AARHUS UNIVERSITY

MRS2015

6th INTERNATIONAL WORKSHOP ON MAGNETIC RESONANCE IN THE SUBSURFACE

June 8-10, 2015

At Aarhus University, Aarhus, Denmark

MRS2015 / 6th International Workshop on Magnetic Resonance

IRIS instruments

Danish Ministry of the Environment
Environmental Protection Agency

VISTACLARA INC.
NMR Geophysics

RAMBØLL

MRS2015 / 6th International Workshop on Magnetic Resonance

Dear colleagues

We are delighted to welcome you to this 6th International Workshop on Magnetic Resonance in the Subsurface, MRS2015. We would also like to acknowledge the international NMR community for giving us the opportunity to host this event, and we hope that the venue will live up to your expectations.

The workshop takes place at Aarhus University, located in the center of the historic city of Aarhus. The university is an important part of daily life in Aarhus, as more than 10% of the city's inhabitants are engaged at the university either as students, scientific staff or as technical and administrative staff. The university dates back to the 1930s where the first of the characteristic yellow brick buildings was raised. The architectural design of the university has been created in harmonious interplay with the rolling hills of the University Park, and the uniform building style creates an attractive campus, which has achieved international recognition and has been selected as one of the most beautiful in the world. The newly renovated auditoriums at the Department of Chemistry will frame the talks and the poster sessions. The highly appreciated local Chemistry Canteen will provide lunch and afternoon tea and coffee during the workshop. You will have direct access to the park from the venue, and we encourage workshop attendances to take a stroll during breaks to enjoy a classic example of Danish architecture.

The workshop is free of charge due to generous donations from our sponsors, the Danish Environmental Agency, Vista Clara, Iris Instruments, and Ramboll. We hope that this unique opportunity has extended the list of participants, hereby collecting the entire community within this exciting and prosperous research field.

The workshop will present the most recent findings and developments within the fields of NMR applied to geophysical, hydrological and environmental problems. We would therefore also like to encourage conference presenters to support the special issue in the well-estimated journal Geophysics, by submitting your scientific results. Further guidelines for the submission procedure can be found through the workshop homepage.

Finally, we would like to acknowledge the scientific committee for their evaluation of the workshop contributions. Through your evaluation, we have secured a high level of scientific standard for both oral and poster presentations. We would also like to thank conference participants, and especially the presenters for sharing their achievements, and short course lecturers for sharing their expertise. That said we wish all an interesting and fruitful workshop, and we wish you a pleasant stay in Aarhus.

Best regards

Esben Auken, Jakob Juul Larsen, Troels Norvin Vilhelmsen, and Ahmad A. Behroozmand

MRS2015/6th International Workshop on Magnetic Resonance

Sunday 7 June

17:00 – 18:30 **Ice Breaker**

Dept. of Chemistry
Auditorium I
Aarhus University
Langelandsgade 140
DK-8000 Aarhus C

HydroGeophysics Group
AARHUS UNIVERSITY

Monday 8 June

9:00 – 9:30 **Welcome**

by Niels Chr. Nielsen, Professor and Dean of the Faculty of Science and Technology, Aarhus University and Esben Auken, Professor and leader of the HydroGeophysics Group, Department of Geoscience, Aarhus University.

Niels Chr. Nielsen

Esben Auken

Session A

Chairs: Ugur Yaramanci, Elliot Grunewald

9:30 – 9:55 **A01 Inversion of magnetic resonance data considering varying geomagnetic field**

Anatoly Legchenko (IRD, LTHE), Jean-Michel Vouillamo (IRD, LTHE), Fabrice Messan Amene Lawson (University of Abomey Calavi,), Christian Alle (University of Abomey Calavi), Marc Descloitres (IRD, LTHE), Marie Boucher (IRD, LTHE)

It is known that at the scale of MRS field setup the Earth's magnetic field may vary in space and in time.These variations are caused by different natural factors and cannot be compensated by accurate tuning of the measuring devise. Varying geomagnetic field causes nonresonance conditions of excitation that affect both amplitude and phase of the MRS response. Usually variations of the Earth's magnetic field do not exceed a few hertz and their effect on the amplitude is relatively small permitting to assume a constant geomagnetic field for inversion. However, under some specific conditions both the amplitude and the phase may vary sufficiently for rendering inversion erroneous if the off-resonance conditions are not taken into account. We have developed and tested a new algorithm of inversion of MRS measurements considering varying Earth's magnetic field. We tested this approach using synthetic and field data and we have found that inversion was improved. For demonstration purposes, we present inversion of MRS data measured in Benin (Western Africa) with time varying Earth's magnetic field. Because of improved modeling of the phase shift, the newly developed algorithm allows to use inversion of complex signals, which allows better resolution than inversion of the amplitudes. We show that inversion of complex signals provided inverse model better corresponding to the ground truth.

9:55 – 10:20

A02 A feasibility study on underground nuclear magnetic resonance detection using cooled coils and pre-polarization field

Tingting Lin (Jilin University), Yi Zhang (Forschungszentrum Jülich) Yong-Ho Lee (Korea Research Institute College of Instrumentation and Electrical Engineering), Jun Lin (Jilin University)

Applying surface nuclear magnetic resonance (SNMR) principle to underground environment (UNMR), e.g. in tunnels and mines, one faces a major challenge of using small size of transmitter/receiver (Tx/Rx) without compromising sensitivity. In order to detect UNMR signals, we propose the use of a cooled Rx coil at 77 K to improve the receiver system sensitivity and the introduction of a pre-polarization field Bp with Tx to increase proton magnetization. A cooled Rx coil system was optimized and reached a field sensitivity of 2 fT/√Hz at Larmor frequency of the earth field (~0.05 mT), which is 3 times better compared to the sensitivity at 300 K. Applying Bp from 0.05 to 0.25 mT in the simulated realistic conditions, the amplitude of free induction decay, i.e, signal-to-noise ratios, could be enhanced proportionally to Bp. In addition, Bp + Bac (traditional alternating current pulse) in the shield room by using larger water volume have been tried. The forward and inversion modelling were performed concerning ac sequence to locate the water aquifer and evaluate the water volume. This feasibility study suggested that to use Bp(with or without Bac) combined with a cooled coil enable the reliable acquisitions of UNMR signals in underground conditions, especially when the noise condition is unsatisfied.

10:20 – 10:45

Break

10:45 – 11:10

A03 Localizations and fluid characterization of a thin oil layer using a slim NMR borehole tool

Raphael Dlugosch (Leibniz Institute for Applied Geophysics), Thomas Günther (Leibniz Institute for Applied Geophysics), Tamàs Lukàcs (Eötvös Loránd University), Mike Müller-Petke (Leibniz Institute for Applied Geophysics)

Applying surface nuclear magnetic resonance (SNMR) principle to underground environment (UNMR), e.g. in tunnels and mines, one faces a major challenge of using small size of transmitter/receiver (Tx/Rx) without compromising sensitivity. In order to detect UNMR signals, we propose the use of a cooled Rx coil at 77 K to improve the receiver system sensitivity and the introduction of a pre-polarization field Bp with Tx to increase proton magnetization. A cooled Rx coil system was optimized and reached a field sensitivity of 2 fT/√Hz at Larmor frequency of the earth field (~0.05 mT), which is 3 times better compared to the sensitivity at 300 K. Applying Bp from 0.05 to 0.25 mT in the simulated realistic conditions, the amplitude of free induction decay, i.e, signal-to-noise ratios, could be enhanced proportionally to Bp. In addition, Bp + Bac (traditional alternating current pulse) in the shield room by using larger water volume have been tried. The forward and inversion modelling were performed concerning ac sequence to locate the water aquifer and evaluate the water volume. This feasibility study suggested that to use Bp(with or without Bac) combined with a cooled coil enable the reliable acquisitions of UNMR signals in underground conditions, especially when the noise condition is unsatisfied.

11:10 – 11.35

A04 Noise removal in MRS applications: field cases and filtering strategies

Jean-François Girard (BRGM), Sébastien Penz(BRGM), Aurore Texier (BRGM), Jean-Michel Baltassat (BRGM), Anatoly Legchenko (IRD, LTHE)

The usefulness and reliability of magnetic resonance information to characterize water bearing geological structures has been widely demonstrated these last two decades all over the world and many future applications just begin. The main limitation of MRS applicability is its sensitivity to the electromagnetic noise which results in a long and site dependent measuring duration, and generally prove to be impossible in urban conditions. Many improvements have been performed all along the development of MRS technology. Nowadays, numerous mono and multi-channel processing schemes have been published, but efficiency remains site and time dependent. We have reviewed data

from various contexts and compared the noise removal efficiency and impact of the filtering on synthetic signal added to real noise data. We also used methods derived from magneto-telluric to study the structure of the noise and present a continuous EM field monitoring during a storm event in mountain where we performed a MRS survey. We observed that the reconstruction of natural noise is a percentage of the ambient noise, the ratio is almost stable. Despite this observation of stable removal performance, it means that when the level of noise is multiplied by 10 to 100 and more… it is better to stop measuring MRS and wait for a quiet period of time.

11:35 – 12:00 **A05 An Assessment of the Relationship for Estimating Hydraulic Conductivity from NMR Measurements in Unconsolidated Sediments**

Jeremy Maurer (Stanford University), Rosemary Knight (Stanford University)

Nuclear magnetic resonance (NMR) logging provides a new means of estimating the permeability (k) or hydraulic conductivity (K), of unconsolidated aquifers. The estimation of K from the measured NMR parameters can be accomplished using the Schlumberger-Doll Research (SDR) equation. The SDR equation includes empiricallydetermined constants. Decades of research for petroleum applications have resulted in standard values for these constants that can provide accurate estimates of permeability in consolidated formations for petroleum applications. This study examines whether similar global constants can be derived for near-surface applications that would yield accurate estimates of K in unconsolidated aquifers. We apply four new methods of analysis to re-analyze data from three field sites in North America to determine the range of values for the SDR constants that fit the data. We show that all the wells in our dataset can be explained by a single value or narrow range of values for the constants. We also show that the porosity term can be removed from the SDR model without significantly affecting the quality of our fit to the data. These results suggest that we can define standard constants that can be used to obtain high resolution, cost effective estimates of K from NMR logging in unconsolidated aquifers. The methodologies we employ provide an effective approach to evaluating the performance of the SDR model.

12:00 – 13:00 **Lunch and poster session**

Session B

Chairs: Mike Müller-Petke, Lin Jun

13:00 – 13.25 **B01 Multiple-purpose MRS in Multidisciplinary Projects**

Mette Ryom Nielsen (Ramboll Denmark), Jesper Hannibalsen (Danish Ministry of the Environment), Tom Hagensen (Danish Ministry of the Environment)

In Denmark there is a long tradition of governmental groundwater management based on detailed groundwater mapping as part of the environmental plans of ensuring high quality drinking water supply based solely on naturally clean and chemically untreated groundwater.

Groundwater mapping in Denmark is conducted through multidisciplinary projects within each survey area. In several stages of these multidisciplinary projects the Magnetic Resonance Method (MRS) has been implemented with multiple purposes. In 2013 a large groundwater mapping project consisting of nine different Danish survey areas were performed with a total of 125 MRS with multiple purposes. The MRS results have contributed greatly to several different stages of the large multidisciplinary groundwater mapping project. Research borehole locations were determined partly based on the MRS results. New and previous unknown hydrostratigraphic structures were indicated by MRS and subsequently confirmed by research boreholes. In other cases research boreholes were spared since the hydrological conditions were evaluated as being satisfactory described by MRS. The MRS results were beneficially used in the hydrostratigraphic 3D-models. In certain areas the existing geophysical SkyTEM data did not resolve the hydrostratigraphic structures of the area, since no resistivity contrast was present between the quaternary sandy aquifer and the prequaternary mica sediments. However, MRS succeeded in discriminating these formations and thus, the MRS results gave

crucial input to the hydrostratigraphical modelling. Finally, the MRS results provided essential input to the sparse hydraulic data input to the numerical hydrological models.

13:25 – 13:50 **B02 Internal gradients in sediments and their impact on NMR measurements**

Emily Fay (Stanford University), Denys Grombacher (Stanford University), Rosemary Knight (Stanford University)

Internal magnetic field gradients in porous materials can impact NMR measurements of the transverse relaxation time (T2) and the diffusion coefficient (D), leading to possible interpretation errors. Internal gradients can shift signal to faster relaxation times and alter the shape of the T2 distribution, complicating the link between pore size and measured T2. Internal gradients can also cause errors in the calculation of D from NMR data, which will cause problems if we are interested in using D to separate signal from multiple fluid phases or to investigate pore geometry. The aim of this work is to increase our understanding of when and how internal gradients impact NMR data, and how the magnitude of observed internal gradients are related to sediment properties. We use modelling and laboratory measurements of T2 and D-T2 to investigate the impact of internal gradients on NMR measurements in sediments. We assess the correlation between the internal gradients that we observe and measured sediment properties. The results of this study indicate that internal gradients could have a significant impact on borehole measurements of D-T2 and of T2 in sediments with moderate to high magnetic susceptibility. In contrast, due to the scaling of internal gradients with the background magnetic field, we expect the effect of internal gradients on surface NMR data to be negligible due to the lower field.

13:50 – 14:15 **B03 MRS contribution for better understanding the quaternary aquifer of Lake Chad basin in Cameroon**

Kemgang Dongmo T. (DST / FS / Université de Ngaoundéré), Ngounou Ngatcha B. (DST / FS / Université de Ngaoundéré), Boucher M. (LTHE, IRD / UJF / CNRS / G-INP), Favreau, G. (HSM, IRD / UM2 / CNRS), Mvondo V.Y.E (DST / FS / Université de Ngaoundéré), Legchenko A. (LTHE / UJF / CNRS)

In the Far north of Cameroon, the main source of drinking water is the Quaternary sedimentary aquifer. In this semi-arid region, with high population growth, the groundwater resource is affected by climate and land-use changes but also by the impact of Lake Chad level variation. For better quantifying the role of each of these processes, it is necessary to improve our knowledge about aquifer characteristics. Thus, 13 MR soundings were performed in 2012 and 2103 for characterizing hydrodynamic properties of aquifer in the vicinity of the Limani-Yagoua sand-ridge which is considered by many authors as the limit of the Mega-Lake Chad during the last humid period of Holocene (~-6000 years BP). Despite of difficult conditions of measurement (high natural electromagnetic noise in the afternoon and low Lamor frequency), data of acceptable quality were obtained with a fairly efficient velocity of execution (1 sounding per day). MRS results are in good agreement with available geological logs and with the water levels measured in neighboring wells. They also show high heterogeneity of aquifer characteristics: the water content ranges from less than 2% to 25.5 %, the thickness from 4 to 25 meters and the transmissivity (calibrated with available data in literature) varies from 6×10-5 to 1 ×10-4 m2/s. No water was found within the first 30 m of the Limani-Yagoua sand ridge, confirming the absence of water storage in this formation laid on the regional quaternary aquifer. During this study, the main limitation for MRS was the depth of investigation (~ 30 meters) with the equipment we employed (Numis Lite). Thus a new field survey is scheduled in March 2015 with more powerful equipment (Numis Plus).

14:15 – 14:40 **B04 Study of error propagation in NMR well logging data processing**

Tamás Lukács(Eötvös Loránd University), László Balázs, (Eötvös Loránd University), Péter Filipszki

The T2 distribution derived from NMR measurements is very important input data for some petrophysical parameter. Therefore the uncertainties of T2 data are appear in the further calculation. Analyzing the NMR data processing permits to study the error

propagation through the inversion at different signal to noise ratios. The error analysis consists of two parts. At first the study were carried out on artificially created datasets with simulated noise, which also gives the opportunity to investigate the effect of measurement parameters such as sample rate. Then the real datasets were used in the analysis with varying signal to noise ratios

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14:40 – 15:10 **Break**

15:10 – 15:35 **B05 Mapping of heterogenic geological setting at a hospital construction site using geophysical surveying and NMR logging**

Kerim Martinez (COWI A/S), Ole Frits Nielsen (COWI A/S), Jarle Henssel (COWI A/S),, Elliot Grunewald (Vista Clara Inc.)

NMR logging was employed as part of integrated geophysical and geotechnical site investigations for a new planned new hospital in Hillerød, Denmark. Due to the complex hydrogeological conditions, where localised discontinuous sand lenses can affect excavation during construction, NMR logging was integrated to supplement hydrological and geological investigations, in order to localise and describe local heterogeneities. NMR logging was carried out in 4 geotechnical boreholes using Javelin system indicated that increase mobile water was present at the bottom of the sand lense aquifer, corresponding to where borehole logs indicated more gravel composition. Not all sand lenses indicated the same degree of mobile water and permeability estimates, indicating hydraulic discontinuity of these sand lenses. Information gained from NMR logging at meter scale of variability in flow within aquifers mapped by logging are relevant to optimise design of excavation construction where meter scale is needed to design appropriate dewatering systems during construction.

15:35 – 16:00 **B07 Despiking of magnetic resonance sounding signals**

Jakob Juul Larsen (Aarhus University), Esben Auken (Aarhus University)

In this paper a new method of removing spikes from magnetic resonance sounding (MRS) signals is proposed and investigated. We show that most spikes in MRS signals recorded with a Numis Poly instrument can be efficiently modelled as an impulsive excitation of a 4th order bandpass filter. When the models of spikes are subtracted from the acquired signals an efficient reduction of noise is obtained. An example of the method is given using data from Norsminde, Denmark. The analysis shows that there is no correlation between the remaining noise in the primary coil and in the reference coils when powerline harmonics and spikes have been removed using our model-based approach. Directions for future research into optimized signal processing of MRS data are discussed.

16:00 – 16:15 **Short summing up and practical information**

Session C

16:15 – 18:00 **Poster session, drinks & snacks**

C01 Multichannel magnetic resonance sounding with wirelessly operated coils – A design study

Klaus Bahner (VIA University College), Jakob Juul Larsen (Aarhus University), Esben Auken (Aarhus University)

The invention of multichannel MRS instruments, where additional channels are used for reference measurements of noise has been successful in improving the signal to noise ratio of MRS measurements, but the signal to noise ratio is still inadequate for reliable measurements in many places of interest. To further improve on noise reduction, better methods for dealing with complex noise fields are needed. In available systems the reference channels are connected to a base station by wires. In this paper we argue that by using reference channels with wireless connections to the base station improvements in noise reduction can be expected. We present and discuss a design study of an MRS

receiver system using wireless reference channels. The design is based on using as many standard components as possible e.g. GPS disciplined oscillators for time synchronization and WiFi for communication between units.

C02 Joint use of MRS and TDEM for characterizing sedimentary aquifers in peri-urban area in tropical climate – Case study in the neighbourhood of Douala city (Cameroon)

Marie Boucher (IRD, LTHE), Benjamin Ngounou Ngatcha University of Ngaoundere), Jejung Lee (University of Missouri), Ibrahim B. Goni (University of Maiduguri), Guillaume Favreau (IRD, HSM), Roger Feumba (University of Yaounde)

The “Geoscientists Without Borders” (GWB) program aims to train students to innovative geophysical technics for solving an humanitarian issue. In this framework, we applied MRS and TDEM for characterizing the sedimentary aquifer of Doula city in order to propose solution for the problem of cholera. Six sites were investigated for sampling both the shallow and the deep aquifer of Douala. Four MR soundings and six TDEM soundings of good quality were obtained despite difficult field conditions (tropical peri-urban context). Our results suggest that the shallow aquifer is vulnerable to surface pollution (high permeability) but the deep aquifer seems like a good water resource in term of quantity and quality (absence of saltwater). However these preliminary results should be confirmed by additional measurements for a better representativeness.

C03 Laterally constrained smooth and block inversion of quasi-two dimensional magnetic resonance tomography

Jiang Chuandong (Jilin University), Shang Xinlei (Jilin University), Lin Tingting (Jilin University), Fan Tiehu (Jilin University), Lin Jun (Jilin University)

We adapt a laterally constrained smooth and block inversion (LCSI and LCBI) scheme to increase themoderate and deep resolution of magnetic resonance tomography (MRT) for imaging quasi-two dimensional subsurface water-bearing structures. All the envelope data of the MRT signals from a profile are inverted together to produce the water content and relaxation time T2 * distribution with vertical and lateral smooth transitions in the LCSI, while in the LCBI, the vertical thickness of the aquifer is also a solution with the lateral smooth transitions. Examples from synthetic 2D model and a field test show that the model reconstruction of a subsurface approximate layered aquifer is improved using LCSI and LCBI approach when compared with a combined 1D inversion and a 2D smooth inversion.

C04 Inversion of time-lapse MRS for estimating unsaturated flow parameters by including hydraulic modeling in the forward calculation

Stephan Costabel, BGR,Germany)

The Combination of time-lapse MRS measurements with infiltration experiments has a great potential for estimating unsaturated flow parameters in situ. An inversion scheme is introduced that involves hydraulic modelling in the MRS forward calculation and approximates the measurements at all time steps of the experiment simultaneously. In this way, the hydraulic parameters characterizing the unsaturated zone can directly be estimated. The application of this scheme is shown with a synthetic time-lapse MRS data example, i.e., a simulated MRS monitoring of a virtual infiltration experiment.

C05 SNMR soundings in the Baucau region of Timor-Leste for groundwater management

Aaron Davis (CSIRO), Yusen Ley-Cooper (CSIRO)

We examine some surface nuclear magnetic resonance soundings, which are tied into an airborne electromagnetic survey, for groundwater management and water exploration. In this paper, we discuss the locations of SNMR sounding sites, based on the AEM, and show some of the groundwater models obtained to inform a drilling program for obtaining more groundwater for the town of Baucau, Timor-Leste.

C06 Improving Parameter Estimation for Surface-NMR Data by Singular Spectrum Analysis Framework

Reza Ghanati (University of Tehran), Mohammad Kazem Hafiti (University of Tehran), Mahdi Fallasafari (University of Tehran)

A major drawback of applying surface-NMR to hydrogeophysical investigations is high vulnerability to electromagnetic interferences that severely affect the signal quality of surface-NMR measurements. In this paper, we describe an application of a powerful denoising method based on singular spectrum analysis (SSA) technique. The aim of SSA is to decompose the original time series into a sum of small numbers of independent and interpretable components such as slowly varying trend, oscillatory components, and noise components. The time series is decomposed into noise free original time series components and noise components at the first stage, at the second stage the denoised time series is reconstructed by using the noise free components extracted from the initial section. The signal retrieval process through the SSA algorithm strongly depends upon two parameters: the window length of the embedding operation and number of needed singular values. To evaluate the performance of the proposed strategy, the method is tested on synthetic signals added to noise-only recordings obtained from surface-NMR field survey. Our results show that the proposed algorithm can enhance the signal to noise ratio significantly, and gives an improvement in estimation of the surface-NMR signal parameters.

C07 Groundwater and Surface Water Interactions Assessed with MRS

Mette Ryom Nielsen (Ramboll Denmark), Marianne Jeppesen (Lyngby-Taarbæk Supply Company)

The EU Water Framework Directive (WFD) has the objective that the entire aquatic environment achieves ‘good status’ by 2015. Interaction between groundwater and surface water can affect the quality of both water systems and therefore it is of great importance to be able to assess the degree of interaction between groundwater and surface water. Various issues related to interaction between surface water and ground water can threaten one of the systems. The work presented here is related to assessments of the possibility that interaction could take place between groundwater and the water in protected ponds in the large nature park Jægersborg Dyrehave north of Copenhagen. The assessments are of great importance to the evaluation of whether a planned new water supply well field at the edge of the park could have any effect on the protected ponds. Twelve Magnetic Resonance Soundings (MRS) and twelve ground based Transient Electromagnetic soundings (TEM) were conducted in the nature park Jægersborg Dyrehave of which seven are placed close to ponds. In six of the cases there appear to be a clear separation between the surface water and groundwater, and thus there are no signs that the new abstraction will affect the water in the ponds.

C08 MRS dynamic monitoring study of landslide in Hefeng East Mountain, Anhui (China)

Yang Zhang (Jilin University), Ling Wan, (Jilin University) Jun Lin (Jilin University), Tingting Lin (Jilin University)

We have proposed MRS monitoring method of landslide. We first analysed the distribution of resolution in array coil measuring mode, and then obtain that in this mode we can achieve fast 2D detection of groundwater in a wide range under the condition of higher resolution. By a way of MRS monitoring in wet season and dry season, we realized 2D MRS imaging of landslide in Anhui Hefeng East Mountain. We accurately determined the scope of shallow landslide 3-7 m. And comprehensive analysis the rapidity, accuracy and effectiveness of the method, making it become a main way in landslide exploration and monitoring.

C09 Evolutionary Algorithms for MRS Single and Joint Inversion

Thomas Günther (Leibniz-Institute for Applied Geophysics), Irfan Akca (Ankara University), Mike Müller-Petke (Leibniz-Institute for Applied Geophysics)

As inversion of magnetic resonance data requires a resistivity model, joint application of MRS with VES or TEM is inevitable. Moreover, joint inversion, e.g. by common block models, can improve resolution and decrease ambiguity. In contrast to derivative-based methods, global optimization can provide a variety of models that reflect uncertainty. We apply different evolutionary algorithms (e.g. GA, PSO) to data sets from the North Sea island of Borkum. Computations with the open Python library inspyred show that the individual algorithms have different properties concerning convergence and diversity. Joint inversion of MRS and VES is achieved by a non-dominated sorting genetic algorithm. The Pareto rank of the achieved models shows how well the two data can be fitted.

B06 A preliminary research of 2D surface-NMR tomography based on coincident loops

Bin Chen (China University of Geosciences), Xiangyun Hu (China University of Geosciences), Warous Assiah (China University of Geosciences)

Surface Nuclear Magnetic Resonance (SNMR) is a relatively new geophysical method for groundwater exploration and aquifer characterization. So far, the practical application of SNMR technique is mostly based on 1-D forward and inversion strategies, which are inappropriate for investigating isolated water occurrences and using in complicated hydrological environments. What's more, most of the inversions only employ the real part of the voltage response data. In order to expand the application scope and inversion resolution of SNMR method, we investigate a 2-D forward and inversion scheme considering the elliptical polarization and phase lag effect. After calculating the transmitted oscillating magnetic field by Chave algorithm, we construct 4 synthetic aquifer models and obtain their forward complex response. Then we compare and analysis the inversion results of applying (1) real data, (2) imaginary data and (3) joint with real and imaginary data through Marquardt method for these models. By numerical simulation, we find that the Marquardt can reconstruct the original models correctly and the imaginary part data is illustrated to be more sensitive to 2D dimension structures than the real part of the signal. Joint inversion not only stabilizes the inversion process but also improves resolution, so we should make the best of imaginary part data if it is possible, especially for exploration in complicated hydrological environments.

Tuesday 9 June

Session D
Chairs: Anatoly Legchenko, Kristina Keating

9:00 – 9:25

D01 Evaluation of NMR parameters for porosimetry of sandstones

Gordon Osterman (Rutgers University), Kristina Keating (Rutgers University)

In this laboratory study we examine the relationship between NMR relaxation times and parameters describing the pore geometry of sandstones. Using measurements on 45 cores spanning fourteen geological formations, we compare characteristic relaxation times determined from the NMR relaxation time distribution, including the mean log relaxation time, the median relaxation time, and the peak relaxation time, to characteristic pore geometry parameters, including the surface-area-to-volume ratio, the median pore size, and the peak pore size. Our objective is to determine which characteristic NMR relaxation times best correlate to which parameters describing the pore geometry. By improving our ability to model characteristic pore geometries, we can build better models of permeability using NMR data. Our results show that for samples with little to no iron oxide, the mean-log relaxation time correlates with the surface-area-to-pore-volume ratio while the median and peak relaxation times correlate well with the median and peak pore size, respectively. When we consider a range of iron oxide rich cores the petrophysical relationships become more complex and we must consider developing separate petrophysical models for cores with different mineralogies.

9:25 – 9:50

D02 Improved resolution and signal-to-noise ratio of magnetic resonance sounding data using a central loop configuration

Ahmad A. Behroozmand (Stanford University), Esben Auken (Aarhus University), Gianluca Fiandaca (Aarhus University), Simon Rejkjær (Aarhus University)

Magnetic resonance sounding (MRS) is an emerging geophysical method used for direct investigation of the subsurface water content. In this study, we introduce the MRS central loop geometry, in which the receiver loop is smaller than the transmitter loop and placed in its centre. In addition, we show how this configuration helps to better estimate the subsurface model as compared with the typically used coincident loop configuration. We describe advantages of the MRS central loop geometry in terms of superior behavior of the sensitivity function, increased sensitivity values, reduced noise level, improved resolution matrix and reduced instrument dead time. The results of our field example are in good agreement with complementary geophysical and hydrologic data.

9:50 – 10:15

D03 Emerging Applications of NMR Logging in Groundwater Monitoring and Environmental Remediation

David O. Walsh and Elliot Grunewald (Vista Clara Inc.), Catherine Kirkland and Sarah L. Codd (Montana State University), Kristina Keating and Carl Rosier (Rutgers University), Kenneth H. Williams (Lawrence Berkeley National Lab)

New applications of NMR logging tools in groundwater and environmental applications have been developed and demonstrated. Long-term in-situ measurements with NMR logging tools were used to detect and monitor biofouling and biogeochemical changes in aquifers on measurement scales ranging from days to years. NMR logging measurements in flowing or pumping wells were shown to be sensitive to the distribution of groundwater flow velocities in adjacent unconsolidated aquifers. NMR diffusion measurements with an NMR logging tool were shown to be capable of separating and measuring the bulk fluid concentrations of water and diesel fuel with different fluid fractions saturating a natural medium to coarse sand.

10:15 – 10:45

Break

10:45 – 11:10 **D04 T_1 or T_2 – A simple choice?**

Mike Müller-Petke (Leibniz-Institute for Applied Geophysics)

It is well known that both T1 and T2 relaxation time compared with FID measurements provide superior information to derive hydraulic properties as they are less affected by magnetic gradients. Within the last years, measurement sequences and techniques have been developed that allow for estimating both parameter. However, one may ask which one to take? In this abstract advantages and disadvantages in the context of determining the water content and the relaxation time from measured data are discussed to help making decisions.

11:10 – 11:35 **D05 Geophysical characterization of a crystalline hard rock using MRS, TEM and ERT methods: A case study**

Subash Chandra (CSIR-National Geophysical Research Institute), Jean-Francois Girard (BRGM), Shakeel Ahmed (CSIR-National Geophysical Research Institute), J.J. Baltassat (BRGM), Anatoly Legchenko (IRD, LTHE), Saurabh K. Verma (CSIR-National Geophysical Research Institute)

The paper presents the results of combined study of electrical resistivity tomography (ERT), transient electromagnetic (TEM) and magnetic resonance sounding (MRS) in an over-exploited granitic terrain at Maheshwaram watershed carried out during 1999-2003 under a collaboration between the CSIR-NGRI, India and BRGM, France. The integrated analysis has helped in assessing the total groundwater resources. The water content in the area is found varying in the range of 0-8% down to the depth of 25 m below ground level (bgl). Maximum percentage of water content is found at around 15 m (bgl). Comparative MRS response in 1999 and 2003 revealed drastic fall of the free water content from 5% to negligible (MRS signal level is less than the instrumental noise of 5 nV). In this weathered granite setting MRS show greater sensitivity to groundwater depletion than ERT. While the sensitivity of the instrument is sufficient for characterizing the water-saturated saprolite, in the fissured zone (FZ) where the water content is much lower, the magnetic resonance signal is accordingly lower. The method sensitivity may then not be sufficient and this formation cannot be fully resolved.

11:35 – 12:00 **D06 Frequency-cycling for compensation of off-resonance effects and improved stability of complex inversions in surface NMR**

Denys Grombacher (Stanford University), Mike Müller-Petke (Leibniz-Institute for Applied Geophysics), Rosemary Knight (Stanford University)

To produce accurate images of subsurface properties using the surface Nuclear Magnetic Resonance (NMR) technique we require accurate modelling of the physics of the excitation process. This demands precise knowledge of the Larmor frequency at all locations in the subsurface. In practice, this is infeasible to achieve. Therefore, we present a method, called frequency-cycling, that ensures an accurate forward model in the presence of an uncertain Larmor frequency estimate. Frequency-cycling reduces sensitivity to the influence of an unknown offset between the estimated and true Larmor frequencies improving the ability of surface NMR to generate images that are representative of the true subsurface. Additionally, frequency-cycling stabilizes the complex inversion of surface NMR data exploiting resolution enhancements associated with complex inversion. We demonstrate the advantages of the frequency-cycling method in both synthetic and field studies.

12:00 – 13:00 **Lunch and poster session**

Session E
Chairs: Thomas Günther, Ahmad Behroozmand

13:00 – 13:25 **E01 Surface-NMR modeling and inversion**

Aaron Davis (CSIRO)

I present a method for compressing the entire surface NMR data set for a set of basis parameters that is most in accord with the measured data. Each basis parameter generates an amplitude and phase for each pulse moment of the recorded SNMR experiment, and keeps track of all uncertainty in the data.

From the compressed data set, I present several methods of inverting in-phase and quadrature data for developing a groundwater porosity image that is most consistent with the data. In particular, I employ the principle of maximum entropy and show, with conservative prior estimates of groundwater quantity in the subsurface, the most conservative posterior distribution of groundwater that is consistent with the data. These results are consistent with typical L2 inversion schemes, with proper regularisation, as well as with a full Monte-Carlo Markov Chain analysis of the full complex data set.

13:25 – 13:50 **E02 CEEMD-DFA and Variance Criterion Based De-noising Method Applied to Magnetic Resonance Sounding**

*Reza Ghanati (University of Tehran), Mohammad Kazem Hafiti (University of Tehran), Mahdi Fallasafari (University of Tehran)*One of the most important tasks in magnetic resonance sounding (MRS) is the noise removal prior to the signal extraction process. In this work a new time-domain method based a non-linear adaptive decomposition technique called complete ensemble empirical mode decomposition (CEEMD) in conjunction with a statistical optimization process for enhancing the signal-to-noise ratio of the MRS signal is developed. The filtering scheme starts with applying the CEEMD method to decompose the noisy MRS signal into a finite number of intrinsic mode functions (IMFs). Afterwards, a threshold region based on de-trended fluctuation analysis (DFA) is defined to identify the noisy IMFs, and then the no-noise IMFs are used to recover the partially de-noised signal. In the second stage, we applied a statistical method based on the variance criterion to the signal derived from the initial phase to remove the remaining noise. To demonstrate the functionality of the proposed strategy, the method was evaluated on an added-noise synthetic MRS signal, and on field data. The results show that the proposed procedure allows us to improve the signal to noise ratio significantly, and consequently, extract the signal parameters from noisy SNMR data efficiently.

13:50 – 14:15 **E03 Sensitivity of surface NMR to sediment properties and structure below permafrost lakes**

Andrea Creighton (University of Wyoming), Andrew Parsekian (University of Wyoming)

Thermokarst lakes form due to the infilling of decayed ground ice with water. Taliks are unfrozen bodies within the permafrost that occur under these thermokarst lakes and play an important role in permafrost hydrology and carbon cycling. Due to the possible depths of these taliks, extending tens of meters, direct measurement of talik depth is costly and surface NMR provides a direct measurement of the liquid water content without ambiguity. We utilize forward modelling of NMR data to explore the effect of liquid water column thickness to accurately resolve talik depth beneath thermokarst lakes with as few input parameters as possible. Field data was collected at a thermokarst lake near Fairbanks, Alaska, which had a known structure. Smooth inversions of field data yielded better results than did blocky inversion models. Forward models were created to test the effect of varying water column thickness to resolve the depth of taliks with parameters similar to the geometries most likely to be seen in late-winter thermokarst lake field studies. Blocky inversion models were used to invert the forward model data as they more accurately represent the sharp water content transitions expected in the environment; however, they currently do not accurately account for the high water content of the liquid water column or constrain the talik depth at water column thicknesses of greater than 0.5 m.

14:15 – 14:40 **E04 Development of Adiabatic Pulses to Enhance Speed and Sensitivity of Surface NMR Measurements**

Elliot Grunewald (Vista Clara, Inc.), Denys Grombacher (Stanford University), David O. Walsh (Vista Clara, Inc.)

We present a new approach to improve the sensitivity and efficiency of geophysical surface nuclear magnetic resonance (NMR) measurements. An extremely powerful tool in groundwater investigations, surface NMR inherently has a relatively low signal-to-noise ratio (SNR), which sometimes necessitates long survey times for signal averaging. In pursuit of faster survey speeds, we show that replacing the standard on-resonance excitation pulse with an adiabatic, frequency-swept pulse can provide significant increases in the NMR signal amplitude. This increase results from the fact that adiabatic pulses can excite larger volumes of groundwater more efficiently than conventional pulses. Using numerical simulations and full-scale field experiments, we show that adiabatic pulses can provide a factor of ~3 increase in signal, and suggest other advantages for groundwater imaging. The signal increase alone allows for data of equivalent SNR to be acquired in a fraction of the time required for conventional on-resonance pulses. Ultimately, these improvements can allow surface NMR to be exploited in an expanding range of applications.

14:40 – 15:10 **Break**

15:10 – 15:35 **E05 Exploring the Link Between the NMR Measurement and Pore Geometry**

Matias Nordin (Stanford University), Rosemary Knight (Stanford University)

Most theoretical treatments of Nuclear Magnetic Resonance (NMR) assume ideal (smooth) geometries (i.e. slabs, spheres or cylinders) with well-defined surface-to-volume ratios (S/V). This same assumption is commonly adopted for naturally occurring materials, where the pore geometry can differ substantially from these ideal situations. In this paper we study the effect of local geometrical features such as surface roughness on the T2 relaxation spectrum. It is found that the NMR relaxation typically underestimate the true surface-to-volume but is more prone to global changes in the geometry. Further investigations of the eigenfunctions of the system revealed that the NMR relaxation experiment typically reports an averaged pore radius, that local variations of the surface in general have little impact on the relaxation times and that the steady state solution does not differ much from an idealized smooth geometry.

15:35 – 16:00 **E06 On determining uncertainties of MRS estimated transmissivities**

Troels Norvin Vilhelmsen (Aarhus University), Steen Christensen (Aarhus University), Esben Auken (Aarhus University)

This paper demonstrates a method to determine uncertainties of MRS derived transmissivity estimates. The method uses linear approximations to compute uncertainties of parameter estimates obtained from joint inversion of TEM and MRS data. To ensure the validity of the linear approximation we compare the uncertainties to those obtained from a full nonlinear analysis of the same datasets. It is documented that the uncertainties obtained from the nonlinear analysis are slightly higher than those obtained from the linear analysis, but the results are comparable in general. The outcome of this analysis facilitates the incorporation of MRS estimated transmissivities into groundwater flow models in an objective manner by using the uncertainty estimates to define weights given to the MRS based transmissivity estimates.

16:00 – 16:45 **E07 Panel discussion (Chairman: Esben Auken)**

Panel members:

Rosemary Knight (Stanford University),, Anatoly Legchenko (IRD, LTHE), Mike Müller-Petke (Leibniz-Institute for Applied Geophysics), Kristina Keating (Rutgers University), David Walsh (Vista Clara Inc.),, Saurabh K. Verma (CSIR-National Geophysical Research Institute)

Session F

16:45 – 17:45 **Poster session & drinks**

F01 First evidence of T2 SNMR measurements with SQUID sensors

Aaron C Davis (CSIRO), Mike Müeller-Petke (Leibniz-Institute for Applied Geophysics), Raphael Dlugosch (Leibniz-Institute for Applied Geophysics), Matthias Quietsch (Friedrich-S-University), James Macnae (RMIT), Ronny Stolz (LIPT)

We discuss the theoretical development of the measurement of the 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 with a SQUID sensor at the hydrogeophysical test site in Schillerslage, Germany

F02 Long relaxation times in surface NMR sounding

E.V. Kalneus (ICKC SB RAS), M.A. Bizin (ICKC SB RAS)

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 thesizes of pores in which groundwater resides. In this work we focus on registering MRS signal with long (about 1 s) relaxation times T2 *, 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.

F03 MRS inversion for water volume

Anatoly Legchenko (IRD, LTHE), Jean-François Girard (BRGM), Jean-Michel Baltassat (BRGM), Naomi Mazzilli (Université d'Avignon et des Pays de Vaucluse)

In this paper we present an approach for analyzing uncertainty in the MRS inversion. Additionally to any other inversion strategy we propose to use the total or partial volume of water under MRS loop as the criterion for estimation of possible variations in the selected solution so that the maximum and the minimum volumes of water correspond to two extreme but still equivalent inverse models. We apply jointly the Monte Carlo and regularization methods for investigating solution space using uncertainty in the water content provided by the SVD analysis. A big advantage of the Monte Carlo modeling is its suitability for both linear and non-linear inversion and the possibility to use the Monte Carlo method without specific assumptions about investigated inverse problem. Experience gained from the numerical modeling and processing of field data shows that this approach is very convenient and has particular advantage when the volume of water under MRS loop is one of the subjects of MRS study.

F04 High-efficient MRS noise cancellation using independent component analysis

Tingting Lin (Jilin University), Siyuan Zhang (Jilin University), Ling Wan (Jilin University), Jun Lin (Jilin University)

This paper addresses feature extraction of the higher order statistics, which can effectively characterize the transients, using independent component analysis (ICA) for the SMRS signal, and then proposes a novel automatic technique for detecting the harmonic and random noise in MRS signals with the low signal-to-noise ratio by ICA feature extraction. The basic principle of the ICA-based transient detection method is that the independent components (ICs) coefficients of the transients and the noise can be effectively distinguished by their different properties. Specifically, the proposed method

for processing the MRS signal mainly includes three steps: denoising the harmonic noise by creating the channel structure; cancelling the random noise by ICs coefficients using the shrinkage function; and reconstruct the MRS signals through the ICA basis functions. Experimental results through the simulated signal analysis and field MRS signal analysis show that the ICA-based method is very effective for acquiring high quality MRS signal when only 3 stacks were needed.

F05 A multi-channel SNMR instrument with integrated broadband and narrowband filter

Yongxing Qu (Jilin University), Jun Lin (Jilin University), Chuandong Jiang (Jilin University), Tingting Lin (Jilin University)

To date the main multi-channel surface NMR instrumentation is GeoMRI system internationally. It can accomplish the MRS signal detecting and acquisition by adaptive noise cancellation technology and 1D/2D imaging technology. However, the GeoMRI system has a bandwidth of approximately 10 kHz. Althrough it shorten the dead time to some extent, it limited the application range of MRS instrument because of the channel saturation in the case of high environmental and cultural noise (e.g. Power line noise, mines and tunnel detection environment). For solving this issue, we designed the signal conditioning circuit integrating broadband and narrowband filter which has a bandwidth of approximately 300Hz. The narrow-band filter of low coefficient of rectangular was used to suppress amplifier saturation in noisy environment. In addition, by adjusting the programmable gain amplifier, the signal conditioning circuit can be set to broadband mode which could shorted the dead time of the instrument. Therefore, the application mode of MRS system could be changed according to the different environment situations.

F06 UMRS applications of groundwater induced disaster forecasting in tunneling

Jun Lin (Jilin University), Tiehu Fan (Jilin University), Xiaofeng Yi (Jilin University), Shengwu Qin (Jilin University), Qingming Duan (Jilin University), Xiaofeng Lv (Jilin University), Shilong Wang (Jilin University), Ling Wan (Jilin University), Tingting Lin (Jilin University)

Underground Magnetic Resonance Sounding applications for tunneling disaster forecasting are introduced. Some challenges has to overcome when UMRS is carried out in underground engineering operations, including advance detection theories, detection with small coils in the extreme underground narrow space, adaptive signal processing for suppressing the strong electromagnetic noises, underground whole space forward modeling and inversion, 2D/3D disaster water data processing and inversion, joint detection of UMRS and TEM methods in complex geological environments. Some case studies of UMRS applications are given in this paper. Compared with other forewarning methods for some practical tunneling operations, we found that in UMRS applications, the signal strength of groundwater induced disaster can be directly detected with the practical identification of fractures containing large volumes of water ahead of the tunneling face.

F07 MRSMATLAB – processing, modelling and inversion of MRS data

Mike Müller-Petke (Leibniz-Institute for Applied Geophysics), Martina Braun (TUB), Marian Hertrich (NAGRA), Stephan Costabel (BGR), Jan Walbrecker (SmartCAE)

MRSMATLAB is designed to provide tools for processing, modelling and inversion of MRS (Magnetic Resonance Sounding) data. The toolbox is MATLAB based. Ongoing from its origin, several researchers have implemented their work over the last years as the project intends to be open for the implementation of current developments. Latest progress includes the processing and inversion of spin echo data, off-resonance excitation and complex inversion. This abstract reviews the general capabilities, provides insight into the handling of MRSMATLAB and in particular the used numerical implementation, and introduces current developments.

F08 The experimental research on Magnetic Resonance Sounding underground water exploration using 2m antenna

Xiaofeng Yi (Jilin University), Tingting Lin (Jilin University), Hao Lin (Jilin University), Jun Lin (Jilin University)

The effective MRS signal with meter scale antenna is the key point of the application in narrow detection space, such as, underground engineering. At present, there is no public literature suggests that effective MRS signal can be received with 2m antenna. Based on the optimal parameters with 2m antenna, started with theoretical calculation, I developed the exploration antenna experimental research with different characteristic parameters. Finally, I received the effective MRS signal which SNR is above 4.5 in experimental field, which is contribute to established the foundation of expand the MRS method application scope.

F09 Using borehole NMR data to determine the effective porosity and estimate the groundwater resource of a shallow semi-confined aquifer, western New South Wales, Australia

Kok Piang Tan (Geoscience Australia), Ken Lawrie (Geoscience Australia), Jared Abraham (XRI Geophysics) Ross S. Brodie (Geoscience Australia)

Estimating groundwater storage volumes is important for assessing the potential capacity and recovery efficiencies of Managed Aquifer Recharge (MAR) strategies. However such volume estimates are vexed by poor characterisation of factors such as the effective porosity of the aquifer. These issues were faced by the Broken Hill Managed Aquifer Recharge (BHMAR) project which aimed to define key groundwater resources and aquifer storage options in the lower Darling River floodplain of western New South Wales, Australia. The project was multi-disciplinary and utilised airborne electromagnetics (AEM), borehole nuclear magnetic resonance (NMR), LiDAR DEM data, and lithological, hydrostratigraphic, and hydrochemical information to develop a suite of hydrogeological and groundwater property maps and products.
Part of the BHMAR project was a study to determine if the NMR free-water data depicts the effective porosity of the sediment and could be used in a workflow to estimate groundwater storage volumes in the target aquifer.
In 2011, 29 sonic drilled bores were logged using the Vista Clara Javelin system operated at single frequency (245 kHz) and 2.25 ms echo spacing. Ten bores were re-logged in 2013 using the improved system with dual frequency (245 kHz and 290 kHz) and shorter echo spacing (1.5 ms). An investigation ensued to validate these NMR results. This included examination of the NMR data processing parameters and optimal regularization factor, additional matric potential and gravimetric water experiments to determine the fractional water and total porosity of sediment, and inquiring into the magnetic susceptibility and mineralogical composition of the sediments. It was concluded that a calibration error in the Javelin tool had caused the detected lower water contents in the 2011 data. A linear factor of 1.2 was applied to rectify this issue. The laboratory experiments showed comparable results to the NMR free-water and total water for sand and muddy sand, but the NMR underestimated the total water in mud. Having established that NMR free-water is a surrogate for effective porosity, the lower and upper quartiles of the NMR free-water (recalibrated 2011 data set) for each of the five hydraulic texture classes were used to estimate the groundwater storage volumes in the target aquifer.

18:30 - … **Dinner at** RAMBØLL

Address: Rambøll A/S, Olof Palmes Allé 20, 8200 Aarhus N.

Wednesday 10 June

Session G

Chairs: Rosemary Knight, Jakob J. Larsen

9:00 – 9:25

G01 Fast Excitation Magnetic field of MRS Computation for layered earth

Ling Wan (Jilin University), Tingting Lin (Jilin University)

We have developed a fast numerical algorithm for computing the excitation magnetic field distribution of MRS for layered earth. We first give the expressions of the MRS response in layered earth, and then obtain the unknown parameters in the expressions using the boundary conditions. We use a new method named quadrature-with-extrapolation (QWE) to solve the problem of dual Bessel function's calculation when the integral is divergent. We validate the results of applying our algorithm against the commercial software, and apply our method to a number of MRS synthetic examples. Surprisingly, our method is faster than the commercial software for all layered models, and the accuracy is acceptable.

9:25 – 9:50

G02 The use of SNMR to determine the variability of permafrost in Adventdalen, Svalbard

Kristina Keating (Rutgers University), Victor Bense (University of East Anglia), Andrew Bingley (Lancaster University), Remke L. Van Dam (Queensland University of Technology), Hanne Christiansen (The University Centre in Svalbard), Casey McGuffy (Rutgers University),, Sara M. Cohen (The University Centre in Svalbard)

Knowledge of the thickness and ice/water content of permafrost in arctic regions is critical for assessing the impacts of surface warming on environmental processes such as groundwater flow and the release of green house gasses from areas of degrading permafrost. In this study, we performed a geophysical survey using surface nuclear magnetic resonance (SNMR) and controlled source audio-magnetotellurics (CSAMT) to map the state of the permafrost in Adventdalen, Svalbard, a river valley in a coastal Arctic landscape. SNMR was used to determine the unfrozen water content at depths down to ~80 m. CSAMT was used to determine the total thickness of permafrost. In the parts of the valley above the marine limit (~80 m above sea-level) SNMR did not detect any unfrozen water content. However, the SNMR soundings along the valley up to several kilometers from the coast show a substantial signal due to unfrozen water content. The CSAMT observations suggest that permafrost thickens substantially along the ~12 km long transect from the coastal area inland. The electrical resistivities observed are relatively low, compared to mountain permafrost environments, which is most likely attributed to the high salinity of the pore water in our study area. Our study illustrates the ability of CSAMT and SNMR to map permafrost characteristics in saline environments. Future work enabling a more thorough interpretation needs more data on ice-content, the thermal state of the deeper permafrost, pore water salinities, and the geological development of the study area.

9:50 – 10:15

G03 A New Method for Parameter Estimation of Magnetic Resonance Sounding

Lichao Liu (Jilin University) and Jun Lin (Jilin University)

Magnetic resonance sounding (MRS) allows for a direct, non-invasive and in-situ determination of the water content of the surface, accurate parameter estimation is the key to a successful MRS survey. The initial phase $\varphi$of free induction decay (FID) as well as phase and amplitude of power line harmonics are obtained by Fast Fourier Transform (FFT), power line harmonics are subtracted from MRS signal. Cross-correlation is proposed to suppress the random noise and spikes, in order to reconstruct FID signal, an approximation formula is given. Estimation of MRS initial amplitude E0and spin-spin relaxation time T2*by using a Duffing oscillator is investigated. Simulation results show

that the proposed method has a relative error 1.8%, 6% and 1.7% in φ, $E0$ and $T2^*$ respectively when SNR is as low as –32dB.

10:15 – 10:40 **G04 Magnetic Resonance Sounding (MRS) investigation of volcanic aquifers using Spin Echo measurements at Mayotte and Martinique (French overseas departments)**

Jean-Michel Baltassat (BRGM), Jean-François Girard (BRGM), Anatoly Legchenko (IRD, LTHE), N. Coppo (BRGM), B. Vittecoq (BRGM), L. Arnaud (BRGM), J. Deparis (BRGM)

Volcanic aquifers well documented with hydraulic characteristics from boreholes, 3D resistivity model and high resolution magnetics were investigated using MRS Spin Echo measurements in Mayotte island (mainly basaltic) and Martinique island (mainly andesitic). Magnetic susceptibility of both basaltic and andesitic formation is varying but high, ranging from a few hundred to several thousand 10-5 SI. Amongst 18 investigated sites, SE signal was only observed at one where magnetic susceptibility ranges from 200 to 500 10-3 SI : inversion results are in reasonable agreement with borehole results but water content is low compared to what is expected for such a sandy aquifer. In several other sites where no signal is observed, magnetic susceptibility is significantly higher ranging from 1000 to 4000 10-5 SI. It is supposed that as magnetic susceptibility increases, relaxation increases : with the lower susceptibility (100-1000 10-5 SI), part of signal becomes too short to be detectable and then for higher susceptibility (>1000 10-5 SI) the whole signal is undetectable with current equipment such as NumisPlus.

10:40 – 11:10 **Break**

11:10 – 11:35 **G05 TorusMRS – MRS using a moveable helium-filled balloon**

Stephan Costabel (BGR), Raphael Dlugosch (Leibniz-Institute for Applied Geophysics), Mike Müller-Petke (LIAG), Annika Steuer (BGR)

A concept is introduced to increase the MRS measurement progress in the field. The main idea is to install the circular measurement loop on a helium-filled donut-shaped balloon, which enables moving this system effectively along large profile lines. To take advantage of the fast positioning of the measurement loop, the duration of each sounding is reduced by decreasing the number of pulse moments at the expense of vertical resolution. However, using effective datasets and inversion schemes, i.e., MRS data collected using a pulse moment distribution optimized for identifying a specific target, we expect that the benefit of acquiring horizontal information compensates for the general loss in vertical resolution. For determining the optimum pulse distribution, a priori information at single fixing points in the area of investigation must be available, e.g. obtained from boreholes or common MRS measurement with higher vertical resolution.

11:35 – 12:00 **G06 Imaging shallow water bearing structures using three dimensional magnetic resonance tomography with separated loops**

Jiang Chuandong (Jilin University); Mike Müller-Petke (Leibniz-Institute for Applied Geophysics); Lin Jun (Jilin University); Ugur Yaramanci (Leibniz-Institute for Applied Geophysics)

The technique of surface NMR has been applied to image 1D, 2D and recently 3D sub-surface structures. While limited resolution is reported for imaging deep 3D structures using a coincident loop configuration, high resolution is obtained for shallow 2D structures by including separated loop configurations. We adapt the concept of separated transmitter and receiver loops to obtain increasing resolution for imaging 3D shallow structures. We present a numerically efficient approach to calculate the 3D kernel with sufficient accuracy but small number of elements. Using synthetic data, we show that including separated loop layouts enhances 3D image reconstruction. To evaluate our 3D inversion approach, a field campaign including surface NMR with various layouts and GPR measurements was conducted on top of a frozen artificial barrier lake in the Harz Mountains (Germany, Lower Saxony) with a well-known geometry. We show that results obtained from measurements using the coincident loop layout gives a rough approximation of the lakes bathymetry while including separated

loop layouts provides an more detailed view into the subsurface. In particular, the obtained image match not only the known water content of 100%, but the geometry known from construction plans and estimated from ground penetration radar profiles. In addition to the 3D assessment, a 2D profile is extracted from the 3D data set to demonstrate the need for 3D inversion.

12:00 – 12:25 **G07 MRS characterization of a mountain hard rock aquifer: the Strengbach Catchment, Vosges Massif, France**

*Marie Boucher (IRD, LTHE), Marie-Claire Pierret (University of Strasbourg), Marc Dumont (CNRS, LTHE), Daniel Viville (CNRS, LHyGES), Anatoly Legchenko (IRD, LTHE), Antoine Chevalier (Joseph Fourier University), Sebastien Penz (BRGM)*The study of mountainous crystalline aquifers is a scientific challenge due to their complexity and is an important issue for the water resources in a context of changes in precipitation regime. The small Strengbach catchment (0.8 km2) was densely investigated with MRS (23 sites). Our results allowed constructing a conceptual model of hydrogeological functioning that will aid to better resolve the hydrological balance at the catchment scale. The approach we used here can be applied to other small complex hydrological systems. From a methodological geophysical point of view, we tested both FID (free induction decay) and SE (spin echo) sequences. FID measurements seem more suited to the study site, but is slightly perturbed in the northern part of the area where geology differs from south.

12:50 – 13:15 **End and goodbye**

13:15 – 13:45 **Lunch**