MAPPING AND INVESTIGATING DIRECTIONAL EFFECTS THROUGH ANALYSYS OF MICROTREMORS: THE CASE OF PALAEO-PINIADA VALLEY, CENTRAL GREECE

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Abstract

The Horizontal to Vertical Spectral Ratio, or "HVSR", has become popular in the last decades, especially because it leverages on inexpensive equipment and minimal workforce. One of the most attractive aspect is that elastic shear wave resonance frequency of a sedimentary basin can be retrieved and readily used to obtain an estimate of the depth of the major elastic impedance contrast(s). Additionally, the shear wave velocity (Vs) distribution can be obtained through dedicated inversion procedures. We performed more than 300 microtremor measurements across the Piniada Valley (Central Greece), distributed along and between several transects planned roughly perpendicular to the mean valley trend. Such an effort was carried out to understand the palaeogeographic and tectonic evolution of this area by first estimating the geometry at depth of the bedrock underlying the fluvial deposits of the Pinios River. Initially, the estimate was performed using a simplified approach, obtaining an approximate 3D model. We performed the directional analysis to investigate if effects connected to the sloping bedrock at the valley borders can be recognized. Finally, HVSR curves were inverted to refine the subsurface model and to estimate its uncertainty.

Introduction

Alluvial plains are generally the locus of fluvial deposition, whose accumulation rate depends on several factors, like the creation of accommodation space generally by tectonic activity, the dimension of the upstream hydrographic basin, the regional climate conditions, the water discharge and its seasonal regimes, the outcropping lithologies in the catchment area and hence the amount of bed and suspended load and their proportion, the mean gradient of the plain as well as of the main water course, the occurrence and/or formation of local base levels and/or knickpoints and their relative altitude, etc. The longest river draining Greece is represented by the Pinios (216 km) that collects waters from large sectors of the Antichasia, Pindos and Othris mountains as well as the western Pilion and southern Olympus. In the present study, we focus on the hydrographic anomaly characterizing the reaches between two major plains crossed by the Plinios river, Karditsa and Larissa. In particularly, we investigate the Piniada Valley and the Kalamaki Gorge (figure 1). The former morphological feature is characterized by a 1-3 km-wide alluvial plain bordered by the Palaeozoic-Triassic bedrock belonging to the Pelagonian Zone (Caputo, 1990). This intermountain valley progressively narrows downstream to few hundred meters north of the village Koutsochero and completely disappears in correspondence of the Kalamaki Gorge, where the river bed is directly entrenched in the sloping bedrock. In the former reach, the river is characterized by several meanders with a sinuosity index ~ 1.6, while in the final sector and especially within the gorge it becomes almost linear (sinuosity ~ 1).

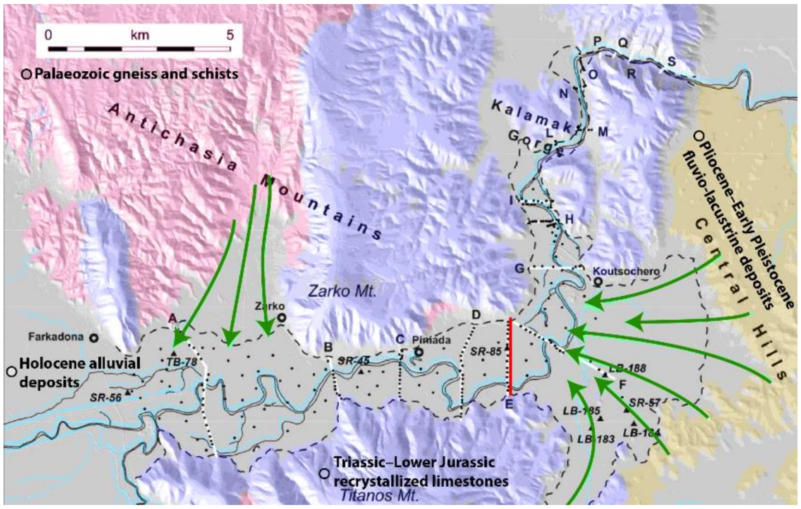

Figure 1: Map of Piniada valley. Microtremor measurements are highlighted by dots. Background color highlights different lithologies. The location of a transect, discussed in the following is marked with the red line.

One of the major aim of this research is to reconstruct the geometry at depth of the Piniada Valley, in particular the bedrock. Additionally, we use the directional analysis to investigate if and how the thickening of sediments at the border of the valley impacts the recorded seismic noise. Finally, HVSR curves were inverted to refine the Vs model and estimate its uncertainties.

Method

The HVSR method (Nakamura, 1989) has largely grown in popularity in the last decades, and its applications span a variety of scientific disciplines (Abu Zeid et al., 2012; Obradovic et al., 2015, Abu Zeid et al., 2016; 2017a, 2017b, D'Alessandro et al. 2016; Bignardi et al., 2017b; Martorana et al. 2018). Data acquisition is based on recording the three components of the seismic noise (often in terms of velocity), which are then divided in windows of finite length. Each data window is Fourier transformed, properly smoothed, and the spectral ratio of the horizontal over the vertical component is computed. In the process, anomalous windows are discarded. Finally, the "HVSR curve" is computed by averaging the curves of all the surviving windows. It is well understood that when the subsurface is constituted by low compacted sedimentary deposits residing on hard bedrock, the HVSR curve exhibits one or more peaks. The exact nature of the wavefield responsible for such a feature (e.g. body waves, surface waves, etc.) is in general impossible to determine However, it is quite established that the peaks will occur at the resonance frequencies of the shear waves (Albarello and Castellaro, 2011). The significant peak with lowest frequency is generally associated with the fundamental resonance frequency f_0 of the sedimentary cover. Complete guidelines to the method can be found in SESAME (2004). We performed over 300 measurements systematically covering the valley. Part of which intentionally distributed to form nine transects intercepting the transversal section of the valley (Figure 1). Acquisitions were performed with digital tromograph Tromino$^{(R)}$. Duration of measures varied between 18 and 30 minutes at a sampling rate of 128 Hz. While part of the result (Mantovani et al. 2018) was obtained from HVSR curves processed with the software Grilla (http://www.moho.world), in the present study the dataset was re-processed using the OpenHVSR-Processing-Toolkit (Bignardi et al., 2018a; 2018b). Data were split 20 seconds long time windows, smoothed using the Konno-Ohmachi approach (b = 20). The main assumption for the interpretation of a HVSR curve is that the subsurface is well described as a soft layer (low Vs), lying over a fast bedrock, both homogeneous and viscoelastic, while the seismic noise is assumed to be isotropic. In such a framework the fundamental peak is found at

$$f_0 = \frac{\bar{V}_S}{4H} \tag{1}$$

where $\bar{V}_S$ and H are the shear waves velocity and the thickness of the layer, respectively. In practice, equation 1 is often used in connection with an estimates average Vs of the sedimentary stack to establish an approximated relation between the f_0 and H. Bignardi (2017a) showed that eq. 1 should be used with care. However, it still represents a valid tool to obtain a preliminary structural information. Indeed, our preliminary bedrock geometry was actually based on equation 1, with constraints on the bedrock depth from some local boreholes. An example of the geometric information contained in the microtremor is shown in figure 2b, where the HVSR curves were tiled into a 2D section (HVSR-Profiling: Herak, 2010). The lateral variation of f_0 clearly highlights the bedrock geometry. Subsequently, the directional analysis was performed to investigate directional effects connected with sloping bedrock near the valley edges (Bignardi et al., 2012, 2013, 2014, Dietiker et al. 2018). An example from one selected location is shown in figure 3c, while figure 3a shows a preliminary evaluation of the preferential direction of incoming waves. Finally, data were inverted using the software OpenHVSR-Inversion (Bignardi et al, 2016). to refine the model and evaluate the uncertainty.

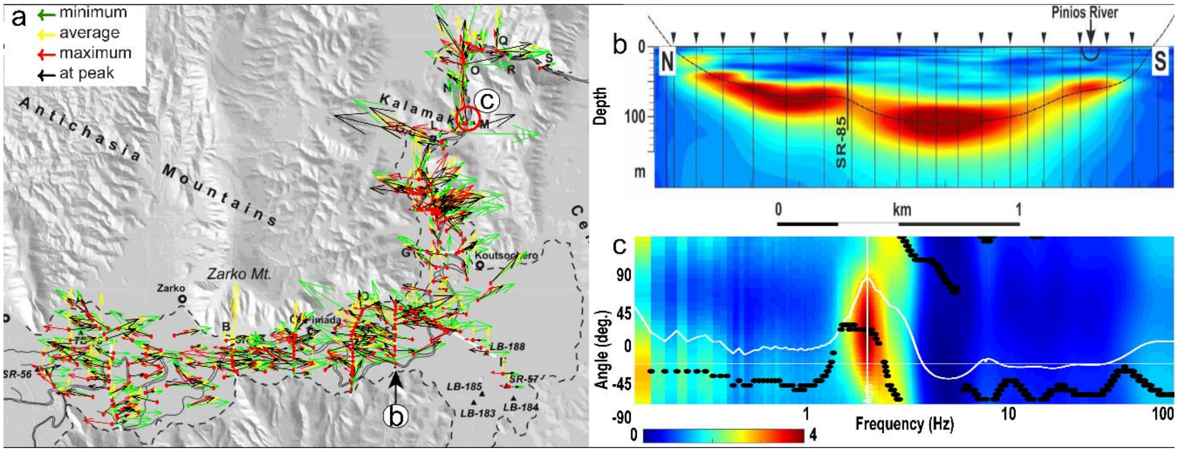

Figure: 2; a) Study of the preferential direction of incoming waves. b) Profile obtained by interpolating HVSR curves from some aligned locations (Frequency was converted to depth). The lateral variation of f_0 highlights the structure of the bedrock. c) example of directional analysis for one selected location.

Conclusion

The results of an extensive field campaign based on the systematic measurement of the seismic noise within the alluvial plain of the Piniada Valle (Greece) have been presented. The investigated area represents a major morphological anomaly along the hydrographic network of the Pinios River, the longest water course in Greece. To gain insight on the origin of this geographic and geological anomaly we carried out microtremor measurements at more than 300 sites and applied the HVSR technique. The main resonance frequency ranged between 0.6 and 20 Hz with markedly clear spectral ratio peaks. The mean shear-wave velocity characterizing infilling sediments overlying the bedrock was estimated using available stratigraphic logs and HVSR curves computed at the corresponding boreholes for calibration purposes. Consequently, Vs varied across different portions of the valley and ranged between 320 and 430 m/s, values typically found for poorly consolidated alluvial deposits. This Vs estimate was used to convert the HVSR curves from frequency to depth, so obtaining a rough but very effective 3D representation of the bedrock geometry. Additionally, the directionality of the seismic natural noise was investigated to infer whether effects connected with the sloping bedrock, especially in the proximity to the valley borders can be observed and highlighted. Finally, HVSR curves where inverted to refine the model and estimate uncertainties.

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