First results from stratigraphic investigation of Chiselet tell (Romania) using seismic full waveform inversion

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Abstract
In this paper we analyze the applicability of seismic full-waveform inversion (FWI) for investigation of tells, which are often characterized by heterogeneous and small-scale stratigraphy. Major aim is to identify location and shape of settlement layers and house remains. Furthermore, a paleochannel, which is important to understand the interaction between tell and the surrounding landscape, was found at the tell flank.

Keywords
archaeological prospection; full-waveform inversion (FWI); seismic; stratigraphy; tell

Introduction

Neolithic tell settlements are, due to their size, topography and heterogeneity, challenging targets in the field of archaeological prospection. Since traditional geophysical prospection methods are often limited by penetration depth or resolution, a sufficient 3D reconstruction of an entire tell is often unachievable. To overcome these issues seismic full-waveform inversion (FWI) has been proven as promising method and is therefore increasingly integrated to multi-method approaches for geophysical prospection of heterogeneous stratified archaeological targets like settlement mounds.

For a case study we performed measurements at a Chalcolithic tell (Fig. 1d) from Gumelnița culture (4600 – 4250 BC) in the lower Danube basin near Chiselet in Romania (Fig. 1a) to prove the applicability of our seismic FWI integrated multi-method strategy to geophysical investigation of prehistoric settlement mounds. Aim of our investigation was to reconstruct stratigraphic units of different settlement phases, to identify archaeological features like house remains, pits or trenches and to analyze the relation between tell and the surrounding paleo landscape.

Methods

The seismic data were recorded using a GEOMETRICS seismic system in SH-configuration along two profiles (Fig. 1b, c) of 95 m length with 10 Hz horizontal component geophones in 1 m distance. Whereas profile 1 is crossing the entire tell in direction from west to east, profile 2 is running down the southern tell flank into the surrounding plane. For excitation of shear waves a sledge hammer source was positioned along the profiles in intervals of 2 m.

The data was analyzed using two-dimensional, elastic FWI in time-domain based on inversion of dispersive Love- and refracted SH-waves. For this purpose, we

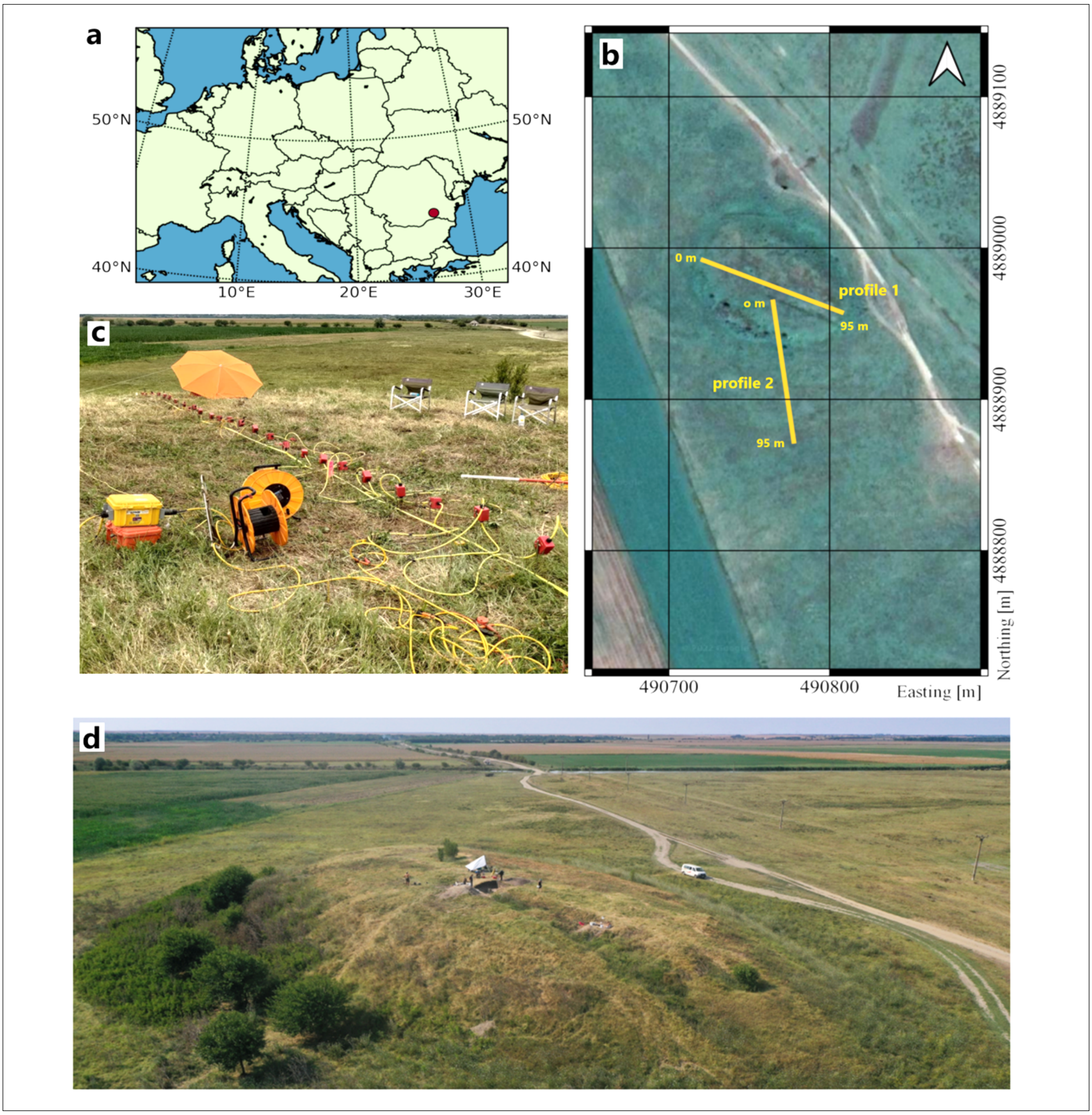

Fig. 1: a) Location of Chiselet; b) Map of Chiselet tell including measured seismic / ERT profiles (orange lines) (base map: Google ©2023 CNES / Airbus, Imagery; ©2023 CNES / Airbus, Maxar Technologies); c) Photo of seismic and ERT setup (M. Zolchow); d) Aerial photo of Chiselet tell (G. Bilotti).

used the FWI-code DENISE (Köhn et al. 2012). The data fit was improved by inverting for shear wave velocity v_s and density ρ simultaneously, while seismic quality factor Q_s was assumed to be constant. The required initial model of the shear wave velocity was determined using ray-based first arrival traveltime tomography (FATT) on the basis of refracted SH-waves with the software Reflexw (Fig. 2a, 3a). Proceeding from this initial seismic velocity model, a density model was calculated via an empirical relation (Ulugergerli and Uyanik 2007) valid for unconsolidated sands. The constant value of the quality factor Q_s = 30 was optimized by best data fit after multiple forward modeling runs with different quality factors. Since the existing code is based on rectangular grids, we used an oversampled spatial discretization of 0.05 m together with the improved vacuum formulation (Pan et al. 2018)

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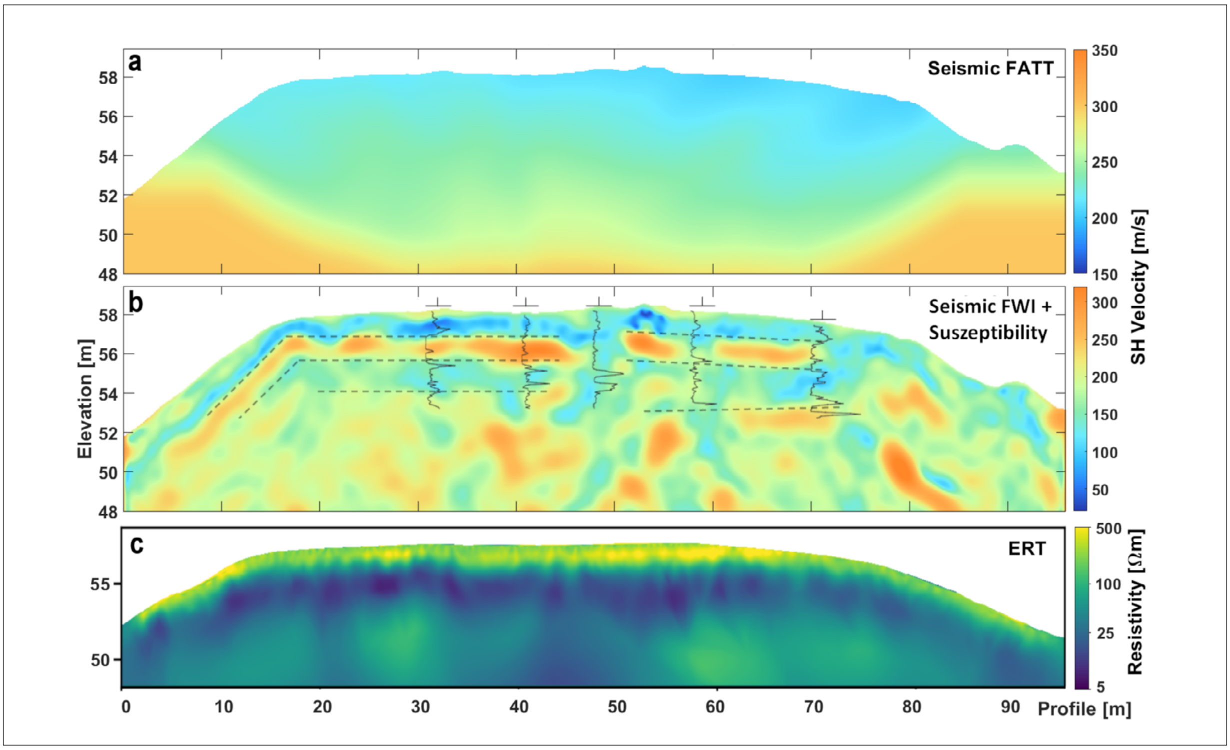

Fig. 2: a) Comparison of seismic FATT (a), seismic FWI (b) including 1D-depth curves of magnetic susceptibility (black curves) and marked layer boundaries (dashed lines) and ERT (c) of profile 1.

to implement accurate free-surface boundary conditions in the presence of strong topography. In order to obtain stable and interpretable results despite the strong non-linearity of the full-waveform inversion, a multi-stage inversion strategy was implemented. This combines a sequential lowpass filter strategy including alternating offset windowing with a high frequency bandpass filter strategy (Köhn et al. 2019) in order to ensure a similar waveform-adaptation of Love- and SH-wave.

To enhance and verify interpretation, the FWI results are compared to results of electrical resistivity tomography (ERT), down-hole measurements of magnetic susceptibility, corings and small-scale archaeological excavations.

Results and discussion

The results of seismic FWI (Fig. 2b) at profile 1 show several horizontal layers of alternating low (< 200 m/s) and high (> 200 m/s) shear wave velocity with thickness of 1 - 2 m, while the uppermost layer is characterized by comparatively very low (< 120 m/s) velocity. The layer boundaries correlate with peaks of increased magnetic susceptibility in 1D - depth curves, measured with down-hole probes at five positions along the profile. The anomalies of positive magnetic susceptibility can be related to settlement layers known from coring and excavation. Therefore, it remains open, whether the high shear wave velocities are caused by consolidated leveling layers or by massive layers of house remains and ceramics, which could be identified in a small test excavation trench. Furthermore, the FWI result shows no clear layer boundary or velocity difference between anthropogenic settlement layers and underlying natural sediments, which was identified by corings in a depth of 7 – 8 m. Therefore, both units must be assumed to feature comparable seismic material parameters. ERT measurements on profile 1 (Fig. 2c) are interfered by a high degree of dehydration at the ground surface resulting in low penetration and weak depth resolution.

On profile 2 at the southern tell flank anomalies of low seismic velocity (Fig. 3a) and electric resistivity (Fig. 3b) may refer to a former paleochannel. A vertical boundary between high seismic velocities (> 250 m/s) of the tell and lower velocities (< 150 m/s) of the surrounding plane sediments indicate an erosional impact of the paleochannel at the tell flank.

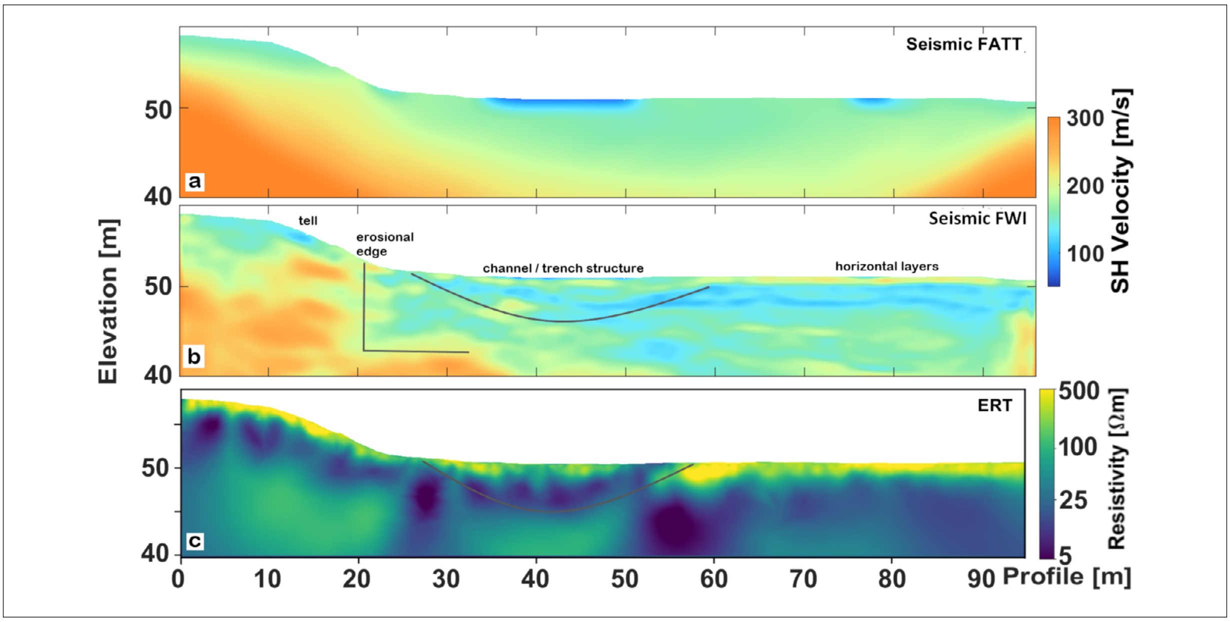

Fig. 3: a) Comparison of seismic FATT (a), seismic FWI (b) including interpretation (black lines) and ERT (c) of profile 2.

Conclusion

Although further investigations including seismic cross profiles and intensified bore-hole geophysics are necessary to verify the current results and enhance interpretation, the presented seismic FWI results illustrate the potential of the method for archaeological prospection of settlement mounds.

Acknowledgments

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