al. 2005
[11] Vött et al.[11] 2006a
[12] von Marées 1907, Partsch 1907
[13] Jahns 2005, Vött et al. 2006b
[14] Sachpazi et al. 2000: 303

(Scordilis et al. 1985, Hatzfeld et al. 1995, Louvari et al. 1999). At Lefkada Island, there are frequent shallow-depth earthquakes (Galanopoulos 1952, 1954). The last strong earthquake occurred on August 14, 2003 and caused considerable damage to the infrastructure of the island (Papadopoulos 2003). Thus, the area is characterized by a high tsunamigenic potential (Papazachos and Dimitriu 1991: Fig. 4).

3. Historical aspects of the Sound of Lefkada

In the 7th century BC, ancient Lefkada was founded by the Corinthians at the northeastern flank of Lefkada Island. There is evidence from different literary sources that, at that time, a natural isthmus existed east of the city which connected the island to the Plaghia Peninsula. Although if it is still unclear and a matter to intense discussion where exactly the isthmus was located it is broadly accepted that the Corinthians cut a navigable passage through it[15]. Later, in the 5th century BC, they built the so called "mole of the Corinthians" at the southern end of the sound[16]. The archaeological remains of the mole are well preserved and can be found today in water depths of at least 1.4 m below the present sea level[17]. They represent one of the most impressive indicators for a considerable relative sea level rise during the past 2500 or so years. The mole was probably built in order to close off a harbour basin protected from the open waters of the Bay of Drepano. It may be expected that, at that time, the sound was still navigable through the canal which had been dug out two centuries before. At 427/425 BC, during the Peloponnesian War, however, warships had to be dragged over the isthmus[18] documenting that the sound was silted up or at least impassable. Murray[19], based on the Periplus of Pseudo-Skylax[20], found out that the canal was redredged at some time before 348/347 BC re-establishing the navigability of the sound. There are no information about further siltation of the sound until the end of the 3rd century BC when, at 218, Philip V used it as a shortcut for his fleet[21]. The situation was completely different when, by 197 BC, the canal was impassable due to sandy shallows which had formed sometime east of ancient Lefkada[22]. Another effort to regain the navigability of the canal must have been undertaken successfully before 50 BC. At that time, Cicero sailed through the sound on a merchant coaster. Shortly afterwards, however, during the Augustean period, the canal was barely navigable. Those ships who wanted to pass it were dependent on local pilots and their tugboats who managed the passageway through the shallow lagoonal waters[23]. For the 1st century AD there is a

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[15] Strabo 1, 3, 14; Partsch 1907: 273ff.
[16] Murray 1988: 14ff.
[17] Murray 1988: 101
[18] Thukydides 3, 81; 4, 8
[19] Murray 1982: 245
[20] Pseudo-Skylax, Periplus 34
[21] Murray 1982: 246, 261
[22] Livy 33, 17, 6; Lehmann-Hartleben 1923: 266f.
[23] Murray 1982: 246f.

report from Plinius who stated that the canal was choked by a sandbar[24]. In the 2nd century AD the navigable route through the sound was marked by wooden sticks thus enabling a time-consuming passage[25]. It is assumed that the shallows at that time were made up of sand[26]. Then, there is no information about the navigability of the sound and the state of the canal for a very long period of time. Under the auspices of the English occupying force a new ship canal was excavated across the shallow waters of the Sound of Lefkada in 1844[27]. This canal was dredged and partly renewed by the Greek authorities in 1902[28].

To sum up, the Sound of Lefkada has a history full of changes. According to historical data it was choked by sediments for at least three times since it was first opened by the Corinthian settlers in the 7th century BC. It is worth noting that the material which plugged the strait was at least partially sandy. Modern flow dynamics of the lagoonal waters are characterized by quiescent conditions and the predominant deposition of clay and silt.

4. Research methods

In the Lefkada coastal zone, we carried out geomorphological mapping and vibracoring of near-coast geological archives by means of an Atlas Copco vibracoring device with core diameters of 5-6 cm and a maximum recovery depth of 18 m below surface (b.s.). According to Walther's law of the correlation of facies sedimentological and geochemical as well as macro- and microfaunal studies of sediment samples were used to determine lateral as well as vertical changes of sedimentary facies and reconstruct palaeogeographical conditions. Geostatistical analyses of geochemical parameters helped to detect the palaeo environment[29]. Additionally, original material from a core out of the Lake Voulkaria which was retrieved by E. Grüger und S. Jahns (University of Göttingen) in 1997 was studied. Ostracod species and assemblages were valuable indicators of palaeoenvironmental conditions and sedimentological events[30]. Further, we studied thin sections to find out the mineral composition, fossil content and (post-)sedimentary structure of the sediments. The geochronology for the sedimentary history is based on ^{14}C-AMS-datings of plant remains or carbonate produced by marine organisms, on radiocarbon data published by Jahns[31] and on the relative age determination of diagnostic ceramic fragments. A Leica differential GPS was used to measure the location and elevation of vibracoring sites and interesting geomorphological structures.

[24] Pliny HN 4, 1, 5
[25] Partsch 1907, Lehmann-Hartleben 1923: 264
[26] Oberhummer 1887: 13
[27] Naval Intelligence Division 1945: 337
[28] von Marées 1907
[29] Vött et al. 2002
[30] Handl et al. 1999, Frenzel and Boomer 2004
[31] Jahns 2005

5. Tsunami deposits in the Lefkada coastal zone

Along a coastal strip between Lefkada city and the Lake Voulkaria east of Aghio Nikolaos we discovered several interrelated types of deposits which are characteristic for high energy event. They are evidence of repeated strong tsunami impact on the coast during the past 3000 or so years. In the following, we present the main characteristics of the different tsunami deposits which were encountered. For further details see Vött et al.[32].

5.1 Multitype tsunami deposits

Washover fans

The northern shore of the Lagoon of Lefkada is closed off from the Ionian Sea by beach ridges, up to 10 m high. These beach ridges are made up of sandy to gravelly littoral deposits. However, we found several triangle-shaped washover fans, so called chevrons. These chevrons cross the beach ridges and extend from the littoral zone into the lagoon. The longitudinal axes of the structures generally trend in NNW-SSE to NW-SE directions. The largest chevron is located near Cape Gyrapetra to the northwest of Lefkada city. It covers an area of at least 50 hectares. Vibracoring several of the chevrons revealed thick packages of coarse grained sediment on top of lagoonal mud. The coarse unit shows a bimodal grain size distribution characteristic for tsunamigenic influence[33]. The triangular fan-like shape of the chevrons document a high-energy impact. We exclude storm events from being responsible for these morphological features as the underlying lagoonal deposits do not show any signs of temporary interferences from the littoral zone. Thin layers of intercalated sand, for instance, would relate to influence by storms. Additionally, the large size of the Gyrapetra fan, almost 50 hectares, cannot be explained by storm dynamics. It has also to be taken into account that the fan is located behind a 10 m high beach ridge unit which is not in danger to be overwashed by pure storm waves. Further, von Marées[34] found linear dam-like structures of dislocated beach gravel in the midst of the lagoonal bay north of Lefkada city, some kilometers distant from the shore where this material comes from. We consider this to be another strong argument for tsunmigenic influence to the Lefkada coast.

Dislocated mega-blocks

The Plaka is completely made up of beachrock and represents the remains of a N-S running beach ridge system. Its surface lies around present sea level. It is partly submerged and partly exposed to subaerial conditions. We found an extended in-situ beachrock unit which is broken into numerous blocks due to the high seismo-tectonic activity of the area. Fissures predominantly trend in SSW-NNE

[32] Vött et al. 2006a
[33] Scheffers and Kelletat 2003
[34] von Marées (1907)

and NW-SE directions following the predominant strikes of Lefkada Island. On top of the Plaka, above sea level, and to the east of it, below sea level, we found numerous dislocated beachrock blocks of different sizes. Some of these blocks are isolated and partly embedded in sandy to silty marine deposits. Some other blocks are clearly imbricated. Obviously, the blocks were torn out of the original beachrock unit, uplifted, transported landwards and re-deposited. The maximum size of the blocks is at least 6 m^3 with an estimated weight of minimum 14 t. Some of the blocks were turned by 180° so that the original surface with bioerosive marks now faces downwards. The maximum distance from the in-situ beach rock unit is at least 50 m. Originally, there were much more and even bigger mega-blocks than can be seen today. They were removed during the past centuries, when large parts of the Plaka were used as a quarry.

It is possible to estimate approximate heights of storm waves which are necessary for moving blocks of different sizes based on an algorithm presented by Nott[35]. A block of 6 m^3 and 14 t needs wave heights of around 30 m to be moved by storm action[36]. However, storm waves of that dimension are not known for the Mediterranean. We therefore assume that the mega-blocks found at the Plaka were dislocated by tsunami impact.

Fields of scattered stones and blocks

Higher parts of the rocky promontory which separates the Bay of Aghios Nikolaos from the Bay of Cheladivaron, between 5 m a.s.l. and 15 m a.s.l., show numerous and irregularly scattered limestone blocks and stones with holes formed by marine boring mussels. In some cases, even in-situ specimens were found. The holes are produced by marine bioerosion and indicate that the material comes from the rocky littoral zone of adjacent coastal areas. The area affected is about 500 m^2 large, the blocks showing diameters of up to 100 cm. The findings undoubtedly document that the Cheladivaron promontory was heavily affected by tsunami wave dynamics from a western direction. Water masses piled up in front of the promontory, broke out numerous blocks and threw them on top of the adjacent plateau. As the highest findings of scattered stones and blocks were located at 14.80 m a.s.l. we assume a minimum tsunamigenic wave activity of 15 m.

Runup/backwash and breakthrough sediments

Several vibracores were drilled along a transect at the eastern shore of the Bay of Cheladivaron in the vicinity of Aghios Nikolaos. Vibracore ANI 4, for instance, is located close to the modern harbour mole of the village. It revealed Pleistocene to early Holocene deposits which were partly eroded under high energy conditions and covered by several layers of poorly sorted, but clearly laminated sand

[35] Nott 1997
[36] see also Bartel and Kelletat 2003

which we assume to represent reworked allochthonous material. Some layers, although lying partly above present sea level, contain numerous fragments of marine molluscs. A subsequent brownish palaeosol is overlain by sandy sediments with abundant marine shells followed by a weathered brown sandy colluvisol. Further cores in this area show a similar structure indicating a twofold strong tsaunmigenic influence to the site. It is assumed that the deposits found correspond to runup/backwash sediments.

Vibracores were also drilled at the western shore of the Lakoe Voulkaria bexond the Aghios Nikolaos bedrock sill. Vibracore ANI 7, for example, is located around 50 m west of the shore of the lake. The base of the profile shows weathered Neogene marls which are covered by fine grained silty freshwater lake deposits. Subsequently, the site came under swampy conditions with two distinct phases of peat formation. Then appears an erosional unconformity followed by a more than 2 m thick package of clearly laminated coarse material, mostly sand and fine gravel with abundant shell fragments of marine mollusks. The coarse grained layer is covered by peat. Profile ANI 7 exemplarily documents that a high energy event hit the swampy freshwater environment and caused the deposition of thick layer of allochthonous material originating from the sea side. Storm waves may absolutely be excluded as potential agents as they do no reach the inner Bay of Cheladivaron at all. It is known at least since the tsunami events in southeast Asia on December 26, 2004 that tsunami sediments may be clearly laminated due to runup/backwash flow dynamics[37].

Suspension deposits in the Lake Voulkaria

In 1997, Grüger and Jahns carried out sediment coring in the Lake Voulkaria and studied the evolution of the vegetation based on palynological investigations[38]. In the midst of the 7.5 m thick sedimentary sequence they found a 32 cm thick “brown layer” which intersects homogeneously grey freshwater deposits. Micromorphological studies and microfaunal analyses which we were able to carry out using original material from Grüger and Jahns revealed that the brown layer is made up of predominant fine sand and contains shell detritus of marine organisms as well as plant remains from subaerial environments[39]. Further, it could be shown that temporary saltwater influence to the lake caused strong eutrophication. It is therefore concluded that the brown layer is directly related to the tsunamigenic breakthrough sediments found at the western shore of the lake documenting that soil and plant fragments were eroded, mixed with marine deposits, flushed through the breakthrough channel at the Aghios Nikolaos bedrock sill and partly redeposited in the Lake Voulkaria as suspension deposit.

After limnic conditions reestablished for a certain period of time, the lake came again under the influence of saltwater, probably due to the opening of Cleopatra’s canal which connected the lake to

[37] Kelletat and Scheffers 2005; Kelletat 2005, pers. comm.
[38] Jahns 2005
[39] Vött et al. 2006a

the Bay of Cheladivaron. Later, saltwater influence decreased and conditions turned slightly brackish to almost purely limnic.

5.2 Dating of tsunami impacts

There are several possibilities for indirect dating of tsunamigenic influence to the Lefkada coastal zone based on geoarchaeological findings.

On top of the bedrock sill at Aghios Nikolaos, for example, close to the breakthrough channel and as a part of the breakthrough fan we found a field of scattered stones, 200 m^2 large, with stone diameters up to 25 cm. Most of the stones are characterized by abundant boreholes from boring organisms. We even encountered articulated boring mussels in growth position. The average elevation at the site is 4.50 m a.s.l. The material obviously originates from the rocky littoral zone of adjacent areas. This is also confirmed by findings of stones made up of beachrock within the same stone field. As the nearest site where autochthonous beachrock can be found is the Plaka, some 6 km to the west, this is another strong argument for tsunamigenic wave action. Nearby archaeological remains of a large building[40], possibly of a pylon belonging to a Roman bridge[41], mostly consist of stones from the breakthrough fan. They document that the corresponding tsunami event occurred before Roman times and thus represent a *terminus ante quem*.

Along the peak of the beach ridge south of the Plaka we encountered numerous rectangular beachrock plates up to 2,5 m^2 large and 30 cm thick lying up to 4.5 m a.s.l. Further imbricated beachrock slabs were found at the closeby strandline. Thus, we suggest that the blocks were transported by tsunami wave action. A fragment of a roof tile cemented in one of the beachrock plates on top of the beachridge dates from Classical-Hellenistic time[42] and represents a *terminus post quem* for the tsunami impact at this site.

The fort of Santa Maura is located on top of the beach ridge system northeast of Lefkada city. Vibracores around the fort revealed thick passages of tsunami deposits made up of coarse sand and gravel. We therefore suggest that the fort itself was built on top of tsunami deposits. The fort of Santa Maura was built around 1300 AD by J.I. Orsini[43] resulting in another a *terminus ante quem* for tsunamigenic impact on this part of the coast.

Based on ^{14}C-AMS-datings of plant remains and shells of marine organisms which were found in the vibracores between Lefkada city and Aghios Nikolaos and show close relations to high energy events it was possible to detect at least four generations of tsunami impact on the Lefkada coastal zone during

[40] Daux 1960: 744
[41] Melisch 2005, pers. comm.
[42] Melisch and Lang 2005, pers. comm.
[43] Papadatou-Giannopoulou 1999

the past 3000 or so years. Radiocarbon dating results published by Jahns[44] for the Lake Voulkaria were reevaluated and incorporated into the analysis. Detailed results of radiocarbon datings and conversion of ^{14}C-dates into calibrated ages (cal BC/AD) are listed in Vött et al.[45]. Subsequently, resulting dates for tsunami impacts were compared to regional tsunami and earthquake catalogues in order to find potential correlations between seismo-tectonic events and tsunamigenic influences. The following paragraphs give a short summary of what we found until now[46].

A mega-tsunami occurred around 1000 cal BC approaching the Lefkada coastal zone from a northwestern direction. It stroke the Plaka which was the coastline at that time, flushed the beach ridge material towards the east and thus completely uncovered the Plaka beachrock base. Subsequently, the water masses ran up the coast at Aghios Nikolaos. Partly, they left runup/backwash deposits close to the modern harbour, partly they broke through the bedrock sill and created a breakthrough fan into the Lake Voulkaria. The inflush produced a suspension flow which was deposited as brown layer within the limnic sedimentary sequence. There are at least four independent radiocarbon ages dating this event. It is assumed that this extreme event was triggered by a large turbidity current flowing down the north African shelf towards the deep sea regions of the Ionian Sea[47].

A smaller tsunami which hit the coast from a northwestern direction around 300 cal BC created several washover fans south and west of the Plaka. This event fits to the *terminus post quem* represented by the cemented roof tile fragment of Classical-Hellenistic age found in a dislocated beachrock slab.

The Gyrapetra chevron was formed, according to radiocarbon dating results, around 430 cal AD. Considering possible inconsistencies in dating and calibrating dating results this event may have been triggered by the 365 AD earthquake in Crete which affected large parts all over the eastern Mediterranean.

A second mega-tsunami seems to have occurred around 1000-1400 cal AD and to be responsible for the dislocation of mega-blocks at the Plaka. The tsunami waves rolled further southeast and hit the Cheladivaron promontory creating the field of scattered stones on its surface. Our results show further impacts to the coastline northwest of Aghios Nikolaos.

There is sedimentary evidence even for younger tsunami impacts on the Lefkada coastal zone possibly dating to the 17th-20th centuries AD. However, exact age determination of these young events by radiocarbon dating is difficult and will have to be complemented by analysing historical data and by the application of alternative dating methods.

[44] Jahns 2005
[45] Vött et al. 2006a
[46] see Vött et al. 2006a for further details
[47] see Vött et al. 2006a for full detailed chain of arguments

6. The Sound of Lefkada – generated by tsunami impact?

Our results show that the Lefkada coastal area has been repeatedly struck by tsunami events. The region represents an extraordinary sediment trap for high frequency and mid to high magnitude tsunamis which is due to the nearby Hellenic Arc and the Cefalonia transform fault as well as to the funnel-like coastal topography. This topography obviously intensifies tsunami signals and offers various sediment traps.

It has to be assumed that the large water masses which hit the coast north of Lefkada city and around the Plaka must have also affected adjacent areas, for instance in the form of washover, flush through or backwash activities. Against the background of the changeful history of the Sound of Lefkada – being navigable at one time and chocked by sediments at another[48] – it seems logical to assume that the geographical evolution of the sound is closely related to multiple tsunamigenic impacts on the Lefkada coastal zone. Another argument is given by historical accounts reporting on the widespread sandy sediments which, from time to time, plugged the strait. Recent sediment deposition in the Sound of Lefkada is dominated by quiescent conditions related to the accumulation of silt and clay. Sand grains need considerable flow energy to be transported. Such kind of flow energy is not known from the present inner sound except for a small area parallel to the (modern) canal. We thus conclude that the sound was repeatedly affected by large tsunamigenically driven water masses flowing across the strait from north to south and which left considerable sediment masses due to a rapid decrease of flow velocity and to diverging effects as soon as they had reached the Bay of Drepano.

Vibracore profile LEF 11 which was drilled at the northeastern fringe of the former saltworks of Lefkada exemplarily shows that there are stratigraphic inhomogeneities which might be explained by tsunamigenic influence to the sound. The base of the sequence shows deposits of an ephemerally limnic environment covered by a thick package of freshwater lake deposits. Subsequently, the lake came under the temporal influence of saltwater as indicated by several findings of fragments of a brackish macrofauna. A following palaeosol documents that terrestrial conditions prevailed for a certain time. The palaeosol was partly eroded and covered by bimodal, sandy to gravelly high energy deposits, which, in their upper part are strongly weathered. Subsequently follows a thick unit of lagoonal mud with several intersecting layers of shell debris. As well as the coarse layer below, these intersections seem to be due to tsunamigenic influence to the sound. However, further vibracores and radiocarbon datings are necessary in order to convincingly prove this assumption.

7. Conclusions and future research

Based on the comparisons of geological evidence from the Lefkada coastal zone with historical data documenting the history of the Sound of Lefkada the following conclusions can be made.

[48] see Section 3

(i) As reported by the ancients, an isthmus existed east of ancient Lefkada which was cut through by the Corinthians in the 7th century BC. The passageway, however, silted up soon afeterwards. We assume that the original isthmus consisted of tsunami deposits. Further, it seems possible that the siltation of the strait was also caused by tsunami wave action.

(ii) A tsunami occurred during Classical-Hellenistic times and may have naturally reopened the canal.

(iii) The shallows described by ancient accounts from the inner sound seem to have been made up of coarse tsunami deposits untypical of the autochthonously quiescent sedimentary conditions.

(iv) The fact that the canal across the sound is not mentioned in history after the 2nd century AD may be due to further tsunami events which choked the strait after that time.

Further research within an interdisciplinary and multinational project between 2006 and 2009 will focus on intensified field work and laboratory analyses in order to improve the tsunami database for the Lefkada area. It is planned to carry out further vibracores, to study profiles opened by excavations, to detect the underwater geomorphology by side scan sonar, sub-bottom profiling, and echo sounding, to apply geophysical methods at terrestrial sites to find tsunami deposits and to investigate the manifold archaeological data. The overall aims are (i) to reconstruct how and where the Lefkada coastal area was affected by tsunami events, (ii) how these events influenced the palaeogeographical evolution and (iii) which were the complex interactions between man and environment.

The results presented let us suggest that the Lefkada area is, at present, exposed to a considerable tsunami hazard. The vulnerability of the region is high as it attracts many thousands of tourists year by year and hosts an important NATO airport nearby. Thus, local economy, politics and administration should take into account modern approaches to tsunami risk assessment in order to be prepared for the future.

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Figure captions

Fig. 1: The coastal zone between Lefkada city and Preveza including the Sound of Lefkada, the Bays of Aghios Nikolaos and Cheladivaron and the Tongue of Actio. Locations of vibracores and of sediment core retrieved from the Lake Voulkaria by Jahns (2005). Modified from Vött et al. (2006a).

Fig. 2: Locations of multitype tsunami deposits between Lefkada city and Aghios Nikolaos. Black dots mark vibracorings in near-coast geological archives. 1 – Gyrapetra chevron, 2 – chevron system south of the Plaka, 3 – Plaka with dislocated mega-blocks, 4 – fields of scattered blocks and stones at the Cheladivaron promontory, 5 – runup/backwash sediments at Aghios Nikolaos, 6 – sediments of the breakthrough fan across the Aghios Nikolaos bedrock sill, 7 – Lake Voulkaria with suspension deposits. Corona satellite image (June 04, 1970). Modified from Vött et al. (2006a).

Fig. 3: Lagoonal area northwest of Lefkada city with several triangular shaped washover fans of tsunamigenic origin (chevrons). The longitudinal axes of the chevrons indicate the approximate flow direction. Corona satellite image (June 04, 1970).

Fig. 4: Tsunami deposits encountered at the beach ridge south of the Plaka. Some of the dislocated beachrock blocks at the coastline are turned upside down, some are imbricated (a). Beachrock slabs can be found up to 4.5 m above present sea level on top of the present beach ridge and are up to 1 m^2 large (b). At the crest of the beach ridge a fragment of a roof tile was found cemented in a dislocated beachrock slab (c). The tile fragment dates to Classical-Hellenistic times and represents a *terminus post quem* for the tsunami impact at this site. Photos taken by A. Vött (a-c), S. Brockmüller (d), 2005.

Fig. 5: Facies profile of vibracore LEF 11 drilled at the northeastern fringe of the former saltworks east of ancient Lefkada. The top/up direction for the core segments is to the left. Missing sections are due to rodding. The facies distribution pattern shows several potential intersections by tsunamigenic activities. See text for further explanation. Photo taken by M. May, 2006.