# SECTION 4
# POSTER ABSTRACTS

# POSTERS WILL BE ON DISPLAY FROM SUNDAY 26 FEBRUARY, 1700 TO WEDNESDAY 29 FEBRUARY, 1600 IN THE EXHIBITION AREA, HALL 1

Each poster will have a card noting when the presenter will be available to discuss their poster.

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## GEOPHYSICAL INVERSION & EM

### 1. 3D INVERSION OF SPECTREM AND ZTEM DATA FROM THE PEBBLE CU-AU-MO PORPHYRY DEPOSIT, ALASKA

*Jean Legault[1]*, P. Pare[2], L. Cox[3], A. Gribenko[4], G. Wilson[3], M. Cuma[4], M. Zhdanov[4], J. Smit[5] and L. Polome[5]*
[1]Geotech Ltd., Aurora, Ontario, Canada
[2]Anglo American Exploration (Canada) Ltd, Vancouver, BC, Canada
[3]TechnoImaging LLC, Salt Lake City, Utah, USA
[4]TechnoImaging LLC and University of Utah, Salt Lake City, Utah, USA
[5]Spectrem Air Ltd, Johannesburg, South Africa
*jean@geotech.ca*

This case study compares 3D inversion results from Spectrem Air's SPECTREM fixed-wing time-domain airborne electromagnetic (AEM) system, and Geotech's Z-axis Tipper Electromagnetic (ZTEM) airborne audio-frequency magnetics (AFMAG) system flown over the Pebble Cu-Au-Mo deposit in Alaska. Within the commonality of their physics, 3D inversions of both SPECTREM and ZTEM recover conductivity models consistent with each other and with the known geology. Both 3D inversions recover conductors coincident with pyrite-rich mineralisation, sulphide veins, and alteration associated with both Pebble East and Pebble West deposits. The 3D interpretation of both surveys has yielded improved understanding of the geology, alteration and mineralisation of the Pebble system. We conclude that 3D inversions of AEM and ZTEM surveys add significant value to exploration.

### 2. AEM INVERSION OF VTEM DATA FROM A RESISTIVE TERRAIN

*Ross Brodie*
Geoscience Australia, Canberra, ACT, Australia
*ross.c.brodie@ga.gov.au*

Data from a VTEM airborne electromagnetic survey over resistive terrain is examined. Forward modelling and analysis of high-altitude lines shows that the amplitudes of random noise, bucking error, processing corrections and geological signals can be large compared to the geological signal in the resistive terrain. The negative impacts of the low geological signal to noise ratio on conductivity estimates generated by layered-earth inversion and conductivity transformations are demonstrated. The reader is alerted to the degree of uncertainty and non-uniqueness that is inherent in conductivity estimates generated from similar datasets.

### 3. STUDY ON THE TEM RESPONSE DUE TO THE GROUNDED WIRE WITH SHORT-OFFSET

*Guoqiang Xue[1]*, S. Yan[2], G. Wenbo[3] and L. Mei-Fang[4]*
[1]Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China
[2]School of Computer Science and Telecommunication Engineering, Jiangsu University, Jiangsu, China
[3]School of Geology and Survey, Chang'an University, Xi'an, Shaanxi, China
[4]Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China
*ppxueguoqiang@163.com*

This study presents a strategy for detecting geological targets in the deeper stratum using the sophisticated detection methods and treatment technologies of TEM which is also fast, efficient and easy to implement. Its main contents are to do the transient electromagnetic detection in the near field and to make the processing and explanation of the observational data with the whole field area theory. Because the observation point is closed to emission source, the non-dipole effect must be adjusted. That is to say, the emission loop are considered as the sum of numerous dipoles, and the field response of the observation point equals the sum of those field responses induced by each dipole of the emission source loop.

In this paper, the apparent resistivity formula of whole field area is established and the different geoelectric models are designed. The apparent resistivity is calculated using the established formula of the TEM with the short-offset GES, and the results are consistent with that of the given model. The proposed method is helpful to obtain more accurate information about the shape, size and location of an underground target body and possesses important significance for the detailed study of geological structures, and also shows that TEM with the short-offset GES is a method worthy of further development.

### 4. HIGH-RESOLUTION REGIONAL-SCALE 3D INVERSION MODELLING USING THE NATIONAL COMPUTATIONAL INFRASTRUCTURE

*James Goodwin[1]*, N. Williams[2] and D. Oldenburg[3]*
[1]Geoscience Australia, Canberra, ACT, Australia
[2]Ivanhoe Australia Ltd., Melbourne, VIC, Australia
[3]Geophysical Inversion Facility, University of British Columbia, Vancouver, BC, Canada
*james.goodwin@ga.gov.au*

3D inversion of potential-field data is a powerful technique for investigating subsurface geology. A common problem for any geophysicist performing 3D potential-field inversion is acquiring sufficient computational power to produce models that cover the area of interest at an appropriate resolution. Being limited by computing power often means that models are degraded in either their resolution or scale to ensure they are computed within available resources, in turn, limiting the resulting geologic interpretation. A collaborative arrangement between Geoscience Australia and the National Computational Infrastructure (NCI) hosted by the Australian National University has increased Geoscience Australia's capabilities to ensure that potential-field inversions are calculated at a resolution appropriate for the available national-scale gravity and magnetic data. High-resolution regional-scale inverse models have been built for the Wallaby Plateau and Capricorn region of Western Australia using UBC-GIF software with future projects planned for the Yilgarn-Officer-Musgrave region. This work is designed to complement recently collected seismic data and aid in its interpretation. The method by which the inverse models are being built involves model-based trend removal whereby a local model is nested within a regional model to account for the regional trend in the data. Constraints are then added to models from seismic interpretations, forward models and 3D geologic models. The final products provide insight into the crustal-scale architecture of each region and highlight the benefit of using increased computing power to achieve higher grades of detail in 3D inversion modelling.

## 5. THE APPLICATION OF TSIM IN DEFINING SILLS IN COAL SEAMS: A CASE STUDY AT COPPABELLA MINE

*Joanne Henry*[1]*, *A. Buck*[1], *K. Henderson*[2] *and W. Smyth*[1]
[1]GeoConsult, Brisbane, QLD, Australia
[2]Macarthur Coal, South Brisbane, QLD, Australia
*jhenry@geoconsult.com.au*

Thiel Surface Impedance Method (TSIM) is a surface electromagnetic device that uses VLF radio waves at a single frequency to measure apparent resistivity changes in the subsurface. The technique allows the interpreter to accurately delineate known geological features and identify previously unrecognised discontinuities.

The aim of the TSIM survey at Coppabella Mine was to determine areas of heavy intrusion in the coal as it was recognised that mining efficiency could be improved by demarcating zones of minor intrusion from the more heavily intruded areas. The survey was conducted in a grid pattern with 16 lines and a total line length of 3,600 m.

The results show five key areas of low apparent resistivity which are zones of interest and a linear trending high apparent resistivity feature. The zones of low apparent resistivity identified by the TSIM survey are bound by areas of high apparent resistivity. These indicate intrusion within the coal seams.

TSIM has been successfully used at Coppabella Mine to identify areas of low apparent resistivity occurring where intrusion is expected.

## 6. 3D INVERSION OF SURFACE AND BOREHOLE ELECTROMAGNETIC DATA

*David Annetts*
CSIRO, Perth, WA, Australia
*david.annetts@csiro.au*

Inversion of electromagnetic data for a one-dimensional earth is commonplace in ground geophysics. However, the earth is not one dimensional, and it is known that significant errors can arise when underlying dimensionality is not properly accounted for. The CSIRO program Loki, which models the magnetic field response of the earth using hexahedral finite elements, was modified to invert data. Sensitivities were computed using the method of domain differentiation with respect to cell conductivities. As a capability demonstration, a small SIROTEM-like multiple line fixed-loop survey was modelled. The underlying model consisted of a near-surface paleochannel and a three-dimensional target, both underlying a conductive regolith. Good fits between numerical modelling data and the response of the inverted model were obtained when inversion initial models contained some structure but not when starting from resistive halfspace, suggesting a combination of 1D methods to invert for a background with 3D methods to invert for structure.

# AIRBORNE EM

## 7. THE FROME AIRBORNE ELECTROMAGNETIC SURVEY

*Ian Roach*
Onshore Energy and Minerals Division, Geoscience Australia, Canberra, ACT, Australia
*ian.roach@ga.gov.au*

The Frome airborne electromagnetic (AEM) survey is the last and largest of three regional AEM surveys flown under the 5-year Onshore Energy Security Program (OESP) by Geoscience Australia (GA) in the interests of reducing risk and stimulating exploration investment for uranium by providing reliable pre-competitive data. The Frome AEM survey was flown between 22 May and 2 November 2010, is approximately 95 450 km$^2$ in area, and collected 32 317 line km of new data at an average flying height of 100 m. The Frome AEM survey includes the Marree (pt), Callabonna (pt), Copley (pt), Frome (pt), Parachilna (pt), Curnamona, Olary and Chowilla (pt) 1:250 000 sheets in South Australia and was flown largely at 2.5 km line spacing, with the northern portion flown at 5 km line spacing. Survey partners included GA, the Department of Primary Industries and Resources South Australia, and an industry consortium.

The survey results indicate a depth of investigation (depth of reliable signal penetration) of up to 400 m in areas of thin cover and resistive basement (e.g. Adelaidean rocks in the Olary Ranges) and up to 100-150 m in Cenozoic Mesozoic sediments in the Frome Embayment and the Murray Basin. A range of under-cover features are revealed, including (but not limited to): extensions to known palaeovalley networks in the Frome Embayment; the under-cover extent of the Benagerie Ridge; regional faults in the Frome Embayment and Murray Basin; folded and faulted Neoproterozoic rocks in the Adelaide Fold Belt; Cenozoic Mesozoic stratigraphy in the Frome Embayment; neotectonic offsets in the Lake Eyre Basin; conductive Neoproterozoic rocks associated with copper-gold mineralisation; and, coal-bearing structures in the Leigh Creek area, as well as groundwater features.

## 8. AIRBORNE TEM FOR RECOVERY OF BASIN SCALE SOLUTE DISTRIBUTION; PERTH BASIN, WA

*Robert Martin*[1]*, *B. Harris*[1] *and D. Schafter*[2]
[1]Department of Exploration Geophysics, Curtin University, Perth, WA, Australia
[2]Department of Water, Perth, WA, Australia
*r.martin@student.curtin.edu.au*

In recent years there has been a sharp increase in the demand for high quality groundwater in Western Australia. This demand is fuelled by population growth and a booming resource sector. The Allanooka area at the Northern tip of the Perth Basin appears to have potential as a groundwater resource. For major development to occur, analysis of hydrogeology spanning an area of many thousands of square kilometres is required. A key element of the hydrogeology of the Northern tip of the Perth Basin is the large scale distribution of dissociated salts in solution. We demonstrate how a large airborne TEM data set can be converted to estimate solute concentration distribution at the basin scale. We first build empirical relationships between total dissolved salts and electrical conductivity obtained from water samples pumped from nested monitoring wells with screens set at many depths, with formation resistivity derived from wire-line logging. We then extend the empirical relationship, including TEM derived formations resistivity. We demonstrate how wire-line logging combined with a geological framework developed from drilling and seismic reflection can firstly constrain the airborne TEM inversion and ultimately the interpretation of large scale solute distribution model. We consider error bars for our interpretation based in part on TEM inversion statistics and the relationship between formation

resistivity and solution concentration. The layers of interpretation for the basin are slowly revealing the drivers for the systems hydraulic and solute distribution and will ultimately feed into large scale flow and transport modelling for the area.

### 9. REGIONAL TERRAIN CORRECTED GRAVITY GRID PRODUCTION, EXAMPLES FROM SOUTH AUSTRALIA

*Philip Heath*, G. Reed, T. Dhu, T. Keeping and L. Katona*
Geological Survey of South Australia, PIRSA, Adelaide, SA, Australia
*philip.heath@sa.gov.au*

Traditional Bouguer corrections assume that the Earth behaves as a flat slab (Bouguer reduction), an assumption that is incorrect. A more accurate method of removing the effects of an Earth model is to take into account the terrain information, and assume a curved Earth. Terrain corrections are becoming more commonplace in individual surveys as computer power increases. We have produced a regional (state-wide) scale terrain-corrected gravity grid, using a 1-second DEM to calculate the correction. The correction adds a subtle change to the state wide gravity, removing some regional lows. It can be used as a simple visual tool to determine where terrain corrections are more appropriately undertaken.

### 10. FINITE ELEMENT BASED INVERSION OF AEM DATA USING STOCHASTIC OPTIMIZATION

*Eldad Haber* and C. Schwarzbach*
Geophysical Inversion Facility, University of British Columbia, Vancouver, BC, Canada
*haber@math.ubc.ca*

Modern data acquisition technology in airborne electromagnetics (AEM) produces huge data sets which cover areas of considerable extent. Both the large size of the domain of interest, in general a three-dimensional volume, and the large number of transmitters and receivers pose challenges to any type of modelling or inversion software. Solution of the inverse problem requires repeated solves of the forward problem. The time to solve one forward problem in turn scales linearly with the number of transmitters. In this paper we examine stochastic optimisation techniques for the solution of the inverse problem which essentially allow us to work with small subsets of transmitters/receivers and, thus, reduce the computational load significantly.

### 11. A NEW PROCESSING SYSTEM FOR VERY EARLY TIME SKYTEM101 DATA

*Cyril Schamper*, E. Auken and K. Sorensen*
HydroGeophysics Group, Aarhus University, Aarhus, Denmark
*cyril.schamper@geo.au.dk*

Early times are of interest for near-surface surveys and have been the object of developments during the last decade, both in the electronics and the processing domains. The new SkyTEM system, called SkyTEM101, has a very short turn-off of 3 μs which authorises the use of gates between 3 and 10 μs, and to increase the vertical resolution of the near-surface. However, a reliable monitoring of the Coil Response (CR) is necessary to get these very early time gates usable. For this, a new Coil Response Correction (CRC) has been developed which allows removing the CR in the first early gates before the inversion process. Application of this CRC correction to high altitude and production measurements has shown its efficiency to reduce the CR to the noise level. A new adaptive data filtering has also been developed to maintain the best lateral resolution above different areas like open fields or forests above which the signal to noise ratio varies due to the change of the helicopter altitude. This improvement of the lateral resolution has great value for environmental surveys where definition of local and shallow heterogeneities is a critical issue.

### 12. REVIEW OF THREE AIRBORNE EM SYSTEMS

*Shane Mule*, R. Miller, H. Carey and R. Lockwood*
Fugro Airborne Surveys Pty Ltd., Perth, WA, Australia
*smule@fugroairborne.com.au*

Time Domain Airborne Electromagnetic (TDEM) systems are defined by a set of technical specifications, which include dipole moment, bandwidth, transmitter waveform and transmitter-receiver geometry.

Comprehensive analysis of these specifications is fundamental in understanding how they define the target response. For example, a system optimised for mapping deep, discrete ore bodies is not necessarily the ideal solution for mapping regolith where good vertical resolution may be required.

Data acquired by three TDEM systems developed by Fugro Airborne Surveys are used to demonstrate the effects that different system specifications have on the response of an exploration target.

## POTENTIAL FIELDS – GRAVITY

### 13. SELF-GRADIENT EFFECTS FOR AIRBORNE GRAVITY GRADIOMETRY

*Paul Johnston*
School of Physics, The University of Western Australia, Perth, WA, Australia
*paul.johnston@uwa.edu.au*

The method by which an airborne gravity gradiometer measures gravity gradients and is stabilised within the aircraft affects the magnitude of the observed gravity gradient due to the nearby masses in the aircraft. To first order, the gravity gradient due to masses within the aircraft can be modelled using point masses. When the centre of mass of the instrument is stationary with respect to the aircraft, self-gradient is caused by rotation of masses about the centre of mass of the instrument resulting in a modest contribution to changes in observed gravity gradient. Movement of the centre of mass of the instrument with respect to the aircraft produces a larger self-gradient signal. In either case, the self-gradient signal correlates well with aircraft motion and can be easily removed from the observations by post-processing without the need for a complex model of the mass distribution within the aircraft.

### 14. DEPTH ESTIMATING FULL TENSOR GRAVITY DATA WITH THE ADAPTIVE TILT ANGLE METHOD

*Colm Murphy[1]*, J. Dickinson[1] and A. Salem[2]*
[1]Bell Geospace Ltd., Aberdeen, United Kingdom
[2]GETECH, Leeds, United Kingdom
*cmurphy@bellgeo.com*

Depth estimation procedures for potential field data are well recognised techniques. Both Euler and Werner methodologies are typically used as a series of automated steps and applied to both gridded and profile data. The Tilt Derivative Depth method works on gridded data and has been used extensively on magnetic data. Its advantage is its ability to produce a focused set of solutions and is now being commonly adopted for potential field data.

This paper describes an Adaptive Tilt Angle method for depth estimating Full Tensor Gravity data. The method is an adaptation of the Tilt Derivative depth estimation procedure adopted for magnetic data.

The procedure works on four of the independently measured Tensor components and produces sets of solutions that are more easily interpreted. The tilt angle method is defined as a ratio of the Tensor components in each of the X, Y and Z directions and assumes a vertical contact geological setting. The implementation of a scaling factor allows the technique to work on horizontal contacts. The scaling factor is essentially similar to the concept of a Structural Index as used with Euler depth estimation methods.

The technique was tested successfully on an Air-FTG® survey data set over a shallow salt feature onshore USA and is now being routinely deployed. The benefits of the direct depth estimation technique are immense in that it not only provides constraint on other interpretative processing techniques, but quickly establishes a starting depth model for any detailed forward/inverse modelling exercises.

## 15. JOINT 3D INVERSION OF MUON TOMOGRAPHY AND GRAVITY DATA TO RECOVER DENSITY

*Kristofer Davis* and Doug Oldenburg*
Geophysical Inversion Facility, University of British Columbia, Vancouver, BC, Canada
*kdavis@eos.ubc.ca*

Cosmic rays producing muons shower the Earth daily. These natural, high-energy particles decay as they pass through matter and are directly affected by density. Recently, sensors have been placed in existing tunnels and mine shafts that observe muon flux in a brown-field mining scenario. To our knowledge, this is the first application in exploration geophysics of muon data. We have developed an algorithm to invert these data individually, or jointly with gravity data, to recover a 3D distribution of density. Muon and gravity data are both linear functionals of density but the associated sensitivity functions are substantially different. These differences in physics between muon ray-paths and gravity data provide a unique insight into the subsurface. This is illustrated through synthetic examples. Inversion of a set of field data, obtained at a mine site in south-west British Columbia, Canada, illustrates the potential benefits and challenges for the technique to be used in field surveys.

## 16. APPLICATION OF CURVATURES TO AIRBORNE GRAVITY GRADIENTS

*Carlos Cevallos*, M. Dransfield, J. Hope and H. Carey*
Fugro Airborne Surveys Pty Ltd, Perth, WA, Australia
*ccevallos@fugroairborne.com.au*

The application of equipotential surface curvatures to airborne gravity gradient data is presented. The differential curvature, as measured by the FALCON airborne gravity gradiometer system, the mean curvature, and the direction of maximum curvature of the equipotential surface should improve the understanding and geological interpretation of gravity gradient data.

It has been shown that the horizontal gradients of the vertical component of the gravity vector form the curvature of the gravity field line. As this line is orthogonal to the equipotential surface, its curvature is related to how successive equipotential surfaces change and it may not be needed to interpret.

The theoretical basis for the method is discussed. Practical applications of utilising the curvature method are presented on a synthetic model and FALCON airborne gravity gradiometer data from the western zone of the Halls Creek Orogen, Western Australia.

## 17. INTERPRETATION OF AIRBORNE GRAVITY GRADIOMETRY AND MAGNETIC DATA USING CROSS-GRADIENTS

*Carlos Cevallos*, M. Dransfield, J. Hope and H. Carey*
Fugro Airborne Surveys, Perth, WA, Australia
*ccevallos@fugroairborne.com.au*

Computing the cross-gradient product of airborne vertical gravity and magnetic intensity data provides a means to combine information about two different physical properties into the same image, thereby aiding interpretation. The method utilises the angle and cross product values between the horizontal gradients of each dataset to produce two images in which structural similarities are enhanced.

The theoretical basis for the method and results of its application to the survey data are discussed.

The cross-gradient method was tested on a synthetic model and applied to FALCON airborne gravity gradiometer data from the Halls Creek Orogen, Western Australia. The vertical component of the gravity vector and the reduced to magnetic pole total magnetic intensity, were used as inputs.

## 18. UNDERSTANDING GRAVITY GRADIOMETRY PROCESSING AND INTERPRETATION THROUGH THE KAURING TEST SITE DATA

*Yaouguo Li* and C. Martinez*
Colorado School of Mines, CGEM, Golden, Colorado, USA
*ygli@mines.edu*

With the technological advancements in gravity gradiometry instrumentation, there is a need for understanding both the information content of modern gravity gradiometry data relative to traditional gravity data, and for developing processing and interpretation tools that assess the myriad of measured components and information they contain. The Kauring gravity gradiometry test range and associated data provide a unique and important opportunity to address these two aspects and to explore the applicability of existing tools. We present a systematic study of using both observed and simulated data at the site in this paper.

First, we assess the information content of current and next-generation gradiometry data by applying a suite of current processing tools to the observed gravity data and derived gravity gradiometry data. From the observed ground gravity data, we

calculate full-tensor gravity gradient data and typical components from newer gradiometer in development by using a regularised equivalent source method. These derived gravity gradient data are then subjected to appropriate noise and low-pass filters to simulate realistic data. We then interpret the simulated data by inverting various components for 3D density distributions and perform quantitative evaluations.

Secondly, to explore the procedure for processing and interpreting gravity gradient data, we utilise a synthetic dataset simulated for the Kauring Test Range by Rio Tinto. We carry out full processing of the dataset from terrain correction, noise characterisation, and 3D inversion by using the original observed curvature components and the converted tensor components. We again carry out quantitative evaluations to understand the advantages and drawbacks of working with the original observed components versus the converted full-tensor components.

### 19. MAPPING BASEMENT RELIEF OF ABU GHARADIG BASIN, WESTERN DESERT OF EGYPT USING 3D INVERSION OF PSEUDO-GRAVITY DATA

*Ahmed Salem[1]*, C. Green[2], D. Fairhead[2] and E. Aboud[3]*
[1]GETECH, Leeds, United Kingdom & Nuclear Materials Authority of Egypt, Cairo, Egypt
[2]GETECH, Leeds, United Kingdom
[3]Faculty of Earth Science, King Abdulaziz University, Jeddah, Saudi Arabia
*asks@getech.com*

There are a number of magnetic inversion methods that have been developed to map the structure and depth of sedimentary basins, assuming that sediments are non-magnetic and underlain by magnetic basement. Gridding/mapping the basement depth estimates from such methods has two significant problems: (1) the magnetic results are dominated by signals coming from the top edges of basement faults such that the depth information from the downthrown sides of the faults is not captured; and (2) within the centres of large basins there is often little variation in the magnetic anomaly to provide depth estimates such that when gridding the depth data, grid interpolation has to rely on a sparse distribution of estimated depths.

In this study we convert the magnetic data into pseudo-gravity which is then inverted to produce a 3D basin model with a constant susceptibility basement. This overcomes the interpolation problem since the 3D model now uses the complete pseudo-gravity field as well as the magnetic depth estimates to constrain the depth model. The method is applied to the Abu Gharadig basin, Western Desert, Egypt and generates results which match well controls on basement depth. The advantages of this method over 3D gravity inversion are that the pseudo-gravity response is not affected by structure within the sediments and is not compensated isostatically as the gravity response of basins often is affected.

## POTENTIAL EXPLORATION

### 20. RICH, ATTRACTIVE AND EXTREMELY DENSE: A GEOPHYSICAL REVIEW OF AUSTRALIAN IOCGS

*James Austin and Clive Foss*
CSIRO, Sydney, NSW, Australia
*james.austin@csiro.au*

Iron Oxide Copper-Gold deposits (IOCGs) are an important source of Australia's most valuable mineral exports, including iron, gold, copper and uranium. Australia hosts two of the world's major IOCG provinces: the Mount Isa Block, which includes Ernest Henry, Mt Elliot, Osborne, and the Gawler Craton which is home to Olympic Dam, Prominent Hill and others.

IOCGs geophysical signatures vary widely, particularly their magnetic and gravity signatures. For example, the Olympic Dam deposit produces a huge 17 mGal gravity anomaly, but only a 1,000 nT magnetic anomaly, while at the other end of the spectrum, Ernest Henry produces a ~2 mGal gravity anomaly and 7,000 nT magnetic anomaly. Most IOCGs were initially discovered through regional magnetic and gravity targeting. However, paradoxically, there have been few published investigations of their geophysics at deposit scale, and particularly as a class of deposit.

This study focuses on magnetic and gravity anomalies associated with several IOCGs and assesses their variability as a function of five main physical characteristics: (1) size; (2) percentage of iron; (3) depth below surface; (4) magnetite vs. hematite content; and (5) Koenigsberger ratio (i.e., induced: remanent magnetisation). The results are the basis for discussion of geophysical exploration criteria for IOCGs in the Gawler and Mount Isa provinces.

3-D magnetic and gravity inversion and forward modelling are used to generate 3-D bodies, whose physical characteristics are then modified to assess the utility of magnetic and gravity data to IOCG exploration. The hypothesis that IOCGs form as fault and/or pipe bound hydrothermal breccias is consistent with their geophysical signatures. These modelling experiments highlight that gravity data is a more robust tool for IOCG exploration than magnetics, and that high resolution gravity data is critical to the identification of IOCG deposits in the Gawler and Mount Isa provinces.

### 21. POTENTIAL FIELD MODELLING OF THE TINGHA MONZOGRANITE AND TIN MINERALISED GILGAI GRANITE, INVERELL NSW

*Astrid Carlton*
Geological Survey of NSW, Department of Trade & Investment, Maitland, NSW, Australia
*astrid.carlton@industry.nsw.gov.au*

The Gilgai Granite and the Tingha Monzogranite are located south of Inverell in northeastern NSW. Potential field data has been modelled to determine the morphological relationship of these two granites. Total Magnetic Intensity (TMI) data, acquired by the NSW government Discovery 2000 program, was used to generate a 2.5D model. Presented within this paper are the results of modelling the southwestern corner of the Gilgai Granite, which accounts for approximately one third of the Gilgai Granite that is visible in TMI imagery.

The Gilgai Granite is highly mineralised with disseminated and vein-type cassiterite and polymetallic sulfide occurrences. Tin has been historically mined, mainly from shallow workings. Better understanding the mineralisation and formation controls may increase exploration in this area.

Eleven TMI cross-sections were modelled. The results indicate that the Gilgai Granite is steeply dipping and tapers with increasing depth. It has a vertical extent of approximately

1000–1400 m and intruded around and over the Tingha Monzogranite, but not beneath the Tingha Monzogranite. The Gilgai Granite has sill-like bodies, isolated masses and/or roof pendants that intrude the Tingha Monzogranite. The source rock has magnetic zonation, with modelled magnetic susceptibilities ranging from 4.8–14.0 × $10^{-3}$ SI with a mode of 5.5 × $10^{-3}$ SI.

## 22. ESTIMATING THE AGE OF VOLCANISM IN SEAMOUNT PROVINCES OF THE NORTHEAST INDIAN OCEAN

*Rajat Taneja* and C. O'Neill*
Macquarie University, Sydney, NSW, Australia
*rajat.taneja@mq.edu.au*

The breakup of the Australian landmass from Greater India, part of the late dispersal of Gondwana, started around 136 Ma. Concurrent with this breakup was the eruption of significant volumes of volcanics, on both the continental margins of Australia and India, including the North-West shelf, and in the ocean basin separating the two. Later submarine volcanism occurred within the Christmas Island Seamount Province (ChrISP), of which Christmas and Cocos (Keeling) Islands are two subareal examples. These volcanic events significantly impacted the thermal evolution of these margins, but the ultimate cause for this disparate volcanism, and the relationship between margin volcanics and later submarine volcanic events, remains unclear. This study tries to establish a relation between the volcanic activities and look for any evidence of these volcanic episodes.

The study uses gravity, magnetic, and subsidence modelling to attempt to constrain the structure and ages of seamount volcanism within the Christmas Island Seamount Province, including the Wharton Basin and Argo Abyssal Plain. Gravity modelling helps to determine the crustal structure and constrains the depth of limestone cap, which further helps in calculating when the seamount was subaerially exposed and approximates the time since its last exposure. The relationship between the volcanism observed in the ChrISP (Late Cretaceous to Eocene) and that recorded earlier on the NW shelf continental margin, remains ambiguous, and will be better constrained with forthcoming geochemical analysis. But the results presented here point to a rich and complex history of volcanism within the Indo-Australian plate.

## 23. POTENTIAL FIELD INTERPRETATION OF THE KARS ZONE, WESTERN NSW

*Robert Musgrave*[1]***and E. Johnson*[2]
[1]Geological Survey of NSW, Department of Trade & Investment, Maitland, NSW, Australia
[2]Discipline of Earth Sciences, University of Newcastle, Newcastle, Australia
*robert.musgrave@industry.nsw.gov.au*

The Cambrian Ponto Group of the Koonenberry Belt is a suite of fore-arc rocks of the Mt Wright Arc, and includes basalts that are associated with copper mineralisation. Magnetic derivative maps allow the Ponto Group to be followed southwest under shallow cover, where they define the magnetic texture of the Kars Zone that flanks the southeastern margin of the Curnamona Craton. Shallow-sourced positive magnetic anomalies in the Kars Zone are superimposed on a longer-wavelength magnetic low; this contrasts with their equivalents along the Koonenberry Belt, which sit on a broad magnetic high. Gravity images of the Koonenberry Belt suggest that shallow dense sources associated with the Ponto Group overlie deeper mass excesses, while equivalent shallow and deep mass excesses appear to be uncoupled in the Kars Zone. Joint magnetic and gravity modelling of a profile across the Kars Zone suggests that high-susceptibility, dense bodies representing the Ponto Group have been displaced to the northwest, over-riding in their path >10 km deep magnetic sources below the Menindee Trough. Similar deep magnetic sources below the Bancannia Trough have been interpreted as very large intrusive features forming the base of the Mt Wright Arc. Together, the potential field imagery and modelling suggests very large scale, low-angle thrusting of the Mt Wright fore-arc over a rigid basement of the Mt Wright Arc.

## 24. SKELLEFTE MINING DISTRICT IN 3D: RESULTS FROM INTEGRATED INTERPRETATION OF POTENTIAL FIELD, RESISTIVITY/IP AND REFLECTION-SEISMIC DATA

*Saman Tavakoli*[1]**, T. Bauer*[1]*, P. Skyttä*[1]*, S. Elming*[1]*, H. Thunehed*[2] *and P. Weihed*[1]
[1]Luleå University of Technology, Luleå, Sweden
[2]Geovista AB, Luleå, Sweden
*saman.tavakoli@ltu.se*

Located in northern Sweden, the Skellefte mining district has been subject to several geological and geophysical investigations, as it hosts abundant volcanic-hosted massive sulfide deposits. The importance of mineral exploration at greater depths in the Skellefte District has been increased since most of the mineralisation at shallow depths has already been discovered and exploited. Therefore, geophysical methods become particularly important as they can improve our knowledge about spatial relationships between geological features at depth. In the first part (local-scale) of this study, we used resistivity/IP data to map the subsurface geometry down to 430 m. Furthermore, the results of the resistivity/IP studies were constrained with potential field data down to 1.5 km depth. In the second part (regional-scale), potential field data were used to constrain the interpretation of the reflection-seismic data down to 5 km depth. The result from the first part indicated a good correlation between the initial resistivity model and the magnetic and gravity field calculated from that model. In Part II, the gravity and magnetic data were investigated to better understand the contact between the Skellefte Group volcanic rocks and the Bothnian Basin sedimentary rocks. Furthermore the method was used to constrain the geometry of late-orogenic gabbro-diorite and granite intrusions which occur along inferred shear zones that are only poorly indicated, or not visible at all on the reflection-seismic profiles. As the main outcome, the proposed integrated 3D model of the central Skellefte District (CSD) revealed crucial information about the spatial relationship between key lithologies which will be further used to understand the evolution of CSD in the fourth dimension, time.

## 25. GEOLOGICAL MILIEU OF THE BIJAWAR BASIN BASED ON INTERPRETATION OF GEOPHYSICAL DATA; CENTRAL INDIA

*Anand Kumar Chaturvedi*[1]**, P. Kovac*[2]*, A. Pathak*[1]*, C. Cevallos*[2]*, T. Rawat*[3]*, R. Miller*[2]*, R. Wiseman*[2] *and P. Parihar*[1]
[1]Atomic Minerals Directorate for Exploration and Research, Hyderabad, India
[2]Fugro Airborne Surveys, Perth, WA, Australia

[3]Atomic Minerals Directorate for Exploration and Research, Delhi, India
*headasrs.amd@gov.in*

Integrated interpretation through physical properties of rocks provides a better approach towards understanding of geological set-up. A high resolution heliborne time domain electromagnetic, magnetic and radiometric dataset acquired over Palaeo Proterozoic Bijawar Basin has been interpreted to enhance the geological understanding. The process involved knowledge driven analysis through correlation with geological units that outcrop and data driven analysis for extrapolation of information. Radiometric data in conjunction with spectral remote sensing data was used for generation of a surface geology map. Spatial distribution of rock magnetisation properties defines the subsurface extension of litho-structural elements and magnetic basement configuration. Electromagnetic data aided demarcation of resistive basement topography and various conductive layers. Radio-elemental distribution refines the unconformable contact shared by Bijawar Group with overlying and underlying group of rocks and also outlined the formational boundaries of arenaceous-argillaceous-carbonate-volcano-sedimentary sequence. Subsurface extent of basic volcanics is much more than its surface manifestation and appears to extend well below the overlying Vindhyan Supergroup of rocks. The unconformable contact of the Bijawar Group with underlying basement and the overlying Vindhyan Supergroup is marked by a distinct change in conductivity and has been outlined in depth to resistive basement topography. The fault system and its manifestation over different litho-units indicates multiple tectonic episodes.

## POTENTIAL FIELDS – MAGNETICS

### 26. MAPPING USING MAGNETIC DEPTH SPECTRA

*Roger Clifton*[1,2]
[1]Northern Territory Geological Survey, Darwin, NT, Australia
[2]The University of Western Australia, Perth, WA, Australia
*roger.clifton@nt.gov.au*

Developed in previous oral ASEG presentations, the method of magnetic depth spectra is here applied to the mapping of some covered basalts flows in the Northern Territory.

Previous demonstrations applied it to isolated ironstone bodies. It is now being applied to the rather more difficult prospect of mapping the depths to an extended magnetic body. Comparison with borehole results will be included.

Using an image of the vertical derivative, a location is selected that is most likely to yield clear depth spectra. Software especially written for the purpose then yields a series of depth spectra derived from the nearest flight line to the location. Depths are assessed from the spectra by eye and accumulated as point depths in a GIS layer. The process is repeated until a map of the depths to the body is accumulated.

During the presentation, indications of automating the process will be explored and the results demonstrated. At the time of writing, nothing beats the point by point procedure. At least as a pointwise interpretation, the method of magnetic depth spectra is demonstrated to be reliable.

### 27. GEOSCIENCE AUSTRALIA'S GEOMAGNETISM PROGRAM – ASSISTING GEOPHYSICAL EXPLORATION

*William Jones*, P. Crosthwaite, A. Hitchman, A. Lewis and L. Wang*
Geomagnetism Section, Geoscience Australia, Canberra, ACT, Australia
*bill.jones@ga.gov.au*

The Geoscience Australia Geomagnetism Program monitors the changing geomagnetic field using a network of nine geomagnetic observatories and fifteen repeat stations. The observatories collect calibrated vector data with 1-second sample interval and scalar data with 10-second samples which are sent to Geoscience Australia in near real-time. Among their many uses, these data have excellent application as base station data for magnetic surveys or remote reference data for MT surveys.

These variations also contain the subtle signal of the slowly changing main magnetic field that originates in Earth's outer core. An understanding of the scalar main field is essential for main-field removal, and of inclination and declination for reduction to the pole techniques, in magnetic survey data sets. Across Australia, the scalar field is 25% stronger in southern Australia than in the north, the angle of inclination is 60% steeper in the south than the north, and the declination angle varies from about –3 degrees in Western Australia to +15 degrees in Tasmania. Additionally, the rates of change of these field components also differ across the country.

This temporal and spatial dependence of the main field is represented in Australian and international geomagnetic reference field models. In Australia, both the Australian Geomagnetic Reference Field model (AGRF), produced by Geoscience Australia, and International Geomagnetic Reference Field model (IGRF), produced by an international group of modellers, are available to users. Each has its pros and cons and users may select the model most appropriate to their needs.

### 28. 3D MAGNETIC INVERSION IN HIGHLY MAGNETIC ENVIRONMENTS USING AN OCTREE MESH DISCRETIZATION

*Kristofer Davis* and Doug Oldenburg*
Geophysical Inversion Facility, University of British Columbia, Vancouver, BC, Canada
*kdavis@eos.ubc.ca*

Standard techniques for inverting magnetic field data are marginalised when the susceptibility is high and when the magnetised bodies have considerable structure. A common example is a Banded Iron Formation where the causative body is highly elongated, folded, and has susceptibility greater than unity. In such cases the effects of self-demagnetisation must be included in the inversion, which can be accomplished by working with the full Maxwell's equations for magnetostatic fields. This problem has previously been addressed in the literature but there are still challenges with respect to obtaining a numerically robust and efficient inversion algorithm. In our paper we use a finite volume discretization of the equations and an adaptive octree mesh. The octree mesh greatly reduces the number of active cells compared to a regular mesh, which leads to a decrease of the storage requirement as well as a substantial speed up of the inversion. Synthetic and field examples are presented to illustrate the effectiveness of our method.

## 29. AN ITERATIVE APPROACH TO OPTIMISING DEPTH TO MAGNETIC SOURCE USING THE SPECTRAL METHOD

*Alan Meixner* and S. Johnston*
Geoscience Australia, Canberra, ACT, Australia
*tony.meixner@ga.gov.au*

Knowledge of the depth of cover is poor across large areas of Australia. The spectral method is an efficient method of producing reliable depth to magnetic basement estimates across large regions of the continent.

A semi-automated work-flow has been created that enables the generation of depth to magnetic source estimates from windowed magnetic data using the Spector and Grant method. The work-flow allows for the correction of the power spectra, prior to the picking of straight-line segments, to account for the fractal distribution of magnetic sources. The fractal parameter ($\hat{I}^2$) varies with depth and was determined by picking multiple depth estimates in regions of outcropping magnetic basement which have been upward continued to different levels in order to simulate different amounts of burial beneath non-magnetic sediments. A power law function best approximates the decay of $\hat{I}^2$ with depth.

An iterative schema used to determine the optimum $\hat{I}^2$ where the depths of magnetic sources are unknown, has been incorporated into the workflow. Preliminary testing in a region of known magnetic basement depth has produced encouraging results, although further testing is required. The decrease of $\hat{I}^2$ with increasing depth suggests that the fractal distribution of magnetisation becomes less correlated, or fractal, over larger volumes of observation.

## 30. DEPTH TO MAGNETIC SOURCES IN THE OFFSHORE NORTHERN PERTH BASIN

*Stephen Johnston* and P. Petkovic*
Geoscience Australia, Canberra, ACT, Australia
*stephen.johnston@ga.gov.au*

During 2009–11 Geoscience Australia completed a petroleum prospectivity study of the offshore northern Perth Basin. Basement in the northern Perth Basin is deep and generally not resolved in the reflection seismic data. Recent improvements to the magnetic ship-track database and magnetic anomaly grid allowed an assessment of depth to magnetic sources, and estimation of sediment thickness, providing new insight into basement depth and trends. 2D models along seismic transects and analysis using spectral methods indicate that penetration of the deepest sediments by high-susceptibility bodies is probable. The reflection seismic evidence for these bodies is not clear, though in some cases they may be associated with faults and structural highs. Where the modelled bodies penetrate the sediments they are mostly below or within the Permian strata. A moderate positive magnetic anomaly (the Turtle Dove Ridge) is modelled by massive bodies whose tops are 5–15 km below sea floor. The depth to magnetic basement map highlights sub-basins and structural highs within the northern Perth Basin, with up to 12 km of sediment in the Zeewyck sub-basin.

## 31. FROM SURFACE TO MANTLE: AN OVERVIEW OF DOWNLOADABLE MAGNETOTELLURIC DATA FROM SOUTH AUSTRALIA

*Tania Dhu[1]*, G. Heinson[2], S. Thiel[2], K. Selway[2], G. Boren[2], P. Milligan[3], J. Duan[3], T. Fomin[3] and J. Maher[3]*
[1]Geological Survey of South Australia, PIRSA, Adelaide, SA, Australia
[2]The University of Adelaide, Adelaide, SA, Australia
[3]Geoscience Australia, Canberra, ACT, Australia
*tania.dhu@sa.gov.au*

Magnetotelluric (MT) techniques measure natural time variations in the Earth's magnetic and electrical fields to infer subsurface electrical conductivity structure. Data are collected over a range of frequencies providing insights into how this structure varies with depth. Depending on the conductivity and frequencies used, information can be obtained from the near surface to depths of 100 s of kilometres.

MT surveying has been used in a wide variety of geological scenarios from investigations of continental scale structures to mineral and geothermal exploration, and even the search for water. Recently surveys have been conducted under the Geoscience Australia Onshore Energy Security Program in collaboration with the University of Adelaide and the Geological Survey of South Australia, PIRSA across the Gawler Craton and Curnamona Province. Given the wide range of applications for MT data it is proposed to deliver these data online as EDI files, starting with these datasets.

This paper presents an overview of the presently available data within South Australia with references to interpretation and modelling reports for these datasets. All data are available for download online through the South Australian Resources Information Geoserver (SARIG).

## 32. INTERPRETATION OF MAGNETIC GRADIENT TENSOR FOR AUTOMATIC LOCATING A DIPOLE SOURCE

*Hyoungrea Rim*, Y. Sue-Park and H. Key-Jung*
Korea Institute of Geoscience and Mineral Resources, Daejeon, Korea
*rhr@kigam.re.kr*

In this paper, I propose the algorithm that the location of a magnetic dipole can be detected from the magnetic gradient tensor. I induced the location vector of a vertically magnetised dipole from magnetic gradient tensor. Deficit of magnetic moment makes the location information incomplete in result of induction. However if the observation of magnetic gradient tensor would be collected on one more points, the algorithm is able to catch the location of the magnetic dipole by clustering the solution of the proposed algorithm. For example, I show the synthetic case of borehole observation of magnetic gradient tensor found the source location successively by picking common solution area.

## 33. ISSUES RELATED TO DETERMINATION OF THE CENTRE OF MAGNETISATION

*Blair McKenzie[1]*, C. Foss[2] and D. Hillan[2]*
[1]Tensor Research Pty Ltd, Sydney, NSW, Australia
[2]CSIRO Earth Science and Resource Engineering, Sydney, NSW, Australia
*k.blair.mckenzie@gmail.com*

The direction of magnetisation of a compact source causing a magnetic field anomaly can be found without concern for the details of its shape using magnetic moment analysis (MMA). This provides assistance in the successful inversion of magnetic anomalies due in part to an unknown remanent magnetisation direction. However, the success of MMA is dependent on the analysis being positioned appropriately over the centre of the source body and to date, errors in the location of the centre of magnetisation have been a major source of error in the resulting estimates of magnetisation direction. MMA itself returns an estimate of the centre of magnetisation and we have investigated the conditions for stable convergence of iterative solutions. We report on sensitivity to offset of the initial estimate of the centre of magnetisation and on the rate of convergence as a function of various imperfections introduced to the magnetic field data and separation of the anomaly from other field variations. Finally, we investigate application of these methods using Australian case studies for which we have centres of magnetisation and magnetisation directions estimated from independent, staged inversions of the magnetic field data.

### 34. AN IMPROVED SEARCH FOR MAGNETISATION DIRECTION

*Blair McKenzie[1]*, D. Hillan[2] and C. Foss[2]*
[1]Tensor Research Pty Ltd, Sydney, NSW, Australia
[2]CSIRO Earth Science and Resource Engineering, Sydney, NSW, Australia
*k.blair.mckenzie@gmail.com*

Magnetic field interpretation is often conducted on an incorrect assumption that remanent magnetisation is insignificant and that the resultant magnetisation direction is in the local geomagnetic field direction. For compact anomalies various methods exist to test this hypothesis and return estimates of magnetisation direction utilising trial reduction to pole (RTP) transforms. We have developed an analysis to return the magnetisation direction which generates the most symmetric RTE anomaly and have shown that this approximately also matches input magnetisations of synthetic compact anomalies. Estimation of magnetisation direction from elongate anomalies is more problematic and intrinsically less reliable, but nevertheless we found that we were able to recover approximate magnetisation direction from these anomalies using cross-correlation of an analytic signal function computed from vertically integrated gradients (which we term the 'total vertically integrated gradient' or TVIG) with RTP and RTE grids computed for trial magnetisation directions. The various methods are readily and automatically obtained from scanning TMI grids. The resulting magnetisation direction estimates are empirical rather than analytic and are approximate. They are best used as initial estimates prior to application of more rigorous, manual methods.

### 35. CORRECTION SCHEMES FOR SELF-DEMAGNETISATION

*Dean Hillan* and Clive Foss*
CSIRO Earth Science and Resource Engineering, Sydney, NSW, Australia
*dean.hillan@csiro.au*

Aeromagnetic surveys collected over bodies of high susceptibility record fields that have been significantly affected by self-demagnetisation. These effects complicate interpretation as the amplitude of the magnetic response scales non-linearly with the susceptibility. Analytic modelling is only carried out for compact ellipsoidal bodies and most approaches break down in the high susceptibility limit. It is therefore of interest to develop tools for understanding and modelling of self-demagnetisation effects to support geophysical exploration. We present a modelling scheme based on multiple prismatic sub-volume bodies in a 3D grid for investigating and testing self-demagnetisation effects. This scheme, and another recent iterative scheme based on multiple spherical voxels, is tested to demonstrate self-demagnetisation effects on simple bodies. The schemes are verified against the known analytic results for a spherical body and the results for a cubic body. The prismatic scheme is then used to model a dipping magnetite sheet for comparison against real data where self-demagnetisation effects are thought to be important. Finally, we demonstrate the main advantage of the correction scheme by modelling multiple magnetic bodies in a 3D grid. These correction schemes are aimed at improving current magnetic modelling techniques and providing solutions for dealing with complex and highly susceptible bodies.

## ENVIRONMENTAL AND ENGINEERING GEOPHYSICS

### 36. INVESTIGATION OF THE WEATHERING LAYER USING SEISMIC REFRACTION AND HIGH-RESOLUTION SEISMIC REFLECTION METHODS, NE OF RIYADH CITY

*Ghunaim Al-Anezi[1]*, A. Al-Amri[2] and H. Zaman[2]*
[1]King Abdulaziz City for Science & Technology, Riyadh, Saudi Arabia
[2]King Saud University, Riyadh, Saudi Arabia
*ganezi@kacst.edu.sa*

Five seismic refraction and five high resolution seismic reflection profiles were carried out in the northeastern part of Riyadh to investigate depth of the weathering layer. Results obtained from seismic refraction survey reveal the depths of weathering layer at 12, 25, 17, 12, and 16 metres, respectively. On the other hand, high resolution seismic reflection stack sections illustrate the depths of weathering layer at 14, 28, 20, 13, and 18 metres, respectively. The weathering layer is composed of alluvial sediments and gravel, which is underlain by a sequence of limestone and dolomite layer. Seismic results from site no. 2 have been found to be in good agreement with lithological information reported from the adjacent water-well.

The high resolution seismic reflection data generally reveal better signal-to noise ratio and enhanced resolution compared to the refraction data. Although, the high resolution seismic reflection data failed in achieving high quality common midpoint (CMP) stacking profile at site no. 3, it provided an improved image of the subsurface features than the refraction data, recognising it as a potential seismic technique.

### 37. INTEGRATED DETECTION OF LANDMINES USING NEUTRON BACKSCATTERING AND MAGNETIC GRADIENT TECHNIQUES

*Mohamed Elkattan[1]*, A. Osman[2], A. Salem[3], F. Soliman[1], A. Kamel[4] and H. El-Hennawy[4]*
[1]Nuclear Materials Authority, Cairo, Egypt
[2]Atomic Energy Authority, Cairo, Egypt
[3]GETECH, Leeds, UK
[4]Ain Shams University, Cairo, Egypt
*emtiazegf@hotmail.com*

The main problem in demining process is to locate and characterise the landmines in the ground, as their different types and sizes make them difficult to detect using a single technique. In this paper we present results of an experimental study of integration between Neutron Backscattering and magnetic gradiometer techniques. The experiment was established in a test site located in Cairo using different types of landmines buried at different depths. The Neutron Backscattering technique provided information about the hydrogen content of the buried object and was successful to detect almost 85% of the used objects. The magnetic gradiometer detected most of the objects with ferro-metallic contents. Integration of both techniques increases the detectability to reach 100%. Such integration is very effective in decreasing the high false alarm rate resulting from the magnetometers sensitivity to any metal debris and detects landmines of relatively deeper depths which are not sensed by Neutron Backscattering sensor. The results suggest multi-sensors detection approach of landmines would help greatly in the demining process.

### 38. LONG-RANGE GROUND DEFORMATION MEASUREMENT USING INTERFEROMETRIC SYNTHETIC APERTURE RADAR DATA ON BOTH UP-GOING AND DOWN-GOING ORBITS

*Shuichi Rokugawa*
The University of Tokyo, Tokyo, Japan
*rokugawa@gpl.t.u-tokyo.ac.jp*

The objective of this study is to evaluate the capability of InSAR analysis using both up-going and down-going orbits data for monitoring the long-range ground deformation caused by the volcanic disaster. Differential InSAR (DInSAR) analysis and InSAR time series analysis were performed around disaster areas of the Kirishima Mountains in Japan. The data used in this study were images from the ALOS/ PALSAR observed from 2007 to 2011. We performed DInSAR analysis and InSAR time-series analysis with commercial software and attempted to precisely estimate vertical and horizontal displacements by the vector composition method from the observation data of both orbits. The results show that InSAR analysis is effective for the disaster monitoring of volcanic eruptions. Uplift and subsidence were detected around the Kirishima Mountains before the last eruption on January 26, 2011. This result suggests that long-range InSAR analysis has a capability to detect the symptoms of volcanic eruptions.

### 39. AEM BATHYMETRY AND CONDUCTIVITY ESTIMATION IN VERY SHALLOW HYPERSALINE WATERS OF THE COORONG, SOUTH AUSTRALIA

*Julian Vrbancich*
Defence Science & Technology Organisation, Sydney, NSW, Australia
*julian.vrbancich@dsto.defence.gov.au*

The Coorong is a shallow (typically 1–2 m) narrow coastal lagoon extending approximately 110 km parallel to the coastline, and forms an extensive wetland area of international significance. It is divided into two lagoons, the North and South lagoons. The northern lagoon section opens into the mouth of the Murray River and the southern lagoon section is closed. During periods of extended drought where there is no flooding to flush the lagoon system, hypersalinisation gradually increases, especially in the southern lagoon section where salinity may be in excess of four times that of seawater. A helicopter time-domain EM (TEM) system was flown along the Coorong, as extensive flood waters from Queensland (2010) were reaching the North lagoon lowering the salinity. The derived bathymetry from TEM data was shown to be in good agreement with known bathymetry in areas of high salinity. The conductivity of the saline water in the North Lagoon and underlying sediment was estimated from inversion of TEM data using the known water depth as a fixed parameter. The derived conductivity varied from ~1.6 S/m in the north of the North lagoon to ~8–9 S/m at its southern end, underestimating the gradient (~0.6 to ~13 S/m respectively) observed from a sparse distribution of fixed conductivity meters located in the Coorong. These results show that AEM has the potential to remotely map water conductivity gradients using known bathymetry to monitor hypersalinisation in these wetlands where changes in the ecology have been linked to high salinity.

## SEISMIC PROCESSING AND INTERPRETATION

### 40. OIL AND GAS EXPLORATION ACTIVITIES IN NEPAL

*Devi Nath Subedi*[1]*, *S. Mahato*[2], *S. KC*[1] *and J. Ghimire*[1]
[1]Petroleum Exploration Promotion Project (PEPP), Kathmandu, Nepal
[2]Department of Mines and Geology, Kathmandu, Nepal
*devi_subedi@hotmail.com*

Systematic geological investigations in Nepal started late in comparison with the start of such studies in other countries. The topographical feature of Nepal varies from 100 metres in the south to 8848 metres in altitude in the north. Physiographically, Nepal is separated into four zones similar to the geological zones. They are Terai plain (Indo Gangetic plain), Siwalik range (Churia range), lesser Himalaya and higher Himalaya region. The Terai and Siwalik region in the foreland of Nepal Himalaya are known for sedimentary basins with considerable thickness. These regions are targeted for hydrocarbon exploration.

In this paper, we describe the possibility of oil and gas occurring in Siwalik, Surkhet, Gondwana and Lakharpata (Vindhyana) groups of rocks based on the results from field investigation and geochemical analysis of collected samples.

The seismic interpretation of Terai region indicates evidence of unconformities between Siwalik sediments and the underlying meta sediments group of rock which are equivalent to the oil bearing formation of unnamed formation in the northern India. This group contains potential source and seal rocks. One exploration well drilled, though dry, gave valuable information to petroleum exploration.

### 41. DEPTH IMAGING WITH AMPLITUDE CORRECTION FOR LOCALIZED ABSORPTION ANOMALIES: A CASE STUDY FROM THE NORTH-WEST AUSTRALIAN SHELF

*Sergey Birdus* and A. Artyomov*
CGGVeritas, Perth, WA, Australia
*sergey.birdus@cggveritas.com*

Seismic amplitudes within target intervals are often affected by localised absorption anomalies in the overburden. In the North-West Australian shelf and in many other regions, such anomalies are often caused by gas trapped in shallow sediments. We apply Q-tomography (amplitude tomography) and Q-PSDM to take this

effect into account in geological settings typical for the North-West Australian shelf. We propose and apply a mixed absorption model that combines standard Q-compensation with frequency independent absorption. This model allows a much better fit with the real seismic data than previously used methods.

## 42. STORAGE AND PERFORMANCE ISSUES IN REVERSE TIME MIGRATION

*Suhas Phadke* and S. Dhubia*
Computational Research Laboratories Limited, Pune, India
*suhasmphadke@gmail.com*

Prestack Reverse Time Migration (RTM) algorithm for depth imaging has now become feasible due to advances in high performance computing and clever programming techniques. RTM makes use of full acoustic two-way wave propagation algorithm for both forward and reverse time extrapolation and therefore can image all kinds of arrivals. It is a computationally expensive process because wave propagation is carried out using higher order finite difference techniques. The program run times are large in terms of CPU cycles and disk storage. The computational challenge is overcome by making use of large Linux clusters and distributing the workload by domain decomposition. The forward propagated wavefield has to be stored for all time steps for cross-correlation with the back propagated recorded wavefield during imaging. A large amount of storage is required for this purpose. Several techniques have been proposed to write and read the wavefield as efficiently as possible. Normally a large central storage attached to the cluster is used. However, this involves a large amount of communication from all the nodes of the cluster. If adequate storage is not available then one can compute the forward wavefield twice. But this technique increases the compute time by fifty percent. In this paper we propose the use of local disk space available on each node to write the forward wavefield. Then we compare this technique with the other two methods. The use of local disk space reduces the communication time to the central storage and hence provides an improvement in performance. This will be demonstrated with some examples.

## 43. MODELLING OF SEISMIC WAVES IN LAYERED MEDIA AND THE INVERSION OF SOURCE PARAMETERS

*Dmytro Malytskyy*
Carpathian Branch of Subbotin Institute of Geophysics (CB IGPH), Lviv, Ukraine
*dmytro@cb-igph.lviv.ua*

This paper is organised as follows. After a discussion of the differential equations for wave propagation in the horizontally stratified medium and of the initial and boundary conditions, we derive the displacements on the free surface of the layered medium for plane waves when a point source is located on the imaginary boundary at depth (physical parameters of the layers s and (s+1) are put to be identical). Then, the source will be represented as a single force of arbitrary orientation and a general moment tensor point source. Further, primary field for a point source will be introduced. The method for the solution of the direct seismic problem is considered based on the matrix method of Thomson-Haskell. The tensor represents a superposition of three single couples without moment along the x, y, z-axes and three double couples in xy, xz, yz-planes. Further, we give the results for the field of displacements on the free surface. The results of this direct problem we use in the inversion of source parameters. The inverse method relies on inverting for components of the moment tensor and a determination of an earthquake source-time function.

## 44. IMPROVEMENTS TO SHALLOW SEISMIC VELOCITY TOMOGRAPHY METHOD

*Virgil Bardan[1]*, P. Cristea[1], V. Manj[1], P. Neculae[2] and C. Nitica[1]*
[1]Geological Institute of Romania, Bucharest, Romania
[2]OMV Petrom S.A., Bucharest, Romania
*virgil_bardan@yahoo.com*

The errors in seismic velocity reconstruction in straight rays tomographic method are unsatisfactory for the incompletely displayed seismic array around the panel. To improve resolution in these approaches, we propose a processing procedure consisting in re-applying the standard procedure after the obtained velocity model has changed. This modification is carried out based on the statistical analysis of the results obtained after the standard procedure was applied for the first time. The procedure was tested on theoretical models and real data sets.

# PETROPHYSICS

## 45. LABORATORY COUPLING TESTS FOR OPTIMUM LAND STREAMER DESIGN OVER SAND DUNES SURFACE

*Hashim Almalki[1]*, M. Alata[2] and T. Alkhaliafh[3]*
[1]King Abdulaziz City for Science & Technology, Riyadh, Saudi Arabia
[2]King Saud University, Riyadh, Saudi Arabia
[3]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
*halmalki@kacst.edu.sa*

Use of land streamers in seismic exploration is increasing in popularity due to their ability to reduce the cost and field effort associated with seismic land acquisition. One of the challenges of designing such a land streamer is to guarantee desirable coupling of the geophone with the ground surface. This is more critical when acquisition takes place over sand dune surfaces, where the sand dune surface is not sufficient enough for geophone planting because of loose sediments. This causes poor coupling of geophones with the surface and hence possibly loss of higher frequencies and delay arrival than usual. However, that is not all; the situation becomes even more of a dilemma when one realises that friction and sand accumulation over land streamer which means increased weight and larger pulling force is required. These problems should be solved for achieving the ultimate efficiency of land streamer. As such we have studied the impact of weight and base plate surface area on the seismic signal quality, as well as the friction factor of different designs.

## 46. LOW-FREQUENCY MEASUREMENTS OF THE MECHANICAL PARAMETERS OF SANDSTONE WITH LOW PERMEABILITY

*Maxim Lebedev[1]*, V Mikhaltsevitch[1], and B. Gurevich[1,2]*
[1]Department of Exploration Geophysics, Curtin University, Perth, WA, Australia
[2]CSIRO, Perth, WA, Australia
*m.lebedev@curtin.edu.au*

A study of the pore fluid effects on the elastic and anelastic properties of sedimentary rocks is important for interpreting seismic data obtained for reservoirs, as well as for monitoring the fluid movement during both fluid extraction in producing fields and injection of $CO_2$ for storage purposes. In most sedimentary rocks low intrinsic permeability and, as a consequence, low fluid mobility lead to a situation where relative motion between pore fluid and rock skeleton has significant influence on acoustic wave propagation, even at seismic frequencies. Therefore, in many cases the experiments conducted only at seismic frequencies are not sufficient to validate commonly used theoretic models of elastic moduli dispersion and attenuation.

We present data obtained with a new version of low-frequency laboratory apparatus designed for measurements of Young's moduli and extensional attenuation of rocks at seismic (1–400 Hz) and teleseismic (1Hz) wave frequencies. The apparatus can operate at confining pressures from 0 to 70 MPa. Elastic and anelastic parameters of dry and water-saturated sandstone quarried in Donnybrook, Western Australia, were measured at various confining pressures and room temperature. A peak of attenuation in a water-saturated sample with 14.8% porosity and 7.8 mD permeability was found at frequency 0.8 Hz.

## 47. ESTIMATING POROSITY FROM CT SCANS OF HIGH PERMEABILITY CORE PLUGS

*Brett Harris*, A. Squelch and M. Almalki*
Department of Exploration Geophysics, Curtin University, Perth, WA, Australia
*b.harris@curtin.edu.au*

We have analysed CT scans of core plugs obtained from high permeability sandstones in the Wanneroo Sandstone member of the Leederville formation in the Perth Basin. Plugs taken from drill core at representative sections of aquifer horizons have been scanned in a SkyScan CT scanner and the resulting greyscale image stacks analysed to estimate hydraulic transport parameters of the aquifer horizon. These parameters are compared with laboratory measured values obtained from standard physical tests.

The analysis of the CT data provides support for understanding parameters derived from standard core plug analysis and wire line logging. However it also allows for a localised study of different zones within the core plug volume that is not possible with more 'holistic' laboratory measurement. Also, the mechanical framework of the grain and pore structure can be extracted as 3D geometric models for additional types of analysis and numerical modelling.

We estimate values for porosity for distinct zones within the core plugs and for the full width of the core plug. The full width values are compared with the equivalent laboratory values and for calibration. In addition, the possible impact of millimetre to centimetre zonation for grain size and shape distribution is considered with reference to anisotropy in larger scale physical measurements from wire-line logging.

## 48. LABORATORY MEASUREMENTS OF FREQUENCY-DEPENDENT SEISMIC PROPERTIES OF CRACKED AND FLUID-SATURATED MEDIA

*Ian Jackson[1]*, H. Schijns[2] and D. Schmitt[2]*
[1]Research School of Earth Sciences, Australian National University, Canberra, Australia
[2]Department of Physics, University of Alberta, Edmonton, Canada
*ian.jackson@anu.edu.au*

The capability to perform laboratory measurements with both low-frequency forced-oscillation and high-frequency wave-propagation methods, under conditions of independently controlled confining and pore-fluid pressure, offers the prospect of new insight into the frequency-dependent seismic properties expected of cracked and fluid-saturated rocks of the Earth's upper crust. An important step in the development of such broad-band capability has been the modification of existing laboratory equipment to newly allow flexural, as well as torsional, forced-oscillation testing of cylindrical rock specimens. Flexural oscillation tests on an experimental assembly containing a fused silica control specimen yield results indistinguishable from those of numerical modelling with both finite-difference and finite-element methods - demonstrating the viability of the method. Both torsional and flexural oscillation methods along with complementary high-frequency wave propagation methods have been applied to specimens of dense polycrystalline alumina and quartzite, each thermally cracked to generate an interconnected network of cracks of low aspect ratio, and tested dry, and saturated with either argon or water. The shear and flexural moduli vary systematically with effective pressure - providing clear evidence of pressure-induced crack closure. Similarities and differences between effective moduli measured under different conditions of pore-fluid saturation are tentatively interpreted in terms of the timescales for stress-induced redistribution of pore fluid.

# SEISMIC AND OTHER APPLICATIONS

## 49. SHALE GAS: POTENTIAL ENERGY RESOURCES WITH FUTURE PROSPECTS

*Sunjay Sunjay*
Geophysics, Banaras Hindu University, Varanasi, India
*sunjay.sunjay@gmail.com*

With a view to energy security of the world, unconventional energy resources – coalbed methane (CBM), Methane Gas Hydrate, shale gas, basin centred gas, tight gas, oil shale and heavy oil – exploration and exploitation is a pertinent task before the geoscientist. Shale gas is natural gas from shale formations which acts as both the source and the reservoir for the natural gas. Each shale gas reservoir has unique characteristics. Shale has low matrix permeability, so gas production in commercial quantities requires fractures to provide permeability. For a given matrix permeability and pressure, gas production is determined by the number and complexity of fractures created, their effective conductivity, and the ability to effectively reduce the pressure throughout the fracture network to initiate gas production. Understanding the relationship between fracture complexity, fracture conductivity, matrix permeability, and gas recovery is a fundamental challenge for shale gas development. Shale gas reservoirs almost always have two different storage volumes (dual porosity) for hydrocarbons – the rock matrix and

the natural fractures. Because of the plastic nature of shale formations, these natural fractures are generally closed due to the pressure of the overburden rock. Consequently, their very low matrix permeability, usually on the order of hundreds of nanoDarcies (nD), makes unstimulated, conventional production impossible. Almost every well in a shale gas reservoir must be hydraulically stimulated (fractured) to achieve economical production. These hydraulic fracture treatments are believed to reactivate and reconnect the natural fracture matrix.

## 50. PHASE-BASED IMAGE ANALYSIS OF 3D SEISMIC DATA

*Peter Kovesi[1]*, B. Richardson[1,2], E. Holden[1,2] and J. Shragge[2]*
[1]Centre for Exploration Targeting, The University of Western Australia, Perth, WA, Australia
[2]Centre for Petroleum Geoscience and $CO_2$ Sequestration, The University of Western Australia, Perth, WA, Australia
*peter.kovesi@uwa.edu.au*

Automated image analysis techniques can be effectively used to detect discontinuities (e.g. faults, pinchouts, channels, etc.) within seismic data in a non-subjective manner. Conventional image processing techniques, such as the coherency cube, typically locate discontinuities by finding regions of sharp intensity shifts and are thereby sensitive to contrast variations and noise. Here, we present a phase-based technique that offers contrast-invariant and noise-robust feature characterisation through local phase and orientation information.

Phase congruency is an edge-detection algorithm that differs from traditional approaches by defining edges as points where the Fourier components of a signal are maximally in phase. Applying 2D phase congruency to horizontal time slices extracted from a 3D seismic volume is problematic though, because horizons are rarely parallel to horizontal time slices, causing horizon boundaries to appear artificially discontinuous. To better detect 3D seismic discontinuities, we extend phase congruency to a 3D algorithm using conic spread filters that provides a localised, multi-scale and dip-independent feature detector.

Preliminary results show that 3D phase congruency is capable of detecting velocity anomalies, but has some limitations in identifying fault boundaries in seismic data. However, it can provide an increased level of feature detail over conventional coherency cube processing. More importantly, these results indicate the potential for using multidimensional phase-based algorithms in 3D/4D seismic processing and imaging workflows, with particular applications in image denoising, image registration, feature detection, and velocity model verification.

## 51. FEASIBILITY ANALYSIS OF DRILL BIT TRACKING USING SEISMIC WHILE DRILLING TECHNIQUE

*Baichun Sun[1]*, B. Zhou[2], A. Bona[1] and R. Pevzner[1]*
[1]Curtin University, Perth, WA, Australia
[2]CSIRO, Brisbane, QLD, Australia
*baichuns@yahoo.com.au*

Check-shot survey measures the first arrival time with a known depth receiver in borehole to assess formation velocity. This information can be used in correlation with sonic log and surface seismic products for adjustment of interpretation. Check-shot survey can also be implemented with seismic-while-drilling using drill bit noise as the source. This differs from usual check-shot survey as source is in the borehole. It provides a real time, cost saving, and safe measurement.

Check-shot survey needs a known receiver depth, thus velocity can be obtained by fixed wave travel path and the measured first arrival time. However, in seismic-while-drilling (SWD), drill bit position can vary a lot from vertical drilling to deviated drilling. To address this issue, we present a method that finds the location of the source and estimates the velocity of the formation at the same time. Using a synthetic model, with medium receiver offsets, this method shows good estimation of the drill bit depth location and formation velocity in a layered Earth model.

## 52. QUANTITATIVE REGULARITY ANALYSIS OF OFFSET-VECTOR SAMPLING FOR SEISMIC ACQUISITION GEOMETRY

*Wei Wei* and L. Fu*
Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China
*caswei@gmail.com*

Symmetric acquisition geometry consisting of identical sampling of shots and receivers, can maintain the spatial continuity of the wavefield automatically, according to symmetric sampling theory. However, asymmetric geometry is often adopted in practical seismic exploration applications. Such geometry can cause uneven sampling and is necessary to be assessed for its sampling performance prior to acquisition. In conventional survey design, based on the common mid-point (CMP) analysis for a horizontally layered earth or common reflection point (CRP) analysis for a complex subsurface structure, the quality of acquisition geometry is generally judged by such bin properties as effective fold, offset scalar and azimuth distributions. However, these conventional approaches are limited by an incomplete understanding of the offset-vector sampling. Therefore, we propose a new method for quantitatively evaluating the continuity of offset-vector sampling including four spatial coordinates of shot and receiver. On the basis of physical potential energy and force-balance principle, it analyses the regularity coefficient of offset-vector sampling as a whole using potential function model and takes into account fold, offset-scalar, and azimuth distribution factors. Combining regularity coefficients of every bin can produce spatial continuity distribution of offset-vector sampling. Similar to symmetric sampling, this approach emphasises the spatial relationships between adjacent bins rather than single bin attribute, since it aims to maintain the spatial continuity of the wavefield which allows the faithful reconstruction of the underlying continuous wavefield. Using this method, we can quantitatively compare spatial continuity distribution for different seismic acquisition geometries, and then choose the better acquisition scheme.

## 53. 3D SEISMIC SURVEYING IN KEVITSA OPEN PIT MINE

*Petri Valasti[1]*, A. Malehmir[2] and C. Wijns[3]*
[1]Kevitsa Mining, Finland (a subsidiary of First Quantum Minerals Ltd)
[2]Uppsala University, Uppsala, Sweden
[3]First Quantum Minerals Ltd, Perth, WA, Australia
*petri.valasti@fqml.com*

A 3D reflection seismic survey was conducted over an area of about 9 $km^2$ at the Kevitsa Ni-Cu-PGE (platinum group

elements) deposit, northern Finland. About 1000 active receivers and 3000 shots in nine overlapping swaths were used to acquire the data. The principal objective of the survey was to image major fault and fracture zones at depth. Understanding the geometry of these zones is important for designing a steep open-pit for mining. Geological structures are complex and a varying thickness overburden combined with various weather conditions during the data acquisition made the data processing very challenging. However, a careful processing design combined with our experience on this type of data helped to produce interesting results. Processing results suggest that the 3D seismic survey has been successful in imaging both gently dipping and steeply dipping reflections as shallow as 50 ms (or about 150 m), many of which correlate with fault systems and lithological contacts observed at the surface. Several new target areas, bright spots, are identified in the seismic data that require further investigations for their mineralisation potential.

### 54. MULTIMODAL DIRECT FITTING OF SPAC COEFFICIENTS USING AMPLITUDE RESPONSE

*Tatsunori Ikeda*[1]*, *T. Matsuoka*[1], *T. Tsuji*[1] *and K. Hayashi*[2]
[1]Kyoto University, Kyoto, Japan
[2]Geometrics, Toyko, Japan
*t_ikeda@earth.kumst.kyoto-u.ac.jp*

We usually analyse microtremors without any considerations of higher modes of surface waves. However, recent studies have demonstrated that the use of higher modes would improve estimated velocity models. In this study, we apply multi-mode analysis with amplitude response to the direct fitting method in SPAC method. The proposed method has the advantage that we don't need to identify observed modes, which can avoid mode misidentification. The proposed method was applied to synthesised microtremors. Estimated SPAC coefficients agreed well with theoretical ones proposed in this study, even if in the frequency where two modes have about the same power fractions. The S-wave velocity was then successfully inverted by the direct fitting of SPAC coefficients. The proposed method also works well in the analysis of field data acquired in Tsukuba City, Japan. In the inversion performed in this study, we do not use prior information about velocity structure. It is concluded that the multi-mode analysis proposed here is very robust in the multimodal analysis in SPAC method.

## GROUNDWATER

### 55. WATER SEEPAGE INVESTIGATION USING GEO-ELECTRIC STREAMERS

*David Allen*
Groundwater Imaging Pty. Ltd., Dubbo, NSW, Australia
*david@groundwaterimaging.com*

Seepage from canals and reservoirs can be identified using geo-electric streamers. About 10 kilometres of canal can be surveyed by two people in one day. In electrical conductivity (EC) imagery created, seepage pathways through the substrate reflect the EC of surface water from which seepage was sourced as well as substrate permeability and clay content which enhances EC. Seepage tends not to occur readily through clay and the result, within EC imagery, is generally clear definition of seepage pathways through the substrate. In Australia, canals are typically situated on clayey, low flow regime sedimentary deposits where evapotranspiration has concentrated salt in shallow sediment, particularly clays, and seepage has preferentially flushed out this salt resulting in a very clear EC signature regardless of water table depth. In high flow regime environments, such as much of New Zealand, seepage pathway anomalies are usually more conductive than the host substrate which is usually cobbles, glacial rock flour and air.

A practical imaging system has been created using a submerged streamer towed behind a floating waterproof equipment capsule housing geo-electric, DGPS, sonar, data logging, and often other instrumentation. The capsule is towed either behind a boat or by two ropes pulled by walkers on each canal bank. Operation is via a Wi-Fi connection. The capsule is light enough to lift over the numerous obstacles that cross most canals. Imaging is presented in 3D within Google Earth so that water managers can readily handle and use the data.

### 56. MICRO GRAVITY AND CROSS-HOLE SEISMIC TO MONITOR WATER STORAGE CHANGES IN AQUITARDS

*Anna Greve*, A. Rogan, W. Timms and I. Acworth*
National Centre for Groundwater Research and Training, University of New South Wales, Sydney, NSW, Australia
*a.greve@wrl.unsw.edu.au*

Aquitards surround many aquifers. Due to their comparatively high storage capacity, they will control the hydraulics of aquifers in the long term. Long term management of aquifers therefore requires a good understanding of aquitard characteristics. To quantify water storage changes in an alluvial sequence a micro gravity station has been set up adjacent to an agricultural field in the Liverpool Plains in NSW, Australia. Gravity changes over time will provide an integrated signal of the total water storage changes at the site. Piezometers at the site will be used to determine at which depth the storage change is occurring. To derive water storage changes from the water level changes in the aquitards and confined aquifers at the site, the specific storage (Ss) of the formation needs to be known. Two insitu methods to derive Ss are applied. Firstly, Ss is derived based on the bulk modulus, which is obtained in a cross hole seismic survey and secondly Ss is derived based on pressure analysis in the lysimeters. Ss values derived from the pressure analysis in the lysimeters are one magnitude higher than those based on the cross hole seismic. This difference needs to be further investigated and might be due to the thick unsaturated zone (20 m) at the site, which appears to interfere with the pressure analysis in the lysimeters.

### 57. NUMERICAL MODELLING FOR FLOW, SOLUTE TRANSPORT AND HEAT TRANSFER IN A HIGH-PERMEABILITY SANDSTONE

*Jie Jian Leong*[1]*, *B. Harris*[1] *and L. Reid*[2]
[1]Curtin University, Perth, WA, Australia
[2]WAGCOE/CSIRO CESRE, Perth, WA, Australia
*jiejian.leong@student.curtin.edu.au*

Demand for water in the Perth metropolitan Area, Western Australia, is increasing and new water supply options need to be considered. Aquifer replenishment by injection through wells is seen as part of the solution, however before any large scale implementation of an injection well field is considered several trials are being completed.

Time-lapse induction and temperature logging have been performed as part of two aquifer replenishment trials in the Perth metropolitan area. The intention of the time-lapse logging is to characterise the movement of injected water from the injection well into the Leederville formation. A hydrothermal computer model constrained by the measurements has been created to understand the movement of water and heat during injection into the Wanneroo sandstone formation.

As with most practical numerical modelling, a level of non-uniqueness in the model parameters selected exists. It is demonstrated that the calibration to time-lapse logging results provides an important constraint on the range of flow, solute transport and heat parameters that can be used to build a reasonable hydrothermal computer model. First, the flow and solute transport model is constrained with time lapse electrical conductivity distributions at the monitoring wells. Next, the model is expanded to include heat transport. Heat flow and solute transport of total dissolved solids can be identified based on the model's time lapse measurements. Results of our modelling provide the first field scale estimates of heat parameters in the Leederville Aquifer in Perth.

## 58. AIRBORNE ELECTROMAGNETIC SURVEYS FOR GROUNDWATER CHARACTERIZATION

*Jared Abraham*[1]*, *B. Minsley*[1], *P. Bedrosian*[1], *B. Smith*[1] *and J. Cannia*[2]
[1]USGS, Crustal Geophysics and Geochemistry Science Center, Denver, Colorado, USA
[2]USGS, Nebraska Water Science Center, Lincoln, Nebraska, USA
*jdabraha@usgs.gov*

Airborne electromagnetic (AEM) surveys provide densely sampled data over large areas (typically several hundred sq. km) that cannot be covered effectively using ground-based methods. AEM data are inverted to estimate the three-dimensional distribution of electrical resistivity structures from shallow depths to several hundred metres. These models convey unparalleled details that are used to make inferences about hydrogeologic properties and processes at the watershed and local scale. This information is being used in groundwater models that are critical to water management decisions, to better understand geologic frameworks, and to improve climate change models. The U.S. Geological Survey (USGS) has been engaged in the application of AEM to many watershed and local scale groundwater projects within United States. We present the results of several frequency- and time-domain AEM surveys acquired by the USGS that have been used for mapping alluvial valleys, buried glacial aquifers, fault-bounded basins, and understanding permafrost distributions.

## 59. STONELEY WAVE DISPERSION IN A HIGH PERMEABILITY SANDSTONE: PERTH BASIN, WESTERN AUSTRALIA

*Majed AlMalki*, B. Harris and C .Dupuis*
Curtin University, Perth, WA, Australia
*malmalki@gmail.com*

We evaluate four monopole full wave acoustic data sets acquired in the mudded drill hole M345-1/09 at the Mirrabooka Aquifer Storage and Recharge (ASR) site in Perth, Western Australia. To increase the spectral range of the data the hole was logged four times with transmitter centre frequencies set at 1 KHz, 3 KHz, 5 KHz, and 15 KHz. Data was recorded in four receivers spaced at 0.3 m intervals with the first receiver at 0.9 m from the transmitter. Stoneley waves are clearly identified in the frequency range 1 KHz to 5 KHz. Observations of the dependence of phase velocity on frequency were made by using multi filter and phase shift transform techniques. We compare the methods and identify advantages and disadvantages for each. The Mirrabooka site is ideally suited for analysis of the relationship between Stoneley waves and hydraulic conductivity because the injection interval is heterogeneous and hydraulic conductivity is very well constrained. That is, (a) there are a large number of flow logs completed over the injection interval, (b) hydraulic testing has been completed at the injection well, (c) time lapse induction and temperature logging also constrain fast flow pathways, and (d) several permeability measurements have been made on core plugs. A positive correlation has been identified between fast flow pathways identified in the time lapse logging data and Stoneley wave dispersion.

## 60. FACILITATING LONG-TERM OUTBACK WATER SOLUTIONS – COMBINING SOME OF THE OLD WITH SOME OF THE NEW

*Tim Munday*[1]*, *I. Jolly*[2], *F. Leaney*[2] *and R. Crosbie*[2]
[1]CSIRO, CESRE, Perth, WA, Australia
[2]CSIRO, Land and Water, Adelaide, SA, Australia
*tim.munday@csiro.au*

Mining and energy developments in the far north of South Australia are set to have a significant effect on demand for the water resources of the region. The scale of the planned developments and potential from current mineral and energy exploration programs, facilitated by the South Australian Government through the Plan for Accelerated Exploration (PACE Program), will result in a substantial increase in infrastructure requirements, including access to water resources. Securing a reliable and sustainable supply of water has been identified as a key infrastructure need for the mining and energy industry sectors with consequences for the State's future economic development. However, in many priority areas for development, particularly those in the State's arid north, a lack of knowledge about the character and variability of groundwater resource, the sustainability of this resource, and its relationship to environmental and cultural assets, remain some of the major limiting factors to inform the definition of appropriate policy. In addressing these issues, the South Australian Goyder Institute has initiated research, through its FLOWS Project, to explore new water resources of the South Australian Arid Lands. Initially focusing on the Musgrave Block, and the North-west Gawler Craton, the project is employing historical AEM data sets, and other geophysical data to better define the location, and characteristics of aquifers, their capacity, and the quality and variability of the contained groundwater resources. The conjunctive use of airborne geophysics to define variability associated with near surface and deeper aquifers represents a departure from their normal application. When coupled with hydrochemistry and environmental tracer studies to better understand surface water-groundwater interactions, including processes of groundwater recharge and discharge we believe the FLOWS project will help better define the accessibility and sustainability of the State's groundwater resources, particularly those that are suitable for mineral processing and energy supply.

## 61. FAULTING AND GROUNDWATER IN ARID ENVIRONMENTS: AIRBORNE ELECTROMAGNETICS IN SUPPORT OF FRAMEWORK HYDROLOGY IN THE NORTHERN MOJAVE DESERT, SOUTHERN CALIFORNIA

*Paul Bedrosian[1]*, J. Densmore-Judy[2], P. Martin[2], M. Burgess[2], V. Langenheim[3] and R. Jachens[3]*
[1]USGS, Crustal Geophysics and Geochemistry Science Center, Denver, Colorado, USA
[2]USGS, California Water Science Center, San Diego, California, USA
[3]USGS, Geophysical Unit Menlo Park, Menlo Park, California, USA
*pbedrosian@usgs.gov*

Groundwater basins within the Mojave Desert of the southwestern United States are often compartmentalised by faults. As part of an effort to understand and manage groundwater resources in arid environments, the U.S. Geological Survey is investigating a number of basins within the Fort Irwin National Training Center (NTC) using multiple surface geophysical methods. Gravity, aeromagnetic, ground-based and airborne time-domain electromagnetic (TEM) data were collected over Leach Basin, a geologically complex, internally-drained basin bisected and flanked by Quaternary faults including the Garlock and Death Valley fault zones.

The airborne TEM data show abrupt changes in earth response across faulted boundaries, reflecting the strong resistivity contrast between igneous rocks and basin sediments. The distribution of faults throughout the basin can be directly obtained from the airborne data. A resistivity stratigraphy has been developed by integrating borehole geophysical logs, lab resistivity measurements, and ground-based gravity and TEM soundings. The results are applied to the airborne resistivity models and are used to trace aquifer hydrostratigraphy throughout the basin. Interpreted parameters include the depth to basement, the depth to water, and the thickness of the primary aquifer. Together with hydrologic investigations, these results are being used to estimate groundwater storage within the basin.

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