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● *Short Communication*

SURFACE NMR MEASUREMENT OF PROTON RELAXATION TIMES IN MEDIUM TO COARSE-GRAINED SAND AQUIFER

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A surface NMR investigation of groundwater in the geomagnetic field is under study. To detect the surface NMR a wire loop with a diameter of about 100 m, being an antenna for both an exciting field source and the NMR signal receiver, is laid out on the ground. A sinusoidal current pulse with a rectangular envelope is passed through the loop to excite the NMR signal. The carrier frequency of the oscillating current in this pulse is equal to the Larmor frequency of protons in the Earth's magnetic field. The current amplitude is changed up to 200 amps and the pulse duration is fixed and is equal to 40 ms. The exciting pulse is followed by an induction emf signal caused by the Larmor nuclear precession in geomagnetic field. The relaxation times T_1, T_2, and T_2^* were measured by the surface NMR for both groundwater in medium to coarse-grained sand at borehole and for bulk water under the ice surface of frozen lake. To determine T_1, a longitudinal interference in experiments with repeated pulses was measured. A sequence with equal period between equal excitation pulses was used. The relaxation times T_1, T_2, measured for bulk water under the ice of the Ob reservoir were 1.0 s and 0.7 s, respectively. To estimate an influence of dissolved oxygen T_1 of the same water at the same temperature was measured by lab NMR with and without pumping of oxygen. The relaxation time T_1 measured for water in the medium to coarse-grained sand is 0.65 s. The relaxation time T_2 estimated by spin echo sequence is found to be equal to 0.15 s. The relaxation time T_2^* is found to be about 80 ms. This result contradicts published earlier phenomenological correlation between relaxation time T_2^* and grain size of water-bearing rock. This could be as a result of unsound approach based on grain size or influence of paramagnetic impurities. Copyright © 1996 Elsevier Science Inc.

Keywords: **NMR; Surface NMR; NMR-relaxation; Earth's field; Groundwater; Water; Sand.**

INTRODUCTION

A surface NMR investigation of groundwater in the geomagnetic field is under study. The original idea of this method was proposed by Anderson.[1] First device, physical model, and mathematical inversion software were developed by Semenov et al.[2] The surface NMR of groundwater in electroconductive media was investigated by Shushakov and Legchenko[3,4] and Trushkin et al.[5] The effects of variations in the Earth's field $\mathbf{H}_0$ on the surface NMR signal were discussed by Trushkin et al.[6] Different antenna types, such as noise-reducing figure-of-eight-shaped antenna, are investigated by Trushkin et al.[7]

To detect the surface NMR a wire loop with a diameter of 100 m, being an antenna for both an exciting field source and the NMR signal receiver, is laid out on the ground. A sinusoidal current pulse with a rectangular envelope is passed through the loop to excite the NMR signal. The carrier frequency ω of the oscillating current $I \cdot e^{-i\omega t}$ in this pulse is equal to the Larmor frequency ω_L of protons in the Earth's magnetic field $\mathbf{H}_0$ $\omega_L = \gamma_H \cdot H_0$, where γ_H is the gyromagnetic ratio of protons. The current amplitude I is changed up to 200 amps and the pulse duration τ_p is fixed and is equal to 40 ms. The exciting pulse is followed by an induction emf signal caused by the Larmor nuclear precession in geomagnetic field.

To determine T_1 a longitudinal interference in experiments with repeated pulses was measured. A se-

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quence with equal period T between equal excitation pulses gives the surface NMR signal

$$E(I, T, t) = (\omega/I) \int_V M_{\perp}(\mathbf{r}, I, T) H_{1\perp} \times (\mathbf{r}, I) dV(\mathbf{r}) \cdot \exp(-t/T_2^*) \quad (1)$$

with

$$M_{\perp}(\mathbf{r}, I, T) = M_0(\mathbf{r}) \cdot [1 - \exp(-T/T_1)] \cdot \sin \times \theta(\mathbf{r}, I)/[1 - \cos \theta(\mathbf{r}, I) \cdot \exp(-T/T_1)] \quad (2)$$

and

$$\theta(\mathbf{r}, I) = 0.5 \cdot \gamma_H \cdot H_{1\perp}(\mathbf{r}, I) \cdot \tau_p, \quad (3)$$

where $\mathbf{H}_{1\perp}(\mathbf{r}, I)$ is the alternating field component that is normal to $\mathbf{H}_0$ and $M_0(\mathbf{r})$ is the macroscopic nuclear magnetisation of the unit volume element of ground water-bearing layer.

The relaxation times T_1, T_2, and T_2^* were measured by the surface NMR for both groundwater in medium to coarse-grained sand at borehole #37 (Fig. 1) and for bulk water under the ice of the Ob reservoir near Novosibirsk. A thickness of ice was about 1 m and depth of bulk water was from 1 to 11 m. Proton resonance frequency was about 2500 Hz and Earth's field inclination was 73°. Resistivity of near-surface soil and bulk water was about 50 ohm m.

The relaxation times T_1, T_2, measured for water under the ice of the Ob reservoir were 1.0 s and 0.7 s, respectively. To estimate an influence of dissolved oxygen T_1 of the same water at the same temperature 0.2°C was measured by lab NMR at 90 MHz and was found to be equal to 1.4 s, and 1.8 s with pumped O_2, that corresponds to the O_2 concentration of the order of 10^{18} sm^{-3}.

The relaxation time T_1 measured for water in the medium to coarse-grained sand (borehole #37) is 0.65 s. The relaxation time T_2 estimated by spin echo sequence is found to be equal to 0.15 s. The relaxation time T_2^* is found to be about 80 ms. This result contradicts published earlier phenomenological correlation between relaxation time T_2^* and grain size of water-bearing rock.[8] This could be as a result of unsound approach based on grain size[8] or influence of paramagnetic impurities.

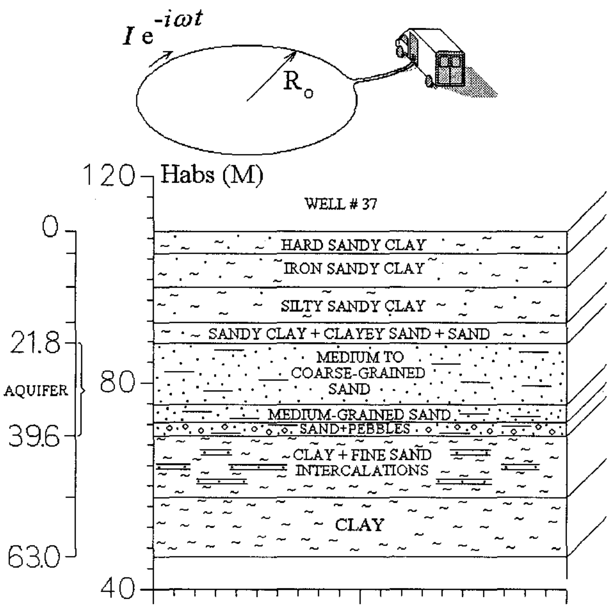

Fig. 1. Lithological log of the borehole #37 and a general arrangement of equipment during the surface NMR experiment. Schematically shown are the wire loop of the radius R_0 = 50 m and a sinusoidal current $I \cdot e^{-i\omega t}$ pulse passed through the loop with a rectangular envelope, amplitude I up to 200 amps and the carrier frequency ω equal to the Larmor frequency of protons in the Earth's magnetic field. The equipment is mounted on a van.

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