EXPERIMENTAL STUDY OF A CHALK FORMATION USING MAGNETIC RESONANCE SOUNDINGS (MRS) AT LE BOIS DE CIZE, NEAR AULT (PICARDY, FRANCE)

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INTRODUCTION

In coastal areas of France where chalk makes up the shore line (Picardy, Normandy), knowledge of its mechanical stability is important in evaluating the risk of natural hazard. The presence of water within chalk has a consequence on pore pressure, whereas the amount of water can influence the rock's mechanical characteristics. Water content thus constitutes one of the major parameters controlling collapse mechanisms.

Within the framework of the ROCC programme, nine MRS measurements (T1 to T9) were carried out along a profile perpendicular to the chalk cliff at the 'Le Bois de Cize' site near Ault (Figure 1). The aim of this survey was to test the efficiency of MRS in characterizing chalk aquifers and locating internal inhomogeneities in the chalk by mapping the water content from the surface.

Other geophysical investigations and boreholes reveal that the subsurface is composed of 5 to 10 m of clay, underlain by weathered chalk down to 30 m, and fresh chalk beneath. The chalk structure in the unsaturated zone is laterally very inhomogeneous: ranging from rather compact to karstified rocks.

RESULTS

During this survey, the NUMIS system of IRIS-Instrument was used. As the noise conditions varied along the profile, three out of nine soundings were carried out using a figure-of-eight shaped loop (Trushkin, *et al.*, 1994) with 56-m sides for each square. The depth of investigation with this loop is about 60 m. For other soundings, a 75-m-side square loop was used, giving a depth of investigation of about 100 m. The field data were inverted using the well-known Tikhonov regularization method, which provides a quasi-continuous solution (Legchenko and Shushakov, 1998).

It is known from previous experience (Legchenko *et al.*, 2002) that where the subsurface is composed of chalk or limestone, MRS can detect not only aquifers (free water), but also water in the unsaturated zone (bound water). When water in the unsaturated zone is the target, the relaxation time of the MRS signal T_2^* is usually short ($T_2^* < 80$ ms), which is comparable with the typical pulse duration for the NUMIS system ($\tau \approx 40$ ms). Under these conditions, a quantitative interpretation of the water content requires a model that takes into account the relaxation during the pulse. However, currently available models were developed with the assumption of $\tau << T_2^*$, which obviously is not respected for short signals. Consequently, MRS water content estimates provide only relative variations of water content in the subsurface. When the investigated object is a lateral heterogeneity of the water content distribution in the subsurface, MRS can be readily used. For a quantitative estimation of water content, however, the MRS results should be calibrated.

In full accordance with previous experience, the field measurements reveal very short MRS signals from bound water in the chalk. The relaxation time T_2^* varied from 25 to 130 ms along the profile. Shorter values correspond to shallow parts of the MRS log, and water in the aquifer (about 30 m deep) produces longer signals. For all soundings, the MRS response was estimated as $E_{mean} = \int_T e(t)dt$, where $e(t)$ is the amplitude and T is the recording window. Mean amplitude (E_{mean}) was used as it is considered as a more stable parameter than amplitude for comparing different soundings, especially when the relaxation time is short. Results of E_{mean} measurements against the pulse parameter are presented in Figure 2. These soundings with varying amplitude indicate that the distribution of water in the subsurface is very heterogeneous, which corresponds well to other data.

The inversion results of amplitude and relaxation time are presented in Figure 3.

The water-content cross section (Figure 3a) shows a significant amount of water above the static water level. Consequently, based only on the water content, it is not possible to distinguish between an aquifer and the unsaturated zone. Variations in the water content in the unsaturated zone, accompanied by short relaxation times, may correspond to variations in the chalk structure (compact or weathered chalk). Water in the aquifers is characterized by longer relaxation times.

The decay-time cross section (Figure 3b) shows that the water level detected by MRS (longer relaxation time) lies at a depth of 30 to 40 m in the southeastern part of the profile, and that it appears to drop suddenly to 55 to 60 m about 400 m from the cliff edge. These results are coherent with a) regional knowledge that the water level is about 40 m below the surface on the chalk plateau, and b) the borehole drilled 120 m from the cliff edge showing a water level at a depth of 73 m. The sudden drop in the water level could be related to a small valley named "Deuxième Val" on the IGN map (Figure 1), and which may reflect a preferential drainage structure that could be the cause of water-table depression.

CONCLUSIONS

This first attempt to apply the MRS method to investigating water-content distribution in weathered chalk proved promising. The results show that the method is able to locate aquifers below the static water level, and that it is sensitive to variations in the water content throughout the unsaturated zone and thus can be applied to subsurface characterization above the static water level.

Measuring the amplitude of MRS signals could enable the identification of lateral inhomogeneities in the water distribution throughout the chalk and that could be associated with variations in the rock's mechanical properties.

As the relaxation time of the MRS signal is comparable with pulse duration, quantitative estimation of the water content requires development of a mathematical model that takes into account the relaxation during the pulse. Otherwise, only relative variations of the water content can be derived from MRS measurements. It is possible, however, that some empirical relationship could be established between MRS estimation of the water content and its true values, thus providing realistic estimations of water content from MRS data.

Since the geometry of the chalk is often in 3D rather than 2D or 1D, errors when applying 1D inversion should be expected.

Additional field and laboratory study is necessary for calibrating the water content derived from MRS data.

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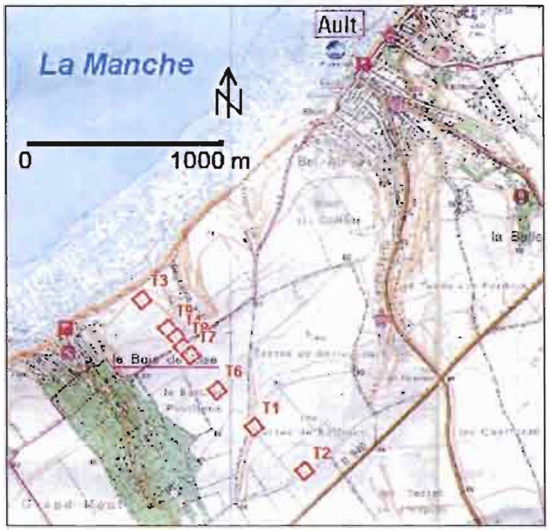

Figure 1. Location map of the MRS sites.

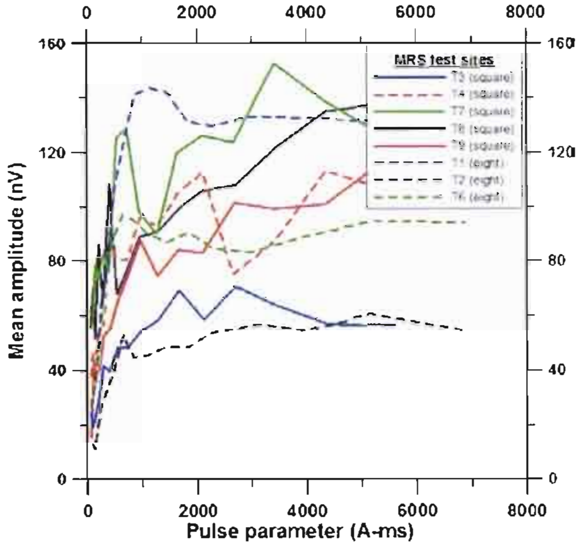

Figure 2. MRS signals.

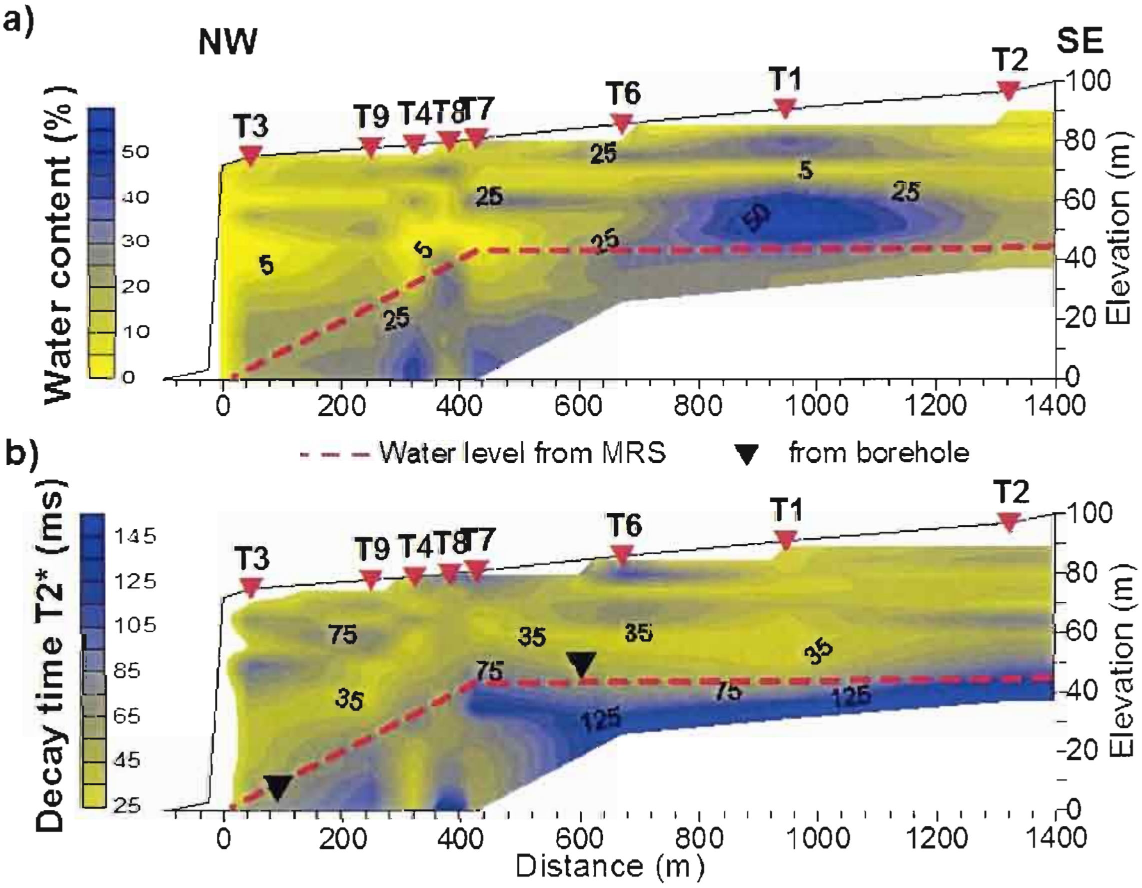

Figure 3. MRS cross sections of a) water content and b) decay time

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