Bedrock and soil resistivity mapping as a tool for characterizing soil thickness on cultivated hillslopes. A case study in Seuilly, SW Parisian Basin, France

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1. INTRODUCTION:

Soil apparent resistivity, or its converse soil conductivity, is a parameter commonly used to predict soil properties, such as porosity, water content, particle size, clay content… It has also been used for soil thickness mapping, but the resulting data can be misinterpreted, due to inter-relationships between soil resistivity and the physical and chemical properties of soils, which may be related to bedrock lithology. Soil thickness mapping using resistivity measurements thus gives results only when the bedrock is electrically homogeneous and presents a high resistivity contrast related to soil. It therefore appears necessary to precisely characterize the bedrock resistivity variability before interpreting soil resistivity measurements.

In this study, the relationships between surficial apparent resistivity at different depths of investigation and soil thickness – defined as the summation of organo-mineral and structural (A+B) horizons – were tested to predict soil thickness over large areas.

STUDY SITE:

The study site corresponds to a 100 ha cultivated hillslope located near the village of Seuilly (SW Parisian Basin, France). It covers 3 types of Upper Cretaceous sedimentary formations (**Fig. 1.1**): a. Lower and Middle Turonian white chalk (**TWC**), b. Upper Turonian yellow sandy limestone (**TYSL**), and c. decarbonated yellow sandy limestone enriched in clay by deep weathering (**DYSL**).

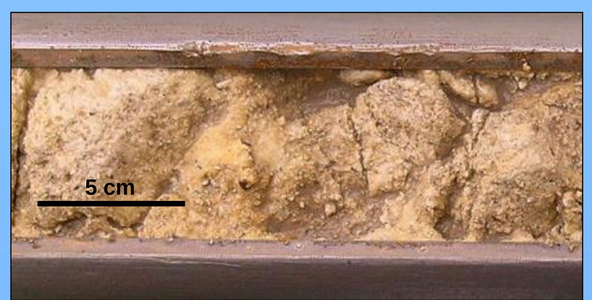


Fig. 1.1: two bedrock types

a: Lower and Middle Turonian white chalk (**TWC**)

b: Upper Turonian yellow sandy limestone (**TYSL**)

2. SOIL CHARACTERISATION:

Inside the study site, a 16 ha test zone representative of the whole site was chosen for the establishment of the soil thickness / resistivity correlations. Soil thickness was measured at 686 points thanks to manual augerings (**Fig. 2.1**). The site shows a wide range of soil thicknesses (from 0.2 m to more than 2 m in lynchets) due to the fragmentation by field limit networks (**Fig. 2.2**).

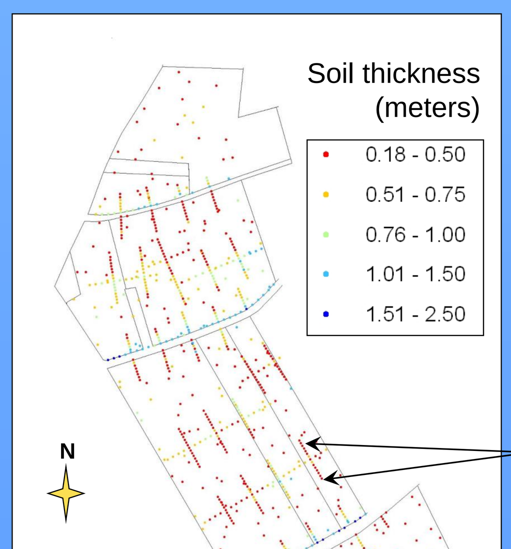


Fig. 2.1: Soil sampling and thickness (16 ha test zone)

Finally, soil properties (particle size, organic carbon and carbonate content) were analysed at 248 points and compared to soil resistivity to assess the relationships between soil resistivity and each soil property.

Fig. 2.2: Series of manual soil augerings oriented perpendicularly to the axis of an « undulation » due to former field limit and showing the associated soil thickening. The distance between soil augerings is 4 m.

3 – SOIL RESISTIVITY:

The resistivity of the soil was measured using an **ARP** (Automatic Resistivity Profiling) survey at 3 different depths of investigation (0.5, 1 and 2 meters). The average measurements interval along the profiles is 0.2m, whereas the spacing between the profiles is 6m. We finally obtain about 160 km of ARP profiles within the prospected area, representing 800,000 measurement points. The resulting maps are presented below:

ARP equipment (Seuilly)

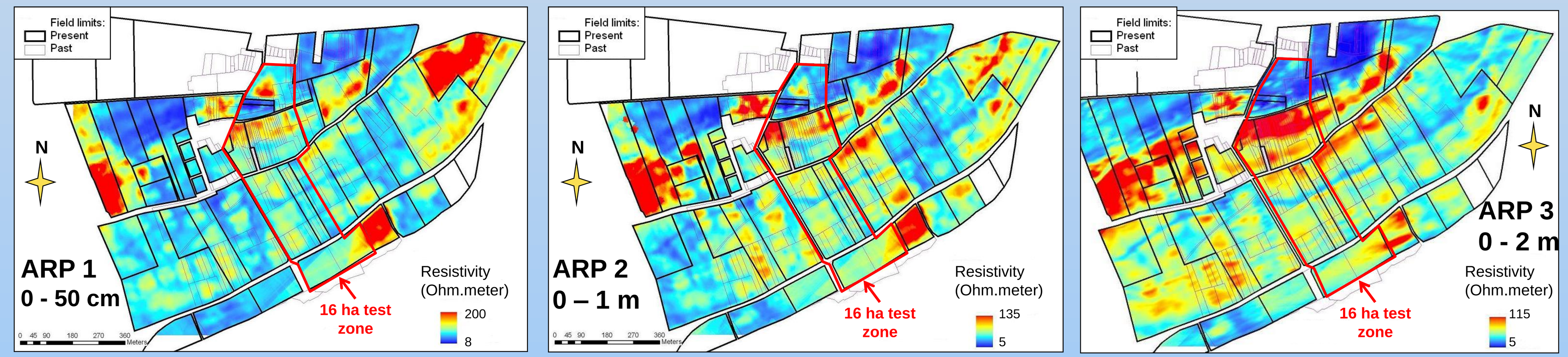
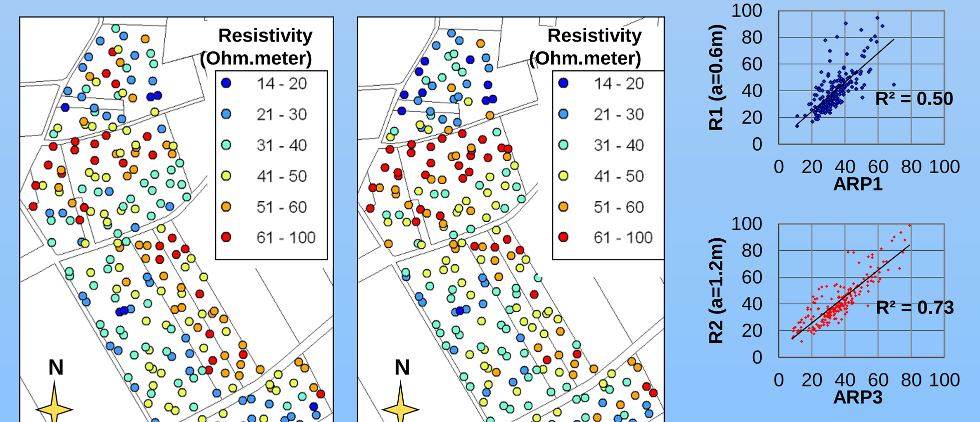


Fig. 3.1: Soil resistivity maps at 3 different depths of investigation

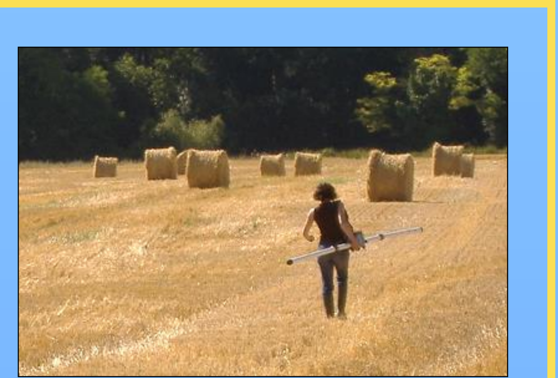
Soil resistivity was also measured directly on 241 soil augerings using a quadripole Wenner array with a=0.6m and a=1.2m inter-electrode spacing. We observe a rather good correlation between the interpolated ARP values and the measured resistivity values, especially for large investigation depth (ARP3)



Measured resistivity vs. calculated (ARP) resistivity (Ohm.meter)

4 – BEDROCK RESISTIVITY:

The resistivity of the bedrock was measured using an electromagnetic survey with an EM31 conductivity meter (Slingram method), which gives a large investigation depth (about 6m), making this instrument quite insensitive to soil variability.



EM31 conductivity meter (Seuilly)

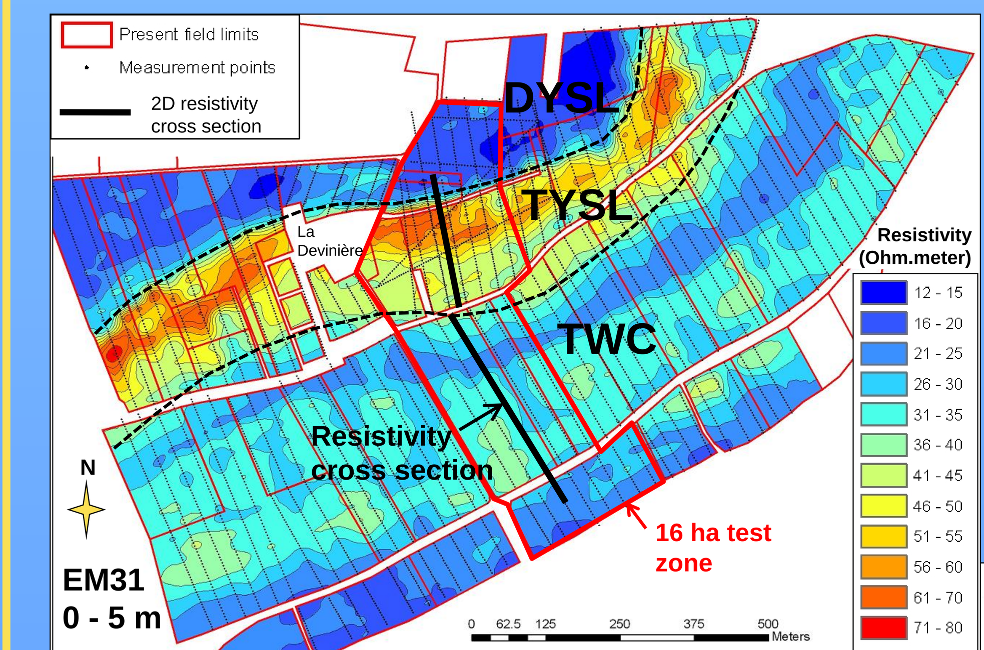


Fig. 4.1: Bedrock resistivity Map (dotted lines indicate the approximate boundaries of the 3 identified bedrocks)

34 electrical soundings were also performed along a transect covering 700m from top to bottom of the hillslope, allowing the establishment of a 2D resistivity cross section of the bedrock:

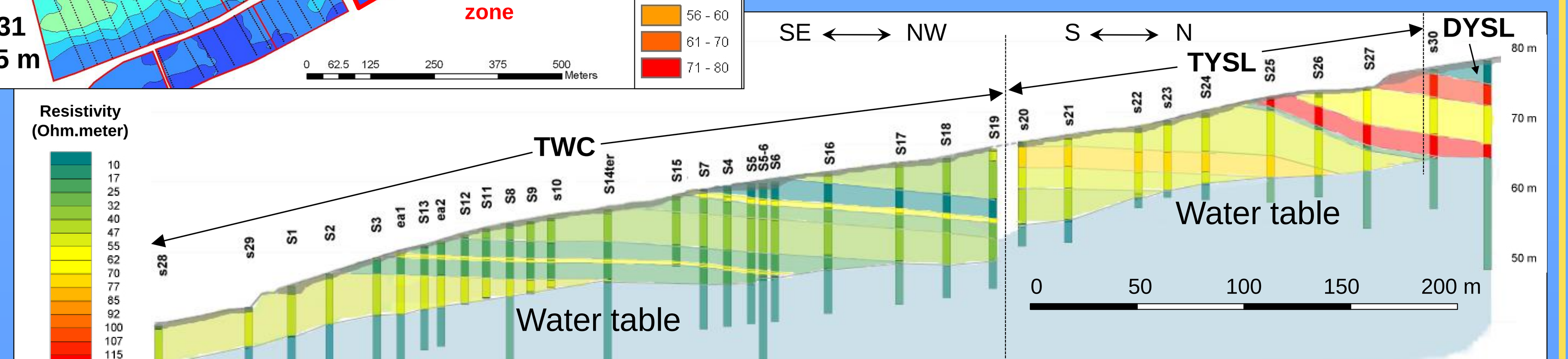
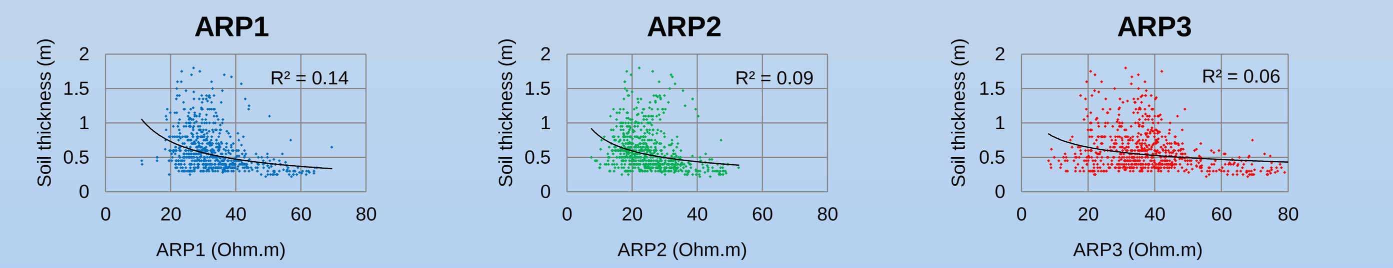


Fig. 4.2: 2D resistivity cross section of the bedrock

5 – RESULTS:

- **Soil thickness – resistivity correlations for the whole test site:**

If we compare all the measured soil thicknesses (**Fig. 2.1**) with the soil resistivity values calculated at the same points (ARP1, ARP2 and ARP3; **Fig. 3.1**), we observe no evident correlation, making impossible soil thickness mapping from geophysics:



- **Soil thickness – resistivity correlations for each bedrock type:**

The electromagnetic survey results (**Fig. 4.1**) and the electrical soundings (**Fig. 4.2**) show that the 3 bedrock types are characterized by different resistivity values.

- The Upper Turonian yellow sandy limestone (**TYSL**) presents the highest resistivity (45 to 130 ohm.m), whereas soil resistivity does not excess 30 ohm.m. In this area, soil thickness / resistivity correlation is good (R^2=0.66 for ARP3), allowing high resolution digital soil thickness mapping from the ARP measurements (**Fig. 5.1**).

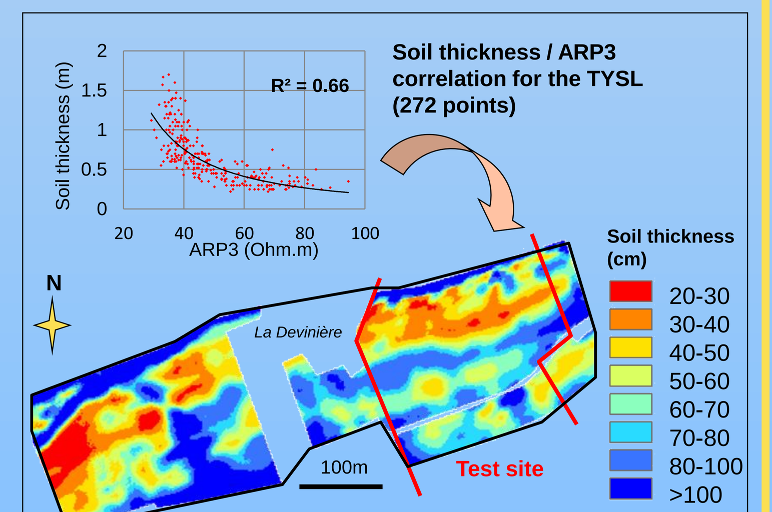


Fig. 5.1: Map of calculated soil thickness (geophysical model) for TYSL

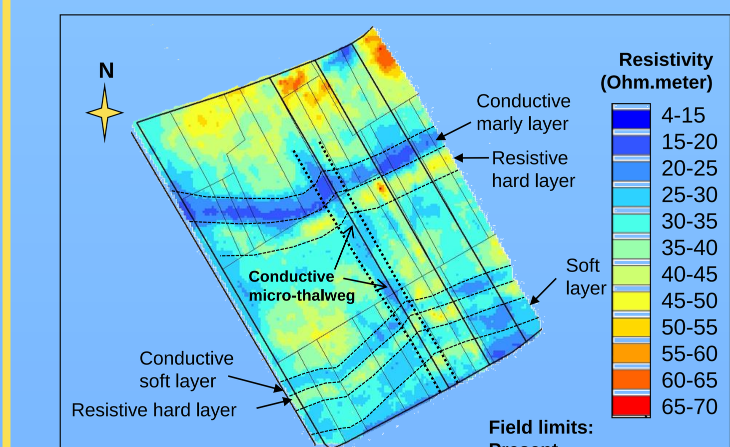
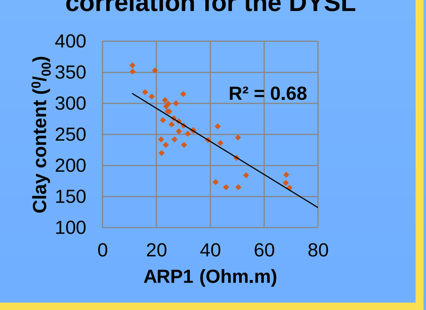


Fig. 5.2: ARP3 resistivity map of TWC (test site)

- The Lower and Middle Turonian white chalk (**TWC**) presents lower resistivity values (20 to 50 ohm.m) and is electrically heterogeneous, making the soil thickness / resistivity correlation insufficient (R^2=0.3) to map soil thickness correctly. However, the ARP mapping gives precise information on bedrock heterogeneities (**Fig. 5.2**).

- Finally, the decarbonated yellow sandy limestone (**DYSL**) is characterized by low resistivity values (< 20 ohm.m) similar to soil resistivity, making impossible soil thickness prediction. In this area the ARP results seem more correlated with the soil particle size (i.e. clay content)

Clay content / ARP1 correlation for the DYSL



6 – CONCLUSIONS AND PERSPECTIVES:

→ These results show the importance of characterising precisely the electrical response of the bedrock (variability and resistivity contrast related to soil) before using soil apparent resistivity as a tool for digital soil thickness mapping, and more generally for soil properties mapping.

→ Attempts: we will explore geostatistically the spatial relations between the various soil properties, soil thickness and soil apparent resistivity for the 4 different investigation depths simultaneously (filtering; principal component analysis…)

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