G. Gönnert, B. Pflüger & J.-A. Bremer
Von der Geoarchäologie über die Küstendynamik zum Küstenzonenmanagement
Coastline Reports 9 (2007), ISSN 0928-2734, ISBN 978-3-9811839-1-7
S. 115 - 125

Evidence of tsunamigenic impact on Actio headland near Preveza, NW Greece

Simon Matthias May, Andreas Vött, Helmut Brückner & Svenja Brockmüller

Faculty of Geography, Philipps-Universität Marburg

Abstract

The coastal zone north and east of Lefkada city, NW Greece, has been affected by several tsunami events during the late Holocene. In 2006 and 2007, numerous vibracores were retrieved from south of Preveza Strait in search of tsunamigenic influence on the Actio area, including the nearby ancient sanctuary of Apollo. Underwater surveys of the Plaka, a partly submerged palaeo coastline made up of beachrock, were realized by means of scuba diving. This study presents results of selected vibracores from the southern and northern parts of Actio headland.

The geomorphological underwater survey of the Plaka revealed ridges of isolated beachrock fragments as well as numerous separate blocks und boulders east of the in-situ Plaka. These findings indicate block dislocation by wave action and are related to tsunami impact. Moreover, sediments of shallow marine origin were detected in ~7 m a.s.l. in the north-eastern part of the Bay of Aghios Nikolaos, also pointing to tsunamigenic origin. Vibracores drilled on Actio headland show a sudden input of unsorted marine sediments into limnic and terrestrial environments. The two sedimentary units are separated by erosional unconformities indicating high energy wave activity with erosive effects. In conjunction with results of previous studies in the area between Aghios Nikolaos and Lefkada, the abrupt change of sedimentation dynamics can be attributed to at least one major tsunami event. According to ^{14}C-AMS datings of plant remains and molluscs from several vibracores a major tsunami impact happened around or after 1300 cal BC.

Our findings reflect the high vulnerability of the Lefkada coastal zone which attracts thousands of tourists and hosts an important NATO airport nearby.

1 Introduction

Study area

Tsunami events during historical times are known from several parts of the Eastern Mediterranean (Soloviev et al. 2000, Tinti et al. 2004). Unfortunately, historical sources exist only for the last 2500 or so years (Papazachos & Dimitriu 1991). Within the last 15 years, several authors presented evidence of tsunamigenic influence in numerous coastal areas by the detection of tsunamigenic sediments (e.g. Dominey-Howes et al. 2000, Kelletat & Schellmann 2002, Scheffers & Kelletat 2003, Reinhardt et al. 2006). These sediments as well as their chronological interpretation help to better understand the main characteristics of tsunami events, to develop tsunami catalogues, and to decipher the potential tsunami risk of an area.

The area between Lefkada Island (NW Greece) and Preveza at the entrance to the Ambrakian Gulf is exposed to the northern part of the Hellenic Arc (Fig. 1b and 1a). Here, the Adriatic microplate is subducted by the Aegean microplate. The Cefalonia transform fault (CF), situated west of Lefkada Island, connects this zone of subduction with an area of continent-continent collision beginning at the coast of southern Epirus (Fig. 1a). The CF has been responsible for numerous strong earthquakes during history (Cocard et al. 1999, Louvari et al. 1999, Sachpazi et al. 2000, Papadopoulos et al. 2003, Benetatos et al. 2005). The study area belongs to the seismically most active regions of the Mediterranean. According to Papazachos & Dimitriu (1991) and Soloviev (1990), it thus owns a high tsunamigenic potential.

The coastal zone to the north and east of Lefkada city has been repeatedly affected by tsunami events during the late Holocene (Galanopoulos 1960, Papazachos & Papazachou 1997, Soloviev et al. 2000, Vött et al. 2006b, 2007a, 2007b). Vött et al. (2006b, 2007a) identified chevron-shaped washover fans of littoral sediments in the northern Lagoon of Lefkada (Fig. 1b, box 1; Fig. 2a), mega-boulders on top of the Plaka, a partly submerged palaeo coastline made up of beachrock (Fig. 1b, box 2; Fig. 2b), and the temporary interruption of Lake Voulkaria's limnic sequence by (i) coarse-grained marine sediments at its western shore (Fig. 1b, box 3; Fig. 2c) and (ii) suspension deposits of marine origin in its central part (Fig. 1b, box 4; Fig. 2d).

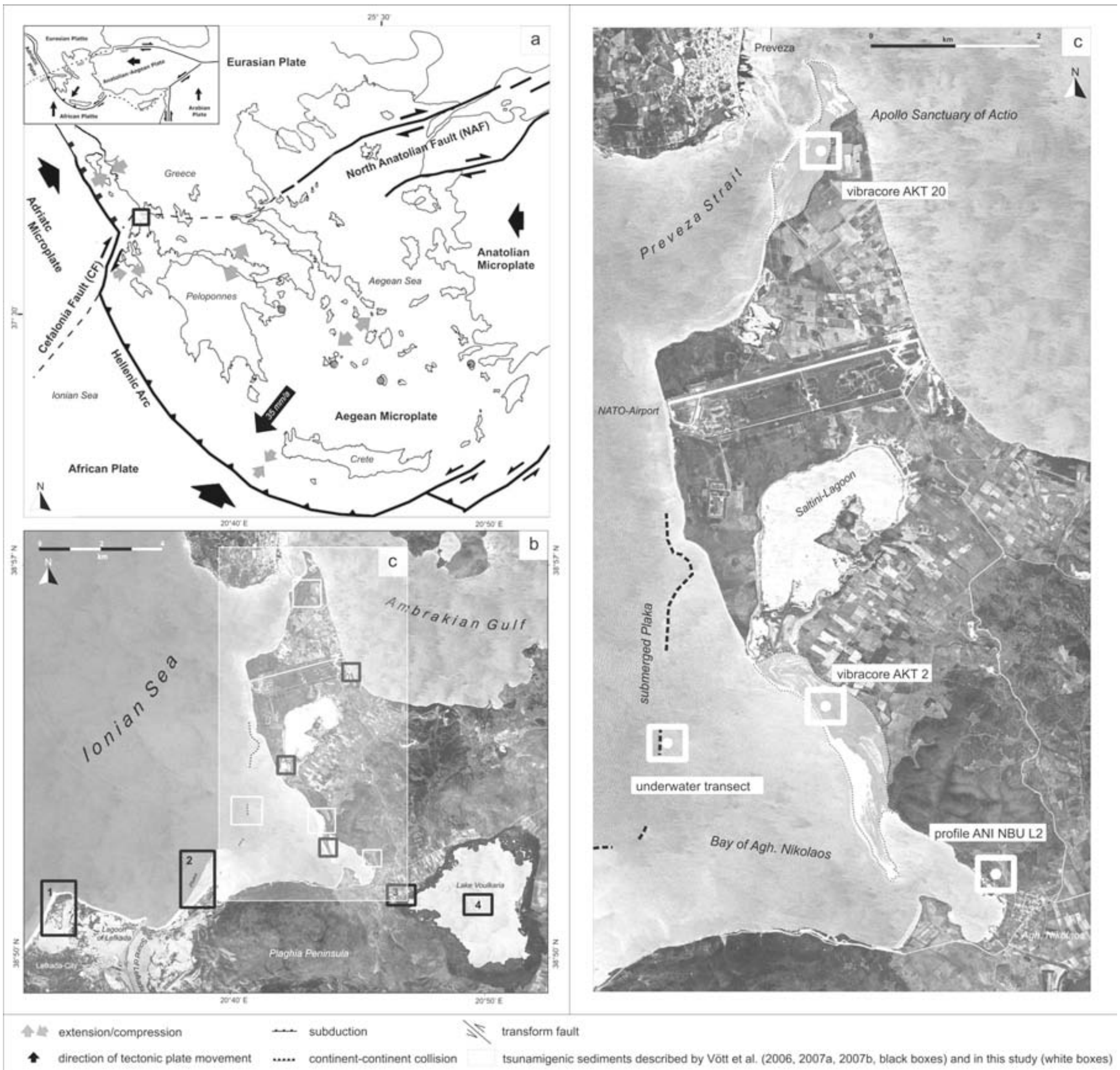

Figure 1: (a) Tectonic setting of the eastern Mediterranean. The study area is marked by a black frame. (b, c) Overview of the study area and location of different geological archives showing tsunamigenic sediments presented within this study (white frames) and by Vött et al. (2006b, 2007a, 2007b; black frames).

In 2006 and 2007, numerous vibracores were drilled south of Preveza Strait within the framework of an interdisciplinary study in search of tsunamigenic deposits, including geoarchaeological investigations around the nearby sanctuary of Apollo. This study presents results of selected vibracores from the southern and from the northern parts of the headland. Moreover, a sediment profile from the Bay of Aghios Nikolaos and observations from geomorphological underwater surveys around the Plaka are documented (Fig. 1c).

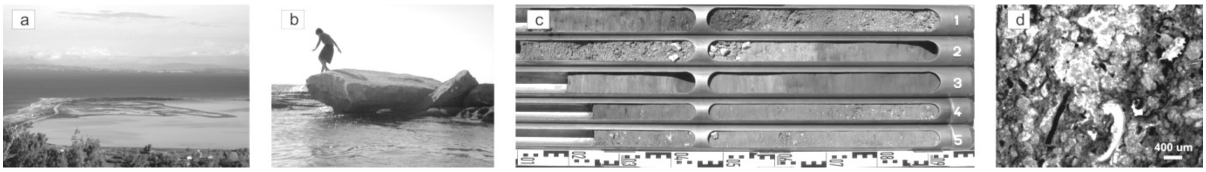

Figure 2: Different types of tsunamigenic sediments from the southern part of the study area described by Vött et al. (2006b): (a) Chevron-shaped washover fans in the Lagoon of Lefkada, (b) overtoppled boulder of 16 m^3 on top of the Plaka, (c) coarse-grained sediments of marine origin at the western shore of Lake Voulkaria (vibracore ANI 10) and (d) suspension deposits of marine origin in its central part (VOUL 1).

Methods

Field work comprised DGPS measurements, terrestrial and underwater geomorphological mappings, the examination of sediment profiles as well as the realization of vibracorings in near coast geological archives. Vibracorings were performed by means of an Atlas Copco Cobra mk 1 corer and sediment cores of 5 cm and 6 cm diameter. The sediment profiles were recorded and sampled in the field. Grain size classification was based on Ad-hoc-AG Boden (2005). Sedimentological, geochemical and macro- and microfaunal analyses were realized in the laboratory. Organic material and mollusc remains taken from the samples were dated by the ^{14}C-AMS technique. ^{14}C-AMS ages were corrected for a marine reservoir effect of 402 years if necessary (Stuiver et al. 2007, Reimer & McCormac 2002). Detailed information of the methodological background of geomorphological and palaeogeographical studies are described in Vött et al. (2002) and Brückner (2007).

2 Results

Evidence from northern Actio headland

Vibracore AKT 20 (Fig. 3) was drilled 200 m south of the ancient sanctuary of Actio and 350 m east of the present-day coastline (Fig. 1c, see also Vött et al. 2007b). The profile can be subdivided into three stratigraphic units which are also depicted by selected geochemical parameters. It shows clayey to silty limnic sediments, partly weathered under terrestrial conditions at its base (2.75 m – 1.66 m below surface, b.s.). Here, high values of organic content as well as relatively low Na-concentrations, typical of terrestrial conditions, were measured. These deposits are abruptly covered by marine sediments, consisting of unsorted sand and gravel and showing a remarkable increase of the contents of calcium carbonate and Na (1.70 m – 0.52 m b.s.). The corresponding facies change is marked by a clear erosional contact at 1.70 m b.s. A well developed soil established on top of this sequence (0.52 m – 0.00 m b.s.), represented by high values of organic matter and, due to pedogenetic processes, by decreasing content of calcium carbonate.

Plant remains, possibly root fragments, taken from the limnic-terrestrial sequence, 25 cm below the erosional unconformity, yielded a ^{14}C-AMS age of 2476-2346 cal BC (AKT 20/10 PR, 1.91 m b.s., Table 1). Hence, it seems as if limnic and terrestrial conditions at AKT 20 lasted until at least ~2400 cal BC. The ^{14}C-AMS age of a mollusc fragment taken from the marine material shows that high energy wave influence must have taken place around or after ~1300 cal BC (AKT 20/7 M, 1.48 m b.s., Table 1). Intense soil formation on top of this sequence indicates subaerial exposure over at least a few hundred years.

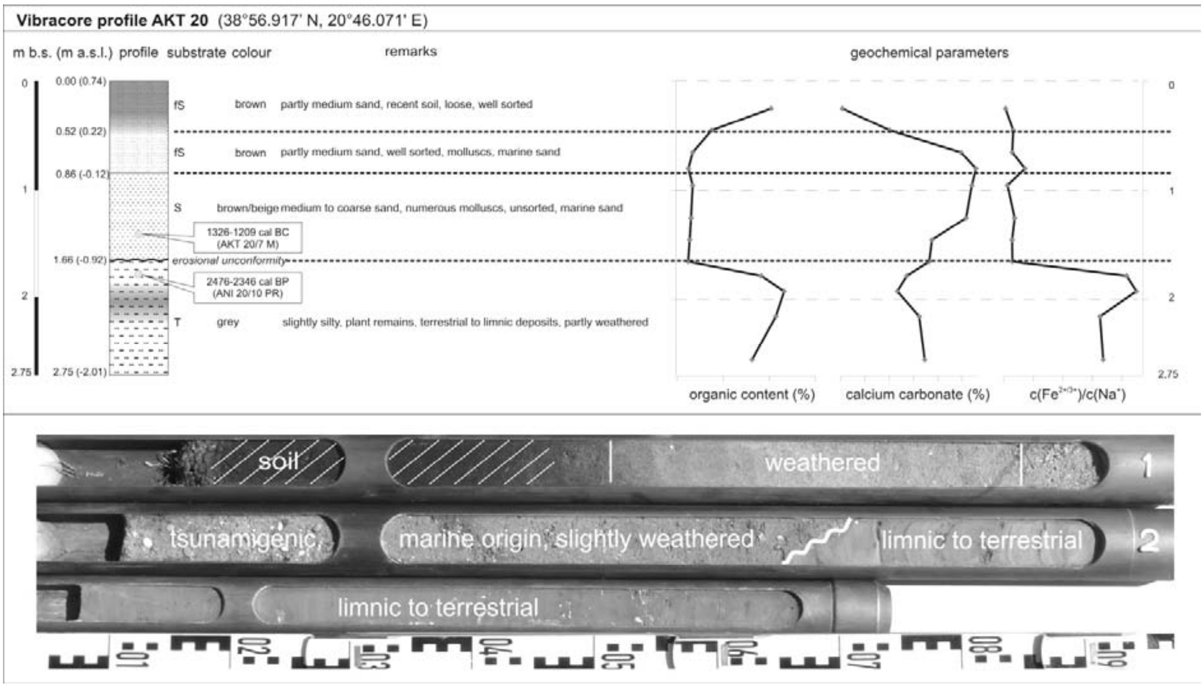

Figure 3: Photography of vibracore AKT 20 and schematic profile with selected geochemical parameters. Sedimentological and geochemical results show three stratigraphic units within the vibracore sequence.

Evidence from southern Actio headland

Vibracore AKT 2 (Fig. 4) was drilled north of the so called Phoukias spit, an accretional sand spit located in the south-western part of Actio headland and reaching about 900 m into the Bay of Aghios Nikolaos (Fig. 1c, see also Vött et al. 2007b).

Table 1: Radiocarbon dating results for selected samples from Actio headland. b.s. – below surface; artic. spec. – articulated specimen; 1σ max-min cal BC – calibrated ages; Lab. No. – laboratory number, University of Kiel (KIA); * - marine reservoir correction with 402 years of reservoir age.

Sample	Depth (m b.s.)	Lab. No.	Sample description	$\delta^{13}C$ (ppm)	^{14}C age (BP)	1σ max-min (cal BC)
AKT 2/9 PR	2.80	KIA31674	unidentified plant remains	-5.2	4160 +- 31	2872-2679
AKT 20/7 M	1.48	KIA31668	*Tellina planata*, artic. spec.	-3.1	3350 +- 35	1326-1209*
AKT 20/10 PR	1.91	KIA31669	unidentified plant remains	-27.0	3930 +- 38	2476-2346

The profile starts with a sequence of deeply weathered sandy and silty sediments, probably of pre-Holocene or early Holocene age. In the upper part of this sequence, soil formation took place. From 3.81 m - 2.79 m b.s., green-grey, slightly sandy and clayey silt with in-situ plant remains is interpreted as limnic or lagoonal deposits. High values of organic content and the high Fe/Na-ratio as well as the lack of carbonate indicate a former surface, developed under subaerial conditions. Comparable to vibracore AKT 20 (Fig. 3), the following sediments (2.79 m – 1.68 m b.s.) were deposited by high energy dynamics. This is also shown by the erosional contact in 2.79 m b.s. The marine sediments consist of grey sand with numerous articulated specimens of molluscs and mollusc fragments and are characterized by low values of organic and a high content of calcium carbonate. Above (1.68 m – 0.70 m b.s.), the marine sands were exposed to subaerial conditions. In contrast to the underlying unweathered marine sequence, high values of the Fe/Na-ratio could be measured. The following layer of well sorted fine sand represents the subsequent deposition of aeolian material, on which the (sub)recent soil formation has developed.

Plant remains taken from 2.80 m b.s., just below the erosional unconformity, were dated to 2872 – 2679 cal BC (AKT 2/9 PR, 2.80 m b.s., Table 1). Thus, the change towards high energy conditions and the accumulation of the marine material must have taken place after ~2800 cal BC.

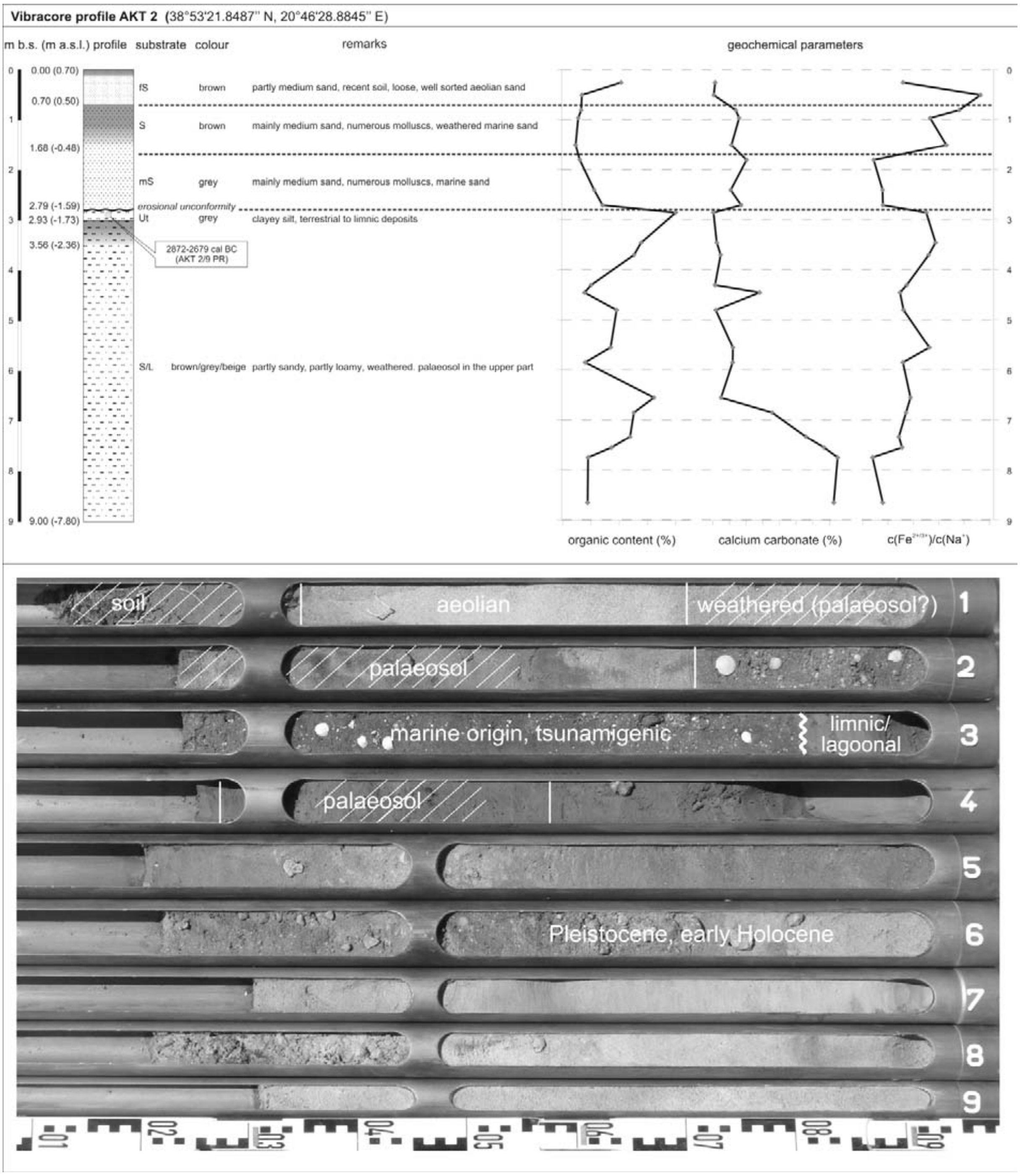

Figure 4: Photography of vibracore AKT 2 and schematic profile with selected geochemical parameters. Sedimentological and geochemical results show characteristic differences within the profile and allow to distinguish between several stratigraphic units.

Evidence from the Bay of Aghios Nikolaos

In the north-eastern part of the Bay of Aghios Nikolaos, 7.06 m above present mean sea level (a.s.l.), a small pit, 38 cm deep, revealed marine sediments deposited in a terrestrial environment (Fig. 5). The base of the profile shows slightly sandy, clayey silt of red-brown colour (0.38 m – 0.33 m b.s.), containing fragments of the underlying bedrock. This basal horizon can be interpreted as a palaeosol. On top of this layer, a crust of calcium carbonate, 5 cm thick, was encountered. Numerous fragments of marine molluscs and several specimens of foraminifera were found within this crust (Fig. 5f).

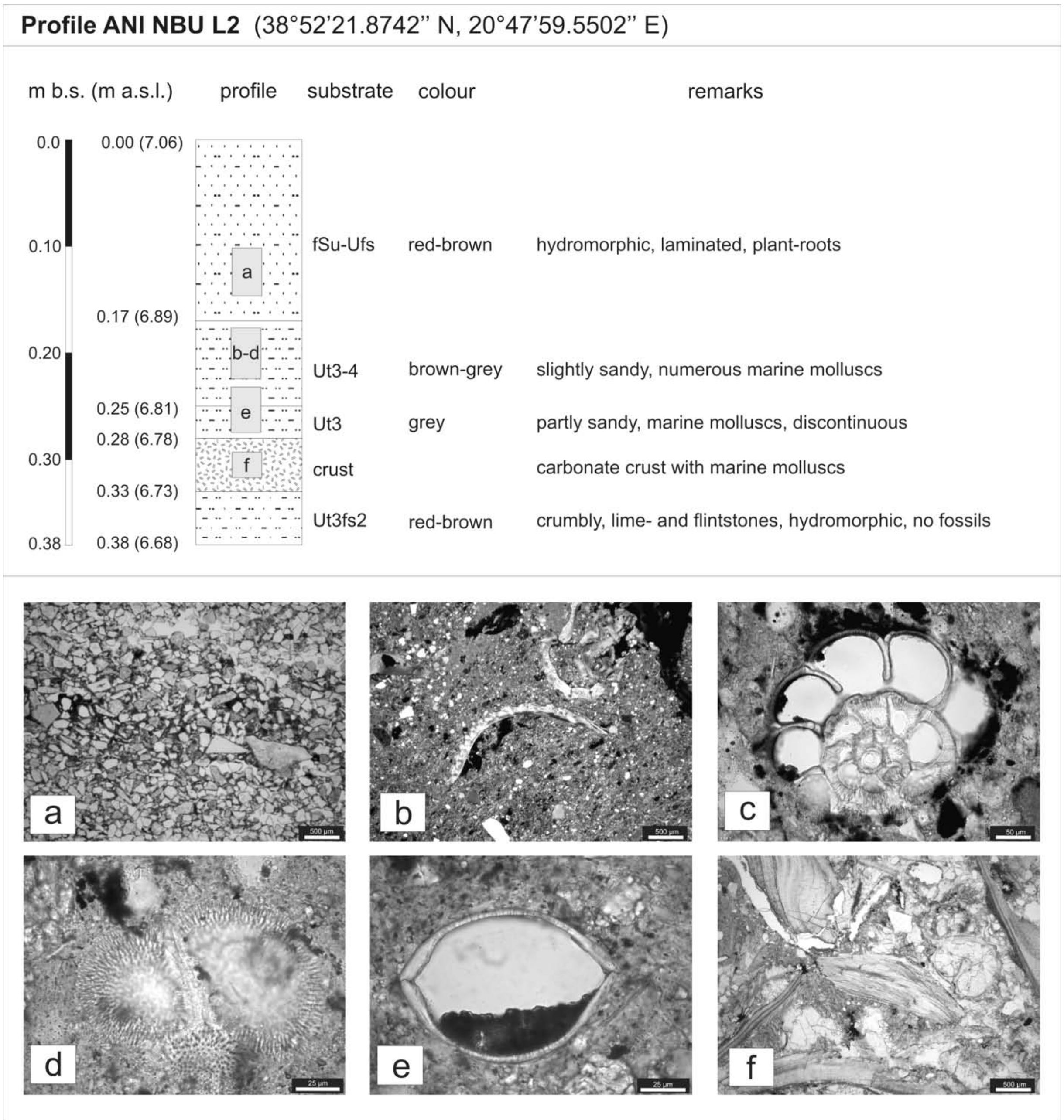

Figure 5: Stratigraphy of profile ANI NBU L2, 7.06 m a.s.l., excavated in the north-eastern part of the Bay of Aghios Nikolaos (see also Fig. 1c) and thin sections of distinct horizons showing (a) angular components in the upper part of the profile (ANI NBU L2/1 DS, 0.10-0.15 m b.s.), (b) mollusc fragments (ANI NBU L2/2 DS, 0.18-0.23 m b.s.), (c) specimen of a benthic foraminifera (order: Rotaliina, ANI NBU L2/2 DS, 0.18-0.23 m b.s.), (d) specimen of a planctonic foraminifera (*Globigerina* sp., ANI NBU L2/2 DS, 0.18-0.23 m b.s.), (e) specimen of an undetermined ostracod (ANI NBU L2/3 DS, 0.25-0.28 m b.s.) and (f) carbonatic crust with fragments of marine molluscs (ANI NBU L2/4 DS, 0.30-0.33 m b.s.).

In the following sediment layers out of clayey silt (0.28 m – 0.17 m b.s.), marine fossils, intensely weathered, are still abundant. Thin sections show an aragonitic composition of the mollusc shells without calcite conversion. Moreover, numerous well preserved specimens of benthic (order Rotaliina, Fig. 5c) and planctonic (*Globigerina* sp., Fig. 5d) foraminifera as well as ostracods (Fig. 5e) could be detected. Intense weathering of the sediments led to the solution, displacement and crust-like secondary deposition of carbonate in the underlying horizon. Above 0.17 m b.s., laminated brownish-red silty fine sand was found. These sandy deposits are free of carbonate and marine components. Thin sections (Fig. 5a) exclusively show angular components, suggesting a colluvial origin.

The sequence proves the accumulation of fine grained sediments of marine origin between 6.73 - 6.89 m a.s.l. Both stratigraphy and sediment texture of the marine deposits found at ANI NBU L2 exclude the deposition of these sediments as a consequence of a former sea level high stand. This is supported by Vött (2007) and Vött et al. (2006a, 2007b), who did not find any indication for a Holocene sea level higher than the present one along the adjacent Akarnanian coast. Consequently, we conclude that a tsunami induced the deposition of the sequence. Absolute dating of these sediments will be necessary to ensure the Holocene age of the deposits.

Evidence from the underwater survey of the Plaka

The shallow lagoonal waters of the Lefkada Sound are sealed off from the open Ionian Sea by an extended barrier beach system the base of which is made up of beachrock down to approximately 12 m below present mean sea level (b.s.l). Towards the north, the recent beach ridge is shifted eastwards and thus separated from its beachrock base – the so called Plaka – which is partly submerged, fragmented and, due to the effects of earthquakes, partly broken. Here, the remains of the Plaka represent a palaeo coastline. However, it protects the Bay of Aghios Nikolaos from the open sea and reduces wave energy (Fig. 1b and c).

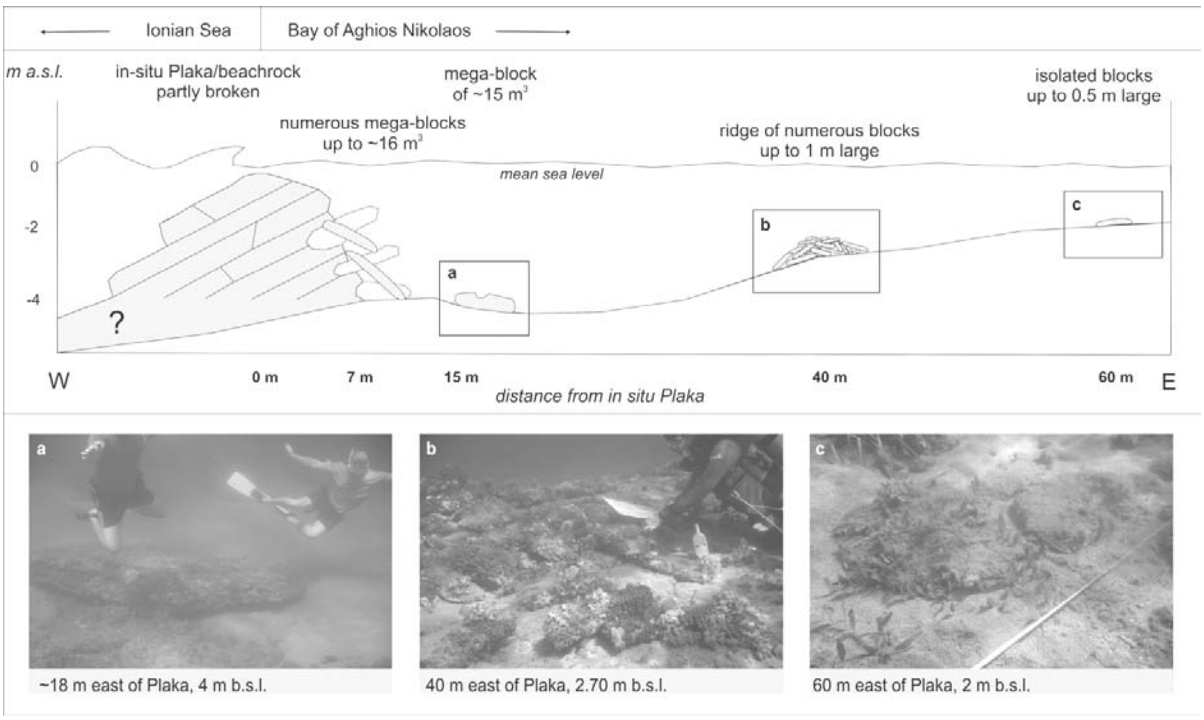

Figure 6: Schematic profile of the underwater transect east of the Plaka. Photos illustrate a dislocated mega-block of ~10 m^3 at 18 m (a), a ridge of numerous blocks at ~40 m and (c) isolated beachrock slabs, up to 50 cm long, at 60 m east of the in-situ Plaka.

Underwater surveys revealed numerous separate blocks und boulders east of the in-situ Plaka as well as a ridge of isolated beachrock fragments down to 4 m water depth. A transect, 60 m long, was studied on the leeward side of the submerged Plaka by means of (scuba) diving (Fig. 6).

Up to about 20 m east of the Plaka, numerous boulders of up to 10 m^3, some even 16 m^3, have been detected (Fig. 6a). These boulders, partly broken into pieces, must have been transported from the in-situ lying Plaka. A ridge of beachrock fragments, variable in size up to 1 m^3, was found around 40 m east of the Plaka (Fig. 6b). Dislocated blocks, up to 50 cm large, could be traced as far as ~60 m east of the in-situ Plaka along the transect (Fig. 6c). Without exception, these fragments are densely and homogeneously covered with marine organisms, such as algae. This fact excludes (i) that they are continuously moved by wave action or storms and (ii) a step-by-step formation of the ridge by storm activity, which would produce an inhomogeneous organic cover. Consequently, block dislocation must have been triggered by high energy wave events at least since the late Holocene. We therefore conclude that these findings indicate block dislocation by tsunami wave action.

3 Discussion

According to sedimentological and geochronological results from further vibracores drilled in the north-eastern part of the Lefkada Sound, the north-eastern part of the Plaka developed around 5300 cal BC, resulting in the establishment of lagoonal conditions east of a corresponding beach ridge system (Vött 2006b, 2007a, 2007b). The formation of the northwards following branch of the Plaka, the remains of which now separate the Bay of Aghios Nikolaos from the Ionian Sea, must have taken place at approximately the same time. Considering the geochronological results of vibracore AKT 2, this palaeo coastline existed at least until ~2800 cal BC. At that time, relative sea level must have been below 1.59 m b.s.l. as limnic to terrestrial sequences were formed at AKT 2 and AKT 20.

In the northern (AKT 20) and in the southern parts (AKT 2) of Actio headland, our results show a strong and sudden input of unsorted marine sediments into limnic and terrestrial environments. Erosional unconformities, located in 1.59 m b.s.l. (AKT 2) and 0.92 m b.s.l. (AKT 20), indicate high energy wave activity with erosive effects. Regarding the sedimentological and geochronological results of vibracores AKT 20 and AKT 2, the abrupt transition related to the erosive unconformity in both drillings may be attributed to a morphodynamic event which was dated to around or after 1300 cal BC. However, there is indication of a tsunami event which affected the eastern shore of Actio headland around 2800 cal BC (Vött et al. 2007b). Thus, it cannot be excluded that AKT 20 and AKT 2 document two different events which changed morphodynamics on Actio headland.

Moreover, both profiles show intense weathering of the upper part of the marine material, leading to the formation of a well developed soil (Fig. 3). The remarkable change of depositional conditions was accompanied by the activation of littoral dynamics, subsequently initiating the formation of the Phoukias sand spit and, to a certain extent, accretional beach sequences (Fig. 1c, white marked areas). Regarding (i) the well developed soil in vibracore AKT 20 and (ii) the period of time needed for the intense weathering of the marine sediments and the development of the following aeolian overlay in vibracore AKT 2, the period of subaerial weathering of the marine sediments must have been at least several hundreds of years long.

Studies of recent tsunami events and its effects on coastal morphology showed that tsunami waves may induce severe erosion and the shifting of beach systems and coastlines (e.g. Altinok et al. 2001, Keating 2005, Polngam et al. 2005, Meltzner et al. 2006). Our results from the underwater survey east of the in-situ lying Plaka remains give evidence of block dislocation by tsunami impact. Sediments of marine origin have been detected in ~7 m a.s.l. in the north-eastern part of the Bay of Aghios Nikolaos – we assume a tsunamigenic origin of this sequence as well. Together with these findings and the results of previous studies in the area between Aghios Nikolaos and Lefkada (Vött et al. 2006b, 2007a, 2007b), the influence of at least one tsunami event on the formation of the erosional unconformities and the distinct change of morphodynamics at vibracore sites AKT 2 and AKT 20 is likely. As to the findings of marine sediments reaching up to 0.50 m a.s.l. (AKT 2) and 0.58 m a.s.l. (AKT 20), it has to be clarified if these sediments are definitely part of event deposits and represent sand-sheet like, partly well sorted tsunami deposits or if they may have been formed by a higher relative sea level. According to geochronological data found for AKT 20, one tsunami event may have occurred around or after 1300 cal BC. These results fit well with the conclusions of Vött et al. (2006b, 2007a, 2007b) who presented sedimentological and geochronological evidence of tsunamigenic impact in the area around 1000 cal BC and of several other events.

4 Conclusions

Using geomorphological, sedimentological and palaeogeographical methods, we identified clear signs of tsunamigenic impact in the study area. We were able to encounter distinct morphological changes at the northern and southern coastal zone of Actio headland. The following results can be summarized:

(i) Underwater surveys of the Plaka, west of the Bay of Aghios Nikolaos, revealed block dislocation by tsunami wave action. Dislocated mega blocks, a rubble ridge and isolated blocks could be documented in distances of up to 60 m east of the Plaka (see also Vött et al. 2007a).

(ii) We presented clear evidence of a tsunami event which hit the north-eastern part of the Bay of Aghios Nikolaos. Here, sediments of marine origin, intensely weathered, were encountered in 7 m a.s.l.

(iii) According to sedimentological and geochronological results, the northern part of the Plaka developed around 5300 cal BC (Vött et al. 2007a). At least until 2800 cal BC, it constituted a stable coastline.

(iv) After ~2800 cal BC (AKT 2) and ~2400 cal BC (AKT 20), respectively, the northern and southern parts of Actio headland were hit by high energy wave dynamics. This transition is marked by erosional unconformities found in vibracore profiles. Against the background of previous studies in the Lefkada area, a tsunamigenic origin of these sedimentological features is most likely (Vött et al. 2006b, 2007a, 2007b).

(v) The abrupt morphodynamic change and the related accumulation of marine material was accompanied by the activation of littoral processes.

5 Acknowledgements

Radiocarbon dating was carried out at the Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research (Christian-Albrechts-Universität, Kiel). We thank R. Schmidt-Effing and M. Handl (Marburg) for the determination of microfossils. Scuba diving was realized by U. Ewelt and R. Grapmayer (Grünberg). We gratefully acknowledge funding of the research project by the German Research Foundation (DFG, Bonn, VO 938/2-1).

References

Ad-hoc-AG Boden der Staatlichen Geologischen Dienste und der Bundesanstalt für Geowissenschaften und Rohstoffe (ed.) (2005): Bodenkundliche Kartieranleitung. 5th edition. Schweizerbart, Stuttgart, 438 p.

Altinok, Y., S. Tinti, B. Alpar, A.C. Yalçincer, Ş. Ersoy, E. Bortolucci & A. Armigliato (2001): The tsunami of August 17, 1999 in Izmit Bay, Turkey. Natural Hazards 24, 133-146.

Benetatos, C., A. Kiratzi, Z. Roumelioti, G. Stavrakakis, G. Drakatos & I. Latoussakis (2005): The 14 August 2003 Lefkada Island (Greece) earthquake: Focal mechanisms of the mainshock and of the aftershock sequence. Journal of Seismology 9, 171-190.

Brückner, H. (2007): Holozäne Umweltrekonstruktion und Geoarchäologie. In: Dikau, R., K.M. Moldenhauer & J. Bedehäsing (eds.): Die Erdoberfläche – Lebens- und Gestaltungsraum des Menschen. Zeitschrift für Geomorphologie N.F., Suppl.-Bd. 148, 55-58.

Cocard, M., H.-G. Kahle, Y. Peter, A. Geiger, G. Veis, S. Felekis, D. Paradissis & H. Billiris (1999): New constraints on the rapid crustal motion of the Aegean region: recent results inferred from GPS measurements (1993–1998) across the West Hellenic Arc, Greece. Earth and Planetary Science Letters 172, 39-47.

Dominey-Howes, D.T.M., A. Cundy & I. Croudace (2000): High energy marine flood deposits on Astypalaea Island, Greece: possible evidence for the AD 1956 southern Aegean tsunami. Marine Geology 163, 303–315.

Galanopoulos, A.G. (1960): Tsunamis observed on the coasts of Greece from antiquity to present Time. Annali di Geofisica X111/4, 371-386.

Keating, B.H., C. Helsley, Z. Waheed & D. Dominey-Howes (2005): 2004 Indian Ocean Tsunami on the Maldives Islands: Initial Observations. Science of Tsunami Hazards 23/2, 19-70.

Kelletat, D. & G. Schellmann (2002): Tsunamis on Cyprus: Field Evidences and ^{14}C Dating Results. - Zeitschrift für Geomorphologie N.F., Suppl.-Bd. 137, 19-34.

Louvari, E., A.A.Kiratzi & B.C. Papazachos (1999): The Cephalonia Transform Fault and its extension to western Lefkada Island (Greece). Tectonophysics 308, 223–236.

Meltzner, A., K. Sieh, M. Abrams, D.C. Agnew, K.W. Hudnut, J.P. Avouac & D. Natawidjaja (2006): Uplift and subsidence associated with the Great Aceh-Andaman earthquake of 2004, J. Geophys. Res. 111, doi 10.1029/2005JB003891.

Papadopoulos, G.A., V.K. Karastathis, A. Ganas, S. Pavlides, A. Fokaefs & K. Orfanogiannaki (2003): The Lefkada 2003 Strong Earthquake - The Lefkada, Ionian Sea (Greece), Shock, (Mw 6.2) of 14 August 2003: Evidence for the Characteristic Earthquake from Seismicity and Ground failures. Earth, Planets and Space 55/11, 713-718.

Papazachos, B. & C. Papazachou (1997): Sea Waves associated with Earthquakes in Greece. In: Papazachos, B. & C. Papazachou (1997): The Earthquakes of Greece, 71-76, Thessaloniki.

Papazachos, B.C. & P.P. Dimitriu (1991): Tsunamis In and Near Greece and Their Relation to the Earthquake Focal Mechanisms. Natural Hazards 4, 161-170.

Polngam, S., T. Sanguantrakool, E. Pricharchon & S. Phoompanich (2005): Remote sensing technology for Tsunami Disasters Along the Andaman Sea, Thailand. 3rd International Workshop on Remote Sensing for Post-Disaster Response. September 12-13, 2005, Chiba, Japan. http://ares.tu.chiba-u.jp/workshop/Chiba-RS2005/Paper%20supapis.pdf [access: July 10, 2007].

Reimer, P.J. & F.G. McCormac (2002): Marine radiocarbon reservoir corrections for the Mediterranean and Aegean Seas. Radiocarbon 44, 159-166.

Reinhardt, E.G., B.N. Goodman, J.I. Boyce, G. Lopez, P. van Hengstum, W.J. Rink, Y. Mart & A. Raban (2006): The tsunami of 13 December A.D. 115 and the destruction of Herod the Great's harbor at Caesarea Maritima, Israel. Geology 34/12, 1061-1064.

Sachpazi, M., A. Hirn, C. Clément, F. Haslinger, M. Laigle, E. Kissling, P. Charvis, Y. Hello, J.-C. Lépine, M. Sapin & J. Ansorge (2000): Western Hellenic subduction and Cephalonia Transform: local earthquakes and plate transport and strain. Tectonophysics 319/4, 301–319.

Scheffers, A. & D. Kelletat (2003): Sedimentologic and geomorphologic tsunami imprints worldwide - a review. Earth-Science Reviews 63, 83-92.

Soloviev, S.L. (1990): Tsunamigenic Zones in the Mediterranean Sea. Natural Hazards 3, 183-202.

Soloviev, S.L., O.N. Solovieva, C.N. Go, K.S. Kim & N.A. Shchetnikov (2000): Tsunamis in the Mediterranean Sea 2000 B.C. - 2000 A.D. Dordrecht.

Stuiver, M., P.J. Reimer & R. Reimer (2007): CALIB Radiocarbon Calibration. http://calib.qub.ac.uk/calib [access: July 9, 2007].

Tinti, S., A. Maramai & L. Graziani (2004): The new catalogue of Italian tsunamis. Natural Hazards 33, 439-465.

Vött, A. (2007): Relative sea level changes and regional tectonic evolution of seven coastal areas in NW Greece since the mid-Holocene. Quaternary Science Reviews 26, 894–919.

Vött, A., H. Brückner, M. May, F. Lang, R. Herd & S. Brockmüller (2007a): Strong tsunami impact on the Bay of Aghios Nikolaos and its environs (NW Greece) during Classical-Hellenistic times. Quaternary International (available online: http://dx.doi.org/10.1016/j.quaint.2007.02.017). Amsterdam.

Vött, A., H. Brückner, M. May, F. Lang & S. Brockmüller (2007b): Late Holocene tsunami imprint at the entrance of the Ambrakian Gulf (NW Greece). Mediterranée 108, 43-57.

Vött, A., H. Brückner, A. Schriever, J. Luther, M. Handl & K. van der Borg (2006a): Holocene palaeogeographies of the Palairos coastal plain (Akarnania, NW Greece) and their geoarchaological implications. Geoarchaeology 21/7, 649–664.

Vött, A., M. May, H. Brückner & S. Brockmüller (2006b): Sedimentary evidence of late Holocene tsunami events near Lefkada Island (NW Greece). In: Scheffers, A. & D. Kelletat (Eds.): Tsunamis, hurricanes and neotectonics as driving mechanisms in coastal evolution. Zeitschrift für Geomorphologie N.F., Suppl.-Bd. 146, 139–172.

Vött, A., M. Handl & H. Brückner (2002): Rekonstruktion holozäner Umweltbedingungen in Akarnanien (Nordwestgriechenland) mittels Diskriminanzanalyse von geochemischen Daten. Geologica et Palaeontologica 36, 123-147.

Address

Dipl.-Geogr. Simon Matthias May
PD Dr. Andreas Vött
Prof. Dr. Helmut Brückner
Dipl.-Geogr. Svenja Brockmüller
Faculty of Geography
Philipps-Universität Marburg
Deutschhausstr. 10
D-35032 Marburg/Lahn

matthias.may@staff.uni-marburg.de