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Integrated Geophysical Profiles and H/V Microtremors Measurements for Subsoil Characterization

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SUMMARY

The application of traditional geophysical techniques such as seismic or electrical resistivity tomography (ERT) in broad areas requires large period of time. In this work a methodology is proposed in order to optimize the data acquisition time in the determination of the weathered materials thickness overlaying the unaltered rock in a large area. This methodology is based on combining traditional geophysical techniques and H/V microtremor measurements. The test site is in an area located in the NE part of Iberian Peninsula, close to the Mediterranean coast. Geologically it is mainly made of granitoides (Catalan Coastal Pluton) highly altered on its surface. In this context we found the suitable conditions for the application of this methodology: strong contrast of geophysical (mechanical and electrical) properties. The proposed methodology allows us to characterize the sediment properties and the bedrock depth.

Introduction

Subsoil characterization in alluvial systems is a key issue in hydrogeological studies to understand processes related to different sediment nature (gravel/sand opposite to clay-silt), to estimate the thickness of weathered materials and to delineate bedrock topography. In near-surface scale (depth <100 m), traditional geophysical techniques such as seismic or electrical resistivity tomograghy (ERT) can provide these properties. However, data acquisition requires a large period of time to cover an extended area.

The objective of this work is to find a methodology that fits both time-efficiency and subsoil characterization. This methodology is based on combining traditional geophysical techniques (ERT and seismic tomography) and H/V microtremor analysis. The test site is an area located in NE part of Iberian Peninsula close to the Mediterranean coast (Figure 1). Geologically, the alluvial system is formed by Quaternary deposits (gravel, sand and clays). These sediments are underlain by weathered, fractured and fresh granite. In this context, this site offers the suitable conditions (high physical properties contrast) to test the proposed methodology.

Proposed Methodology

Microtremor H/V technique (Nogoshi and Igarashi, 1971; Nakamura, 1989) has been chosen in order to obtain bedrock geometry. This method consists of estimating the ratio between the Fourier amplitude spectra of the horizontal and the vertical components of ambient noise vibrations. It is generally accepted that this spectra provides a good estimate of the fundamental frequency of soft soil ($f_{H/V}$). Some authors (Ibsvon Seht and Wohlenberg, 1999; Delgado et al., 2000) have used this technique to obtain sediment thickness proposing $f_{H/V}$-bedrock depth empirical relationships.

The first step of the methodology used in this work is to obtain a draft of the bedrock geometry using microtremor H/V technique. The advantage of this method is that microtremor measurements and analysis can be carried out in a short period time (e.g 50 stations/day with 10 minutes record length). From this result, location of 2D geophysical profiles can be chosen (e.g. sectors with significant changes of bedrock topography and maximum sediment thickness). These profiles assure on one hand, physical properties of the sediment cover and on the other hand, an estimation of bedrock depth. The points with overlapping H/V and geophysical measurements are used to obtain a new $f_{H/V}$-bedrock depth empirical relationship which will be suitable to the maximum study depth. This empirical relationship can be applied to the whole study area using microtremor measurements providing bedrock depth.

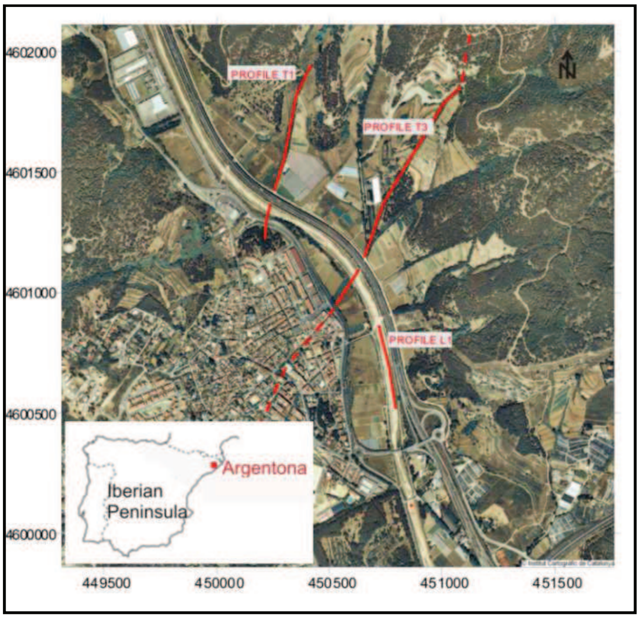

Figure 1. Location of geophysical survey lines. Longitudinal profile L1, Transversal profiles T1 and T3. Cartography map 1:5000 (IGC).

Data acquisition and processing

Microtremor H/V technique. Three profiles were carried out with a total of 75 stations (red lines in Figure 1). The ambient noise vibrations were recorded using a six-channel Cityshark datalogger connected to two Lennartz LE-3-D sensors (three components velocimeters having a 5 seconds of natural period). The two seismometers were located 50 meters apart acquiring simultaneously microtremor data in two stations. Microtremors were recorded in a 10 minutes time window and a sample rate of 100 samples/s. The H/V ratios were calculated using the Geopsy software.

Seismic tomography method. Seismic profiles were performed using DMT seismic recorder with 48 channels. Four seismic profiles were carried out in the target area (Figure 1). Three P-wave profiles were acquired using the energy from hammer as seismic source, with a variable total length to 115 m from 235 m (L1 and sectors of T1 and T3). The distance between 40-Hz geophones was 5 m. Another seismic profile (L1) was acquired in order to obtain S-wave (SH configuration). In this case, the seismic source and the horizontal geophones were placed perpendicular to the direction of the 2D profile. Signals from the two orientations of a polarized source have been stacked in order to reduce P-wave energy. Source position has varied along a fixed geophone spread in order to have data suitable for refraction analysis. *Rayfract* software has been applied to obtain seismic velocity models from first arrivals.

Electrical resistivity tomography (ERT) was performed on three profiles (L1 and sectors of T1 and T3, Figure 1). The automatic SYSCAL Pro with 10 channels and six multicore cables of 12 connections was employed. Each electrode connection has a separation of 5 m. The L1 and T3 profiles have a total length of 355 m. In the profile T1 a roll along is applied (overlapping 175 m) and, as a consequence, the total length increases to 535 m.

On each profile, the two configurations Wenner-Schlumberger and Dipole-Dipole were applied with the unit spacing equal to 5 meters. The Wenner-Schlumberger array was selected for its good and stability signal strength, while dipole-dipole array for its sensitivity to lateral heterogeneities. The dipole-dipole array did not provide a sufficient data quality, especially at larger dipole spacing (major investigation depth), therefore, only the data with Wenner-Schlumberger configuration has been considered in this work. The data obtained from all survey lines were processed by the widely used commercial software *Res2dInv* (Loke, 2004).

Results

Figure 2A shows a compilation of the velocity and seismic models for T1 profile. The joint interpretation of velocity and resistivity models allows us to characterize the lithology. We can distinguish: a first zone with velocities smaller than 1500 m/s that have been interpreted as non-saturated sediments. Resistivity models detect these materials as layers of conductive materials (clays and silt, 100-400 Ohm·m) and more resistive materials (unsaturated sands and gravels, 300-700 Ohm·m). The underlain zone, showing velocities ranging from 1500 to 2500 m/s and resistivity values lower than 100 Ohm·m, have been interpreted as saturated sediments. Sectors with velocities between 3000 and 4000 m/s corresponding to resistivity values ranging from 400 and 1800 Ohm·m may be related to weathered and fractured granite. The fresh granite top has been delineated in the zone with a considerable increment in both velocity and resistivity (values higher than 4000 m/s and 1800 Ohm·m, respectively). The impedance contrast between weathered and fresh granite has been considered as the cause of the soil resonance. Therefore, an empirical function has been built from fundamental frequency values (υ, in Hz) and bedrock depth (H, in meters) obtained at two profiles (T1, L1);

$$H = 141.9\cdot\upsilon^{-1.08} \quad (1)$$

The validity of this relationship has been confirmed calculating the bedrock depth from $f_{H/V}$ in a third profile (T3) and comparing to the values obtained from the resistivity and seismic models. The application of empirical relationships calculated in other geological contexts (Ibsvon Seht and Wohlenberg, 1999; Delgado et al., 2000) is not suitable in this study since underestimates the bedrock depth. Figure 2B shows a complete transect of bedrock topography calculated from $f_{H/V}$ values and equation 1. In addition, two H/V spectral ratios are shown as representative of zones with deep and shallow bedrock.

Conclusions

In this study we found that H/V method is an efficient tool to define the 2D geometry of bedrock in large areas.

On the basis of both ERT and seismic refraction tomography, different materials have been characterized (clay, sand, gravel, weathered granite) as well as water table and bedrock depth. Seismic technique reaches higher investigation depth (around 70 m) than ERT (< 40 m).

A new $f_{H/V}$-bedrock depth empirical relationship is obtained and has been tested in this area. The application of this equation to other areas with similar geological context will be performed in a future work.

The good correlation between results obtained from the different techniques (ERT, seismic refraction tomography and H/V microtremor techniques) validates the proposed methodology which will be extended to other areas with high physical parameter contrast as soft-sediments versus igneous rock targeted in this work.

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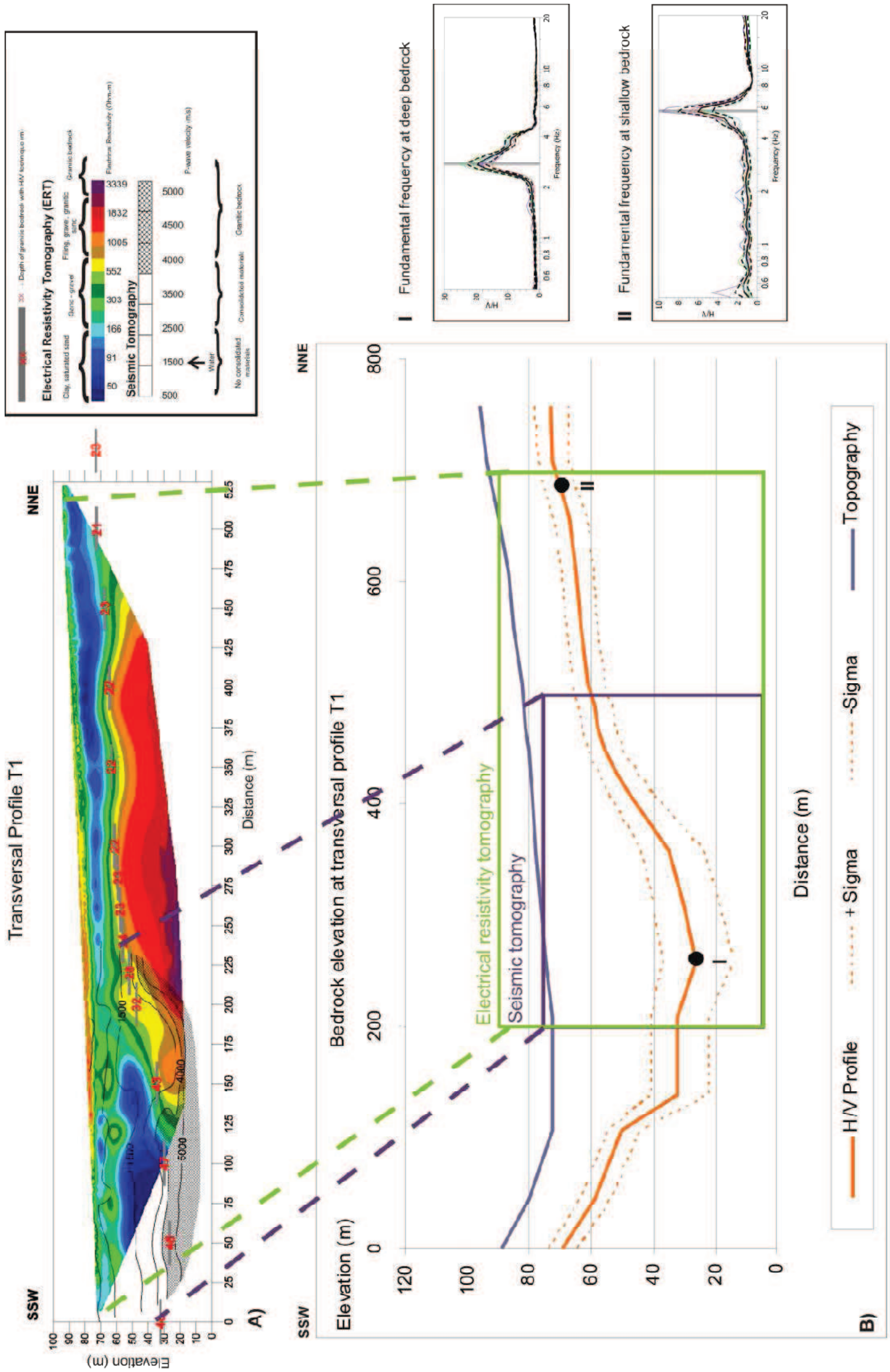

Figure2. A) Seismic velocity and electrical resistivity models, and depth of granitic basement from H/V method (sector of T1 profile). B) Bedrock elevation obtained from H/V measurements. I and II show representative H/V microtremor spectral ratios corresponding to shallow and deep bedrock (complete T1 profile).