STUDY OF THE MAGNETIC RESONANCE SOUNDING (MRS) TECHNIQUE IN GROUNDWATER INVESTIGATION

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ABSTRACT

Ground water investigation carried out with traditional methods usually leads to good qualitative success, even if an evaluation of the quantity of water present into the ground is not possible due to the indirect relation between the physical parameter measured and the water. However, in the last decade, a new technique based on the Magnetic Resonance phenomenon has been developed in routine applications for direct detection of the presence of water from surface measurements through the excitation of the hydrogen protons of the water molecules. The advantage of magnetic resonance sounding (MRS) as compared to other classical geophysical methods is in its water selective approach and reduced ambiguity in determination of subsurface free water content and hydraulic properties of the media due to the nuclear magnetic resonance (NMR) principle applied. This technique is based on proton Magnetometry, where the hydrogen protons located in the sensor casing are activated to determine their precession frequency, hence the magnitude of the Earth magnetic field. The hydrogen protons of the underground water molecules are activated to characterize the water layer. The main applications of this technique concern the determination of water level and total quantity of water available in the depth. A loop laid on the surface of the ground is used for both transmitting the excitation pulse and measuring the response of the H proton. The linear relation between the measured signal and layer porosity allow interpreting the 1D sounding. A set of field data of various places points out both the advantages and the limitations of this technique.

Keywords: *Magneto Resonance Sounding, Nuclear magnetic resonance, Permittivity, porosity, permeability, ground water*

INTRODUCTION

The Proton Nuclear Magnetic Resonance method, also called the Magnetic Resonance Sounding method (MRS), after having been a research tool during a long maturation period, is in the way of being more and more applied in the groundwater surveys for complementing the traditional geophysical methods. Its capacity to give quantitative information for characterizing the water layers such as depth and thickness, porosity, permeability after calibration, give it a special place in the range of geophysical tool for hydro geologists.

Magnetic resonance sounding is a recently developed technique for hydro geophysical exploration. The very first soundings were carried out between 1979 and 1981. While the efficiency of the MRS applied to ground water related studies is already proven, many technical details are under development. A new generation of hardware and continuing progress with software are expected to improve accuracy of this technique.

Because of the low levels of the signals which are measured in Magnetic Resonance field surveys, to make the method efficient, one must take special care of the accuracy of the Larmor frequency used in relation with the local Earth Magnetic field and of the filtering of the natural and industrial electromagnetic noises. This study will report on the advantages and the limitations of this technique.

RESEARCH ELABORATIONS

PRINCIPLE OF THE MRS TECHNIQUE

Hydrogen atoms of water molecules (or H-proton) are energized by pulses of alternative current at the proper frequency (i.e. Larmor frequency), transmitted into a loop laid on the ground. The magnetic field they produce in return is measured and analyzed for various energizing pulse moments. The interpretation of measurements permits to estimate the water content and the mean pore size (i.e. hydraulic conductivity or Permeability = (yield/section)/Pressure gradient, expressed in ms^{-1}) of each layer at depth. These parameters are useful to determine the prospects of a groundwater reservoir before drilling. Figure (1) represents the basic principle of the MRS technique.

Three magnetic fields have to be considered in figure: 1:

a. The Earth magnetic field, the amplitude B of which determines the precession frequency f of the hydrogen protons: f (Hz) = 0.04258 B (in nT)
b. The excitation magnetic field produced by a current put into a loop laid on the surface of the ground at this precession frequency

c. The relaxation magnetic field produced in return by the protons after they have been excited by the previous field measured within the same loop.

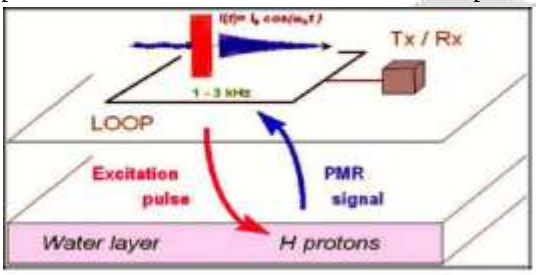

Figure: 1 basic principle of MRS technique.

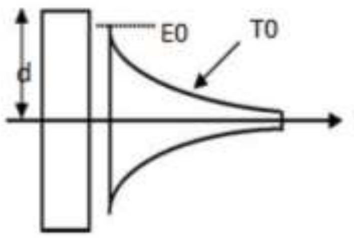

Figure: 2 MRS curves, Where,
E_0: initial amplitude of signal (in nV),
T_0: Decay constant of signal (in ms),
d: Investigation depth (in m)

METHODOLOGY

In this method, it is first necessary to compute a matrix giving the theoretical response of thin water layers located at various depths and prepare a set of field data. This matrix will take into account the general configuration of the measurements such as loop dimension, Earth's field inclination, ground resistivity, the computation of this matrix may usually takes about an hour on a PC but the results will be valid for all the soundings of a given survey. Then the inversion itself of one set of data will take only a few seconds, the results can thus be available in the field before moving the equipment to the next site. The inversion procedure is fully automatic, no initial model is required. The operator has the possibility to manually change the value of the regularization parameter for smoothing or enhancing the variations of the water content with depth according to the local context.

The MRS theory states that, for a given loop size, the investigation depth of a measurement varies with the moment of the excitation pulse (product of the intensity of current at the resonance frequency by the duration of the pulse). It is therefore possible to sound the ground with MRS surface measurements. For interpreting a MRS sounding, it is assumed that the underground is stratified at the scale of the loop dimensions. The inversion gives values of the water content, estimations of permeability, and the depth of each layer, after processing of the raw data for the whole set of pulse moments. The porosity is one of the tool to estimate the under water level (or under vadose zone); it is the ratio between the volume of the pores and that of the rock. By measuring the transmitted current into the loop, and measure the initial amplitude of the response of the protons, the porosity of the formation at depth can be evaluated, it is expressed in %.

After the excitation field is turned off, the protons lose their magnetic energy progressively, at a rhythm which depends on their mean free displacement. This is the reason why when pores have a small size, the time constant of decay in short, while when the pores have large dimensions this time is longer. The time constant of decay is thus linked to the permeability of the rocks. The complete empirical formula for the permeability from Magnetic Resonance data is given by,

Estimated permeability = coefficient × porosity × (time constant)^2

In the same way, the transmissivity is also written as,

Estimated transmissivity = coefficient × porosity × thickness × (time constant)^2

The product of the porosity by the thickness represents the total quantity of water available. The coefficient can be determined after a calibration with results of pumping test in the respective area. Figure (3) & (4) represents the typical response of aquifer layers and curves respectively.

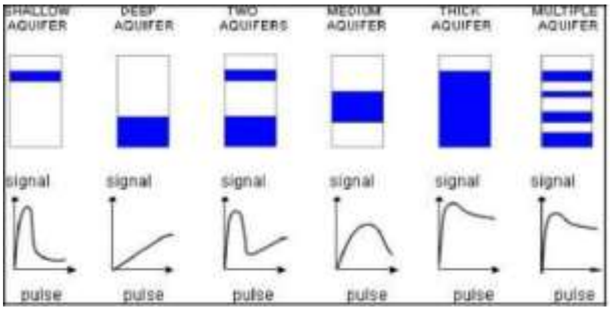

Figure: 3 typical responses of aquifer layers

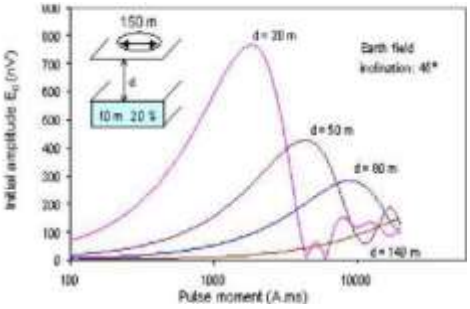

Figure: 4 Theoretical Magnetic Resonance Sounding curves for a 10m thick aquifer layer having 20% water, at 20, 50, 80 and

FIELD EXAMPLES

A set of MRS data have been collected in various geological contexts (sand, chalk, limestone, altered granite) where the results of pumping tests were available, in order to compare the hydrogeological parameters obtained in both cases (Legchenko *et al*., 2002). In a sandy area where the water is very fresh (with a conductivity of about 100µS/cm), the DC electrical soundings do not permit to distinguish wet sands from dry sands inter-bedded between clayey formations. Figure 5 shows a neat response of the Magnetic Resonance Sounding curve over a 40m depth, at least 50m thick aquifer layer having of the order of 20% of free water. The complete sounding has been carried out in 45 minutes. The method has been used to map the extension of the aquifer zone for the evaluation of the whole water resource of the area. In granitic areas, it is often the altered part of the granite which contains most of the water. South of Hyderabad, a survey has been carried out to locate the places where there was more water. Figure 5 displays a MRS curve which points out a 3% water layer, 10m thick, at 3m depth. The initial amplitudes measured did not exceed 35nV, which implied a stacking of two and a half hours to counter balance the EM noise due to power lines.

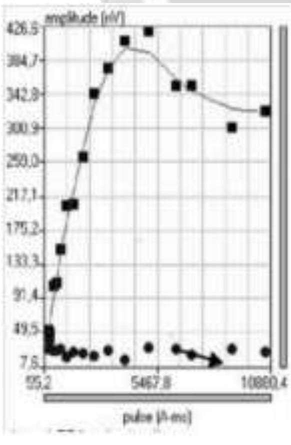

Figure: 5a. MRS data in a Sandy area at West Africa Showing a thick aquifer layer, 40m deep (PHY Company data, loop size: 100 x 100m)

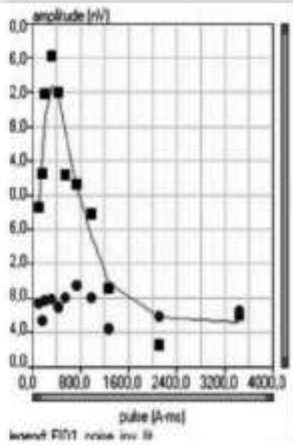

Figure: 5b. MRS data in India on altered granite (BRGM data)

CONDITIONS OF APPLICABILITY

The experiments and surveys carried out up to now in various geological backgrounds permit to identify the conditions where the Magnetic Resonance Sounding method has the best chance of success:

1. The water layer to investigate has to be located in the first 100 to 150m. This depth can be decreased if the ground is conductive.

2. There should not be magnetic material around or within the aquifer layer, since in such a case the Earth magnetic field is usually non homogeneous which prevents the hydrogen protons to have the same excitation frequency

3. The electromagnetic noise should be as low as possible: the amplitudes of the MR signals are very low and power lines, pumps, fences, pipes and magnetic storms sometimes create difficult situations not allowing getting good readings.

CONCLUSIONS

Both theoretical and experimental developments show interesting opportunities for the Magnetic Resonance Sounding technique in groundwater investigations. The ability of directly detecting the presence of water gives the
possibility to quantify the resource both in terms of porosity as well as permeability before deciding if a borehole has to be drilled or not, for optimizing the survey costs. The integration of this technique with the conventional indirect methods has to be examined on a case to case basis according to the capabilities of each one of the methods.

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