THE EVIDENCE OF TSUNAMIGENIC DEPOSITS IN THE GULF OF CORINTH (GREECE) WITH GEOPHYSICAL METHODS FOR SPATIAL DISTRIBUTION

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The evidence of tsunamigenic deposits in the Gulf of Corinth (Greece) with geophysical methods for spatial distribution: Drill core sampling in coastal areas in the Mediterranean proved evidence for tsunamis. Sedimentary analyses were conducted to identify tsunamigenic deposits, but did not reveal larger scale sedimentary structures or spatial distribution of tsunamites in a regional scale. We used ground penetrating radar (GPR) in combination with electrical resistivity tomography (ERT) measurements and sedimentological research methods in different areas. The combination of these three methods allows us to generate 3D visualizations, which give clues for tsunamite distribution and sediment architecture. GPR data indicate unconformable thicknesses of tsunamigenic layers, channel-like structures of backwash deposits, in some extent non-planar erosion basement, as well as abrasion-scours in various places, and boulder accumulation inside the deposits.

Key words: tsunami, GPR, ERT, Greece

INTRODUCTION

Former studies of various authors on tsunamis mainly focused on a hydromechanical analysis of specific tsunami events (e.g., Bondevik et al., 2005) or sedimentary analyses of drill cores (e.g., Reicherter et al., 2010; Shiki et al., 2008; Vött et al., 2009). The latter method encompasses sieve curves as well as magnetic susceptibility measurements and micropaleontology to prove tsunamigenic features. Characteristics of the sediments, such as fining-upward sequences, coarse shell debris, upward rising magnetic susceptibility and marine foraminifera in sandy sediments, give amongst others evidence for tsunami events. X-ray fluorescence spectroscopy measurements (XRF) were performed in some cases. OSL and 14C-dating can be used for dating.

All of these studies defined characteristics of the deposits (e.g., Bryant et al., 2005; Shiki et al., 2008), but do not show the spatial distribution of an event or the larger scale sediment structures of tsunami deposits. With the knowledge of spatial distribution and extent of erosion due to tsunamis it would be easier to understand processes during a tsunami event and to estimate the possible damage by a future tsunami. Since drilling is time-intensive and expensive (depending on extend), this method can by far not cover an entire coastal area. As the distribution and preservation of tsunamigenic deposits is highly variable according to several studies (e.g., Dawson & Stewart, 2007), there is a strong interest in a low-cost and easy to use imaging technique.

Only one published study dealt with GPR for detecting tsunami deposits. Switzer et al. (2006) investigated a wash-over fan, but did not validate the data by other geophysical methods. Therefore, it is still not clear whether or not the detected sediments were deposited by a tsunami. Furthermore, a limiting factor of GPR measurements is a wet environment. A shallow ground water table or even sea water intrusions close to the ocean can reduce data quality significantly. Relative dielectric permittivity $\varepsilon_r$ and the conductivity $\sigma$ of tsunamigenic deposits are unknown. However, we can show that GPR has the ability to distinguish between tsunami deposits made up of marine sands, boulders and shells and clayey background sediments although this is an ambitious challenge.

STUDY AREA

Our study area is located near Lechaion, one of the ancient harbors of Corinth (Fig. 1). It was probably the most important harbor of this type in antiquity, and one of the most important harbors in Greece for more than one millennium (Rothaus, 1995). Today it is partially buried by up to 2 meters of sediment.

Fig. 1: Study area in Greece, Lechaion close to Corinth, brown areas illustrate topographic elevation; red box indicates area of GPR measurements (see Fig. 2 for details); green arrow displays possible tsunami propagation

Lechaion may very well have been affected by a series of seismic events and possible tsunamis in late fourth century after Christ. Reconstruction of the
We collect GPR data in combination with drill cores and electrical resistivity tomography (ERT) in order to test our method in an extraordinary environment, an ancient harbor which could have been affected by a tsunami (Soloviev, 1990).

Fig. 2: Map of the study area with locations of drill points and GPR measurements

METHODS

GPR measurements were performed in patterns directly adjacent to drilling locations and ERT profiles. We used the GSSI 400 MHz antenna with a survey wheel, the SIR-3000 unit, and a handheld GPS (Fig. 3).

Fig. 3: GPR with 400 MHz antenna, survey wheel, SIR-3000 unit and GPS

Trace increment was set to 0.02 m for detailed investigation, the range was set to 120 ns TWT and the sample rate to 512. From drillings and field observations a target depths up to 3.50 m could be assumed. The thickness of the assumed tsunami sediment layer reaches up to 2.00 m, so the 400 MHz antenna promised the best compromise. Data processing included static correction, background removal, gain adjustment and velocity adaption for depth calculations based on a hyperbola analysis. Boulders were detected due to hyperbolic features in the data. Results of sedimentary drill cores (Fig. 4) and ERT profiles in the study area give evidence for three tsunami events (Hadler et al., this volume).

VISUALIZATION & RESULTS

Three GPR profiles were taken parallel to the coast, one profile was recorded perpendicular to the shoreline (Fig. 2). Three drill cores (Fig. 4) were taken between 50 and 150 meters away from GPR profiles in the ancient inner harbor. All GPR measurements took place on the top of the ancient harbor facility, which is buried under a possible third tsunami event layer. The base and inner structures of the possible tsunami deposits could be imaged in all the profiles.

Fig. 4: Correlation of drill cores in the study area of Lechaion; two possible tsunami layers were detected (red boxes with red dashed lines for correlation); these layers include fining-upward sequences as well as erosive bases
The combination of ERT and GPR measurements in the study area suggests that there are bigger channel structures with erosive bases and boulder deposits inside these channels (Fig. 5 & 6). They point toward the ocean and are not part of the buried harbor. The channels can be part of a flow-system during the backwash processes after a tsunami (Dawson & Stewart, 2007). In some cases, channel-
like structures could also be interpreted as abrasion-scours, which can originate by backwash processes with high backflow velocities. Some kind of cross-bedding is visible in the GPR data as well (Fig. 5). The tsunamigenic deposits reaches depths up to 2.00 m. The sedimentary evidence from the drill cores could not be verified due to high attenuation in lower depths (>2.50 m). The inner layer-structures of the tsunamites (maybe due to multiple waves) show an unconformable thickness (Fig. 5). Boulders in the sediments appear as hyperbolas ($v = 0.12 \text{ m/ns}$). Boulders with diameters larger than the resolution limit of the 400 MHz GPR antenna are located inside the deposits and could be detected by GPR. ERT profiles show as well electrical resistivity contrasts at the boundary between the tsunamigenic deposits and underlying harbor sediments. For the other GPR profiles the correlation with ERT data has been done similarly, if ERT profiles were available.

**CONCLUSIONS**

Due to highly variable sedimentation processes and materials (gravels, sand or silt/clay to some extend with boulders) in the Mediterranean and worldwide in the context of a tsunami event, deposited sediments differ extremely. Therefore, no specific values for relative dielectric permittivity $\varepsilon_r$ or the conductivity $\sigma$ can be declared for these variable sediments. Drill cores or outcrops are always necessary to prove tsunami characteristics and to correlate these results with the GPR data. Distinctive contrast changes in the GPR data help proving the spatial distribution of tsunami deposition interfaces. Only the combination of the presented methods is the key for conclusions on detailed spatial distribution of tsunamites.

The main result is the visualization of channelized structures in the tsunamigenic horizon. The structures most likely originate from backwash processes. Our data lead us to conclude that the topography of an affected area plays an important role for the expansion of the channels, since we observed different channel types as well e. g., in Spain. It is possible to detect the upper and lower boundary of the tsunamiite in some cases, depending on the grain size of the tsunamigenic material in contrast to the background sedimentation.

With the 400 MHz GPR antenna it is also possible to detect bigger structures like abrasion-scours, unconformable thicknesses of tsunamigenic bedding, in some extent non-planar erosion basement and boulder accumulations inside the deposits. Typical thinning-inland structures (Dawson, 1994) could not be detected in this case within the GPR profile perpendicular to the coast. A GPR with higher resolution should be useful to detect further sedimentary structures in tsunami deposits in the future.

**OUTLOOK**

In the future, GPR and other shallow geophysical methods will be used to detect run-up distances and for creating large-scale models considering topography to detect sediment thickness and volume. With these data it would be possible to calculate the physical power and the possible damage of the tsunami wave and typical sediment structures. Due to account on spatial distribution information it could be possible the reconstruct the topography of the landscape before and after a paleo-tsunami.

Another aim is to get detailed information of the deposits by trenching and using methods like LiDAR, multispectrometry, magnetic susceptibility and the documentation commonly used in archeological excavations. 3-dimensional data or block-plots can be generated based on these methods to evaluate new features and characteristics of tsunami deposits.

**References**


