SECTION 4
POSTER ABSTRACTS

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Posters will be on display from Monday 12 August, 1030 to Wednesday 14 August, 1600 adjacent to the Session Rooms, Level 2, Melbourne Convention Centre

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REGIONAL STUDIES

1. 3D ARCHITECTURE BETWEEN THE YILGARN CRATON AND MUSGRAVE PROVINCE

Tim Jones, J. A. Goodwin, T. Brennan and M. Nicoll*
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In 2011, Geoscience Australia collected 484 km of deep-crustal (22 second) seismic reflection data. The survey (11GA-YO1) traverses the north-eastern edge of the Yilgarn Craton, the Officer Basin and the western end of the Musgrave Province. The purpose of the seismic survey was to delineate broad crustal architecture and define the Moho, with particular interest in the Yilgarn-Musgrave boundary.

To compliment the seismic survey, a 3D geological model was constructed that incorporates interpretations derived from seismic, potential field, surface geology and borehole data. Forward and inverse modelling techniques were applied to the potential field data to extrapolate the seismic interpretations into 3D space. Borehole data was used to constrain the interpretation of upper crustal sequences where available. The model was later used to constrain 3D potential field inversions of the area.

This poster presents a 3D geological model of the YOM region as well as the geological and geophysical constraints that were used to construct it. Some of the fundamental and technical limitations of the model are also discussed.

2. FORWARD MODELLING ALONG THE SOUTHERN CARNARVON DEEP SEISMIC REFLECTION LINE – USING GRAVITY DATA TO INVESTIGATE SEISMIC INTERPRETATIONS

*James Goodwin**
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Forward modelling was undertaken to test the architecture of the Southern Carnarvon deep seismic reflection survey (11GA-SC1) interpretation against gravity data. The seismic data extends to ~60 km depth and images the crust-mantle boundary (Mohorovičić discontinuity) allowing it to be incorporated in the forward modelling.

Using average density values for the upper mantle, granulite to amphibolite facies mid to lower crustal rocks, and upper crustal felsic and sedimentary rocks, a model was generated which explains the observed gravity anomalies and is consistent with the seismic interpretation.

This work highlighted areas where the seismically inferred models were inconsistent with the gravity data and the importance of understanding regional trends, such as those generated by the crust-mantle boundary. The modelling undertaken in this study reflects the most up to date understanding of the regional geology in this area.

3. POTENTIAL FIELD MODELLING OF MAFIC AND EXHALATIVE ROCKS IN THE GIRILAMBONE-TRITTON MINE AREA, WESTERN NSW

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Aeromagnetic anomalies of regional significance are investigated in the Coolabah 1:100 000 map sheet area (approximately 70 km east of Cobar) where regional geological mapping is being carried out by the Geological Survey of New South Wales. Drill intercepts and sparse outcrops indicate several source lithologies, including mafic schist (volcanic rocks), quartz-magnetite-hematite horizons (exhalative rocks), ultramafic intrusions, serpentinite, and late intermediate to mafic dykes. These occur within very monotonous sequences of turbiditic metasedimentary rocks which dominate the map sheet.

The magnetised features are important as they include altered mafic and ultramafic units associated with copper mineralisation in the vicinity of the Girilambone mine pits, and magnetite alteration reported at the Tritton copper mine. There is also potential for nickel or platinum occurrences associated with ultramafic rocks, for metallic mineralisation synchronous with recently-mapped exhalative rocks, and for structurally-controlled gold occurrences.

The strong gravity gradient in the southwest of the area forms part of the regional contrast between the Hume Gravity Low and the Parkes Terrace. Analysis of multi-scale edge gradients and tilt filter imagery has helped define the high gravity features which have little or no surface expression, and to locate deeply-sourced structures.

Section modelling of magnetic and gravity data (in ModelVision) highlights the dimensions and structures of the mafic, ultramafic, and quartz-magnetite-hematite rocks across the Coolabah map area. The modelling procedure has been multi-stage, with simple starting bodies adjusted after assessment of inversion outcomes. It was guided and constrained by field observations and petrophysical measurements where available. Geological mapping is increasing understanding of stratigraphic controls on local VHMS deposits, and this modelling is helping to develop the 3D concepts of regional stratigraphy and tectonics.

4. TOWARDS UNDERSTANDING THE INFLUENCE OF DATA-RICHNESS ON INTERPRETATIONAL CONFIDENCE IN IMAGE INTERPRETATION

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Geological interpretations of aeromagnetic and gravity images are highly subjective but are rarely accompanied by a quantitative confidence assessment, which is a key limitation on the usefulness of the results. This paper outlines a method with which the relative level of data richness can be assessed quantitatively, leading to an improved understanding of spatial variations in interpretational confidence. Simple rules were used to quantify the likely influence of several major sources of uncertainty. These were: 1) the level of geological constraint, using the local abundance of outcropping rock and the quality of geological mapping; 2) the interpretability of the data,

considering the strength of edge-like features and the degree of directionality of these features, a proxy for structural complexity; 3) data collection and processing errors, including gridding errors, derived from the statistical error returned during kriging, and the influence of anisotropic line data collection on the detection of gradients. From these individual sources of uncertainty an overall data richness map was generated through a weighted summation of these grids. Weightings were assigned so as to best match the result to the interpreter's perception of interpretational confidence. This method produced a map of data richness, which reflects the opportunity that the data provided to the interpreter to make a correct interpretation. An example from central Australia indicated that the data influences were preserved over a moderate range of weighting factors, and that strong bias was required to override these. In addition to providing a confidence assessment, this method also provides a way to test the potential benefits of additional data collection.

SEISMIC METHODS

5. A COMPARATIVE OVERVIEW OF VELOCITY-INDEPENDENT IMAGING METHODS

Mohammad Javad Khoshnavaz and Milovan Urosevic*
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Relatively poor performance of full pre-stack migration in hard rock seismic exploration is related to our inability to produce accurate velocity field which, is caused by complicated structures, highly variable reflectivity, and low signal to noise ratio. That is why the estimation of velocities becomes a significant problem in hard-rock environment. Consequently we wish to use imaging approaches which are loosely dependent or completely independent of the knowledge of rock velocities. To get there, we review and analyse different velocity-independent imaging techniques developed over nearly past three decades.

However, seismic imaging in complicated geological conditions often requires more than just one parameter such as accurate velocity field. Improvements of signal to noise ratio and data regularisation are typically necessary to enable construction of high resolution, high quality images. In such data, pre-conditioning should enable enhanced performance of velocity-less imaging techniques since their performance is critically dependent on input S/N ratio. The final approach, then, involves merging several techniques such are denoising, wave-field reconstruction/interpolation and velocity-independent tools together to improve image quality in hard-rock environment.

6. DEVELOPMENT OF THE HIGH SENSITIVITY MEMS ACCELEROMETER FOR OIL AND GAS EXPLORATION

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Seismic reflection survey is the main technique for exploring the underground. While the position is not expected to change in the near future, the data quality in resolution and S/N ratio is always subject of improvement. The authors have developed the high resolution MEMS accelerometer for oil and natural gas exploration. In this research, the form of a MEMS element, size and electronic circuit were modified to enhance sensitivity of a prototype of MEMS to use in a MEMS accelerometer. The MEMS sensor made as an experiment by this research surpassed –130 dB/√Hz which is the world highest ever by the performance evaluation test carried out. We are striving towards disseminating the developed MEMS sensors.

7. NATURAL HAZARD MONITORING BY INSAR ANALYSIS

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Differential InSAR(DInSAR) analysis and InSAR time series analysis were performed in Kyushu area. The data used in this study were ALOS/PALSAR images acquired from 2006 to 2011 in the Kyushu area. In the field survey, we confirmed the result of InSAR analysis, and conformity of local landslide area. As a result, the effectiveness of hazard monitoring in the wide area by InSAR analysis was clearly demonstrated through the detection of the local landslide.

8. CASE STUDY: SUCCESSFUL APPLICATION OF 3D DEPTH PROCESSING IN EROMANGA BASIN, QUEENSLAND

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The Eromanga Basin is a large Mesozoic sedimentary basin in Central and Northern Australia. It covers an area of 1,000,000 km^2 and is the location of important onshore petroleum and natural gas deposits in Australia including the nation's largest onshore oilfield at Jackson.

We performed a pre-stack time migration and later on a pre-stack depth migration sequence on a 300 sqkm block in the basin with the objective to map out intricate formations for detection of areas with high potential for gas hydrocarbon. The basin contains an ancient meteorite crater (astrobleme) which distorts seismic images, and is made of sandstone, siltstone, mudstone, coal and shale. The oil and gas producing interval is located around 1,200 m below the surface.

Vibroseis seismic data was processed through an amplitude-preserved and surface-consistent sequence followed by offset-class regularisation and pre-stack migration. Refraction and residual statics were applied to correct for near surface time distortions.

The time migrated data illustrates high signal-to-noise ratio with generally flat rock beddings with some noticeably complicated formations at known horizons, forming strong velocity boundaries. These formation oddities generally appear from Cadna-Owie (C) Formation and deeper; the Top C horizon is of significance for exploration as the top of the unit approximates a distinctive seismic reflector and is mappable over the entire basin.

During depth-velocity modelling it was revealed that there are significant velocity variations (500m/s) at Top C and other boundaries. Time imaging was not able to image these intervals properly. Depth migration improved seismic image quality especially in fault shadow zones, and areas with complex seismo-geological settings. The benefits of depth imaging on the Eromanga Basin data were demonstrated by significant uplift in

structural conformity and increased confidence in interpretation results.

9. SIGNIFICANT VSP DATA QUALITY IMPROVEMENTS THROUGH THE USE OF A BROADBAND SOURCE

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Seismic vibrators are the preferred sources for vertical seismic profile (VSP) surveys as they are relatively repeatable, controllable, have high energy, have a low environmental impact and are cost-effective. Unfortunately, due to the mechanical and hydraulic constraints of the vehicles, the typical swept bandwidth has been quite limited, typically of the order of 3 octaves. In this paper show that dramatic improvements in seismic data quality can be achieved by extending the bandwidth used for Vibroseis VSPs. These increases are reliant, however, on the use of modern vibrators, specialised low-frequency enhancing sweeps, and downhole sensors with an extended frequency response range.

10. LABORATORY MEASUREMENT OF SEISMIC VELOCITY DISPERSION IN CRACKED QUARTZITE

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Reversible fluid flow within low aspect ratio cracks is expected to cause seismic velocities in hard rock to be strongly frequency dependent. Experimental measurements are necessary to constrain theoretical velocity dispersion models in order to allow comparisons between laboratory measurements at megahertz frequencies, sonic logging at kilohertz frequencies and in-situ exploration seismic at typically 10–300 Hz frequencies, but are rare due to the complexity of low frequency measurements on core samples. Quartzite samples from Cape Sorell, Australia and Alberta, Canada are thermally cracked to induce ~2% crack porosity with aspect ratio <0.01. The shear and Young's moduli of the samples are measured at frequencies of 0.01–1 Hz and 1 MHz while the samples are dry, saturated with argon and saturated with water over effective pressures of 10–150 MPa. As anticipated, no dispersion is exhibited while the samples are dry. Similarly, no dispersion is observed while the samples are argon saturated as a result of the low viscosity and high compressibility of argon. Water saturation, however, causes significant dispersion in both the shear and Young's moduli of the samples between the low and high frequency measurements.

11. ADVANCED BOREHOLE SEISMIC ACQUISITION CHALLENGES AND SUCCESSES IN LARGE LNG PROJECT

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In this paper we will describe the operational success of largest offshore borehole seismic job which paved the way for several advance borehole seismic projects in Gorgon, Wheat-stone and other projects.

The primary objective of the survey was to obtain true vertical time-depth relation and high resolution 2D image below and around the well path for better understanding of reservoir while secondary objective was anisotropy parameters estimation to improve the reprocessing of surface seismic.

The following were the main challenges to this project:
(a) Finding a suitable boat/crane for deployment of sources at safe distance from boat hull;
(b) Acquisition sequence was switching between different surveys i.e. Walkabove and Walka-ways, which made acquisition quite complex;
(c) Finding a properly trained navigator for the job;
(d) Minimising rig time;
(e) Noise attenuation.

The followings are main conclusions and recommendations:
(a) VSP modelling was essential for survey design;
(b) Survey lines were optimised to minimise the rig time;
(c) Good prejob planning is a key of operation success;
(d) Poor coupling noise have successfully attenuated during processing;
(e) Successful acquisition of a comprehensive Walkabove & Walkaways data sets;
(f) Combined Walkabove and Walkaway VSPs and Surface Seismic helped to better under-stand the reservoirs;
(g) Integration of different data sets multiply the value of each of the elements;
(h) Reliable time, depth and velocity information was achieved from Walkabove data set;
(i) Recommendations for future acquisition work based on lesson learnt on first well.

12. ROBUST SCALING STRATEGY FOR FREQUENCY-DOMAIN ACOUSTIC FULL WAVEFORM INVERSION

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The purpose of seismic full waveform inversion (FWI) is to identify subsurface physical properties that yield waveforms similar to those of recorded data. Because subsurface physical properties are important to characterise reservoirs in oil and gas exploration, FWI has attracted the attention of geophysicists and applied mathematicians. Nevertheless, FWI is still not practical and has some problems to be resolved for real data application. One of the problems encountered when we apply FWI to real field data is noise. Because real field data contain various types of noise with non-uniform distributions, the inverse problem for real seismic data involves many uncertainties. There have been attempts to increase the robustness of FWI for noisy data by introducing new objective functions. However, most objective functions have not provided robust inversion results for the incoherent random noise, such as ambient ground motions. To minimise the influence of random noise in frequency-domain acoustic FWI, We propose a frequency-depth scaling strategy that combines the spectral scaling strategy using the denoise function and the depth scaling strategy using the constraint of the Levenberg-Marquardt method.

The inversion results for synthetic data containing low-frequency random noise for the modified Marmousi-2 model show that the denoise function is approximately proportional to the signal-to-noise ratio and effectively filters out the noisy single-frequency gradient directions. In addition, the flexible damping factor acts

like a depth filter, controlling the energy concentration in the gradient. In the early iterations, the energy of the gradient is concentrated in the shallow parts, whereas in the later iterations, the energy concentration moves to the deeper parts. The denoise function and the damping factor are determined with little human intervention and without any prior information about the subsurface structure during the inversion and improve the inversion results for data containing random noise.

13. A NEW STRATEGY FOR 2D VTI SEISMIC FULL WAVEFORM INVERSION

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We develop an inversion strategy for seismic full waveform inversion (FWI) for 2D vertical transversely isotropic media (VTI). In our strategy, we use Lamé constants (λ and μ) instead of C33 (=λ + 2μ) and C44 (=μ). For C11 and C13, we redefine them by Lamé constants and residuals between anisotropic parameters (C11 and C13) and Lamé constants. Accordingly, these residuals represent anisotropic characteristics. In FWI, we invert Lamé constants and residuals, and then we extract C11, C13, C33 and C44 from the inverted parameters.

We validate our new strategy by comparing inversion results obtained by the new inversion strategy to those obtained by the isotropic inversion and the conventional VTI inversion for a modified version of the overthrust geological model. Results obtained by the isotropic inversion are reliable only for isotropic layers. On the other hand, anisotropic layers cannot be recovered well by only λ and μ. In case of the conventional VTI inversion, C33 and C44 are well inverted. These results agree well with the isotropic inversion results. The C11 and C13 models inverted by the conventional VTI inversion are reasonable, but their resolutions are poorer than those of the C33 and C44. On the other hand, the C11 and C13 models inverted by the new inversion strategy are much improved compared to those of the conventional VTI inversion.

From these results, we note that anisotropic properties in subsurface media cannot be recovered by the isotropic inversion, whereas the developed inversion strategy can provide reasonable anisotropic characteristics. In addition, elastic parameters by the new inversion strategy are more precise and stable than those of the conventional isotropic and VTI FWIs.

14. DIFFERENTIATING BETWEEN POTENTIAL RESERVOIRS AND HARDROCK WITH A HOLISTIC QUANTITATIVE SEISMIC INTERPRETATION METHOD

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Easily recognised bright events on seismic data can infer a host of phenomena; ranging from lithology interplay to indicating lucrative prospects in relatively greenfield settings. The availability of seismic angle stacks afford the petroleum explorationist more options to reduce obviously incorrect conclusions and help to identify the more likely cases of these bright events within the seismic data. A combination of simultaneous seismic inversion and far and near angle stack comparisons gave more confident deductions on certain recognised seismic features as well as identifying potential interesting prospects to pursue and study in the context of petroleum exploration in that area. We present some examples of features that were identified on seismic data and sought to deduce their prospectivities.

15. A REVISED CHRONOSTRATIGRAPHIC FRAMEWORK FOR THE ONSHORE OTWAY BASIN, IMPLICATIONS FOR UNDERSTANDING THE EARLY DEVELOPMENT OF AN INTRA-CRATONIC RIFT MARGIN

*David Briguglio**
Monash University

This paper utilises modern reflection seismic data, surface geology and well information, including petrophysical/lithological characteristics and biostratigraphy. The aim is to construct a new chronostratigraphic framework for the Onshore Otway Basin, while answering unresolved questions about the basin's early rift history. These include the order in which individual depocentres were formed, the corresponding timing of deposition of laterally varying stratigraphic packages, and which units were confined to individual rift depocentres. The integration of stratigraphic correlations, petrophysical interpretation, drill-core descriptions, petrological/lithological analysis and biostratigraphy with interpreted seismic data resulted in the identification of at least two extra chronostratigraphic sequences. This study focused on high-resolution volumetric modelling of all stratigraphic sequences within the Otway rift system. Particular attention was paid to the Early Cretaceous stratigraphy following the identification and mapping of the two previously undocumented sedimentary sequences within the Victorian section of the basin. This led to a revised chronostratigraphic framework for the Onshore Otway Basin, which, in-turn, served to explain the relationship between fluvio-lacustrine sedimentation and tectonism during the early history of intercontinental rift systems.

16. BROADBAND PROCESSING OF CONVENTIONAL AND DEEP TOW MARINE STREAMER SEISMIC DATA

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We have developed WiBand, a de-ghosting and broadband processing method that can be applied to conventional streamer data acquired with single component streamers. We review two case studies of WiBand processing. In the first case study, data with streamers towed at different depths is used. We apply WiBand to each track independently to remove the effects of the source and receiver ghosts. We compare the WiBand results from a deep tow track to conventionally processed result from a shallow tow track to validate the phase fidelity of the de-ghosting process. We conclude from the results that WiBand correctly removes the ghosts and recovers broadband data from deep tow streamer data. In the second case study, we compare inversion results from conventional processing and WiBand processing, and observe improved correlation with well logs.

17. SUB-SEGMENTATION WAVEFORM ANALYSIS INTERGRATED WITH WELL CONTROL: CASE HISTORY ONSHORE CANNING BASIN (BUNDA 3D SEISMIC SURVEY)

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Improved seismic acquisition and processing techniques are producing ever more detailed and higher quality seismic 3D volumes. To realise the full potential of this data, seismic interpreters are integrating new technologies that utilise 'global' interpretation methods into their existing workflows.

In this paper we demonstrate the guided sub segmentation of waveforms automatically extracted using genetic algorithms inspired by the Human Genome Project. These maps are validated and calibrated with the 22 wells tied within the Bunda 3D Seismic survey. The calibrated maps are used to help understand the structure and stratigraphic aspects of the past and present successful and unsuccessful drilling results.

Using automated pre-interpretation to extract all surfaces enables the review of large amounts of data rapidly and in an unbiased manner. Further sub segmentation analysis of these populations of genetically similar waveforms enables targeted analysis of reservoir seal pairs at multiple target zones. This approach has enabled a rigorous and time efficient method of analysing large volumes of data revealing new insights about remaining opportunities within the production license.

18. TOP SEAL EFFICIENCY OF THE LAKES ENTRANCE FORMATION, GIPPSLAND BASIN: SOME CONSTRAINTS FROM SEISMIC INVERSION AND ATTRIBUTES

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The Gippsland Basin is a potential site for CO_2 storage which is dependent on the regional top seal in providing secure subsurface containment. Earlier investigations confirmed the containment potential although natural leakage of hydrocarbons was locally noted as a concern to containment security. This study provides further insight to top seal efficiency using 2D seismic attributes along the southern flank of the basin.

An important factor in top seal efficiency is the spatial variation of its shale content. The empirical relationship between acoustic impedance and shale content was used to estimate Vsh from seismic inversion and other seismic attributes in the study area. Eight 2D lines with a well control were selected with amplitude preserved, post-stack time migrated data. At each well, composite seismic amplitude and acoustic impedance traces were constructed to establish a tie with the well-derived reference Vsh. Using a multi-attribute regression analysis, a transformation was established from seismic attributes and impedance to Vsh and used to define Vsh pseudo-traces and vertical profiles. The Vsh samples for the top seal were averaged to achieve a mean and interpolation of this data set revealed the first order trend in the spatial variation of the Vsh.

The top seal efficiency is also related to seal integrity which could be undermined by faults. Spectral blueing and attributes were used to achieve a fault interpretation at the limit of seismic resolution. A blueing operator was designed to shape the post-stack seismic amplitude spectrum to the amplitude spectrum of the logs to increase the high frequencies in the data. A meta-attribute that sharpens the faults and suppresses non-fault discontinuities was designed and similarity attributes were applied to detect faults. Automated mapping of the faults provided fracture density maps which depict the intensely deformed areas with potentially decreased seal efficiency.

19. EFFECTS OF VERTICAL VELOCITY HETEROGENEITY ON STACKING VELOCITY AND DEPTH CONVERSION

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Each layer of rock or sediment has its own velocity, that is, there are different velocities along the subsurface layers of the earth. Moreover, each layer has various values for different types of velocity. Therefore, the suggestion raised was to study the effects of vertical velocity heterogeneity on stacking velocity and depth conversion with different spread lengths, i.e., a small spread with a maximum offset of 2000 m and a large spread with a maximum offset of 4000 m. This study focused on the variation between stacking velocity and average velocity. In addition, the traveltime equation of Taner and Koehler (1969) for two terms and three terms was examined in order to find out which one provided better results.

Understanding the variations between the different types of velocities was crucial to this approach, which was carried out using data from the Tirrawarra-29 well in the Cooper Basin, South Australia. Well log data are used to calculate different types of velocities such as average velocity, root-mean-square velocity (for both short offset and three terms) and stacking velocity.

The results for both the T-X plots and the T^2-X^2 plots for small (2000 m) and large spreads (4000 m) proved that the variation between average velocity and stacking velocity increases with offset. Furthermore, using the traveltime equation for three terms on the residual moveout plots for small and large offsets provided better results than using only two terms.

UNCONVENTIONALS

20. UNCERTAINTY IN SURFACE MICROSEISMIC MONITORING

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Uncertainty in a migration based approach to surface and near surface microseismic monitoring occurs in two ways: uncertainty in the validity of detected events and uncertainty in the estimated position of the event. Synthetic modelling and comparison to case studies show that sign-to-noise-ratio is a key indicator of both types of the uncertainties.

In this paper we present an analysis of both types of uncertainty using synthetic modelling to illustrate the performance characteristics of the migration process in terms of signal detection and false-alarm rates, along with uncertainties in positional estimates. Examples from two case studies will illustrate that this kind of performance is achievable in actual monitoring surveys.

Signal-to-noise-ratio (SNR) is a key indicator of the uncertainty in migration based imaging of microseismic events. Reliability, in terms of the ability to detect the complete set of events is a nearly binary function of SNR. Events with SNR above a threshold of 2-3 are readily detected, while events with SNR below the threshold are missed. Positional uncertainties likewise are driven by SNR. While vertical uncertainty is more sensitive to noise, both horizontal and vertical uncertainties decrease rapidly with increasing SNR.

21. CONTINUOUS LAND SEISMIC RESERVOIR MONITORING OF THERMAL EOR

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A permanent reservoir monitoring system has been installed for Shell, on a medium heavy-oil onshore field situated in the NE of The Netherlands, in the context of re-development of oil production by Gravity Assisted Steam Flood. The challenge was to continuously monitor with seismic reflection the lateral and vertical expansion of the steam chest injected in the reservoir during production over more than a year.

The main problems for onshore time-lapse are caused by near-surface variations between base and monitor surveys which affect the seismic signal coming from the reservoir. Here, a set of permanent shallow buried sources and sensors have been installed bellow the weathering layer to both mitigate the near surface variation and minimise the environmental footprint. The very high sensitivity of our buried acquisition system allows for the detection and mapping of tiny changes within the reservoir on a daily basis and permits to follow very small variations of the reservoir physical properties in both spatial and calendar domains.

The 4D reservoir attributes obtained from seismic monitoring fit the measurements made at observation, production and injector wells (pressure, temperature and oil/water production).

'4D movie' if the reservoir properties allows proposing a scenario which explains the unexpected behaviour of the production and confirms that the steam does not follow the expected path to the producer wells but rather takes a more complicated 3D path within the reservoir.

ELECTRICAL METHODS

22. EVOLUTION OF TEMPEST

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Fugro Airborne Surveys

Since its inception in 2000, TEMPEST, a fixed wing time domain electromagnetic (TDEM) system, has been used in mineral, environmental and groundwater exploration and regolith and salt mapping. The versatility of the system can be attributed to its broad operational bandwidth, multifaceted software approach and distinctive calibration technique which allows both early and late time ground response to be imaged.

In the last decade the system has undergone a range of hardware and software developments with the aim of satisfying the changing landscape of geophysical exploration. Recent developments have resulted in improved system compensation, spatial resolution and noise levels which have helped further expand the systems applications.

Forward and inverse modelling results and survey data are used to demonstrate the impact of recent developments on enhancing the systems ability in a range of geophysical environments and exploration targets.

23. ELECTRICAL GEOPHYSICS OF CARBONATE MOUND SPRING COMPLEXES OF THE SOUTH-WESTERN GREAT ARTESIAN BASIN

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Artesian mound springs occur along the south-western edge of the Great Artesian Basin, in northern South Australia, but their underground structure and relationship to faulting is not well understood. We have performed geophysical surveys over three different systems using a range of techniques: early-time TEM, self-potential, and magnetotellurics.

The self-potential data contains a local response due to specific spring vents, and also a broader stronger response due to laterally extensive upwelling in the lower part of the Bulldog Shale, at depths of approximately 100 m. Modelling of TEM and magnetotelluric data show that the confining Bulldog Shale, which is generally very conductive, contains resistive areas underneath springs and spring complexes which are believed to be related to spring-related carbonate deposition. Magnetotelluric modelling in particular indicates that anisotropic resistivity in the form of vertical sheets at a depth of 100 to 200 m, can explain the observations more readily than a conductive 2D feature, suggesting that the structures underlying the springs are sets of closely-spaced faults. The orientation of this anisotropy matches the regional NNW/SSE orientation of spring complexes.

24. FORWARD MODELLING FLUID FLOW USING 2-DIMENSIONAL ELECTRICAL ANISOTROPY

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Electrical anisotropy, defined as the directional dependence of electrical conductivity within a medium, causes changes in the electromagnetic signal measured by magnetotellurics (MT) and as such is an important property to consider when interpreting MT data.

This study concentrated on replicating the MT response measured at two distinctively different geological settings using a series of 2-dimensional anisotropic forward models.

Results presented in this study show that 2-dimensional anisotropic forward modelling is able to account for subtle differences in subsurface anisotropic resistivity structures.

Specifically, 2-dimensional anisotropic forward modelling is able to reproduce the measured difference in MT response between pre- and post-fluid injection conditions at the Paralana Geothermal System using an anisotropic fluid volume.

These findings provide a case supporting the use of 2-dimensional anisotropic forward modelling as a means of modelling changes caused by the flow of a fluid through the crust.

25. 3D MT DATA MODELLING USING MULTI-ORDER HEXAHEDRAL VECTOR FINITE ELEMENT METHOD, INCLUDING ANISOTROPY AND COMPLEX GEOMETRY

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We will present the progress made on the development of a computational algorithm to model 3D Magnetotelluric data using Vector Finite Element Method (VFEM). The differential equations to be solved are the decoupled Helmholtz equations for the secondary electric field, or the secondary magnetic field, with a symmetric conductivity tensor. These equations are modified to include anisotropic earth and complex geometry (such as surface topography, and subsurface interfaces). The primary field is the solution of an air domain, homogeneous half-space or layered earth.

This study will compare the application of two boundary conditions, the Generalise Perfect Matched Layers method (GPML) versus Dirichlet boundaries. Dirichlet boundary conditions are applied on the tangential fields, assuming that the boundaries lie far away from the inhomogeneous model. The GPML scheme defines an artificial boundary zone that absorbs the propagating and evanescent electromagnetic fields, to remove boundary effects (Fang, 1996).

In this algorithm, high order edge elements are defined based on covariant projections for hexahedral elements (Crowley, et al., 1988). The vector basis functions are defined for the 12 edges (linear) element, 24 edges (quadratic) element, and 48 edges (cubic) element. By this definition, the vector basis will have zero divergence in the case of rectangular elements and relatively small divergence in the case of distorted elements. They are defined to study their numerical accuracy and speed, and to see if the divergence correction is automatically satisfied.

MINERALS – DEEP EXPLORATION

26. MACQUARIE ARC AND THE LACHLAN OROCLINE HYPOTHESIS: MAGNETIC ANALYSIS AND DEVELOPMENT OF GEOLOGICALLY CONSTRAINED FORWARD MODEL OF LITHOSPHERIC MAGNETISATION

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Potential field analysis, with focus on magnetic interpretation is ideally suited to geological problems where the targets are deep, totally undercover, or when there is little or no outcrop available for mapping or sampling. In these scenarios understanding the location, orientation and relationships between deep geological structures is the key to developing a clear picture of an areas tectonic history.

In this project, we conduct a comprehensive magnetic analysis of the Lachlan Orocline and Macquarie Arc, both located in the Lachlan Orogen, eastern Australia to test the potential relative rotation of this block to the surrounding units. These results are compared with palaeomagnetic data from the region and a series of geologically constrained crustal-scale forward models of lithospheric magnetisation for the project area, with focus on the large-scale structural components of the Lachlan Orocline.

The forward model method treats each geological unit present in both the Macquarie Arc itself and the surrounding areas as independent parameterised stratigraphic units. Using a Geographical Information System (GIS) approach, known geological, structural and physical properties are used to produce a series of vertically integrated value grids. These grids are then used as input to model the regional magnetisation in the global scale magnetic field forward model.

27. A REGIONAL SCALE FIXED-WING TDEM SURVEY OF THE PALAEO-PROTEROZOIC BRYAH BASIN, WESTERN AUSTRALIA: PROVIDING INSIGHTS INTO A GEOLOGICAL SETTING HIGHLY PROSPECTIVE FOR VMS CU–AU AND MESOTHERMAL AU SYSTEMS

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The Bryah Basin is part of the Capricorn Orogen, a collision zone between the Archaean Pilbara and Yilgarn Cratons in western Australia. The Basin is host to significant mineralisation, including mesothermal orogenic gold, copper–gold volcanogenic massive sulphides. Among the challenges in the exploration for these mineral systems is the paucity of outcrop and the extent and variability of a complex regolith cover. To better understand this regolith, a reconnaissance, regional-scale, fixed-wing time domain AEM survey was undertaken over the Bryah Basin in 2012. The resulting data were inverted using a smooth model layered earth inversion. In

this paper we compare results on mapping regolith variability obtained from the full inversion of the AEM data against that defined from the fast approximate transform of the same data set. The inverted data show the most dominant regolith features are associated with sediment filled palaeovalleys. The regional regolith framework determined from this study provides a basis for better understanding and interpreting an extensive regolith geochemical data set with respect to metalloid anomalies linked to buried Cu-Au mineral systems

28. CRUSTAL FLUID PATHWAYS IMAGED USING MAGNETOTELLURICS – IMPLICATIONS FOR THE SOUTH AUSTRALIAN HEAT FLOW ANOMALY

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The global demand for clean energy alternatives is constantly increasing, creating significant interest for more sustainable energy resources such as uranium and geothermal. Australia is host to over 25% of the world's known uranium resources as well as having significant geothermal potential. The Mount Painter Domain, in the Northern Flinders Ranges in South Australia, is in a region of anomalously high heat flow generated by radiogenic decay of uranium and thorium rich granites. Two distinct uranium deposits have formed from dissolved uranium carried from the ranges by fluids, being deposited where reduction in sediment pH precipitates uranium. In May 2012 a magnetotelluric profile was collected, extending from the Northern Flinders Ranges to the Lake Frome embayment to help constrain existing resistivity models. Precipitation of uranium at the Beverley Mine site is anomalous as no surface water flow is present, suggesting the presence of subsurface processes. This pathway is linked to a 50 ohm.m conductive body at the brittle-ductile boundary of the mid-crust, directly under the Paralana geothermal prospect. 3D modelling of the Paralana geothermal prospect suggests deep conductive features connecting with features at the surface.

29. POTENTIAL FIELD MODELLING OF VHMS AND SEQUENCES IN THE CAPTAINS FLAT AREA, NSW

*Astrid Carlton**
Geological Survey of NSW

The Geological Survey of New South Wales has commenced 2nd edition geological mapping of the Captains Flat area, southeast of Canberra. This project is a southern extension to the recently completed mapping over the Braidwood 1:100 000 and Goulburn 1:250 000 scale map sheets. Silurian Devonian extensional basin sequences, within the Braidwood and Goulburn sheets, extend into the Captains Flat area. The basin sequences are known to host economic Zn, Cu and Pb VHMS mineralisation (e.g. Woodlawn, Currawang, Captains Flat). The Captains Flat area has syn-rift middle- to late Silurian sequences consisting of felsic and intermediate to mafic centres. Sequences dominated by Ordovician turbidites (Adaminaby, Bendoc and Margules groups) have been faulted to the surface on the eastern limbs of the basin. The preserved sequences at Captains Flat have been interpreted by geologists to form a highly-deformed, folded, east-dipping syncline that has been heavily faulted. These sequences appear in TMI imagery as curvilinear, near-parallel anomalies.

Potential field modelling of aeromagnetic data acquired under the NSW Government's New Frontiers initiative is underway. The models are geologically constrained and will aid geological interpretation. Preliminary models for magnetic sources indicate discontinuous steeply-dipping bodies. Modelled sources, interpreted as Captains Flat Formation, are generally 200 m wide with susceptibilities of 2-5 – 10-3 SI. The Kohinoor Volcanics, which host the larger VHMS deposits in the area, have a similar width and dip but have a higher susceptibility of approximately 10 – 10-3 SI. In contrast to the Silurian sequences, formations in the Ordovician sequences (within the Margules and Bendoc groups) have negative anomalies and the modelled sources are generally wider. As yet the hinge for the syncline is not evident, indicating that it could be located at a greater depth than is resolvable.

58. ASSESSING THE CALIBRATION OF THE SYDNEY BASIN THERMAL STRUCTURE MODEL – ARE SHALLOW GROUNDWATER BORES A GOOD SUBSTITUTE FOR DEEPER MEASUREMENTS

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Estimating subsurface temperature and assessing the thermal structure in numerical models requires a vast database of measured values, a detailed geological model and the ability to identify, incorporate and constrain uncertainty in the parameters to provide a reliable and robust result. Sparse datasets with limited results required additional observables to be gathered. Using groundwater bores temperature in the shallow crust can be measured over a widely distributed area and in depth profiles. Calibration of the Sydney Basin thermal model has shown that using shallow groundwater bores strong constraints on parameters can be made, thus reducing overall model uncertainty. Deep measurements are limited therefore shallow groundwater bores are a good data substitute. The largest sources of uncertainty are the parameters governing temperature dependent thermal conductivity of the basement and Permian Coal Measures, as well as the basal temperature condition and unconstrained heterogeneities in the basement rocks. Variance in these parameters may significantly influence the resulting estimate of subsurface temperature. However through calibration the possible variance is limited due to the large number of available calibration points.

Key words: thermal structure, temperature, calibration, groundwater, numerical simulation, Underworld.

HARD ROCK SEISMIC

30. DIRECT MINERAL TARGETING THROUGH SEISMIC IMAGING IN HARD-ROCK ENVIRONMENTS

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Based on physical property measurements of core samples and the often observed difference in elastic properties from these there should be a significant difference in seismic amplitude

between mineralisation and the surrounding host rocks. These results indicate that relative amplitude preservation processing may be of importance in the use of seismic data for the targeting of mineral resources, particularly in the case of massive ores. Such 'true amplitude' processing is not easy to achieve due to intrinsically low signal to noise ratio in hard rock environments, complex 3D geology, steeply dipping structures, high seismic velocities and often patchy and poor reflectivity.

To help reduce the ambiguity in targeting and increase the likelihood of success we have worked on careful re-processing of 3D seismic data with the application of true amplitude preservation. We compare the anomalous amplitude zones that are related to massive sulphide bodies using a true amplitude seismic cube and a conventionally processed cube with the application of AGC (automatic gain control). A higher level comparison is conducted after seismic calibration with boreholes and an acoustic impedance inversion is calculated. The zonation and precision of targeting is discussed in this paper.

31. SEISMIC ANISOTROPY IN CRACKED CRYSTALLINE ROCK FROM OUTOKUMPU, FINLAND

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Lattice and shape preferred orientation of minerals, along with aligned fractures and microcracks, is expected to cause significant seismic velocity anisotropy in crystalline rocks. As seismic surveys in hard rock environments become more common, quantifying and accounting for this anisotropy in seismic processing becomes increasingly important.

Outokumpu, Finland is the site of a historic base metal mine and is a classical ore province known for its Cu-Co-Zn sulphide deposits. The 2.5 km deep ICDP borehole shows the lithology in the area of the Outokumpu 2006 2D seismic survey to be primarily composed of a biotite-rich schist. Three walk-away VSP profiles were used to quantify the tilted orthorhombic in-situ anisotropy. Laboratory measurements of the qS1, qS2 and qP waves along the axial directions and in select off-axis directions at confining pressures from 10–200 MPa, and effective medium modelling were used to further inform the seismic anisotropy of the schist. Strong anisotropy is observed both in-situ and on the laboratory measurements, and a 3D velocity distribution is calculated from modelling of these results.

32. IMAGING BAUXITE LAYER USING THE HIGH-RESOLUTION SEISMIC REFLECTION METHOD

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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 aluminium present. The economic importance of extracting aluminium 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 5m. 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.

33. IMPROVING TIME-LAPSE SEISMIC REPEATABILITY: OTWAY SITE PERMANENT GEOPHONE ARRAY FIELD TRIALS

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The proposal for Stage 2C of the Otway project involves injection of a small amount (around 10,000 tonnes) of CO_2/CH_4 gas mixture will be injected into Paaratte formation at a depth of ~1.5 km. The seismic time-lapse signal will depend largely on the formation properties and the injection scenario, but is likely to be relatively weak. In order to improve time-lapse seismic monitoring capabilities by decreasing the noise level, a buried receiver arrays can be used. A small-scale trial of such an array was conducted at Otway site in June 2012. A set of 25 geophones was installed in 3 m deep boreholes in parallel to the same number of surface geophones. In addition, four geophones were placed into boreholes of 1 to 12 m depth. In order to assess the gain in the signal-to-noise ratio and repeatability, both active and passive seismic surveys were carried out. These experiments were accompanied by acquisition of VSP data in CRC-1 borehole using 24-channel hydrophone string. The surveys were conducted in relatively poor weather conditions, with rain, strong wind and thunderstorms increasing the noise level. We found that noise level for buried geophones is on average 20 dB lower compared to the surface ones. Furthermore, the combination of active and passive experiments has allowed us to perform a detailed classification of various noise sources.

34. 3D SEISMIC RESPONSE OF COMPLEX HARD ROCK GEOLOGICAL STRUCTURES

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Seismic response of excessively complex geological structures, as typically found in hard rock environments, is poorly understood. 3D seismic surveys are still rare in mineral sector and typically lack correlation with borehole logging. Intrinsically low signal to noise ratio, poor reflectivity and regolith heterogeneities present additional challenge for understanding seismic response and subsequent formation of geologically

meaningful images. It is therefore of interest to use numerical simulations to understand what type of information can surface seismic provide in a complex hard rock environment, what are the likely pit faults in velocity analysis, migrations artefacts and what can be confidently imaged with current technology. To evaluate these tasks the numerical experiments will be based on best known mineral deposits in Australia and worldwide. One such case is the mineral prolific Kambalda dome in Western Australia. To evaluate the seismic response we constructed a physical model that represent geological setting typically found around the dome and conducted post and full pre-stack 3D seismic modelling experiments. Pre stack geometry was based on several 3D seismic surveys conducted in Kambalda region. We analyse the data to understand the seismic response and associated imaging issues of such complex structures. We then decimate the data to come up with a 'poor man' 3D geometry that would still provide data of sufficient quality for mineral exploration objectives. Such approach could make seismic 3D methods more accessible to mineral industry.

AIRBORNE EM

35. AN ASSESSMENT OF 3D ZTEM RESULTS OVER THREE DEPOSITS

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The ZTEM airborne EM system was introduced by Geotech Ltd. into commercial service in 2008. Based on measuring the tipper ratios of AFMAG frequencies, ZTEM provides conductivity information about the earth's near surface that can assist in the exploration for a variety of mineral deposit styles. The results of surveys over three deposits will be examined; a skarn-style or carbonate replacement deposit in Mexico, a porphyry copper deposit in British Columbia and an epithermal precious-base metals deposit in the Yukon. For each study, both 2D and 3D processing has been undertaken and the outcomes evaluated in light of known geology. A simple technique will be discussed which has been developed to assess data sets to establish whether or not 3D processing (which requires more time and hence more costly) is required.

36. DELINEATING THE KITUMBA IOCG DEPOSIT WITH THE ORION 3D DCIP/MT

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An ORION 3D DC/IP survey was conducted over Blackthorn Resources™ Kitumba IOCG deposit in Zambia. The survey results provided 3D models that successfully delineated the known deposit and provided an enhanced understanding of the three-dimensional geometry of the mineralisation. With this improved understanding of their deposit, Blackthorn was able to refocus their ongoing drilling program to best target possible extensions of the existing mineralisation.

37. DEVELOPMENTS IN FREQUENCY DOMAIN AEM; TACKLING DRIFT AND NOISE WITH A MULTICOMPONENT, FERRITE-CORE, RECEIVER TRIPLET

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The polar oceans sea ice cover is a challenging geophysical target to map. Current state of practice helicopter-electromagnetic (HEM) ice thickness mapping is limited to 1D interpretation due to common procedures and systems that are mainly sensitive to layered structures. We present a new generation Multi-sensor, Airborne Sea Ice Explorer (MAiSIE) to overcome these limitations. As the actual sea ice structure is 3D and in parts heterogeneous, errors up to 50% are observed due to the common 1D approximation. With MAiSIE we present a new EM concept based on one multi frequency transmitter loop and a three component receiver coil triplet without bucking The small weight frees additional payload to include a line scanner (lidar) and high accuracy INS/dGPS. The 3D surface topography from the scanner with the EM data at from 500 Hz to 8 kHz, in x, y, and z direction, will increase the accuracy of HEM derived pressure ridge geometry significantly. Experience from two field campaigns shows the proof-of-concept with acceptable sensor drift and receiver sensitivity. The preliminary 20 ppm noise level @ 4.1 kHz is sufficient to map level ice thickness with 10 cm precision for sensor altitudes below 13 m.

59. EXPLORING MODEL SPACE VIA 1D EXTREMAL INVERSION OF AIRBORNE TEM DATA: DETERMINATION OF DEPTH AND CONDUCTIVITY BOUNDS OF SEAWATER AND SEDIMENT IN SHALLOW COASTAL WATERS

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The aim of extremal inversion is to construct models with maximal or minimal characteristics, but which nonetheless fit the observed data acceptably well. Given one model which fits the data, extremal inversion enables the user to explore the permissible range of model parameters, hence determine parameter uncertainty. A 1D extremal inversion algorithm has been developed for horizontal loop TEM. Extremal inversion is effected via linear programming. The objective is maximisation or minimisation of a particular layer conductivity or depth. Bounds (on conductivity or depth) can be imposed explicitly as inequality constraints. Extremal models can differ markedly from the first model which fits the data. Extremal inversion is non-linear and is not confined to a neighbourhood which is "linearly close" to the first model. As an example of the application of this method, 1D extremal inversion is applied to airborne TEM data acquired over shallow seawater to determine upper and lower bounds on depths of seawater and bedrock and on conductivities of seawater and marine sediment. The results compare favourably with available ground truth data. Estimates of parameter uncertainty derived from extremal inversion are as follows: ±0.6 S/m for seawater conductivity, ±0.2 S/m for sediment conductivity, ±0.7 m for seawater depth, and ±8 m for bedrock depth.

ENGINEERING – ENVIRONMENTAL

38. TOWED TRANSIENT ELECTROMAGNETIC SURVEY USING VARIOUS LOOP CONFIGURATIONS

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Towed transient electromagnetic (TEM) survey, coupled with resistivity modelling software is an effective method of detailing small scale groundwater conceptual models and assisting with near surface geological investigations. Practical investigation depth ranges from 1 m to 100 m or more given the restrictions of today's electronics and practical trailer dimensions.

Towed TEM survey using loops on trailers behind land vehicles or boats may be conducted using various loop configurations. Due to the loop area and separation requirements of loops from each other and from towing vehicles, design of trailers and/or sleds must be tightly integrated with design of loop configurations. Although separated loops (slingram configuration) are good for avoiding mutual inductance problems and may permit exploration to maximum possible depth, they are difficult to tow, especially around corners. Alternative arrangements with overlapping loops or bucking coils, all on a single platform, permit design of more practical platforms. On such platforms, not only must mutual inductance of coils be minimised but practical means of minimisation are limited by achievable dimensional accuracy and stability of towed platform designs. Design is further restricted by the need to avoid use of metallic materials in most places and the need to separate and/or de-couple the metal survey vehicle from the loops.

Case studies showing results of survey conducted with various platforms will be presented.

39. SPATIO-TEMPORAL VARIATIONS IN FLOODPLAIN SOIL/SEDIMENT CONDUCTIVITY: GREAT DARLING ANABRANCH

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Spatio-temporal information on the distribution of salt in floodplain soils and groundwater is integral to effective floodplain management strategies along the Great Darling Anabranch in NSW. It is particularly important as an aid to our understanding of the links between surface flow manipulation, groundwater pumping and artificial recharge on soil salinity and floodplain vegetation health. Geophysical technologies have the potential to provide detailed spatial information on the variability of salt stored in the near surface and for monitoring surface water -groundwater interactions across the floodplains, and in particular looking at the spatial controls on those processes. The research sought to examine the role of hydrogeophysical methods in monitoring changes in floodplain sediment condition, linked to ecological investigations.

A two stage investigation, to examine the role of a low cost, near surface, geophysical method for monitoring changes across several sites located adjacent to the Great Darling Anabranch in NSW. It represented a short term spatio-temporal investigation of inundation on salt in the floodplain either in response to flooding or environmental flows.

The results clearly show changes in the conductivity distribution at the sites surveyed. These changes can be attributed to variations in the flows over the year, pumping of groundwater and changes in vegetation.

The survey showed that EM techniques are a useful tool in aiding our understanding of floodplain processes resulting from changes in flows along the Anabranch and could be applied in other floodplain environments as a low cost survey to observe changes in conductivity in the near surface.

It is an effective method to monitor variations in conductivity in the floodplains due to changes in environmental flows and can aid in understanding changes in sediment conditions and can be used to validate floodplain processes, contributing to ecological investigations of river floodplains.

40. SEISMIC AND GEOELECTRIC STUDY OF THE BASALTIC SEQUENCE IN THE SOUTH OF AL-MADINAH

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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.

41. MAPPING SHALLOW GROUNDWATER AQUIFER BY PERFORMING HIGH-RESOLUTION SEISMIC REFLECTION TECHNIQUE IN WADI NISAH

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This study was carried out in Wadi Nisah in south-west of Riyadh, Saudi Arabia, at latitude of 2of 24° 14′ 28″ N and longitude of 46° 29′ 59″ E. The main objectives of this study are to investigate the depth of the shallow groundwater aquifer and the geological structures that could affect the ground water bearing layer in the area. Six 2D seismic lines were acquired in the study area. Since the complex subsurface structure of the area, a high-resolution seismic reflection technique was performed along the lines and one metre spacing between the receivers was applied. The seismic sections revealed that the depth of the water bearing layer lies in the range of 100 m to about 240 m. In addition, the results show faulting that affect the surface of the water bearing layer in the study area. We have

found that high resolution seismic reflection Technique can be an effective method for determining water bearing layer depth in study area. This formation is correlated with Biyadh Formation as confirmed by the drilled near water wells.

42. SEISMIC MICROZONATION OF EARTH'S SURFACE LAYERS USING BOREHOLE DATA AND SHEAR WAVE VELOCITY ANALYSIS CASE STUDY; GORGAN, IRAN

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The most important factors in an earthquake are the casualties and financial losses, therefore it can help city managers to be ready before the events by a good simulation of what can happen in such disaster and recognising vulnerable regions and consequently estimation of the amount of casualties and damages. Accordingly, one of the most important steps in developing Gorgan's earthquake scenario was estimation the amount of destruction after the earthquake. Beside the site study, site effects study performs an important role in determining the amount of destruction after earthquakes. Our data for site study condition in Gorgan were: log data available in the offices, field study and geological reports, and soil geotechnical tests done by some special housing projects and urban development organisation, used as important information in the Gorgan's earthquake scenario process. Fortunately, bores that we used have an appropriate distribution in the city, in a manner that we could study site conditions in Gorgan by relying on their information. After that we modelled the bore loges information in Pro-Shake, and then we selected and applied a referenced accelerogram which used to calculate shear wave velocity, displacement and acceleration on Earth's surface for output. In comparison of input accelerogram and output accelerogram we can find site amplification factor in a given point. By calculating this ratio in the centre of squares with 250*250 metres dimensions, site amplification zoning map in the Gorgan region was provided, which was one of the information layers in developing of Gorgan earthquake scenario.

43. THE 2012 NEWCASTLE AND SYDNEY SPAC MICROTREMOR SURVEYS USING GEOPSY SOFTWARE AND COMPARISONS

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Since the 1989 Newcastle ML5.5 earthquake, the city of Newcastle, Australia, has become a focus for earthquake risk assessment. Surficial geology in the area varies from deeper alluvial deposits near the Hunter River, to shallower soils overlying weathered rock on the valley margins. Ambient vibration techniques, based on the dispersion property of surface waves in layered media, are promising for assessing the subsurface geophysical structure, in particular the shear-wave velocity (Vs). Using one such technique, the Spatial Auto-Correlation (SPAC) method, we characterise soil deposits at 23 sites in and around the city of Newcastle. Results show that values for soil overlying bedrock ranges from 200 m/s to 1000 m/s, with the higher velocity values observed in shallow soils which are relatively consolidated and distal to the river. Bedrock depth varies from 6 to 56 m, but an accurate quantification is hampered by the low frequency picks (< 2 Hz) which are either unavailable or of dubious quality. Some Vs profiles show two abrupt changes, the first at ~4–15 m depth and the second ~19–56 m. Low Vs values are of particular interest as they may indicate areas of higher seismic hazard.

44. EFFICENCY OF MASW IN DETECTING NEAR-SURFACE CAVITIES

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The purpose of this study is to evaluate the efficacy of using multichannel analysis of surface wave (MASW) to detect the near-surface cavities. The methods used in this study include interpreting dispersion curves and amplitude mapping of the multichannel analysis of surface wave technique and interpreting the delay in first arrivals of compressional waves. To test these methods, a seismic survey was conducted above a known near surface cavity in Al-Suman Area, Saudi Arabia. The cause of the cavity is carbonisation in the area; there are many cavities similar to this one. The seismic data were collected using a seismograph system with 48 vertical geophones. Both techniques show a tangible result for detecting the cavity. The 2D section of shear wave velocity, which was obtained by inverting the dispersion curves from the MASW technique, leads us to determine the shape of the cavity, as described by a low-velocity zone. Frequency against relative offset is plotted and shows a significant frequency drop in the presence of the cavity, which also provides an indication to the presence of cavity underneath. This interpretation is matched by the interpretation of observed delays in first arrivals of compressional waves. The integration of both P-wave seismic refraction and MASW gives confidence in the result and matches observations of the existing cavity closely.

INVERSION AND IMAGING

45. EFFECTIVE METHODS TO HIGHLIGHT AND DELINEATE ANOMALIES FROM GEOPHYSICAL IMAGES

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Geophysical data interpretation is largely an anomaly detection task which involves recognising and synthesising anomalous patterns within single or multiple datasets. The accuracy and efficiency of these interpretations heavily relies on the skills and practices of interpreters, thus the greatest challenge is to minimise personal biases to produce objective and consistent interpretation outcomes. We present an innovative data visualisation method which can empower interpreters to effectively delineate anomalies of varying frequency scales within aeromagnetic data using a single image display. This is achieved by harnessing the power of image enhancement and visualisation techniques to assist interpretation.

We adapted and extended the use of colour composite techniques to present different frequencies presented in potential field data. Aeromagnetic data from an area in Kirkland Lake, Ontario, Canada is used for our experiment. Long wavelength and short wavelength anomalies are identified from the data using low pass- and high pass filters respectively. These two different frequency enhanced images and the original image are

represented as separate colour channels which are then combined to generate a composite image. The luminance of the composite image is scaled to highlight high frequency signals as they hold the key for detailed structure interpretation. We use a technique called dynamic range compression, which preserves the integrity of the phase component of the signal while performing high pass filtering. The resulting display is compared to the geological map of the area to validate the effectiveness of the method. The proposed technique is widely adaptable for different types of datasets.

46. BOOTSTRAPPING AS A MEANS OF SOLUTION ENSEMBLE BASED UNCERTAINTY ANALYSIS IN GEOPHYSICAL INVERSION MODELLING

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Many geophysical models are created without satisfactory uncertainty analysis. Most geophysicists are aware of their models limitations, but if the model is passed on to a third party, this information is lost and the risk of misinterpretation arises.

This project develops multi-solution inversion techniques to improve inversion and joint inversion modelling of geophysical data in mineral exploration. The main focus is the advancement of the probability and uncertainty analysis of inversion models to increase their reliability.

To create solution ensembles, a bootstrapping resampling approach is taken, which produces reduced data sets from a base data set by random omission of data points. Each of these new data sets is run through a conventional inversion process to produce a variety of solutions with minor variations.

In the appraisal stage the solution ensemble is statistically analysed to infer model uncertainties, which are then visualised to allow easy communication of the results. The process yields a clear and easy to interpret uncertainty map for the connected model and we demonstrate its effectiveness with several case studies.

Furthermore, we are currently investigating swarm intelligence based global search algorithms as a second approach to solution ensemble creation.

47. GEOPHYSICAL AND VOLCANOLOGICAL INSIGHTS INTO THE SUBSURFACE MORPHOLOGY AND ERUPTIVE HISTORIES OF COMPLEX MAAR VOLCANOES WITHIN THE NEWER VOLCANICS PROVINCE, WESTERN VICTORIA

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In order to better characterise the eruptive histories and the subsurface structures of maar volcanoes, forward and inverse geophysical modelling has been combined with a detailed study on the geology of the volcanic centres. The maar volcanoes under investigation include several maars within the Red Rock Volcanic Complex (RRVC), Ecklin maar the Mount Leura Volcanic Complex (MLVC) and Anakie.

High resolution gravity and magnetic data was acquired across each of these maars in a series of cross-cutting traverses and the data was subsequently modelled in two and three dimensions to understand the subsurface morphology of the volcanic vent and its feeder dykes. Models of the maars subsurface structures were constrained by the regional geology, pyroclastic deposits, petrophysical properties and the interpretation of gridded geophysical data.

Varied geophysical responses are observed across each of the maars surveyed, indicating the complex and variable nature of the subsurface volcanic vent, even when they are similar in surface morphology. Where corresponding gravity and magnetic lows are detected across a maar crater, it is suggested that all the available magma was erupted and the maar diatreme (subsurface collapse structure) was not intruded by any dykes. The gravity low arises because of lower density lake sediments and pyroclastic debris infilling the diatreme. The lack of any intrusive dykes or remnant vents within the diatreme suggests that plenty of groundwater was available for phreatomagmatic explosions.

Maars with corresponding gravity and magnetic highs indicate a large volume of subsurface basalt is present, resulting from the ponding of magma at the surface of the vent. This results from a lack of groundwater for magma to interact with during the eruption, which facilitates magma rising upwards through the diatreme where it can be fragmented at shallow levels.

48. IMPROVEMENTS TO THE VIRTUAL GEOPHYSICS LABORATORY (VGL): HARNESSING CLOUD COMPUTING FOR POTENTIAL FIELD AND OTHER GEOPHYSICAL INVERSIONS, PHASE II

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CSIRO, Geoscience Australia (GA) and the National Computational Infrastructure (NCI) collaborated for over 12 months to build a Virtual Geophysics Laboratory (VGL; previously known as the Virtual Exploration Geophysics Laboratory). VGL allowed geophysical data, software and computer resources to be linked by seamless workflows and allowed access to them via an internet portal. This proved the concept that access to parallel grid computer services via the internet (termed cloud computing) could be harnessed to enable complex geophysical modelling on large datasets. VGL also utilised a provenance tool that enabled users to record their input data and processing methods. This is a crucial tool for providing transparency and repeatability when undertaking geophysical processing and modelling.

VGL has now been broadened to include new workflows, access to original point and line data, gridded data and open-source modelling software for electromagnetic and potential field inversions. VGL aims to provide better online access to a wider variety of geophysical datasets and increased access to geophysical processing codes developed within the research, resource and government communities. Access to a diverse range of computing resources is also important and VGL aim to provide access to super computer, cloud computing and GPU resources in future versions.

49. CONSTRAINTS ON THE STRUCTURE OF THE BORDER RANGES FAULT SYSTEM, KENAI PENINSULA, ALASKA FROM THE PRELIMINARY RESULTS OF THE 3D INVERSION MODEL OF GRAVITY DATA

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We tested plausible initial 3D density models across the eastern Cook Inlet basin to constrain the geometry of the Border Ranges fault system (BRFS). The BRFS forms the structural boundary between the forearc-arc structures and accretionary terranes of the Aleutian subduction zone in southern Alaska. We used 2D density cross-sections as starting '*a priori*' models to constrain the 3D inversion model. We computed the theoretical gravity based on the inversion, compared it to the observed gravity, and determined the gravity misfit. We tested the 3D inversion solutions on the lowland regions where the densest spacing of gravity points is located using three surfaces defining the topographic ground level, the top and base of the sediment layers within Cook Inlet basin to build the preliminary 3D models. Preliminary results show the 3D inversion is able to constrain the simple shape of Cook Inlet basin with geologically reasonable densities. We will produce several alternative starting models for the entire Cook Inlet forearc basin and the BRFS. The most reasonable models will be used as starting models for the structure of the entire study area.

MINERAL EXPLORATION

50. MINERAL GEOPHYSICS – TWO DECADES OF CHANGE

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Over the last couple of decades, mineral geophysics has benefited from well documented advances in various technologies. Airborne gravity gradiometry, DGPS, GIS integration, radiometric noise reduction, 3D electrical/seismic acquisition, 3D inversions of potential field and electrical data are particular examples. These have been partly enabled by advances in computing technology, including faster data processing and expanded storage options, email, internet, mobile and satellite telephony, and the move towards industry standard software and data formats for the vast quantity of government and open file data now available in some countries.

Less documented are the extra demands placed on mining company geophysicists. Examples include formulating safety management plans and auditing air safety compliance, monitoring field safety as much as technical details and complying with relevant legal restrictions in different jurisdictions. All the while the modern geophysicist must stay abreast of an increasing number of software applications, ensure quality communication with geologists on issues of target generation and method limitation, while geophysical staff numbers have typically decreased. The vast amount of data available in the 21st Century has added to the importance of 'sorting the wheat from the chaff'.

Geological and geochemical ideas have also evolved over the last two decades, and geophysicists must understand terms such as IOCG, porphyry and low-sulphidation epithermal. Geophysical responses and tools need to be evaluated for each deposit style and an objective and critical consideration maintained to constantly review whether the exploration model is appropriate or too restrictive. Pushing the search to new frontiers by proposing new, deeper and more conceptual targets as a part of the exploration portfolio is important to help limit excessive revisitation of previous outcropping targets.

As for the next 20 years, some possibilities include more airborne methods, UAVs, and better models.

51. MAGNETIC RESPONSES FROM AN IRON-RICH GOSSAN IN A VOLCANIC TERRANE AND A LIMESTONE-HOSTED STRATA-BOUND MANGANESE DEPOSIT, CENTRAL PROVINCE, PAPUA NEW GUINEA

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To interpret magnetic responses ('magnetic signature') of different mineral settings in Papua New Guinea (PNG), field campaigns were conducted by the Geological Survey Division in mineral fields in the Rigo District, Central Province of Papua New Guinea.

Geological mapping accompanied by a ground magnetic survey was conducted over iron-rich gossans within a volcanic sequence at Kore. A similar program was undertaken in a sedimentary-hosted manganese field near Kemaea village.

The gossans are within the Middle Miocene Kore Volcanics which are bounded to the south by the Middle Miocene Gidobada Limestone. In contrast, the manganese nodules at Kemaea, are within the Late-Middle Eocene Port Moresby beds and are bounded to the north-east by the Early Eocene-Middle Oligocene Sadowa Gabro.

The results of the magnetic survey show significantly different responses that are apparently related to the style of mineralisation.

The total magnetic response of a gossan within the volcanic rock unit is characterised by high frequency signals that require extensive filtering to outline the trend of distinct magnetic source. In contrast, the limestone-hosted strata-bound manganese deposit has a well-defined north-westerly structural trend that is easily distinguished within the response of the total magnetic field.

Applying a reduced to magnetic equator algorithm and generating an upward continuation of the magnetic field enhances these structural trends. The analytical signal of the magnetic field also enhances the interpretation of the signal from the two different sources.

The results of the survey demonstrate that background knowledge of mineral systems, including major mineral composition and style of deposit is essential to interpret imagery from ground magnetic surveys of mineral deposits and that different styles of mineralisation generate unique magnetic responses.

52. A REVIEW OF AEM DATA IN SOUTH AUSTRALIA

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Subsurface resistivity is a key component of many mineralisation models including unconformity-related uranium, palaeochannel hosted uranium and nickel sulphide exploration. It is also a key component in understanding environmental aspects of the subsurface including groundwater detection, and civil engineering applications including detection of buried pipes and cables. Measuring subsurface resistivity is the aim of electromagnetic (EM) geophysical techniques. It involves transmitting an electromagnetic field into the Earth, and then recording this field – and the Earth response – on a receiver. The transmitted field signal can be removed from the received field to determine the Earth response.

Airborne EM (AEM) is a geophysical technique that allows this process to be undertaken from an airborne (aeroplane or helicopter) platform. AEM exploration first commenced in South Australia with AFMAG (Audio-Frequency Magnetic technique) surveys in the 1960s, and VLF (Very Low Frequency) surveys from 1971. Numerous platforms including RepTEM, GeoTEM, Input, QUESTEM, HoistEM, TEMPEST and VTEM are now routinely used within South Australia. Each technique provides a different view of the subsurface dependant on the system parameters and the processing undertaken on the data.

Given the increase in AEM surveying within South Australia and the wide applications available for this data a review of this technique within the State has been undertaken. This poster presents a summary of AEM within South Australia, focussing on a number of significant surveys and their outcomes. Surveys in the Cariewerloo Basin and Fowler Domain in particular have been used to model uranium prospectivity and help define nickel deposits. All data reviewed is now downloadable online via SARIG.

53. HELICOPTER AFMAG (ZTEM) SURVEY RESULTS OVER THE AD DUWAYHI INTRUSION RELATED GOLD DEPOSIT (IRGD) IN THE WESTERN ARABIAN SHIELD, KSA

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As part of a larger survey campaign in the western Arabian Shield, helicopter electromagnetic survey tests were performed using the ZTEM (z-axis tipper electromagnetic) passive airborne EM (AFMAG) system over the 30.6Mt Ad Duwayhi gold porphyry deposit, in order to determine its airborne geophysical signatures. Ad Duwayhi is a Precambrian, shear-zone/vein-hosted, gold porphyry deposit that is located approximately 450 km SW of Riyadh and 450 km E/NE of Jeddah, KSA. The deposit is hosted within a late- to post-orogenic, Neoproterozoic age, northwest oriented granite body and a comagmatic, square quartz-porphyry that is possibly a younger phase of the granite. The Ad Duwayhi gold mineralisation is characterised by low sulphide and base-metal content that typifies gold porphyries.

The survey appears to have been able to characterise the regional geologic and localised resistivity signatures associated with the Ad Duwayhi gold porphyry deposit. It defined the larger, low porosity felsic-rich/quartz-altered intrusive host as a resistivity high, whereas the more fractured/porous vein systems that host the mineralisation are defined as more localised, weak, linear resistivity lows. The resistivity high signature appears to lack a well-defined, surrounding resistivity low halo, due to phyllic-propyllitic alteration, that normally characterises other copper-porphyries surveyed. More importantly, a flanking resistivity and magnetic high feature was mapped 1.5km further west, below a thin layer of conductive overburden, and might also represent another target of interest. The survey results suggest that Ad Duwayhi remains open to the southwest. The combined aeromagnetic and passive AEM signatures (high resistivity and low magnetic susceptibility) for Ad Duwayhi might be distinguishing characteristics for similar porphyry gold deposits regionally. Although 2D inversion modelling supports the interpretation of the ZTEM data in plan, more advanced 3D inversion and ground follow-up are required to further validate these targets of interest.

54. CET EXSIM: MINERAL EXPLORATION EXPERIENCE VIA SIMULATION

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Undercover mineral exploration is a challenging task as it requires understanding of subsurface geology by heavily relying on remotely sensed (i.e. geophysical) data. In order to increase the chances of success cost-effective exploration is essential. This requires effective decision making in both selecting the optimum data collection methods and accuracy in the subsequent interpretation. Traditionally, developing the skills, behaviour and practices of exploration decision making requires multi-year experience through working on exploration projects under various geological settings, commodities and levels of available resources. This implies long periods of sub-optimal exploration decision making, prior to this experience being successfully obtained.

To address this critical industry issue, our on-going research focuses on the development of the unique and novel e-learning environment, exSim, which simulates exploration scenarios where users can test their strategies and learn the consequences of their choices. This simulator provides an engaging platform for self-learning and experimentation in exploration decision strategies, providing a means to build experience more effectively. The exSim environment also provides a unique platform on which numerous scenarios and situations (e.g. deposit styles) can be simulated, potentially allowing the user to become virtually familiarised with a broader scope of exploration practices.

Harnessing the power of computer simulation, visualisation and an intuitive graphical user interface, the simulator provides a way to assess the user's exploration decisions and subsequent interpretations. In this paper, we present the prototype functionalities in exSim including: simulation of geophysical surveys, follow-up drill testing, and interpretation assistive tools.

55. INVESTIGATION OF THE SO-CALLED MAGNETIC NORTH IMMEASURABLE AREA IN THE SOUTH SEA OF KOREA BY A NEWLY ASSEMBLED THREE AXIS MAGNETOMETER

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An area on the South Sea of Korea exists where the magnetic compass is said to turn round and round not giving a fixed direction to the navigator.

We newly assembled a three axis magnetometer system composed of a three axis fluxgate magnetometer, a GNSS compass, a two axis clinometer, and a multi-channel data logger, to investigate if there really exists such an area. We supposed that there the horizontal component of the vectorially measured magnetic field will be too small to maintain the magnetic compass' needle to one fixed direction. We processed the measured data mainly through two steps. Firstly we transformed the random coordinate system into a fixed coordinate system, i.e., into the geographical coordinate system. Secondly we performed an inversion to eliminate the effect of the ship itself from the measured data.

On the finally achieved anomaly map we could not find such an area where the horizontal component is so small that it could not maintain the magnetic compass' needle to a fixed direction.

We concluded that such statement about the existence of the so-called magnetic north immeasurable area in the South Sea of Korea does not have a strict scientific base.

56. PETROPHYSICAL CONSTRAINTS FOR INVERSION MODELS OF THE EASTERN GAWLER CRATON IOCG PROVINCE

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The Eastern Gawler Craton IOCG province, South Australia, hosts a variety of deposits associated with Hiltaba Suite magmatism. Adjacent to the southern margin of the Carrapateena haematite breccia deposit lies the Emmie Bluff and Punt Hill regions which host skarn mineralisation in the palaeoproterozoic Wallaroo Group beneath 1 km of cover. Within those two smaller regions are two distinct iron and copper skarn styles of mineralisation. Exploration methods under deep cover rely upon geophysical signatures from airborne and ground surveys to select drill targets, define the cover sequences and basement.

This process can be improved using petrophysical properties to constrain 3D inversion models. A wide range of petrophysical properties have been collected over the area to relate the known geology with geophysical surveys. Magnetic susceptibility and specific gravity have been captured to characterise altered units.

The Emmie Bluff and Punt Hill regions have been the subject of 3D inversion modelling projects undertaken by the Geological Survey of South Australia which required geological constraints due the distinct styles of alteration and mineralisation. Within the Wallaroo Group, the both gravity and magnetic sources within Emmie Bluff are controlled by iron oxide alteration, whereas in the neighbouring Punt Hill region the density characteristics are dominated by skarn alteration and the magnetic source appears independent of the altered stratigraphy. This work presents characterisation of mineralised stratigraphy used for 3D inversions of the region. The data is available for download from the SARIG website.

57. FROM CRATON TO CORE TRAY: A MULTI-DISCIPLINARY, MULTI-SCALE QUEST FOR COPPER IN THE CURNAMONA

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The journey from the early stages of project generation to the focussed exploration of an established project requires a collaborative effort from many workers with varied expertise. Geophysical methods provide a key component of the interdisciplinary exploration team at a number of scales; from imaging lithospheric-scale structures, to interpolating geology and structure between isolated areas of data (e.g. outcrop) at the craton-scale, to the direct detection of mineralisation.

This presentation will outline the important role that interpretation of geophysical data has played in advancing MMG's copper project in the Palaeo- to Mesoproterozoic Curnamona Province of South Australia. From project generation to area selection and drillhole targeting; gravity, magnetic, seismic and electrical data have all been used in conjunction with geological and structural observations as well as other datasets (e.g. geochemical) to build a firm strategy with which to explore this largely covered and underexplored piece of the Australian continent.