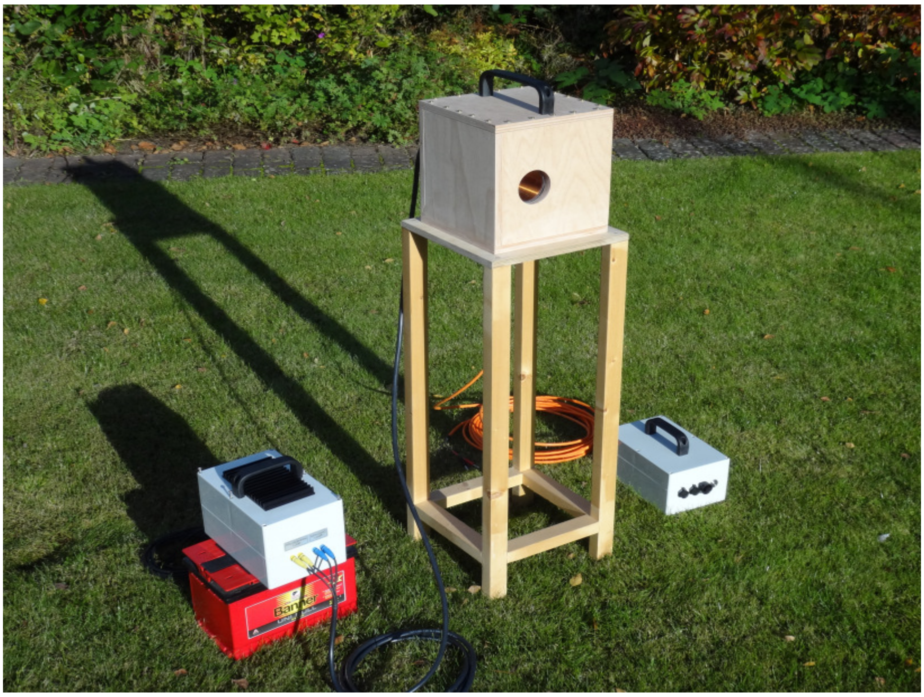
NMR-MINI-3

- **Mobile NMR instrument for investigations of porous sediment samples**

Nuclear Magnetic Resonance

Geophysics



The ***NMR-MINI-3*** system measures the Free Induction Decay (FID) of hydrogen protons in water filled porous samples. From this the absolute content of the free pore water can become estimated. It also gives information about the dominating pore-sizes. The measurement is accomplished in the earth's magnetic field. A PC operating software calculates main frequency, peak amplitude, phase and the transversal relaxation time T_2*. Time series can be stored for user specific calculations. In addition the longitudinal relaxation time T_1 can be measured. To estimate T_2, the Spin-Echo technique was implemented. The ***NMR-MINI-3*** instrument is a low-cost alternative to conventional laboratory instruments. It enables NMR measurements in remote areas as well as in a noisy laboratory environment. Base Unit and Receivers are compatible with ***MRS-MIDI*** system. Sensors are available for samples with 40 mm and 65 mm diameter.

NMR-MINI-3 equipment consists of:

- Base Unit with AD converters and USB
- Transmitter with signal generator
- Sensor with Transmitter Loop, Receiver Loop and Sample Holder
- 1-4 Receiver with Amplifier and BP filter
- Noise Sensor (2 Reference Loops)
- PC operating software to control: polarization, recording, visualisation, processing & data storing

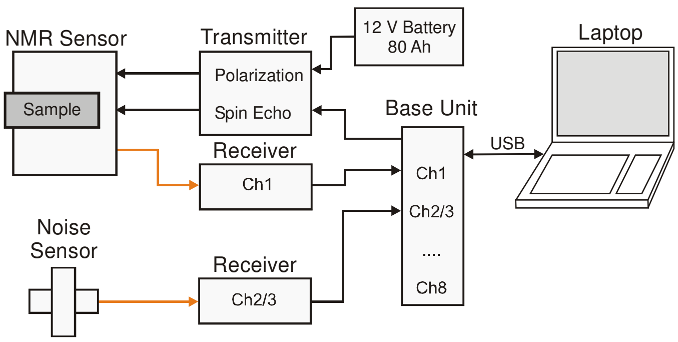


Fig. 1: *NMR-MINI-3* schematic diagram

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OPERATING SOFTWARE

The operating software displays each FID immediately after its recording. Full times series can stored for user specific processing. The frequency will be estimated with an accuracy much better than the FFT can do. The software supports a stacking of the records. This increases the data quality even if the water content is low or if the external noise is high. The strength of the earth's magnetic field changes continuously. For this reason each record is automatically frequency corrected before it is added to the stack. The user can choose the parameters: sample rate, record length, numerical band pass filter, pulse duration and other.

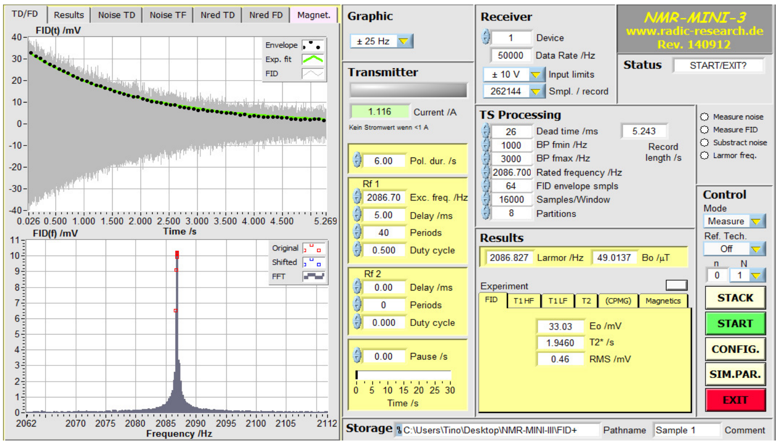

Fig. 2: Main screen of PC operating software. The screen shot shows the recorded FID of 100 ml dest. water.

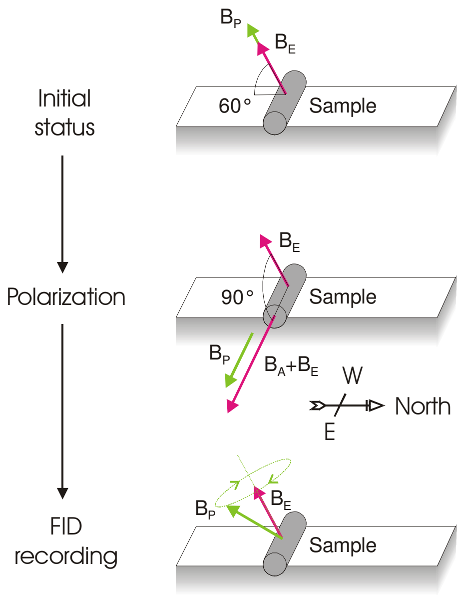

Fig. 3: B_A: Polarizing field, B_E: Earth's mag. field, B_P: FID

FID MEASURING SCHEMA

A strong static field polarizes the protons and aligns these orthogonal to the earth's magnetic field (fig. 3). Immediately after the current is suddenly cut off the induced field collapses, and the Protons precess back into the initial direction - parallel to the earth's field. This FID is recorded at a frequency of ~2 kHz (fig. 2 & equ. 2). The precession frequency is direct proportional to the earth's field strength (equ. 1).

$$\omega_0 = \gamma_p B_0 \qquad \gamma_p = 0.267 * 10^9 \text{ Hz/T} \qquad \text{Larmor frequency} \qquad (1)$$

$$E(t) = E_0 \sin(\omega)\, e^{-\frac{t}{T_2^*}} \qquad \text{Free induction decay} \qquad (2)$$

The instrument is also a proton magnetometer with a frequency resolution of better than 0.1 Hz (±2.5 nT).

CASE HISTORIES

The evaluation of the recorded FID's delivers important pore space parameters. The peak amplitude E_0 is direct proportional to the content of free pore water. If the probe is saturated, the porosity can be estimated from E_0. The T_2^* time is correlating with the diameters of the water filled pores. To estimate the NMR parameters the envelope is calculated from the FID's. Fitting this envelope delivers all parameters. Figure 4a illustrates this for different rock samples. Contaminated samples may saturated with non aqueous fluids. Fig. 4b shows data from different oils.

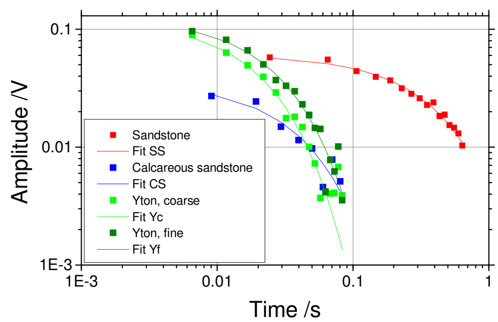

Fig. 4a: FID's of four water saturated natural and artificial rock samples. 62 ml, 4 stacks.

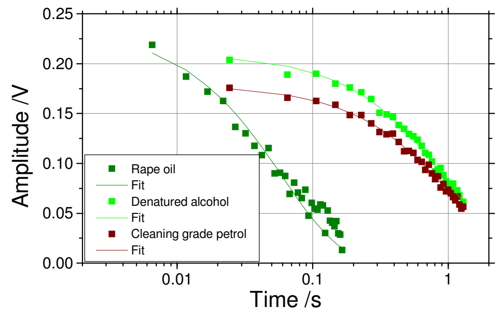

Fig. 4b: FID's of some non aqueous fluids. The relaxation time depends on the viscosity and the peak amplitude on the 1H density.

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EVALUATING WATER QUALITY

Dissolved salts with paramagnetic ions like chrome, iron, nickel or copper shorten the T2* time. This can be used to evaluate the water quality without any contact. Figure 4c shows the influence of the concentration of copper sulphate on the FID's. As a reference demineralised water is also shown. We can estimate that the detectability is ~0.02% of a saturated solution.

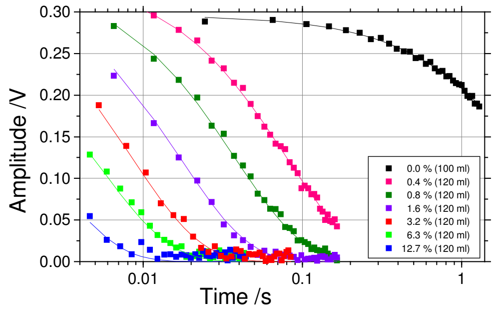

Fig. 4c: FID's from water with different concentrations of dissolved copper sulphate (coloured). Black: demineralised water.

T_1 TIME MEASUREMENT

Unfortunately, a large earth's field gradient dephases the protons and reduces the T_2^* time significant. Another important parameter, the longitudinal relaxation T_1, is not corrupted. The T_1 time can be measured by the ***NMR-MINI-3*** in two ways. One is the inversion recovery technique. The other one is evaluated from the relation between the peak amplitude E_0^* and the duration of the polarization pulse using equation 3. Figure 5 shows the result from a water sample.

$$E(t) = E_0^* (1 - e^{-\frac{t}{T_1}}) \qquad (3)$$

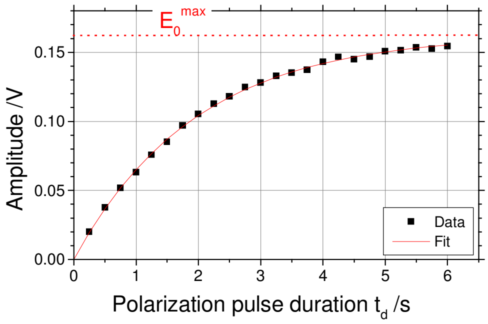

Fig. 5: 50 ml water sample. FID peak amplitude vs. pulse duration. Exp. fitting results: E_0^{max}=163 mV, T_1=1.96 s

SPIN-ECHO-TECHNIQUE TO ESTIMATE T_2

Figure 6 shows a typical Hahn spin-echo sequence. As soon as the FID had completely relaxed a 180° pulse was applied at 450 ms. Further 450 ms later a spin echo can be registered. Out-door the T_2^* time of water is ~2 s and almost as those of T_2 and T_1. In-door the T2* time is often reduced because of an inhomogeneous earth mag. field.

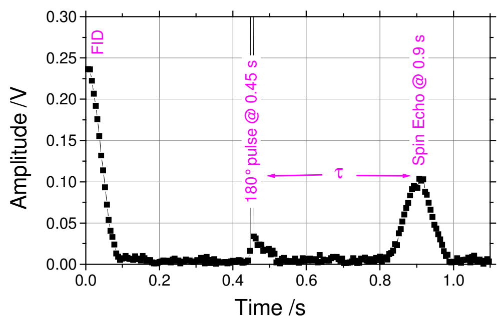

Fig. 6: Example for a registered spin-echo. Delay τ (here 450 ms) and duration of 180° pulse (here 38 µs) can be set in steps of 100 ns. 8 stacks.

Technical specifications

Sensor

- Weight: 11 kg
- Size: 25 x 25 x 30 cm^3

Sample

- Volume: 430 ml
- Size: ∅ 65 mm, L 130 mm

Transmitter

- Weight: 2 kg
- Size: 16 x 20 x 25 cm^3
- Power Sup: ext. 12 V (battery)

Receiver

- Noise: 1 nV $Hz^{-1/2}$
- BP filter: 1000 - 3000 Hz
- Dead time: <4 ms
- Weight: 1 kg
- Size: 16 x 18 x 25 cm^3

Base Unit

- 8 Channels, USB Interface
- 16 Bit AD converter
- Sample rate: up to 400 kHz

Minimum PC Requirements

- 1 GHz, 512 MB RAM
- Display: 1024 x 768
- USB Slot

PC Software

- Windows XP, 7
- Control of the whole system
- Time series recording, storing, displaying and stacking. multi-exponential fitting, calculation of FID peak amplitude, phase, T_2*, T_2, T_1

Other specifications on request

TRIFLUOROETHANOL

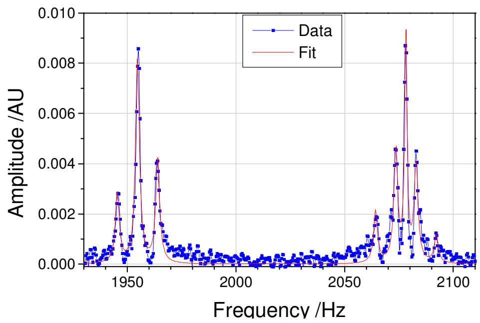

Fig.7: Trifluoroethanol is a fluid with a more complex spectrum. The molecules contains the polarizable atoms: ^1H & ^{19}F. Blue: NMR-MINI-3 data, red: fit from Bernarding & Macholl (Uni. Magdeburg).

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