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Contribution of Geophysics to Geochemical Study

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SUMMARY

A study of spatial heterogeneity of groundwater geochemistry is conducted within an abandoned underground quarry of chalk.
An associated geophysical study (electromagnetic mapping at low induction number, and electrical resistivity tomography) is carried out on the surface.
It allows to determine the structural geometry of superficial formations, in order to understand the link between the geochemical spatial variability of the lakes and the properties of the environmental medium.

Introduction

An abandoned underground quarry of chalk near Beauvais (France) is of particular interest to study critical zone, infiltration and dissolution processes because it enables the access to the interface between the unsaturated and the saturated zone. It is located at Saint Martin le Nœud, about 80 km north of Paris (France), on a topographic dome on the northeast flank of the anticline of Bray, in the Paris Basin. This quarry extends over 1200 m long (in the northwest-southeast direction) and 150 m wide, with a depth between 20 and 30 m from the surface. The amount of water that percolates downward from the top of the quarry has a seasonal dependence. The water table outcrops in the quarry creating several permanent underground lakes into the senonian chalk formation. This formation is covered by a superficial formation of soil and clay-with-flints.

A study of spatial heterogeneity of groundwater geochemistry is currently conducted within the quarry (Barhoum et al. 2014). Different measurements within the lakes (conductivity, temperature, level) and analyzes on water samples (major ions: Na^+ , NO_3^- , Mg^{2+} ...) are regularly carried out since 2011. The groundwater quality varies widely in space due to different agricultural land use above the quarry (NO_3^- is associated to fertilizers), thickness of subsoil and so time for water to crossed the unsaturated zone (Na^+ is associated to atmospheric input), and also probably due to the nature of the different superficial covers above the chalk (Mg^{2+} could be associated to cationic exchange with clay minerals, or to the unsaturated zone thickness, or to the different layers of chalk crossed by water).

The objective of our geophysical study is to determine the structural geometry of superficial formations, in order to understand the link between the geochemical spatial variability of the lakes and the properties of the environmental medium.

Method

Different geophysical surveys (electromagnetic mapping with conductivity-meter at low induction number in vertical dipole mode, and electrical resistivity tomography, i.e. ERT) have been carried out on the surface (Figures 1 and 2) to describe the cover of chalk (Chalikakis et al. 2011).

The electromagnetic map has been obtained with the EM31 device (Geonics Ltd.) in the vertical dipole mode following profiles separated by approximately 5 m. This sampling allows describing the first 5 m of depth over an area of about 20 ha located above the quarry. The two electrical tomographies have been obtained with resistivity-meter SyscalPro (Iris Instruments) using Wenner-Schlumberger array and inter-electrodes spacing of 2.5 and 3.5 m which gives geo-electrical vertical cross-sections until respectively 30 m- and 60 m-deep.

Three holes (Figure 3) have been dug until chalk formation was reached. Their locations were chosen directly above three lakes in which geochemical analyzes were performed. It gives isolated information about the structure of superficial formations.

Results

The conductivity ranges from about 20 to 85 mS.m^{-1} (Figure 1). As clay-with-flints has higher water content than chalk and therefore a higher electrical conductivity, the most conductive zones (northeast of the map) are interpreted as the areas with the thickest clay-with-flints cover. The electrical conductivity measurements indicate that the clay-with-flints cover thickness varies above the quarry. The western part of the quarry is characterized by the low thickness of the superficial layers (red area), while in the east (blue area), the thicknesses are higher at the top of the plateau.

The electrical cross-sections (Figure 2) show conductive layer above resistive basement. It also shows the geological slope of the northeast flank of the anticline of Bray.

Observations of the three holes dug above the quarry (Figure 3) corroborate the conductivity results. A soil thickness of 25 cm was encountered in the three holes. Below, the superficial layer composed

of clay-with-flints is reached. Its thickness varies greatly from one hole to another (less than 5 cm at 'lac Pedro', (3), and over 245 cm at 'lac des Stalactites', (2)). Below clay-with-flints, more or less unweathered chalk is encountered (with varying thicknesses). Clay-with-flints lenses can be observed up to a depth of 2 m above the 'lac Bleu' (1). The observation of these three holes highlights the strong spatial heterogeneity of the superficial layer thickness

From hypothesis and information provided by the three holes made on the surface. An inversion of electromagnetic data mapping (Bendjouidi et al. 2002) provides information on the spatial variation of the thickness (not shown in this abstract) of the layers of soil and clay-with-flints.

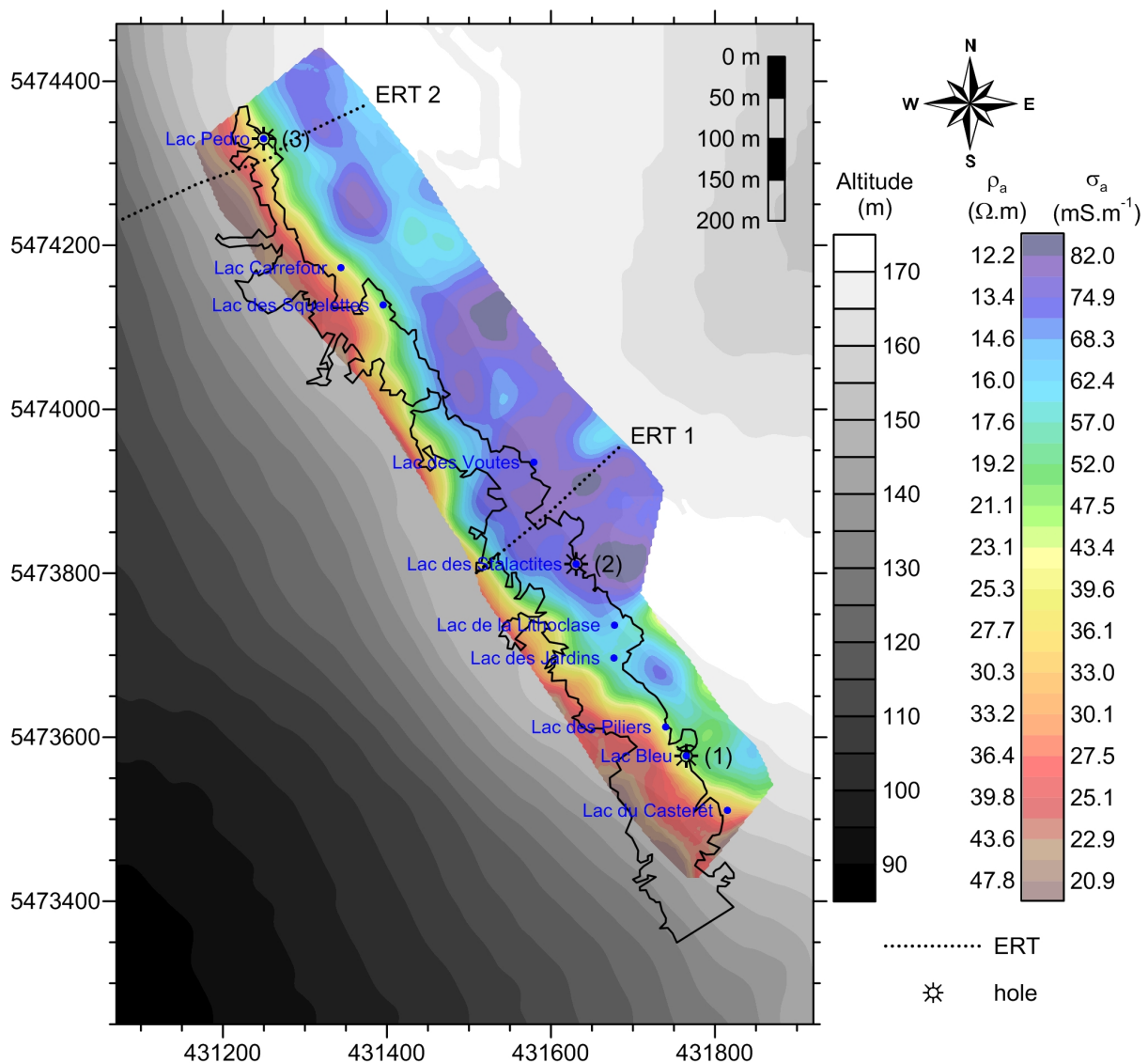


Figure 1 Electrical conductivity map (obtained with EM31, Geonics Ltd., conductivity-meter in vertical dipole mode) superimposed to the topographic map, the location of the underground quarry and of the lakes in this quarry, the location of two electrical resistivity tomographies, and the location of the three holes carried out above three lakes: 'lac Bleu' (1), 'lac des Stalactites' (2), 'lac Pedro' (3)

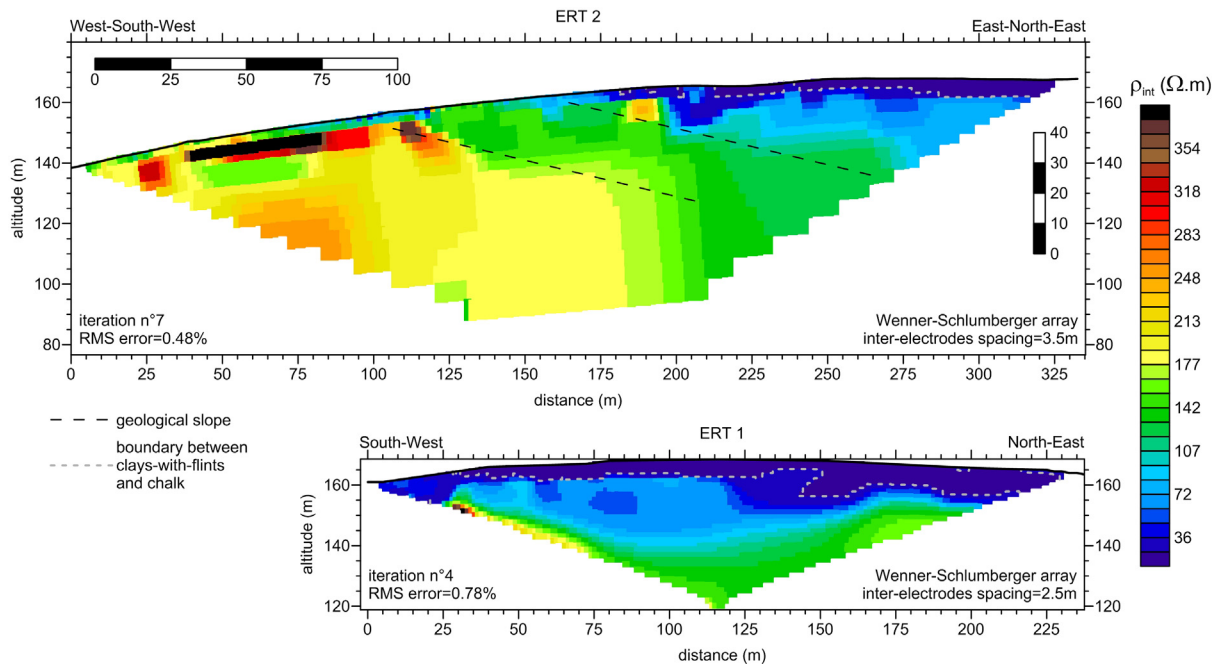


Figure 2 Electrical resistivity tomographies located in Figure 1.

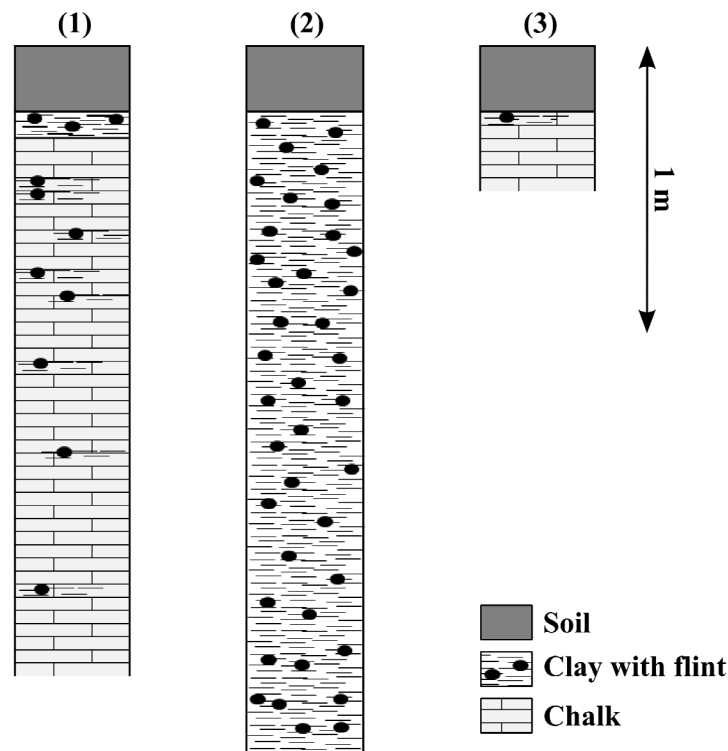


Figure 3 Geological sketches of the three holes dug above: 'lac Bleu' (1), 'lac des Stalactites' (2), 'lac Pedro' (3), and located in Figure 1.

Correlations between geophysical data (conductivity which is interpreted as related to the clay-with-flints thickness) and geochemical properties of the chalk groundwater (not shown in this abstract) have been done. The results show that: (i) Mg^{2+} is mainly provided by clay-with-flints, (ii) Na^+ concentration depends on unsaturated zone thickness and (iii) high unsaturated zone thickness delays the transportation of ions related to agricultural practices (NO_3^- excess) toward the water table.

Conclusions/Perspectives

Geophysical data show that over the quarry, chalk is covered by a variable thickness of soil and clay-with-flints.

The contribution of geophysics to characterize the critical zone and to give information about the chemical properties of soil and water in the basement is demonstrated in this study.

A monitoring of the geophysical survey during a hydrological cycle (at different groundwater level/condition) should be done to investigate the possible process of water storage in the clay-with-flints.

Implementation of geophysical measurement between the surface and the top of the quarry should be considered to be closer to sources of anomalies and better characterize the environmental medium.

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