Combination of electrical resistivity and magnetic resonance sounding data for mapping an aquifer layer in Mauritania

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Summary

Within the framework of a groundwater survey for camel breeding purposes, electrical resistivity soundings have been carried out for delineating the depth and the lateral extension of an aquifer layer in the Dhar Nema area located in the South-East part of Mauritania. The geology basically consists in sand and sandstones, with clay occurrences. In the middle part of the aquifer, the DC resistivity soundings could point out the presence of water. However, in the edge parts, they could not clearly make the difference between dry rocks and fresh water aquifer layers.

On the contrary, the magnetic resonance soundings could identify the presence of water at depths of 60 to more than 100m, and gave estimations of the values of the porosity and of the permeability. The low EM noise levels and the significant quantity of water existing into the ground explain the good quality of the data. As a whole, more than 60 MRS soundings have been carried out in the area of approximately 150 x 100 km, and permitted to delineate the limits of the aquifer layer.

The first drill-hole confirms the depths determined with the magnetic resonance soundings. A campaign of new drill-holes with pumping tests is planed to ascertain the groundwater resources of this area.

Introduction

The Dhar Nema area is a 35 000 km² desert plateau located in the South East of Mauritania, slightly tilting towards the East. Its West limit close to the city of Néma consists in a 150m height cliff. The geology includes four differentiated layers, from bottom to top:

-Palaeozoic fractured shales with dolerites, which have a poor groundwater potential (Hodh series). - Mesozoic impermeable clay formations (Néma series) - Mesozoic continental sandstones which form the main continuous aquifer layer (Dhar series) -Cenozoic sand dunes covering the main part of the area with some occurrences of clay

The contact between the clay and the sandstones is a paleo-topography and includes faults. Thus, the water cannot be found everywhere, but only at places where the sandstones are located under the piezometric level. In particular, the sandstones of the West part of the area are dry due to the East dipping topography (Figure 1).

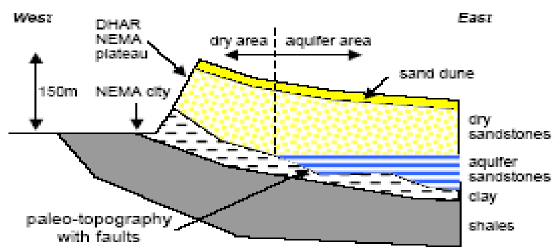

Figure 1: Simplified geological cross section the Dhar Néma area (South-East of Mauritania)

The average rain fall is of the order of 200mm per year and no surface water is available; the fractured shales can only provide a few m3/h yields during short periods. This is the reason why the sandstones represent the main resource for developing the water supply for cattle breeding (camels, sheeps, …) and for domestic needs of small towns. The delineation of the aquifer part of these sandstones has been the goal of a geophysical survey with electrical resistivity and magnetic resonance soundings, planned to fill the gap between satellite image analysis and drill hole campaigns.

Electrical resistivity soundings

A set of 250 Schlumberger resistivity soundings has been carried out with an AB transmitting line of 1000 to 2000m, and with one sounding every 0.5 - 1 km. On the whole studied area, these soundings permitted to clearly identify the depth of the shales (bottom of the sandstones), thanks to the low resistivity of this basement (Figure 2).

From the inversion results, the following approximate values of resistivity can be given to the various layers:

- clay and shales: 20 to 500 ohm.m -wet sandstones: 300 to 4 000 ohm.m - dry sands and sandstones: 3 000 to 10 000 ohm.m -quartzites: 20 000 ohm.m

In the central part of the aquifer layer (50% of the data), the Schlumberger soundings also permitted to check if the sandstones had water or not. However, in the West part of the aquifer, it has been much more difficult to determine the presence or the lack of water, the difference between curves becoming insignificant.

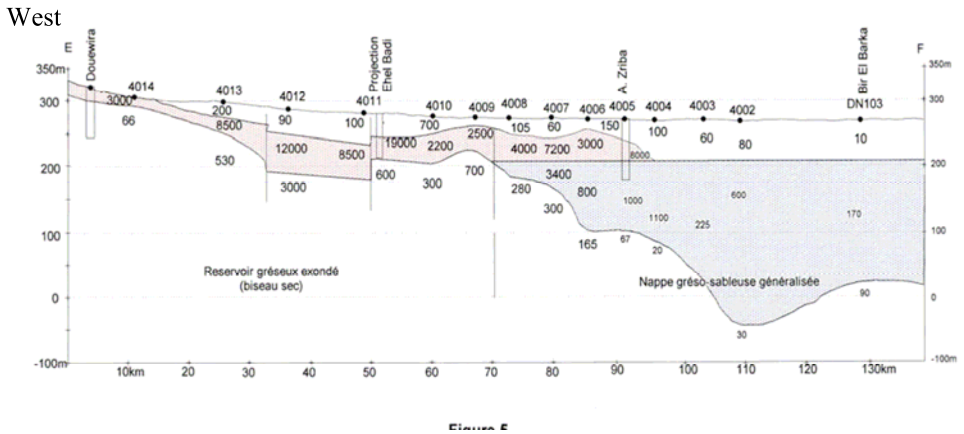

Figure 2: Interpreted resistivity section from Schlumberger soundings, in the Dhar Nema area

As a matter of fact, the water being only little salty (more than 50% of the samples taken in existing wells have a conductivity lower than 200 microS/cm, corresponding to a resistivity greater than 50 ohm.m, see Figure 3), the apparent resistivity sounding curve is not so much influenced by the presence of water when the potential aquifer layer is not very thick, as shown in Figure 4.

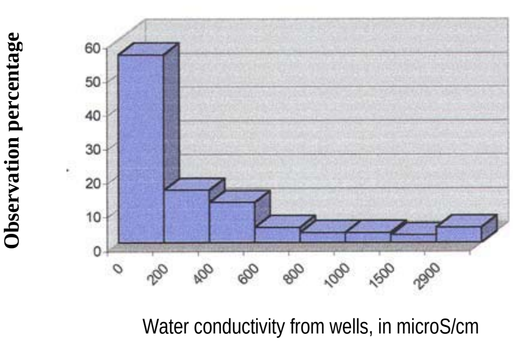

Figure 3: Statistical data of water conductivity from existing wells, Dhar Néma area

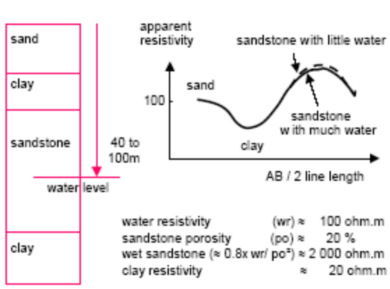

Figure 4: Schlumberger typical sounding curves close to the dry / wet wedge of the Dhar Nema plateau

To better delineate the aquifer area in its West part, the magnetic resonance sounding method (MRS) has been used, based on a direct detection principle

Magnetic resonance sounding principles

Initiated by the ICKC Institute in Russia (Semenov, 1987), the methodological developments of the magnetic resonance sounding method have been continued at BRGM in France (Letgchenko et al., 1995; Valla, 2002), Berlin Technical University in Germany (Yaramanci et al., 1999) and ITC in The Netherlands (Lubczynski, Roy, 2003), among other groups.

The methods consist in exciting the H protons of the water molecules with a magnetic field at a specific frequency (the Larmor frequency, depending on the amplitude of the Earth field) and in measuring the magnetic field produced in return by these protons.

The same loop is used for transmitting the excitation pulse and for analysing the relaxation signal (Figure 5).

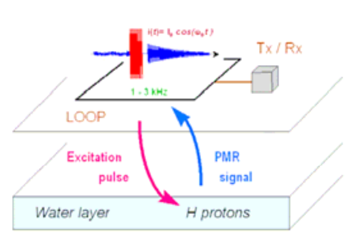

Figure 5: Principle of the magnetic resonance method

The initial amplitude E0 of the relaxation (Figure 6) measured just after the excitation current has been switched off is directly proportional to the number of protons which have been reacting, namely the water content (porosity).

The time constant (T2*) of the relaxation curve is linked to the mean pore size of the material, fine grain sediments giving short decays (a few tens ms) while coarser grain sediments lead to longer decays (a few hundreds ms). The time constant is thus related to the permeability of the layer. By a double excitation pulse technique, it is possible to determine the T1 time constant known as the longitudinal time constant which permits to make a quantitative estimate of the permeability of the aquifer. A proportionality coefficient can be used to calibrate such a relation, after the comparison with the results of pumping tests (Bernard, 2003).

The intensity of the excitation pulse (its moment I.Δt, product of the intensity of the current by the pulse duration) controls the depth of investigation, small pulses for shallow, high pulses for deeper. The size of the loop used on the surface is controlling the maximum depth reachable.

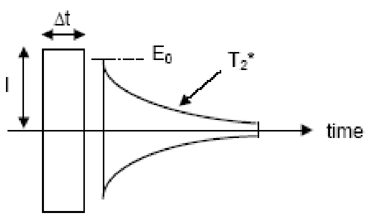

Figure 6. Envelops of the excitation pulse and of the magnetic resonance relaxation signal: I is the intensity of the current, Δt its duration, E0 the initial amplitude of the signal, T2* its time constant

This property of the pulse moment makes it possible to sound the ground at a given position of the transmitting / receiving loop laid on the surface of the ground. A sounding curve represents the variations ot the signal initial amplitude versus the pulse moment, which gives, after inversion, the porosity versus the depth.

The determination of the porosity is submitted to equivalence laws, the invariant parameter being the product of the porosity by the thickness, that is to say the total quantity of water located in a given layer. Figure 7 gives examples of MRS sounding curves for various types of aquifer layers.

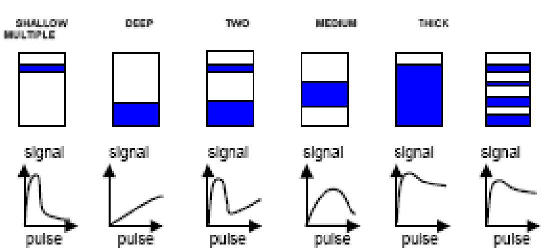

Figure 7: Typical magnetic resonance responses of aquifer layers, for various types of thicknesses and depths.

Magnetic resonance sounding data

This direct water detection MRS method has been used to delineate the sandstone aquifer in the Dhar Néma area (Figure 8).

Figure 8: Field set up of the NUMIS Plus MRS equipment in Mauritania.

A total of 67 soundings have been carried out, using a 100 x 100m loop (Figure 9). The low EM noise observed in this desert zone permitted to obtain good quality data, with signal amplitudes of up to 300 nanovolts, intensities of current of up to 300 A, and pulse duration of 40 ms. The Larmor frequency is of the order of 1 450 Hz.

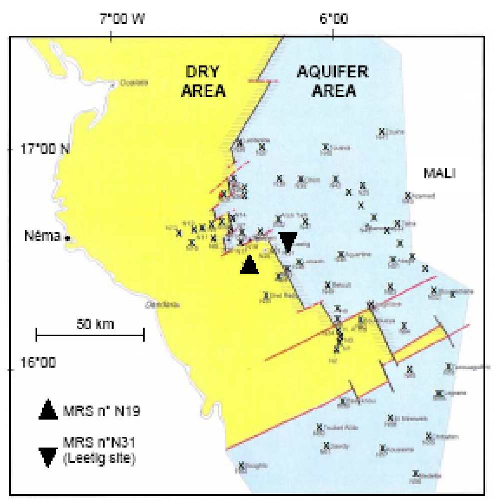

Figure 9: Location map of the 67 MRS soundings of the Dhar Néma area

The raw data and the inversion results of two representative soundings are given in Figure 10: -MRS sounding n° N19, does not show any significant response (amplitude after stacking lower than 30 nV), which suggests that there is no water at this place. - MRS sounding n° N31, where a 300 nV signal amplitude has been measured, which suggests that this site is located inside the aquifer area. Indeed, a borehole carried out at this location found water at 75m depth with a test airlift yield of 14 m3/h, confirms the inversion results of the MRS sounding.

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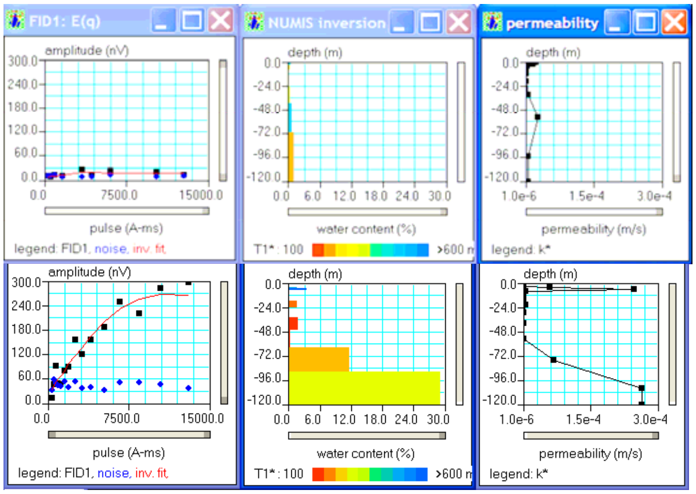
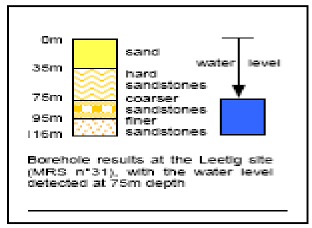


Figure 10: MRS Sounding data and interpretation: on top, MRS n° 19, located in the aquifer area. From left to right: sounding data, interpreted porosity (water content), interpreted permeability (before any calibration).



A statistical analysis (Figure 11) shows that the median value of the interpreted porosity is 20%, which may appear rather high for a fractured sandstone; the median value of the interpreted permeability (before calibration) is of the order of 10-4 m/s, a priori compatible with the type of yield obtained at the MRS n°31 Leetig borehole.

Conclusions

The electrical resistivity soundings permitted to identify the presence of the aquifer in its thicker central part. However they could not determine its western limit.

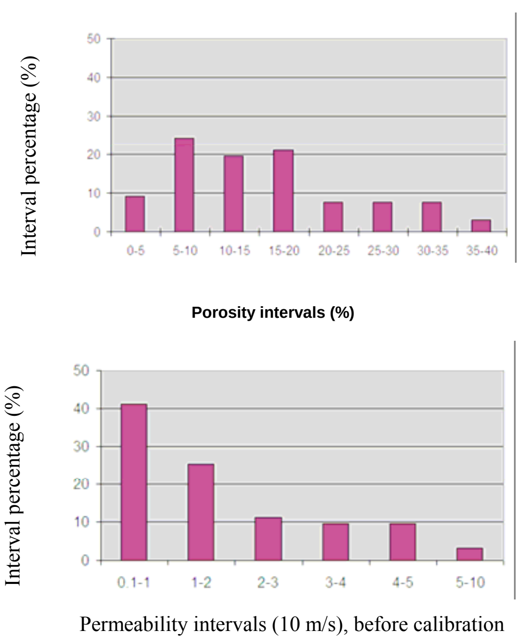


Figure 11: Statistical analysis of the interpreted MRS data

The magnetic resonance soundings shown a clear response from the water, including on the edge of the aquifer part of the sandstones. A first drill hole confirmed the depth found by the MRS sounding (75m). More drill holes will be carried out in a second phase of this project, which will permit, through pumping tests, to calibrate the permeability values interpreted from the MRS soundings

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