Comparisons of diachronic ERT and Spectral Analysis of Surface Waves for estimating bedrock depth

G. Coulouma[1]*, P. Lagacherie[1], K. Samyn[2], and G. Grandjean[2]
[1]INRA – UMR LISAH, 2 place Viala 34060 MONTPELLIER CEDEX 2
[2]BRGM - Natural Risks and CO2 Storage Safety Division, 3 av C.Guillemin 45060 ORLEANS CEDEX 2
coulouma@supagro.inra.fr

Abstract

Bedrock depth is an important property for a lot of environmental and agricultural applications. Direct estimates of bedrock depth from destructive soil observations are too costly for being extended to large areas. Geophysical methods are often cited as possible alternatives. This study examine the ability of the Spectral Analysis of Surface Waves (SASW) method combined with classical high resolution Electrical Resistivity Tomography (ERT) one to predict soil and rooting depths of vineyard soils in French Mediterranean area. Results showed that none of the two tested geophysical methods was able to predict soil depths in all pedological situations.

Keywords : Electrical Resistivity Tomography (ERT), Spectral Analysis of Surface Waves (SASW), bedrock depth, grapevine

Introduction

The bedrock depth (BD) constitutes the main physical and chemical discontinuity between the regolith and the solid bedrock without weathering. For the water, the bedrock generally constitutes the impermeable layer of shallow groundwater. For the plants, bedrock depth is often reliable to the rooting limit and this knowledge is significant to determine the shape of the root system (shenk & Jackson, 2002), soil water availability and crop production potential. Moreover, describing the bedrock geometry seems to be essential to define the limits of the Critical Zone outline.

Although the knowledge of the BD remains an important issue in soil sciences, few studies concern its determination, either by using classical or new methodologies. Direct estimates of BD from destructive soil observations constitute punctual data and they are too costly for being extended to large areas, so that geophysical methods appear as a possible non-invasive alternative and provide continuous data. Classical Electrical Resistivity tomography (ERT) is used to determine bedrock depth in case of high contrasts of resistivity between soil layers and bedrock. Another way to predict bedrock consists in studying diachronic ERT to extract the water uptake localisation (Srayeddin & Doussan, 2009).

However the efficiency of ERT drops with poor resitivity contrasts between soil layers and bedrock (Coulouma et al, 2010). Moreover, in case of saturated porous media like shallow groundwater, ERT signal can be dissociated from soil and bedrock electrical properties. Besides ERT, seismic methods are not so established in soil sciences but could be particularly promising to solve these problems. Due to the development of subsurface characterization studies for environmental or geotechnical purposes, the efficiency of seismic methods for estimating ground velocity structures and mechanical properties has been in real progress in the last decades and has found various applications in several fields like: waste disposal (Lanz et al., 1998), landslides (Grandjean et al., 2007), or hydrogeophysics (Sturtevant et al., 2004). Recent equipments, generally featured with 48 or 72 recording channels and PC-piloted acquisition software, made this method very operational and contributed to its dissemination.

The aim of this paper is to compare new approach of classical geophysical methodologies, e.g. diachronic ERT and SASW methods, in the complex cases of various types of pedological situation in French Mediterranean area.

Material and Methods

<u>Sites description</u>
The study area was located in the Languedoc-Roussillon French mediterranean region (southern France). Four vineyard blocks of 2 ha were chosen in relation to their contrasted types of bedrock and to their contrasted rooting limits. Each site corresponds to a representative transect (150 m on average) of each block. The geo-pedological characteristics are outlined in Figure 1.

<u>geological and pedological measurements</u>
A borehole (2-4 meters deep) every 20 m was realized along each site to describe soil layers and determine the bedrock depth. Each borehole was described and morphological parameters were observed in the field (texture, structure, colour, stone and classes of calcium carbonate content). Bedrock depth was also estimated in relation to this description.

<u>geophysical measurements</u>
The SASW method is a new seismic method used to determine shear wave velocity (*Vs*) models. Measurements are performed directly at the surface, without invasive actions. Data were acquired along each site in January 2011 with 24 takeouts at fixed 0.5 m interval. Each takeout is attached to a single self-orientating, gimbals-mounted, vertical geophone able to record signals from 10 to 200 Hz frequencies approximately. A 24-channel Geometrics Geode seismograph was used to record impacts of a hammer source able to generate signals in the 1 to few tens of Hz frequency range. We processed the seismic data in order to put in evidence the wave dispersion. A 2D wavefield transform method is commonly used to determine experimental dispersion curves. The inverse problem aims at finding the parameters that characterize in the best way the soil layers (here *Vs* value and thicknesses of layers) from dispersion curves.

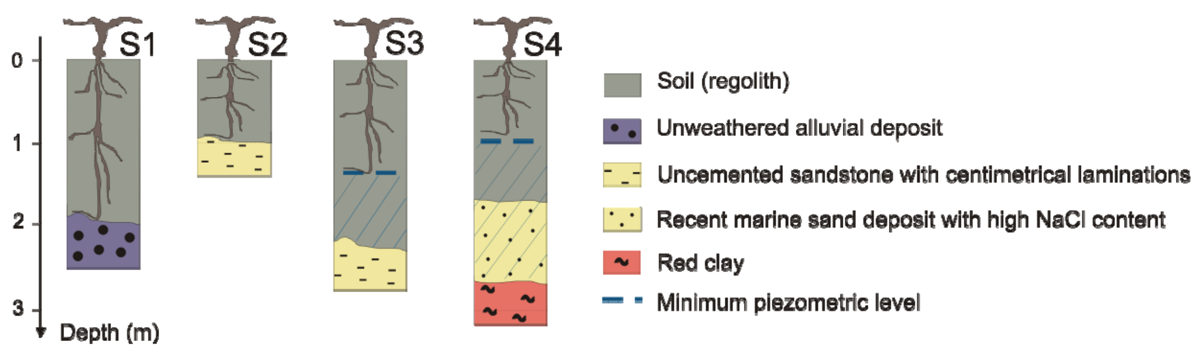

Figure 1. Schematic geo-pedological description of the four sites

2D Electrical Resistivity Tomography (ERT) sections were made along the same transect in each site in August 2010 in dry conditions and in February 2011 in wet conditions. ERT measurements were performed using a Wenner-Schlumberger array with an electrode spacing of 1 m. 50 electrodes were used simultaneously on each transect to provide the apparent electrical resistivity over the profile at ~0.5 m increments down the profile until a maximum depth of 5m. The electrical resistivity for each soil layer and bedrock was derived from the apparent electrical resistivity measurement using an inverse method, i.e. the Gauss-Newton code Res2dinv as described by Locke (2002).

Bedrock depth (BD) determination from geophysical data

From each seismic data points, bedrock depth (BD) was then estimated on the 1D vertical Vs profiles, considering the inflexion point between the low-velocity coverage layer and the high-velocity underlying layer. From each electrical data points, bedrock depth (BD) was then estimated on the punctual inverted diachronic ERT data, considering the depth further down which no significant differences in electrical resistivity were observed between wet and dry conditions.

Results

Table 1. Estimation of BD from geophysical data compared to measured BD

	RMSE (m) of bedrock depth estimation			
	S1	S2	S3	S4
Diachronic ERT	0.25	0.3	1.3	0.6
SASW	0.38	1.3	0.4	1

In this study we consider the bedrock as geological material without major weathering features. In case of S1, soil is developed from weathering of alluvial phyllosilicates pebbles. RMSE of BD estimation is low because of the high contrast of resistivity between clayey soil and pebbles. In the same way, high V(s) in pebbles allow a determination of BD from SASW with low RMSE. In case of S2, the contrast between soil and bedrock is lower. The grapevine roots colonize the whole part of the soil and an analysis of diachronic ERT give a good estimation of BD. In the other hand, the bad BD estimation from SASW is due to perturbation of the signal in case of low BD. However, in case of S3, resistivity of soil layers and diachronic ERT are disrupted by groundwater. SASW is not modified by groundwater and give good estimation of BD. Finally, estimation of BD are divergent with both SASW and diachronic ERT in case of S4. SASW detect the deeper limit between loose marine sand and red clay and ERT is disrupted by groundwater and salinity. This site corresponds to the most complex case with salt groundwater and very loose marine sand as the bedrock.

Conclusion

Analysing the pattern of the water uptake by grapevine constitute a way to determine the rooting depth and the bedrock depth in case of very low contrasts in resistivity. However, this methodology cannot be efficient in case of presence of groundwater or in case of bedrock depth larger than the rooting depth. Seismic surface waves have therefore a great potential for discriminating between loose and competent materials and are not sensitive to the water content. These preliminary results show the high dependency of each methodology to the soilscape characteristics. According to a prior pedological knowledge such soil maps, the combination with sensor based on different physical parameters may enhance the bedrock detection.

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