Seismic refraction tomography and multichannel analysis of surface waves for imaging offshore Cultural Heritage in very shallow water: Results from a synthetic study and real data

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In archaeology, applied geophysics helps to discover new findings of our hidden cultural heritage. However, these methods have been particularly developed in terrestrial environments, leaving the shallow marine ones almost unexplored. This paper examines the effectiveness of Multichannel Analysis of Surface Waves (MASW) and Seismic Refraction Tomography (SRT) on imaging submerged and buried antiquities in a very shallow marine environment. For this purpose, synthetic seismic data sets were created to examine the optimum parameters for the most efficient visualization and interpretation of shallow underwater buried man-made targets. The modeling results outlined that targets wider than 0.5m are reconstructed, both with the SRT and the MASW methods, provided that they are buried close to the seabed. In addition, short spread of the receivers with the MASW provided the most satisfactory outcome concerning the location of the submerged targets. In general the modeling results are quite encouraging and together with the successful application of MASW method in real data can form the basis for establishing the applicability of these geophysical methods in mapping submerged archaeological structures in shallow water environments.

A. Seismic Refraction Tomography – Synthetic Data

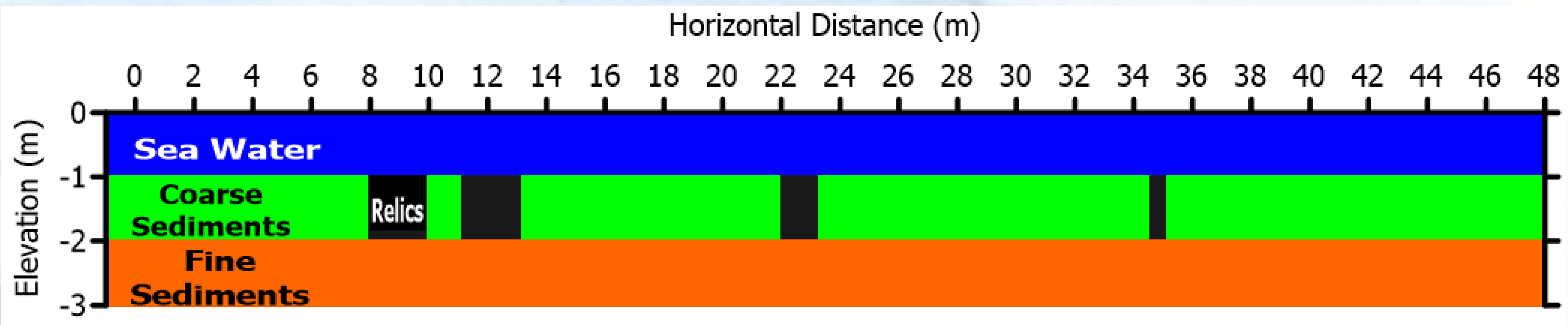

Figure 1: 2D section of the model used to create the synthetic seismic data.

	Vp (m/s)	Vs (m/s)	density (g/cm^3)
Sea Water	1500	0	1.0
Coarse Sediments	1700	200	1.6
Fine Sediments	2000	540	2.0
Relics	2500	500	2.1

Several tests were carried out in order to select the optimum configuration of the experiments

The examined parameters were: the model size, the number of the sources and the receivers, their spacing and the model cell size

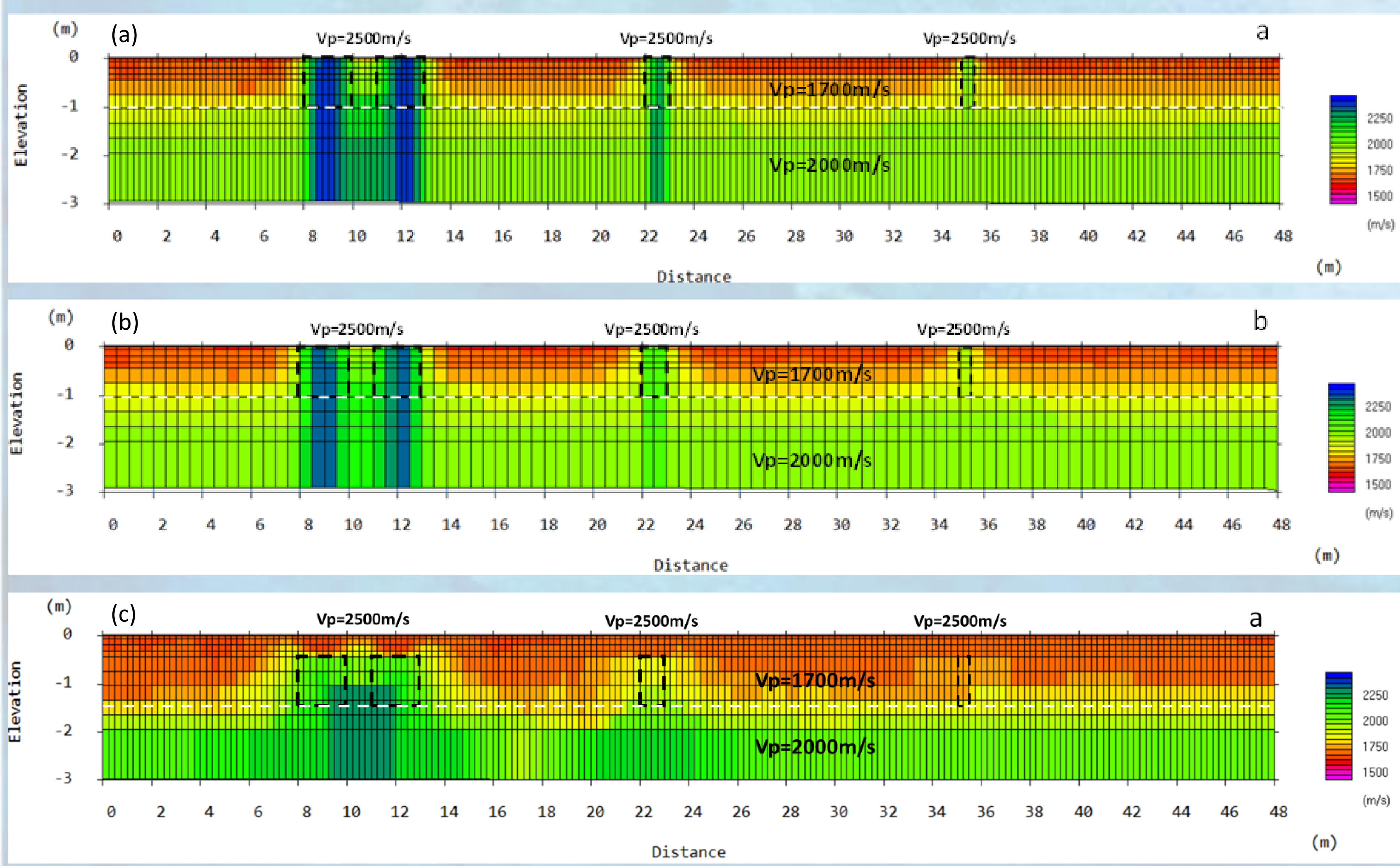

Figure 2: SRT P-wave velocity tomograms from the inversion of first arrivals deduced from the model of Figure 1. Sources and receivers were laid on the sea floor equally spaced at a) 0.25 m and b) 0.5 m intervals, respectively. Black dashed lines indicate the boundaries of relics while the white one, the interface between coarse and fine sediments. c) The same Vp tomogram from the modified model with the buried targets using 0.25m receivers intervals. The higher Vp values bellow the targets, are due to the extrapolation of the shallower ones, since ray coverage is limited to depths less than 2m.

Two inversion parameters were tested in order to get the optimum inversion outcome:

(1) the selection of the initial model (Vp=2000m/s)

(2) constraints on the allowable range of the Vp velocities (Vp range 1500-2500m/s)

B. MASW – Synthetic Data

Receivers' spread length examination for the efficient mapping of targets boundaries and layer interface using forward and reverse seismic source layouts and 0.25m receivers interval:

- 7 receivers array (1.5m length)
- 15 receivers array (3.5m length)
- 23 receivers array (5.5m length)

The layout, which gave the most satisfactory results, in terms of reconstructing the targets, was the one with the 7 receivers

The upper surface of the thinner (0.5m) relic (located at 35m) is not well resolved while, the wider targets appear as "dipole" velocity anomalies

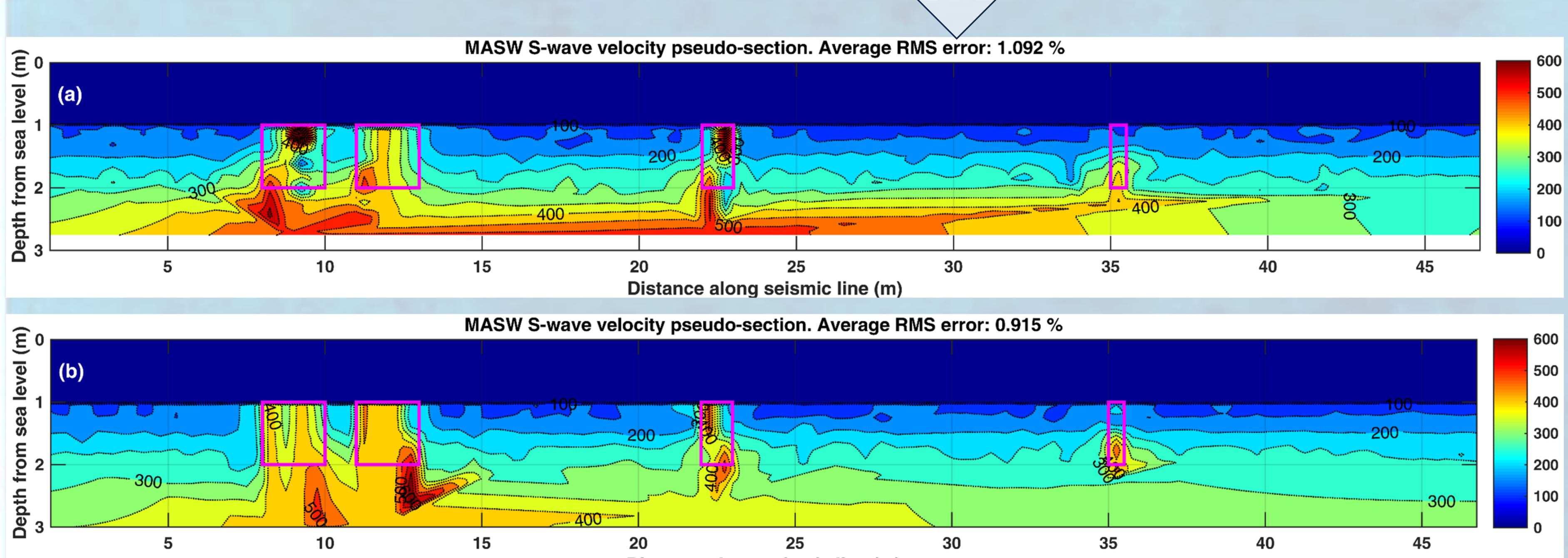

Figure 3: MASW S-wave velocity pseudo-sections deduced from synthetic data with (a) forward and (b) reverse source layouts, where forward and reverse source layouts refer to the position of the source, located in front of the first and behind the last receiver, respectively. The magenta rectangles delineate the positions of the relics. The color scale represents the Shear wave velocity (Vs).

C. The case study from Stomio

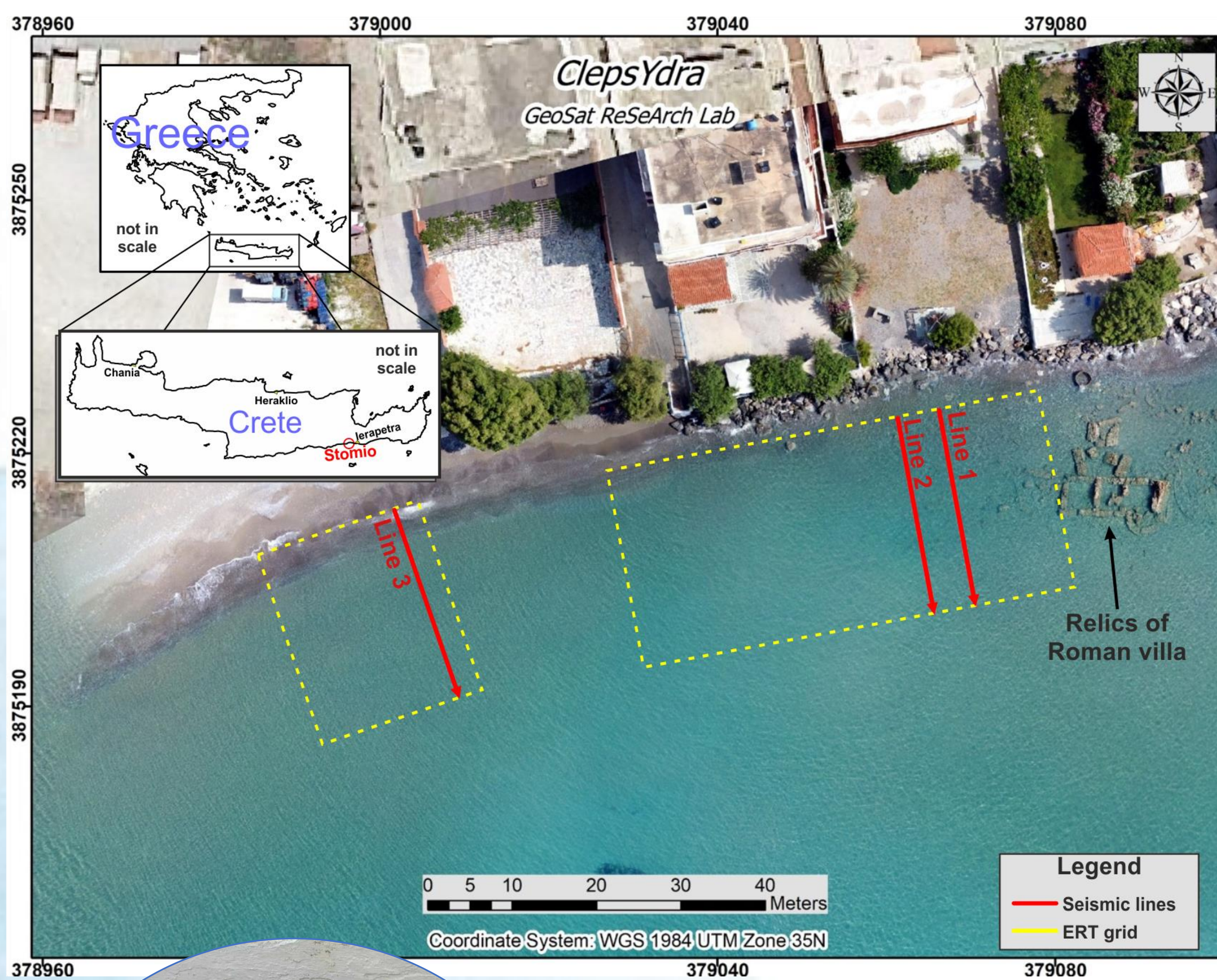

Figure 4: Aerial photo of the investigated area. Seismic lines were surveyed along Lines 1 and 2 near the relics of a submerged Roman villa.

Surveyed area: Stomio, SE Crete, Greece, 6km west from the city of Ierapetra. This site is of particular archaeological interest, since a Roman villa has been discovered at a shallow water depth

Seismic data acquisition equipment & parameters:

- 12-channel hydrophone streamer (MP25SW of Geospace) with sensors at 0.5m intervals
- 12-channel GEODE (Geometrics) seismograph

- 1 kg hammer with a metallic plate as a source
- Piezoelectric device for triggering
- Sampling interval: 31.25μs
- Record length: 100ms

SRT method, Line 1 & 2: Problems in recording of accurate first arrivals, due to random delays in triggering using the piezoelectric device

SRT method, Line 3: Solution step 1: Acquisition of seismic records with 10ms pre-trigger time

SRT method, Line 3: Solution step 2: Processing: a) first arrival picking b) trigger delay corrections c) inversion

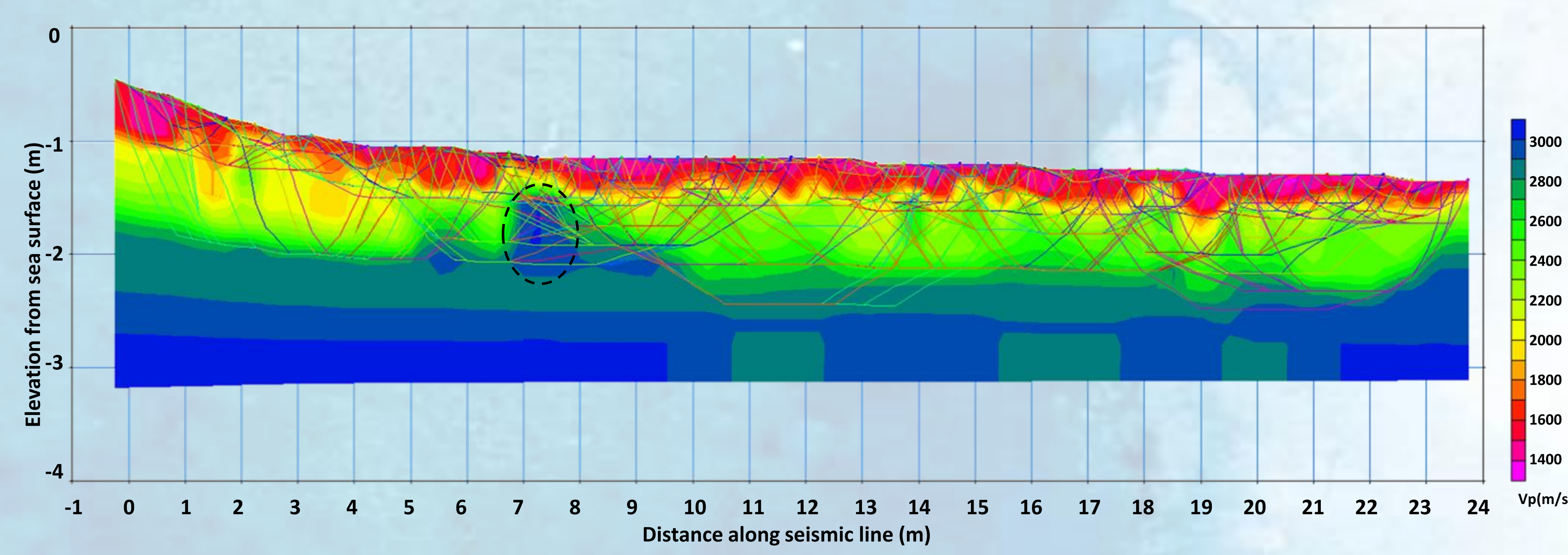

Figure 5: SRT P-wave velocity tomogram from the data of Line3. Dashed ellipse indicate a high velocity area, possibly attributed to buried submerged relics.

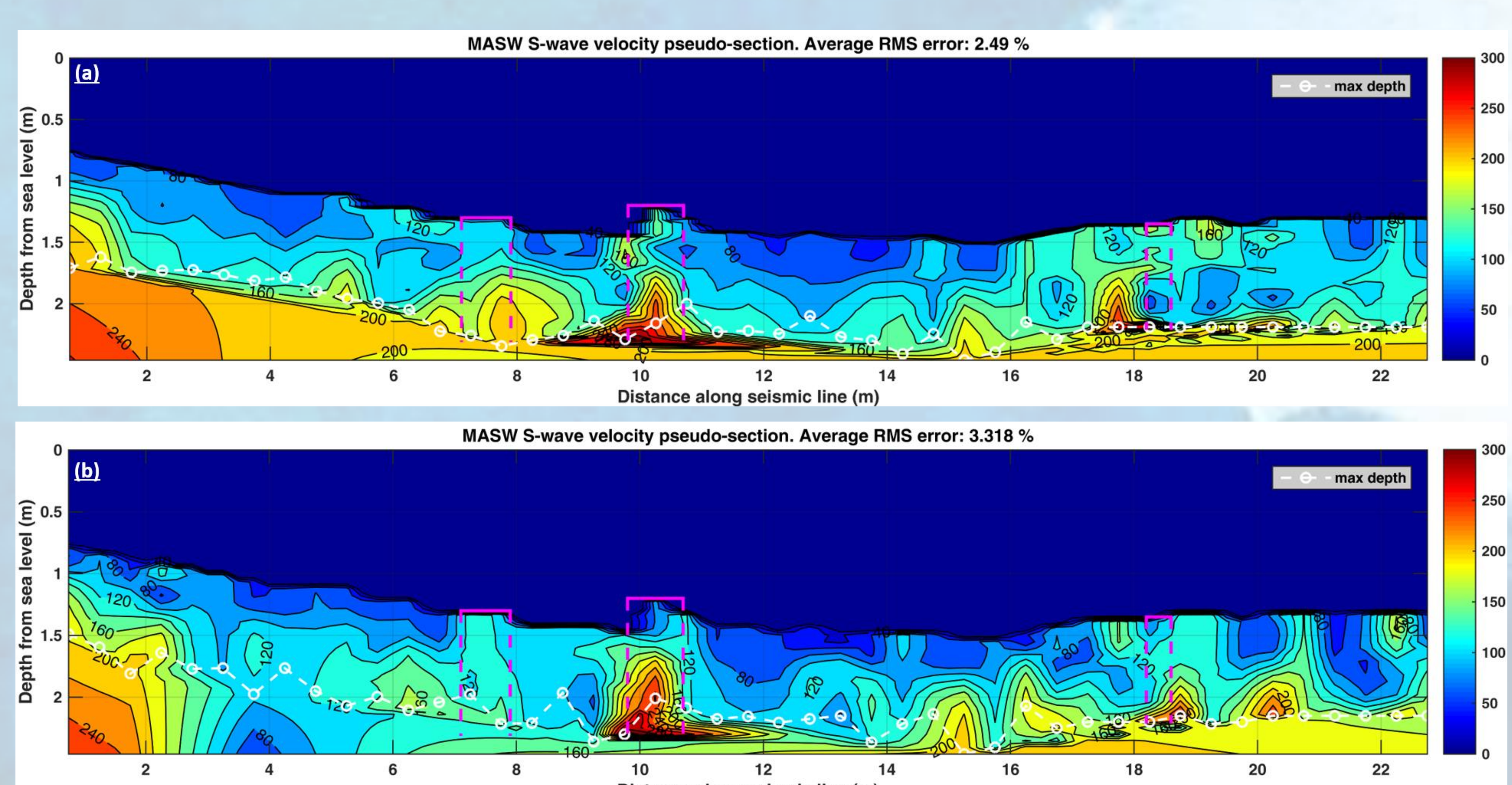

Figure 6: MASW S-wave velocity pseudo-sections deduced from the real data of Line 1 with (a) forward and (b) reverse source layouts. The magenta frames delineate the positions of the relics while the dotted white line with circles the max depth of investigation. The color scale represents the Shear wave velocity (Vs).

D. Conclusions

- SRT processing: homogeneous half-space as initial model and use of velocity range constraints
- SRT spacing: 0.5m gave acceptable results, concerning the location of the targets
- SRT acquisition: Resolve technical difficulties in real data acquisition, concerning the delays in recording
- MASW array: the shorter receiver array length, the better the localization of the shallow targets
- MASW artifacts: "dipole" velocity anomalies are mirrored in forward and reverse source layouts
- Synthetics proved useful for imaging shallow targets of archaeological interest using seismic methods

E. Acknowledgments

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