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The harbour(s) of ancient Ostia. Archaeogeophysical prospection with shear wave seismics, geoelectrics, GPR and vibracorings

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INTRODUCTION

The ancient city of Ostia is situated at the mouth of the river Tiber. Together with the neighbouring harbour of Portus, it was the largest distribution centre of the Mediterranean

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in the 2nd century AD. Before that Ostia was a secondary transit harbour for Rome, mostly responsible for the safety of the mouth of the Tiber.

The central urban area of ancient Ostia has been investigated thoroughly and large parts excavated, whereas the harbour area to the west of the archaeological site, today silted-up completely, has hardly been explored. Recent geoarchaeological investigations revealed two different harbour types: an early lagoonal and subsequently fluvial harbour, separated by a high-energy event layer of most likely tsunamigenic origin (Vött *et al.* 2015).

The aims of the recent joint geophysical–geoarchaeological exploration effort at the port of Ostia presented here were:

1) to determine the depth and extent of the original harbour basin,
2) to determine the stratigraphy of the sedimentary fill, and
3) to search for remains of harbour structures.

The paper at hand presents the results of geophysical investigations by shear wave seismics, electrical resistivity tomography (ERT) and ground penetrating radar (GPR) covering the whole harbour area. The geophysical results are then interpreted in correlation with the local stratigraphical records obtained by vibracoring (Vött *et al.* 2015).

METHODS

ERT

Thirteen profiles covering all of the harbour area were measured using Syscal R1 Plus Switch 48 (Iris Instruments) and RESECS (GeoServe) equipment with dipole-dipole, Wenner and Schlumberger configurations. The inversion was done with BERT (boundless electrical resistivity tomography, e.g., Günther *et al.* 2006) software.

Seismics

Seismic measurements using SH-waves were acquired on eight profiles in the harbour area, partly at the same locations as the ERT profiles, using three Geodes (Geometrix) and 4.5 Hz OYO horizontal geophones. The profiles were processed by multi-channel analysis of Love-waves (MASW) (e.g., Park *et al.* 1999) yielding S-wave velocity–depth profiles. Local wavefield segments were transformed into the slowness-frequency domain. Spectral maxima were fitted with dispersion curves for 1D S-wave models at each position using prticle swarm optimization (Wilken and Rabbel 2012). Forward modelling was done with the modified Thompson-Haskell code of Wang (1999).

GPR

GPR measurements were applied in the area around the harbour site to map probable buildings and to detect the floor of the silted-up harbour basin. The equipment used was a 400 MHz antenna and SIR-3000 (GSSI). Parallel profiles were interpolated in a 3D data cube and horizontally cut into timeslices.

Corings

Within the harbour area, vibracoring was carried out in order to study the stratigraphical record of the harbour basin and as a base to calibrate geophysical datasets. Eight vibracores

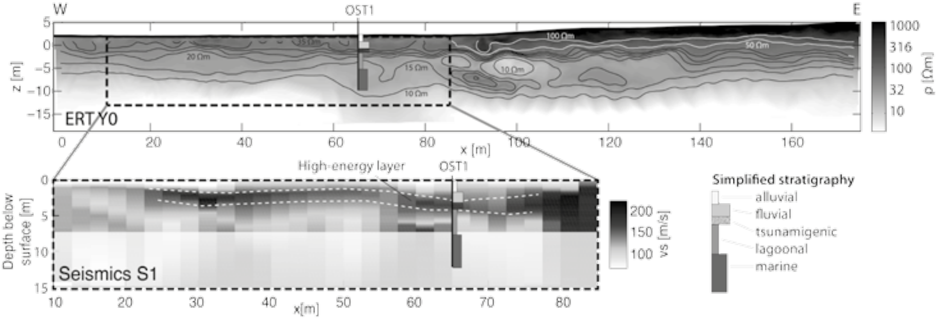

Fig. 1. Comparison of ERT and a seismic profile crossing the harbour basin from west to east. Together with vibracore stratigraphy, the high seismic velocity layer is assigned to the high-energy facies separating a lagoonal and a fluvial harbour phase

were drilled down to 12 m below ground surface (m b.s.) using a Nordmeyer RS 0/2.3 automotive drill rig. Vibracores were photographed, described and sampled with regard to different facies. The position and elevation of each vibracoring site was measured using a Topcon HiPer Pro DGPS device (type FC-250). In the laboratory, selected sediment samples were analysed to determine grain size distribution, geochemical parameters and microfossil content. The geochronological framework is based on radiocarbon dating and age estimates of diagnostic ceramic fragments.

RESULTS

The 2D-inversion of all ERT profiles and the compilation into a 3D-model show very clearly the outline of the harbour basin by a distinct change from higher resistivities (outside) to lower resistivities (inside) with an overlap of a near-surface high-resistivity layer from outside about 10 m into the basin. The "electrical stratigraphy" inside the basin seems to be quite homogeneous laterally, but shows a continuous decrease in the electrical resistivities with increasing depth. The inversion of Love-waves shows that the basin fill consists of fine-grained sediments with typical S-wave velocities of about 120 m/s (Fig. 1). A special feature is a horizontal, 1–2 m thick band of 100%(!) increased shear wave velocities about 2 m below the surface. The top of this layer can also be seen in the ERT results, while the bottom of this layer is not resolved. Vibracore stratigraphy allows shear wave velocities and electrical resistivities to be assigned to distinct sediment facies and geoarchaeological layers, to be tracked across the harbour area. Compared to all vibracore stratigraphies (Fig. 1), our results show that this band corresponds to a high-energy event layer made of coarse-grained deposits, mostly sand and gravel, separating a lagoonal from a fluvial harbour phase (Vött *et al.* 2015).

Because of high electrical conductivity and attenuation of GPR waves in the harbour basin, the GPR measurements provided results only outside the harbour area. GPR timeslices in the area surrounding the harbour basin show foundations of buildings and infrastructure (possibly sewage tunnel or gully), reaching as far as the previously assumed border of the harbour.

CONCLUSION

Based on a combination of seismics, ERT, GPR and vibracoring, a two-phase harbour was explored at ancient Ostia: a) an older lagoonal and b) a subsequent fluvial harbour. Inversion of seismic surface waves visualized a 1–2 m thick band of 100% increased shear wave velocities associated with a coarse-grained high-energy layer of most likely tsunamigenic origin documented in the vibracore stratigraphies, whereas ERT could only resolve the top of this layer. GPR helped to map foundations and infrastructure around the basin.

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