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Geological environment of karst within chalk using airborne time domain electromagnetic data cross-interpreted with boreholes

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ABSTRACT

The ability of airborne Time Domain ElectroMagnetic (TDEM) to image plurikilometric chalk heterogeneities and its implications for the development of a karstic system is addressed in this study. A heliborne TDEM survey was conducted around Courtenay (France) over the Paris Basin Upper Cretaceous chalk. This aquifer is known as a highly weathered and karstified horizon both strongly modify chalk petrophysical properties. Numerous boreholes and one recently reprocessed seismic line were used in order to strengthen TDEM interpretations. We performed cross statistics between boreholes and the resistivity model. This allowed defining empirical resistivity ranges corresponding to the main geological formations within the area. We were therefore able to map large scale heterogeneities in the chalk over the study area. First, the TDEM method highlighted probable weathering corridors in the chalk, related to the tectonic activity, consistent with faults previously interpreted in the seismics at deeper levels. Second, it was possible to image a large scale undulating geometry in the chalk with a SW–NE orientation, this direction is consistent throughout the Paris Basin, and well defined on the cliffs of Normandy (Channel coast, north of France). This geometry has revealed two separate chalk deposits C1 and C2 in Courtenay area: C1 is more resistive than C2. The resistivity model has then been compared to piezometric measurements acquired as part of previous hydrological studies. The karstic drainage appears to be developed within C1 chalk deposit and most of the piezometric domes seem to be associated to intermediate resistivity zones in C1, interpreted as weathered. According to the results obtained from this study, we were able to suggest a geological framework for the development of Courtenay karstic system.

1. Introduction

Chalk is the main Late Cretaceous deposit in northwestern Europe, long considered as monotonous (Robaszynski et al., 1982). It is in fact a complex deposit with numerous depositional environments from shallow water carbonate to deep sea turbidites (Lasseur et al., 2009; Surlyk et al., 2003). Chalk is known as having a dual porosity (Edmunds et al., 1995; Price et al., 1993). The matrix, composed by Coccolithophorids bones, has a high microporosity and a large storage capacity but a low permeability (Edmunds et al., 1995). The permeability increases with the development of fracture networks and it becomes even higher under the action of water circulation (Crampon et al., 1993), due to the karstification process; chalk is highly affected by dissolution (Quesnel, 1997). Thus, weathering and depression (dolines) features, commonly observed in the topography or in cross-section along cliffs (Laignel, 1997; Quesnel, 1997; Sperling et al., 1977; Waltham et al., 2005) are witnesses and the main indicators of the presence of karst systems (Legrand and Stringfield, 1973; Mangin, 1975). Nevertheless, the non-homogeneous nature of the karstification process and of the fracture network, plugged or not, induces high variations in chalk permeability. In order to complement the field evidences, it is critical to improve our knowledge of karstic systems at depth in order to better model the groundwater flow, which is required for the water resource management and its protection from anthropic pollutions (Baran et al., 2008).

Studies have also shown that chalk may display complex lenticular plurihectometric to plurikilometric wavelength-undulating geometries (Esmerode and Surlyk, 2009; Lasseur, 2007; Quine and Bosence, 1991; Surlyk, 1997; Surlyk and Lykke-Andersen, 2007), with varying sedimentary facies and petrophysical characteristics (Collin et al., 2012; Quine and Bosence, 1991).

Despite some limitations specific to each method (resolution, depth of penetration, the measured physical parameter…), documented in Chalikakis et al. (2011), geophysical surveys can help in characterizing chalk and, to some extent, karst systems. Regarding resistivity/conductivity surveys, chalk appears to be relatively resistive, around 100 Ω·m (Andrews et al., 1995; Barker, 1982; Roberts and Lewis, 1997; Robins and Lloyd, 1975), but its resistivity may be lower for clayey chalk (down to 30 Ω·m; Andrews et al., 1995; Robins and Lloyd, 1975), higher in presence of voids (around 140 Ω·m; Roberts and Lewis, 1997) and depends on the degree of saturation, on the porosity of the chalk

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and on the chemistry of the groundwater (from 20 Ω·m for a brackish water to more than 100 Ω·m for fresh water; Barker, 1982). Some karst features could also be imaged, such as collapse areas, which appear conductive (Gibson et al., 2004; Guérin et al., 2009; Rigby-Jones et al., 1997; Valois et al., 2011; Zhou et al., 2002), or karstic caves, which appear resistive (Gibson et al., 2004; Vouillamoz et al., 2003).

As part of a regional research project, airborne TDEM measurements were carried out by SkyTEM ApS. in February 2009 near Courtenay city, in the south-center of Paris Basin. The airborne survey, requested by BRGM (French geological survey) for geological and hydrogeological purposes, was flown along the N–S direction with 400 m line spacing over a total of about 185 km^2 (Fig. 1), representing about 540 km of flight lines. The spacing between each EM sounding along flight lines is approximately 30 m and the nominal height of the loop was about 40 m above the ground.

The original aim of this study was to use airborne TDEM data to better characterize large scale heterogeneities in the chalk. Although historically developed for mining purposes (see Palacky and West, 1991, for a review), the ability of airborne TDEM method to provide increasingly detailed resistivity mapping of the subsurface progressively

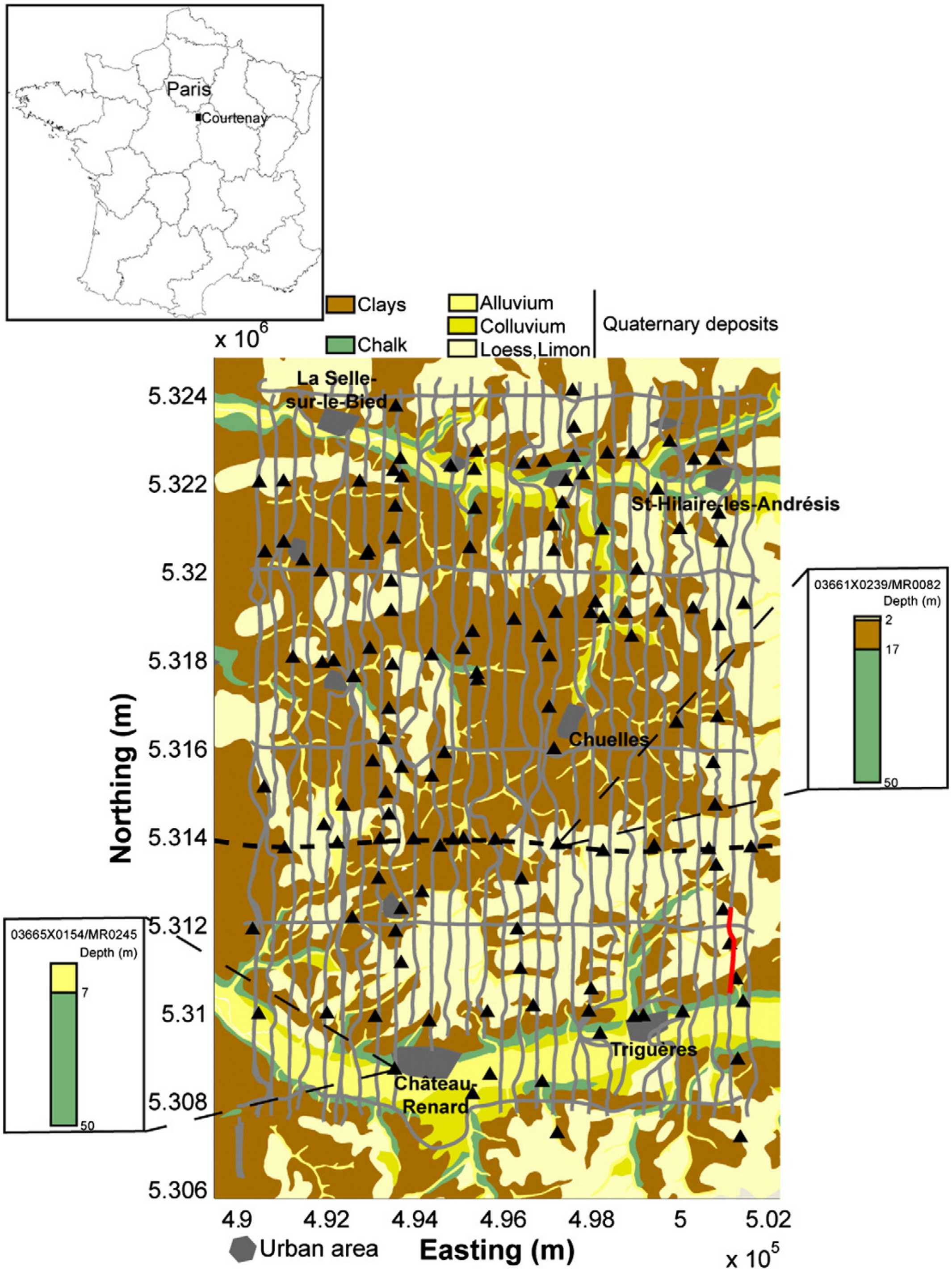

Fig. 1. Simplified geological map of the study area (modified from Pomerol, 1988). Flight lines are displayed in gray. Boreholes are indicated by black triangles and the reprocessed seismic line is represented by thick dashed black line. The red line shows the location of the resistivity profile displayed in Fig. 4. The black rectangle on the geographic map in the box locates the study area with respect to Paris.