MAGNETIC RESONANCE SOUNDING: APPLICATION TO THE CHARACTERIZATION OF THE CRYSTALLINE BASEMENT AQUIFERS OF BURKINA FASO

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INTRODUCTION

Basement aquifers are of particular importance in tropical regions both because of their widespread and accessibility and because there is often no readily available alternative source of water supply. Even in more humid regions, water quality considerations can favour their use (Wright, 1992).

Basement aquifers are developed within the weathered overburden and fractured bedrock of crystalline rocks which are mainly of Precambrian age. The usual conceptual model of the basement aquifer describes several zones in the lithological sequence. The alterites (regholith) consist in weathered and decayed rock; their permeabilities vary in accordance with lithology but is usually low; they play the major part of storativity in aquifer functioning. The underlying weathered-fissured zone (saprock) and the fractured bedrock present typically low storativity, but permeability commonly increases at lower levels due to a lesser development of secondary clay minerals and a high permeability of open fractures (Lachassagne, 2001).

There are a number of important constraints to development of basement aquifers. The failure rate of low yield boreholes for rural water supply is high in the drier regions (typically in the range of 40 to 50 %), and the implementation of high yield boreholes for urban or irrigation purposes is always a challenge for hydrogeologists. Furthermore, the low storativity of basement aquifers often leads to unsustainable yield of boreholes.

Therefore, there is an important need both to improve the current methodology for high yield borehole implementation and to evaluate more precisely the overall resources and aquifer occurrence to assist development efficiency and long-term sustained control.

In this paper, the contribution of Magnetic Resonance Sounding (MRS) to the characterisation of basement aquifers in Burkina Faso is presented.

BACKGROUND

Basement aquifers are of significant extent in Burkina Faso territory (around 80% of the total country surface area). To measure the contribution of MRS method to characterise these aquifers, a survey was conducted from November 2002 to January 2003 in granite and associated rocks of Precambrian age.

MRS were implemented around recent boreholes drilled both in the alterites, in the weathered-fissured zone and in fractured bedrock. All of the 13 boreholes were tested with step-test pumping tests (total pumping duration of 4 hours), and 6 of them were used to conduct aquifer tests (pumping duration of 72 hours). The aquifers local transmissivities were calculated from the recovery period of step-tests, and the storativities were calculated from piezometers records with Theis and Jacob methods (Kruseman, 2000). The geometry of the aquifers was deducted from boreholes reports and the water static level (WSL) was measured while implementing the MRS. The Numis^{Plus} ® equipment was used to set up the MRS with a square loop of a typical 150 meters side. The adapted saturation recovery method was used to measure the longitudinal relaxation time (Legchenko et al., in press) and the storativity and transmissivity of the aquifers were estimated from MRS as (Vouillamoz, 2003) :

$$S_{MRS} = 4{,}3 \cdot 10^{-3} \cdot (w \cdot \Delta z)$$
$$T_{MRS} = 3 \cdot 10^{-7} \cdot \left(S_{MRS} \cdot \left(T_1^*\right)^2\right) \qquad (1)$$

where S_{MRS} is the MRS storage coefficient, T_{MRS} is the MRS transmissivity (m²/s), w and Δz are respectively the MRS water content (%) and saturated thickness (m), and T_1^* is the observed longitudinal relaxation time.

MAIN RESULTS

Field results obtained in Burkina Faso show that the reservoir type could be estimated from MRS data. The Table 1 indicates that the average value of water content is higher and the average value of longitudinal relaxation time shorter for water in alterite reservoirs than for water in fissured-fractured reservoirs. According to equations (1), it means that the storativity is higher and the transmissivity is less for the alterites than for the fissured-fractured zones, which is in accordance with the typical hydrogeological conceptual model. However, the values margins are large and ambiguity still remains when interpreting the MRS data alone.

Table 1 : MRS parameter and reservoirs type.

Reservoir	Water content (%)			T^*_1 (ms)		
	Max.	Average	Min.	Max.	Average	Min.
Alterites	6	3	1	600	400	180
Fissured-fractured bedrock	2,5	1	0,2	1500	650	350

The reservoir geometry is described by MRS in 1D with an average difference with boreholes data of +/ 12% for the depth to the top of the saturated reservoir, and +/- 17% for the depth to the fresh bedrock (Figure 1).

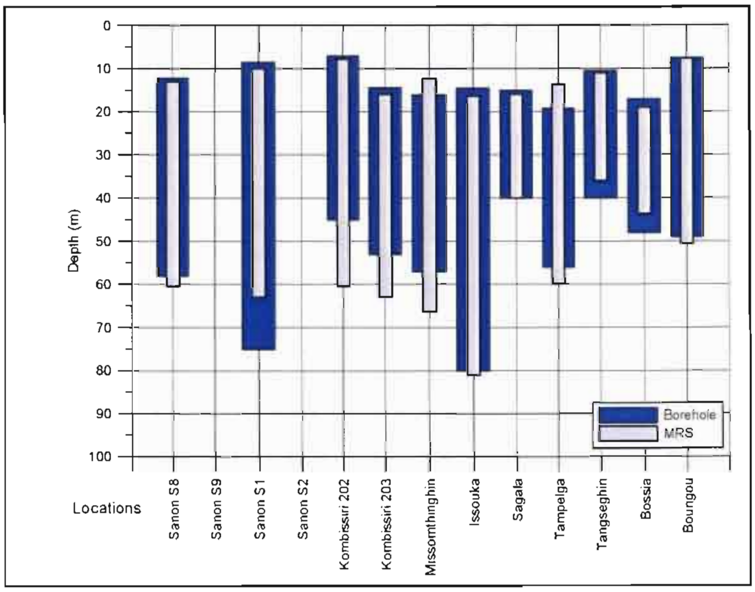

Figure 1 : geometry 1D of the aquifers.

The aquifer hydraulic properties were estimated after a calibration process, according to equation (1). The average difference with properties calculated from pumping tests data are respectively +/- 80% for the storativity (Figure 2) and +/- 41% for the local transmissivity (Figure 3).

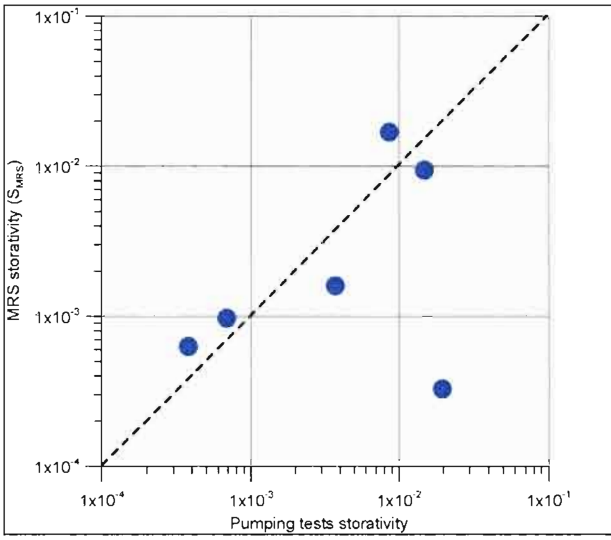

Figure 2 : aquifers storativity.

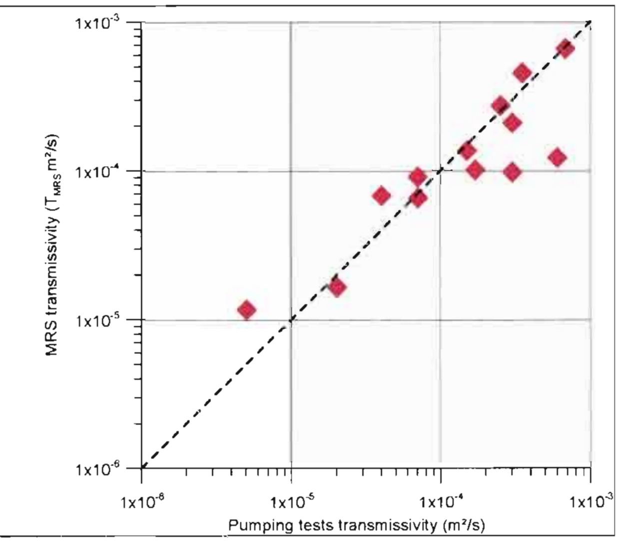

Figure 3 : aquifers local transmissivity.

The main limitations of MRS in such geological contexts are (1) the duration of data acquisition which ranges between 6 and 20 hours due to the low signal to noise ratio, (2) the 1D measurement which does not allow to describe the reservoir structure over a scale corresponding to the loop size, and (3) the loss of resolution with depth which does not allow to measure small signal coming from depth productive fractures (Figure 4).

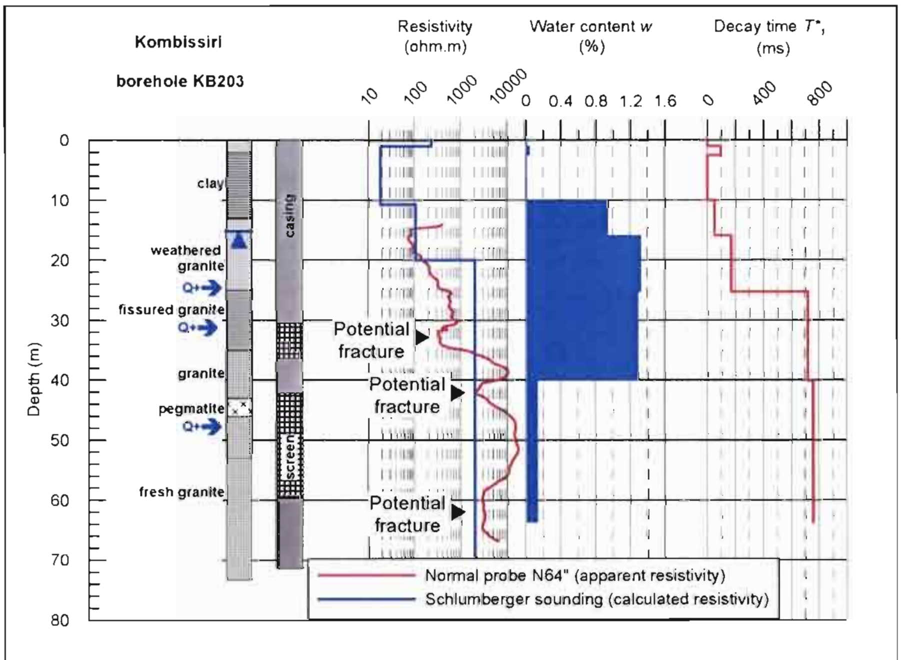

Figure 4 : MRS loss of resolution with depth : the deepest fracture zone is not identified by the MRS.

However, the characterisation of aquifer is improved if the MRS is jointly interpreted with electrical resistivity methods. When the MRS resolution is not sufficient in depth, the 1D electrical soundings is often able to precise the depth of the substratum. In heterogeneous contexts, the 2D electrical imaging can underline the structures of the aquifers.

With the available data, the type of reservoir is well estimated when it is jointly characterised with its electrical resistivity and its MRS transmissivity (Figure 5).

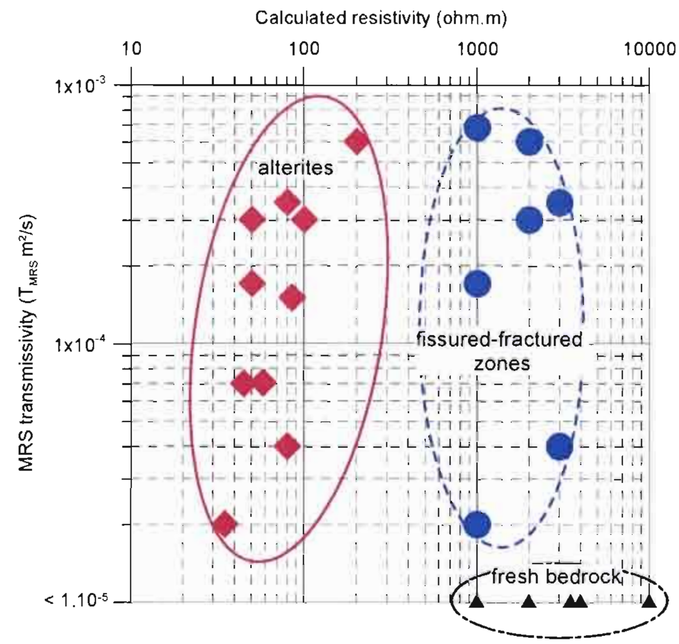

Figure 5 : type of reservoir defined with both electrical resistivity and MRS transmissivity.

CONCLUSION

The main conclusions of the comparison between the MRS results and the borehole data are : 1) the geometry of the weathered part of the aquifer is well describe by the MRS, 2) the storativity and the transmissivity can be reasonably estimated from MRS data after calibration, 3) the main MRS limitations are the 1D approximation in high heterogeneous contexts and the loss of resolution when looking for deep narrow fractures, 4) MRS is a useful tool to characterize aquifer in crystalline context. Its joint use with 1D electrical sounding and 2D resistivity imagery is promising to support hydrogeologists for both borehole implementation and reserve evaluation.

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