Porosity analysis with a mobile NMR scanner

J. Arnold[1], S. Anferova[2], R. Pechnig[1], B. Blümich[2], C. Clauser[1],
[1] Applied Geophysics, RWTH Aachen
[2] Institute of Technical and Macromolecular Chemistry, RWTH Aachen

Motivation

The focus of this research project is set on the calibration of a mobile nuclear magnetic resonance (NMR) scanner, the NMR-MOUSE® [Eidmann et al., 1996], which is used to determine porosity, possibly even pore-size distribution and permeability on cores from ODP/IODP. Further goals are to adapt current NMR processing techniques, development of new measurement routines, and to evaluate precision and accuracy of this method. Finally we will calibrate the NMR results with a large collection of petrophysical data sets. Investigations will concentrate on Leg 204 (Hydrate Ridge), where NMR logging was performed for the first time in ODP by Logging-While-Drilling (LWD) technology. That affords the unique opportunity for comparison studies between the NMR core scanner and the NMR logging data with respect to petrophysics and sedimentology of the Gas Hydrate Ridge.

Theory

Using NMR the magnetization of hydrogen protons in strong magnetic fields is measured by radio-frequency (rf) spectroscopy. Hydrogens are aligned by application of an external, static magnetic field (B_0). The protons precess about an axis parallel to the B_0 direction exhibiting a longitudinal net magnetization. The precessional frequency f, called the Larmor frequency, is given by

$$f = \frac{\gamma B_0}{2\pi},$$

where γ is the gyromagnetic ratio, which is a measure of the strength of the nuclear magnetism [Coates et al., 1999]. By pulsing an oscillating magnetic field (B_1) perpendicular to B_0, spins are tipped from the longitudinal direction to a transverse plane. When the frequency of B_1 equals the Larmor frequency of the protons relative to B_0, nuclear magnetic resonance occurs and protons precess in phase with one another. When the B_1 field is turned off, protons begin to dephase and the transversal magnetization decreases with the time constant T_2, whereby the longitudinal magnetization T_1 increases with the time constant T_1. Dephasing is caused by inhomogeneties of the static magnetic field B_0. The proton magnetization vectors in the transverse plane can be re-phased by a 180° B_1 pulse. The detectable signal is called spin echo. In our project we use a 90° pulse followed by a long series of 180° pulses. This pulse sequence is called CPMG (Carr-Purcell-Meiboom-Gill) sequence. The time constant of the transverse magnetization decay is called the transverse relaxation time, referred as T_2.

Method

The main advantage of the NMR scanner compared to conventional methods is its small size and weight, which is particularly attractive for the shipboard use and on any drilling platform envisioned for IODP (Fig. 1). Whereas conventional NMR employs homogeneous magnetic fields, the NMR MOUSE® employs highly inhomogeneous magnetic fields.

The NMR MOUSE® (Nuclear-Magnetic-Resonance-Mobile-Universal-Surface- Explorer) is a portable 2.5 kg palm-size device. It is constructed from two permanent magnets mounted on an iron yoke with anti-parallel polarization to form the classical horseshoe geometry (Fig. 1a). The rf field B_1 is generated by a figure-8 rf coil placed in the gap [ANFEROVA ET AL., 2002]. It is highly inhomogeneous with volume-averaged magnetic field gradient of about 20T/m at 21 MHz. With the proton Larmor frequency of 22 MHz corresponding to a magnetic field (B_0) strength of 0.52 T a penetration depth of 3 - 4 mm into the core is achieved. For analysis by the NMR MOUSE® core samples are split into half cylinders and investigated from the flat surface (Fig. 1b).

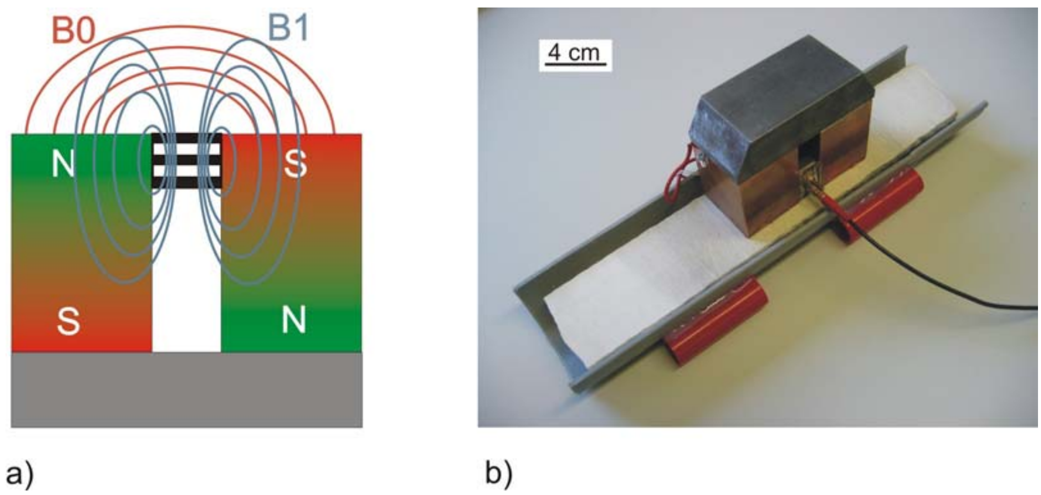

Fig. 1: a) Schematic drawing of the NMR MOUSE. b) NMR MOUSE with a ODP core.

Sandstone samples of different porosity of the Allermöhe borehole of the northern German sediment basin and limestone samples from ODP Leg 165 were investigated by transverse relaxation with the NMR MOUSE® used the CPMG sequence. All samples were saturated with destilled water. A regularized Laplace-transform analysis by the UPEN program [BORGIA ET AL., 1998] provided a transverse relaxation time (T_2) distribution (Fig. 2).

Results

For samples with low porosities (<3.5%) the signal-to-noise ratio is not good enough for an inverse LaPlace transformation. Data from samples with higher porosities (>8%) proved suitable for the LaPlace transformation. The shapes of the T_2 distributions of the Allermöhe samples are similar but integral intensities clearly scale with the porosity of the samples. In contrast, the T_2 distribution of the ODP limestone is shifted to lower T_2 times, which corresponds with the smaller grain size of these rocks (Fig. 2).

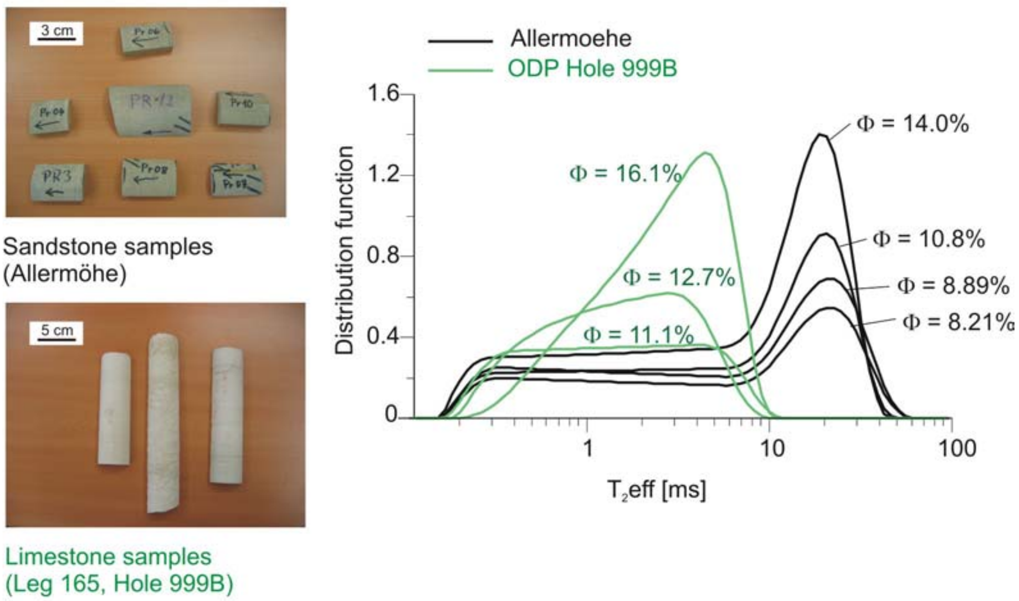

Fig. 2: Left hand: Samples with different porosity from Allermoehe borehole of the northern German sediment basin and ODP Leg 165. Right hand: T_2 distribution of sediment samples with porosities in the range from 8.81% to 14%.

Due to the inhomogeneous field of the NMR MOUSE®, always the same volume content is sampled. Therefore it is easy to calibrate the NMR measurements to porosity, which can be done in two ways:

1. The amplitudes in CPMG experiment are calibrated to the amplitude measured on pure water with 100% porosity (Fig.3a).
2. The integrals from probability density curves (SP = d P/d log T_2) are calibrated with independently measured porosities (Fig.3b).

Both methods worked well. Satisfactory results have already been obtained.

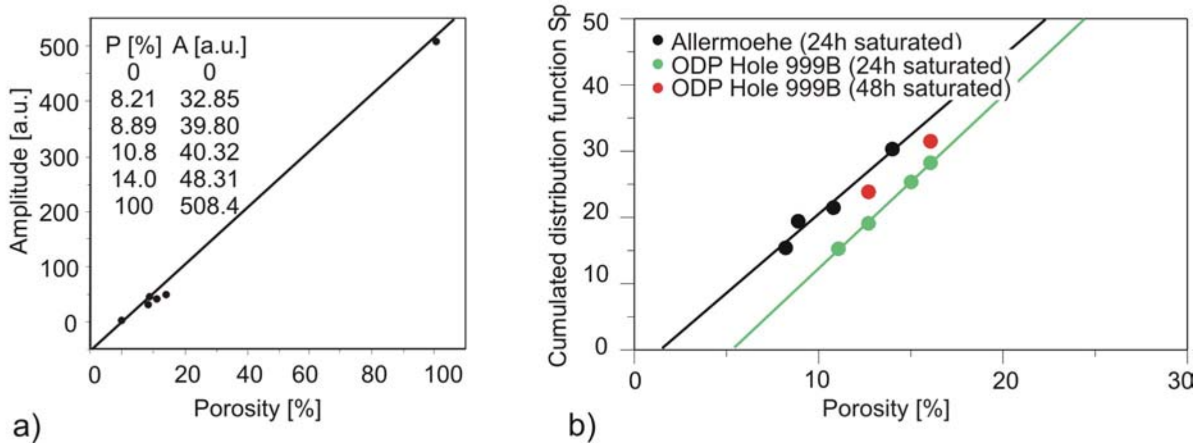

Fig. 3: a) Normalized amplitudes from CPMG experiments compared with core plug porosities of Allermoehe samples. b) Integrals (Sp =d P/d log {T2}) versus core plug porosities. Off-set between ODP and Allermöhe samples can be explained by uncomplete saturation of the samples due to the fine grained texture of the ODP limestones.

Outlook

Besides improving the calibration of the NMR MOUSE® for porosity, the objectives of the close future are further interpretation of T_2 distribution curves regarding to estimate the free and capillary bound water as well as extending interpretation of NMR measurements in respect to permeability. The study will also be focused on the general comparability of NMR log to NMR core data on the basis of Leg 204.

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