MAGNETIC RESONANCE SOUNDINGS APPLIED TO LOCALIZATION OF SATURATED KARST AQUIFERS

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INTRODUCTION

The main advantage of the Magnetic Resonance Sounding method (MRS), compared with other geophysical tools for water prospecting is that the MRS is sensitive only to subsurface water. Inversion of MRS field data reveals the water content $w(\mathbf{r})$ and the relaxation time $T_1(\mathbf{r})$ with $\mathbf{r} = r(x, y, z)$ being the coordinate vector (Legchenko, and Shushakov, 1998; Legchenko, et al., 2002). In a porous medium the relaxation time T_1 is proportional to the mean pore size $1/T_1 \sim S/V$ (Kenyon, et al., 1997), where S and V are the surface and volume of pores respectively. Usually MRS is applied to characterization of continuous aquifers. However it can be also a tool for localization of saturated karst aquifers.

MRS AS A SATURATED KARST DETECTOR

Schematically a karst system can be presented as it is shown in Figure 1 (Mangin, 1975). A correspondence between MRS response and schematic karts zones is presented in Figure 2. Consequently, for aquifer karst localization two estimators can be used:

$$k_x(z) = \frac{w_x(z)T_{1x}^2(z)}{w_r(z)T_{1r}^2(z)}, \qquad T_x = \frac{\int_z w_x(z)T_{1x}^2(z)dz}{\int_z w_r(z)T_{1r}^2(z)dz},$$

where x and r are two of N MRS stations $(1,..,x,..,r,..N)$. The reference station r is often (but not necessary) selected so that $\{\, k_{x\max}(z) \le 1 \,\}$ or $\{\, T_{x\max} \le 1 \,\}$ for all soundings $(x = 1,..,N)$. In fact, the estimators k_x (K-estimator) and T_x (T-estimator) are normalized MRS permeability and transmissivity of aquifers. Water in saturated dissolution figures (i.e. conduit and cave) is usually characterized by a strong increase in both K and T estimators in comparison with unsaturated and epikarstic zones (Figure 3).

Using $T_1 > 400ms$ criterion for dissolution figures identification, the capability of MRS to detect water in function of its depth and volume was investigated (Figure 4). Modeling results show that water in saturated dissolution figures can be easily identified at shallow depth. For deeper investigation, larger volume of water is necessary : 100 m^3 of water is detectable at 5 m deep whereas 250 m^3 is needed at 15m.

FIELD EXAMPLE

MRS tests have been carried out over a well-known karst system near Montpellier (France) (Vouillamoz, et al., 2003). A profile of several soundings crosses a saturated karst conduit (Figure 5). To improve the signal to noise ratio the eight-shape loop was used (Trushkin, et al., 1994). The investigated volume can thus be approximated by a parallelepiped of 120x50x50 m. It is an obvious limitation of 1D technique applied to investigation of 2D/3D target.

Using the T-estimator, MRS map was build (Figure 5). It shows clearly a high-transmissivity channel that fits well the known conduit. For more detailed investigation, a cross section was drawn using the K-estimator (Figure 5). The location of the saturated conduit is underlines by an increase of the K-estimator, and the water bearing epikarst is also identified (stations 11, 12); it is probably drained in the northern part of the section (stations 9, 10).

CONCLUSIONS

The MRS is a useful tool which could take place in the hydrogeologist toolbox : it could estimate the spatial variations of permeability and transmissivity which underline karstic structures bearing water (as the epikarst, conduits and caves). The permeability and transmissivity estimators are calculated from magnetic resonance signal sent out by the hydrogen atom of water molecule : it causes the main advantage of MRS, i.e. to measure a signal induced exclusively by groundwater. But it leads also the main limit of the MRS, i.e. the groundwater quantity has to be enough to send out a signal which can be measured. Using Figure 4, it becomes possible to estimate if the targeted karst anomaly could be detected by MRS.

One should also keep in mind that the geometry of the 3D structures could only be approached with 1D soundings.

For low magnetic signals, i.e. small or deep amount of water, the measurement duration of a MRS could reach up to 20 hours : in karstic environment, an average of 1 sounding per day should be planed.

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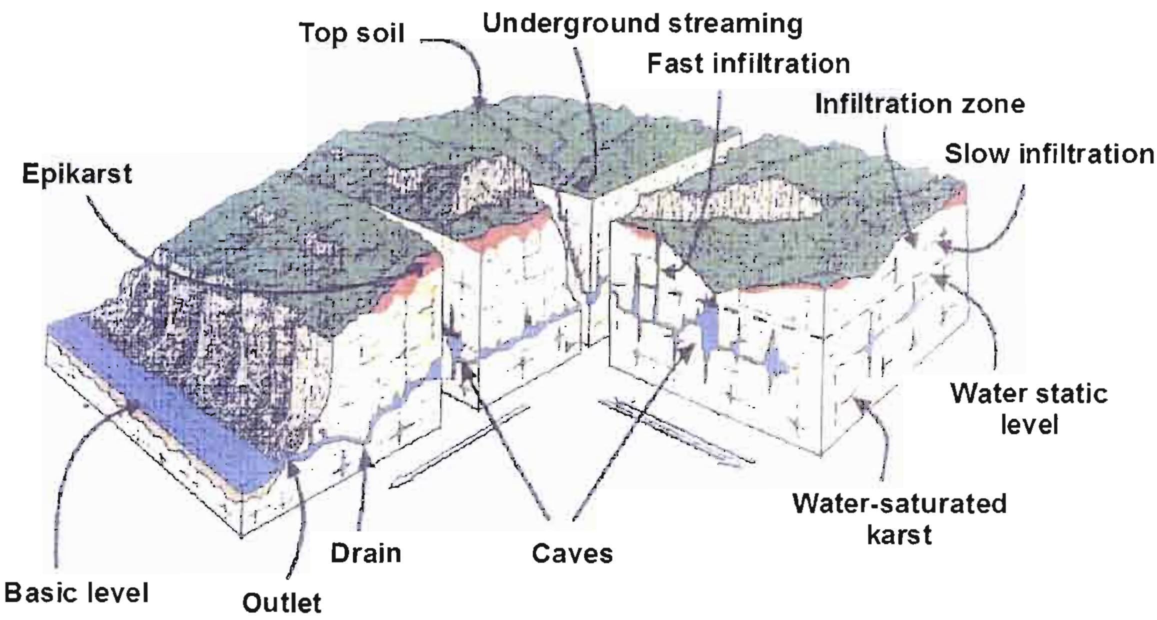

Figure 1. Schematic presentation of a karst system (Mangin, 1975).

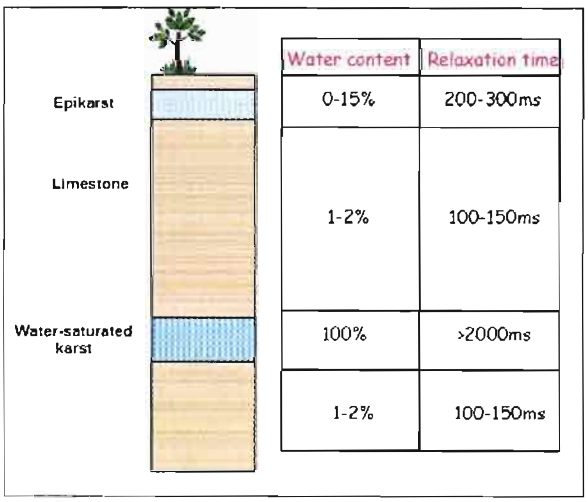

Figure 2. MRS response from a karst system.

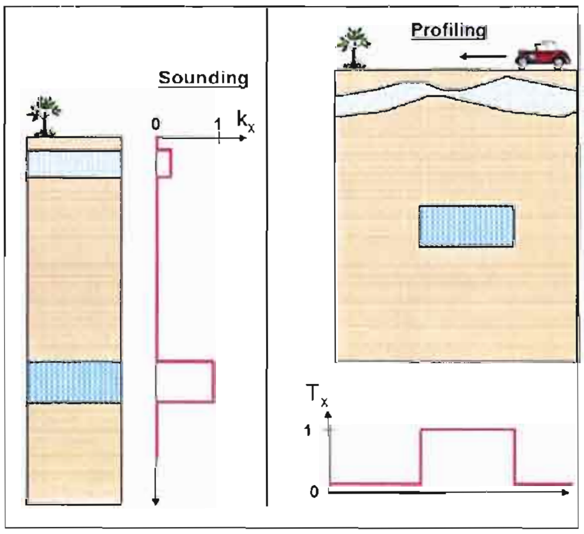

Figure 3. MRS application scheme.

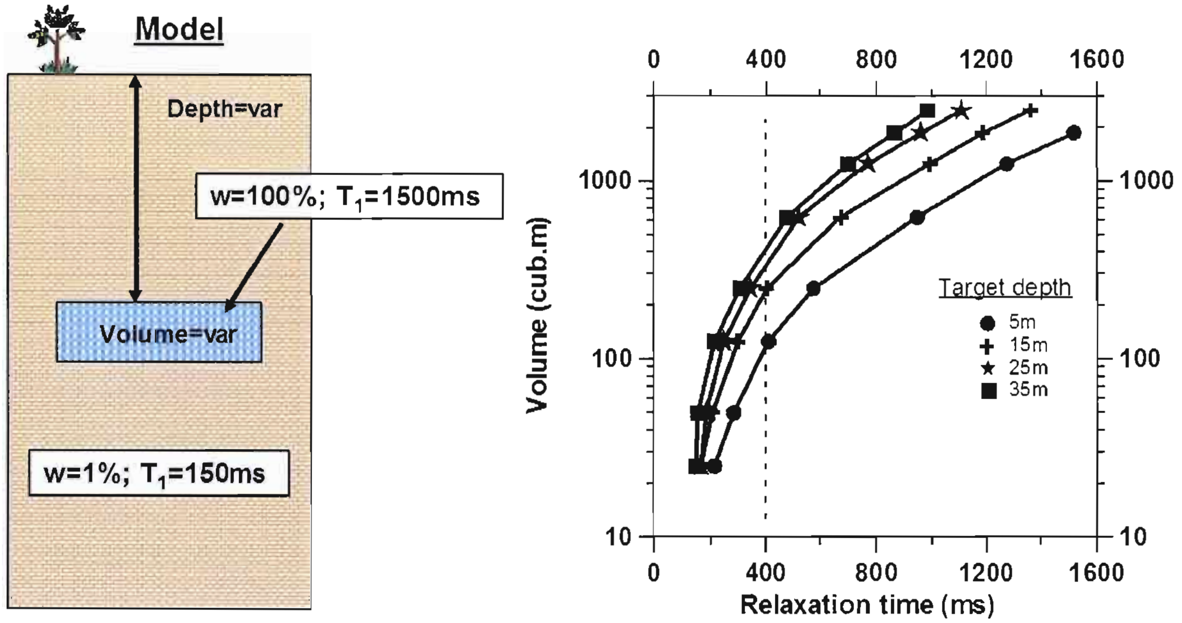

Figure 4. Modeling of MRS relaxation time from water-saturated karst.

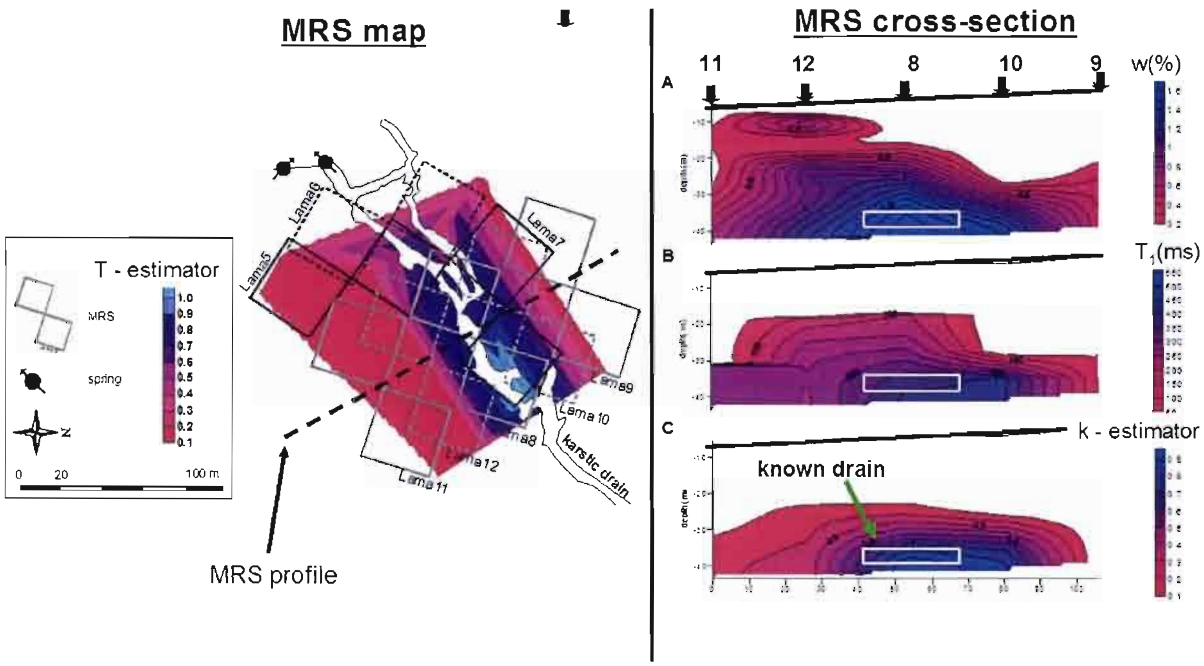

Figure 5. Example of MRS application to karst localization (Lamalou, France).

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