ON THE POSSIBILITY OF MRS MONITORING OF CHALK AND LIMESTONE AQUIFERS

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INTRODUCTION

Magnetic Resonance Sounding method (MRS) was initially developed for the detection of free water in aquifers. MRS capability of separation of groundwater into free and bound water is based on the measurement of signal relaxation time constant T_2^*. In some rock, bound water is characterized by shorter relaxation time constant (<30 ms) and longer time constant (>30 ms) corresponds to free water. As actually available MRS instruments cannot measure short signals, it can be said that MRS is measuring the response from mostly free water. However, relaxation time T_2^* depends not only on pores size but also on magnetic susceptibility of rocks. If the susceptibility is very low ($<10^{-5}$ SIU), then even bound water may produce relatively long signals (60-80 ms) that can be measured by MRS (Legchenko et al., 2002). For example, bound water can be measured in chalk and limestone. Thus, MRS technique could be used for monitoring of the water distribution in the unsaturated zone. In this paper, a theoretical estimation of this possibility and very first experimental results are presented.

NUMERICAL MODELING OF MRS RESPONSE FROM WATER IN CHALK

Experimental laboratory study of the water content distribution in a chalk formation in France (Weng et al., 2002), reveals a quasi-constant profile of the water content (Figure 1). The total porosity of chalk is composed of the matrix porosity and fractures porosity. While the matrix is equally saturated in both aquifer and unsaturated zone, fractures are filled with water in the aquifer and with air in the unsaturated zone. In a chalk formation, it makes the difference in the total water content of about 2 to 3% between the aquifer and unsaturated zone.

Measurements of MRS signal from water in chalk reveal a quite different profile of the water content from that measured in laboratory (Figure 2). We explain this difference by increasing size of the pores from the top towards the aquifer due to alteration of the chalk and decreasing of clay content. As the relaxation times of the magnetic resonance signal is extremely sensitive to the distance between pore walls and water molecules (a few molecular layers), slightly thinner layer of water around chalk grains close to the surface produce very short signal and thus it is barely seen by MRS instrument. This hypothesis still needs to be confirmed, but for a monitoring at the same site we could use an MRS model of water in chalk derived from experimental observations (Figure 2).

Basing on the hydrogeological model of water flow through the unsaturated zone (De Marsily, 1981) a simplified model for estimation of expected variations in the MRS signal caused by variations of the water content in the subsurface has been build. Two mechanisms that may cause variations of the water content in the unsaturated zone are considered: infiltration after rainfalls and variations of the water level (Figure 3). Modeling consists of computing the MRS response considering a water distribution given by the hydrological model and inversion of MRS theoretical signals.

As a parameter for MRS monitoring of water amount in the unsaturated zone, the MRS water volume was used. It is defined as $V_{MRS} = \int_{\Delta z} w(z)dz$, where $w(z)$ is the MRS water content, and Δz is an investigated thickness. Physically MRS water volume corresponds to a volume of water per surface unit within the interval Δz. For the models given by Figure 3, modeling results are presented in Figure 4. The error bars represent experimentally estimated accuracy of commercially available NUMIS system (Girard et al., 2003). One can see that taking into account experimental errors, only large changes in the subsurface can be reliably detected. For example, if the water level changes less than a few meters, then this variation cannot be detected.

EXPERIMENTAL STUDY

Modeling results were compared with a one-year-long monitoring of a chalk aquifer in the Somme region of France. At this site, the static water level is at about 30 m. For all measurements NUMIS^{plus} system and the 37-m-side eight-shape loop were used.

MRS results and water level variations measured in borehole are presented in Figure 5. During the observation period the water level change was four meters. Corresponding MRS water volume was measured from 0.9 to 1.5 m^3/m^2 what makes 0.6 m^3/m^2 variation around a year. If we compare these observations with the modeling results (Figure 4a), then we find that the expected variation is from 1.9 to 2.4 m^3/m^2 (0.5 m^3/m^2). Taking into account that for computing MRS signal the relaxation during the pulse was neglected, and the observed variations in the signal are close to the threshold of the instrument we consider this experience as encouraging. However, an important difference in shape of MRS water volume and water level graphics was observed. While after 21 January both graphics are in an agreement, a disagreement is observed before. It can be explained by accumulation of rain water in the unsaturated zone before causing changes in the water level. However, this hypothesis requires of serious instrumental verification.

CONCLUSIONS

Modeling results show that in the unsaturated zone composed of chalk and limestone, MRS can be a useful tool for monitoring of variation in the water content.

However, commercially available NUMIS^{plus} system is able to detect only large changes of the water content. For really efficient application of MRS to measurement of the water content in the unsaturated zone, accuracy of MRS equipment should be improved by a factor of 5 to 10 (<1% errors).

REFERENCES

De Marsily, G., (1981). Hydrologie quantitative. *Masson*. Paris. 215p.

Girard, J.-F., Legchenko, A., Boucher, M. (2003). Stability of MRS measurements and estimation of the data quality. In proceedings of the *2nd International Workshop on the Magnetic Resonance Sounding method applied to non-invasive groundwater investigations*, November 2003, Orleans, France, accepted.

Legchenko, A., Baltassat, J.-M., Beauce, A., Bernard, J., (2002). Nuclear resonance as a geophysical tool for hydrogeologists. *Journal of Applied Geophysics*. 50 : pp. 21-46.

Weng, P., Amraoui, N., Noyer, M.L. (2002). Projet Crue : transferts d'eau dans la zone non saturée crayeuse, éléments de réflexion pour la mise place d'un site expérimental. *Rapport BRGM RP-52009-FR*. 28 pages.

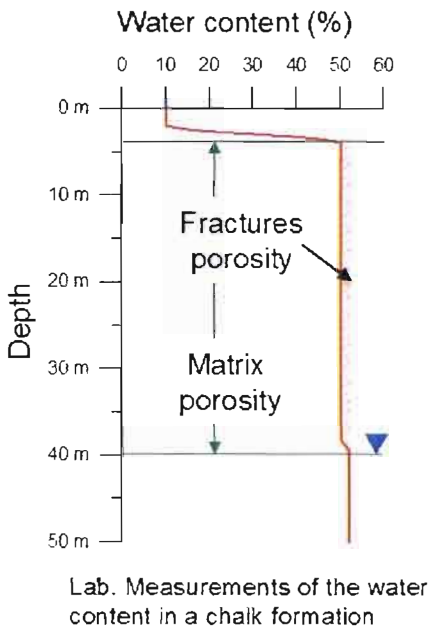

Figure 1. Water content in a chalk formation.

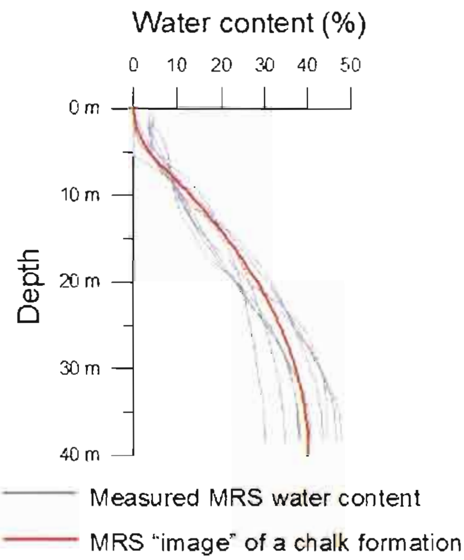

Figure 2. MRS image of a chalk formation.

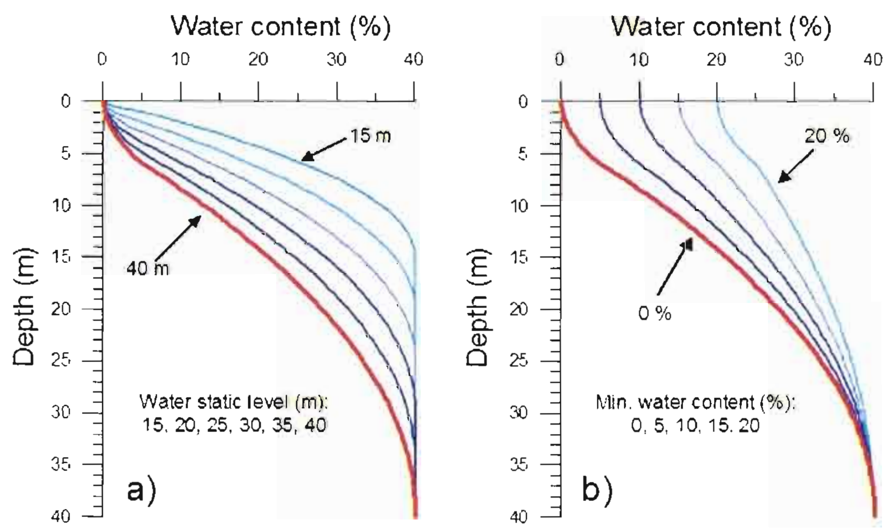

Figure 3. Modeling of MRS water content in a chalk formation.

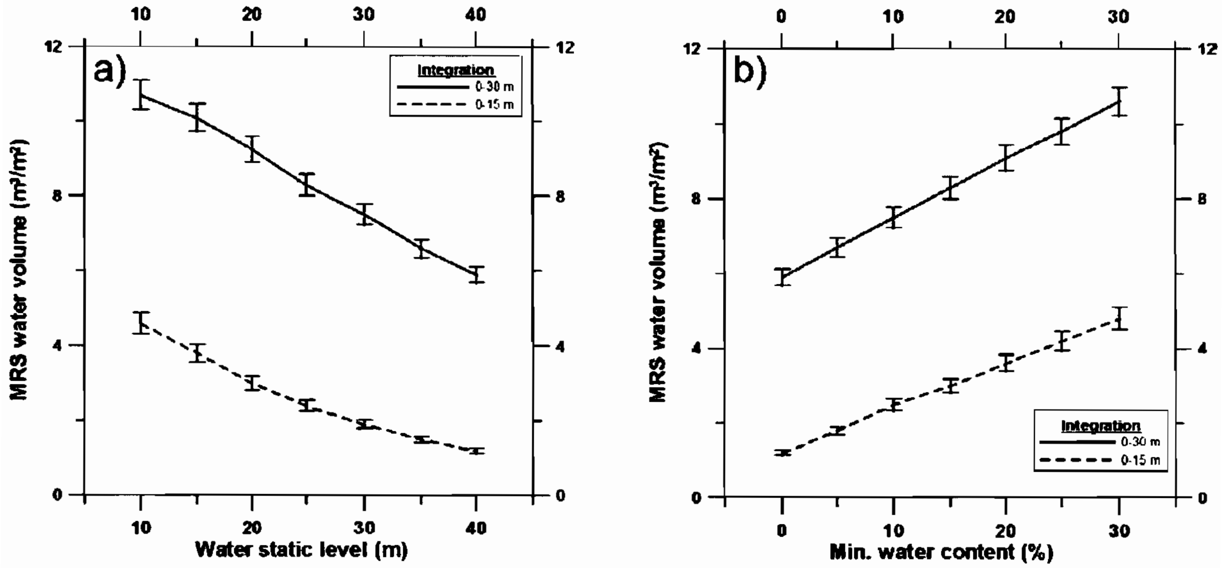

Figure 4. Modeled MRS water volume in a chalk formation.

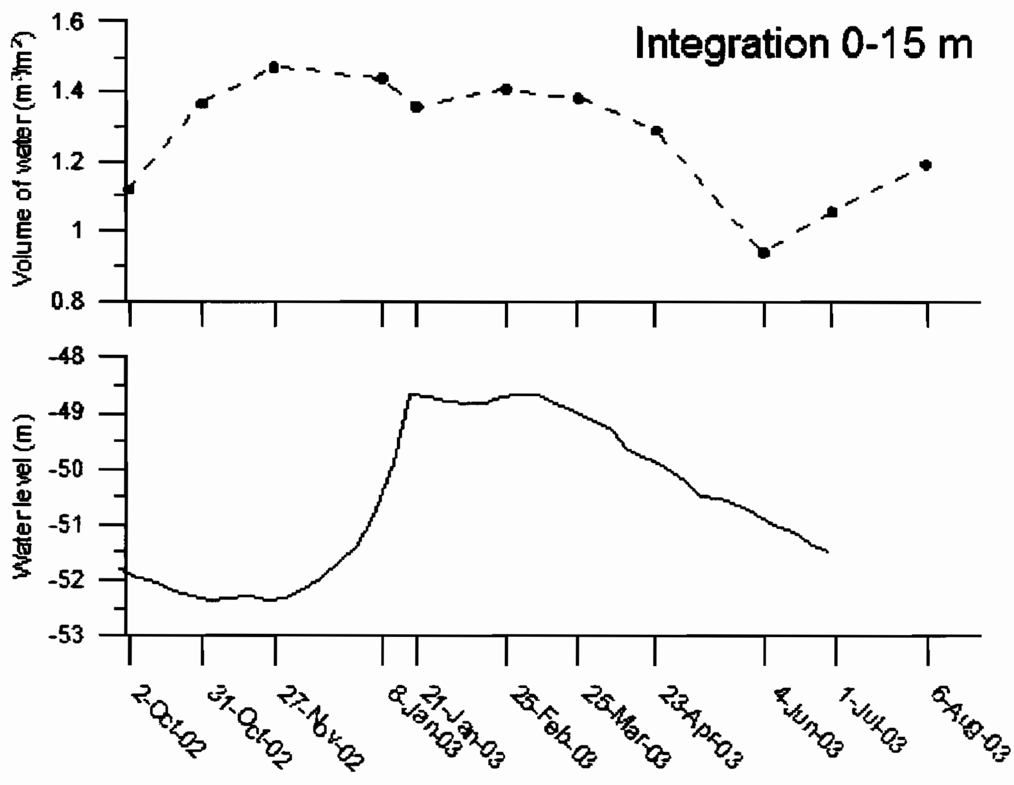

Figure 5. Experimentally observed MRS water volume in a chalk formation (France).

MRS

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