Society of Exploration Geophysicists

Expanded Abstracts with Biographies

1995 Technical Program

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The initial amplitude of the NMR signal corresponds to the location and bulk water volume of the aquifers, decay time correlates with the mean grain size of water-saturated rock and phase follows the rock electrical conductivity (Legchenko *et al.*, 1990).

Inversion of the equations (2) and (3) allows determination of water concentration ($n(z)$), mean value of the NMR signal decay time ($T_2^*(z)$) and rock resistivity ($\rho(z)$) as a function of depth.

For inversion, the well-known Tikhonov regularization method was used (Tikhonov and Arsenin, 1977). Antenna impedance data were also taken into account (Trushkin *et al.*, in press).

Data interpretation

The following information about each of the aquifers can be obtained from the NMR signal:

1) water concentration $n(z)$ enables determination of depth, thickness and bulk water volume. Absence of the NMR signal ($E_0(q) = 0$ for any q) guarantees with high reliability the absence of subsurface water.

2) decay time ($T_2^*(z)$) corresponds to the mean grain size of the water-saturated rock. There is an empirical correlation between rock type and decay time for sedimentary rocks (Shirov *et al.*, 1991). There is a general tendency for decay time to be longer for coarser-grained material (up to 700-800 ms for free water in a lake), and shorter for fine-grained material (less than 30 ms in clay).

There is a relationship between the borehole yield in the study area and both water concentration and decay time. The yield may be estimated without any additional data using the NMR method, but borehole pumping test results at one of the sites of the area must be used for a precise determination of its absolute value. Experience gained from long term application of the surface NMR method for water prospecting in Russia indicates that the number of required boreholes can be significantly reduced.

Results and discussion

Field experiments with the 'Hydroscope' instrument were carried out in France in 1992 over well-known aquifers, studied previously, using traditional methods including borehole tests, by BRGM. Where antenna diameter is D, the area investigated using NMR can be approximated to a vertical coaxial cylinder of 2D in the horizontal plane and 1D in the vertical plane.

At the first test area of St-Cyr-en-Val, three aquifers were determined during the BRGM geological study. The upper aquifer consists of a stratum of mixed gravel, sand and clay, approximately 20-25 m thick. The two other aquifers consist of water-saturated karst limestone separated by a sandstone layer at a depth of 50-60 m. The total thickness is about 70-80 m and the average porosity is approximately 10%. Water transmissivity is around 0.28 sq.m/s.

At the Bazancourt test area there is an aquifer made up essentially of cracked chalk but with other material in the top few meters, and with an average porosity of about 40%. The permeability of the chalk mainly depends on its consolidation and the development of fractures. This aquifer is fairly homogeneous and its thickness is approximately 100-120 m. Water transmissivity is about 0.036 sq.m/s.

Amplitude, decay time and phase parameters of the NMR signal were measured. Experimental data (dots), depicted in Figures 2, 3 and 4, indicate a significant difference between signals recorded at these two sites.

The lithological log of borehole N268, situated approximately 600 m from the NMR test site, and the interpretation results of the NMR data are presented in Figure 5. The observed difference between the depth of the detected shallow aquifer and the water table may be explained both by existing moisture detected by NMR, and noise influence on the interpretation results. Due to the lack of a borehole at the test site itself, it is not possible to verify the exact location of this fairly irregular aquifer. The limestone aquifer between 28 and 52 m is quite extensive throughout the area. It is well-detected by NMR. No water was found below 55 m. This negative result may be easily explained by the existence of an electrically conductive shallow layer whose screening effect decreases the depth of investigation. The determined NMR signal decay time values for both aquifers are in good agreement with the geological description of the water-saturated rocks (material is quite coarse grained). The observed resistivity distribution indicates lower values for the shallow aquifer. For the comparison, DC resistivity method data are presented.

In the Bazancourt area, borehole N22 is located 325 m from the test site. Unfortunately, no deeper borehole exists close to the test site. A lithological log and interpretation results of NMR data are presented in Figure 6. Two aquifers were detected by the NMR method. The location of the upper layers coincides well with the measured water table level. Due to the lack of geological data it is not possible to discuss the observed dry interval between 33 and 38 m. According to geological data, the chalk aquifer must be approximately 100-120 m deep, but the lack of resolution with depth does not enable detection of its base with NMR. Short decay time of the signal was observed which is normal for fine-grained material, and correlates very well with much lower values of water transmissivity at Bazancourt compared to the other test site of St-Cyr-en-Val.

The results of antenna impedance measurements and water chemical analysis, and the geological description of the area prove the absence of high conductivity in the rocks, as indicated by NMR.

Reconstructed theoretical signals of detected aquifers (solid lines on Figures 2, 3 and 4) correspond quite well with true measurements.

Electromagnetic interference observed during the tests did not affect the interpretation results.

Conclusions

A large variation of the measured NMR signals over selected aquifers (water transmissivity differs about 10 fold) demonstrates the high sensitivity of this method to aquifer parameters.

Parameters obtained during study of the aquifers are in quite good agreement with existing geological data.

The presented method, based on direct measurement of the NMR signal from subsurface water, generally enables determination of aquifer parameters (depth, thickness, water content and mean grain size) without any information regarding the subsurface structure in a variety of geological environments.

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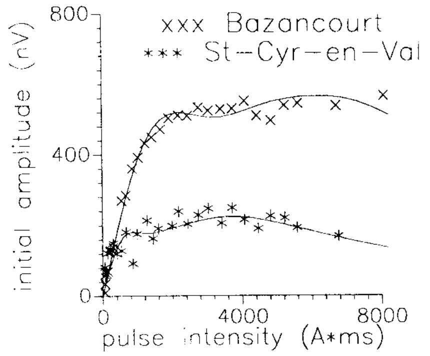

Fig.2. NMR signal amplitude.

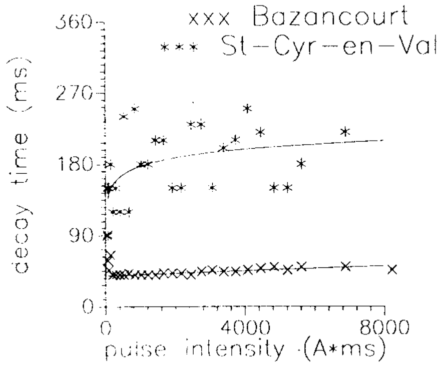

Fig.3. NMR signal decay time.

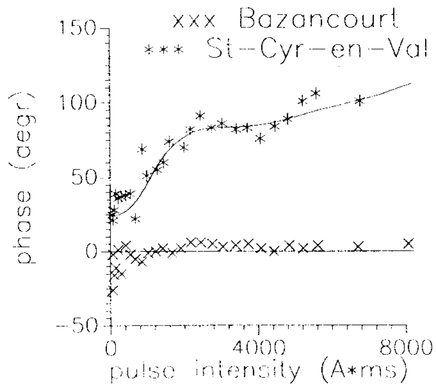

Fig.4. NMR signal phase.

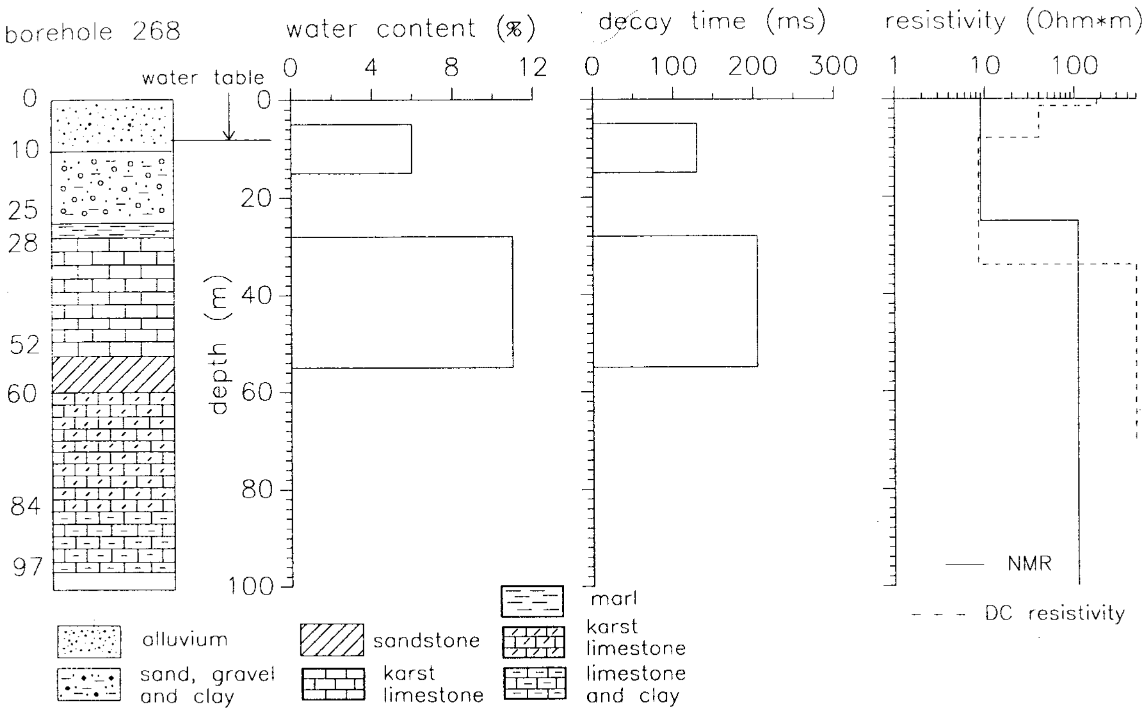

Fig.5. Interpretation results. St-Cyr-en-Val area.

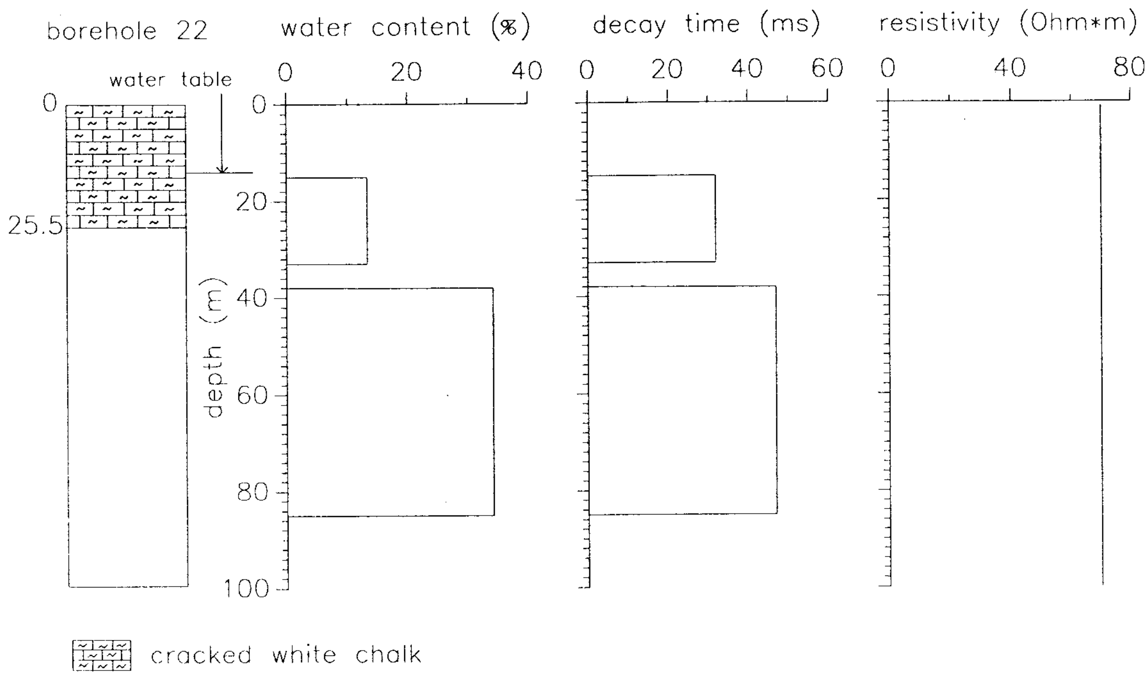

Fig.6. Interpretation results. Bazancourt area.