IP2016 / 4th International Workshop on Induced Polarization

Detailed Program

Sunday 5 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 6 June

9:00 – 9:25 **Welcome**

Session A – Morning
Chairs: Esben Auken & Christian Camerlynck

9:25 – 9:50

A01 Induced polarization and pore radius – a discussion

Andreas Weller (Institut für Geophysik, TU Clausthal), Zeyu Zhang (Southwest Petroleum University), Lee Slater (Rutgers University), Sabine Kruschwitz (Bundesanstalt für Materialforschung und –prüfung), Matthias Halisch (Leibniz-Institut für Angewandte Geophysik)

Permeability estimation from spectral induced polarization (SIP) measurements is based on a fundamental premise that the characteristic relaxation time (τ) is related to the effective hydraulic radius (r_{eff}) controlling fluid flow. The approach requires a reliable estimate of the diffusion coefficient of the ions in the electrical double layer. Others have assumed a value for the diffusion coefficient, or postulated different values for clay versus clay-free rocks. We examine the link between τ and r_{eff} for an extensive database of sandstone samples where mercury porosimetry data confirm that r_{eff} is reliably determined from a modification of the Hagen- Poiseuille equation assuming that the electrical tortuosity is equal to the hydraulic tortuosity. Our database does not support the existence of 1 or 2 distinct representative diffusion coefficients but instead demonstrates strong evidence for 6 orders of magnitude of variation in an apparent diffusion coefficient that is well correlated with both reff and the specific surface area per unit pore volume (S_{por}). Two scenarios can explain our findings: (1) the length-scale defined by t is not equal to r_{eff} and is likely much longer due to the control of pore surface roughness; (2) the range of diffusion coefficients is large and likely determined by the relative proportions of the different minerals (e.g. silica, clays) making up the rock. In either case, the estimation of r_{eff} (and hence permeability) is inherently uncertain from SIP relaxation time.

9:50 – 10:15

A02 Modeling the evolution of spectral induced polarization during calcite precipitation on glass beads

Leroy Philippe (BRGM), Li Shuai (Imperial College), Jougnot Damien (CNRS), Revil André (CNRS), Wu Yuxin, (LBNL)

When pH and alkalinity increase, calcite frequently precipitates and hence modifies the petrophysical properties of porous media. The complex conductivity method can be used to directly monitor calcite precipitation in porous media because it is very sensitive to the evolution of the pore structure and its connectivity. We have developed a mechanistic grain polarization model considering the electrochemical polarization of the Stern layer surrounding calcite particles. This model depends on the surface charge density and mobility of the counter-ions in the Stern layer. Our induced polarization model predicts the evolution of the size of calcite particles, of the pore structure and connectivity during spectral induced polarization experiments of calcite precipitation on glass beads pack. Model predictions are in very good agreement with the complex conductivity measurements. During the first phase of calcite precipitation experiment, calcite crystals growth, and the inverted particle size distribution moves towards larger calcite particles. When calcite continues to precipitate and during pore clogging, inverted particle size distribution moves towards smaller particles because large particles do not polarize sufficiently. The pore clogging is also responsible for the decrease of the connectivity of the pores, which is observed through the increasing electrical formation factor of the porous medium.

10:15 – 10:30 **Break**

10:30 – 10:55

A03 Field evaluation of wideband EIT measurements

M. Kelter (Institute of Bio- and Geosciences, Agrosphere), J. A. Huisman (Institute of Bio- and Geosciences, Agrosphere), E. Zimmermann (Central Institute for Engineering), H. Vereecken (Institute of Bio- and Geosciences, Agrosphere)

Field applications of wideband electrical impedance tomography (EIT) remain challenging, despite recent advances to obtain images of the complex electrical conductivity with sufficient accuracy for a broad range of frequencies (mHz – kHz). The aim of this study is to evaluate to what extent recent improvements in the inversion and processing of wideband field EIT measurements have improved the accuracy and spectral consistency of images of the real and imaginary part of the electrical conductivity. In a first case study, timelapse surface EIT measurements were performed during an infiltration experiment to investigate the spectral complex electrical conductivity as a function of water content. State-of-the-art data processing and inversion approaches were used to obtain images of the complex electrical conductivity in a frequency range of 100 mHz to 1 kHz, and integral parameters were obtained using Debye decomposition. Results showed consistent spectral and spatial variation of the phase of the complex electrical conductivity in a broad frequency range, and a complex dependence on water saturation. In a second case study, borehole EIT measurements were made in a well-characterized gravel aquifer. These measurements were inverted to obtain broadband images of the complex conductivity after correction of inductive coupling effects using a recently developed procedure relying on a combination of calibration measurements and modelbased corrections. The inversion results were spatially and spectrally consistent in a broad frequency range up to 1 kHz only after removal of inductive coupling effects.

10:55 – 11:20

A04 3D TEM-IP inversion workflow for galvanic source TEM data

Seogi Kang and Douglas W. Oldenburg (University of British Columbia)

Electrical induced polarization (EIP) surveys have been used to detect chargeable materials in the earth. For interpretation of the time domain EIP data, the DC-IP inversion method, which first invert DC data (on-time) to recover conductivity, then inverts IP data (off-time) to recover chargeability, has been successfully used especially for mining applications finding porphyry deposits. It is assumed that the off-time data are free of EM induction effects. When this is not the case, an EM-decoupling technique, which removes EM induction in the observation, needs to be implemented. Usually responses from a half-space or a layered earth are subtracted. Recent capability in 3D TEM forward modelling and inversion allows us to revisit this procedure. Here we apply a 3D TEM-IP inversion workflow to the galvanic source example. This includes three steps: a) invert DC and early time channel TEM data to recover the 3D conductivity, b) use that conductivity to compute the TEM response at later time channels. Subtract this fundamental response from the observations to generate the IP response, and c) invert the IP responses to recover a 3D chargeability. This workflow effectively removes EM induction effects in the observations and produces better chargeability and conductivity models compared to conventional approaches.

11:20 – 12:00

Poster Presentations – session A

Presentations of all the posters of session A (two minutes for each presentation).

The list of posters can be found at the end of the day's program.

12:00 – 13:00

Lunch & Poster session A

Session A – Afternoon
Chairs: Estella Atekwana & Andreas Weller

13:00 – 13:25

A05 SIP investigation at historical mining slag heaps

Tina Martin (Federal Institute for Geosciences and Natural Resources (BGR), Thomas Günther (Leibniz Institute for Applied Geophysics (LIAG)

Geophysical investigations at historical slag heaps are increasingly in focus due to economic, environmental or archaeological reasons. We present in this study the investigation of a historical slag heap in the Harz Mountains, Germany, where laboratory and field measurements were conducted.

Previous detailed laboratory measurements of different synthetic mineral-sand mixtures have shown that there is a relationship between chargeability and mineral concentration as well as between relaxation time and mineral grain size. With the development of a new approach for the simultaneous fitting of the whole spectral field data set to different models we are now able to interpret the field measurements further. We started to show that the relationships found in laboratory can be in principle transferred to the field data.

However, in situ samples also show that the SIP response can be very different between samples from the same heap. So a general statement of the mineral content/grain size of a slag heap only from some field profiles is not possible.

With the help of additional mineralogical, chemical and optical methods we try to characterize the different SIP response with the aim of rough classification of slag heap areas.

13:25 – 13:50

A06 Spectral induced polarization in a sandy medium containing semiconductor materials: study of the polarization mechanism

Feras Abdulsamad (Sorbonne Université UPMC-CNRS), Nicolas Florsch (Sorbonne Université, UPMC-IRD), Christian Camerlynck (Sorbonne Université, UPMC-CNRS)

Induced polarization (IP) is useful for mineral exploration. In the presence of sulphides (more generally speaking: semi-conductors), the charge carriers inside particles are electrons and electron gaps. The inner diffusivity and the charge concentration are very high with respect to the background solution ones. Mechanisms of induced polarization are still under questioning in those cases. In order to improve our knowledge about the mechanisms controlling IP in such mediums, we propose new lab experiments on unconsolidated mineralized medium and begin numerical modelling by using the Poisson-Nernst-Planck (PNP) equation set as well. Four different types of semi-conductors (graphite, pyrite, chalcopyrite and galena) are involved in the experiments. The polarization effect of grain size, mineral concentration as well as electrolyte salinity and type are investigated at the lab scale. We find that the total chargeability of the medium is a function of the mineral volume but is independent of the electrolyte salinity and electrolyte type. However, the time constant (τ) is highly dependent on the grain size and the electrolyte salinity, and is slightly dependent on the mineral type. These results appear to be in agreement with the classical Wong's theory, but we assume here that no significant redox phenomenon does happen at the grain surface. The observed dependence of the chargeability and the time constant on the salinity could be explained by considering the mineral grain as a dipole impacting the potential and consequently charge distribution in its vicinity. This dipole is generated inside the particle to compensate the primary electrical field and the whole particle is –as a first approximation- a spherical boundary (and volume) with a constant potential on (and in) it. The distribution of the charged particles in the area around the dipole electric will respond accordingly to this boundary condition and is driven by the potential. Since the equations are coupled, the potential depends on return on the resulting ions distribution. Although the finite-element numerical approach used here is still preliminary, it opens wide perspectives in the understanding of IP in more complex media.

13:50 – 14:15

A07 Quantification of Rock Structures with High Resolution X-Ray µ-CT for Laboratory SIP Measurements

Matthias Halisch (Leibniz- Institut für Angewandte Geophysik (LIAG), Sabine Kruschwitz (Bundesanstalt für Materialforschung und –prüfung (BAM), Mayka Schmitt (Federal University of Santa Catarina), Andreas Weller (Institut für Geophysik, Technische Universität Clausthal)

Spectral Induced Polarization (SIP) measurements are used in many different ways to characterize natural rocks and soils. Main foci of interest are the enhanced characterization of the causes of IP-effects in clastic rocks (especially sandstones), the interactions between the matrix-fluid-system and within the electrical double layers as well as the correlation with "classical" petrophysical parameters, such as specific surface area, permeability, mercury intrusion capillary pressure (MICP) and others. Nevertheless, for all of these investigations, knowledge of the inner structure of the sample material is essential in order to create reliable and validated models as well as to interpret and to assess the data most completely. Unfortunately, many of the methods used, to get access to the inner structure of rocks are destructive (e.g. MICP, thin sectioning, etc.) and the valuable sample is lost. In addition, data is either of volume integrated nature or only available for the 2D case and the usage of sister cores does not necessarily lead to reliable results. In this paper, the authors showcase the possibilities of non-destructive and three dimensional X-ray computed tomography and of enhanced image analysis capabilities for the quantification of rock structures at the pore scale.

14:15 – 15:15

Break & Poster session A

15:15 – 15:40

A08 Decay-Curve Analysis for the Quantification of Data Error in Time-Domain Induced Polarization Imaging

Adrián Flores Orozco (TU-Wien), Jakob Gallistl (TU-Wien),, Matthias Bücker (TU-Wien), Kenneth H. Williams (Lawrence Berkeley National Lab)

Recent studies have demonstrated the advantages of a careful processing of induced polarization (IP) imaging datasets. In particular, inversion results based on an adequate quantification of data error provide IP images with enhanced contrasts and a better correlation with subsurface structures and processes. The analysis of the discrepancy between normal and reciprocal readings is a widely accepted measure to assess quality of imaging datasets and parametrize error models. However, the collection of reciprocal measurements increases acquisition time and is not always feasible. Therefore, we propose an alternative methodology to quantify data error of time-domain IP (TDIP) imaging measurements based on the analysis of the recorded IP decay curve. Our approach provides detailed information about data error as required for the identification of outliers and the quantification of error parameters without the need of reciprocal measurements. Comparison of the error parameters and imaging results following our proposed decay-curve analysis (DCA) and the conventional normal-reciprocal analysis revealed consistent results, demonstrating the accuracy of our approach. We illustrate the practical applicability of our approach with the inversion results for an extensive field data set collected at the floodplain scale aiming at the localization of so-called "biogeochemical hot-spots", which are areas characterized by high rates of microbial activity and the accumulation of iron sulphides.

15:40 – 16:05

A09 Advances in spectral inversion of time-domain induced polarization

Gianluca Fiandaca, Esben Auken, and Anders Vest Christiansen (Department of Geoscience, Aarhus University)

The extraction of spectral information in the inversion process of time-domain (TD) induced polarization (IP) data is changing the use of the TDIP method. Data interpretation is evolving from a qualitative description of the subsurface, able only to discriminate the presence of contrasts in chargeability parameters, towards a quantitative analysis of the investigated media, which allows for detailed soil- and rock-type characterization. In this work a review of the recent advances in spectral inversion of TDIP data is presented, in terms of: supported IP parameterizations; modelling of transmitter waveform; support for buried electrodes; model regularization; computation of the depth of investigation.

16:05 – 16:30 **A10 Viezzoli Andrea (Aarhus Geophysics ApS), Vlad Kaminski (Aarhus Geophysics ApS), Gianluca Fiandaca (Department of Geoscience, Aarhus University)**

There have been multiple evidences in the literature in the past several years of what has been referred to as IP effect in the Time Domain Airborne EM data (TDEM). This phenomenon is known to be responsible for incorrect inversion modelling of electrical resistivity, lower interpreted depth of investigation and lost information about chargeability of the subsurface as well as about other valuable parameters. Historically there have been many suggestions to account for the IP effect using the Cole-Cole model. In current paper we are showing the possibility to extract IP information from airborne TDEM data including inverse modelling of chargeability from airborne TDEM, both synthetic and actual VTEM data with a field example from Russia (Amakinskaya kimberlite pipe). The synthetic examples illustrate how it is possible to recover deep chargeable targets (depths to over 130 m) in association with both high electrical conductivity and in resistive environments. Furthermore, modelling of IP effects allows corrected resistivity models. The Amakinskaya kimberlite pipe results highlight the relevance of chargeability for kimberlite exploration.

16:30 -18:00 **Field/software demo & Poster session A**

Poster Session A
Chair: Gianluca Fiandaca

PA01 Effect of mineralogy on Spectral Induced Polarization of sediments: A conceptual model of membrane polarization

Konstantin Titov and Daniil Chuprinko, St. Petersburg State University

We discuss a membrane polarization effect produced by the difference in mineral composition of walls of two sequential pores, which can occur, for example when the first pore is encased in calcite and the second – in alumosilicate. We assume that the zeta potential values of these minerals differ from each other. This leads to a difference in the cation and anion transference numbers (even if the above two pores are of the same radius) and, therefore, to a membrane polarization when an electrical field is applied. We model this effect for two pores filled with water of low salinity (1 and 10 Mol.m3), and for three pore radius values (10-6, 10-7 and 10-8 m). We assume that one pore is "passive," i.e., the interface potential is zero, and the other pore is "active", with zeta potential of -75 mV. We calculate the maximum values of phase shift and the corresponding values of peak frequency as a function of lengths of the active and passive pores.

We show that the maximum phase shift corresponds to a case where the pores have the same length. The shift values are between 13 and 210 mrad depending on the ion concentration in free water and on the pore radius. The peak frequency distributions for all modeled cases are very similar and, therefore, depend mostly on the pore length. We assume that the ratio of the pore length to its diameter can achieve values between 10 and 50. With this assumption, for the pore radius of 10-8, 10-7, and 10-6 m, the membrane polarization effect can be detected in the frequency range from 1.6 kHz to 1MHz, from 20 Hz to 1 MHz, and from 0.20 Hz to 1 MHz, respectively. Our modeling shows that the effect of mineral composition can appear superimposed on the polarization effect of the Stern layer, which coats the mineral grains.

PA02 Evaluation of low frequency polarization models using well characterized sintered porous glass samples

Jan Volkmann and Norbert Klitzsch, Applied Geophysics and Geothermal Energy, E.ON Energy Research Center

We assess the results of published theoretical and experimental findings regarding low frequency rock polarization for a reference system, consisting of sintered porous glass samples. Thereby, we benefit from well characterized samples, which allow for direct tests of theoretical predictions and empirical relations. We find that: (1) The correlation σ''~Sm is stronger than σ''~Spor for a wide range of fluid conductivities and frequencies above 1 Hz. (2) Correlation coefficients for the imaginary conductivity to inner surface area relations are strongly frequency dependent. (3) Normalized chargeability, obtained by fitting a Cole–Cole model to the spectral data, provides a fair alternative to single frequency information. (4) Salinity dependence of proportionality factors a1=Sm/σ'' and a2=Spor/σ'' due to a salinity dependent partition coefficient is confirmed qualitatively. Quantitative theoretic predictions of a1 or a2 fail due to the assumption of non-reduced Stern layer mobility for clay free silica. (5) Earliest grain size related models provide the best quantitative estimate of relaxation time. (6) Results agree well with published data for sands and sandstones with respect to (i) quantitative estimates of a1 or a2 and (ii) influences of rock structural parameters on relaxation time.

PA03 SIP of the three-phase system CO2-brine-sand under reservoir conditions

Jana H. Börner, Volker Herdgen, Jens-Uwe Repke, Klaus Spitzer, TU Bergakademie Freiberg

We present laboratory measurements of the spectral complex electrical conductivity of water-bearing sand samples during exposure to and flow-through by carbon dioxide. Pressures up to 300 bar and temperatures up to 80°C were applied. Steady-state experiments serve for investigating the physicochemical equilibrium of the fluid phases. Dynamic experiments aim at analysing the impact of partial saturation and chemical interaction on complex conductivity.

The steady-state dissolution experiments show that be-sides the conductivity-increasing dissociation a second opposing process may be observed, which results in a significant reduction of conductivity at high salinities despite the added CO2. We explain our observations with a semi-analytical formulation for the electrical conductiv-ity taking into account the interactions of ion and neutral species.

A significant reduction of saturation is observed during CO2 flow and drainage. The spectral complex conductivi-ty maps both changes in saturation and chemical interac-tion. Including the semi-analytical correction for pore-water conductivity allows for a good reconstruction of saturation from SIP-measurements. Additionally we get access to an indicator for changes of the inner surface area, which is related to mineral dissolution or precipitation processes.

PA04 Predictive relationships for the permeability of unconsolidated sands based on SIP and pore surface fractal dimensions

Malcolm Ingham and Sheen Joseph, Victoria University of Wellington

We present calculations of specific internal surface (S_{por}) and pore surface fractal dimension (D) based on measurements on unconsolidated sand samples. It is found that for these samples, for which the effective hydraulic radius is greater than $10\ \mu m$, $D \approx 2$ and the generalized PaRiS model of Weller et al. (2015) gives a good prediction of permeability both for the unconsolidated samples and for the sandstone samples reported by Zhang and Weller (2014). We use fitted relationships to S_{por} for both the SIP time constant (τ) and the measured imaginary part of the conductivity at a frequency of $1\ Hz$ (σ'') to deduce predictive relationships for permeability based on τ and σ'', on the assumption that $D = 2$. These relationships both overestimate permeability but improved predictions are obtained by using a slightly lower value of D commensurate with the average of the calculated values.

PA05 Induced polarization of seafloor massive sulfides

*Andreas Hördt, Katharina Bairlein (TU Braunschweig), G. Spagnoli (Bauer Maschinen GmbH), M. Jegen, M. Hannington, S. Petersen, T. Laurila (GEOMAR Helmholtz Centre for Ocean Research)*We investigate under which conditions membrane polarization might be relevant for realistic pore space geometries. We review some basic properties of the theoretical model and illustrate general constraints by modelling studies. We focus on geometrical parameters of the model, e.g. radii r and lengths L of two cylindrical pores. In principle, a wide range of spectra can be generated, covering orders of magnitude in both maximum phase shift and characteristic time scales. One ingredient to obtain large phase shift is a small radius of the narrow pore in the range of tens of nm. Time scales are mainly controlled by pore lengths. Generating large time scales and phase shifts at the same time in principle requires large ratios between pore lengths and radii. However, within the four-dimensional parameter space, which exhibits regimes of different behaviour, examples can be found where moderate L/r ratios (10:1) can produce time scales in the range of seconds with phase shifts of a few mrad. The results encourage further attempts to combine impedances of 2-pore systems to approach the simulation of real rock systems.

PA06 On the α-polarization of bacterial suspensions: SIP measurements on E. coli K12 and Rhodococcus erythropolis T902.1

Tamara Pilawski (University of Liège), Wolfgang Tappe (Forschungszentrum Jülich GmbH), Egon Zimmermann (Forschungszentrum Jülich GmbH), Johan Alexander Huisman (Forschungszentrum Jülich GmbH), Frank Delvigne (University of Liège), Frederic Nguyen (University of Liège)

The influence of bacteria on the electrical properties of porous media has been explained by different mechanisms. A few studies have also reported direct bacterial polarization using measurements on bacterial suspensions at frequencies below 10 kHz, so-called α-polarization. These measurements were performed by dielectric spectroscopy techniques relying on two electrodes and models to correct for electrode polarization at low frequencies. We performed complex conductivity measurements on bacterial suspensions from 0.01 to 45,000 Hz with an impedance spectrometer (phase accuracy better than 0.1 mrad below 1 kHz for a measurement on water) that used four-point measurements and thus does not require large corrections for electrode polarization). Two strains were studied: Escherichia coli (Gram-negative bacterium) and Rhodococcus erythropolis (Gram-positive bacterium). The imaginary parts of the complex conductivity of suspensions of both strains were very similar to the one of water. These preliminary results suggest that microbial alterations of the complex electrical conductivity measurements of porous media observed in previous studies are more likely related to other mechanisms than α-polarization of the bacteria, such as bioclogging, biomineralization, and growth and attachment of microbial cells to the sediment grains. We are planning to test additional strains to verify these results.

PA07 www.sip-archiv.de – an internet based, interactive archive and database for SIP data

Matthias Halisch, Jens Gramenz, Lothar Gorling, Klaus Krause, Iakov Bolotovski, Leibniz Institute for Applied Geophysics (LIAG)

Long-term storage of scientific data has become a topic of utmost importance for the scientific community. Due to European and national (here: German) initiatives, new guidelines and laws have been validated to ensure a reliable storage and documentation of scientific primary data. As a result of a workshop and discussion round of the working committee induced polarization (AK-IP) of the German Geophysical Society (DGG), the Leibniz Institute for Applied Geophysics (LIAG) accepted the challenge to develop and create a safe, free and easy to use, internet based database and archive for SIP measurements.

PA08 Methods for measuring the complex resistivity spectra of rock samples in the context of mineral exploration

Tina Martin (Federal Institute for Geosciences and Natural Resources (BGR) Stephan Costabel Federal Institute for Geosciences and Natural Resources (BGR), Thomas Günther (Leibniz Institute for Applied Geophysics (LIAG)

For the geophysical exploration of mineral resources knowledge about petrophysical parameters of the expected investigation material is essential. If it is not possible to measure samples in a common geometry, new approaches have to be developed. In this preliminary study three approaches for adequate and proper measurements of spectral induced polarization at rock samples are introduced. First results show that additionally to the measurement in a common 4-point measuring cell, also measurements with stuck electrodes connected to rock samples with irregular geometry seem to be promising. Furthermore the detection of a buried antimonite sample in a sand-box could be demonstrated by the strong phase anomaly it produced. Nevertheless further investigations are necessary, such as considering possible anisotropy effects and verification of the methods for a broader range of samples with irregular geometry. Also the electrode material for the measurements in the sandbox should be modified to avoid unwanted polarization effects. In addition, alternative materials for coupling the electrodes directly to the rock surface will be tested in the future.

PA09 Influence of plant roots on induced polarization of cultivated soil columns

Sophie Maloteau (UR TERRA, Gembloux Agro-Bio Tech, ULg), Guillaume Blanchy (Gembloux Agro-Bio Tech, ULg), Frédéric Nguyen (Bât. B52/3 Géophysique appliquée), Sarah Garré (UR TERRA, Gembloux Agro-Bio Tech, ULg)

Here the influence of plant roots on geophysical measurements is tested. For this purpose, electrical resistivity (ER) and induced polarization (IP) measurements are conducted on cultivated soil columns with one plant of Brachypodium.The preliminary results in known media show that acceptable values are obtained from the IP measurements. Even though, we are still testing the specific impact of the electrodes and the column layout on the IP measurements, the decay curves display the expected form and behaviour. The results from this experiment will give us a first idea of the ability of IP to serve as a proxy for the presence of roots in a column. This, combined with ERT and TDR measurements, should lead us to a better understanding of the electrical signature of bulk soil with roots at different soil moisture levels.

PA10 Concept of our New Multi-Channel SIP Instrument: SIP256D

Tino Radić (www.radic-research.de)

The quality of SIP measurements is largely determined by the hardware concept of the measuring instrument. High frequency impedance measurements are only possible with the shortest possible current and potential cables. For this, the transmitter should always be located at the electrodes. The current and potential measurement should also be carried out directly at the corresponding electrodes. Our newly developed instrument SIP256D satisfies all these requirements.

PA11 Spectral Inversion of SIP field data using pyGIMLi/BERT

Thomas Günther, Leibniz Institute for Applied Geophysics (LIAG), Tina Martin (Federal Institute for Geosciences and Natural Resources (BGR), Carsten Rücker (Berlin Institute of Technology

With the developing SIP instruments there are increasing applications of spectral induced polarization in the field. The spectral content of the electric parameters has the potential of characterizing the subsurface and must therefore be retrieved from inversion. Up to now there is no open available inversion package for researchers. We present the open-source library pyBERT, a C++-Python library for inversion of field resistivity data. It is able to analyse the measured spectra with a variety of different approaches. A Python manager class allows non-programmers to access and visualize in different ways and includes pre-processing of the data as well as post-processing of results, e.g. fitting Cole-Cole models.

We give an impression on how to use these codes and present results based on a synthetic model demonstrating that spectral parameters can be reliably retrieved.

PA12 On the Effectiveness of 1D Inversions of TEM Data affected by Induced Polarization

Marc Seidel and Bülent Tezkan (Institute of Geophysics and Meteorology, University of Cologne)

In case of a polarizable subsurface, effects of inductively induced polarization (IP) can have an impact on timedomain electromagnetic measurements (TEM) and may lead to nonmonotonous voltage responses or even sign reversals in the recorded transients. For this reason, we developed a new 1D inversion algorithm for the centralloop and the separate-loop TEM configurations using the Cole-Cole relaxation model. 1D forward calculations for a polarizable homogeneous half-space were conducted with the aim of analyzing the impacts of varying Cole-Cole parameters on TEM transients with respect to possible sign reversals.Additionally, we considered the variation of geometrical parameters like the transmitter size and the receiver offset. For the inversion of TEM data, one consequence of these modelings is the large number of equivalences that arise from the additional Cole-Cole parameters. Subsequently, 1D inversions of synthetic data were performed to study the potentials and

limitations of the new inversion algorithm regarding the resolution of the Cole-Cole parameters. The obtained findings were eventually adopted on the inversion of real TEM field data that contained considerable IP signatures such as sign reversals. One field dataset was recorded at the Nakyn kimberlite field in Western Yakutiya, Russia in the central-loop configuration. The second field dataset originates from a waste site in Cologne, Germany, and was measured utilizing the separate-loop configuration

PA13 Characterization of Abandoned Mine Tailings by means of Time- and Frequency-Domain Induced Polarization Imaging

Jakob Gallistl, Adrian Flores Orozco, Matthias Bücker (TU-Wien)

Induced Polarization (IP) imaging datasets were collected in both time domain (TDIP) and frequency domain (FDIP) for the characterization of abandoned mine-tailings and in order to assess possible down-gradient transport of sulphide minerals. The study area is characterized by measurable iron and copper concentrations of fine-grained minerals (gain size < 1 mm), which are expected to cause a distinct IP response. This study aims at the evaluation of the applicability of TDIP and FDIP at the field scale, its capability to quantify metallic volumetric content and to discriminate between different metallic minerals. Furthermore, the analyses of water samples down gradient from the tailings have revealed significant concentrations of heavy metals, such as arsenic and mercury. Hence, imaging results of an extensive mapping campaign were used to delineate preferential flow paths of sulphides and the extensions of the contaminated volume.

PA14 2D Cole-Cole Inversion of Time-Domain IP Data Measured in Krauthausen, Germany

Hannah Langenbach, Bülent Tezkan (Institute of Geophysics and Meteorology)

In October 2012 and 2013 overall 14 time domain IP profiles were measured in Krauthausen, Germany using the Terrameter LS. A gradient array with an electrode distance of 2.5 m was used. The data quality conforms to the high requirements of the inversion algorithm. Time series were measured at every profile for at least 200 electrode combinations. Every time series consists of 7-11 transients. For inversion of our IP time series we use the time dependence of the resistivity and evaluate the Cole-Cole models in time domain. Using an approximate solution the forward model for every time point is solved directly in time domain and independently from each other. For each cell a composed transient is inverted into a homogeneous Cole-Cole model independently of each other. We were able to achieve a satisfying Cole-Cole model for the survey area. A two layer resistivity model is estimated. The second more resistive layer is also more chargeable. Model areas with high chargeability are correlated with areas with higher frequency exponents and higher relaxations times.

PA15 Mapping the lithotypes using the in-situ measurement of time domain induced polarization: El-log

Esben Auken, Gianluca Fiandaca, Anders V Christiansen, Pradip Kumar Maurya, Helle Holm(Department of Geoscience, Aarhus University)

This study presents a novel application of the El-log-drilling technique for measurement while drilling of the DC, time domain IP and gamma log. In addition pore water samples can be taken at arbitrary levels. The technique itself is developed in Denmark and has been widely used in the field of ground water and environmental studies. The El-log drilling method yields detailed information on small changes in lithology, sediment chemistry and water quality and with data comparable to what can be obtained in the laboratory.

We collected the data at a landfill site located near Grindsted in the southern part of Denmark. The purpose of the study was 1) to obtain a direct correlation between the undisturbed geophysical logs and surface measurements, 2) correlation of IP parameters to lithology and grain size distribution and 3) to investigate any correlation with effluent and IP parameters. We inverted the recorded resistivity and IP decays using full decay modelling with the Cole –Cole model and found that the chargeability correlates very well the clay content in the sandy aquifer.

PA16 Is the IP response related to geology or contaminants in a leachate plume at the Grindsted Landfill, Denmark?

Ingelise Møller (GEUS), Pradip K. Maurya (Department of Geoscience, Aarhus University), Nicola Balbarini (Technical University of Denmark), Gianluca Fiandaca (Department of Geoscience, Aarhus University), Anders V. Christiansen (Department of Geoscience, Aarhus University), Helle Holm (Department of Geoscience, Aarhus University),, Vinni K. Rønde (Technical University of Denmark), Knud E.S. Klint (GEUS), Esben Auken (Department of Geoscience, Aarhus University), Poul L. Bjerg (Technical University of Denmark)

Contaminants in leachate plumes from landfills and other contaminated sites are a threat to the environment. Efficient site characterization methods are needed. The perspectives of the IP method are investigated in combination with geological sampling and chemical analyses of water samples. Along a leachate plume from a landfill hosting both household and chemical waste, borehole IP data, geological samples, grain size, and contaminant concentrations in water samples are examined for correlations related to geology and concentrations of contaminants. Results relating the Cole-Cole parameters with sediment types and pore water resistivity representing the concentrations of the contaminants show that the formation resistivity primarily is controlled by

the contaminant concentrations while the IP parameters primarily are related to the clay content and grain size distribution of sandy sediments at the site.

PA17 Mapping and characterization of Induced Polarization in airborne TEM data from central East Greenland – application of a Self-Organizing Map procedure

Anaïs Brethes (GEUS), Thorkild M. Rasmussen (Luleå University of Technology), Pierpaolo Guarnieri (GEUS), Tobias Bauer (Luleå University of Technology),

Induced Polarization (IP) effects were observed in airborne Time Domain EM (TEM) data acquired in central East Greenland in the context of exploration for disseminated sulphides in a sedimentary basin. Some of the IP anomalies were targeted by drilling which revealed the absence of mineralization. In order to understand the possible causes of the IP effects we first identified them in the TEM data. IP indicators were extracted from the shape of the transient curves at every measurement location and were analysed by using a Self-Organizing Map (SOM) procedure. Results from K-mean clustering of the SOM are visualized on a geographical map showing the transient curves' characteristics. Some of the clusters are clearly correlated with the geology whereas others merely reflect recordings below the noise level. In order to interpret the cause of the IP anomalies the airborne TEM data were inverted for the Cole-Cole parameters.

Tuesday 7 June

Session B – Morning
Chairs: Adrian Flores-Orozco & Yuxin Wu

9:00 – 9:25

B01 SIP time constant based petrophysical relations for two sandstone formations: the role of pore volume normalized surface area

Judy Robinson (Rutgers University-Newark), Lee Slater (Rutgers University-Newark), Kristina Keating (Rutgers University-Newark), Beth Parker (University of Guelph, CA), Carla Rose (University of Guelph, CA), Tonian Robinson (Rutgers University-Newark)

Recent models propose the prediction of permeability for spectral induced polarization (SIP) data using estimates of formation factor and a hydraulic length scale related to fluid flow based on either a dominant relaxation time (τ) or a representative imaginary conductivity (σ''). We acquired SIP and supporting petrophysical data on two sandstone fractured rock sites in the United States. The time constant based model describes the permeability reasonably well from one site that is characterized by relatively low values of pore volume normalized surface area (S_{por}). However, the fitting is poor for the samples from the second site that are characterized by higher values of S_{por} and a wider variation in S_{por}. We find that imaginary conductivity is related to S_{por} and that our samples are consistent with a previously defined empirical relation determined for a wide range of samples spanning multiple datasets. We also find that imaginary conductivity of our samples is correlated with permeability, supporting the application of models based on the formation factor (F) and σ''. However, such models involve F raised to a large exponent, meaning that highly accurate estimates of the formation factor are needed for reliable permeability prediction.

9:25 – 9:50

B02 Identifying pollutants in soils using spectral induced polarization

Idit Shefer (Technion), Nimrod Schwartz (Catholic university of Louvain), Alex Furman (Technion)

The main objective of this study is to examine SIP as a tool for identifying and quantifying the presence of organic and inorganic pollutants in the soil. Several experiments were performed in this study. First the influence of a free-phase organic liquid on the SIP signature was examined on an unsaturated sandy loam soil. The added non-aqueous phase liquid (NAPL; decane) caused a decrease of the imaginary part of the soil's complex conductivity as well as the relaxation frequency. We suggest that membrane polarization is the main polarization mechanism responsible for these results. Altering the characteristic pore throat length, due to the interaction between water and decane, controls the SIP response when a free-phase compound is added to the system. Further, we used Loess soil (calcium rich) to investigate the SIP effect of several different organic pollutants and their mixtures, in order to examine the ability to distinguish them by the SIP method. The same trend of decreasing polarization was observed. However, the real part of the conductivity had a clear decrease when decane was added. The calcium rich environment had apparently contributed to the formation of different surface interactions of the polar organic compounds in the presence of decane. Furthermore, we present an artificial neural network classification with preliminary satisfying ability to indicate the existence of a specific contaminant. Third, the soil solution and adsorbed phase inorganic composition influence on the SIP signature was examined. A clear influence on the soil's electrical signature was observed. Coherent changes exist in the relaxation time and chargeability when the chemical composition of the soil was changed. Addition of divalent cation to the porous media causes an instantaneous shift in the relaxation frequency, while the polarization magnitude is affected in a more gradual way. Three types of data driven models to potentially predict inorganic species are introduced. Dominant species were fairly well predicted.

9:50 – 10:15

B03 Doubling the spectrum of time-domain induced polarization: removal of non-linear self-potential drift, harmonic noise and spikes, tapered gating, and uncertainty estimation

Per-Ivar Olsson (Engineering Geology, Lund University), Gianluca Fiandaca (Department of Geoscience, Aarhus University), Jakob Juul Larsen (Engineering, Aarhus University) Torleif Dahlin (Engineering Geology, Lund University), Esben Auken (Department of Geoscience, Aarhus University)

This paper presents an advanced signal processing scheme for time-domain induced polarization full waveform data. The scheme includes several steps with an improved induced polarization (IP) response gating design using convolution with tapered windows to suppress high frequency noise, a logarithmic gate width distribution for optimizing IP data quality and an estimate of gating uncertainty. Additional steps include modelling and

cancelling of non-linear background drift and harmonic noise and a technique for efficiently identifying and removing spikes. The cancelling of non-linear background drift is based on a Cole-Cole model which effectively handles current induced electrode polarization drift. The model-based cancelling of harmonic noise reconstructs the harmonic noise as a sum of harmonic signals with a common fundamental frequency. After segmentation of the signal and determining of noise model parameters for each segment, a full harmonic noise model is subtracted. Furthermore, the uncertainty of the background drift removal is estimated which together with the gating uncertainty estimate and a uniform uncertainty gives a total, data-driven, error estimate for each IP gate. The processing steps is successfully applied on full field profile data sets. With the model-based cancelling of harmonic noise, the first usable IP gate is moved one decade closer to time zero. Furthermore, with a Cole-Cole background drift model the shape of the response at late times is accurately retrieved. In total, this processing scheme achieves almost four decades in time and thus doubles the available spectral information content of the IP responses compared to the traditional processing.

10:15 – 10:30

Break

10:30 – 10:55

B04 An analysis of Cole-Cole parameters for IP data using Markov chain Monte Carlo

L. M. Madsen, C. Kirkegaard, G. Fiandaca, A. V. Christiansen, and E. Auken (Department of Geoscience, Aarhus University)

The Markov chain Monte Carlo (MCMC) method is used to invert time-domain induced polarization (TDIP) data. A novel random-walk algorithm samples models from a probability distribution based on a realisation of the model covariance matrix, allowing the algorithm to vary step lengths according to parameter uncertainty. The algorithm was found to converge to the posterior distribution over one hundred times faster than a standard Gaussian distributed model proposer. Synthetic TDIP data, simulating homogenous half spaces and three-layer models, are inverted using the MCMC method. The results show bell-shaped posterior distributions for all spectral Cole-Cole parameters with clear correlations between the parameters. Small values of the frequency exponent (C) are found to decrease the resolution of the model parameters. A comparative analysis between the standard deviations of the MCMC posterior distributions and the results of a linearized inversion shows that the linearized approach works well with well-resolved model parameters. We have compared inversion results of different acquisition times and current waveforms. We found that as the time range decreases the parameter correlations become nonlinear and the parameters become poorly resolved or completely unresolved. Combined, the inversion results show that it is possible to extract the spectral Cole-Cole parameters from time-domain IP data and that a linearized approach is justified for a sufficient acquisition range.

10:55 – 11:20

B05 Simulation of membrane polarization for 2D and 3D pore networks

Hermann Stebner Andreas Hördt (TU Braunschweig)

We extend an existing membrane polarization model to 2D and 3D pore combinations networks, which are numerically solved to obtain an overall SIP response. We investigate the behaviour of these networks by varying the distribution function of the pore combinations and the size of the network. Equally distributed pore combinations show a dominance of high phase shifts. For empirically distributed combinations, obtained from measured pore radii distributions, high phase shifts tend to dominate only in big 3D networks. Our simulations show that for networks, which are comparable to real rocks, higher maximum phase shifts than the mean of the original pore combinations are possible. The results suggest that networks may allow a simulation of more realistic pore geometries than the original 2-pore system.

11:20 – 12:00 **Poster Presentations – session B**

Presentations of all the posters of session B (two minutes for each presentation).

The list of posters can be found at the end of the day's program

12:00 – 13:00 **Lunch & Poster session B**

Session B – Afternoon
Chairs: Jakob Juul Larsen & Lee Slater

13:00 – 13:25

B06 Lithological characterization of a contaminated site using Direct current resistivity and time domain Induced Polarization

Pradip Kumar Maurya, Gianluca Fiandaca, Esben Auken and Anders Vest Christiansen (Department of Geoscience, Aarhus University)

Characterization tools for contaminated sites have become advanced with the continued development of geophysical methods. Resistivity methods and time-domain induced polarization methods have proven their capability to delineate the subsurface properties by complementing each other. In the present study a large contaminated site in Denmark was investigated using direct current resistivity and time domain induced polarization (DCIP). For this purpose 14 profiles were collected alongside a stream in order to investigate the contamination and delineate the lithological units. 2D inversion using a cole-cole model of two selected profiles are presented. They show that the resistivity model alone cannot depict the geology as inferred in the borehole. However, when including the models of chargeability and mean relaxation time the geological units are clearly defined, which helps in identifying the possible contaminations.

13:25 – 13:50

B07 Spectral induced polarization of sand-biochar mixtures: experiments and modeling

Z. Gao, F.-H. Haegel, J.A. Huisman and H. Vereecken (Institute of Bio- and Geosciences, Agrosphere)

Biochar attracts increasing research interest due to its potential for agricultural and environmental purposes such as soil amendment and greenhouse gas reduction. To better monitor and investigate biochar in soil, non-invasive measurement approaches that can be applied in the laboratory and at field scale are needed. The goal of this work is to examine the sensitivity of the spectral induced polarization (SIP) method to the presence of disseminated biochar in sand. We investigate the complex electrical conductivity of saturated mixtures of sand and sieved biochar, and use a mechanistic SIP model that accounts for the redox reactions at the surface of the polarized particles to invert the measured data. The magnitude of the measured complex electrical conductivity showed a positive correlation with the mass fraction of biochar, while the peak frequency of the imaginary part showed a negative correlation with the particle size of the biochar. The model provides reasonable fitting results for low mass fraction of biochar in the mixtures.

13:50 – 14:15

B08 Numerical correction of phase errors due to leakage currents in wideband EIT measurements

E. Zimmermann (Central Institute for Engineering, Electronics and Analytics, Electronic Systems), J. A. Huisman (Institute of Bio- and Geosciences, Agrosphere), A. Mester and S. van Waasen (Central Institute for Engineering, Electronics and Analytics, Electronic Systems)

Advanced model-based data correction methods are needed in order to determine the small phase response of low-polarizable soils and rocks in the higher frequency range up to 10 kHz. Methods have been developed to correct several system-dependent errors, such as amplification errors, signal drift, current measurement errors, potential measurement errors due to high electrode impedances, propagation delay of the signal due to the long cables, and phase errors introduced by inductive coupling between the electrode cables. However, measurements at test sites with high resistivity have shown a new dominating phase error, which was found to be related to capacitive leakage currents between system ground and the soil. In order to correct this error, we enhanced the FEM modelling used for the reconstruction of the electrical conductivity distribution. Using this new formulation of the FEM forward model, this source of error was reduced by a factor of five or more. This enables an electrical conductivity reconstruction for frequencies up to 10 kHz. In future work, it will be investigated whether the capacitive leakage currents can be reduced by optimization of the cable layout. In any case, it is helpful to use the leakage current as a proxy for data error during data filtering, and it can also be used to decide if the enhanced FEM model presented here should be used.

14:15 - 15:15 **Poster session B**

15:15 – 15:40 **B09 Comparison of Cole-Cole and Constant Phase Angle modeling in time-domain induced polarization**

Myriam Lajaunie (EOST, Ecole et Observatoire des Sciences de la Terre), Pradip Kumar Maurya and Gianluca Fiandaca (Department of Geoscience, Aarhus University)

The Cole-Cole model and the constant phase angle (CPA) model are two prevailing phenomenological descriptions of the induced polarization (IP), used for both frequency domain (FD) and time domain (TD) modeling. The former one is a 4-parameter description, while the latest one involves only two parameters. Choosing between a Cole-Cole description and a CPA one to invert a specific frequency domain data set is easy, since a look at the data is enough to estimate their spectral content. This is, however, not the case with TDIP data. This work aims at understanding how the spectral content is reflected in TDIP data, and therefore, at identifying (1) if and when it is possible to distinguish, in time domain, between a Cole-Cole description and a CPA one, and (2) if features of time domain data exist in order to know, from a simple data inspection, which model will be the most adapted to the data. Synthetic forward responses were computed for homogeneous Cole-Cole models, varying both time range of the modeled IP data and Cole-Cole parameters. Subsequently, CPA inversions were carried out on the Cole-Cole data. The inversion results show that it is generally possible to distinguish CPA and Cole-Cole models in time domain, except when the Cole-Cole frequency exponent is small (below 0.1) or for specific combinations of the Cole-Cole parameters. The distinctness increases with the time range of the IP data, but usually two decades in time are sufficient to distinguish the two models. Furthermore, forward modeling of quadrupolar sequences on 1D and 2D heterogeneous CPA models shows that the CPA decays differ among each other only by a multiplication factor. Consequently, the inspection of field data in log-log plots gives insight on the modeling needed for fitting them: the CPA inversion cannot reproduce the shape variability of the IP decays. Field examples of this latter result are presented.

15:40 – 16:05 **B10 Airborne IP for Kimberlite Exploration**

Douglas W. Oldenburg and Seogi Kang (University of British Columbia)

Negative transients in coincident loop airborne time domain electro-magnetic (ATEM) data have often been observed when exploring for kimberlite deposits. It is usually supposed that the negative transients arise from chargeable material such as surficial clays or ice in permafrost. As such, this EM signal is generally regarded as a “problem” in mineral exploration because it distorts the EM signals from the conductive kimberlites, and if not corrected for, results in an incorrect conductivity. However, chargeability could be reflective of the kimberlite, hence the induced polarization (IP) effects can be valuable “signal”. The ATEM surveys at the Tli Kwi Cho (TKC) kimberlite complex have been a testbed for illustrating the existence of negative transients and we focus on that region. The two pipes that constitute TKC have been extensively drilled and the resultant geologic models can be used to validate our inversion results. In addition, the complex impedance of TKC core samples have been measured in the laboratory and the results showed that the kimberlites can be chargeable and that different kimberlite units have different IP characteristics. In this paper, we first address the important issue about depth of resolution of buried chargeable bodies relevant to kimberlite exploration. After showing its potential we remove the EM effects from the IP data and invert them to recover 3D distributions of pseudo-chargeability at multiple time channels. The recovered pseudo-charge-ability at different times provides meaningful information about the diamondiferous portion of the pipe and distinguishes it from other kimberlitic rocks.

16:05 – 16:30 **B11 Geometrical constraints for membrane polarization**

Andreas Hördt, Katharina Bairlein and Hermann Stebner (TU Braunschweig)

We investigate under which conditions membrane polarization might be relevant for realistic pore space geometries. We review some basic properties of the theoretical model and illustrate general constraints by modelling studies. We focus on geometrical parameters of the model, e.g.

radii r and lengths L of two cylindrical pores. In principle, a wide range of spectra can be generated, covering orders of magnitude in both maximum phase shift and characteristic time scales. One ingredient to obtain large phase shift is a small radius of the narrow pore in the range of tens of nm. Time scales are mainly controlled by pore lengths. Generating large time scales and phase shifts at the same time in principle requires large ratios between pore lengths and radii. However, within the four-dimensional parameter space, which exhibits regimes of different behaviour, examples can be found where moderate L/r ratios (10:1) can produce time scales in the range of seconds with phase shifts of a few mrad. The results encourage further attempts to combine impedances of 2-pore systems to approach the simulation of real rock systems.

16:30 – 18:00 **Poster session B**

18:30 - **Workshop Dinner at:**

'Det Glade Vanvid'
Pakkerivej 2b
8000 Aarhus C.

Poster Session B:
Chair: Anders Vest Christiansen

PB01 New technology for delineation of resistive and polarizable kimberlite fissures using TEM method in South Africa

V. Hallbauer-Zadorozhnaya, Council for Geoscience

TEM sounding have been carried out in the Limpopo province, South Africa. The aim of the research is to delineate a kimberlite fissure in some portion of diamond fields. The edge of kimberlite fissure is located at the depth about 20-25 m. Rocks composed the fissure, are quite resistive, polarizable and have low susceptibility. TEM survey had been performed along 10 profiles, all of then crosses the fissure but delineation of fissure had to be done with very high accuracy (about 2-3 meters in lateral). Using TEM FAST 48 we observed that the fissure should be seen at least twice when both sides of square loop locates above the fissure. Using instrument Tsickl 5 and horisontal magnetic dipole we obtained more stronger signals related to the fissure. This phenomenon relates to the theory of electromagnetic field proporation on ingemoginated media. Mathematical modeling of dipped/vertical S plane overlapped by horizontal S plane (both can be polarizable) for both components dBz/dt and dBy/dt have been calculated. The result shows that the preferable TEM configuration for searching quasi vertical objects is large transmitter loop and horizontal magnetic dipole. We are proud to tell that following drillings of seven boreholes opened the fissure in all proposed points.

PB02 Different kinds of IP effects and laboratory measurements samples

V. Hallbauer-Zadorozhnaya (Council for Geoscience), G Santarato (University of Ferrara) L. Maré ((Council for Geoscience)

Several kinds of Induced Polarization (IP) effects occur and will be reviewed in the present paper, namely electrosmosis effect, membrane polarization, Maxwell-Wagner effect and electrolytical polarization. All effects are based on different physical phenomena. The electrosmosis processes occur in all rocks/sediments. However the amount of double electric layer plays the major role. This phenomenon is described by Helmholtz-Smoluhowsky equation and is linear. Decay constant of electrosmosis process is usually in range 10-6-10-2 s and can be mostly observed on Transient Electro-Magnetic (TEM) signals. The membrane polarization is based on constrictivity of pore. When an electrical current flows through rocks containing channels and pores with different sizes, an excess/loss of ions accumulates at the boundaries. The homogeneous diffusion equation, with specified (non-linear) boundary conditions, has been used for solving this problem. This type of polarization is non-linear, depends on applied current and may depend on current pulse length (in TEM method). Duration of membrane polarization can reach 10 s and more. Maxwell-Wagner model consists of isolated pores. The homogeneous diffusion equation also has been used for solving the problem of ions distribution in the pores. However the boundary conditions are linear. The ions move in the pores with constant velocity and accumulated the neighbour of the pore ends. Duration of process of redistribution is comparable with duration of the electro osmosis process. The pores with unallocated ions may be represented by an equivalent electrical circuit (a capacitor). The Cole-Cole or capacitor discharging formula can be used to describe the effect. Numerous laboratory measurements of different types of rocks and minerals and some field TEM data demonstrate different kinds of IP effects.

PB03 Relationship between Cole-Cole model parameters and spectral decomposition parameters derived from SIP data

Maximilian Weigand and Andreas Kemna (Department of Geophysics Steinmann Institute)

Spectral induced polarization (SIP) signatures are ana-lyzed using different phenomenological model descrip-tions. One approach uses the Cole-Cole (CC) model, or variants of it, to describe one or several distinct polariza-tion peaks. The other approach yields a relaxation time distribution (RTD) by using a decomposition procedure which describes SIP data by a superposition of a large number of polarization terms. Based on this RTD, inte-gral spectral parameters similar to CC model parameters can be derived. We here compare chargeability and relax-ation time parameters, obtained with Debye and Warburg decomposition approaches, with the original CC parame-ters used to generate synthetic SIP data. Understanding the relationship between CC decomposition parameters helps to prevent interpretation errors when results from both approaches are combined. We identified potential underestimations of the CC chargeability by up to 80% and deviations of $\tau mean$ from the CC relaxation time by up to three orders of magnitude. These results highlight the importance of consistent SIP data analysis procedures.

PB04 Temperature dependence of complex surface conductivity

Katharina Bairlein and Andreas Hördt (Institute of Geophysics and extraterrestrial Physics TU Braunschweig)

The complex electrical conductivity of water-saturated rocks, measured with induced polarization (IP), is affected by temperature. The main reason for the temperature dependence of fluid conductivity is that the mobility of the ions in the pore fluid is increased with temperature. In addition to the fluid conductivity, surface conductivity is influenced by temperature, but it is not investigated yet, which parameters of the rock surface and the fluid are the dominating factors.

We measured the complex electrical conductivity of a sandstone sample at temperatures between 0 and 40 °C and ion concentrations from 1 to 2000 mol/m3. From measurements at high salinities, we are able to separate surface conductivity from the real part of bulk conductivity and to determine its dependence both on temperature and salinity. The experimental results are compared to calculations of a membrane polarization model.
We use a Walden exponent as a measure of the strength of the temperature dependence. The Walden exponent of the real part of surface conductivity increases, while the Walden exponent of the imaginary part slightly decreases with increasing salinity. Calculations with the model predict a decrease in both the temperature dependence of the real and imaginary part of conductivity. The measured and calculated surface conductivities show, that temperature dependence in the electrical double layer cannot be attributed to an ion mobility similar to the mobility in the free electrolyte.

PB05 Complex Resistivity for Dynamic Imaging of Plant Root Traits and Root – Soil Interactions

Yuxin Wu Susan Hubbard Baptiste Dafflon (Lawrence Berkeley National Lab)

Electrical methods (complex resistivity and ERT) are explored for plant root trait imaging and the study of dynamic root – soil interactions. The links between the moisture dynamics, root architectural and morphological traits and electrical properties of the plant roots and root zone soil are established for a deciduous plant (Acer palmatum) under controlled temperature and soil moisture conditions. Specifically, resistivity – moisture correlation is closely linked with the plant's seasonal growth cycle and the effects of the roots on soil resistivity are evident. In addition to deploying previously tested configurations under controlled laboratory conditions, we employed novel imaging strategies that utilize root systems as distributed electric transmitters to quantify critical root structural and morphological traits and their responses to variable soil and climatic conditions. The links between root architectural (root distribution, rooting depth) and morphological traits (root mass, effective root area) and root dielectric signals are clearly demonstrated during the different stages of plant growth, indicating the dynamic changes of root activity in response to water and nutrient needs and availability during different stages of plant growth. These results demonstrated the potential of electrical methods for the study of root zone dynamics, which can lead to a new direction in developing much needed, minimally invasive and in-situ root phenotyping tools with broad application in terrestrial carbon cycle, forestry and agricultural studies.

PB06 SIP response of compacted natural and lime-cement-treated loam

Carole Kaouane (CEREMA-Normandie Centre), Michel Chouteau (Ecole Polytechnique de Montreal), Philippe Côte (IFSTTAR – Nantes)

We investigate the applicability of Spectral Induced Polarization (SIP) to geotechnical engineering for assessing soil compaction. We make two groups of samples at different compaction levels: group N is made from a silty loam and group T is from the same loam treated with 1% lime and 5 % cement. Groups show distinct complex conductivity spectrums. Debye decomposition is applied to the measured data and we extract the relaxation time distribution (RTD). Group-N samples show an increase of total chargeability M with an increase in saturation and no dependence of the mean frequency on saturation, while group-T samples show a decrease of M and an increase of the mean frequency with an increase in saturation. We suggest that the compacted loam possesses a continuous conductive matrix composed of saturated silt aggregates. We cannot derive firm conclusions on group-T samples because of the possible chemical reactions, which transform the porous matrix of the samples. The observation of the RTD could be a practical tool to monitor those reactions.

PB07 Sodium Persulfate In Situ Chemical Oxidation monitored by geophysical and geochemical methods : laboratory work

T. Maury,M. Franceschi, M. Schmutz (ENSEGID, EA 4592 G&E, Bordeaux University)

Hydrocarbon contamination represents the main situation of polluted sites in France (64%). Among the different technics that are developed for remediation, In Situ Chemical Oxydation (ISCO) showed interesting results in laboratory and field contexts. Anyway, the technic is perfectible and there is a need for an easier and cheaper way to monitor the efficiency and the quality of ISCO remediation. By injecting a strong conductive solution, ISCO seems to be a good candidate for geoelectrical monitoring. Thus, the aim of our study is to evaluate the possibility to monitor ISCO remediation by geoelectrical signals thanks to our laboratory work. For the present study, the chosen hydrocarbon is decane and the oxidative solution is sodium persulfate. The electrical signal of this mixture is monitored in a sample holder within three different media (sands, clayish sands and sands with organic matter). A second sample holder where no oxidative solution is added, is used as reference. During the hydrocarbon degradation, resistivity, IP signal and spontaneous potential will be measured as well as various geochemical parameters of the solution (reactants concentrations, pH, alcalinity, temperature,...) or known to influence ISCO efficiency. The first goal of our experiment is to compare electrical signal variations and geochemical variations to understand the links between both. Then, the second goal is to modelize the phenomenon that take place during the ISCO reaction between decane and sodium persulfate and the signal created. We expect to highlight

possibilities to monitor ISCO reactions by in situ geophysical measurements. Our presentation will deal with the working methodology, flow processing and will present the first results.

PB08 Geoelectrical monitoring during waste biodegradation process

Jouen Thomas, Clément Rémi, Mazéas Laurent (National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA), Loisel Simon (SAS Les Champs Jouault), Moreau Sylvain (IRSTEA)

The aim of this experiment is to provide tools that allow characterisation of waste biodegradation state at a laboratory scale. Four geophysical methods, self-potential, electrical resistivity, temporal and spectral induced polarization, will be monitored from the beginning to the end of municipal solid waste biodegradation cycle. For this reason five columns were filled with waste and equipped with measurement electrodes. The measurements were started in February and will continue until the waste has completely degraded.

PB09 The electrical signature of soils contaminated by heavy metals

Tamar Shalem (Technion), Renduo Zhang (Sun Yat-sen University), Alex Furman (Technion)

Soil and groundwater pollution in general, and by heavy metals in particular, is a major threat to human health, and especially in rapidly developing regions. Fast, accurate and low cost measurement of heavy metal contamination is of high desire. Spectral induce polarization (SIP) may be one alternative to the tedious sampling techniques typically used. The high sorption affinity of heavy metals suggests that their electrical signature may be significant, even at relatively low concentrations. The goal of this research is to examine the electrical signature of soil contaminated by heavy metals, in a non-tomographic fashion. This will be achieved by a series of laboratory experiments and development of data-driven screening model. The work-plan includes 'sterile' experiments looking at the SIP response of mono-ionic soil to various contaminants (heavy metals) and different concentrations, moving to complex contamination 'cocktails', ending with measurement of the SIP response of real contaminated soils (at the Pearl river delta, China). The poster will present the research plan in details and preliminary results of the SIP signature of several different heavy metals.

PB10 Permeability estimation of hydrocarbon reservoirs samples using Spectral Induced Polarization (SIP) and Nuclear Magnetic Resonance (NMR): a laboratory investigation

F. Razavirad (Yazd University), A. Ghorbani (Yazd University), M. Schmutz (ENSEGID, Bordeaux INP University), S. Galaup (ENSEGID, Bordeaux INP University), A. Binley (Department of Environmental Science, Lancaster University), L. Pigot (ENSEGID, Bordeaux INP University)

There is growing interest for using geophysical methods such as spectral induced polarization (SIP) and nuclear magnetic resonance (NMR). Permeability is a key parameter associated with the subsurface production and injection. The goal of this study is to investigate: 1) a relationship between permeability of sample plugs (obtained from a reservoir) and electrical and hydraulic parameters (quadrature conductivity, porosity, surface area per unit pore volume (Spor) and grain size distribution) and 2) permeability estimation of plugs using a joint model between SIP and NMR measurements. We also compare SIP and NMR porosimetry analysis. 30 plug samples have been provided by Iranian Offshore Oil Company (a subsidiary of National Iranian Oil Company). These relatively unconsolidated sandstone plugs have been cored from Soroush oil field located in Persian Gulf. As fluids, tap water and brine will be used for experiments. First, it is desired to study the effect of brine saturation on NMR and SIP responses. It is planned to saturate plugs with tap water (25, 50,75 and 100%) and perform NMR and SIP tests at each step. Next, brine is introduced to the plugs (the brine conductivity is 200, 400, 600 and 800 microsiemens per centimeter) and NMR and SIP response will be measured. These measurements will be done at different saturations.

PB11 On electromagnetic coupling of half-space from Spectral Induced polarization studies

Ahmad Ghorbani (Yazd University) , Myriam Schmutz (EA4592 Bordeaux INP – ENSEGID), K. Malekpour Dehkordi (Yazd University)

Spectral Induced Polarization (SIP) is widely used for environmental and hydrogeophysics, but one major limitation concerns the electromagnetic coupling effect. We investigated inductive coupling properties of a half-space with complex resistivity following the process: Cole-Cole parameters of half-space are used to calculate inductive coupling spectrum using Sunde equation. Then during an inversion process, a Cole-Cole function is superposed to the calculated inductive coupling impedance. At last, Cole-Cole parameters of inversion process (inductive coupling curve properties) are compared with Cole-Cole parameters of half-space. We noticed that the inductive coupling impedance (the integration of P function in Sunde equation) on the half-space with a Cole-Cole model shows a dispersion phenomenon only at higher frequencies while the mutual impedance shows at least two dispersion at both of lower and higher parts of spectrum (1 mHz to 10 kHz) relative to IP and inductive coupling. The results show that Dipole-Dipole parameters (a and n) and DC resistivity of half-space have significant effects on the inductive coupling spectrum. On the contrary, the polarization parameters of half-space (time constant, frequency dependency, and chargeability lower than 0.3) do not have a significant effect on the inductive coupling spectrum. These results show that the mutual impedance of a half-space (known DC resistivity) can be a good estimate of the

inductive coupling impedance if IP effects are not very large. In other words, IP effects of a half-space Cole- Cole model type can be obtained from subtraction of the mutual impedance of a half-space (SIP measurements) and the mutual impedance of a half-space without IP effects (calculation). The resistivity of half-space can be suggested from DC resistivity measurement or from the lowest frequency of real part of impedance. This process is applied to field data and through 2 field examples, we show the impact of inductive effects on real data.

PB12 Combined ERT and IP modelling for monitoring DNAPLs: preliminary results

Panos Tsourlos (Aristotle Univ. of Thessaloniki), Christopher Power (Cape Breton University), Jason Gerhard (Western University), Torleif Dahlin (University of Lund)

In this work we explore the potential of combined time-lapse ERT and induced polarization (IP) techniques for monitoring the remediation of DNAPL source zones. Recently, we have established a realistic DNAPL-geoelectrical ERT linkage model within the time-lapse monitoring framework and we are now seeking to extend this particular approach by also including IP time-lapse models.

In this framework, we propose a modelling approach and present the appropriate tools. Finally, we present preliminary ERT and IP models to investigate the potential of this approach. Preliminary results are encouraging and suggest that the focus needs to be given into a more advanced linkage model between DNAPL flow and the IP response.

BP13 Spectral induced polarization of the ore zone of the gold deposit Sukhoi Log

Andrey Tarasov (Saint Petersburg State University), Grigory Gurin VIRG-RUDGEOFIZIKA JSC)

The spectral induced polarization tomography (ERT-SIP) survey carried out on giant gold deposit Sukhoi Log (Russian, East Siberia). SIP was a part of comprehensive geological and geophysical surveys including geochemistry, gravity, ground magnetic, aerogeophysic (aeromagnetic and aero-gamma spectrometry) methods, audio-magnetotelluric sounding (AMTS) and self-potential method. These surveys provided in the 2013-2014s for testing of the modern searching technology of the gold deposits. The ERT-SIP in the time domain included two sets of IP measurements with different duration of the current pulses (1 s and 8 s). The complicated SIP data processing allowed to determine in geophysical term various morphological types sulfide mineralization.

BP14 Superimposed IP relaxations in sand and silty clay deposits measured in the time domain

Sara Johansson and Torleif Dahlin (Engineering Geology, Lund University)

While the low frequency response of time domain decays commonly can be fitted with a Cole-Cole model, early time gates corresponding to more than 50-100Hz in the frequency domain have been observed to deviate from this shape. Therefore, the aim of this paper is to evaluate if several relaxations can be distinguished and fitted with superimposed relaxation models. The results show that reasonable values can be extracted from two superimpose Cole-Cole models fitted to raw data measured at sand and silty clay. The high frequency relaxations can have their origin in short polarizable length scales or interfacial polarization mechanisms in the geological media. They could also, fully or partly, origin in coupling effects or the distribution of Cole-Cole parameters in the subsurface.

BP15 Spectral time-domain induced polarization and magnetic surveying – an efficient tool for characterization of solid waste deposits in developing countries

David Dotse Wemegah (KNUST University), Gianluca Fiandaca (Department of Geoscience, Aarhus University), Esben Auken (Department of Geoscience, Aarhus University), Aboagye Menyeh (KNUST University), (Sylvester Kojo Danuor (KNUST University)

Time-domain induced polarization (IP) and magnetic data were acquired to map and characterize the decommissioned, un-engineered, municipal solid waste deposit site of the Kwame Nkrumah University of Science and Technology (KNUST), located in the Kumasi Metropolis of Ghana. Thirteen induced polarization profiles 500-800 m long and twenty-six magnetic profiles 600-800 m long were acquired, and two drillings were carried out in order to help in the interpretation of the geophysical data. The study was carried out with the aim of determining the risk posed by the waste deposit to the quality of the soil and the groundwater system, which is the main potable water supply for the Secondary School, the University Teaching Hospital and the Veterinary School, situated within the catchment area of the site. Full-decay 2-D time-domain IP inversions in terms of Cole-Cole parameters were used for interpreting the polarization data. The chargeability, resistivity, and the normalized chargeability distributions, together with the magnetic results, aided in a full characterization of the site geology, the waste and the associated pollution plume. In particular, clear contrasts in resistivity and in the polarization parameters were found between the saprolite layer and the granite bedrock, the main lithological units of the area. Furthermore, it was found that the KNUST waste deposit is characterized by a low-chargeability and low-resistivity signature, and that the low-resistivity area spreads out from the waste deposit into the permeable saprolite layer, indicating the presence of a leachate plume. A fracture zone in the granite bedrock, which is at a risk of leachate contamination, was also identified. The research thus provides the information needed for assessing the future impact of the waste on the water quality in the area as well as for designing risk-mitigation actions.

BP16 Mapping possible flowpaths of contaminants through surface and cross-borehole spectral time-domain induced polarization

Thue Bording, Gianluca Fiandaca, Pradip Kumar Maurya,Esben Auken, Anders Vest Christiansen (Department of Geoscience, Aarhus University)

Traditional methods for mapping possible flowpaths of contaminants in sedimentary environments by boreholes may often be insufficient. Additional information may be acquired by geophysical methods. In the present study, cross-borehole and surface measurements were performed using time-domain induced polarization (TDIP). After measurements the entire test site was dug out, and the geology was described.
A 2D spectral inversion of the combined dataset is presented, which is in great correspondence with the observed geology.

BP17 Evaluation of copper mobility with SIP and geochemical analysis: First results

Luca Peruzzo, Myriam Schmutz, Susan Hubbard, Michel Franseschi (Lawrence Laboratory Berkeley)

The induced polarization (IP) has been shown sensitive to the adsorption of different cations at the laboratory scale. Extending these previous works we present the results of laboratory spectral induced polarization (SIP) measurements investigating the signature of Cu in natural soil samples taken from a vineyard in the Bordeaux area (Fr). The copper concentration is expected to be suitable for our purposes as a consequence of a long-term used of copper fungicides. Our work is supported by the access to the detailed historical register of the products used in the vineyard (treated subarea, day, type and amount of product used). Exploiting this information we will focus on a sloping area. The average slope is about 10% and it decreases towards the bottom. The upper part have been cultivated and treated since a longer time in comparison to the lower part. Thus, our working idea is based on two features: (i) part1 could present a higher copper concentration and (ii) the slope itself could cause a transfer of copper from the top to the bottom whose concentration in this case would increase. Then, both initial explorative ERT and IP field measurements and the consequent collection of the samples will be performed in order to investigate which one of the two previous hypotheses is dominant. Grain size distribution, specific surface area, mineral composition, organic matter content, moisture content, soil pH and Cu concentration are analysed to understand how these parameters affect the SIP response. By changing the Cu concentration and the moisture content we highlight their contributions to the induced polarization response compared to the other parameters which are kept constant. The results will be then combined in an empirical model able to predict the Cu IP signature supporting our investigation on the copper mobility and adsorption on the field.

BP18 Time-domain IP as a tool for observing processes in crystalline rocks?

Jaroslav Jirku (Faculty of Science in Prague), Jan Vilhelm (Faculty of Science in Prague), Jaroslav Barta(G IMPULS Praha spol. s r.o.)

Within the purview of our research we use electrical resistivity tomography (ERT) for long-term, non-invasive monitoring of processes occurring in granite mass, in the close vicinity of an underground excavation. Understanding of such processes can be used for deep geological repositories of nuclear waste. In the Czech Republic crystalline rocks are being considered as the host rock – therefore our in situ experiments are carried out in a granite gallery, directly on the rock wall. Apart from time-lapse apparent resistivity measurements we also measure induced polarization in time-domain. We believe that changes in apparent chargeability can provide additional information on processes and mechanisms in the zone around the gallery´s vault. Our in situ data consists of continuous measurements, when, simultaneously with apparent resistivity measurements, four 2D IP cross-sections per day (i.e. every six hours, approximately ¾ year in total) were collected. Our permanently placed layout consists of 48 stainless electrodes, with 20 cm spacing. Together with field data analysis we discuss possible methodology´s modifications, in terms of using time-domain IP in hard-rocks, i.e. mainly problems of stainless (polarizable) electrodes in high grounding resistance environment, limitations connected with the capacitive coupling phenomenon (in case of a single cable for potential and current loop), or electrode polarization´s appearance in the multichannel ERT protocols.

BP19 Application of spectral induced polarization method (SIP) at complex studying of low-contrast magnetic anomaly

V. Kulikov and A. Solovieva (Lomonosov Moscow State University)

The purpose of this study is to identify the various geophysical and geological section parameters by integrating electrical and magnetic exploration. The object of research is the Miocene paleovalley filled with deposits of clay, loam and sand. The complex geophysical work presented a detailed ground magnetic prospecting, electric profiling and spectral induced polarization method (SIP), which is based on the IP measurements at several frequencies. SIP method was carried out using a symmetrical four-electrode Schlumberger array with special spacing (AB/2) and step between points. This array allows to view data as a result of electric tomography and to carry out two-dimensional inversion. Particular attention was paid to section elements, which are characterized by high values of magnetic susceptibility and chargeability. For all the collected materials complex interpretation was performed, we

received two-dimensional model of resistivity and chargeability and held lithological core analysis. The main conclusion of our research is that the anomalies in the magnetic field and the high values of the induced polarization are due to the presence of finely dispersed iron compounds and the iron in amorphous form.

Wednesday 8 June

Session C
Chairs: Torleif Dahlin & Andreas Kemna

9:00 – 9:25

C01 Pore radius distribution and fractal dimension derived from spectral induced polarization

Zeyu Zhang (Southwest Petroleum University), Andreas Weller (Institut für Geophysik, TU Clausthal)

The pore radius distribution provides a suitable description of the pore space geometry that can be used to investigate the fractal nature of the pore space or to determine a fractal dimension. Fractal dimension describes the size of geometric objects as a function of resolution. It can be integrated into models of permeability predicting.

We investigated the fractal dimension of the pore space of 24 Eocene sandstone samples from China. We propose an approach to use induced polarization spectra to determine the fractal dimension of the pore space. Debye decomposition was used to determine the relaxation time distribution from the spectra The relaxation time was transferred into a curve showing the cumulative volume intensity as a function of pore radius. The slope of this curve in double logarithmic presentation indicates the fractal dimension. Additionally, the fractal dimension was derived from data of the capillary pressure curves from mercury intrusion and the transversal relaxation time distribution of nuclear magnetic resonance. The results were compared and discussed. For samples with an effective pore radius larger than one micrometer, good agreements exist between the values of fractal dimension derived from the three different methods.

9:25 – 9:50

C03 2D DCR/TDIP Two-step Inversion: Detectability of ore deposits and Depth of Investigation

Juliane Adrian and Bülent Tezkan (Institute of Geophysics and Meteorology, University of Cologne)

The joint application of the Direct Current Resistivity (DCR) and Time-domain Induced Polarization (TDIP) methods is a helpful tool to investigate ore deposits with sulfidic content. The combined interpretation yields a resistivity and chargeability model of the subsurface which is superior to a pure resistivity model, especially when dealing with disseminated deposits. We present a newly developed smoothness constrained 2D inversion algorithm for DCR and TDIP data applying a two-step approach. It contains a Finite Element forward calculation on an unstructured triangular mesh which amongst others simplifies the incorporation of topography. The new algorithm is tested regarding the quality of the chargeability resolution with respect to the resistivity model. Furthermore, the resolution of the lower boundary of a highly chargeable model block is investigated and compared to the depth of investigation which is determined by the coverage matrix. Finally, 2D inversion results of field data acquired on a sulfidic copper ore deposit in Turkey are shown using the newly developed algorithm and a feasible interpretation is given

.

9:50 – 10:15

C04 Large Scale IP Survey at Önneslöv in Southern Sweden

Torleif Dahlin, Per-Ivar Olsson, and Matteo Rossi (Engineering Geology, Lund University)

A DCIP survey, i.e. a geoelectrical survey with combined measurement of DC resistivity and induced polarization (IP), was conducted in southern Sweden. The purpose was to identify soil depth and bedrock structures and variations in rock quality. Data were acquired data with 100% waveform from which IP of good quality data were extracted. The inverted model sections show a wide variation in the electrical properties of the bedrock that are expected to relate to variation in rock quality. The results, together with results of other geophysical methods, form the basis for a drilling program in order to identify variations in quality rock of importance to the construction of an underground facility.

10:15 – 10:30 **Break**

10:30 – 10:55 **C05 An Approach for Microscale Simulation for Induced Polarization**

Dr. Norbert Klitzsch and Saurabh Singh(E.ON ERC, RWTH Aachen University)

In this paper, we discuss an approach for the microscopic simulations for Induced Polarization that describes the dynamics of ion transport with the help of the Nernst-Planck-Poisson (NPP) model. The NPP model is governed by coupled diffusion and migration equations. The equations are solved by means of the Finite Difference Method and Euler schemes. The goal is to develop SIP simulation tool that takes the inner 3D microstructure of the porous media into account. So far we have successfully verified and validated the 1D and 2D NPP models. We also introduced time dependent IP simulations on simple 2D models.

10:55 – 11:20 **C06 Non-invasive geophysical monitoring of subsurface biogeochemical processes under redox oscillating conditions**

Adrian Mellage, Geertje J. Pronk, Tatjana Milojevic, Anthony L. Endres (University of Waterloo, Earth & Env. Sciences), Estella A. Atekwana (Oklahoma State University, School of Geology), Alex Furman (Technion), Fereidoun Rezanezhad and Philippe Van Cappellen (University of Waterloo, Earth & Env. Sciences)

In order to determine the effects of water table dynamics on subsurface biogeochemistry, we are currently conducting state-of-the-art automated soil column experiments with fully integrated monitoring of hydro-bio-geophysical variables under both constant and oscillating water table conditions. An artificial, homogeneous mixture consisting of minerals and organic matter is used to provide a well-defined starting material. The artificial soil is packed into 60 cm high, 7.5 cm wide columns. In this experiment, three replicate columns are incubated while keeping the water table constant at mid-depth, while another three columns alternate between drained and saturated conditions. Periodic spectral induced polarization (SIP) measurements are performed, in order to monitor the development of the soil's geophysical signature and relate this to the observed changes in biogeochemical properties. Thus far, during the initial "wetting and drying" cycle of the experiment, the measured imaginary conductivity (σ'') response in the fluctuating column shows a decrease during the wetting phase, followed by an increase during the drying phase. Also, the magnitude of σ'' increases with decreasing depth, despite the expected lower moisture content closer to the surface. These results are opposite of what would be expected based on the saturation-σ'' relationship and have potential implications as to how σ'' data are interpreted in variably saturated media. Concurrent measurements of pore-water geochemistry and solid phase microbial analyses will allow us to track changes in soil biogeochemistry and relate these back to the observed complex conductivity response, in order to develop a full theoretical understanding of the processes controlling the observed signals. The experiment is ongoing with an expected total duration of 6 months.

11:20 – 11:45 **C07 The IP response of black shales in the Oslo graben, Norway**

Asgeir Kydland Lysdahl, Erik Endre (Norwegian Geotechnical Institute (NGI), Tino Radic (Radic Research), Jürgen Scheibz Norwegian Geotechnical Institute (NGI)

This work presents time-domain IP and resistivity field measurements of a black shale lithology in the Oslo graben, as well as a frequency-domain laboratory characterization of the complex impedance of core samples from the same lithology. The time domain inversion models resemble well the known lithology and the black shales stands out with high (40 msec) chargeability. A large phase shift (up to 19 degrees) is recorded in the complex impedance data at low frequencies in two out of three black shale samples. Both results show a significant IP response and suggest the existence.

11:45 – 12:10 **C08 Bayesian inference of spectral induced polarization parameters at the Canadian Malartic disseminated gold deposit**

Charles Lafrenière-Bérubé, Michel Chouteau (École Polytechnique Montréal), Gema R. Olivo (Queen's University)

Spectral induced polarization (SIP) parameters can be extracted from field or laboratory complex resistivity measurements, and even airborne or ground frequency domain electromagnetic data. There is a growing interest in application of SIP to environmental problems and mineral exploration. SIP measurements were conducted on 211 rock samples from the Canadian Malartic disseminated gold deposit to study its electric signature that could be detected by geophysical prospecting. Then, the SIP parameters were inferred using Markov-chain Monte Carlo simulation with the Cole-Cole, Dias, Debye decomposition and Shin models. Meta-sedimentary rocks with a well-defined schistosity and pyrite alteration produce higher chargeability peaks than pyrite-poor or silicified samples. The characteristic relaxation time is also inversely related to the observable quantity of finegrained (1 to 100 microns) pyrite per unit area. Metasedimentary rocks of Canadian Malartic with a pyrite content of 1 to 5% are commonly associated with gold contents above 1 ppm, and they produce a chargeability peak at short relaxation times (0.01 to 0.1 s). Nonmineralized rocks with fewer, larger pyrite grains produce a chargeability peak at longer relaxation times (0.1 to 10 s). Spectral induced polarization may be the key in defining the electric footprint of the Canadian Malartic and similar disseminated gold deposits, where high gold grades are associated with finely disseminated sulphides.

12:10 – 12:30 **Goodbye and prizes**

12:30 – 13:30 **Lunch and individual departures**