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# SECTION 4
# POSTER ABSTRACTS



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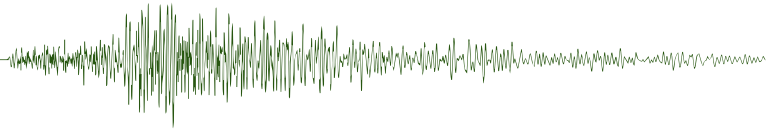

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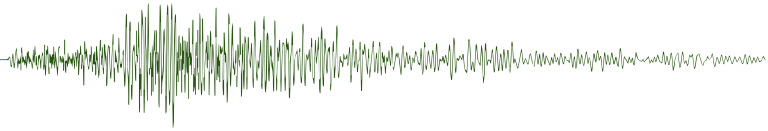

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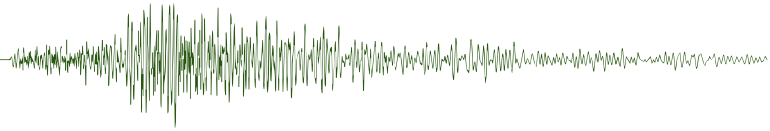

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## MINERALS – 21ST CENTURY EXPLORATION: METHODS AND TECHNOLOGIES

### 1. RESISTIVITY AND INDUCTION POLARIZATION TECHNIQUE FOR MAPPING HEMATITE RICH AREAS IN IRAN

*Ida Hooshyari Far*[1]*, *Anton Kepic*[1] *and Shahriar Javadipour*[2]
[1]Curtin University
[2]TESLA Explorer Engin

Hematite mineralisation loses magnetic susceptibility as it oxidizes. The absence of a significant magnetic response means that exploration using magnetic methods is ineffective.

Mineralogy of the study area shows the mineralisation is generally dominated by iron oxides, mainly hematite, but it also contains anomalous concentrations of sulphides. For this reason the induced polarisation-resistivity method can potentially be used during exploration since the sulphides increase chargeability. The induced polarisation-resistivity method is cost efficient and relatively fast.

In this study, we examined the applicability of the induced polarisation-resistivity method for iron ore exploration in Iran. The interpretation of the results was constrained by known geology and confirm that this technique is a possible alternative to magnetic exploration methods.

### 2. A COMPARISON OF 3D DCIP DATA ACQUISITION METHODS

*David Farquhar-Smith*[1]* *and Darcy McGill*[1]
[1]Quantec Geoscience Ltd

Several approaches to 3D DC resistivity are examined by using data acquired by a high resolution pole-dipole omnidirectional 3D DCIP survey that successfully mapped a known mineralised zone. Subsets of the real-world data are used to examine the effects of reduced numbers of receiver dipoles and also reduced numbers of current injections. To compare the full-scale 3D survey results with other commonly-used systems, a third data subset simulates an offset-injection type survey. The results show that the high-density omnidirectional method produces superior resolution of geologic structures compared to other methods that collect less dense and directionally biased data.

### 3. RESULTS FROM SGL'S AIRGRAV AIRBORNE GRAVITY SYSTEM OVER THE KAURING AIRBORNE GRAVITY TEST SITE

*Luise Sander*[1]* *and Stefan Elieff*[1]
[1]Sander Geophysics

A Sander Geophysics AIRGrav airborne gravity system was flown over Geoscience Australia's Kauring airborne gravity test site. Comparisons with both Geoscience Australia ground data and airborne gravity gradiometer data acquired by CGG using the Falcon system are presented. A series of band pass filters of the vertical gravity and vertical gravity gradient are employed to highlight performance at different wavelengths. While the Falcon system is best suited to the shortest wavelengths present at the Kauring test site, the AIRGrav system is also able to resolve relatively short wavelength features. This is due to noise reduction through the oversampling present with tight line spacing, combined with the unique characteristics of the AIRGrav system. Additional results with wider line spacing more commonly employed in airborne gravity surveys are shown using data acquired over both the Kauring test site and Papua New Guinea.

### 4. 3D JOINT INVERSION OF GRAVITY GRADIOMETRY AND MAGNETIC DATA IN SPHERICAL COORDINATES WITH CROSS-GRADIENT CONSTRAINTS

*Haoran Wang China*[1]*, *Yaoguo Li*[2] *and Chao Chen*[1]
[1]University Of Geosicences
[2]Colorado School of Mines

Earth observing satellites offer exciting new opportunities to study the large-scale regional or global lithospheric structures by producing reliable potential-field data sets including gravity, gravity gradiometry, and magnetic data that are publicly accessible. Joint inversions may offer an effective means of utilizing these different types of data to improve the construction lithospheric models. In this paper, we develop a joint inversion algorithm for satellite gravity gradiometry and magnetic data in the spherical coordinates for simultaneously constructing the density and susceptibility distributions in the lithosphere. Given the undetermined relationship between the two different physical properties, we apply the cross gradient to constrain the two recovered models so they structurally similar. We use a synthetic data example to illustrate the algorithm and its potential benefits. We will also demonstrate the algorithm by applications to field data sets in the presentation.

### 5. AN IMPROVED TILT DERIVATIVE METHOD COMBINED WITH THE MMTS E USING IN FRACTURE SYSTEM IDENTIFICATION FOR THE SWIR 49°E AREA

*Qiuge Wang*[1]*, *Chao Chen*[1], *Zhikui Guo*[1], *Shuangxi Zhang*[1], *Haoran Wang*[1] *and Duan Li*[1]
[1]China University of Geosciences (Wuhan)

Seafloor hydrothermal sulfide deposits occurring at plate boundaries and convergent plate boundaries are mainly concentrated in extensional tectonic belt with abundant fault structure, which is always correlated with the severe potential field signals changes. Considering the common magnetic anomaly components cannot reflect the field sources correctly as magnetic field around the ocean ridges is extremely infected by the residual magnetism, based on the obvious superiority of the magnitude magnetic transforms (MMTs) centricity and low dependence on the magnetization vector direction, we used the MMTs for geological boundaries identification. We improved the Tilt derivative method to indentify the boundaries of the geological structure on the basis of both the MMTs E and R, and find that the MMTs E combined with the improved Tilt derivative method performs better . We applicant this method in the 49° E zone (48°E~52°E, –39°S~–37°S) of the Southwest India Ridge (SWIR), with the help of the 2-arc minute high resolution magnetic model EMAG2, the fault system distribution of the study area was obtained and described primarily.

### 6. 3D IP INVERSION OF AIRBORNE EM DATA AT TLI KWI CHO

*Seogi Kang*[1]*, *Douglas W. Oldenburg*[1] *and Michael S. McMillan*[1]
[1]University of British Columbia

In this study, we revisit three airborne EM surveys over Tli Kwi Cho (TKC). These consist of a frequency domain DIGHEM data

set, and two time domain surveys, VTEM and AeroTEM. Negative transients have been recorded in both of the time domain surveys and we interpret these as arising from chargeable bodies. The kimberlite pipes are referred to as DO-27 and DO-18. We look in more detail at the transient data and apply the ATEM-IP inversion procedure to recover a 3D pseudo-chargeability distribution. Important components of the analysis involve estimating a background conductivity for the region. For DO-27 we have used a 3D parametric inversion to recover the conductivity from TEM data. The IP signal for the inversion is obtained by subtracting the time domain responses estimated by EM inversion from the observed background signal. This process also removes EM coupling noise that might be contaminating the data. The resultant IP data are inverted with a linear inverse approach using the sensitivity from the background conductivity. This yields a 3D model of pseudo-chargeability.

## 7. NEAR SURFACE SEISMIC INVESTIGATION OF THE REGOLITH IN SOUTH AUSTRALIA

*Stephanie Vialle*[1]*, *Konstantin Tertyshnikov*[1], *Sinem Sinem*[1] *and Bai Chun Sun*[1]
[1]Curtin University

Investigation of the regolith is an important part of mineral exploration. Large areas are overlaid by the regolith rocks and recent trends show an increase in exploration under cover. Thorough regolith exploration involving geophysical techniques is required for deep mineral discoveries. Knowledge about regolith structure and properties is necessary for designing mines and production as well.

A short 2D seismic profile was acquired to investigate regolith structure and properties at the Hillside prospect, situated on the Yorke Peninsula, South Australia. A small 3D dataset has also been acquired to evaluate the potential for seismic imaging of deep structures. The survey was designed to be able to collect useful data for various types of seismic analysis simultaneously. Data analysis included processing and interpretation of surface, refracted and reflected waves. The study also involved an application of diffraction imaging to detect faults and fracture zones.

The experiment has demonstrated a cost effective near surface seismic setup that is capable of obtaining a comprehensive set of information about the sub-surface. The results include imaging of the regolith's structure, estimating dynamic elastic properties of the ground and obtaining images of deep structures.

## 8. GEOLOGICAL KNOWLEDGE DISCOVERY AND MINERALS TARGETING FROM REGOLITH USING A MACHINE LEARNING APPROACH

*Matthew Cracknell*[1]*, *Anya Reading*[1] *and Patrice de Caritat*[2]
[1]University of Tasmania
[2]Geoscience Australia

We identify and understand the diverse nature of Ni mineralisation across the Australian continent using Self-Organising Maps, an unsupervised clustering algorithm. We integrate remotely sensed, continental-scale multivariate geophysical/mineralogical data and combine the outputs of our machine learning analysis with Ni mineral occurrence data. The resulting Ni prospectivity map identifies the location of Ni mines with an accuracy 92.58%. We divide areas of prospective Ni mineralisation into five clusters. These clusters indicate subtle but significant differences in regolith and bedrock geophysical/mineralogical footprints of Ni sulphide and Ni laterite deposits. This information is used to identify and understand the nature of potential Ni targets in regions where prospective bedrock mineralisation is concealed by regolith materials. Our machine learning approach can be applied to the analysis of other mineral commodities and at local-/prospect-scales.

## 9. HYDROPHONE DESIGN UTILISING SPECTRAL-SHIFTS FROM STRAIN-OPTIC INTERACTIONS

*Vladimir Bossilkov*[1]*, *Anton Kepic*[1] *and Anna Podolska*[1]
[1]Curtin University

Alternative technologies for the production of hydrophones using optical sensing are reviewed with respect to performance and manufacturability. Sensor designs utilising spectral shifts as a result of strain-optic interactions are uncommon, and we believe they merit further investigation as geophysical sensors due to good sensitivity and relative ease of manufacture Specifically, a Long Period Fibre Grating placed onto a mandrel appears to be as promising candidate as a future compact hydrophone sensor.

A mathematical model has been created for a compliant mandrel coupled with a Long Period Fibre Grating inscribed into plastic fibre. The modelling results indicate that such a sensor should provide a sensor of minimal size, with desirable sensitivity characteristics. Compared to the Rayleigh based optical fibre sensors being evaluated in geophysical applications currently the modelled sensor is predicted to have significantly greater sensitivity, with the mandrel acting as a mechanical amplifier. The main limitation of the spectral shift method is the number of sensors that can be multiplexed on a single fibre. However, a combination of time-domain and wavelength domain multiplexing could significantly increase the number of sensors per fibre to usable numbers for geophysical applications.

## 10. HARMONISING DIVERSE 3D GEOMETRIES IN A HARD ROCK ENVIRONMENT FOR PRE-STACK IMAGING

*Sasha Ziramov*[1]* *and Milovan Urosevic*[1]
[1]Curtin University of Technology

Four 3D seismic surveys were acquired by HiSeis Pty Ltd over two years across an existing mining camp. The main objective of these seismic surveys was definition of structures which could assist characterization of mineralised zone that consists mainly of massive sulphides.

Initial processing of seismic data started shortly after acquisition in 2011. Preliminary products have shown great promise in resolving complex structural environments and showed potential for direct targeting form seismic data. Our motive for reprocessing the dataset was in integration of all 2011 and 2012 seismic data in an amplitude consistent routine which could bring new value for amplitude based analysis of massive sulphide bodies. Conventional 3D deep-move out corrections (DMO), followed by a post-stack migration algorithm has not been successful in merging diverse datasets. Considerable improvement was achieved through the application of pre-stack time migration (PSTM) algorithm. This allowed us to use unique bin size for all merged seismic surveys.

Successful imaging of merged datasets has been challenged. The main reason was that 3D seismic datasets had vastly diverse offset and azimuth distribution. Highly irregular migration fold coverage is an obvious problem which had to be overcome by exclusion of unsuccessful imaged events prior to stacking.

## 11. MODELLING USING RECEIVER WAVEFORM AND THE UNEXPECTED IMPORTANCE OF SYSTEM POSITION

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Conductivity-depth sections (CDI) produced from a recent airborne TEM exploration survey showed a poor fit to the expected geology of the area (a known conductive layer was appearing deeper than expected). The source of the problem was found to be the use of an incomplete description of the system geometry which had the effect of dramatically scaling the secondary field. In many modelling programs, including in this case EMFlow, the system geometry may be used to determine transmitter-receiver coupling which is used to compute the apparent primary field. This paper explains why system geometry can be critical for precise modelling of TEM data. By specifying the correct transmitter orientation and de-rotating receiver pitch for both primary and secondary fields, the match between known geology and CDI depth was greatly improved.

## 12. BUILDING A MACHINE LEARNING CLASSIFIER FOR IRON ORE PROSPECTIVITY IN THE YILGARN CRATON

*Andrew Merdith*[1]*, *Thomas Landgrebe*[1] *and Dietmar Müller*[1]
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High resolution, large-scale geophysical data have recently become readily and freely available for the majority of the Australian continent; yet there have been few efforts to create a synthesis of these datasets for mineral exploration. Considering the rising cost of finding new deposits and the recent economic downturn, there is a focus on using low expenditure, large-scale explorative techniques to assist in finding deposits. Using sophisticated machine learning algorithms coupled with increases in computational power, we present a methodology that tests and trains a classifier using six geophysical datasets in conjunction with 37 iron ore locations in the Pilbara Craton that accurately predicts the locations of iron ore deposits throughout the Yilgarn Craton. Our selected classifier uses principal component analysis and mixture of Gaussian classification with reject option, and it successfully identifies 88% of iron ore locations. We use cross-validation (10 fold, 70% testing 30% training) to ensure the generalisation of our classifier. We apply our classifier to the Yilgarn Craton, an area not used for the training and testing phase, and compare the predictive confidence map to previously published locations of iron ore occurrences. We find that our classifier correctly locates key known Yilgarn iron ore deposits, in addition to highlighting other areas that could potentially be prospective for iron ore.

## 13. 2D CROSS-GRADIENT JOINT INVERSION OF MAGNETIC AND GRAVITY DATA ACROSS THE CAPRICORN OROGEN IN WESTERN AUSTRALIA.

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In order to contribute to the recent efforts to produce a combined interpretation of the Capricorn Orogen in Western Australia, we performed the 2D cross-gradient joint inversion of the gravity and magnetic data available along the trace of the seismic section 10GA-CP2. This methodology establishes that even in the absence of analytical relationships between the physical properties underlying disparate geophysical methods, we expect a degree of structural similarity in the images that they provide. Our results show that the major subsurface structures interpreted on the seismic section are readily detected by the 2D cross-gradient joint inversion. We also illustrate how this structural framework acquires further geological significance when the framed density and magnetization properties are interpreted together and correlated to the expected geological materials within the Capricorn orogen.

## 14. IDENTIFYING TECTONIC NICHE ENVIRONMENTS OF SOUTH AMERICAN PORPHYRY MAGMATISM THROUGH GEOLOGICAL TIME: A SPATIO-TEMPORAL DATA MINING APPROACH

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Porphyry ore deposits are well known to be associated with arc magmatism related to subduction on the overriding plate. Furthermore, the regional mechanisms for magmatism and the resulting formations of porphyry deposits are well established. Specific parameters leading to these events have been inferred, but not formally tested. We aim to identify the specific set of tectono-magmatic parameters that result in a subducting slab producing particular types of magmatism on the overriding plate, and their link to the formation of ore deposits. We use a four-dimensional approach to reconstruct age-dated magmatism back through space and time to isolate the tectono-magmagic parameters leading to the formation of a metalliferous deposit during subduction. By utilising machine learning techniques we identify and quantify geodynamic parameters that are robust predictors of back-arc magmatism and porphyry formation. The 'random-forest' ensemble and 'support vector machines' learning classification methods are employed to prioritise parameters that are considered influential in the development of magmatism and the subsequent metallogenesis of porphyry ore deposits. We find that a combination of convergence rates and directions, seafloor age, subduction obliquity, and the distance to a trench edge help predict whether magmatism and related ore deposits occur.

## 15. CUTTING THE LINE IN WIRELINE WITH AN AUTONOMOUS SONDE

*Anna Podolska*[1]*, *Anton Kepic*[1], *Andrew Greenwood*[1], *Christian Dupuis*[2] *and Gordon Stewart*[3]
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[2]Univereite Laval
[3]Globaltech

Rock core has long been one of the pillars of mineral exploration strategy. This strategy, however, is becoming less viable as the depth of exploration targets continue to increase. Exploration strategies based on physical and chemical attributes of the rock-mass measured in-situ have the best chances to deliver efficient exploration programs by providing new data channels that can be used to improve the models of the deposits. Unfortunately, the logistic costs of acquiring these data using conventional wire-line methods have precluded their widespread use in the mineral industry.

The autonomous sonde concept presented in this work drastically reduces the logistics costs of acquiring in-situ measurements. The autonomous sonde has been developed to integrate fully with the normal operations of current drill rigs. As such, it requires no specialised operator or equipment and no rig modifications.

In this work, we present the results of field trials of the autonomous sondes at two Australian field sites. In the first experiment, we show that a pressure transducer can be used to evaluate the position of the sonde and to depth register the natural gamma data. In the second experiment, we show data acquired when the autonomous sonde protrudes through the bottom of the drill string and is brought back to surface by pulling up the rods. The results show a good repeatability between logging runs and data quality compares favourably to traditional wireline data.

## 16. 1D MAGNETOTELLURIC FORWARD MODELLING WEB APP

*Andrew Pethick*[1]* *and Brett Harris*[1]
[1]Curtin University

Geophysical computing within the cloud appears to be the way of the future. The instantaneous, on-demand character of modern life is now firmly established. We present an integrated 1D magnetotelluric forward modelling web app. This basic web app combines a scientific python back end and a front end built upon PHP and HTML5 web technologies. It has also been packaged as an easy to install plugin for the popular Wordpress framework. The application simulates the 1D magnetotelluric response over any isotropic geo-electrical earth model. MT forward modelling can be performed on any internet enabled device containing a HTML5 compliant browser with our WebMT application. This includes mobile phones, tablets and desktop PCs. This research demonstrates one approach to geophysical web application development and promotes future development and innovation within the geophysics community.

## 17. IMAGING THE ELECTRICAL LITHOSPHERE OF SOUTH AUSTRALIA - 2D PROFILES AND PRELIMINARY RESULTS OF AUSLAMP SA

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The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) has the goal of mapping the electrical resistivity of the Australian lithosphere to constrain the geodynamic framework of the continent. Between August 2014 and May 2015, 125 long-period magnetotelluric (MT) data will be collected across the Gawler Craton and the south-eastern part of South Australia at intervals of 50 km. Results will be compared to existing 3D models highlighting enhanced conductivity in the sub-lithospheric mantle of the Gawler Craton. Initial results of 1D depth transformations show a significant change in resistivity at mantle lithosphere depths (100 km). The results will also be tied to the newly acquired Eucla MT line and a new 1000 km NS MT profile extending north from the central Gawler Craton into the Arunta Province, NT.

## MINERALS - GEOLOGY FROM GEOPHYSICAL DATA

## 18 . MAPPING SANDSTONE-HOSTED URANIUM MINERAL SYSTEMS IN THE CALLABONNA SUB-BASIN (SOUTH AUSTRALIA) USING AEM

*Marina Costelloe*[1]*
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The Frome TEMPEST® airborne electromagnetic (AEM) survey was designed to provide reliable pre-competitive AEM data to aid the search for energy and mineral resources around the Lake Frome region of South Australia. Flown in 2010, a total of 32 317 line km of high-quality airborne geophysical data were collected over an area of 95 450 km$^2$ at a flight line spacing mostly of 2.5 km, opening to 5 km spaced lines in the Marree–Strzelecki Desert area to the north. Interpretations of the data show the utility of regional AEM surveying for mapping crucial elements of sandstone-hosted uranium mineral systems as well as for mapping geological surfaces, structures and depth of cover over a wide area. Data from the Frome AEM survey allow mineral explorers to put their own highresolution AEM surveys into a regional context. Survey data were used to map and interpret a range of geological features that are associated with, or control the location of, sandstone-hosted uranium mineral systems, and have been used to assess the uranium prospectivity of new areas to the north of the Flinders Ranges.

## 19. INSIGHTS INTO THE CONTINENTAL STRUCTURE OF SOUTHEAST AUSTRALIA AND TASMANIA FROM PASSIVE SEISMIC AND MAGNETIC DATASETS

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The continental crust of southeast Australia is a complex and highly prospective area. Southeast Australia comprises the Delamerian and Lachlan Orogenies which, together with the Eastern Tasmania Terrane, are understood to have Phanerozoic

basement. In contrast, the Western Tasmanian Terrane comprises areas of exposed Neoproterozoic basement which were assembled along the proto-Pacific margin of East Gondwana. In this study, the crustal structure across southeast Australia and Tasmania is considered using seismic and aeromagnetic methods. We use previous passive seismic results and present a new analysis of magnetic data. The Curie temperature, the temperature at which magnetic rocks lose their magnetisation, is investigated using spectral analysis of aeromagnetic data and the Curie point depth (CPD) is consequently determined. CPD is compared to the depth of the seismic Moho discontinuity throughout the study area.

The Moho depth and newly calculated CPD throughout the study area vary from ~20 to >38 km and ~25 to >45 km, respectively. The CPD is slightly shallower than the Moho across the study area. The Delamerian and Lachlan Orogenies are underlain by a 30–35 km and ~40–50 km deep Moho respectively, while average CPD depths are ~30 and ~28 km for these regions. A relatively shallow CPD is observed in the northeast of the study area and corresponds to Cainozoic volcanism in eastern Australia. The shallow Moho beneath Tasmania supports the idea of crustal thinning during Gondwana breakup. In Tasmania, CPD increases in depth from ~21 km in the northwest to >31 km in north. This is consistent with variations in the depth of the Moho from 25 km in the northwest to 37 km in the north.

## 20. NEW GRAVITY IN THE MUSGRAVE RANGES, SOUTH AUSTRALIA

*Philip Heath*[1]*
[1]Geological Survey of South Australia

A gravity survey has been undertaken on the Alcurra, Agnes Creek and Tieyon 1 : 100K mapsheets, in the eastern portion of the Musgrave Ranges, South Australia. A total of 821 readings were collected, incorporating 689 new stations, 88 repeats and 44 base measurements. The data highlights new features giving insight into the underlying geological structure, including a gravity high near Doug's Well.

## 21. DEEP CRUSTAL STRUCTURE OF THE CAPRICORN OROGEN FROM GRAVITY AND SEISMIC DATA

*Abdulrhman Alghamdi*[1]*, *Alan Aitken*[1] *and Michael Dentith*[1]
[1]University of Western Australia

The integration of geophysical data including deep seismic reflection, receiver function and gravity data provides the ability to image the deep crustal structure of Capricorn Orogen. In this study, we aim to reconcile seismic models of crustal structure with gravity measurements.

S-wave seismic velocities from receiver function models were converted to P-wave velocity and density. Geology interpreted from deep seismic reflection profiles was depth converted based on the velocity data.

An initial density model was constructed based on the depth converted seismc interpretation and densities estimated from velocities. To match observed variations in Bouguer anomaly the initial densities were modified based primarily on the comparability the wavelength of Bouguer anomaly and calculated gravity response of the model.

We found that the Bandee Seismic Province (BSP) has a high density compared to the density of the adjacent regions and the underlying lower crustal blocks. This province, a 'deep crustal seismic terrane' without surface expression, recognised from the seismic data. Sensitivity testing suggests the mantle, the lower crust and the upper crust are less likely sources of the coincident high gravity anomaly. This observation is supported by receiver function models that reveal a high S-wave seismic velocity in mid-crust.

Importantly, the region of higher density in the middle crust, unlike the BSP, does not extend south of the Talga Fault. This suggests the Talga Fault is a more significant structure than suggested by previous interpretations and the area around its surface outcrop may be more prospective than previously thought.

## 22. THE SOUTHERN THOMSON OROGEN AEM SURVEY

*Ian Roach*[1]*, *Ross Brodie*[1] *and Marina Costelloe*[1]
[1]Geoscience Australia

The Southern Thomson Orogen airborne electromagnetic (AEM) Survey was flown in 2014 using the Geotech VTEMplus® AEM system. The AEM survey was designed by Geoscience Australia, and its partners the geological surveys of New South Wales and Queensland, to help solve geological problems in the Southern Thomson Orogen as part of the UNCOVER Initiative of the National Mineral Exploration Strategy.

Survey results indicate variable depth of penetration governed by conductive cover, primarily the Cretaceous Rolling Downs Group, and saline groundwater in broad ephemeral drainage systems including salt lakes and channel country around the Paroo River. The unconformity between the Paleozoic rocks of the Eulo Ridge (a partially-exposed palaeotopographic high) and the overlying Mesozoic and Cenozoic cover is well mapped in the central part of the survey area. The survey data reduce risk to explorers in the area by decreasing uncertainty regarding depth of cover for drilling activities and advising where ground and airborne electromagnetic methods can be expected to produce reliable results.

## 23. MAGNETOTELLURIC IMAGING OF A PALAEOZOIC ANDEAN MARGIN SUBDUCTION ZONE IN WESTERN VICTORIA

*Graham Heinson*[1]*, *Michael Stepan*[1], *David Taylor*[2], *Kate Robertson*[1], *Phil Skladzien*[2] *and Goran Boren*[1]
[1]University of Adelaide
[2]Geological Survey of Victoria

A 450 km long transect of broadband (200 Hz – 2000 s) magnetotelluric (MT) sites spaced between 1 and 5 km apart, has been collected across the Palaeozoic Delamerian-Lachlan Orogens in western Victoria. The bandwidth of responses yields resistivity constraints between a few tens of metres in near-surface cover to sub-Moho depths. The passive nature of the source-field means that the MT responses have been collectively assembled in several tranches over ten years, with the last section across the transition between the Orogens collected in June 2014. The MT coverage now completely coincides with a deep crustal reflection seismic transect to generate complementary insight of the crustal structure. We report on preliminary modelling and interpretation.

## 24. 3D GEOLOGY FROM POTENTIAL FIELD GEOPHYSICS: APPLICATIONS TO BATHURST MINING CAMP, EASTERN CANADA

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Interpretation methods and tools for geophysics datasets continue to evolve. Advances in clustering algorithms, the use of implicit functions to create 3D surfaces, new algorithms to estimate source depths and dips, and the availability of clever computational geometry libraries, contribute to the discipline of potential field interpretation techniques, allowing for a much more explicit statement of implied 3D description. While traditional scalar measures of potential fields have benefited from applying new ideas, perhaps more exciting is the reduction in ambiguity imposed from gradient measurement when used as the basis for field interpretation. Full tensor gravity gradiometry in particular, allows for 2D fault dip and throw calculations. Direct detection of high density bodies and faults via state-of-the-art gravity gradiometry is now a reality. Bodies greater than 200 m in lateral extent are detectable. Implicit 3D structural geology modelling techniques derived from gravity curvature attributes of the observed gravity field present a leading edge technique for defining structurally controlled near surface geology geometry. A demonstration from the Bathurst camp dataset is given.

## 25. CASE STUDIES IN INTEGRATED GEOLOGICAL AND GEOPHYSICAL 3D MODELLING: VALUE ADDED TO EXPLORATION AND MINING PROJECTS

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The integration of geophysical with litho-structural models represents a valuable tool for better understanding of subsurface geometries of lithological contacts. Improved subsurface models add value to mineral exploration projects. Geophysical data is used to enhance and validate litho-structural models. The regular distribution of geophysical data allows lithologies and faults to be extended from observed locations into the subsurface. Geological models are validated and improved by comparison of the geophysical signal calculated from the model geology with the observed signal. Discrepancies between modeled and observed signals highlight areas requiring refinements of the geological model. The case studies present examples of how iterative modeling of geological and geophysical data will result in an improved final product. The calculated geophysical signal from two distinct geological interpretations shows how well a certain litho-structural model conforms with the geophysical data. Applications include determining the position of rocks of distinct physical properties, checking the geometry of faults and extending mapped structures into inaccessible/covered areas.

## 26. A MAGNETOTELLURIC SURVEY OF THE NORTH PERTH BASIN: A TECHNICAL CASE STUDY

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Original motivation of this study was to understand important structures with a proven geothermal signature associated with high temperatures in the shallower basin and high flow rates in the aquifers. Anomalous temperatures are recorded around the Beagle Ridge and significant flow rates observed near the Urella Fault, factors important to unconventional geothermal prospects. The focus of this study was therefore a detailed geophysical investigation of several Geothermal Exploration Permits (GEPs) in the North Perth Basin.

Two Magnetotelluric (MT) surveys are conducted over target areas in the North Perth Basin and adjoining tectonic domains to provide information about the electrical conductivity regime of the basin and western margin of the Yilgarn Craton. Existing geophysical data in this part of the basin are sparse and electrical data for the basin in general is limited to shallow Time Domain Electromagnetic (TDEM) data targeting superficial aquifers.

High-resolution MT data, acquired between 2011 and 2013, provide information on mid-deep crustal rocks. In addition, new gravity data and joint interpretation of these data sets are undertaken to improve the geological model of the North Perth Basin and test some existing hypotheses.

We present a best practice case study and workflow for data acquisition and filtering, robust dimensionality analysis and removal of distortion effects from impedance tensor estimates. 1D and 2D inversions are found to be largely sufficient for the majority of these data while 3D modelling provides an additional tool to verify results. Finally, modelling of gravity data and integrated interpretation ensures robust geological models for the area are consistent with all data available.

We conclude with several inferences about the geology in this area. (1) Electromagnetic and gravity data does not seem to support significant crustal thinning beneath the basin. (2) The Dandaragan Trough appears deeper than generally modelled. (3) Extremely high conductivities persist to depth in the basin.

## 27. EVALUATION OF AUTOMATED LITHOLOGY CLASSIFICATION ARCHITECTURES USING HIGHLY-SAMPLED WIRELINE LOGS FOR COAL EXPLORATION

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Wireline logs are a supplemental data source to conventional core logging. The recent explosion of machine learning algorithms has provided researchers with ample opportunity to develop automated statistical tools for classifying lithology from wireline logs, which geologists can use to produce first-pass interpretations or to validate existing interpretations. Such automated interpretations can be particularly valuable information in the case of missing or damaged core samples. There exists, however, a need to evaluate said machine learning algorithms in the case where available wireline logs contain a wide range of different logs which are highly-sampled.

This paper explores different machine learning algorithms and architectures for lithology classification using wireline data from project area Jundah East, 60 km north-west of Wandoan, Queensland, which is well known for coal mineralisation. We used seven well logs each containing 19 wireline logs sampled at 1 cm-1, available through the Queensland Digital Exploration (QDEX) data system. Three popular supervised machine learners, namely the Naïve Bayes classifier, Support Vector Machine, and Multilayer Perceptron (an artificial neural network), are tested under two architectures: committee (one classifier per well log) and singular (one classifier for all well logs). The results show the Naïve Bayes classifier, although computationally simple, achieves good results in general when training using a committee architecture on a large data set. For coal classification in particular, it achieved the sensitivity score of 0.79 and the specificity score of 0.97. While the committee and singular architectures generated similar results, the committee architecture provides the benefits of faster computation time as well as a flexible platform for the training of additional well logs.

## 28. THE GRANITES-TANAMI OROGEN SUBSURFACE GEOMETRY AS REVEALED BY AN INTEGRATED POTENTIAL FIELD GEOPHYSICAL AND GEOLOGICAL STUDY

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The Granites Tanami Orogen (GTO) in central Australia is a significant gold producing province. Future exploration will be facilitated by determining the structural controls on mineralisation and crustal evolution of the orogen. A whole of crust model has been generated through the multi-scale integration and interpretation of geophysical, geological and remote sensing data.

The architecture of the orogen is that of a basin that has been inverted, deformed and intruded during: (a) the collision between the Kimberley and Tanami basins along the Halls Creek Orogen to form the North Australian Craton; and (b) during the amalgamation of the North Australian Craton with the Central Australia Craton. These continent-continent collisions have resulted in a complex structural framework, which is further complicated by deep weathering and extensive regolith across the region. Reconnaissance style outcrop mapping coupled with potential field interpretation has identified two main phases of deformation. The first regional deformation event resulted in north- to northeast-trending isoclinal fold trains of wavelengths ~10 km or greater. These folds are recognised through the interpretation of joint gravity and magnetic anomalies and are confirmed in outcrop. Gold mineralisation within the GTO is coincident with the second regional deformation event, which is recognised in regional aeromagnetic data as poly-phase deformational interference patterns caused by the refolding of earlier folds around axes trending E to ESE.

This defining of upper crustal architecture to structural features observable in sparse outcrop coverage could not be sufficiently identified without this combined geology and geophysical approach.

## 29. INTERPRETATION OF 3D HIGH-RESOLUTION SEISMIC DATA COLLECTED OVER AN IOCG DEPOSIT IN SOUTH AUSTRALIA

*Muhammad Hossain*[1]*, *Milovan Urosevic*[1] *and Anton Kepic*[1]
[1]Curtin University

A 3D high–resolution seismic dataset was acquired to investigate typically complex IOCG deposits in Hillside, South Australia. Petrophysical data measured from the core samples and the density data supplied by the mining company were utilised during the volumetric interpretation. However, petrophysical data show that the boundaries between gabbro and metasediments may not generate acoustic impedance contrast to be clearly detected by seismic reflection method. The base of the top cover is mappable throughout the cube and the tops of the major formations have agreement with magnetic data. The faults extracted from the seismic volume using ant-tracking attribute have good agreement with the company supplied geological interpretation based on the drilling information.

## 30. GEOSCIENTIFIC INVESTIGATION OF A REMANENT ANOMALY – TEETULPA, SOUTH AUSTRALIA

*Tim Keeping*[1]*, *Clive Foss*[2], *Philip Heath*[1] *and Gary Reed*[1]
[1]Geological Survey of South Australia
[2]CSIRO

We investigate a small (100 m width) 150 nT amplitude magnetic anomaly delineated in a high-resolution aeromagnetic survey in the Teetulpa Goldfield of the southern Flinders Ranges. We believe that the anomaly is due to a kimberlite pipe, part of a field already known in the general region. As is quite common with kimberlites, the magnetization is clearly dominated by remanence. Modelling the anomaly reveals that the source is very shallow, and would have outcropped at some stage. Follow-up ground geophysical, geochemical and biogeochemical investigations are planned to establish a methodology for integrated studies as follow-up to high resolution aeromagnetic surveys.

## 31. MAGNETIC MODELLING AND INTERPRETATION OF THE HAY-BOOLIGAL ZONE AND ITS BASEMENT

*Astrid Carlton*[1]*
[1]Geological Survey of NSW

Little is known about the basement of the Hay–Booligal Zone (located in NSW). Magnetic modelling of long wavelength anomalies within the Hay–Booligal Zone indicates that the Hay–Booligal basement consists of serpentinised ultramafic material at depths of 6 to 12 km. This supports interpretation that the Hay–Booligal basement could be similar to the Selwyn Block in Victoria and rather than a crystalline microcontinent.

Also, interpretation of short wavelength semi-parallel TMI anomalies near the previous boundary of the Hay–Booligal Zone has lead to the adjusted the boundary of the Hay–Booligal and Bendigo zones.

## 32. DEFINING MAJOR STRUCTURES AND THEIR DEPTH EXTENT UNDER COVER IN THE SOUTHERN THOMSON OROGEN, NEW SOUTH WALES

*Rosemary Hegarty*[1]* *and Michael Doublier*[2]
[1]Geological Survey of New South Wales
[2]Geoscience Australia

Regional geophysical datasets are critical to the task of uncovering the basement geology of the southern Thomson Orogen in far western New South Wales. As part of a National Collaborative Framework project, aeromagnetic, gravity and seismic data have being processed and interpreted to construct the structural framework. Subdivision into structural domains has been validated and constrained by geological information, relying on observations and measurements from sparse drill holes and outcrops.

Boundaries between structural domains are complex and poorly understood. This study aimed to recognise major faults and, where possible, define their displacements, depth extent, and understand their dynamics and timing. Analysis of available company and government seismic surveys provided details for some of the major fault systems such as the Olepoloko Fault, Culgoa Lineament, and also for many newly recognised fault trends

The seismic interpretations were reconciled with deep sourced aeromagnetic and gravity gradients that were enhanced by multiscale edge analysis. The structural framework will underpin geochronology and mineral systems studies as the Southern Thomson Orogen project continues.

## 34. IMPROVING MODELLING OF AEM DATA AFFECTED BY IP, TWO CASE STUDIES

*Andrea Viezzoli* [1]*, *Vlad Kaminski*[2], *Yusen Ley-Cooper*[3], *Lyndon Hardy*[4] *and Gianluca Fiandaca*[1]
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[4]Abra Mining

Modelling IP parameters, including dispersive resistivity, from AEM data showing clear IP effects is possible. Using the spatially constrained inversion approach, with forward response that account for the full Cole and Cole model, we recover realistic chargeability and 'IP corrected' resistivities sections from two VTEM datasets, from Canada and Australia. The 'IP corrected' resistivity sections often show better agreement with known geological features, while improving dramatically the data fit, with respect to those obtained without IP modelling. While the majority of the IP effect originate from shallow chargeable layers, there also seems to be some positive correlation between an isolated deep chargeable anomaly and known base metal deposit location.

## MINERALS – GEOPHYSICAL SIGNATURES OF MINERAL DEPOSITS

## 36. A CASE FOR REGIONAL SEISMIC REFLECTION SURVEY IN THE GAWLER CRATON, SOUTH AUSTRALIA

*Okan Evans Onojasun*[1]*, *Kepic Anton*[1], *Urosevic Milovan and Ziramov Sasha*[1]
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With the discovery of the world class Olympic Dam iron oxide copper deposit in 1975 by the Western Mining Corporation (WMC), the entire Gawler Craton, South Australia has been subjected to intense exploration by mining community as well as researchers using multidisciplinary exploration approach (geology, geophysics and tectonic analysis) in search of similar deposits. Potential field geophysical methods are traditionally used for exploration of mineral deposits. However, these methods are often lacking depth of penetration or resolving power. As the search for minerals moves towards exploring for deeper structures due to depletion of the near surface deposits, there is a compelling need to develop new and innovative deep exploration tools to meet the global demand for metal. Seismic methods which provide high resolution images at any depth are receiving more attention from the mining community. 3D seismic reflection method in particular provides a possibility for delineation of very complex geological structures and associated rock types. As powerful as 3D seismic method might be, it has never been tested on a tenement scale. No arguments for regional 3D seismic exploration have been proposed probably because a cost-benefit analysis has never been conducted at such scale. In this study we analyse such cases and its benefits in the case of deep cover as is found over large areas of SA where potential for finding new mineral systems is relatively high.

## 37. GRAVITY ANOMALIES AS TRAP SITES IN PROSPECTIVITY MODELLING OF THE EASTERN GAWLER COPPER-GOLD BELT

*Tom Wise*[1]* *and Laszlo Katona*[1]
[1]Geological Survey of South Australia

A geoprocessing methodology has been developed to capture potential field anomalies from residual gravity and reduced to pole total magnetic intensity (RTP TMI) datasets. Anomalies captured using this process are converted to GIS polygons and attributed with descriptive statistics of the underlying grids. The polygons are subsequently included as criteria in a GIS analysis to target IOCG-style deposits beneath extensive cover in the Eastern Gawler Craton. The application of gravity anomaly polygons within this study was as potential trap sites, based on the assumption that a localised increase in density manifested as an anomalous gravity response may be associated with mineral accumulation. The characterisation of residual potential field anomalies for use in prospectivity modelling has resulted in the accurate identification of existing deposits of IOCG-style mineralisation and has suggested additional targets warranting further investigation.

### 38. SUPERVISED NEURAL NETWORK TARGETING AND CLASSIFICATION ANALYSIS OF AIRBORNE EM, MAGNETIC AND GAMMA-RAY SPECTROMETRY DATA FOR MINERAL EXPLORATION

*Karl Kwan*[1], *Stephen Reford*[2], *Djiba Maiga Abdoul-Wahab*[3], *Douglas H. Pitcher*[1], *Nasreddine Bournas*[1], *Alexander Prikhodko*[1], *Geoffrey Plastow*[1] *and Jean M. Legault*[1]*
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[2]Paterson, Grant and Watson
[3]CPG/PRDSM

The amount of multi-disciplinary (geology, geophysics, remote sensing, etc.) and multi-parameter geophysical (potential field, EM, gamma-ray spectrometry, etc.) data available for mineral exploration is ever increasing. The integration and analysis of the data require effective and efficient search engines or data mining tools. The search engines will take the signatures of known mineral deposits or interpreted mineralization targets ('key words'), search the data space and return potential new targets ('matches'), thus providing locations to the decision makers for follow-up. Two supervised feed-forward multilayer neural network (NN) search algorithms will be presented and analysed. The utility of the NN search tools will be demonstrated with the integration and analysis of airborne electromagnetic (EM), magnetic and radiometric data for mineralization targets in Iullemmeden Basin, Niger.

### 39. ACOUSTIC PROPERTIES OF ROCKS COMPACTED FROM POWDERS

*Maxim Lebedev*[1]*, *Olga Bilenko*[1], *Yulia Uvarova*[2] *and Maxim Lebedev*[1]
[1]Curtin University
[2]CSIRO

During the drilling process core samples often are damaged and proper measurements on samples cannot be performed. The objective of this study is to investigate rock powders and evaluate how their seismic properties relate to the seismic properties of their corresponding rocks. Consolidated and poorly consolidated rocks and fine powders made of those rocks have been used in this study to assess such possibilities. A comparison between the seismic properties of dry powders to the properties of wet powders has been done. A correlation in mechanical properties (Young's modulus and Poisson's ratio) between compacted powder and samples from host rock has been found.

### 40. VTEM AIRBORNE EM, AEROMAGNETIC AND GAMMA-RAY SPECTROMETRIC DATA OVER THE CERRO QUEMA HIGH SULPHIDATION EPITHERMAL GOLD DEPOSITS, PANAMA

*Karl Kwan*[1], *Alexander Prikhodko*[1], *Jean Legault*[1]* *and Geoffrey Plastow*[1], *John Kapetas*[2] *and Michael Druecker*[2]
[1]Geotech LTD
[2]Pershimco Resources

In March 2012, a helicopter-borne VTEM electromagnetic (EM), magnetic and radiometric survey was flown over the Cerro Quema high sulphidation epithermal gold deposits in Panama. Geophysical signatures, including Airborne Inductive Induced Polarization (AIIP) effect, characteristic of high sulphidation epithermal gold deposits were observed in the EM, magnetic and radiometric data over the known deposits. This success points to the applicability of regional helicopter EM-Mag-Spec surveys for the exploration of similar high sulphidation epithermal gold deposits to depths <500 m in weathered terrains.

### 41. APPLICATION OF SEISMIC ATTRIBUTES FOR CONSTRAINING MAGNETOTELLURIC INVERSION

*Cuong Le*[1]*, *Brett Harris*[1], *Eric Takam Takougang*[1] *and Andrew Pethick*[1]
[1]DET CRC, Curtin University

Unconstrained inversion of surface magnetotelluric data generates non-uniqueness solutions. Boundaries derived from seismic reflectively images have the potential to substantially improve MT inversion. Seismic should be highly beneficial where significant and strong reflectors can reasonably be associated with contrast in electrical conductivity across well-defined relatively continuous boundaries. We show how seismic reflections can assist in defining such inversion controls as the smoothness penalty across known boundaries. We apply and compare a range of cooperative inversion strategies using large scale co-located magnetotelluric and seismic reflection field data sets from the Carlin style gold district in Nevada USA.

## MINERALS – GEOPHYSICS IN THE MINING OPERATION

### 43. CONSTRAINED MAGNETIC MODELLING OF THE WALLABY GOLD DEPOSIT, WESTERN AUSTRALIA

*Sasha Banaszczyk*[1]*, *Yvonne Wallace*[2] *and Mike Dentith*[1]
[1]University of Western Australia
[2]Southern Geoscience

The Wallaby Gold deposit is located 25 km southwest of Laverton within the Eastern Goldfields Province of Western Australia. Gold mineralisation is hosted within a mafic conglomerate, intruded by a south-plunging magnetite-actinolite-epidote-calcite altered syenite pipe. Regions of low susceptibility within the pipe are associated with gold mineralisation.

Airborne magnetic data from the Wallaby Gold deposit was inverted using the University of British Colombia Geophysical Inversion Facility MAGINV3D code to produce a 3D model of the subsurface magnetic susceptibility.

Magnetic susceptibility measurements acquired at 1m intervals on diamond drill core were used to constrain the results of the inversion. This was facilitated using the Sparse Constraint Model Builder, which creates a physical property model based on existing geological, geophysical or geochemical measurements to then be applied within the UBC-GIF inversion code.

The constrained inversion defined regions of low magnetic susceptibility within the outer high magnetic susceptible zones of the alteration pipe and potential mine-scale structural features can be interpreted. This is useful information given the structural control on gold mineralisation at Wallaby and its association with regions of reduced magnetic susceptibility.

## 44. GEOLOGICAL AND GEOTECHNICAL CHARACTERISATION USING GEOPHYSICAL LOGS - AN EXAMPLE FROM ADRIYALA LONGWALL PROJECT OF SINGARENI COLLIERIES, INDIA

*Binzhong Zhou*[1]*, *Makesh Shanmukha Rao*[1] *and Gudlavalleti Uday Bhaskar*[1]
[1]Singareni Collieries Company Limited

The studies conducted at Adriyala longwall block of Singareni Collieries Company Limited (SCCL) in the state of Telangana, India conclude that geophysical logs comprising electrical, density, neutron, caliper, Full Waveform Sonic (FWS) and acoustic images can provide reliable geological and geotechnical models required for longwall mining. The basic lithological details, sedimentary features and associated geotechnical risks are interpreted using these logs. The P wave velocities obtained from sonic logs are correlated with the lab determined strength parameters such as uniaxial compressive strength (UCS), Tensile Strength (TS) and Young's Modulus. The empirical equations provided a means to construct UCS map of interburden strata of coal seams from sonic data and optimised depending on core data. The Geophysical Strata Rating (GSR) similar to Coal Mines Roof Rating (CMRR) and Rock Mass Rating (RMR) has also been applied to assess the competency of interburden strata right at the exploration stage itself. The in situ stress directions and master cleats orientation are determined from the acoustic image logs. The integrated study of various maps prepared from geological and geophysical inputs provided an effective means to analyse the competency of immediate overburden and roof of Seam-I, which is considered for longwall mining.

Back analysis of behaviour of strata will allow developing predictive models and appropriate strata control strategies to be applied at Adriyala and other mines and also for multiseam extraction.

## 45. PREDICTIVE MODELLING FOR IRON ORE EXPLORATION TARGETING: CASE STUDY: 5–7 BT XAUDUM IRON ORE EXPLORATION TARGET (BOTSWANA)

*Iuma Martinez*[1]*, *Alistair Jeffcoate*[1], *Gaetan Fuss*[2], *Mike de Wit*[1], *McDonald Kahari*[1] *and Omphile Ntshasang*[1]
[1]Tsodilo Resources Ltd
[2]Ecole nationale superieure de geologie

The principal objective of the research was to determine an exploration target estimate for the Xaudom Iron Ore project. Geophysical data inversion modelling was carried out and the results calibrated against local drill hole interpretation-based geological models. The results compared favourably and enabled a number of correction factors to be established. Subsequent drilling and geological modelling have yielded NI 43–101 compliant resources that are similar to the initial inversion based modelling estimates within optimised pit shells, showing the robustness of the Exploration Target technique. The approach discussed here may be useful for delineating exploration targets for other magnetite-rich iron mineralized areas faced with complex deformational histories.

## MINERALS – MINERALS OTHER

## 46. OPEN SOURCE SOFTWARE FOR 1D AIRBORNE ELECTROMAGNETIC INVERSION

*Ross Brodie*[1]* *and Murray Richardson*[1]
[1]Geoscience Australia

Geoscience Australia is releasing into the public domain software for the inversion of airborne electromagnetic (AEM) data to a 1D conductivity depth structure.

The software includes two different algorithms for 1D inversion of AEM data. The first is a gradient based deterministic inversion code for multi-layer (smooth model) and few-layered (blocky-model) inversions. The second is a reversible-jump Markov chain Monte Carlo stochastic inversion algorithm suitable for assessing model uncertainty. A forward modelling program and some other ancillary programs are also included. The code is capable of inverting data from all of the commercial time-domain systems available in Australia today, including dual moment systems.

The software is accessible in three forms. As C++ source code, as binary executables for 64 bit Windows® PCs, and as a service on the Virtual Geophysics Laboratory (VGL). The code is fully parallelized for execution on a high performance cluster computer system via MPI or a multi-core shared memory workstation via OpenMP.

## 47. USING AMT IN THE ZAMBIAN COPPERBLET (ENTERPRISE AND KANSANSHI CASE STUDY)

*Adouley Guirou*[1]*
[1]First Quantum Minerals

During 2012 and 2013 First Quantum Minerals, through its Zambian exploration team, acquired about 300 line km of audio magnetotelluric (AMT) data for copper and nickel exploration in the north-western Zambian copper belt. Kansanshi copper mine and the new Enterprise nickel deposit are the survey locations. I discuss major aspects of the projects, including but not limited to major outcomes and difficulties encountered, as well as solutions for future data acquisition in similar geological settings. Basement faults and many geological features were identified over Enterprise, and dome structures in Kansanshi. However, limiting factors such as mine equipment noise, accessibility, swamps, tropical rain forest and wild life caused difficulties during the survey. Stacking data for a longer time and focusing on lower frequencies will significantly reduce data noise, but survey costs will increase due to slower survey rates. The geological information gained from these surveys has ensured that AMT remains a preferred exploration tool for sedimentary-hosted copper and nickel.

## 48. A MAJOR GEOPHYSICAL EXPERIMENT IN THE CAPRICORN OROGENY, WESTERN AUSTRALIA

*Mike Dentith[1]*, Alan Aitken[1], Sasha Banasazczyk[1], Mark Lindsay[1], Jeffrey Shragge[1], Perla Piña-Varas[1], David Annetts[2], James Austin[2], Yusen Ley-Cooper[2], Tim Monday[2], Brian Kennett[3], Ruth Murdie[4] and Huaiyu Yuan[5]*
[1]University of Western Australia
[2]Mineral Resources Flagship, CSIRO
[3]Australian National University
[4]Geological Survey of WA
[5]Macquarie University

A major geophysical experiment has begun in the Capricorn Orogen in Western Australia. Orogen-scale passive seismic and magnetotelluric surveys are on-going and preliminary results suggest have successfully delineated the base of the crust and major structures and tectonic boundaries. Airborne electromagnetic data have successfully mapped features in the near-surface such as palaeovalleys.

The integration of the different geophysical datasets with each other and with parallel geological studies are intended to lead to a better understanding the Capricorn Orogen and develop exploration approaches and appropriate toolkits that significantly improve our ability to prospect under cover.

## 49. CROSS-HOLE REFLECTION SEISMIC TO DELINEATE A RELATIVELY THIN VOLCANOGENIC MASSIVE SULPHIDE DEPOSIT IN SHALE HOSTED ENVIRONMENT

*Felix Menu[1]*, Andrew Greenwood[1] and Anton Kepic[1]*
[1]DET CRC Curtin University

The seismic reflection method is a high resolution technique that can be used in many exploration environments including mineral exploration. However, mountainous terrain, depth of burial and the steepness of ore bearing structures pose a challenge to the application of surface seismic in mineral exploration. The cross-hole seismic method may present an alternative approach under such conditions. Presented here is a synthetic study examining the capability of the cross-hole seismic method to delineate a volcanogenic massive sulphide ore body in a shale hosted environment.

A simple model typical for volcanogenic massive deposits in Tasmania has been considered. There, an elongated steeply dipping volcanogenic massive sulphide deposit with an average thickness of 10 m is seated within a shale rock. The primary aim of the modelling is to test the capability of the technique to delineate relatively medium sized, steeply dipping volcanogenic massive sulphide lens in shale hosted environment. A second objective is to use the technique to prospect for extensions to mineralization along steeply dipping reflectors.

Synthetic cross-hole seismic records were generated using a 120 Hz energy source. Kirchhoff VSP migration was applied to wavefield separated shot records and Pre-stacked Depth Migrated images created. The resulting migrated images correlate well with the position and dip of the ore body demonstrating the potential of the cross-hole reflection technique to delineate steeply dipping ore structures in challenging environments.

## MINERALS – NO SUB-THEME ALLOCATED

## 50. A WORKFLOW FOR COOPERATIVE INVERSION OF SEISMIC AND MAGNETOTELLURIC DATA

*Eric Takam Takougang[1]*, Brett Harris[1] and Anton Kepic[1]*
[1]Curtin University

We present a cooperative inversion approach for acoustic impedance using seismic and magnetotelluric data. In this approach, the magnetotelluric data, sensitive to the resistivity of rocks are used to get the large scale background spatial trends of the acoustic impedance model, while the seismic data are used to get the small-scale features. The connections between resistivity and elastic properties of rocks are obtained from petrophysical relationships derived from borehole data. Structural constraints derived from seismic are used to improve the magnetotelluric inversion. We present an application of this technique to synthetic data derived from previous interpretation of seismic and magnetotelluric models in a mineral province. The synthetic example shows how an improved result is obtained using our cooperative inversion workflow.

## 51. A STRATEGY FOR MAGNETIC DATA INTERPRETATION IN SOUTH CHINA SEA

*Shuling Li[1]*, Yaoguo Li[2] and Xiaohong Meng[1]*
[1]China University of Geosciences
[2]Colorado School of Mines

Directly interpreting total-field magnetic anomaly data in the South China Sea (SCS) can be difficult because of the complex patterns associated with low-latitude anomaly projection and the presence of remanent magnetization. Additional difficulty arises from the fact that the ambient field direction, thus, the total-field anomaly projection direction, varies over a wide range in the area. To alleviate these difficulties, we present a strategy by using magnetic amplitude data analyses and inversion. Equivalent source processing is used to calculate the amplitude data in the space domain since the wavenumber-domain method is no longer applicable due to low and highly variable inclination. The amplitude data serve the role of reduction-to-pole (RTP) transformation for structural interpretation. We then carry out the amplitude inversion to generate a 3D subsurface distribution of effective susceptibility. The inversion results show that this approach is feasible and effective in SCS.

## 52. BROAD-SCALE LITHOSPHERIC STRUCTURES OF THE AUSTRALIAN CONTINENT FROM 3-D INVERSION OF OBSERVATORY AND MAGNETOMETER ARRAY DATA

*Liejun Wang[1]*, Adrian Hitchman[1], Andrew Lewis[1], Peter Crosthwaite[1] and Bill Jones[1]*
[1]Geoscience Australia

An exploratory 3-D model of the electrical conductivity structure of the Australian continent is presented. The model is derived from the inversion of vertical magnetic-field transfer functions from the Australia-wide Array of Geomagnetic Stations.

The model reveals conductivity differences beneath Archaean cratons in Western Australia, enhanced-conductivity anomalies between Archaean cratonic regions and beneath Phanerozoic terranes in eastern Australia.

## 53. LOCALIZED SMART INTERPRETATION – A DATA DRIVEN SEMI-AUTOMATIC GEOLOGICAL MODELLING METHOD

*Mats Lundh Gulbrandsen*[1]*, *Mats Lundh Gulbrandsen*[1], *Torben Bach*[2], *Knud Skou Cordua*[1] *and Thomas Mejer Hansen*[1]
[1]University of Copenhagen
[2]I-GIS

Localised Smart interpretation (LSI) is a method that infers a statistical model, which describes a relation between the knowledge of a geologist (as quantified by geological interpretation) and the available information (such as geophysical data, well log data, etc.) that a geologist uses when he/she interprets. This model is then used to perform semi-automatic geological interpretation wherever the same kinds of attributes, as used for the initial interpretation, are available. The statistical model is inferred using a combination of a regularized least squares method and cross validation. In this study, we demonstrate the applicability of the method to predict the depth to a low resistivity subsurface layer, based on interpretations from a geological expert, using a 19-layered resistivity model obtained from inversion of airborne electromagnetic (SkyTEM) data.

This study shows that LSI is capable of making prediction with great accuracy. The method is fast and is able to handle large amounts of data of different origin, which suggest that the method may become a very useful approach to assist in geological modelling, based on increasingly large amounts of data of different nature.

## 54. SPM EFFECT IN GLACIAL TILL

*Markku Montonen*[1]*
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The SPM effect is not traditionally associated with glacial tills. However, effects of viscous magnetization, i.e. superparamagnetism, are observed in many places in Northern Finland in high sensitivity and low frequency time domain ground EM surveys. These effects are typically observed on late time channels and they have a very good correspondence with magnetic anomalies. Usually there is also a clear reverse frequency domain RE component anomaly observed simultaneously with the SPM effect. In Ni ore prospecting it is essential to be able to recognize SPM effect because it has a response similar to a deep seated massive nickel ore body i.e. a deep seated very high conductivity conductor. Characteristic feature for SPM effect in time domain dB/dt data is its 1/t decay which can be used as a means to recognize this phenomenon. We also discuss alternative methods to recognize SPM effect.

## 55. THE NATURE OF CHANGING PORE SPACE AT AN IN-SITU WEATHERED/FRESH ROCK INTERFACE AND ITS EFFECT ON THE RESISTIVITY SIGNATURE, DARGUES REEF GOLD DEPOSIT, MAJORS CREEK NSW

*Sanjay Govindan*[1]* *and Eva Papp*[1]
[1]The Australian National University

Hydrothermal Au – Cu mineralisation at Majors Creek, NSW has led to the formation of disseminated sulphides throughout the host granodiorite body. Mineralisation in overburden and shallow bedrock occurs in sparse concentration settings such as quartz veins and potassic alteration. Distinguishing between alterations zones, mineralising features and the fresh-weathered rock boundary is paramount to explorers.

A combination of DC electrical resistivity and CT scanning was employed to delineate the weathered-fresh rock boundary, potential mineralising features and areas of differing alterations. A 500 m survey line was constructed over a known area of mineralisation and passed directly over a drill core sample. CT scanning data will define pore space characteristics of alteration and weathering states of the host granodiorite.

This study has the potential to spark future research into shallow surface exploration throughout the Majors Creek area, building on a potential relationship between, pore space, apparent resistivity and overburden-bedrock characteristics.

## 56. THE QMETER – A PORTABLE TOOL FOR REMANENCE AND SUSCEPTIBILITY

*Phillip Schmidt*[1]*
[1]MagneticEarth

Breiner (1973) described a method to separate induced magnetisation from remanent magnetisation of a drill core or hand sample using a total field magnetometer, thereby allowing the Königsberger ratio (Q) to be calculated. However, the method does not seem to be in general use, and nor has there been any improvement to the method despite recent developments that greatly facilitate data acquisition using handheld devices or notebook computers. Here a new fluxgate based pendulum instrument is described that allows a more controlled implementation of Breiner (1973)'s method.

The instrument accommodates samples of varying sizes although best results are yielded using regular, cubic or cylindrical, shaped samples. The instrument is portable and powered from a USB port of a notebook or similar computer. Sensitivity is high enough to yield accurate results for rocks that cause significant magnetic anomalies (~Am-1). However, for high Q rocks susceptibility is lost in the noise, and likewise for low Q rocks, remanence is lost in the noise.

The instrument is designed to quickly screen core samples at the drill site, or in a core shed, to alert the exploration team if significant remanence is present in which case the magnetic model of the target may require reconsidering. The instrument is not a replacement for laboratory measurements but potentially should save exploration costs by indicating when laboratory measurements should be undertaken.

## 57. NMR ON IRON RICH CORES AND CUTTINGS – THE IMPORTANCE OF SHORT TES

*Timothy Hopper*[1]*, *Daksh Parashar*[1], *Einar Orn Fridjonsson*[2], *Matt Carroll*[3] *and Mike Johns*[3]
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The moisture content of iron ore is a critical factor in determining its subsequent processing, transportation, quality and general handling. In particular, high moisture content can lead to extremely dangerous liquefaction of the ore during sea-transportation, with major financial and safety implications. NMR has long been used to measure moisture content in rocks but the presence of magnetic materials such as iron affects the NMR signal leading to data that cannot be interpreted by known

methods.

There has recently been interest in determining how the properties of the rock affect the NMR signal, particularly where there are different concentrations of magnetic materials or rocks with different mineralogical properties. There has, however, been less work in determining how the measurement techniques should be changed to accommodate these systems.

In this work we measure iron rich rock cores and show the importance of selecting an appropriate echo time in the CPMG sequence. We show that longer echo times can lead to estimations of a T2 distribution that is not representative of the system. This in turn would lead to inaccurate measurements of the water content. We demonstrate the importance of short echo times and show that for the systems studied in this work, an upper limit of 0.4 ms should be imposed.

## MINERALS – VALUE OF PETROPHYSICS TO EXPLORATION SUCCESS

### 58. A NEW APPROACH PROVIDES OPPORTUNITIES FOR SPECTRAL GAMMA ANALYSIS IN BOREHOLES FOR MINERAL EXPLORATION

*Ida Hooshyari Far*[1]*, *Anton Kepic*[1] *and Anna Podolska*[1]
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Wide-spread application of gamma ray logging system in mineral exploration has long been desired by the mining industry, but not achieved. New developments in borehole logging approaches the Deep Exploration and Technologies Commonwealth Research Centre (DET CRC) have recently created Logging-While-Drilling tools, named the Autosonde and Shuttle, to measure natural gamma ray activity during drilling process. The Shuttle in particular will allow the collection of high quality natural gamma spectra by placing a sensor on the core-barrel and logging whilst drilling; a much slower process than wireline logging. Thus, a new approach collecting gamma data provides opportunities to use natural gamma radiation data in ways not normally done with conventional wireline tools.

We have used a prototype spectral gamma sensor using BGO crystal on a wireline to simulate the data that will be collected by a shuttle system to demonstrate the data quality and to test whether more sophisticated data analysis of spectral attributes such as the ratio of Photo-electric to Compton gamma bands, or "heavy minerals indicator", will further lithological information than the standard K, U, Th analysis. Our preliminary results indicate that spectral data collected by the Shuttle will allow the heavy mineral indicator to be used and opens the possibility of better lithology identification tools.

### 59. CLASSIFICATION OF GEOCHEMICAL AND PETROPHYSICAL DATA BY USING FUZZY CLUSTERING

*Duy Thong Kieu*[1]*, *Anton Kepic*[1] *and Cornelia Kitzig*[1]
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In this study, the fuzzy c-mean clustering method was used in an unsupervised manner to automatically classify the different lithologies present at the Hillside prospect (Yorke Penninsula, SA). The algorithm was applied to various combinations of petrophysical and geochemical data to identify the combination that returned the most accurate result and the smallest combination that provides a nearly identical success as the best. We show that by using a combination of geochemical and petrophysical data the likelihood of a correct classification increases by 5% compared to analysing only geochemical data, and by over 20% compared to analysing only petrophysical data.

However, using a few common elements and a few petrophysical values we can achieve almost the same success rate as the best result. Improvements in pretreatment and conditioning of the data should allow the fuzzy cluster algorithm yield even better results. In addition to showing that combining petrophysical and elemental analysis is more robust, we demonstrate that if we could add some targeted elemental analysis to logging while drilling (LWD) then robust automated lithological logging becomes feasible.

## NEAR-SURFACE – ADVANCES IN NEAR SURFACE SEISMIC

### 60. NEAR-SURFACE INVESTIGATION USING HIGH-RESOLUTION SEISMIC REFLECTION TECHNIQUES

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The shallow seismic technique has been used to see subsurface, 595 meters of high resolution seismic reflection profile were carried out. The data were acquired using a Strata Visor with 48-channel, 40 Hz geophones and a vibroseis "IVI Minivib" system as a seismic source. Seismic reflection data were recorded using a CMP (common mid-point) acquisition method. The results for Al muzahimiyah Line are good and show a considerable improvement in signal to noise ratio. There were some problem during processing such as multiples, noise and it was so difficult to see first break because of high frequency. Signal to noise ratio was good in general. Frequent testing was carried out to improve the signal.

## NEAR-SURFACE – ENVIRONMENTAL AND ENGINEERING GEOPHYSICS

### 61. D-LUX: A NEW WAY TO ASSESS THE SAFETY OF EMBANKMENT BY 3D ELECTRICAL SURVEY

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[3]Human & Earth Inc.

A new array, D-Lux, for effective safety assessment of embankment by electrical resistivity survey was proposed and an applied field case was presented. In the D-Lux array, a positive line source is placed on the upstream reservoir along the embankment and a negative line source is located at downstream, expecting the electric current would flow through the embankment in the perpendicular way and its equipotential lines are parallel to the embankment if the material is in normal state. The use of line source clearly brought out the horizontal variation of the material. Any anomalous region is displayed by modified tomography map measured between potential poles crossing the embankment. This approach provided an electric potential map by forward modeling that fitted the observed tomography map and may be converted into resistivity map for

quantitative interpretation. In the field case, the qualitative potential map showed to infer the dominant flow of electric current and the quantitative resistivity map displayed the state of the core material.

## 62. COMBINED USE OF CONTROLLED-SOURCE AND RADIO-MAGNETOTELLURIC METHODS FOR NEAR SURFACE STUDIES

*Mehrdad Basatni*[1], *Alireza Malehmir*[2]* *and Alexandros Savvaidis*[3]
[1]Geological Survey of Sweden
[2]Uppsala University
[3]ITSAK

Combination of the controlled source and radio magnetotelluric, the so-called CSRMT, method has been used in modelling near surface electrical resistivity structures with the main aim of studying mineralization and engineering issues. In the controlled source mode, we used a remotely controlled double horizontal magnetic dipole that transmits signal in the frequency range 1–12.5 kHz. The signal sources for the RMT method are the distant radio transmitters in the frequency range 14–250 kHz. Three near surface case studies are presented in this work. In the first case, conductive hydrothermal stockwork copper deposits in an area in Iran were modelled in 2D and the results were compared to the existing borehole information. In the second case located in Greece using the CSRMT method we could model the location and geometry of a subvertical fault that was covered by conductive quaternary sediments. In the third case from Sweden, 3D resistivity models from the inversion of CSRMT data were used to determine presence and boundaries of quick-clay formation and a coarse-grained layer that is in turn responsible for a peculiar retrogressive landslide type in the study area. The three case studies have proven that a combination of controlled source and radio magnetotelluric methods has a considerable potential in addressing near surface problems. Comparison between the existing borehole data and the resistivity models from the inversion of the CSRMT data in each study area revealed reasonable correlation in delineating target structures especially depth to the good conductors. However, special attention needs to be given when using the CSMT data, especially at lower frequencies where they may be affected by the near-field phenomenon.

## 63. DETERMINING THE BASALTIC SEQUENCE USING SEISMIC REFLECTION AND RESISTIVITY METHODS

*Abdulrahman G. Alanazi*[1]* *and Ayman N. Qadrouh*[1]
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This study was carried out in Harat Rahat (south of Almadinah Almonwarah) using seismic reflection and resistivity methods. The main objectives of this study are to determine the extent of the basaltic layer and to define the subsurface faults and fractures that could affect and control the groundwater movement in the study area. A 2D seismic profile was acquired and the result shows that the subsurface in the study area has a major fault. We obtained a well match when the seismic result was compared with drilled wells. As a complementary tool, the resistivity method was applied in order to detect the groundwater level. The results of the resistivity method showed that six distinct layers have been identified. The interpretation of these six layers show that the first three layers, the fourth layer, the fifth layer and the bottom of the section indicated various subsurface structures and lithologies; various basaltic layers, fractured basalt, weathered basement and fresh basaltic layers, respectively. It is obvious that the eventual success of geophysical surveys depends on the combination with other subsurface data sources in order to produce accurate maps.

## 64. EXPERIMENTAL STUDY OF NONDESTRUCTIVE GEOPHYSICAL METHODS FOR EVALUATING THE CONDITION OF CONCRETE STRUCTURES

*Majed Almalki*[1]
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It is often necessary to evaluate the integrity and reliability of concrete structures that are exposed to extreme environmental conditions over a long period of time. This paper presents a range of nondestructive geophysical methods, including Ultraseismic, Parallel Seismic, and Impulse Response techniques that use elastic-wave properties to inspect concrete-foundation structures. These approaches depend on basic waveform properties such as wave speed, amplitude, and frequency. The goal of this research is to obtain an appropriate test procedure and identify parameters for (i) verifying the wave reflected from internal concrete defects, and (ii) identifying the effective depth of a pre-built test foundation. To do so, we have established an experimental laboratory to calibrate and check the reliability of the measured data and understand the wave properties for different concrete conditions (i.e. fractures). We concluded that the aforementioned geophysical approaches could provide vital information for quality control and rehabilitation purposes.

## 66. PROCESSING AND INTERPRETATION OF SHALLOW-WATER SEISMIC DATA FOR $CO_2$ INJECTION

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[1]Korea National Oil Corporation
[2]Schlumberger

2-D seismic data were acquired in Yeong-il Bay of Korea in search of proper prospects for $CO_2$ injection into an offshore basin. The unfavourable situation for operation and very shallow water prevented the operator from obtaining quality data. Small number of channels and short offsets incapacitated velocity analysis and migration. Main efforts have been thrown into finding out the best processes to attenuate linear noises and strong short-period multiples raised from the shallow water that masked the whole data. The processing methods ascertained to be useful for this purpose are DENOISE, DWD (deterministic water-layer demultiple), and $\tau$-p deconvolution, which were applied by using Omega 2 processing system. The resultant images are successfully free from the strong noise and revealed the geological structures obscured by the noise.

The processed data were geologically interpreted to identify the prospective formations in the basin so as to inject carbon dioxide into them.

## 67. AUTOMATED AIRBORNE EM AND BOREHOLE DATA INTEGRATION FOR DEPTH TO BEDROCK EXTRACTION

*Andreas Pfaffhuber*[1]* *and Craig Christensen*[1,2]
[1]Norwegian Geotechnical Institute
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Airborne electromagnetic (AEM) was used to supplement a geotechnical investigation for a highway construction project in Norway. Variable bedrock threshold resistivity hindered efforts to track depth to bedrock, motivating us to develop an automated algorithm to extract depth to bedrock from both boreholes and AEM data. We developed two variations of this algorithm: one using simple Gaussian or inverse distance weighting interpolators, and another using ordinary kriging and combined parameter probability distribution functions.

Evaluation shows that for preliminary surveys, significant savings in boreholes required can be made without sacrificing bedrock model accuracy. However, issues with AEM noise and data quality likely reduced the comparative advantage that including AEM provided. Moreover, AEM cannot supersede direct sampling where the model accuracy required exceed the resolution possible with the geophysical method. Nevertheless, using AEM in the way can still reduce the number of required boreholes and hence reduce site investigation costs because we can identify high probability zones for shallow bedrock, identify steep or anomalous bedrock topography, and estimate the spatial variability of depth.

## NEAR-SURFACE – GROUNDWATER AND CONTAMINANT MAPPING

### 68. HYDROGEOPHYSICS FOR INFORMED WATER MANAGEMENT DECISIONS IN THE ANANGU PITJANTJATJARA YANKUNYTJATJARA (APY) LANDS OF SOUTH AUSTRALIA

*Andrew Parsekian[1]*, Aaron Davis[2], Tim Munday[2], Denys Grombacher[3], Brady Flinchum[1], Kevin Cahill[2] and Michael Hatch[4]*
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[3]Stanford University
[4]University of Adelaide

The Anangu Pitjantjatjara Yankunytjatjara (APY) Lands of South Australia is an arid environment and the population relies largely on groundwater resources for potable water and agricultural needs. Historically, locating productive wells in the region has been hit-and-miss and even if a water source was found, the quality may be unreliable. In this project, we seek to improve the water security in the APY lands by demonstrating that surface Nuclear Magnetic Resonance (NMR) and Time-Domain Electromagnetic (TEM) geophysical measurements are able to map local aquifers and quantify ground water resources, thereby optimizing site selection for potential future wells. Surface NMR is directly sensitive to water and TEM measurements detecting the electrical conductivity structure and able to image the subsurface over large areas – all entirely non-invasively and with minimal risk of disturbing sites of importance to the local Aboriginals.

### 69. FIRST EVIDENCE OF T2^*IN SNMR MEASUREMENTS WITH SQUID SENSORS

*Aaron Davis[1]*, Mike Mueller-Petke[2], Raphael Dlugosch[2], Matthias Quietsch[3], James Macnae[4] and Ronny Stolz[5]*
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[2]LIAG
[3]Friedrich-S-University
[4]RMIT University
[5]LIPT

We discuss the theoretical development of the measurement of the t2 component from a surface nuclear magnetic resonance (SNMR) experiment using superconducting quantum interference devices (SQUIDS) as a point B-field receiver.

We discuss the differences between point receivers compared to traditional coincident-loop receivers, and demonstrate the first measurements of T2 with a SQUID sensor at the hydrogeophysical test site in Schillerslage, Germany.

### 70. MAPPING OF ELECTROMAGNETIC NOISE IN A MAGNETIC RESONANCE SOUNDING CONTEXT

*Jakob Juul Larsen[1]*, Esben Dalgaard[1], Philip Christiansen[1] and Esben Auken[1]*
[1]Aarhus University

The applicability of magnetic resonance sounding in mapping the water content and the hydrological properties of the sub-surface in industrialized areas is severely limited by electromagnetic noise. Efficient ways of mitigating the noise must be developed before the technique can become a ubiquitous tool. In this paper we demonstrate an instrument developed for efficient mapping of noise at a given site prior to a magnetic resonance sounding. The instrument consists of two small induction coils connected to a digital oscilloscope controlled by a PC. Using the instrument, measurements of the electromagnetic noise are easily performed at several places within the site. Signal processing of the measurements provide a quantified understanding of the contributions from different noise sources, primarily powerline harmonics and impulsive noise. Further the spatial distributions of the noise components are also obtained. Based on this knowledge the optimum spot for a magnetic resonance sounding with the least distortion by noise can be identified. The instrument is now in routine use at the Hydrogeophysics group at Aarhus University.

### 71. SURFACE NMR TO IMAGE AQUIFER PROPERTIES IN A MAGNETIC SUBSURFACE

*Denys Grombacher[1]*, Andrew Parsekian[2], Aaron Davis[3], Tim Munday[3], Brady Flinchum[2], Kevin Cahill[3], Michael Hatch[4] and Rosemary Knight[1]*
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[3]CSIRO
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Surface Nuclear Magnetic Resonance (NMR) is a non-invasive geophysical technique providing the ability to image and investigate aquifer properties. In order to produce reliable images and interpretations of subsurface properties accurate modelling of the underlying physics is required. In magnetic environments, where the background magnetic field varies spatially, challenges can arise that lead to difficulty accurately

modelling the excitation process and interpreting the signal's time dependence. We demonstrate using field data collected in the Anangu Pitjantjatjara Yankunytjatjara (APY) Lands of South Australia that neglecting the influence of the magnetic environment can significantly alter the final images and interpretation of the subsurface structure and properties.

### 73. GEOSTATISTICAL ANALYSIS OF THE RELATIONSHIP BETWEEN AIRBORNE ELECTROMAGNETIC DATA AND BOREHOLE LITHOLOGICAL DATA

*Adrian Barfod*[1]*, *Ingelise Møller*[1] *and Anders V. Christiansen*[2]
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We present a large-scale study of the relationship between dense airborne SkyTEM resistivity data and sparse lithological borehole data.

Airborne electromagnetic (AEM) data contains information about subsurface geology and hydrologic properties; however extracting this information is not trivial. Today, geophysical data is used in combination with borehole data to create detailed geological models of the subsurface. The overall statistical relationship is, however, not widely known. The objective of this study is to develop a method for understanding the relationship between petrophysical properties and lithology, and apply this to get a better understanding of large-scale petrophysical structures of the subsurface.

The data sampling is carried out in a scheme where data is interpolated onto the position of the boreholes. This allows for a lithological categorization of the interpolated resistivity values, revealing different distribution functions for lithological categories.

A very large and extensive dataset is available in Denmark through the national geophysical and borehole databases. These databases contain all geophysical and borehole data in Denmark and covers a large part of its surface. By applying the proposed algorithm to all available airborne electromagnetic data, detailed maps of the large-scale resistivity-lihology structures on a National scale in Denmark are constructed.

## NEAR-SURFACE – NEAR SURFACE OTHER

### 74. PERFORMING HIGH RESOLUTION SEISMIC REFLECTION FOR MAPPING BAUXITE LAYERS

*Ayman N. Qadrouh*[1], *Abdulrahman G. Alanez*[1], *Ibraheem K. Hafiz*[1], *Khyzer Munir*[1] *and Mazen M. Al Yousif*[1]
[1]KACST

The seismic method is able to produce highly accurate images of the Earth's subsurface. Having such detail is not only an important factor in mining, but also in civil engineering. Bauxite exploration attracts both government and industrialists to invest in it because of the high percentage of aluminum present. The economic importance of extracting aluminum from bauxite encouraged us to take this challenge; to image bauxite layers by using a high-resolution seismic reflection method at Al Qassim, Saudi Arabia. Since the subsurface structure of the area is complex, this high-resolution reflection method was carried out along a 2D line with geophone and source interval, with settings at 5 m. The result for the seismic section shows that the depth and thickness of the bauxite layer varied between 20 to 34 m, and 3 to 7 m respectively. In addition, the bauxite layer was sandwiched between clay layers. In order to achieve an even more precise depth than presented by seismic section alone, we tied the drilled wells to the seismic data and we accomplished a well match with an approximation error of 1–2 m, which may have been caused by the upper clay layer or by very shallow loose subsurface material. The seismic method thus applied shows the ability to detect significant details within the near surface of the earth, and is considered more cost-effective than only drilled wells.

## PETROLEUM – 4D/BROADBAND SEISMIC/EMERGING TECHNOLOGIES

### 75. ENHANCED VIBROSEIS: THE NEXT STEP IN LAND 2D – 4D

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The field of vibroseis has seen various advances over recent decades which have been mostly of a gross nature. These include the development and operation of heavier vibrators, improvements in positioning and tracking, the deployment and control of larger numbers of vibrators acting either as part of a fleet or as individual sources. More subtly, improved QC brought about by incorporation into the source decoder of sufficient recording channels which may better define vibroseis signatures has also been available to suitably equipped crews. Meanwhile, some seismic land recording systems also have been able to keep up with these source-related improvements, with the majority of advances made in cableless and hybrid systems which can work with large numbers of independent sources thanks to real time QC options, ease of deployment and a mix-and-match approach of recording system architectures.

The basic assumptions in terms of the frequency and force put into the ground, however, remain fixed on the notion of weighted sum ground force (WSGF) as espoused by Sallas in the 1980's. Most source control equipment and QC methods are still built on the premise that this is a sufficiently good approximation for most circumstances.

However, even basic testing with load cells and/or down hole sensors reveal that this assumption is poor at low frequencies, and potentially significantly inaccurate at high frequencies. The problems resulting from this incorrect WSGF-approach are important limiting factors in terms of taking the next steps in vibroseis productivity and data quality improvement. This is true not only for typical land 2D/3D surveys but also the shortcomings of the WSGF approach may seriously limit the progress that may be made on land 4Ds where far more accurate understanding of source characteristics is essential.

Initial results using The Enhanced Vibroseis method shows the potential to solve many of these issues and may be seen as the next major step the industry needs to make to progress this form of land acquisition.

### 78. DEGHOSTING OF OVER/UNDER TOWED-STREAMER SEISMIC DATA WITH WAVEFIELD EXTRAPOLATION

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In marine seismic acquisition, ghost effect due to the strong reflection of the sea surface causes serious notch trap in the spectrum. Ghost effect can be reduced by over/under towed streamer acquisition. Howerver, most of deghosting technology for over/under streamer acquisition is based on seismic kinematics method, which cannot effectively solve the ghost wave interference and brings incomplete ghost suppression and distortion of the effective signal. In this paper, we propose a new deghosting method for over/under streamer acquisiton based on analytical fk-domain seismic wavefield extrapolation characterized by high computing efficiency. Cases studies of synthetic and real seismic datasets demonstrate that our seismic wavefield extrapolation based on Fourier transform ensures the consistency of the seismic amplitude and phase of over/under streamer seismic data and significantly eliminates the amplitude and phase error of far offset especially for the long streamer condition, which helps to decouple the real wave and the ghost wave and fill notch effect in the spectrum.

### 80. IMPROVED VERTICAL AND LATERAL RESOLUTION IN INVERTED TOWED STREAMER EM DATA AS A FUNCTION OF INCREASED DATA DENSITY

*Atle Aamodt*[1]*, *Kathrin Flisnes Bergh*[1], *Jenny-Ann Malmberg*[1] *and Jenny-Ann Mattsson*[1]
[1]Petroleum Geo-Services

The towed streamer EM marine controlled source electromagnetic (mCSEM) system facilitates cost effective dense spatial data acquisition. Resistivity imaging of the subsurface is dependent on both the spatial and source frequency coverage in the mCSEM data. In particular, the inversion performance can be improved with respect to the resolution by increasing the density of the subsurface image points.

In this study, different settings of sources and receivers are investigated in a series of 2.5D anisotropic inversions. Both vertical and horizontal resolution capabilities of the EM inversions are tested by modelling two resistive anomalies displaced vertically and horizontally, respectively, and by using different acquisition data density for the inversions.

The cases with denser data coverage showed an overall better representation of the targets compared to the sparser cases. Further, the inversion resolution is dependent on the noise level. A higher data density appears to stabilise the inversions and also makes them less susceptible to the noise. Hence, our results emphasize the importance of acquiring sufficiently dense data to ensure robustness of CSEM inversions.

## PETROLEUM – ACQUISITION TO INTERPRETATION CASE STUDIES

### 81. WIDE LINE SEISMIC ACQUISITION TECHNIQUE IN A HILLY TERRAIN OF ONSHORE MYANMAR

*Seehapol Utitsan*[1]*, *Tosapol Tongpet*[1], *Suppakarn Thanatit*[1] *and Wirote Wetmongkongorn*[1]
[1]PTTEP

Myanmar's onshore block EP-2 is a small exploration concession with high potential structures located on the eastern side of the Irrawaddy River. One of the major anticlinal structures can be mapped based on surface geological survey, but the recent 2D seismic data has extremely poor quality due to a severe static and strong side scattered noise. Although the size of this prospect is attractive, the subsurface uncertainties are considered too risky for further drilling operation. An alternative acquisition technique called "2D-wide line" was firstly implemented in Myanmar. Its results provide better stack sections, more reliable velocity function and higher geological probability of success.

### 82. APPLICATION OF 3D ITERATIVE SRME FOR SHALLOW WATER DE-MULTIPLE, A CASE STUDY ON DATA FROM PHU QUOC BASIN IN OFFSHORE VIETNAM

*Hao Zhang*[1]*, *Barry Hung*[1], *Jiwei Jia*[1], *Zhengmin Zhang*[1] *and Anh Tien Ho*[2]
[1]CGG
[2]PVEP

This paper presents our continuous effort on multiples attenuation in shallow water environment. The seismic data were acquired at various locations along the offshore of Vietnam, and the interpretation of the data is made difficult due to the presence of shallow water related multiples. Previously, we have demonstrated a two-step workflow of applying first shallow water de-multiple (SWD) and then surface related multiple elimination (SRME) to handle shallow water multiples. This workflow has been proven to be effective as it has been applied on many marine seismic surveys.

In this paper, we expand our current workflow by incorporating the data before and after SWD as the dual input for 3D SRME model prediction, namely 3D iterative SRME for shallow water for targeting higher order peg-leg surface related multiples that includes the seafloor as one of the multiple generators. Apart from being data driven, 3D iterative SRME for shallow water also takes into consideration the spatially varying nature of subsurface structures.

We demonstrate, through the real-data examples, that our workflow provides an optimal multiple attenuation solution in the shallow water environment.

### 83. INTERPRETING 2D SEISMIC WITH THE ASSISTANCE OF FALCON® AIRBORNE GRAVITY GRADIOMETER DATA IN THE CANNING BASIN

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The interpretation of 'vintage' seismic data acquired in underexplored frontier basins is often challenged by their sparse

coverage. This example from the Canning Basin illustrates how FALCON® Airborne Gravity Gradiometer (AGG) data greatly enhances the 2D seismic interpretation, facilitating exploration in such frontier basins.

The initial seismic interpretation was performed by Buru Energy, and given the 'vintage' data, was limited at best. The integration of the AGG, magnetic, well, and other available data allowed the improvement of seismic interpretation. A basement structure map, and two intra-sedimentary structure maps were produced, resulting in an overall geological model.

In particular, the initial seismic interpretation of seismic traverses perpendicular to strike across the AGG survey could be significantly improved by using images of the AGG data and AGG profile data (GDD and gD). The AGG data and the structure maps were used to constrain fault locations and depths as well as thickness distributions of geological units. The interpreted seismic traverses were validated by 2.5D gravity modelling, ultimately resulting in a conceptual geological model.

This is a key-method to constrain the interpreted geology, providing a more confident interpretation of 'vintage' reflection seismic data with sparse coverage.

## 84. A SEISMIC SURVEY AT THE REGION NEAR THE MOUTH OF FUJI RIVER, SHIZUOKA PREF., JAPAN

*Toshiyuki Yokota[1]*, Shinji Kawasaki[2], Yasuhisa Tanaka[2] and Katsuya Noda[2]*
[1]AIST
[2]JGI Inc.

It is very important to know the subsurface structure and depositional environment from the coastal to the shallow sea region, when studying groundwater flow. However, when we acquire geophysical survey data, since the data acquisition methods of both land and marine cannot successfully acquire the data at the domain from the coastal to the shallow sea regions, such regions are often left as blank of geophysical surveys. Furthermore, in our country, such domains are generally highly developed and even setting up geophysical survey lines are difficult. Therefore, we are investigating the geophysical survey methods appropriate for the surveys beneath the coastal to the shallow sea region. We are also developing the evaluation methods for such regions. Therefore, we conducted a seismic reflection survey to image the subsurface structure of coastal to the shallow sea region of the mouth of the Fuji River, Shizuoka, Japan where the Fujikawa-kako fault group exists, and checked applicability of the technique. As a result, we obtained subsurface structure down to the 5000 m.

## 85. NEOGENE OBLIQUE EXTENSIONAL SYSTEM IN THE NORTH-WESTERN BONAPARTE BASIN, AUSTRALIA

*Muhammad Mudasar Saqab[1]* and Julien Bourget[1]*
[1]University of Western Australia

The North-western Bonaparte Basin offers a very good opportunity to understand the nature of oblique extension system, where Neogene flexure-induced extension was superimposed obliquely to the Mesozoic rift-related structures. The Mesozoic trends strongly control the distribution and style of the younger Neogene structures, both at regional and local scale. The younger Neogene activity produced a new set of NE trending, right-stepping en echelon faults and reactivated the older faults. In addition, episodes of stratigraphic growth provide critical evidence regarding the timing of fault activity. Results demonstrate that, in the study area, main fault activity occurred in several pulses during the latest Miocene to Late Pleistocene. These episodes of fault activity correspond to recently constrained regional tectonic events i.e., the initial collision of the Australian Plate with the Banda Arc, the episodes of uplift of the Timor Island and the timing of lithospheric flexure.

## 86. NORTH SEA CASE STUDY: HEAVY OIL RESERVOIR CHARACTERIZATION FROM INTEGRATED ANALYSIS OF TOWED STREAMER EM AND DUAL-SENSOR SEISMIC DATA

*Atle Aamodt[1]* and Kerry Key[2]*
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[2]Scripps Institution of Oceanography

Integrated analysis of geophysical data can provide valuable information on reservoir properties, on the basis of which exploration, appraisal, and development decisions can be made. Hence, we have introduced a quantitative interpretation workflow that integrates dual-sensor seismic and Towed Streamer controlled-source electromagnetic (CSEM) data. The workflow was designed to facilitate a reliable extraction of the complementary information from the two datasets. The seismic contribution starts with a depth-converted sparse horizon model to initialize the EM inversion, but it is not placed rigidly. This makes good sense when taking into account the uncertainties in seismic data, in the time to depth conversion, and more importantly, the fact that a reservoir can be hydrocarbon-charged to an unknown degree corresponding to the spill-point or less. We show how this approach enables a robust and reliable workflow for integrating EM and 3D seismic data with data examples acquired in an area with the complex geology of the Bressay, Bentley and Kraken (BBK) fields in the North Sea. The three heavy oil reservoirs are injectites, located in close proximity to other high resistivity settings, such as the shallow gas in the overburden, regional Balder Tuff and granite intrusions, resulting in challenging imaging issues.

## 87. FAULT LINKAGE AND REACTIVATION ON THE NORTHERN MARGIN OF THE DAMPIER SUB-BASIN

*Chris Elders[1]* and Sam McHarg[1]*
[1]Curtin University

The north-west margin of the Dampier sub-basin is characterised by a strongly segmented fault pattern. NE trending faults define the edge of the Rankin Platform, and separate it from the Kendrew Trough. However a secondary set of NNE trending faults define smaller scale graben on the edge of the Rankin Platform that preserve Lower and Middle Jurassic sediments. This strongly suggests oblique reactivation of an inherited NE trending basement fabric under WNW oriented extension during Middle Jurassic extension.

## PETROLEUM – FWI/VELOCITY ESTIMATION/SEISMIC IMAGING

### 89. REDUCING DATA STORAGE IN REVERSE TIME MIGRATION

*Weijia Sun*[1]*, *Li-Yun Fu*[1] *and Zhengxing Yao*[1]
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Prestack reverse time migration (RTM) requires extensive data storage since it computes wavefields in forward time and accesses wavefields in reverse order. We first review several successful schemes that have been proposed to reduce data storage, but require more computational redundancies. We propose two effective strategies to reduce data storage during RTM. The first strategy is based on the Nyquist sampling theorem, which involves no extra computational cost. The fact is that the time sampling intervals required by numerical algorithms or given by field records is generally several times smaller than that satisfied by the Nyquist sampling theorem. Therefore, we can correlate the source wavefields with the receiver wavefields at the Nyquist time step, which helps decrease storage of time history. The second strategy is based on a lossless compression algorithm, which is widely used in computer science and information theory. The compression approach reduces storage significantly at a little computational cost. Numerical examples show that the two proposed strategies are effective and efficient.

### 90. RECIPROCITY PRINCIPLE IN FINITE DIFFERENCE MODELLING OF WAVES IN ELASTIC MEDIA

*Kevin Ung*[1]*, *Andrej Bona*[1] *and Mahyar Madadi*[1]
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Reciprocity principle has been used in a number of seismic applications. This principle relates the two wave fields with interchanged source and receiver locations, where the radiation patterns of the source and receiver are interchanged as well. In extending this principle to be used in real-world scenarios where radiation patterns vary in different locations, a number of experiments to determine the validity of this principle were conducted. Given the proliferation of the numerical modelling in today's geophysical data processing and imaging, the verification of validity of the reciprocity theorem for the modelling algorithms is important. We found that the reciprocity principle is not upheld for some instances of finite difference modelling due to the implementation of the free surface boundary condition. In the case of absorbing boundary conditions however, good reciprocity relation can be achieved.

### 91. BOREHOLE HYDROPHONE EXPERIMENTS FOR A NEAR-WELL INVESTIGATION AT AN AQUIFER STORAGE AND RECOVERY SITE, MIRRABOOKA, WESTERN AUSTRALIA

*Majed Almalki*[1]* *and Brett Harris*[2]
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[2]Curtin University

We present borehole experiments conducted at the Mirrabooka Aquifer Storage and Recovery (ASR) site, Perth, Western Australia. Our aim is to investigate a potential method to aid in constructing hydraulic or reactive transport modelling. Two acquisition techniques were implemented to collect the data: (i) walkaway vertical seismic profiling and (ii) zero-offset vertical seismic profiling (ZVSP). These borehole experiments were conducted simultaneously in two monitoring wells: M345-109 and M345-408. The ZVSP experiments were completed in such a way that the data could be acquired at 0.5-m hydrophone intervals over a highly heterogeneous production interval. Dense ZVSP was applied to characterise aquifers above and within the ASR production zone and to assess the field parameters for imaging proposes. We demonstrated the effect of borehole coherent noise (i.e., tube waves) and the low-velocity vadose zone (i.e., variably cemented concretionary rocks). Near-surface heterogeneity resulted in large travel-time statics of ±4 ms as well as wavelet variations at each position of the free-falling weight-drop source. The processing of the reflected wave field yielded high-resolution subsurface imaging for the target layers, confirming the existence of flat-horizon layers of Osborne and Leederville formations. We demonstrated that there is the potential for vertical seismic profiling methods to be applied in shallow weakly consolidated sandstone aquifers.

### 92. IMAGING COMPLEXITY IN THE EARTH – CASE STUDIES WITH OPTIMISED RAY TOMOGRAPHY

*Ed Lewis*[1]*, *Zhijiang Luo*[1] *and John Brittan*[1]
[1]ION Geophysical

In the past 10 years, the resolution of tomographic solutions has seen a continuous increase because of evolving sophistication in methodologies and technology. A vital issue in the data domain is accuracy and density of residual move-out picks that are used to derive tomographic velocity-model updates. A new automated method allows for precise tracking of accurate residual move-out on pre-stack depth-migrated gathers and consequently the fast determination of dense, high quality travel time residuals for seismic tomography. The determination of small-scale anomalies ultimately leads to flatter pre-stack depth-migrated gathers and consequently better-focused structural images.

### 93. VELOCITY ANALYSIS USING ZERO-OFFSET ATTRIBUTES IN COMMON SOURCE DOMAIN

*Mohammad Javad Khoshnavaz*[1]*, *Milovan Urosevic*[1] *and Andrej Bona*[1]
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Most of the migration techniques require an input velocity model. Velocity analysis is one of the most critical stages in seismic data processing. Standard ways to find the velocity model are constant velocity stack and Semblance velocity analysis, which can be time consuming and labour intensive. In this work, we introduce a new approach to obtain the migration velocity and the relevant pre-stack time migration algorithm that is time effective and does not require any input velocity model prior to imaging. The velocity components, in each point in a common source gather, are achieved by calculating the radius of the curvature of seismic reflected wave-front. The corresponding velocity formula is a function of local derivatives of two way travel times with respect to the position of receivers. Computational experiments with synthetic seismic data examples confirm the theoretical expectations and demonstrate the feasibility of the proposed technique.

## 94. HORIZONTAL RESOLUTION OF SEISMIC ACQUISITION GEOMETRIES

*Wei Wei*[1]*, *Li-Yun Fu*[1] *and Weijia Sun*[1]
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Spatial sampling has a crucial influence on the horizontal resolution of seismic imaging, but how to quantify the influence is still controversial especially in complex media. Most of the studies on horizontal resolution focus on the measurement of wavelet widths for seismic migration, but neglect to evaluate the effect of side-lobe perturbations on spatial resolution. The side-lobe effect, as a migration noise, is important for seismic imaging in complex media. In this article, with focal beam analysis, we define two parameters to represent the horizontal resolution of an acquisition geometry: the width of the main lobe (WML) along the inline and crossline directions and the ratio of the main-lobe amplitude to the total amplitude (RMT) in a focal beam. We provide examples of typical acquisition geometries to show that how spatial sampling affects the horizontal resolution, measured in terms of WML and RMT values. WML defines the horizontal resolution to image the target, whereas RMT describes the clarity of the imaging. Migration noise reduces with increasing RMT, indirectly improving both the vertical and horizontal resolutions of seismic imaging. Case studies of seismic migration with 3D seismic data demonstrate how the acquisition geometries with different WML and RMT values influence the performance of seismic imaging. A prior WML and RMT analysis to predict the quality of acquired datasets can optimize acquisition geometries before the implementation of seismic acquisition.

## 95. ROBUST SEISMIC REFLECTION Q TOMOGRAPHY THROUGH ADAPTIVE MEASUREMENT OF SPECTRAL FEATURES

*Kefeng Xin*[1]*, *Yi He*[1] *and Yi Xie*[1]
[1]CGG

In this paper, we describe a robust Q tomographic inversion approach for estimating the subsurface volumetric Q field by using reflection seismic data. The inversion process involves two key stages: adaptively extracting dissipation time information from the change of spectral features of the seismic data in the presence of noise, and integrating the picked dissipation time information from both pre-migration CDP gathers and post-migration CIGs into a ray-based grid tomography for Q model building. This approach can be used together with the Q-PSDM technique to provide better images by honouring the actual wave-paths in both Q estimation and Q compensation. The Q-PSDM results show the reliability of this approach when using it to perform Q estimation in both conventional and broadband seismic data processing.

## PETROLEUM – NO SUB-THEME ALLOCATED

## 96. LATERAL VELOCITY VARIATIONS IN THE DARAI LIMESTONE, PAPUA NEW GUINEA FORELAND

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A combination of exploration and appraisal drilling results from wells on three adjacent discoveries in the Papuan Basin, western Papua New Guinea foreland, shows significant lateral velocity variation across the more than 1 km thick Darai Limestone. Investigation suggests that these are due to alteration, including dolomitisation, of the limestone. Most alteration appears associated with small scale faulting which is typically crestal. Seismic processing velocities are key to establishing the velocity profiles between wells required for depth conversion. Seismic forward modelling studies based on predicted high velocity bodies show processing velocities can develop an oscillatory behaviour in the vicinity of abrupt lateral velocity changes similar to those that may accompany dolomitisation. Similar results are observed on some of the field data.

## 97. APPLICATION OF ROCK PHYSICS AND SEISMIC INVERSION FOR THE DETERMINATION OF RESERVOIR ARCHITECTURE AND CONNECTIVITY FOR COAL SEAM GAS FIELD DEVELOPMENT

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Fluvial systems host coal seam gas reservoirs in various fields of Queensland. However, the lateral heterogeneity of reservoirs properties within these reservoirs can be significant and determining the distribution of these reservoirs is a challenge. This study attempts to predict coal distribution by applying rock physics and post-stack seismic inversion on data set of Scotia field of the Surat Basin. According to rock physics analysis, coal beds have significantly low density. Consequently, this gives low P-impedance as compared to surrounding lithology. Therefore, inverted P-impedance and density volumes can be used to predict coal distribution and connectivity of different coal seam reservoirs. Theoretically, density volumes may provide accurate prediction, but this requires execution of comprehensive pre-stack inversion workflow. We only used a model based P-impedance inversion technique to create P-impedance volumes in order to better image the reservoir and connectivity. Extracted horizon slices by using cutoff based on rock physics analysis, successfully highlights architecture of coal beds. Computed average P-impedance within zone of interest can provide information regarding promising zones for exploration of coal seam gas. Blind test for P-impedance prediction at well locations reveals reasonable match for coal prediction using this method.

## 98. MARINE EM SURVEYS ON COASTAL SHELF AND TRANSITION ZONES

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Seabed EM surveys in shallow water environments have a number of specific particularities. Specifically, there is difficulty with hermetical sealing of EM instruments and the necessity of overcoming electromagnetic noise caused by underwater currents and sea surface disturbances. Another problem is the inability to employ large ocean going vessels in many areas, while the use of small vessels increases the demands on the size and weight of the equipment. There are also certain positive aspects in this, pertaining to the ability to use reliable acoustic communication between the marine EM instrument positioned on the seabed and the sea surface, as well as the use of beacons for identifying the location of the bottom apparatus. In this paper, discussed is a

shallow marine EM data acquisition equipment complex that allows efficient use of standard ground EM instruments for carrying out investigations at a sea depth interval of 0–200 m. This complex consists of 2x – 4x – 5-channel marine EM systems.

### 99. LA LOBE EARLY CRETACEOUS FAN-DELTA (CAMEROON ATLANTIC BASIN)

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From the Campo onshore to the Malabo-Victoria volcanic line, the Cameroon Atlantic Basin comprises two main segments: the Ekité-Kordofan transform-fault basin and the Wouri-Yassem deep-graben structure separated by the Yassoukou-Tissongo-Ossa reverse fault. The major morphologic features of the Ekité-Kordofan transform-fault basin are Kribi-Campo half-graben and the Elombo-Nkoundou internal shear zone.

Detailed analyses of long offset pre-stack depth migrated seismic sections enabled mapping of buried fan-delta at approximately 20 km southwest of the Kribi-La Lobe river mouth. The fan is up to 25 km wide, 4km thick and is morphologically expressed in the form of bank clinoform sequences. By correlation of seismic records with borehole data from adjacent areas, it appears that the fan is divided in two morphologic divisions (upper and lower fan). The lower fan uniformly returns transparent weak seismic record, with intermittent internal reflections. In contrast, the upper fan is characterized by acoustically high amplitude clinoform reflections. Within this package, listric growth faults are common, and the fan tends to mound up were salt domes are present beneath Bedoulian-Aptian boundary. These results opened up Aptian-Albian fan-delta play of the Cameroon Atlantic Basin and help to introduce new hydrocarbon concepts and exploration opportunities.

## PETROLEUM – PETROLEUM OTHER

### 100. MULTIPLE ATTENUATION USING NON-LINEAR PREDICTIVE OPERATORS IN F-X DOMAIN BY VOLTERRA SERIES COEFFICIENTS

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One of the most common artefacts in seismic records is multiples. To have more interpretable images, they must be removed or at least be attenuated. Prediction of such artefacts is being done using two different theories: linear and non-linear predictive theories. Coherent artefacts have linear and non-linear shapes in time-offset domain. Nonlinear artefacts have the shape of Chirp in time-frequency domain. Therefore, modelling and reconstruction of such artefacts using linear operators do not work efficiently. In this paper, we explain the deficiencies of the linear predictive theory for prediction and reconstruction of seismic data. As an improvement on linear predictive theory, we describe the non-linear predictive filters using Volterra series. Our main effort is to rebuild the signals so that they have the minimum difference from the original recorded signals. We compare the relevant results obtained by both linear and nonlinear prediction techniques. We also optimised the previous algorithms to find the best Volterra coefficients. The ability of the theories to remove the seismic multiples is also demonstrated. Different synthetic examples have been used to illustrate the applicability of the mentioned techniques to predict and reconstruct the seismic wave-front and to attenuate the multiples.

### 101. ON THE EFFECTIVENESS OF GEOPHONE ARRAYS FOR ATTENUATING AMBIENT NOISE

*Ben McCarthy*[1]*, *Timothy Dean*[1], *J. Christian Dupuis*[2] *and Laval Raquibul Hassan*[3]
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Historically, arrays have been used to attenuate ambient noise under the assumption that the level of attenuation is directly proportional to the square root of the number of sensors in the array. Given the availability of high channel-count point-receiver systems and the cost associated with laying out large arrays this assumption of 'spatial randomness' requires further analysis. Using measurements of ambient noise made at various sites in Perth, Australia with closely spaced geophones we show that ambient noise is strongly correlated over distances of up to 10 m. This correlation reduces the signal-to-ambient-noise performance of an array considerably. The correlation coefficient can be modelled using an exponential function and the correlation-distance used to determine the efficient geophone spacing.

The optimum geophone spacing on days with a low wind speed (<10 km/h, observed on 27% of days in the area) is 15 m. For days with a very high wind speed (>80 km/h) the optimum spacing is 2.5 m, although this wind speed is very uncommon, occurring on average less than once each year. For more than 90% of days the wind speed is such that the optimum geophone spacing required for ambient noise suppression is 7.5 m.

### 102. THE IMPACT OF TILTED GEOPHONES ON LAND SEISMIC DATA QUALITY

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The moving coil geophone is still the most commonly used sensor for land seismic surveys despite the introduction of other sensors. Modern geophone development has reached the stage where the signal recorded is of very high quality, but it can still be affected by the geophone being placed on an angle relative to the vertical ('tilt').

This paper describes the acquisition and analysis of field measurements using tilted geophones. It is shown that the critical angle of the 10 Hz geophones used for this test is 55°. For data recorded using vertically placed geophones separated by only 10 cm the perturbation level (the difference between the data recorded by adjacent geophones) averaged 8% and increased to more than 50% at tilt angles of 40º. The level of perturbation is heavily dependent on the orientation of the tilt angle relative to the source-detector axis, for example, for a geophone tilted at an angle of 30°, the perturbation varied between 14% and 48%.

The obvious solution to these issues is to record data using sensors that have been planted extremely carefully or to use other sensors, such as digital accelerometers or 3C sensors that have the effect of tilt removed during processing.

## 103. THE PRESENT-DAY STRESS FIELD OF AUSTRALIA: NEW RELEASE OF THE AUSTRALIAN STRESS MAP

*Mojtaba Rajabi*[1]*, *Mark Tingay*[1], *Rosalind King*[1] *and Dennis Cooke*[1]
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The present-day stress field is important for a range of earth science disciplines including petroleum and geothermal geomechanics, mine safety, neotectonics and seismic hazard assessment. So far, many studies have been carried out to understand the state of stress in different parts of the world and the results reveal that the contemporary tectonic stress field can range from being uniform over large areas (100s-1000s of kilometres) to being highly varied over short distances (10s-100s of meters) due to interaction of different parameters. One of the most well-known examples of a heterogeneous stress pattern is observed in the Australian continent, which displays a wide range of stress orientations from province to province that, unlike all other major plates, are not aligned with absolute plate motion.

The Australian Stress Map (ASM) project was started in 1996 to compile a public data set of maximum horizontal present-day tectonic stress information to determine and understand the state of stress in the Australian crust. The early phases of the ASM revealed that plate boundary forces provide the first-order control on the present-day stress pattern. However, all models of the stress field have failed to replicate the stress pattern in Eastern, and particularly north-eastern, Australia. The ASM project commenced again in 2012 with a primary aim of building up the database in Eastern Australia, such as new hydrocarbon provinces, and to help better establish the controls on the Australian stress field at scales ranging from tectonic plate down to individual fields and wells. To date, we have interpreted more than 400 borehole image logs in coal seam gas, mineral and conventional petroleum wells. The results show that local sources of stress (i.e. second and third orders) play a key role in the stress pattern of Australia which is an important issue for geothermal and unconventional exploration and production.

## 104. VARIATION OF NATURAL FRACTURE ORIENTATIONS IN THE CARNARVON BASIN'S RANKIN PLATFORM AND DAMPIER SUB-BASIN, NWS, WESTERN AUSTRALIA

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Natural fractures in the Carnarvon Basin's Rankin Platform and Dampier Sub-Basin are identified using electrical resistivity image logs from 10 petroleum wells. In-situ stresses are diagnosed for the area using data from these and four additional wells, with these results indicating it likely that this study area hosts a relatively isotropic in-situ stress field.

Identified fractures occur at all orientations, and demonstrate no dominant trend. They do not reflect the in-situ stresses, nor the dominant north-northeast to northeast fault strikes. Rather, they most closely reflect the orientation of more local structures which the wells are adjacent to, demonstrating that natural fracture populations may be more dependent on local structure than dominant regional trends.

## 105. STUDY ON INTERNAL MULTIPLE ELIMINATION METHOD ON LAND SEISMIC DATA

*Luqing Cao*[1]* *and Tianyue Hu*[1]
[1]Peking University

Multiple is a tough issue in recent years, especially the internal multiples in deep earth. In this paper we proposed to construct virtual events to predict internal multiples. Then adopt the mean value multi-channel adaptive subtraction method for matching the multiple model and seismic data. However, the results depend on the parameters closely. We propose to apply the dynamic time wrapping method in order to accomplish the precise matching. And the regression of multiples can effectively improve the internal multiple elimination results when internal multiples are interfered with effective signal.

## 106. RELATIONSHIP BETWEEN RADIOGENIC HEAT GENERATION AND HIGH SUBSURFACE TEMPERATURES IN SEDIMENTARY BASINS IN WESTERN AUSTRALIA

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Higher than normal subsurface temperatures are found in the Perth and Carnarvon basins in Western Australia. Both basins are known to be underlain by granitoid rocks which may possess higher than normal levels of the elements uranium and thorium, which in turn contribute to heat generation in those rocks. Airborne and ground radiometric data confirm the presence of radiogenic-granitoid rocks surrounding the Perth Basin, which are believed to be the cause of the observed elevated subsurface temperatures in that basin. Heat generation in these granitoid rocks typically ranges between 2 and 20 $\mu Wm^{-3}$. New radiometric data for crystalline rocks, inferred to underlie the high subsurface-temperature regions of the Carnarvon basin, also indicate regions of anomalously high uranium and thorium. Brief reference to other high-radiogenic rocks in Western Australia and possible implications for heat flow is also made. One and two dimensional static heat-flow models, incorporating new upper-crustal radiogenic information, for the Perth and Carnarvon basins have been developed. The models are used to review the thermal history of these basins.

## 107. CENOZOIC SURFACE UPLIFT FROM SOUTH WESTERN AUSTRALIAN RIVERS

*Nicholas Barnett-Moore*[1]*, *Nicolas Flament*[1] *and Dietmar Muller*[1]
[1]Sydney University

Embedded within Earth's topography is a constantly evolving fluvial network sensitive to variations in horizontal and vertical motions, driving sediment transport from elevated sources to sedimentary basins. The notion that a river acts as a 'tape recorder' for positive vertical displacements suggests that changes in spatial and temporal characteristics of surface uplift can be deduced through the analysis of longitudinal river profiles. The relative tectonic quiescence of the Australian continent during the Cenozoic makes it an excellent natural laboratory to study recent large-scale variations in surface uplift, often linked with mantle convective processes. Here, we analyse X longitudinal river profiles from south Western Australia.

Major knickzones in the longitudinal profiles of rivers in southwest Australia suggest recent surface uplift. Given the lack of recent large-scale tectonic activity in that region, this uplift requires an explanation. Applying an inverse algorithm to river profiles of south Western Australia reveals that this surface uplift started in the Eocene and culminated in the mid-late Neogene. The surface uplift rates deduced from this river profile analysis generally agree with independent geological observations including preserved shallow-marine sediment outcrops across the Eucla Basin and south Western Australia. The timing of this event is also to be compared with offshore stratigraphic sections to link onshore surface uplift to offshore sedimentation. We show that the interplay between global sea level and long-wavelength dynamic topography associated with south Western Australia's plate motion path over the remnants of an ancient Pacific slab is a plausible mechanism driving this surface uplift.

## 108. GEOPHYSICAL AND GEOCHEMICAL CONSTRAINTS ON CRETACEOUS-CENOZOIC MAGMATISM ALONG THE SOUTHERN AUSTRALIAN MARGIN

*Fun Meeuws[1]*, Simon Holford[1] and John Foden[1]*
[1]University of Adelaide

Increasing levels of exploration along rifted continental margins, such as the southern Australian margin, has led to growing recognition of the detrimental impacts of magmatic activity on hydrocarbon prospectivity. Key exploration risks include the impact of intrusions on seal integrity, reservoir quality, source rock maturation and migration pathways. However, the extent and distribution of volcanic rocks along continental margins, such as the Australian southern margin, and the processes by which magma is transported through sedimentary basins are still poorly understood despite the wealth of available seismic datasets. Although classified as a 'non-volcanic' rifted margin, our analysis shows that an extensive and largely undescribed record of Cretaceous-Cenozoic magmatic activity is preserved within the sedimentary successions of the rift basins located along the southern Australian margin. The combination of seismic reflection data and geochronological and geochemical data shows that this magmatic activity cannot be solely attributed to continental break-up and related decompressional melting processes or the presence of a hotspot or plume.

## 109. PROBABILISTIC ANALYSIS OF EM DATA SENSITIVITY AND INVERSION ACCURACY

*Joel Skogman[1]* and Erik Bjornemo[1]*
[1]PGS Technology

Towed streamer EM data offer a possibility to generate a resistivity model of the earth within the sensitivity range of the EM survey, using procedures such as inverse modelling. There is, however, an inherent non-uniqueness in the problem due to noise, uncertainties, finite number of measurement positions and field components. To assess the model uncertainty, and analyse the data information content, we propose the Bayesian method of calculating probabilities for model parameters within a given set of models. Real towed streamer EM noise applied to synthetic EM data in a 3D model, similar to Barents Sea conditions, was used for the evaluation.

The result of this work is a formulation of the posterior probability distribution for a set of sub surface resistivity model parameters. By analysing these probability functions we find that we are able to evaluate how a change in the data, e.g. different frequencies, sensor positions, noise levels or complexity of background, affect the probability of finding a model close to the true model.

## 110. SEISMIC WITHOUT SENSORS – DISTRIBUTED VIBRATION SENSING

*Ben McCarthy[1]*, Timothy Dean[2], Arthur Hartog[2] and Bernard Frignet[2]*
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Making seismic acquisition quicker and/or cheaper requires removing one or more of four major components: the source, the sensors, cables connecting the sensors, or the recording system. In this paper we describe how fibre-optic cables can be used as sensors in a distributed vibration sensing system.

## 111. OPERATIONS SUMMARY DURING RISERLESS DRILLING TO >7700 MBSL IN THE JAPAN TRENCH FOR IODP EXPEDITION 343 & 343T JFAST AND DISCUSSION OF THE RELATIONSHIP BETWEEN DRILLING PARAMETERS AND ROCK DAMAGE

*Virginia Toy[1]*, Sean Toczko[2], Nobu Eguchi[2], Lena Maeda[2], Ikuo Sawada[2], Tonokazu Saruhashi[2] Fred Chester[3] and Jim Mori[4]*
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[4]Kyoto University

During IODP Expedition 343: The Japan Trench Fast Drilling Project (JFAST), five boreholes were drilled from the D/V Chikyu in >6800 m water depth. Three of these crossed the main fault target. A logging-while-drilling (LWD) hole that penetrated to 850.5 meters below seafloor (mbsf) (total depth [TD] = 7740 meters below sea level [mbsl]) was documented using a suite of LWD tools. From an adjacent partially cored hole drilled to 844.5 mbsf (TD = 7734 mbsl) 21 cores were acquired that spanned the two main fault targets. During the follow-up expedition 343T a third borehole was drilled to 854.8 mbsf (TD = 7752.3 mbsl) and a simple temperature observatory was deployed in the wellhead. The drilling operation, which lasted 88 days, was very technically challenging. Notably, the drill string had to be withdrawn a number of times due to high seas, and technical issues.

In certain intervals, rather than core we recovered loose, subrounded fine gravel clasts of the two major lithologies penetrated to those depths (silt and mudstone). Particle shape and size of these clasts was analysed. Results demonstrate (1) particle shape variations apparent visually are not easily quantified, (2) there are distinct variations in particle size distributions. We discuss whether these relate to variations in drilling parameters.

## PETROLEUM – QI/ROCK PHYSICS/SEISMIC GEOMORPHOLOGY/STRATIGRAPHY

### 112. SPECTRAL DECOMPOSITION INFLUENCE ON AVO EFFECT

*Thierry Bertolino*[1] *and Mauricio Herrera Volcan*[1]
[1]Schlumberger

Delineating the extend of a producing reservoir is one of the main challenge of exploration and development interpreters. Our approach to address this challenge is to use "spectral decomposition" of pre-stack data couple with an AVA/AVO studies (Amplitude Versus Angle/Offset).

Seismic spectral decomposition is a known method to determine more accurately the lithology of an area of interest. AVO effect are used to identify and quantify the extend of a fluid anomaly in a potential reservoir. Combine together, the aim of this method is to provide a better delineation of the producing area. A shared earth approach will be used in order to perform cross validation of the results at each step.

The first step is a 1D study well bore centred:

Using well logs information: Vp (compressional velocity), Vs (Shear velocity) and the density to compute a first set of synthetic gather that will constitute our reference. The chosen well has an AVO effect and should be visible on this reference set.

A real set of pre-stack gather at the well bore will then go through a series of tests to identify the best frequency bandwidth that identify more accurately the AVO effect.

In a second phase, this frequency bandwidth will be used to produce two results:

A 3d set of gather with this optimum bandwidth. Producing Gradient and the Intercept of this set, a cross plot of those attributes should confirm the result of the 1D study and will help to delineate the AVO effect spatial extent.

An inversion based on this spectral decomposition should help to delineate more accurately the reservoir lithology

Those results unified well bore information, seismic pre and post stack data, frequency analysis and inversion results. The analysis will tend to demonstrate that lithology and gas anomaly can be better mapped using combined methodology, compare to a juxtaposition of methods.

### 113. SEISMIC ATTRIBUTES SUCCEEDED IN DETECTING AND DETERMINING THE FEATURES OF INCISED VALLEY FILL SANDSTONE

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The main objective of this study is to focus on detecting incised valley fill sandstone in the upper Morrow formation and determining its width, thickness and edges by using appropriate seismic attributes. There are seismic attributes that can display the features of channels and incised valley in seismic horizon slice very clear.

In this study, Coherence, Discontinuity along dip, Relative Amplitude change with X and Y attributes were used to detect the incised valley fill sandstone. Spectral decomposition attribute was used to determine the thickness of the incised valley fill sandstone by using frequencies from 10 Hz to 70 Hz. Most positive and negative curvatures attribute were used to determine the valley's edge. Coherence and discontinuity along dip attributes succeeded to detect the valley and also succeeded to map its width in acceptable resolution. Discontinuity along dip shows its width clearer than coherency.

As for Spectral decomposition, it displayed subtle changes in the incised valley fill sandstone. As for most positive and negative curvatures, positive curvature may indicate highs in structure and less compaction over the incised valley-fill sandstone axis. On another hand, most negative curvature shows the edge of incised valley-fill sandstone and its centre may show shale deposition. As for relative amplitude change with X and Y, they succeeded to determine the direction and the width of incised valley-fill sandstone.

### 114. GEO-PRESSURE VARIATIONS IN THE CARNARVON AND BROWSE BASINS FROM BOTH SEISMIC AND WELL ANALYSIS

*James Leven*[1]*, *Ivar Meisingset*[1], *Julian Coker*[1] *and Finn Johansen*[1]
[1]First Geo

A careful analysis of the geopressure regime in one hundred wells on the North West Shelf (NWS) is integrated with an analysis of apparent overpressure derived from the regional hiQbe™ velocity model. The well analysis is a traditional pressure interpretation, considering all available data and all types of overpressure. The hiQbe™ analysis is based on velocity data, and can therefore detect compaction disequilibrium overpressure. The calibration and integration of these two forms of analysis give new insight into the regional distribution of potentially overpressured rocks in the NWS, and provides a good basis and guidance for well planning.

### 115. APPLICATION AND POTENTIAL ERRORS OF PALYNOLOGY AND VITRINITE REFLECTANCE AS TOOLS FOR OUTCROPS STRATIGRAPHY RESTORATION; A CASE STUDY OF EARLY CRETACEOUS STRZELECKI GROUP COASTAL OUTCROPS, WEST GIPPSLAND, VICTORIA, AUSTRALIA

*Hamed Aghaei*[1]*, *Mike Hall*[1] *and Barbara Wagstaff*[2]
[1]Monash University
[2]Melbourne University

Vitrinite reflectance and palynology are potential approaches for stratigraphy correlation and restoration mainly because they can provide maximum palaeo-temperature and relative age of the sediments respectively. Moreover, fluvial sediment stratigraphic restoration is complex due to several reasons such as unknown size of the sediments. This study presents application of these methods in restoration of non-marine Strzelecki Group, well-exposed along the coastline near the Wonthaggi Township, south Victoria, Australia, and shows how they can support each other's results and cover the potential errors. About 20 km of the coastal outcrops were mapped, logged, and sampled for palynology and VR. Stratigraphy was reconstructed based on maximum palaeo-temperature and an estimated palaeogeothermal gradient of 50oC/km. The restored stratigraphy column was then divided into several blocks based on palynology. The restored

stratigraphy reveals syn-depositional fault activity and provided new ideas on the amount of erosion and preserved section of this group in Wonthaggi area. However, several scenarios were discussed in terms of variation in final results versus using thermally altered VR samples, restoration solely based on VR and restoration using only palynology data. In conclusion, VR and palynology can be hired for fluvial sediment stratigraphic restoration, however, attention needs to be paid in absence of one of the methods.

## 116. IODP EXPEDITION 356: DRILLING TO REVEAL A 5 MILLION YEAR CARBONATE AND SUBSIDENCE HISTORY ON THE NORTHWEST SHELF OF AUSTRALIA

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The late Cenozoic carbonates of the Northwest Shelf are important subsidence history archives that also cause significant sonic velocity problems affecting seismic imaging of underlying strata. Despite their substantial thickness and areal extent, these carbonates have been sampled only in engineering foundation boreholes and as cuttings and rare sidewall cores in petroleum wells. In August-September 2015 the International Ocean Discovery Program (IODP) will drill a transect of shelf to shelf margin cores in this region. Six sites will be drilled over 10° latitude from the Perth Basin to the Bedout sub-basin by RV JOIDES Resolution with continuously cored penetrations of 300 m to 1.1 km. An array of shipboard and post-cruise biostratigraphic, sedimentological and geochemical analyses will be carried out on these cores to achieve three primary aims:

1. Provide empirical input into the spatiotemporal patterns of subsidence along Northwest Australia that can be used to place fundamental constraints on the interaction between Australian plate motion and mantle convection and to ground truth geodynamic models.
2. Determine the timing and variability of regional oceanographic features in order to understand the controls on Neogene carbonate stratigraphy and reef development.
3. Obtain a tropical to subtropical climate and ocean archive, directly comparable to deep-ocean oxygen isotope and ice-core archives, to chart the variability of the Australian monsoon and the onset of aridity in northwestern Australia.

Each site will be triple cored using a combination of Advanced Piston Coring (APC), Extended Core Barrel (XCB) and Rotary Core Barrel (RCB). An array of downhole measurements will be taken using three standard IODP tool string configurations: the triple combination (triple combo), Formation MicroScanner (FMS)-sonic, and Versatile Seismic Imager (VSI). These will be used to correlate the cores to regional multichannel seismic profiles in order to gain a better understanding of Northwest Shelf stratigraphy and neotectonics.

## 117. MONTE-CARLO SIMULATION OF STRESS-ASSOCIATED ULTRASONIC SCATTERING ATTENUATION

*Wei Wei*[1]*, *Li-Yun Fu*[1] *and Weijia Sun*[1]
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Seismic coda waves scattered by small-scale hetero-geneities contain information on stress changes of the medium, as a result of changes in the physical state of materials. Based on the ultrasonic measurements under different stresses for a cylindrical sandstone sample, we investigate the influence of stress changes on ultrasonic S-coda attenuation and aim to characterize its stress-dependent pattern. Considering the complexity of ultrasonic coda waveforms measured from finite-size rock samples in laboratory experiments, the Monte-Carlo simulation is employed to synthesize ultrasonic envelopes, which by incorporating the effect of multiple scatterings and boundary reflections on coda waves. The optimal simulation parameters, estimated by minimizing the residual between the observed and synthesized envelopes, indicate that the rock sample under study presents moderate heterogeneities. The relationship between attenuation and stress is similar for direct and coda S waves and remains fairly stable in the range of high effective stresses around 30–60 MPa, with less stress sensitivity. Enhanced attenuation for both types of waves occurs at lower effective stresses, but with coda attenuation much faster and stronger, presenting a quite different nonlinear behaviour with respect to stress. Coda attenuation increases drastically at extremely low effective stresses below 15 MPa because of the increase in rock compliance, showing much greater sensitivity to high pore pressure than intrinsic attenuation. This study improves our understanding of the mechanism of ultrasonic coda attenuation and its scaling dependence on stress.

## 118. A LABORATORY STUDY OF THE 'BARREL SHAPE' EFFECT IN A VISCOELASTIC CYLINDRICAL SAMPLE AT SEISMIC FREQUENCIES

*Vassily Mikhaltsevitch*[1]*, *Maxim Lebedev*[1] *and Boris Gurevich*[1]
[1]Curtin University

The "barrel shape" effect caused by axial pressure applied to a cylindrical acrylic sample was studied using a low-frequency laboratory apparatus utilizing stress-strain relationship, which was developed to measure the complex Young's moduli of elastic materials at seismic frequencies, confining or axial pressures from 0 to 70 MPa, and strain amplitudes 10-8–10-7. To increase the effect, the experiments were performed at axial pressures only. The elastic and anelasic parameters of the 15 cm length sample were measured with strain gauges glued in the middle of the sample and at two centimetres from one of the ends at axial pressures of 7 MPa and 15 MPa. Our experiments show that all measured parameters are independent from the location of the strain gauges on the sample. These results confirm that the barrel shape of the sample caused by applied stress does not affect reliability of low-frequency laboratory measurements.

### 119. CHANGES IN ELASTIC PROPERTIES OF ARTIFICIAL SHALES DUE TO COMPACTION

*Roman Beloborodov*[1]*, *Marina Pervukhina*[1], *Lionel Esteban*[1] *and Maxim Lebedev*[1]
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The effects of compaction on elastic properties of shales and their anisotropy are important for seismic imaging, seismic to well tie and borehole stability issues. Compaction trends in shales remain poorly studied, but it is well known that porosity of shales rapidly decreases with the increase of burial depth due to mechanical compaction and chemical transformation of clays in particular. These processes affect all the physical properties of shales including their elastic moduli, electrical conductivity and permeability.

In this experimental work we study changes in the anisotropic elastic properties of artificial shales caused by mechanical compaction. Investigation of anisotropy is performed on two specimens made of kaolinite and quartz powder mixtures: (1) 75% / 25 % and (2) 60% / 40%, respectively. An uniaxial stress is applied progressively to achieve distinct levels of porosity. Ultrasonic P- and S-wave velocities in the specimens are measured at every stage of the compaction. Thomsen's anisotropy parameters are calculated from these velocities. Qualitative characteristic of microfabric anisotropy is performed using micro-CT image analysis.

The results allow to conclude that at a given level of porosity of the specimen 2, with 40% of quartz, has higher compressional and shear velocities than the specimen 1 with only 25% of quartz. However, the specimen 1 shows higher degree of elastic anisotropy than the specimen 2 due to higher fraction of anisotropic clay.

## PETROLEUM – UNCONVENTIONAL HYDROCARBONS/ PASSIVE SEISMIC

### 122. FEASIBILITY OF USING PASSIVE SEISMIC DIFFRACTIONS FOR IMAGING AND MONITORING

*Andrej Bóna*[1]*, *Roman Pevzner*[1], *Konstantin Tertyshnikov*[1] *and Mamdoh Alajmi*[1]
[1]Curtin University

We present a feasibility study of using passive seismic data for imaging of diffractors. Imaging and characterisation of seismic diffractors is important for many applications of seismic methods, including carbon geosequestration, since in sedimentary setting the diffractors are associated with terminations of layers at faults, as well as edges of the zones altered through the reservoir depletion or fluid (e.g. CO2) injection. One of the findings is that the diffracted waves from ambient sources can be sometimes incorrectly interpreted as active seismic sources that might lead to wrong conclusions about induced seismicity of processes generating the ambient noise, such as injection of fluids in the subsurface.

### 123. EXTENDED IMAGING CONDITIONS FOR PASSIVE SEISMIC DATA

*Benjamin Witten*[1]* *and Jeffrey Shragge*[1]
[1]University of Western Australia

Seismic monitoring at injection sites (e.g. $CO_2$ sequestration, hydraulic fracturing) has become an increasingly common tool amongst oil and gas producers. The information obtained from these data is often limited to seismic event properties (e.g. location, initiation time, moment tensor), the accuracy of which greatly depends on the assumed or estimated elastic velocity models. However, estimating accurate 3D velocity models from passive array data remains a challenging problem. Extended imaging conditions (eICs) for passive wave-equation imaging algorithms represent a key step towards generating – and verifying – elastic velocity models. By extending imaging conditions away from zero-lag in time and space we can better evaluate the focusing of a given event based on the principle that waves focus at zero lag only when the velocity models are "correct". We demonstrate that given an elastic medium and multi-component recordings, we can propagate and correlate microseismic P- and S-wavefield modes to compute eICs for P- and S- velocity perturbations. We observe that the maximum correlation deviates from the zero-lag in time and space for a P/S cross-correlation imaging condition when using an incorrect P- and/or S-wave velocity, and thus there is sensitivity to velocity error not observable when using individual wavefield components.

### 124. AN IMPROVED METHOD FOR LOCATION OF MICROSEISMIC EVENTS WITH LOW SIGNAL-TO-NOISE RATIOS

*Yuyang Tan*[1]*, *Chuan He*[1] *and Xiaochen Hou*[1]
[1]Peking University

An improved method is proposed in this paper for microseismic source location. The primary goal of this method is to improve the location accuracy for microseismic events with low signal-to-noise ratios (SNR). In contrast to the prevalent location approach, two innovations are implemented in the proposed method. First, instead of using the hodogram, the source azimuth is estimated from a probability distribution function, and second, a new objective function is employed in grid search algorithm to find the source position. The proposed method has been tested using synthetic data examples. The results show that, for these cases, the absolute errors of the estimated source azimuth and position are less than 1° and 3 m, respectively, which proves that an improvement in location accuracy can readily be achieved using the proposed method.

### 125. MICROSEISMIC LOCATION: USING BOTH P AND S WAVES WITH NEW METHODS

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In this paper we develop a new method on the basis of the two exist two methods, using both P and S waves recorded with surface array and borehole data. The new microseismic location method take the full advantage of Generalized Pattern Search Method and Simulated Annealing Method, improving the location accuracy. We use this method to do the cast study. Consequently, using both P and S waves information in the location technique reduces the position uncertainty as compared to single P or S wave relative location. And it will be more applicable to low signal-to-noise ratios data.

## 126. PASSIVE SEISMIC IMAGING WITHOUT VELOCITY MODEL PRIOR TO IMAGING

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There are two types of passive seismic monitoring: down-hole and surface monitoring. In this paper, we introduce a new surface monitoring technique that does not require trigger time and any seismic velocity information prior to imaging. Therefore, this technique can be considered as a velocity independent monitoring technique. We have calculated the radius ot the curvature of the propagated wave-front from the passive source to the receivers deployed on the surface. The passive source coordinates are expressed in terms of the curvature. Computational experiments with synthetic data examples confirm the theoretical expectations and demonstrate the practical feasibility of the proposed technique.

## 127. MEASURING ELASTIC PROPERTIES TO DETERMINE THE INFLUENCE OF TOC ON SYNTHETIC SHALE SAMPLES

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This paper describes the factors that control elastic properties of organic shale, which is crucial for exploration and successful gas production from unconventional reservoirs. Mechanical and dynamic elastic properties are main shale characteristics that are not yet well understood as there have been a limited number of investigations involving organic rich shale samples. Synthetic shale core samples whose clay mineralogy, non-clay mineral content and Total Organic Carbon (TOC) content are known can be used to study variations of elastic parameters in a controlled experimental environment including in-situ stress conditions.

More than 20 synthetic shale samples were created for our investigations under reservoir stress conditions with different mineral composition and TOC percentage. Ultrasonic transducers were used to measure body wave velocities, which were then used to calculate the elastic properties of different shale samples. The results demonstrate that P- and S-wave velocities vary with changing TOC under isotropic stress conditions. It is shown that the velocities of P-and S-waves are inversely proportional to TOC content. In addition, the increase in the TOC produced a decrease in density from approximately 2.4 g/cc to 2.15 g/cc and increase in porosity from approximately 16% to 20%.

## 128. DETERMINATION OF TOTAL ORGANIC CARBON (TOC) IN TIGHT RESERVOIR USING EMPIRICAL MODE DECOMPOSITION-SUPPORT VECTOR REGRESSION (EMD-SVR): A CASE STUDY FROM XX-1 BASIN, WESTERN CHINA

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In the process of formation evaluation for tight reservoirs, extracting quantitative information of kerogen is a potentially important factor. Moreover, Total Organic Carbon (TOC) is not strongly correlated with geophysical well logging data. In this paper, a combinatory algorithm for nonlinear regression based on Empirical Mode Decomposition (EMD) and Support Vector Regression (SVR) is proposed. On the basis of depth matching, sensitive well logging parameters are preferred by core calibration. That, which means should be used to denoise, is a key issue for acquiring precise and high quality data. Then, intrinsic mode functions (IMF) decomposed by EMD algorithm is established and applied for denosing. Further, denoised data is classified into two categories, one for training and the other for validating. Aiming for TOC predicting model, SVR is implemented both for training and predicting, and simultaneously some conventional methods such as ΔlogR, back propagation artificial neural networks (BP-ANN), and multiple linear regressions are also exerted for comparisons. The result shows that EMD-SVR is the best solution for TOC predicting, with the highest correlation coefficient and the smallest mean squared errors. Likewise, this algorithm is applicable for other reservoirs like shale gas.

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