Long relaxation times in surface NMR sounding

Kalneus E.V.
ICKC SB RAS
3, Institutskaya str., 630090 Novosibirsk, Russia
kalneus@kinetics.nsc.ru

Bizin M.A.
ICKC SB RAS
3, Institutskaya str., 630090 Novosibirsk, Russia
bizin@kinetics.nsc.ru

SUMMARY

The geophysical method of surface nuclear magnetic resonance (SNMR) or magnetic resonance sounding (MRS) for groundwater searching is being actively developed in the last couple of decades. In this method the registered signal is due to precession of the magnetic moment of protons in groundwater and thus it is a direct method to detect groundwater. MRS allows detecting and determining the depth distribution of groundwater, as well as estimating from decay time of the MRS signal the sizes of pores in which groundwater resides. In this work we focus on registering MRS signal with long (about 1 s) relaxation times T_2^*, which indicate the presence of groundwater in very large pores and cavities. Examples of observing such signals are given, and conditions for correct determination of initial signal amplitude in this case are discussed.

Key words: Surface Nuclear Magnetic Resonance (SNMR), Magnetic Resonance Sounding (MRS), decay time distribution, pore size.

INTRODUCTION

MRS is being actively developed in the last couple of decades. This is partly due to commercial availability of MRS instruments (Legchenko *et al.,* 2002), (Walsh, 2008). Since the decay of MRS signal depends on pore sizes among other reasons, certain works study the effect of pore sizes on relaxation times of MRS signal (Mohnke and Yaramanci, 2008), (Plata and Rubio, 2008), (Walbrecker and Behroozmand, 2012). As the body of experimental data grows, the method is expanded and improved. Thus, the work of Walsh *et al.,* (2011) demonstrates the possibility of maximum shortening of the period between the end of the excitation pulse and the beginning of registering MRS signal down to 4-10 ms, which allows registering MRS signals with very short relaxation times (about 10 ms). This will likely enable a broader application of surface NMR to include the vadose zone, saturated silts and clays and formations with high magnetic mineral content.

Short relaxation times of groundwater signal are partly due to small sizes of pores, in which the water may reside. Of particular interest is also the other limiting case, when pore sizes may be in the millimeter range, and MRS signal relaxation times may reach about 1000 ms. Although in practice MRS signals with such long relaxation times may be not that common, they have their own features that we shall discuss in this contribution.

METHOD AND RESULTS

In practice NMR signals with long relaxation times may be encountered in different situations, *e.g.*, when sounding is performed in the proximity (meters to tens of meters) to the edge of a natural water reservoir. In this case the question of the possible influence of free water in the reservoir on MRS signal arises. Fig. 1 shows a demonstration of such situation. In this case the measurements to detect groundwater were performed along the profile normal to the flow of Ob River in winter. Top part of Fig. 1 shows a histogram of distribution of relaxation (decay) times of MRS signal in the case when the edge of antenna was placed at a large distance from the river, and the bottom part shows the results for antenna placed partially on ice, over the river bed. It can be seen that in these two cases the distributions of signal relaxation times differ significantly. Free water of the river appears as additional long (about 500 ms) signal relaxation times. In most cases relaxation times of groundwater and water from reservoirs are substantially different, helping to unequivocally identify the source of the registered signal. In several other field experiments the authors obtained average relaxation times of free water about 1-1.3 s. A somewhat lower average relaxation time in the described example can be in part due to river flow. It is intuitively clear that river flow should shorten signal relaxation time the more the faster is the flow, the shallower is the river, and the closer antenna is to river surface.

Another example of registering very long relaxation times of MRS signal is shown in Fig. 2. In this case the slow decay of the signal is exclusively due to groundwater residing in karst caverns. Here the amount of water bound with cavern walls is insignificant in comparison to the total volume, and relaxation times practically correspond to relaxation times for free water. The presence of relatively short relaxation times in the histogram is due to the fact that part of the registered ground water resides in sand, where the amount of bound water is no longer negligible.

For the given example it can be noted that the relationship of the amplitudes of exponents with short and long relaxation time in the development of the original signal does not remain constant depending on the intensity of the excitation pulse. Therefore in the case of such a large difference in relaxation times one can attempt to relatively accurately separate the types of aqueous rocks over the depth.

In the case of slow decay of the MRS signal certain issues should be considered for correct determination of the initial signal amplitude. First, for any intensity of the excitation pulse the next excitation pulse can be provided only after the complete decay of signal induced by the preceding pulse. In practice the time between pulses in these cases should not be shorter than 2 s.

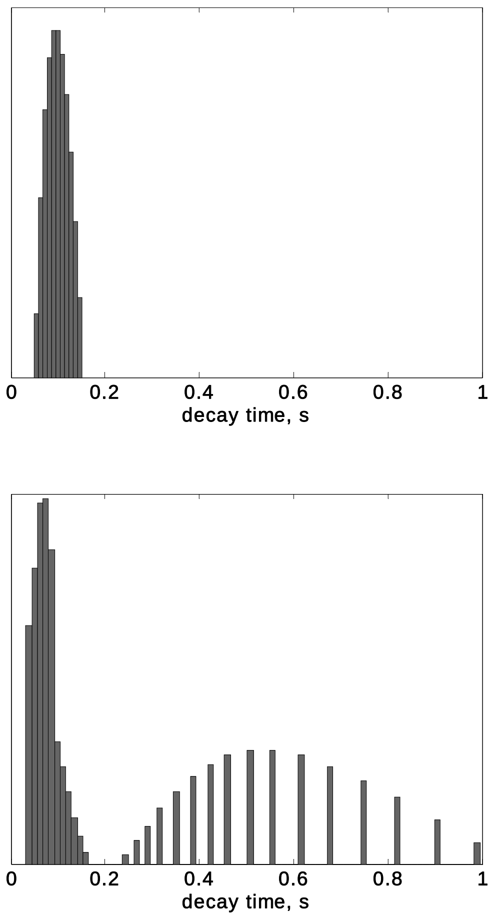

Figure 1. Histogram of the distribution of MRS signal relaxation times in the proximity of Ob River in winter. Signal decay was approximated with a sum of 43 exponents with relaxation times 20 to 1100 ms with inhomogeneous time step. Top histogram is for the case of antenna edge at a distance of 200 m from river edge. Bottom histogram is for approximately half of antenna overlying river surface. Antenna diameter 100 m.

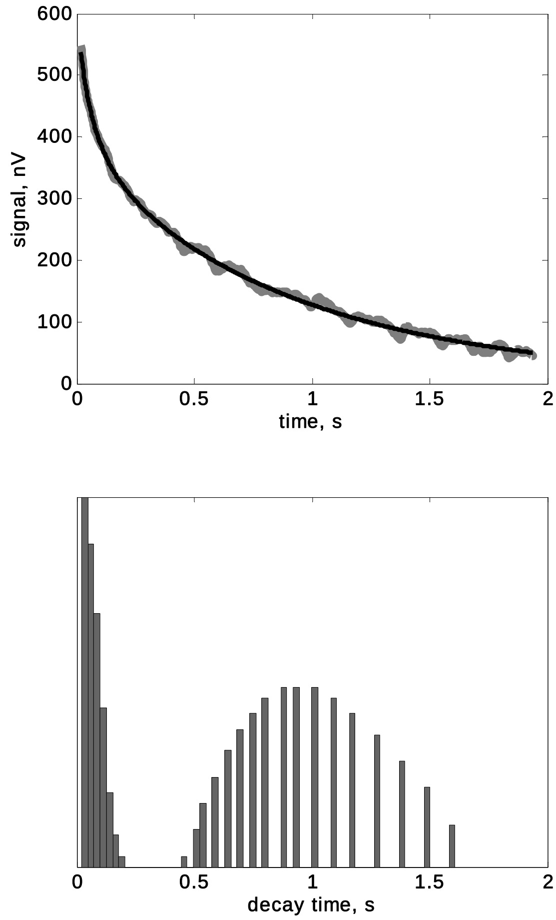

Figure 2. Time dependence of MRS signal decay (bold gray curve) and its approximation with a sum of exponents (black curve) – top panel, and the corresponding histogram of the distribution of MRS signal relaxation times – bottom panel. Signal decay was approximated with a sum of 60 exponents with relaxation times 20 to 2000 ms with inhomogeneous time step. Measurements were performed in Volga region (Russia). Long relaxation times (~ 1 s) are due to registering groundwater in karst caverns.

For high power pulses this condition in MRS instrument is usually met automatically, however, for low pulse moments this condition should be checked deliberately. Second, the duration of signal registration should be large enough to correctly approximate its temporal behavior and more accurately determine the initial signal amplitude. This becomes particularly important at increased noise levels. To meet these two conditions in practice simultaneously it suffices to set signal registration time to 2 s or longer.

To approximate the envelope of MRS signal the authors used the following expression

$$S(t) = \sum_n A_n \exp\left(-\frac{t}{\tau_n}\right) + A_0$$

Parameters n and τ_n are chosen in the process of signal postprocessing after preliminary evaluation. Usually n does not exceed 5. The constant term A_0 is required to take into account the average noise level at the resonance frequency of signal detection after the procedure of synchronous detection.

CONCLUSIONS

This work presents the results of MRS field measurements, in which relaxation times of MRS signal are about 1 s. Possible situations when MRS signal decay can be rather slow are considered. The influence of registration time of MRS signal on the final result is demonstrated, and practical recommendations for its choice in the case of long signal relaxation times are suggested. It is shown that in certain cases to correctly obtain the initial signal amplitude its is necessary to take into account the influence of long relaxation times and the presence of a constant component after the procedure of synchronous detection.

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