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First evidence of T_2^* in SNMR measurements with SQUID sensors

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SUMMARY

We discuss the theoretical development of the measurement of the T_2^* component from a surface nuclear magnetic resonance (SNMR) experiment using superconducting quantum interference devices (SQUIDS) as a point B-field receiver.

We discuss the differences between point receivers compared to traditional coincident-loop receivers, and demonstrate the first measurements of T_2^* with a SQUID sensor at the hydrogeophysical test site in Schillerslage, Germany.

Key words: Surface nuclear magnetic resonance, SNMR, NMR, SQUID, B-field, groundwater.

INTRODUCTION

Surface nuclear magnetic resonance (SNMR) is the only geophysical technique that directly measures groundwater in the subsurface of the earth. As such, it is a technique that is gaining more popularity worldwide in the disciplines of groundwater exploration, detection and aquifer characterisation (eg Davis et al., 2012).

Typical measurements of SNMR involve the use of a large circular or square loop that acts as both transmitter and receiver. The excitation signal is an envelope-limited sine-wave pulse whose frequency is set to the expected Larmor frequency of water, determined by the strength of the ambient earth magnetic field. The excitation pulse serves to tip the nuclear magnetic moments of the groundwater away from the earth magnetic field, while the secondary signal is the relaxation of the ensemble of spins realigning with the external field. In traditional sounding experiments, the secondary signal is measured through the transmitter loop, after the excitation pulse is complete. This means that the measurement of the secondary signal is limited to the transverse component of the relaxation field, perpendicular to the net external magnetic field (ie the earth). Because this is a measurement of the free induction decay, the characteristic time measured is T_2^*.

It is possible, in theory, to improve upon the measurement regime in a sounding experiment by measuring different coordinates of the field, different time constants of the secondary relaxation, and using different instruments during the measurement.
We propose the direct measurement of the SNMR relaxation through the use of SQUID sensors acting as point receivers. We show how the measurement of the SNMR signal using a tri-axial B-field sensor allows for the recovery of complementary information of the relaxation, and demonstrate the first evidence of the measurement of T_2^* using a SQUID sensor in the Schillerslage test site, near Hannover Germany (Davis et al., 2014; Dlugosch et al., 2010).

METHOD AND RESULTS

The Schillerslage study (Figure 1) is located in northern Germany, near Hannover. It is the main hydrogoephysical test site used by the Leipzig Institute for Advanced Geophysics (Dlugosch et al., 2010). The site is characterised by two sandy aquifer layers, separated by a layer of glacial till composed of gravel, sand and clay, overlying Cretacious marls. The water table partially fills the first aquifer which consists of medium to coarse sands with inter-bedded strings of thin peat layers down to about 11 m. A 6 m layer of glacial till and thin sands separates the primary aquifer from the secondary; the saturated secondary aquifer, about 3 m thick, consists of medium sands. An aquitard of Cretaceous marl exists beneath these layers. The test-site is known to have low-noise conditions that make it ideal for SNMR tests; and ground truth obtained from downhole-logging and core analysis is available. Boreholes in the area have been geophysically logged with slimline borehole NMR (Walsh et al., 2013) and natural gamma tools.

Our experimental setup was a 50 m circular loop as coincident transmitter and receiver connected to the Vista-Clara GMR device (Walsh, 2008). The point B-field receiver, positioned in the centre of the transmitter loop, was a low-temperature SQUID, which provided a magnetic field resolution of $1.5\ \mathrm{fT}/\sqrt{\mathrm{Hz}}$ (Chwala et al., 2011). Our sounding consisted of 20 pulse-moments of 40 ms duration ranging from 0.1 As to 10 As over 32 stacks. The Larmor frequency was determined to be 2097 Hz corresponding to a magnetic field of 49 341 nT.

Figure 2 shows the average frequency spectrum of the SNMR signals recorded by the SQUID sensor for the 1 As pulse-moment (panel (a)) and, for comparison, the average noise record taken 1 s later during the experiments (b). A small peak at 2097 Hz is visible in panel (a), which displays evidence of the successful recording of an NMR signal.

CONCLUSIONS

We show that it is possible to measure the secondary field of nuclear magnetic resonance signals with a SQUID sensor in a conventional SNMR sounding. Our results are demonstrated by the evidence of a signal of 2097 Hz, recorded immediately after an SNMR excitation pulse that is consistent with the Larmor frequency expected at the Schillierslage test site.

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REFERENCES

Chwala, A. et al., 2011, Low temperature SQUID magnetometer systems for geophysical exploration with transient electromagnetics: *Superconductor Science and Technology*, **24**(12), 125006.

Davis, A.C. et al., 2012, Aquifer characterisation in the Uley South Basin, South Australia, using NMR: Final Report: CSIRO Water for a Healthy Country National Research Flagship.

Davis, A.C. et al., 2014, First evidence of detecting surface nuclear magnetic resonance signals using a compact B-field sensor: *Geophysical Research Letters*, **41**(12), 4222–4229.

Dlugosch, R. et al., 2010, New hydrogeophysical methods examined at the test-site Schillerslage - Derivation of hydraulic parameters in the field scale, in European Geosciences Union General Assembly.

Walsh, D. et al., 2013, A Small-Diameter NMR Logging Tool for Groundwater Investigations: *Groundwater*, **51**(6), 914–926.

Walsh, D.O., 2008, Multi-channel surface NMR instrumentation and software for 1D/2D groundwater investigations: *Journal of Applied Geophysics*, **66**(3–4), 140–150.

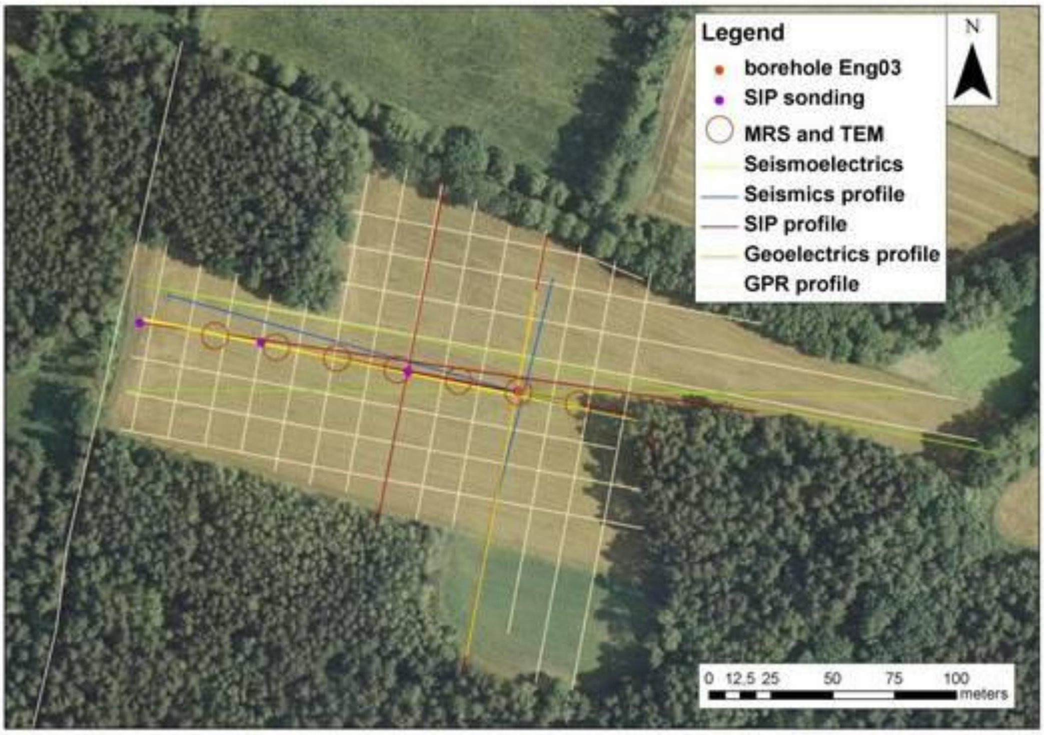

Figure 1. Schillerslage test site near Hannover, Germany.

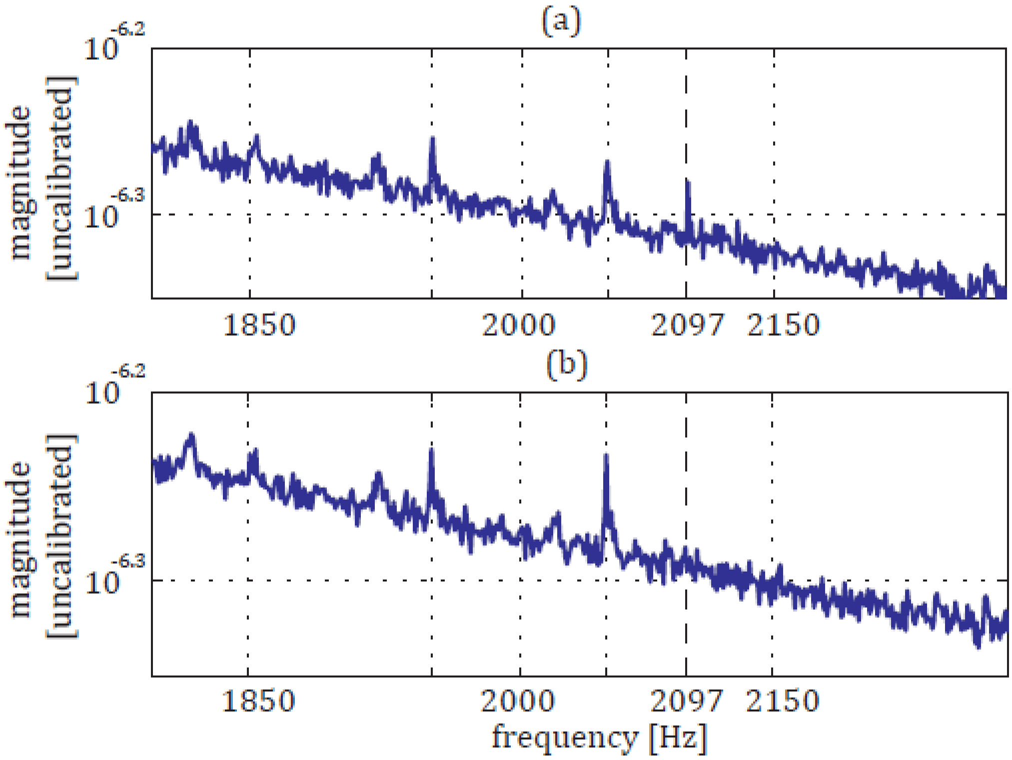

Figure 2. Average power of B-field measurements (a) 50 ms, and (b) 3 s after an NMR transmitter pulse