SE04: Recent trends in exploration geophysics

Conveners: Claire Samson[1], and Alexander Braun[2]

Co-chairs: Claire Samson[1], and Alexander Braun[2]

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Session Description

This session invites contributions on recent trends in exploration geophysics including advances in instrumentation, survey design, data processing and integration, and interpretation. "Exploration" is taken in its broadest sense and is meant to include mineral resources, oil & gas, and groundwater, in both "brown" and "green" field areas. Focus will be on case studies from the Canadian Cordillera and the Western Sedimentary Basin, but the session will include contributions from all regions of Canada. Of particular interest are contributions on the challenges of exploring in rough topography, in complex geological terrains and under overburden cover. New developments in instrumentation, (e.g. gradiometers, airborne IP) and data integration (e,g, joint or stochastic inversion, predictive mapping, 3D subsurface visualization tools) are starting to transform exploration geophysics and will eventually allow for targeting more complex and deeper targets. The session aims at bridging geophysical applications in geology, hydrology and soil science, and therefore contributions featuring how various techniques and approaches can be integrated to increase exploration success are particularly welcome.

Primary Affiliation: CGU Solid Earth Section

NOTE: THIS DOCUMENT CONTAINS INFORMATION FOR ALL SESSION SUB-SECTIONS. PRESENTER ABSTRACTS ARE FOUND AT THE END OF THE DOCUMENT.

SCHEDULE MAY BE SUBJECT TO CHANGE.

ORAL SESSION SE04a

Chairs: C. Samson & A. Braun **Room: ESB 2012**

Monday, May 29th

TIME	AUTHORS	TITLE
11:00	R. Clowes	Geophysics and geology: An essential combination illustrated by *LITHOPROBE* interpretations – Exploration examples
11:15	S.L. Butler	Forward modeling of geophysical electromagnetic techniques using Comsol Multiphysics finite element software
11:30	E. Goldfarb, M. Ramos & N. Tisato	Using Computed Tomography to Map Orientation, Quality, and Quantity of Microfractures in Shale Samples, Before and After Induced Failure from Triaxial Testing
11:45	D. Schouten, J. van Nieuwkoop, R. Gazit, B. Koestlmaeir & D. Furseth	Recent Advances Incorporating Muon Geotomography and Joint Geophysical Inversion for 3D Density Imaging and Monitoring
12:00	A. Braun, E. J. Elliott & O. Dabboor	Monitoring SAGD Reservoirs - a Synergistic Approach

POSTER SESSION SE04

Chairs: C. Samson & A. Braun **Room: ESB Atrium**

Monday, May 29th

Poster No.	AUTHORS	TITLE
P01-SE04	D. W. Kouhi & K. F. Tiampo	Applying structural joint inversion and lateral interpolation techniques to get the most out of airborne geophysical data at Thor Lake, NT
P02-SE04	R. Maedel, A. Braun & D. Ball	Forward and cooperative inverse modeling of petrophysical and geophysical data in Zone 58 at Raglan Mine, Québec, Canada
P03-SE04	C. Walter, A. Braun & G. Fotopolous	Orientation Considerations for Multi-Rotor UAV Magnetometry Surveys

SUBMITTED ABSTRACTS

SE04-01: Geophysics and geology: An essential combination illustrated by *LITHOPROBE* interpretations – Exploration examples

Ronald Clowes[1]

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Abstract

LITHOPROBE was Canada's highly successful multidisciplinary Earth science project that was active from 1984 to 2005. It was spearheaded by seismic reflection techniques but all other geological, geochemical and geophysical subdisciplines provided the scientific context that bound the program into a cohesive, comprehensive project. One of the essential aspects that led to *LITHOPROBE*'s success was geophysicists and geologists working together such that geophysical and geological data were combined to achieve high quality interpretations of those data. Five examples from *LITHOPROBE* 's contributions to exploration are highlighted. The Guichon Creek batholith of south-central B.C. hosts several large, low-grade copper and molybdenum deposits. Based on seismic reflection, magnetics, gravity and geology, the geological units associated with the deposits were outlined to 5 km depth. The Abitibi granite-greenstone belt in Quebec hosts volcanogenic massive sulfide deposits. Using 2D-reflection, geological, borehole and physical properties data, structural characteristics for the Bell Allard deposit are well identified but the deposit itself was not imaged. The Sudbury impact structure in Ontario is famous for its nickel deposits. *LITHOPROBE* carried out a series of geophysical and geological studies that clarified the subsurface structure, possibly indicating where future deposits might be found. This success led to a 3D reflection experiment that imaged a known nickel deposit prior to its development. The Athabasca Basin of NW Saskatchewan comprises a Mesoproterozoic sedimentary sequence that hosts world-grade uranium deposits. Interpretation of reflection images with geological and borehole information identifies the unconformity and basement faults that host the deposits. The diamondiferous Snap Lake kimberlite dyke in the NWT, a 1-5-m-thick sheet dipping gently from subcrop to 1300 m, was delineated by drilling but a less expensive method to identify the dyke and its structural characteristics was desirable. A unique reflection experiment, supported by drill hole, physical properties and modeling data was successful.

Presentation type: Oral Presentation

SE04-02: Forward modeling of geophysical electromagnetic techniques using Comsol Multiphysics finite element software

S.L. Butler[1]

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Abstract
Three dimensional forward modeling of geophysical electromagnetic techniques remains a significant technical challenge and most such efforts use research software or purpose built commercial software with limited flexibility. Comsol Multiphysics has emerged as a simulation tool for almost any continuum system and models are relatively easily created using a GUI. Results can also be post-processed and visualized within the same software. In this presentation, I will show numerical simulation results for the resistivity, magnetotelluric, VLF, frequency-domain electromagnetic and time-domain electromagnetic methods. Simulation results are compared with analytical solutions for simple situations, with laboratory scale analog experiments and with field studies and are found to be in good agreement. I will discuss some of the strengths and limitations of the technology.

Presentation type: Oral preferred.

SE04-03: Using Computed Tomography to Map Orientation, Quality, and Quantity of Microfractures in Shale Samples, Before and After Induced Failure from Triaxial Testing

Eric Goldfarb[1*], Matthew Ramos[2*], and Nicola Tisato[3]

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Abstract
Natural fractures in the subsurface highly influence the exploitation of unconventional hydrocarbon reservoirs. In tight reservoirs, fractures enhance permeability. These fractures also act as planes of weakness, influencing the branching of hydraulically induced fractures. Natural fractures can also be detrimental by creating a conduit for fluid to escape the area of interest during stimulation. Therefore, identifying natural fractures and their distribution in the subsurface is important to optimizing completions in reservoirs. Digital rock physics (DRP) is ideal to quantify the orientation and quantity of fracturing. DRP digitizes rock samples, and uses numerical simulations, to estimate the physical properties of the rocks under study. As core is both expensive and rare, non-invasive DRP tests can spare half a dozen invasive physical tests such as porosimetry and mechanical testing. This study uses X-ray microtomography to quantify pre-existing and stress-induced fracturing in Mancos Shale samples in three dimensions. The samples are from the Cretaceous Western Interior Seaway, and were subjected to deviatoric loading to failure. Two sample categories were used: those intact (non-fractured) and those containing pre-existing fractures. Both were scanned before and after failure testing. DRP was used to evaluate the development of stress-induced fractures, and their potential interaction with pre-existing fractures and sample layering. After dataset segmentation, fractures were mapped. Orientation, quantity and aperture were assigned allowing visualization of mutual interaction. Fracture quality factor (FQF) describes the summation of aperture area in an image, i.e. FQF is "high" when a two dimensional slice contains many microfractures, or a fracture with a large aperture. Results show that the intact Mancos sample failed with one high FQF failure, whereas the sample with pre-existing microfractures failed with two smaller FQF fractures. These smaller stress-induced fractures intersected and terminated at pre-existing fractures. This mapping technique may shed further light on the influence of pre-existing fractures on rock mechanical properties and failure. [306 words]

Presentation type: Oral Presentation

SE04-04: Recent Advances Incorporating Muon Geotomography and Joint Geophysical Inversion for 3D Density Imaging and Monitoring

Doug Schouten[1], Jakobus van Nieuwkoop [1], Rotem Gazit[1], Bernard Koestlmaeir[1], and Don Furseth[1]

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Abstract
While the concept of applying muon tomography in exploration geophysics has been in the literature for decades, it has only become practical and practiced this decade. Muon geotomography has been deployed in underground mines to image dense ore bodies such as Volcanogenic Massive Sulphides and Mississippi Valley Type deposits. Robust field-proven muon detectors have been developed for brownfield geophysical surveys, and joint inversions with gravimetric and assay data are now possible. Although initial projects focused on brownfield mineral exploration this 3D density imaging and monitoring technique has potential applications in oil & gas and hydrology as well as geotechnical imaging, industrial monitoring and security applications. Recent progress in muon geotomography will be reviewed as well as a preview of ongoing work in next-generation detectors, and simulations of unpublished applications.

Presentation type: Oral Presentation

SE04-05: Monitoring SAGD Reservoirs - a Synergistic Approach

Alexander Braun[1*], E. Judith Elliott[2], and Oday Dabboor[1]

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Abstract
Steam Assisted Gravity Drainage is one of the most used enhanced heavy oil recovery methods in the Alberta oil sands region. The life cycle of a SAGD reservoir comprises several years of production and undergoes a number of stages within the life cycle. Among those is the rising phase when injected steam rises above the injector well and heats the heavy oil to mobilize it. Once the steam chamber rises to the top of the reservoir, it starts the spreading phase and connects with neighboring well pair steam chambers. It is economically and environmentally important to know the timing and the location of steam chamber development and bitumen depletion. Monitoring is currently done via 4-D seismic campaigns on a bi-annual basis. We propose to use a range of methods, new to SAGD reservoir monitoring, which in combination may lead to an alternative to expensive seismic campaigns and monitor on shorter time intervals. The proposed methods include gravity gradiometry, resistivity and Muon tomography. Gravity and Muons both sense the reservoir density distribution and resistivity is sensitive to temperature and water content changes. Combined, we expect an improved spatio-temporal sub-surface model, which will be enhanced through the synergies of the different observations. Synergies arise from two facts, i) Muon measures density along a trajectory and represent localized observations, while gravity gradiometry senses the entire sub-surface volume, and ii) resistivity allows for the separation of temperature induced density effects on gravity observations. The combination of the three observation types may enhance inversion modeling and consequently provide a viable monitoring alternative. [257 words]

Presentation type: Oral Presentation

P01-SE04: Applying structural joint inversion and lateral interpolation techniques to get the most out of airborne geophysical data at Thor Lake, NT

Derek W. Kouhi[1]*, Kristy F. Tiampo[1,2]

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Abstract

The acquisition of airborne geophysical data has become a common practice in the mineral exploration industry. This data is used as a relatively inexpensive way to sense subsurface variations in the potential field, which are a product of changes in characteristic geophysical properties in the underlying lithology. The application of inverse modelling is becoming more and more prominent in the exploration industry as a technique for calculating possible subsurface models based on these fluctuations in airborne data. In this study, airborne magnetic and gravitational field data are used to invert for subsurface magnetic susceptibility and density models for the Nechalacho deposit, a world-class rare earth element deposit located at Thor Lake, NT. Methods of structural joint inversion proposed by Lelièvre et al. (2009) are applied in addition to an innovative method of laterally interpolating between subsurface drillhole data. Subsurface models resulting from the application of new interpolation techniques show a distinct improvement in the lateral continuity, especially in regions where drillhole data were sparse. Structural joint inversion techniques were applied by using magnetic and gravitational field data cooperatively. This allows for models to be influenced by multiple geophysical properties simultaneously. Models obtained through these methods display enhanced delineation of the boundaries of the deposit, as well as decreased uncertainty in the final product. Overall, the techniques used are able to delineate a region at shallow depths with anomalously high magnetic susceptibility and density values. This region is interpreted as the Nechalacho deposit and further validates geological models from previous studies.

Presentation Type: Poster

P02-SE04: Forward and cooperative inverse modeling of petrophysical and geophysical data in Zone 58 at Raglan Mine, Québec, Canada

Robin Maedel[1*], Dr. Alexander Braun[1], and Daryl Ball[2]

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Abstract
The utility of forward and cooperative inverse modeling of petrophysical and geophysical data in Zone 58 at Raglan Mine is investigated. Targets are magmatic Ni-Cu-PGE sulphides of typical dimensions of $50m^3$ or larger. Beyond a depth of 400m, these targets are difficult to resolve and interpret using conventional airborne and ground-based geophysics. The geology in the Raglan Mine area presents a challenging geophysical noise environment, including, issues from both magnetic and conductive sediments. This study demonstrates the utility of forward and cooperative inverse modeling of petrophysical and geophysical data towards understanding geophysical signatures of specific geological features, which can aid in determining future exploration targets. The first method involves forward modeling the Total Magnetic Intensity (TMI) field from a geological model built from borehole (BH) data. Then, we compare TMI from forward models with airborne observations. Uncertainties in the geological model arise from: (i) interpolating geology between BH's, and (ii) lack of BH coverage. This study addresses these two limitations by comparing observed magnetic data with two forward models: (a) geological model of known targets, and (b) geological model of dipping ultramafic. By isolating the major magnetic signature in (a) and (b), the geophysical response of geological features can be identified and compared to observed TMI data. This results in two useful exploration scenarios: if the forward model and observed TMI data match, the geological model works; if they don't match, especially in homogenous volcanic country rock, then they could be artefacts or new targets. The second method involves inverting (i) forward modelled data and contrasting it to the original geological model, and (ii) inverting measured TMI data. Once, (i) has been constrained, (ii) can be implemented by running similar parameters for inverse models of measured TMI data. Results highlight differences and similarities between models, which increase geological understanding. [299 words]

Presentation type: Oral Presentation

P03-SE04: Orientation Considerations for Multi-Rotor UAV Magnetometry Surveys

Callum Walter[2], Alexander Braun[1], and Georgia Fotopolous[2]

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Abstract
Current platforms for collecting magnetic data include dense coverage, but low resolution traditional airborne surveys, and high resolution, but low coverage terrestrial surveys. Both platforms result in an observation gap between the ground surface and approximately 100m above ground elevation, which can be navigated by new technologies, such as Unmanned Aerial Vehicles (UAVs). To successfully equip UAV's for use in airborne magnetometry surveys, specific payload characteristics must be optimized. This study outlines the integration of the GEM Systems Potassium Vapour UAV Magnetometer GSMP-35U with the DJI s900 Multi Rotor UAV; Specifically, we investigate the effects that orientation, swing, and rotation changes of a semi-rigidly mounted magnetometer have on magnetic data and signal quality (SQ). A series of orientation surveys were conducted to quantify the extent of yaw, pitch and roll that a magnetometer payload experiences during fair-weather surveying flights, while suspended freely (dangling) underneath the UAV. Analysis of the compiled yaw, pitch and roll survey data resulted in the design of a specialized semi-rigid UAV magnetometer mount that was implemented to limit magnetometer rotation about the yaw axis relative to the UAV. Following this modification to the payload system, a second series of surveys were carried out to quantify how restricted variations in magnetometer yaw, pitch and roll affected parameters. The secondary surveys were carried out on the ground at a magnetically quiet testing site using the measured extent of yaw, pitch and roll, quantified from the first orientation survey to test signal quality and behaviour of the magnetic field data. Periodic variations in both SQ and magnetic field data were identified depending on the magnitude of yaw, pitch and roll. Overall, this study demonstrates that optimizing the orientation characteristics of the UAV magnetometer system, while maintaining yaw, pitch and roll within certain limits can yielded industry standard measurements (+/-0.05nT).

Presentation type: Oral Presentation / Poster