SECTION 3
ABSTRACTS

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Day 1: Monday 12 August 2013

0830–1030
Conference Opening and Plenary Session

1000–1030
Day 1 Session 2 Stream 1

KEYNOTE ADDRESS: THE ROLE OF TECHNOLOGY TO THE MODERN MINERALS INDUSTRY AND ITS POTENTIAL TO MATERIALLY IMPROVE DISCOVERY SUCCESS RATES

*Stephen McIntosh**
Rio Tinto, Australia

The mineral exploration industry's efforts have evolved from rather simplistic prospecting activities that continued through until the mid-1950s to a sophisticated science that is underpinned by a much better geologic understanding of the methods of emplacement and preservation of mineral systems.

By the late 1980s the mineral industry had access to new tools that helped to map and delineate the majority of the Earth's surface. Satellite imagery, new airborne geophysical methods and ever better geochemical analysis capabilities linked with improved geologic insights allowed the industry to move into a more predictive era for the search for mineral deposits.

However, by the late 1980s the industry started to see a decline in discovery rates of new mineral deposits. This trend has continued through until the present time. Access to new technologies has continued to evolve and today we see on-going improvements in the quality and coverage of key datasets such as magnetics, radiometrics and electromagnetics. The next phase of technology development is seeking to deliver high quality airborne gravity data and improve EM methods so one can image deep into the upper crust and also deliver higher quality data from the likes of borehole surveying.

In order to improve discovery rates the industry needs to improve its ability to deliver geologically meaningful geophysical inversions. One of the reasons for the poor discovery track record across the minerals industry has been the general inability to marry the scientific fraternities of geology, geochemistry and geophysics. The role of effective 3D data integration is going to be increasingly important along with the collection of key supporting datasets such as petrophysical data. However, targeting strategies still remains the single most important decision explorers can make as no matter how good the science, if there is no deposit located within the search area then no discovery can be made.

1100–1230
Day 1 Session 2 Stream 1

SEISMIC ACQUISITION – CASE HISTORIES

KEYNOTE ADDRESS: A VIEW ON ADVANCES IN PETROLEUM INDUSTRY SEISMIC ACQUISITION TECHNOLOGY AND WHAT IT MEANS TO AN OIL INDEPENDENT

*David Monk**
Apache Corporation/SEG

Marine seismic acquisition has seen some tremendous changes in technology in the last 3 years. The presentation shows why an Independent Oil company needs to be at the forefront of seismic technology, and highlight the changes that have, and will continue to, delivered more reliable images of the subsurface and better drilling locations.

At its heart seismic acquisition has only 4 elements that might evolve through new technology. The relationship between the sources and receivers (the geometry), the bandwidth of the seismic data, the components of the wavefield that are measured, and the length of the seismic record that is recorded. One might think that most of these elements are difficult to change, but recent technology has radically changed all 4 of these components.

The acquisition geometry, the relationship between sources and receivers, includes the issues of sampling at both the source and receiver end of the raypath. Recent developments in offshore acquisition technology have led to far more flexibility in receiver geometries even with conventional towed streamer systems, and the indication is that we will have the capability of recording up to 1 million traces in each shot record within 5 years. However decoupling the receiver from a recording vessel has become a norm in many situations with the advent of autonomous nodes. The future looks as though such nodes will become completely independent units capable of propelling themselves underwater to a bottom location, recording multi component data continuously, and then coming back to a 'mother ship' for data retrieval. Additionally we have seen development of simultaneous source methods migrate from established methods onshore to offshore applications, which

have allowed far greater flexibility in source geometry through deployment of large numbers of autonomous sources as well. The use of completely independent source vessels and autonomous nodes will be illustrated through real data examples.

The second fundamental issue governed by acquisition technology is the bandwidth of the data acquired. This is limited by both source and receiver, and recent developments have aimed at extending the bandwidth of both as we move towards more sophisticated processing including full waveform inversion. Recently there has been considerable work aimed at extending the low frequency components of the bandwidth of marine data. Such 'BroadBand' methods include new acquisition methods aimed at mitigating the effect of the marine ghost, or processing methods designed to minimize its impact on final data. Comparison data from a test line off the North West shelf of Australia illustrates some of the potential benefits of these methods.

This presentation will highlight some of these advances in acquisition, through illustration with data examples where possible, which highlight the geometry, bandwidth, wavefield sampling and record length changes we are likely to see in the future, and the benefits that these changes may bring to the success of an exploration company.

IMPACT OF SURVEY DESIGN AND ACQUISITION TECHNOLOGY ON 3D MARINE MEGA-SURVEY SUCCESS, A RECENT EXAMPLE FROM SOUTHERN AUSTRALIA

Ted Manning[1], Gary Nicol[2], Eric Green[1], Christian Strand[3], Anthony van der Wal[3] and Averrouz Mostavan[3]*
[1]BP, Jakarta, Indonesia
[2]BP, Perth, Australia
[3]PGS, Singapore, Singapore

The objective of the seismic survey discussed here was to rapidly explore deep targets over 12000 km^2 of frontier permits.

Heavy seas with a strong south-westerly swell and strong ocean currents, coupled with stormy weather conditions create risk for both seismic quality and turnaround, limiting the survey to a tight weather window. These harsh metocean conditions were compounded by the remote setting; both factors strongly influenced the survey design and posed the biggest challenge to delivering a consistent high quality seismic dataset.

The solution required a huge receiver spread covering over 11.5 square kilometres and modern equipment to withstand an extended period in these conditions. Two main technology solutions were also implemented to deliver the project. The first was Fan shooting where cables are laid out with greater spacing at the end or the spread compared to near the vessel. The second is termed intelligent infill modelling where variable coverage is modelled to determine acceptable offset gaps, and then the data quality impact is predicted from actual coverage during acquisition, to aid real time infill decisions. This was calibrated against real data decimation tests before the survey and found to be accurate.

The wide and long receiver spread deployed in this project led to several vendor production records. These included production records for one day at 143.6 km^2, one week at 919 km^2, and one month at 3,056 km^2, while still delivering very high quality seismic data.

The design helped the acquisition to continue in severe swell conditions without introducing detrimental noise in the data, helped by real time, flexible, on-board seismic processing to confirm when swell noise could or could not be removed from the data.

Infill management and fanning of the streamers contributed to an overall reduction of the infill.

DESIGN AND OPERATION OF A 3D SEISMIC SURVEY IN A DENSE URBAN ENVIRONMENT: LONG BEACH 3D

*Dan Hollis**
NodalSeismic LLC, Signal Hill, USA

Presented is a case history of a seven year-plus project to acquire a 3D seismic data over the Long Beach Field. The Long Beach field is a faulted anticline along the Newport-Inglewood Fault Zone and presents challenging survey design considerations just for proper imaging; however, data acquisition is complicated by its location in the dense urban environment of the greater Los Angeles area. Presented is a brief history of discovery and development of the field, lessons-learnt from a failed attempt in 2005 to acquire a 3D survey, application of lessons-learnt and new nodal technology in the design and operation of the successful 2011 survey.

1100–1230
Day 1 Session 2 Stream 2

UNCONVENTIONALS

KEYNOTE ADDRESS: BEYOND CONVENTIONAL SEISMIC FOR UNCONVENTIONAL RESERVOIRS

*Jon Downton**
CGGVeritas

Shale gas reservoirs contain significant heterogeneity so that the pad and well placement can greatly impact the economic return. The seismic method has long been used to identify 'sweet spots' for conventional plays. This presentation examines the evolution and adaption of these workflows for the new objectives common with unconventional reservoirs.

Similar to conventional reservoir work the seismic data is often inverted for density, P-wave and S-wave impedances. With these estimates it is possible to follow conventional reservoir workflows to estimate porosity, lithology and other rock properties. Different methodologies can be employed such as Bayesian probabilistic classification for lithology prediction and multi-linear regression for porosity prediction.

If sufficient offset is available, density may also be estimated. This is of particular importance if the total organic content (TOC) is to be predicted. There often exists a strong correlative relationship between TOC and density and this fact can be exploited in multi-attribute prediction schemes. Further, if density is known geomechanical properties such as the Young's Modulus and the Poisson's ratio can be estimated. These properties are important since they are often used to predict 'Brittleness' or fracability estimates.

It is thought that many of these shale reservoirs are anisotropic. This creates opportunity but also places extra demands on the seismic processing and acquisition. Special azimuthal AVO compliant processing must be performed to achieve the optimal image. Retaining both the offset and azimuthal information places greater demands on the data acquisition, in particular the source and receiver line spacing. With properly acquired and processed seismic data comes the opportunity of generating azimuthal traveltime and amplitude attributes. These may be interpreted to predict fracture intensity and orientation or information about the stress field.

In addition to the established seismic workflows discussed, new technologies such as microseismic have proved important. They allow the engineer to evaluate the hydraulic fracturing program and estimate the stimulated volume.

INTERGRATING WELL AND SEISMIC DATA FOR CHARACTERISATION OF SHALE PLAYS

Pieter Gabriels[1]* *and Ted Holden*[2]
[1]Fugro-Jason Australia Pty. Ltd., Perth, Australia
[2]Fugro-Jason Inc., Houston, USA

Shale plays have revolutionised the oil and gas industry in North America and exploitation of these kinds of plays is steadily gathering pace in other parts of the world. Because hydrocarbon bearing shales usually have insufficient permeability to allow significant flow to a well, production from these unconventional reservoirs comes with unique challenges. Optimizing recoverable reserves from shales requires strategic placement of horizontal wells: placing the well in the best areas, drilling the lateral in the proper direction and keeping the lateral portion of the wellbore in the optimum layer. It further requires production stimulation by hydraulic fracturing (fracking) of the rocks to connect the natural fractures with induced near-well fractures.

In this paper, we present a methodology to identify these optimum areas and layers in the shales using a seismic characterisation workflow where well and seismic data are rigorously integrated. The first part of the approach is well data analysis to extract petrophysical, rock physics and mechanical information. Shale formations have a complex mineralogy requiring a sophisticated petrophysical analysis. Then a seismic inversion is performed to predict rock properties, which characterise the shale reservoirs and importantly allow us to predict how the rocks will respond to fracking. The final part of the methodology is an interpretation of multiple rock property models in terms of defined shale facies. A Bayesian approach was adopted to generate shale facies models that describe the thickness and complex architecture of shale reservoirs. These facies models can be used to significantly reduce the risk of poorly performing wells and improve asset performance.

1100–1230
Day 1 Session 2 Stream 3

HARD ROCK SEISMIC I

MT WOODS 2D SEISMIC REFLECTION SURVEY, GAWLER CRATON, SOUTH AUSTRALIA: AN INTEGRATED MIINERALS EXPLORATION CASE STUDY

Thomas Harris[1]*, *Charles Funk*[1], *Finbarr Murphy*[2] *and Peter Betts*[3]
[1]OZ Minerals, Melbourne, Australia
[2]Fractore, Melbourne, Australia
[3]PGN Geoscience, Melbourne, Australia

Five seismic reflection profiles for ca 130 line km were acquired over the southern Mt Woods Inlier, near the Prominent Hill IOCG deposit in South Australia. The aim was to provide high resolution images of the under-cover region in the shallow to mid crust, to augment existing potential field and drilling data and, through a combined interpretation, to optimise exploration targeting.

The application of seismic reflection using vibroseis sources in hard rock terranes presented significant challenges to processing and interpretation. Notwithstanding this, the resulting 2D images clarified a number of important fault and fold patterns that were also apparent in, but poorly constrained by, the potential field data. The major faults include: the Southern Overthrust imaged as a major north dipping feature that truncates a series of gently dipping reflectors within the Palaeoproterozoic and Archaean basement, and the Bulgunnia Fault as a complex set of steeply dipping divergent faults. The major folds are large amplitude refolded features that include the Kennedys Dam antiform and Larissa synform. The White Hills mafic complex, which has an impressive positive gravity and magnetic response, occupies a broadly synformal position. The Gawler Range Volcanics and their contact with Palaeoproterozoic metasediments is well imaged using the seismic method. A thrust duplex structural setting has been inferred around the Prominent Hill deposit.

SEISMIC IMAGING BENEATH THE EUCLA BASIN LIMESTONES

*Ross Costelloe**
Geoscience Australia, Canberra, Australia

Geoscience Australia in collaboration with the Geological Survey of Western Australia conducted a seismic testing program on the Eucla Basin carbonate sediments during May 2012, during a survey to collect deep seismic data across the western Eucla Basin. These data were collected as part of the Albany-Fraser Seismic Survey that consists of three traverses in south-east Western Australia with a total length of 671 km. The major aim of this survey was to image the basement relationship between the Yilgarn craton, the Albany-Fraser zone, and basement rocks further east. Much of this eastern area is covered by the limestones of the Eucla Basin, and there has been little seismic data acquired in this area. These tests were required to confirm the feasibility of collecting deep seismic data beneath the limestones through the region. Geoscience Australia has had little success in penetrating the limestones of the Eucla Basin in previous surveys.

Several sets of recording parameters were tested, including 10 Hz geophones and lower frequency 4.5 Hz geophones as parallel spreads. Also, linear upsweeps were compared to low-dwell non-linear upsweeps designed to introduce more low frequency energy into the signal. Initial results from the testing program were encouraging. Production data were subsequently collected along the Trans Australia Railway access road as far as Haig, using Geoscience Australia' standard deep crustal seismic acquisition parameters.

HIGH RESOLUTION SEISMIC REFLECTION FOR HYDROGEOLOGY – WHERE IS THE VALUE?

Robert Martin[1]*, *Brett Harris*[2] *and Richard Martin*[3]
[1]HiSeis Pty Ltd, Margaret River, Australia
[2]Curtin Univerity of Technology, Department of Exploration Geophysics, Perth, Australia
[3]Delayed Yield, Fortescue Metals Group, Perth, Australia

With increasing demands on groundwater resources, concerns about the impacts of groundwater abstraction on groundwater dependent ecosystems and the new paradigm of large scale managed aquifer recharge, there comes a requirement for more robust definition for water resources. Seismic reflection surveying offers this higher level of definition for hydrogeological systems. Take up of seismic reflection by the groundwater industry has been slow but is certainly gathering momentum with several high resolution basin scale surveys now providing clear examples of the value of seismic reflection. Seismic reflection surveying is expensive, so the key to success is strategic location of lines and selection of suitable acquisition parameters with sufficient resolution to answer key questions regarding the targeted hydrogeological system. We present several examples from Western Australia aquifer systems, compare the acquisition parameters selected and then clearly identify hydrogeological value of the outcome for each setting.

1100–1230
Day 1 Session 2 Stream 4

EM INNOVATIONS

KEYNOTE ADDRESS: ADVANTAGES TO USING EM SYSTEMS WITH MULTIPLE TRANSMITTERS AND MULTIPLE RECEIVERS: DEEP EXPLORATION, COVERED EXPLORATION AND 'PERFECT' CONDUCTORS

*Richard Smith**

The advantages of EM systems with multiple (distributed) receivers (e.g. Geoferret) have been demonstrated: the multiple receivers provide an opportunity to stack for longer periods from the same transmitter allowing deep bodies to be detected. Similar advantages can be obtained by using multiple transmitters. In one recent experiment, it was demonstrated that combining the signals from multiple transmitters increased the signal-to-noise ratio. A further advantage of the multiple transmitters is that arrays of transmitters can be combined together post-survey directing or focussing the field as specific subsurface locations. This is a generalization of the Infinitem transmitter configuration created to excite deep vertical conductors between two large loops; however, different combinations of multiple transmitters can be used to excite conductors in different orientations. A system with multiple transmitters and receivers can provide a capability for greater depth of exploration.

Theoretical work shows that when a three-component transmitter is used, it is possible to create a field in any orientation in the subsurface. This means that multiple three-component transmitters can be added together to enhance the field at a specific location and orientation. This is termed a 'directed field'. A different combination of fields might also be possible to enhance the strength and orientation at one location while suppressing the strength at a specific orientation in another location. This could ensure maximum coupling with one conductor and minimal coupling with another conductor (e.g. overburden). When collecting data from multiple transmitters and receivers, the large volume of data makes it difficult to display all the data. This can be addressed by creating 'response sections' or imaging subsurface locations that have responded strongly to fields in specific locations/depths/orientations.

Theoretical work using a three component transmitter and receiver shows that it is possible to devise methods for detecting a perfect conductor without a-priori knowing the geometric offset of the transmitter from the receiver.

UNCONFORMITY-TYPE URANIUM EXPLORATION USING A COMBINED AEM AND MT APPROACH

Millicent Crowe[1,2]*, *Graham Heinson*[2]*, *Tania Dhu*[3], *Tania Wilson*[3], *Stephan Thiel*[2] *and Jared Peacock*[2,4]
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[2]University of Adelaide, Adelaide, Australia
[3]DMITRE, South Australia, Adelaide, Australia
[4]USGS, Menlo Park, California, USA

Unconformity-type uranium deposits are characterised by high-grade and constitute over a third of the world's uranium resources. The Cariewerloo Basin, South Australia, is a region of high prospectivity for unconformity-related uranium as it contains many similarities to an Athabasca-style unconformity deposit. These include features such as Mesoproterozoic red-bed sediments, Palaeoproterozoic reduced crystalline basement enriched in uranium (~15–20 ppm) and reactivated basement faults. An airborne electromagnetic (AEM) survey was flown in 2010 using the Fugro TEMPEST system to delineate the unconformity surface at the base of the Pandurra Formation. However highly conductive regolith attenuated the signal in the northern and eastern regions at a depth of 300 m or less, requiring the application of a deeper geophysical imaging methods.

In 2012 a magnetotelluric (MT) survey was conducted along a 110 km transect of the north-south trending AEM line. Broadband (300 Hz – 300 s) MT data were collected at 29

stations and successfully imaged the depth to basement, furthermore providing evidence for deeper fluid pathways. The AEM data were integrated into the regularisation mesh as a-priori information generating an AEM constrained resistivity model, and also correcting for static shift. It was found that the combined techniques provided better structural information over depths of 0–5 km than could be obtained by inversion of each method alone.

1100–1230
Day 1 Session 2 Stream 5

GRAVITY GRADIOMETRY I

THE COMING OF AGE OF GRAVITY GRADIOMETRY

*Daniel DiFrancesco**
Lockheed Martin, Niagara Falls, USA

Gravity gradiometry is coming of age as a resource exploration tool. Systems have been actively used for 15 years in search of mineral and hydrocarbon targets. New and innovative system designs, operational deployments, and applications are coming to realization as both developers and operators mature their understanding of gravity gradient data value. This presentation will provide an update on the current state of the art in system deployments with a view toward the future. New applications and capabilities will be cited with actual survey data cited as appropriate. An analysis of the Value of Information (VOI) of gravity gradient data will also be a focus of the presentation.

RESULTS FROM FALCON AIRBORNE GRAVITY GRADIOMETER SURVEYS OVER THE KAURING AGG TEST SITE

*Asbjorn Norlund Christensen**
Fugro Airborne Surveys, Melbourne, Australia

The Kauring Test Site in Western Australia was established in 2009 to provide a public benchmarking and comparison venue for new and existing airborne gravity and airborne gravity gradiometry (AGG) technology.

Fugro Airborne Surveys flew the fixed-wing FALCON AGG system over the Kauring AGG Test Site over three periods in July 2011, November 2011 and February 2012.

Comparison between the FALCON AGG survey data and the high resolution ground gravity data over the Kauring AGG Test site indicates that the FALCON vertical gravity gradient, GDD, has an error of +/- 5.6 Eo, and that the FALCON vertical gravity, gD, has an error of +/- 0.18 mGal.

Comparison between the digital elevation model (DEM) derived from the fixed wing FALCON survey laser scanner data, and a high-resolution third party DEM, indicates that the error of the vertical position of the FALCON differential GPS is less than 0.5 m. At 60 m terrain clearance this corresponds to a subsequent error in AGG terrain correction of less than 2 eotvos. This terrain correction error is well within the Kauring AGG Test Site FALCON survey noise envelope of 5.6 Eo.

THE EFFECTS OF DENSITY CONTRAST SURFACES ON AIRBORNE GRAVITY GRADIOMETRY (AGG) DATA INTERPRETATION

Luisa D'Andrea and Mark Grujic*
Rio Tinto Exploration, Melbourne, Australia

The accessibility of high-powered computers, plus readily available and detailed topography, allows the explorer to account for the effect of terrain in gravity and gravity gradiometry surveys applied to highlight subterranean density variations.

Similarly, accounting for other known density contrasts can further enhance the geological understanding of a survey area. The bedrock/overburden interface, lake depth and snow thickness can be mapped to provide 3D geometric surface models. The gravity gradient responses of these surfaces are presented.

Overburden and lakes are shown to have significant influence on the survey data. The effect of snow cover on survey data was found to be negligible. However, it may be important for the next generation of airborne gravity gradiometer instruments.

1330–1500
Day 1 Session 3 Stream 1

SEISMIC PROCESSING

KEYNOTE ADDRESS: IT'S NOISE IF YOU DON'T RECOGNISE IT

*Fred J. Hilterman**
Geokinetics Data Processing and Integrated Reservoir Geosciences

Attributes are derived from seismic data based on time, amplitude, frequency, and/or attenuation measurements. But often seismic attributes go unrecognized and in some cases are considered noise. I will share 31 years of elastic modelling that led to shouting *Eureka* numerous times after discovering the physical processes contributing to a seismic problem … moments of converting noise into new seismic attributes.

In 1981, John Sherwood programmed the Thomson-Haskell solution for a shot record in a horizontally-layered media; a program he called SOLID. As inferred, SOLID provides insight and understanding to a wide range of problems that Mother Nature imposes. One of the more difficult problems however, is unravelling and subsequently compensating for near-surface effects. Erroneous subweathering velocities derived from the analysis of apparent refractions can be directly related to thickness variations of either the weathering or subweathering

layers. Moreover, 'shingling' phenomenon often occurs in refraction picking and it is easily explained by elastic modelling which then leads to methods for incorporating shingling into the refraction analysis. In some cases, depending upon Poisson's ratio, the most prominent 'refraction' event may be a true refraction from the high-velocity layer, a reflection from the base of the high-velocity layer or a diving wave; and now the interpretation of the velocity model becomes questionable.

TRUE-AZIMUTH 3D INTERNAL MULTIPLE ATTENUATION WITHOUT IDENTIFYING THE MULTIPLE GENERATORS

Barry Hung, M. Wang and M. Griffiths*
CGG, Singapore, Singapore

We extend our previous work on 2D internal multiple attenuation without subsurface information to a 3D operation. We describe our implementation that involves selecting traces that honour the azimuth of acquisition for constructing multiple contribution gathers and then segmenting the chosen traces in a layer stripping fashion to predict internal multiple model without identifying the multiple-generating interfaces. We demonstrate through synthetic and field data examples that, by including crossline apertures in the prediction process and selecting traces with correct azimuths in the convolution and correlation processes, substantial improvement in image quality can be obtained for those data that exhibit the internal multiple problem.

1330–1500
Day 1 Session 3 Stream 2

CSEM

KEYNOTE ADDRESS: MARINE CSEM: AN ACADEMIC'S PERSPECTIVE ON THE PAST, PRESENT, AND FUTURE

*Steven Constable**
Scripps Institution of Oceanography, University of California, San Diego

APPLICATION OF SYNTHETIC APERTURE CONCEPTS TO TOWED STREAMER EM DATA

Folke Engelmark[1], Allan McKay[2] and Johan Mattsson[3]*
[1]Petroleum Geo-Services, Singapore, Singapore
[2]Petroleum Geo-Services, Oslo, Norway
[3]Petroleum Geo-Services, Stockholm, Sweden

In October 2012 a series of known oil & gas fields in the North Sea were surveyed with the newly developed Towed EM System. This is the first commercial Controlled Source EM (CSEM) system where both source and receivers are towed in a similar fashion as 2D seismic, and the technology is indeed also combinable with 2D seismic facilitating simultaneous acquisition from one vessel. One of the selected targets was an average size producing oil & gas field located 2,100 m below mudline, where approximately half of the recoverable oil has been produced, but with the gas cap still intact. The hydrocarbon column is approximately 52 m, with a 25 m thick gas cap overlying a 28 m oil column.

The strength of the source was 1.2 MAm and it was towed at 10 m. The EM streamer was 8,700 m long and towed at a depth of 50 m. The resulting electric field was measured at 23 offsets ranging from 500 to 7,500 m. The towing speed was 4 kn, and the water depth was 110–125 m in the survey area. An anomaly of 8% above background was detected, and with the newly introduced concept of synthetic aperture processing, the sensitivity can be strongly enhanced, and the bathymetry effects can also be more effectively suppressed.

Additional strengths of the system include the ability to estimate vertical and horizontal resistivity of the rock volumes surrounding the reservoir. This allows us to build quite accurate resistivity and anisotropy models for the background, which is very important information to narrowly constrain the inversion of the EM data. This results in quite accurate quantitative estimates of the transverse resistance for the charged reservoir. Inversion and 3D modelling reveal the anomaly is consistent with the target depth.

1330–1500
Day 1 Session 3 Stream 3

MICROSEISMIC

KEYNOTE ADDRESS: A SHORT HISTORY OF THE SHALE GAS PHENOMENON IN NORTH AMERICA

*Bob Langan**
Chevron Energy Technology Co.

In the year 2000, the natural gas reserves in the United States were projected to last only 10 to 20 more years, plans were being made to import Liquefied Natural Gas (LNG), utilities that

generate electricity were reluctant to build new facilities that used natural gas, and Russia was the largest natural gas producer in the world. It was about this time that continually improving technology and shrinking costs associated with drilling and completing long horizontal wells in shale resource rocks made it profitable to drill these wells in several formations in North America. Ten years later, North America was estimated by some academics to have a 100-year supply of natural gas, the potential LNG import terminals were now being viewed as potential LNG export terminals, and the U.S. was poised to pass Russia as the largest producer of natural gas in the world. By 2013 the abundance of natural gas in North America had driven the market price so low that most gas-only (dry) shale gas 'plays' were no longer profitable on their own merits. The substitution of natural gas for other energy sources in North America was being felt economically around the world in ways that are both obvious and not so obvious. How did this profound change come about? What are some of the potential implications for energy supply in North America and the world?

KEYNOTE ADDRESS: THE LATEST IN PASSIVE SEISMIC MONITORING IN NORTH AMERICA: FROM MAPPING HYDRAULIC FRACTURES WITH MICROSEISMICITY TO ISSUES WITH INDUCED SEISMICITY FROM WASTE WATER DISPOSAL

*Julie Shemeta**
MEQ Geo Inc.

The explosive growth of unconventional resources in North America has been made possible due to the combination of horizontal drilling and multi-stage hydraulic fracturing. Determining the geometry of the dynamic fracture growth and, ideally, the effective drainage area of the hydraulic fracturing program is of great interest to both the simulation engineer involved in frac design and the reservoir engineer for unconventional reservoir management. The hydraulic fracture design (water volume, proppant concentration and injection rate), the horizontal well length and trajectory, the spacing of hydraulic fracture stages along the well are all essential to any unconventional resource development program. The timing and spatial mapping of small earthquakes, 'microseismic' events, typically less than magnitude 0, occurring in and around a hydraulic fracture has proved to be an effective method to assess the hydraulic fracture geometry, growth over time and potentially the placement of proppant. Microseismic mapping is unique to the typical geophysical oil field skill set as it combines earthquake seismology with borehole seismic and reflection seismic processing. The integration of the microseismic events with engineering data such as the pump rate, pressure readings and proppant concentration can create a useful tool for assessing the geometry of the induced hydraulic fractures.

This presentation will review the basics of hydraulic fracture microseismic mapping and give an overview of the latest trends in microseismic mapping in North America using either borehole seismic, surface seismic and buried array techniques or combinations of these acquisition techniques.

Felt earthquakes in the mid-continent USA appear to be increasing in the past few years and researchers have suggested this increase is man-made, due in part to increase in waste water from the increase in hydraulic fracturing activity[1]. The occurrence of these undesired earthquakes, some of them felt by local residents, associated with both hydraulic fracturing and waste water disposal wells will be discussed. The presentation will review a recent publication by the National Research Council (USA) on the potential for induced seismicity in energy technologies. Julie Shemeta was a committee member for the NRC study and assisted in researching and writing the report as well as presenting the results. Regulations related to waste water injection vary from state to state in the USA and there have been legislative consequences in particular areas after the occurrences of induced felt earthquakes.

[1]Ellsworth, W.L., S.H. Hickman, A.L. Llenos, A. McGarr, A.J. Michael, and J.L. Rubinstein. 2012. 'Are Seismicity Rate Changes in the Midcontinent Natural or Manmade?' 2012 Seismological Society of America Annual Meeting abstracts.

MICROSEISMIC MONITORING – METHODS AND INTERPRETATION

*Mike Mueller**
MicroSeismic, Inc., Houston, US

Microseismic monitoring is attracting great interest due to the application of passive seismic to shale play completion activities and the successful expansion of the method from downhole to surface and near-surface acquisition geometries.

Fundamental to this application is the science behind the interpretations: The inherent capabilities and limitations of downhole, surface and near-surface recording systems and the processing and imaging applications enabled by these recordings must be appreciated to understand the results.

These considerations inform issues such as: microseismic event detectability and position uncertainty; the characterization of geological features; sensitivity to hydraulic fracturing methods; rock failure modes; and well to pad to field-wide implications of large scale 'horizontally drill and hydraulically fracture' development programs.

Ultimately interpretation workflows determine microseismic event point sets, modelling of discrete fracture networks and calculation of stimulated rock volumes. As microseismic monitoring matures understanding the relationship of recording geometry, imaging capability and interpretation workflows will fuel expanded utilization.

In this presentation the basic issues surrounding passive seismic acquisition methods and microseismic interpretation will be reviewed and discussed.

1330–1500
Day 1 Session 3 Stream 4

MINERALS – IP

THE INVERSION OF DATA FROM COMPLEX 3-D RESISTIVITY AND I.P. SURVEYS

Meng Heng Loke[1]*, *Kim Frankcombe*[2] *and Dale F. Rucker*[3]
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[2]ExploreGeo, Wangara, Australia
[3]Hydrogeophysics, Inc., Tucson, USA

The search and recovery for base and precious metals in recent years has led to surveys in more challenging areas over complex deposits and in extreme terrains. Such deposits frequently have accessory minerals that can be detected by induced polarization (I.P.) surveys. Due to their complex shapes and host terrains, 3-D surveys and inversion models are necessary to accurately resolve them. However, in some cases, the survey lines are not arranged rectilinearly. To accommodate an arbitrary arrangement of the electrodes, a model discretisation that is independent of the electrode positions is used. The rugged terrain can be accurately modelled by the use of the finite-element method where the surface of the mesh matches the topography. Innovative arrays such as the offset pole-dipole array have been used to rapidly survey large areas at a lower cost compared to traditional dipole-dipole arrays. Such arrays frequently have large geometric factors that make it difficult to accurately calculate the I.P. anomalies with the conventional linear perturbation approach that uses the difference of two resistivity calculations. The complex resistivity method, where the I.P. component becomes the imaginary component of the resistivity model, avoids this problem as it effectively decouples the resistivity and I.P. calculations. Furthermore, time-lapse 3-D surveys using surface and borehole electrodes have been conducted to monitor the flow of sodium cyanide solution directly injected in steep-sided ore rock piles for secondary recovery of gold. A 4-D resistivity inversion method is used to map the flow of the solution during the injection process.

MAGNETIC INDUCED POLARIZATION – USING NEW TECHNOLOGY FOR GREATER DETECTION CAPABILITY OF DEEP AND ELUSIVE MINERALIZATION

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The MIP method was first proposed by Siegel (1974) as an alternative to electrical IP but has not seen extensive commercial application. Most likely, this is due to the inherent difficulties in measuring very small magnetic fields at the low frequencies necessary for MIP. A further complication is the presence of magnetic noise from both natural and synthetic sources which can make it difficult to distinguish the very small MIP magnetic fields from the background noise. With the relatively recent availability of Super Conducting Quantum Interference Devices (SQUID) it is possible to measure low frequency magnetic fields with very high sensitivity. By utilizing two SQUIDS – one for measuring over the target area and a second which serves as a remote reference station, we are able to significantly increase the signal to noise ratio. Using advances in acquisition technology with GPS time stamping, we record data from both SQUID locations and the input current, then synchronize the time series and perform noise cancellation to accurately determine the MIP response.

Similar to traditional electrical IP, MIP has particular application for sulphide-associated, disseminated and vein gold and base metal deposits. However, the higher sensitivity of SQUID MIP, and the inherent ability of MIP to see through conductive cover, means that it can detect these deposits to greater depth, in more difficult environments, and with greater resolution and discrimination. We present our equipment, methods and a number of field trials using both frequency and time domain methods to analyse the MIP responses from porphyry copper, vein gold and unconformity uranium ore bodies.

DECOUPLING INDUCED POLARISATION DATA BASED ON COLE-COLE PARAMETERS

*Michael Hatch**
Centre for Tectonics, Resources and Exploration (TRaX), University of Adelaide, Adelaide, Australia

All resistivity/induced polarisation (IP) data are contaminated to varying degrees by inductive coupling. Spectral IP (SIP) data sets are usually more affected than conventional IP data sets as data are collected at higher frequencies, where coupling is stronger. For SIP surveys interpretation is based on examination of the phase response over the entire frequency range so it is necessary to use relatively sophisticated methods to remove coupling. Unfortunately, most of the methods described in the literature are complicated to implement, or are not described well enough to be practical. Pelton et al. (1978) suggest a method for decoupling based on the commonly used Cole-Cole equation that is relatively simple to implement using a Monte Carlo examination of the solution space. In this approach the Cole-Cole response is separated into two terms, the ground response and the inductive response. For each data spectrum, a random number generator is used to determine a set of test values for each the seven parameters in the extended Cole-Cole equation. The values for each of the seven variables are limited to reasonable levels based on initial testing of the solution space. The randomly generated Cole-Cole parameters are then used to generate magnitude and phase responses at the frequencies used for the survey. These are compared with the field data and the fit is calculated. This is run 1 million times for each data point and the best fit chosen from the complete run. Results from this study are encouraging, but the method requires refinement.

1330–1500
Day 1 Session 3 Stream 5

MINERALS EXPLORATION STRATEGY I

KEYNOTE ADDRESS: FROM MUMBWA TO KITUMBA: REGIONAL TO DEPOSIT SCALE GEOPHYSICS OF THE KITUMBA IOCG DISCOVERY, ZAMBIA

*Tom Whiting**

GEOPHYSICAL VECTORS TO IOCG MINERALISATION IN THE GAWLER CRATON

*Charles Funk**
OZ Minerals, Melbourne, Australia

IOCG deposits within the Gawler Craton are an attractive exploration target that has been the focus of considerable exploration. Due to the extensive Neoproterozoic and Phanerozoic cover over prospective geology, geophysics is the predominant and most cost effective exploration tool.

The eastern Gawler Craton contains multiple deposits and prospects in areas defined by high amplitude gravity and magnetic anomalies. Seismic surveys define the craton boundary and large scale structures. Gravity, magnetics and structural breaks are terrane scale vectors.

Within tenements geological interpretation from geophysical data is critical due the many 'false alarm' anomalies. Vectors to targets from gravity highs, associated offset magnetic responses, chargeability highs and resistivity lows are important. Ambiguity in interpretation due to palaeotopography is a significant issue that seismic surveying is beginning to resolve.

Within an IOCG deposit the geophysical response of iron oxides dominates the sulphide response. Neither direct-detection of, or vectors to mineralisation within a deposit are provided from gravity, magnetics, chargeability, resistivity or acoustic properties.

Geophysics provides excellent vectors to IOCG deposits at the terrane and tenement scale but do not provide vectors within the iron oxide alteration envelope.

1530–1730
Day 1 Session 4 Stream 1

SEISMIC ACQUISITION AND IMAGING

SIMULTANEOUS LONG OFFSET (SLO) TOWED STREAMER SEISMIC ACQUISITION

Andrew Long[1], Eddy von Abendorff[2], Justin Norris[3], Michael Purves[4] and Alcindo Moritz[5]*
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[5]Petrobras

An innovative 3D towed streamer project in offshore Gabon used a dual-vessel continuous long offset streamer configuration to acquire 0-12 km offsets with ten dual-sensor streamers. Streamer control for the 6 km streamers was robust and avoided operational complications or logistical penalties. Simultaneous shooting maximized inline shot density for long record lengths, thus capturing unaliased deep target reflections from rugose base-salt and sub-salt horizons. Survey design benefited from prior 2D survey experiences with a variety of broadband source and streamer technologies, and the use of 2D streamers as long as 12 km. 3D illumination modelling further suggested that offsets as long as 16 km could be expected to yield useful base-salt and sub-salt reflections.

Wavefield separation processing yielded full receiver-side deghosting onboard, followed by an inversion-based separation of simultaneous shots onshore. The ultra-long 12 km offsets combined with strong amplitudes of deghosted low frequencies have yielded encouraging sub-salt and pre-salt imaging.

MITIGATION OF THE 3D CROSS-LINE ACQUISITION FOOTPRINT USING SEPARATED WAVEFIELD IMAGING OF DUAL-SENSOR STREAMER SEISMIC DATA

Andrew Long[1], Shaoping Lu[2], Dan Whitmore[2], Hui LeGleut[3], Richard Jones[4], Nizar Chemingui[2] and Mazin Farouki[5]*
[1]PGS, Perth, Australia
[2]PGS, Houston, USA
[3]PGS, Kuala Lumpur, Malaysia
[3]Lundin Malaysia BV, Kuala Lumpur, Malaysia
[5]PGS, Singapore

A modified one-way equation pre-stack depth migration of up-going and down-going pressure wavefields was applied to two datasets derived from 3D towed dual-sensor streamer data in offshore Australia and Malaysia. The primary objective was to mitigate the well-known cross-line acquisition footprint effects upon shallow data quality and interpretability.

The new separated wavefield imaging methodology introduced here exploits the illumination corresponding to surface multiple energy, and thus exploits what has historically been treated by the seismic industry as unwanted noise. Whereas a strong cross-line acquisition footprint affected the very shallow 3D data using conventional processing and imaging, the new results yield spectacular continuous high resolution seismic images, even up to, and including the water bottom. One implication of these

results is that very wide-tow survey efficiency can be achieved without compromising shallow data quality if dual-sensor streamer acquisition and processing is used, even in very shallow water areas such as that discussed here. The separated wavefield imaging methodology can account for all degrees of lateral variability in the velocity model, full anisotropy, and angle gathers can be created to assist with velocity model building.

SIMPLIFY THE VARIABLE-DEPTH STREAMER DATA PROCESSING THROUGH PRE-MIGRATION DEGHOSTING: A CASE STUDY FROM NWS AUSTRALIA

Keat Huat Teng[1], Joe Zhou[1], Rao Hanumantha[1], Yingjie Feng[1], Zhengmin Zhang[1] and Loic Michel[2]*
[1]CGGVeritas, Singapore, Singapore
[2]CGGVeritas, Kuala Lumpur, Malaysia

Variable-depth streamer acquisition, as one of the key marine broadband solutions, has shown great advantages in providing high resolution seismic imaging and better low frequency penetration than conventional data from examples around the world. By utilizing the notch diversity, the receiver ghost was fully removed through proprietary joint deconvolution method in the imaging domain which produces broadband imaging with bandwidth up to six octaves. However, this post-migration deghosting method requires the receiver ghost to be well preserved prior to final migration thus introduces complexity in key steps like multiple attenuation, velocity analysis and migration than the conventional processing flow.

The objective of this work is to simplify the processing flow by applying bootstrap deghosting method right after shot domain de-noise. After this step, processing flow will be very similar to the conventional flow. This new flow has been tested on the variable-depth streamer data from NWS Australia. Compared to the post-migration deghosting flow, the new results not only provide similar benefit as to broader bandwidth and rich images, but also show improvement on multiple attenuation and primary preservation as well as seismic inversion.

SEISMIC SOURCE COMPARISON IN SURAT BASIN, QUEENSLAND

*Nabeel Yassi[1] and Afsha Kaba[2]**
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[2]Real Energy, Sydney, AU

Onshore Oil and Gas exploration activities are increasingly moving toward environmentally sensitive and urbanised areas. Site access, work permits and approvals are becoming increasingly complex for seismic exploration within such areas.

Seismic industry is evolving new technologies for conventional and unconventional seismic sources to accommodate the special challenges for exploration within sensitive areas; without compromising data quality and even stepping further to improve imaging quality of the acquired seismic data.

Deployment of a seismic source type (dynamite, vibroseis, or weight drop) and seismic source effort is directly related to the environmental/access requirements, surface conditions and the geophysical/geological framework of the survey area.

Decision making on seismic source efforts, i.e. source type/size, number of units, source array, etc. requires comprehensive testing and evaluation at the project's start-up stage to optimise the seismic source. Historically, seismic source efforts are biased toward deploying the highest possible efforts that is economically viable and logistically practical. In many cases, a higher seismic sources effort doesn't necessarily produce a superior seismic data quality.

Seismic data acquisition parameters testing such as signal to noise ratio, frequency bandwidth, imaging depth, resolution, offset ranges and source strength are usually the driving factors when deciding on the seismic source for a particular survey. Planning and implementing data acquisition parameters testing for a survey needs to address geophysical implications, in addition to the feasibility factors of the operation such as survey duration that impact the economics of a project.

This case study shows the methodology, analyses and results of seismic source optimisations from 2D and 3D seismic exploration programs in Australia for conventional Vibroseis and synchronised electromagnetic impulse source 'onSEIS'. Seismic signals from these surface sources were also compared with existing dynamite seismic data.

HIGH PERFORMANCE COMPUTATIONAL MODELING OF 3D SEISMIC WAVEFIELDS OFFSHORE NW AUSTRALIA

James Deeks, David Lumley and Jeffrey Shragge*
CPGCO2, The University of Western Australia, Perth, Australia

Recent significant advances in computer technology are providing geophysicists with more effective tools to explore complex phenomena. This has been facilitated by the increasing availability of GPUs (Graphics Processing Units) and high performance computing (HPC) clusters (with extensive parallelisation), the increasing power of individual processors and increases in memory capacity. We are using these HPC capabilities to run 3D staggered grid elastic finite differencing code to explore the effect of complex wave phenomena in seismic data. There are many important challenges apparent in seismic data from the North West Shelf off Western Australia'' coast including complex overburden effects and azimuthal anisotropy. We are using HPC modelling codes to increase understanding of the mechanisms by which these phenomena affect seismic wavefields. This new capability to run large, 3D, elastic models enables us to simulate realistic wavefields which can be used to more accurately predict and analyse complex wavefield effects in real data, and to test and improve imaging algorithms on full, three dimensional data sets where we know the underlying model/imaging solution.

A 4D-REPEATABILITY INDICATOR BASED ON SIMILARITY BETWEEN SHOTS ILLUMINATION IMPRINTS

Julie Svay, Nicolas Bousquie and Thomas Mensch*
CGG, Massy, France

A new 4D-repeatability indicator is proposed to appraise the quality of positioning during time-lapse marine surveys.

Repeatability of illumination between base and monitor surveys is assessed on selected reservoir horizons at fine discrimination scales, ranging from lines down to individual shots. Similarity between corresponding illumination imprints is evaluated from an adapted Partitioned Intensity Uniformity metric.

Such repeatability indicator can be used to assess jointly source and receivers positioning during 4D towed streamers surveys and under-shoots, or only source positioning over nodes surveys.

It provides a user-friendly tool to qualify the acquisition, or identify and rank preliminary re-shoots needs.

1530–1730
Day 1 Session 4 Stream 2

ROCK PHYSICS AND BOREHOLE SEISMIC

AN EXPLORATORY STUDY OF THE SEISMIC PROPERTIES OF THERMALLY CRACKED, FLUID-SATURATED AGGREGATES OF SINTERED GLASS BEADS

Yang Li[1]*, *Melissa Olin*[1,2], *Andrew Clark*[1,2] *and Ian Jackson*[1]
[1]Research School of Earth Sciences, Australian National University, Canberra, Australia
[2]Department of Engineering, Australian National University, Canberra, Australia

Synthetic analogues for cracked crustal rocks have been prepared by sintering soda-lime-silica glass beads of ~ 300 micron diameter at temperatures near the glass transition, and subsequent thermal cracking induced by quenching from high temperature into water. The resulting microstructure involves a controllable concentration (0.03-0.15) of equant pores connected by a network of cracks of uniformly low aspect ratio a ~ 0.0007. Systematic studies of seismic wave speeds and attenuation in such media saturated with fluids ranging widely in viscosity, with both high-frequency ultrasonic and low-frequency forced-oscillation techniques, and related measurements of permeability, are expected to provide a more robust laboratory-based understanding of poroelastic relaxation. In the first stage of this project, cylindrical specimens of 15 mm diameter and 50-150 mm length were tested in both torsional and flexural oscillation. Such measurements were performed under conditions of independently controlled confining (Pc) and pore-fluid (Pf) pressures. Permeability was measured in situ by isolating the pore fluid reservoirs at either end of the specimen and observing the return to pore-pressure equilibrium following a small pore-pressure perturbation in one of the reservoirs. The same specimens were tested dry and argon-saturated, before and after thermal cracking, in order to isolate the effect of the crack network. The responses to torsional and flexural oscillation are essentially elastic with both shear modulus and Young's modulus E independent of oscillation period (1-100 s) and minimal strain-energy dissipation $1/Q < 0.002$. The permeability and elastic moduli of the cracked material are each markedly pressure dependent for effective pressure $Peff = Pc - Pf < 50$ MPa – consistent with crack closure at pressures ~ Ea. Work in progress with fluid saturants of higher viscosity (water and glycerol) is targeting predicted poroelastic transitions associated with local (squirt) and global (specimen-wide) fluid flow.

ROCK PHYSICS ANALYSIS: A TOOL FOR LITHOLOGY AND FLUID PREDICTION WITHIN THE GULF OF THAILAND

Mirza Naseer Ahmad and Philip Rowell*
Petroleum Geoscience Program, Chulalongkorn University, Bangkok, Thailand

The Tertiary rift basins of the Gulf of Thailand are major hydrocarbon producing areas. The reservoirs in these basins are mostly fluvial sands of Miocene and Oligocene age. Gas is found mostly in central basins whereas there are more oil discoveries in western marginal basins. The main objective of this study is to understand the vertical and spatial trends of different rock physics parameters which can be used to differentiate lithology and fluids in these basins. Cross-plot and fluid substitution analysis were performed to determine lithology and/or fluid sensitive rock properties. Cross-plot analysis shows that sands have low P-velocity and density at shallow depths as compared to shale but the contrast of P-velocity between sand and shale decreases significantly at deeper levels. However, density shows significant contrast between sand and shale throughout the zone of interest and is therefore a more useful lithology discriminator. Density can also distinguish highly gas-saturated sands (80%) from water-wet sands throughout the zone of interest. On the other hand, oil-bearing sands cannot be so easily discriminated from water-wet sands. In comparison Vp/Vs can only successfully resolve high porosity sands (>16%) and gas sands when used in combination with P impedance. This regional rock physics study indicates that appropriate inversion techniques for lithology and fluid prediction studies need to be considered carefully. Post stack P-impedance volumes generated by inversion are very useful at shallower levels down to 1900 to 2000 metres but at deeper levels, density volumes generated by pre-stack simultaneous inversion are more appropriate.

AN EXPERIMENTAL STUDY OF MODULUS DISPERSION AND ATTENUATION IN SANDSTONES AT SEISMIC FREQUENCIES

Vassili Mikhaltsevitch, Maxim Lebedev and Boris Gurevich*
Department of Exploration Geophysics, Curtin University

A study of the low frequency dispersion and attenuation in sedimentary rocks is important for interpreting seismic data obtained during fluid extraction in producing fields or during injection of carbon dioxide for storage purposes. We present the results of the laboratory measurements of elastic and anelastic parameters of dry and distilled water/brine saturated sandstones with low (~7.8 and 9.6 mD) and high (~590 mD) permeability conducted at seismic (1-100 Hz) and teleseismic (0.1-1 Hz) frequencies. The experiments were performed with a laboratory apparatus utilizing stress-strain relationship which was developed to measure the complex Young's moduli of rocks at seismic frequencies. The measurements carried out in saturated sandstones with low permeability at effective pressures from 2.5 to 23 MPa revealed prominent peaks of attenuation in the seismic and teleseismic bands. A significant dispersion of the Young's moduli was also observed. The change in the salinity of the fluid from 0 to 45,000 ppm NaCl did not affect any of the measured parameters. The dispersion of the elastic moduli of the dry sandstones was within the accuracy of our measurements.

QUALITY CONTROL OF DIPOLE ACOUSTIC DATA

Marek Kozak and Jefferson Williams*
Jefferson Williams, Los Angeles, USA

Wave form data excited by an acoustic dipole source should only generate flexural waves. Unfortunately – other acoustic modes can also be created including Stoneley, compressional wave and ringing casing. These undesired modes depend on the tool position, well deviation, borehole size and the presence of casing. Unwanted wave forms might be additionally augmented by a poorly balanced dipole source or receivers. The classic semblance processing method will routinely deliver good looking values even when there are problems with one or more acoustic receivers and/or where the processing parameters are wrong. Therefore we propose to add complex wave form analysis as an additional quality control measure and cross check to the semblance method. We illustrate how to identify a mixed acoustic mode condition and eliminate biases in the shear slowness curves. We also show how to qualify cross dipole data needed to perform shear wave anisotropy analysis.

WALKAWAY VSP – GOING BEYOND AN IMAGE

Konstantin Galybin and Leon Dahlhaus*
Schlumberger PTS, Perth, Australia

Simultaneous AVO inversion of seismic data is an integral part of oil and gas exploration. Traditionally this technique is applied to surface seismic data, relying on availability of various angle stacks as well as on presence of offset wells for low frequency models. This paper investigates how a Walkaway Vertical Seismic Profile (WVSP) can be utilized for localized AVO inversion. Traditionally WVSP are designed for one of the following three purposes: imaging, anisotropy and AVO/AVA analysis. This paper shows a set of conditions that allow for WVSP data to be inverted following a commonly utilized simultaneous seismic inversion technique. The advantage of performing a localized WVSP AVO inversion is that low frequency models are measured during WVSP acquisition. This significantly reduces the ambiguity of the background models for inversion. Another advantage is that the inversion input derived during WVSP migration comes from measured vertical velocities, thus allowing more accurate angle stacks, thus improving the quality of the inversion. Lastly, WVSP images are generally of higher frequency content, thus producing high frequency density, Acoustic Impedance and VpVs images in the vicinity of the wellbore. The results can assist in calibrating the surface seismic inversion once more well data are available as well as making quick drilling decisions for deepening or side tracking wells.

IMPROVING QUALITY AND SAFETY THROUGH THE USE OF A PURPOSELY DESIGNED TRUCK-MOUNTED VIBROSEIS FOR VSP SURVEYS

Timothy Dean[1], Darvin Lane[2], John Tulett[3] and Mark Puckett[4]*
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[2]Schlumberger, Houston, USA
[3]Schlumberger, Fuchinobe, Japan
[4]Schlumberger, Paris, France

Vibrators are the preferred sources for onshore vertical seismic profile (VSP) surveys. Truck-mounted units are especially useful as they are more road mobile than buggy-based units. In particular, they can be driven directly to the wellsite, resulting in improved response times, simplified logistics with fewer vehicles and personnel at the wellsite and improved transport safety.

Acquiring broad-bandwidth, high-quality VSP data, using state-of-the art vibrator equipment, however, has generally required the use of the latest buggy-mounted vibrators, compromising well-site logistics and transportation safety for VSP operations. To deliver optimum performance, two new truck vibrator models specifically designed to take advantage of all of the most recent developments in vibrator technology while retaining the logistical advantages of truck-mounted units have been developed.

These new truck-mounted vibrators offer greatly improved data quality with tests showing that they can transmit a signal with a frequency bandwidth of 6.6 octaves compared to previous models which can only transmit 2.5 octaves. Being mounted on modern truck chassis these vehicles retain all the mobility and HSE advantages of truck vibrators.

15:30–17:30
Day 1 Session 4 Stream 3

LAND SEISMIC

KEYNOTE ADDRESS: HIGH RESOLUTION ACQUISITION MODELING TO MEET IMAGING REQUIREMENTS

*Andreas Cordsen**
WesternGeco

Oil and gas companies had their seismic data acquisition modelled for many years. Our industry has now arrived at a time when realistic earth modelling, together with 3D finite difference modelling of different acquisition geometries, can produce realistic results prior to going to the field, whether onshore or offshore prospect. This comparative effort significantly decreases the risk that is often involved with seismic data acquisition and it increases the likelihood of obtaining data fit for purpose. Modern acquisition techniques require a huge amount of equipment resources, and the investments of the oil companies must be protected.

This presentation will demonstrate the possibilities globally and highlight some local case histories.

CHASING AUSTRALIA'S UNCONVENTIONAL RESOURCES WITH POINT-SOURCE, POINT-RECEIVER, FULL AZIMUTH SURFACE SEISMIC

Anastasia Poole[1], *Peter van Baaren*[2], *John Quigley*[3], *Gabriele Busanello*[1], *Jennifer Badry*[1]*, *Chester Hobbs*[1], *Brendon Mitchell*[4] *and David Schmidt*[4]
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[2]WesternGeco, Sneek, Netherlands
[3]WesternGeco, Gatwik, UK
[4]Drillsearch Energy Limited, Sydney, Australia

Detection of so called 'sweet spots' can be crucial for efficient development of unconventional reservoirs. An example is the REM shale gas interval in Queensland. Adequately sampled surface seismic has the potential to decrease risk in well planning. Identifying areas of the reservoir which are already naturally fractured or where minimum effort is required for stimulation is the ideal objective.

Seismic methods can be utilized in unconventional resources characterization studies to achieve an improved understanding of the entire reservoir heterogeneity, structure and stress orientation. This leads to identification of production sweet spots and more efficient well placement. To enable this type of study with surface seismic, we need to analyse the data not only against offset (reflection angle) but also azimuth (compass direction). This requirement places a larger demand on the seismic than would be needed for a purely structural image.

In this paper we will describe the use of best-practice solutions based on experience in Australia and elsewhere for the design and implementation of the high specification Winnie 3D seismic survey. This survey featured broad-band point-sources using a non-linear Maximum Displacement sweep of 1 to 100 Hz and broad-band point-receivers. The omnidirectional symmetrical dense sampling, in combination with long offsets, resulted in uniform azimuthal coverage and extremely high trace density. This design makes the ideal 'antenna' for the azimuthal analysis and the broad-band approach enables prestack inversion and seismic attributes extraction.

We will demonstrate how this 3D design, specifically tailored for unconventional targets, resulted in good signal-to-noise datasets. Early stage data processing was suitable for detecting velocity anomalies. These may correlate with overpressure zones, representing potential prospective areas and identify possible drilling hazards such as volcanic intrusions. We will also demonstrate how the coordinate driven noise attenuation approach produced good quality prestack gathers for AVO/AVAz analysis.

COMPARISON OF NEAR-SURFACE PROPERTIES DERIVED FROM NON-LINEAR INVERSION OF REFRACTION AMPLITUDES VERSUS THE REFRACTION CONVOLUTION SECTION

Alan Meulenbroek[1,2]*
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The amplitude of a critically-refracted arrival is proportional to the strength of the shot and inversely dependent on the offset at which the refraction energy is measured. The constant of proportionality is the head-wave coefficient. This term is itself a function of the physical properties of the layers through which the wave propagates. With knowledge of the sub-weathering layer velocity, it is theoretically possible to derive the surface-layer velocity from the head-wave coefficient. This can be of use when the surface-layer velocity is unknown, e.g., surveys in which a surface source is used. Improved understanding of the surface-layer velocity has practical value in statics solutions and geotechnical engineering.

In order to derive near-surface properties from the head-wave coefficient, the effects of the shot and offset must be removed. One published method of doing this is to calculate the amplitude product of forward and reverse shot records which have been convolved together (RCS method). The resulting amplitude product is proportional to the square of the head-wave coefficient. An alternative approach is to formulate the problem as a surface-consistent, non-linear inversion scheme. The Levenberg-Marquardt algorithm is used to invert observed amplitude into constituent shot, receiver and offset terms. The receiver term is assumed to be representative of the head-wave coefficient.

This paper applies this inversion technique to a Vibroseis dataset acquired by Geoscience Australia near Wirrinya in NSW in 1999 which has been previously analysed using the RCS method. Regularisation of the inverse problem is also discussed in the context of the speed of the problem converging to a stable solution and potential effects on the solution itself.

IMPROVEMENTS IN LAND SEISMIC STATIC CALCULATION VIA SIMULTANEOUS JOINT INVERSION AND INTEGRATED EARTH MODELING

M. Mantovani[1], *M. Clementi*[1], *F. Ceci*[1], *G. Busnello*[2], *I. Guerra*[2] *and G. Kramer*[2]*
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[2]WesternGeco, Perth, Australia

With the growth in geographic scale of land seismic exploration, increasingly complex near-surface modelling capabilities are being employed for static corrections in seismic data processing. Conventional techniques making use of first-break refraction arrivals tend to fail when first-arrival quality is poor (as is common with vibroseis sources) and are also challenged by geological complexity of the near-surface such as presence of velocity inversions or low-velocity zones. Automated first-arrival picking can introduce systematic error to the process, but the introduction of other data types can be used to improve the quality of the result.

In GLI Refraction Statics or GRM information on the velocity of the weathered near-surface layer is required. In the case of vibroseis acquisition, near-surface velocity information typically requires a separate uphole survey.

Simultaneous Joint Inversion (SJI) is an emerging technique that allows exploitation of multiple data types linked through the earths' geometrical or petrophysical properties. Used as static solver, the tool allows replacement of uphole shots by more economical surface soundings such as gravity, electromagnetics, and/or Rayleigh waves to build a velocity model. Single domain inversions of the individual data types are used to determine a near-surface starting model which is then refined through joint inversion with links provided by rock physics relations. This approach has proved effective and robust in overcoming local or systematic errors in seismic first-break interpretation.

While penetration depth and resolution will vary with the type of complimentary data available, the P-Velocity obtained through SJI of surface data generally extends deeper than what is required for static correction. Velocity models developed through this approach do not suffer from velocity-depth ambiguity and provide a well resolved shallow model for seismic depth imaging.

We will present the theory of this approach with examples drawn from recent projects.

DECONVOLUTION OF CORRELATION NOISE IN CODED-IMPACT SEISMIC SYSTEMS

Stewart Fletcher[1,2]*, *Steve Hearn*[1,2] *and Shaun Strong*[1,2]
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For several decades, Vibroseis has been the default surface source for land seismic reflection. There are, however, situations where Vibroseis is not appropriate, for logistical, environmental or economic reasons. An alternative is provided by coded-impact systems such as Mini-SOSIE or SIST (Swept Impact Seismic Technique). These systems use a smaller, impulsive source (e.g. road compactor, jackhammer) delivering a sequence of low-energy impacts in a controlled pattern. Stacking yields a signal with good bandwidth and acceptable signal-to-noise ratio.

Coded-impact sources can provide very effective in-fill for zones where Vibroseis is not viable. The main disadvantage is much slower production than Vibroseis. Improved productivity can be achieved by using a more rapid impact sequence, or multiple simultaneous sources. However, this has the undesirable side effect of degraded record quality, due to increased correlation noise (also known as stacking noise).

The level of correlation noise on Mini-SOSIE records depends mainly upon the human operator being able to effectively randomise the timing of impacts. This in turn is limited by the design of the source equipment. SIST generates the impacts in a 'sweep' of increasing impact frequency. It has the potential for more rapid acquisition than Mini-SOSIE, with more repeatable record quality. Unfortunately, the non-random nature of the impact sequence can potentially lead to significant correlation noise.

This paper introduces an elegant approach to correlation-noise attenuation, utilising a Weiner filter designed on the known impact sequence. Numerical models demonstrate that the algorithm can achieve very significant attenuation of correlation noise in both Mini-SOSIE and SIST records. The practical viability of the approach is examined with reference to real-data examples.

This procedure has the potential to provide records of acceptable quality from rapid impact sequences, yielding significant productivity benefits over current Mini-SOSIE and SIST approaches.

1530–1730
Day 1 Session 4 Stream 4

MINERALS & GEOTHERMAL – RESISTIVITY & MT I

JOINT SENSING OF B AND DB/DT RESPONSES

*James Macnae**
RMIT University, Melbourne, Australia

In electromagnetic exploration using broadband sensors and systems, joint recording of B and dB/dt data derived from the same physical sensor allows for a greater number of 'signal' bits that lie above sensor noise. Optimum choice of a crossover frequency where the gains of B and dB/dt data match may double the number of useable bits. Field data confirms general expectations that B mode of operation is good at low frequencies, dB/dt operation good for high frequencies, but that both can be collected from the same ARMIT sensor.

ORION TRUE 3D DCIP – WHY DOES IT GIVE SUCH HIGH DEFINITION?

*Wayne Stasinowsky**
Quantec Geoscience, Toronto, Canada

True 3D IP is defined to mean acquisition where the current flow is sampled in multiple directions up to and including orthogonal from a single injection point.

To achieve this, orthogonal receiver electrodes must also be used to prevent losing coverage where electrodes might otherwise be null coupled.

Using this configuration, Quantec Geoscience's Orion system has demonstrated far greater geological definition than any conventional configuration including offset IP or multiple 2D lines inverted as a 3D dataset.

The reasons for the greater definition lie in several key aspects of the Orion layout including not only the large number of data points recorded but also that these data points are recorded in a true omnidirectional fashion. All receivers on the grid record the response for each current injection. This results in multiple intersecting current paths over the entire survey area.

3D inversions can use the multiple intersecting current paths to create a more geologically realistic inversion model with no acquisition directional bias.

Results from actual field surveys show this increased definition through a high correlation with drill results.

RESULTS FROM LONG-PERIOD MT ARRAY IN THE NEWER VOLCANIC PROVINCE, WESTERN VICTORIA, AUSTRALIA

Sahereh (Sasha) Aivazpourporgou[1]*, *Stephan Thiel*[2], *Patrick Hayman*[1], *Louis Moresi*[1] *and Graham Heinson*[2]
[1]Monash University, Melbourne, Australia
[2]The University of Adelaide, Adelaide, Australia

The Newer Volcanic Province (NVP), western Victoria, Australia, represents the most extensive and youngest volcanism

of the entire intraplate volcanic field of eastern Australia. The nature of, and mechanism(s) for, melting of the source magma of the NVP is still unclear. Previous teleseismic studies associate the magma genesis for the NVP to conduits of a mantle plume.

Here we present data from a long-period MT array conducted over the same grid as the teleseismic survey, across the southern end of the Lachlan and the Delamerian Orogenies, western Victoria in a rectangular grid with nominal 270 km × 150 km dimensions. Forward modelling of MT data suggests that the lithosphere beneath the Lachlan orogeny is more conductive than the Delamerian counterpart by several orders of magnitude, perhaps associated with thinning of the lithosphere beneath the Lachlan orogeny. The phase tensor analysis illustrates that there is an increasing conductivity trend beneath the Central Highlands, observed up to 500s, that is perhaps associated with NVP magma source region. Furthermore, the geoelectric strike direction beneath the Central Highlands is aligned parallel to the NW-SE Mesozoic-Cenozoic fracture zones, which coincides with the highest density of eruptions of the volcano field.

MAGNETOTELLURIC CHARACTERISATION OF THE HABANERO GEOTHERMAL EGS PROJECT – INITIAL RESULTS ON FLUID INJECTION MONITORING AND REGIONAL GEOLOGY

Stephan Thiel[1]*, *Yohannes Lemma*[1] *and Jared Peacock*[2]
[1]SACGER, University of Adelaide, Adelaide, Australia
[2]US Geological Survey, Boulder, USA

Magnetotelluric data has been collected across the Habanero geothermal site in the Cooper Basin, South Australia, in view of delineating the crustal structure underneath the geothermal area and to monitor fluid injection of the Habanero 3 borehole. Two surveys have been carried out. Initially, two perpendicular profiles have been established, each about 20 km long, to obtain 2D profiles across the Habanero site. The aim is to estimate the sediment thickness to allow for constrained 3D forward modelling for fluid injection scenarios. Furthermore, the broadband data with periods up to 1000 s allows a view into the crust. Geochemical data from the Mound Springs shows that the seeping water contains a minor component of mantle CO_2. MT can be used to image the fluid pathways if such a connection exists. The results will be compared to recent findings from fluid pathways in the Lake From embayment a few hundred km south of the Cooper Basin. Additionally, initial results from the fluid injection monitoring experiment of the Habanero 3 borehole will be shown. In November 2012, fluids were pumped at depth of around 4 km for a period of two weeks. The fluids exceed the amount introduced into the Paralana EGS in July 2011, however a pre-existing fluid reservoir from a prior fluid injection exists. We report on surface MT response changes due to the fluid reservoir at depth.

MAGNETOTELLURIC EXPLORATION AT TENDAHO HIGH TEMPERATURE GEOTHERMAL FIELD IN NORTH EAST ETHIOPIA

Yohannes Lemma Didana [1]*, *Stephan Thiel* [1] *and Yiheyis Kebede* [2]
[1]The University of Adelaide, Adelaide, Australia
[2]Geological Survey of Ethiopia, Addis Ababa, Ethiopia

Tendaho is one of the high temperature geothermal areas in Afar depression in north east Ethiopia. A total of 129 MT sites were acquired from Tendaho high temperature field. The 2D inversion of MT data from Tendaho high temperature field revealed three main resistivity structures down to a depth of 15 km: low resistivity surface layer underlain by a resistive layer followed by good conducting structure. The low resistivity surface layer show areas with either sediments, lateral flow of geothermal fluids or zeolite-clay alteration zone. Below the conductive layer, is a high resistivity zone that can be correlated to Afar stratoid basalts or epidote alteration zone. The high resistivity structure has been associated with the deep reservoir of the geothermal system. The deep good conductive body is probable heat source of the geothermal system. The possible fracture zone inferred in the Afar stratoid basalts may give high temperature and high permeability. The 2D resistivity elevation slices showed possible upflow zone south east of the exploratory wells drilled in Dubti area.

VIRTUAL GEOPHYSICS LABORATORY (VGL) VERSION 1.1: RECENT DEVELOPMENTS TO INCORPORATE 3D GEOLOGICAL MAPS AND THERMAL MODELLING USING THE UNDERWORLD SOFTWARE

Alison Kirkby[1]*, *John Mansour*[2], *Steve Quenette*[2], *Josh Vote*[3], *Ryan Fraser*[3], *Terry Rankine*[3] *and Richard Goh*[3]
[1]Geoscience Australia, Canberra, Australia
[2]Monash University, Melbourne, Australia
[3]CSIRO, Australia

One of the major impediments to the successful development of Australia's geothermal energy resources is uncertainty around the temperature distribution in the crust. Although significant in number, the coverage of temperature measurements from wells is unevenly distributed across the continent. To overcome this impediment, thermal modelling applied to 3D geological maps is a means of predicting temperature distribution between and beneath measurement points.

Underworld is a parallel, 3D geodynamic modelling code which can be used to model the temperature distribution in 3D (Quenette and Moresi, 2010). Despite its scalability and the fact that it is open-source, its uptake to date has been limited by the fact that it is not easily usable by non-specialists. In particular, the process of converting 3D geological maps and physical property data to a format that can be numerically analysed in Underworld is not straightforward.

As part of a NeCTAR funded project, Geoscience Australia is working with Monash University, CSIRO, and the National Computing Infrastructure (NCI) at the ANU, to develop tools to streamline the process of importing a 3D map to Underworld, running a model and exporting the results for analysis and visualisation. The project will incorporate Underworld into the Virtual Geophysics Laboratory (VGL), an environment which enables geoscientists to store, discover, retrieve and process datasets. The goals of the project are:
1. With Monash University, develop code that allows Gocad format 3D maps to be imported to Underworld.
2. Incorporate the 3D geological maps, and Underworld, into VGL to provide an interface for both discovering and selecting 3D maps, and importing and running them in Underworld.

1530–1730
Day 1 Session 4 Stream 5

MINERALS GRAVITY GRADIOMETRY & AEM

EVALUATING GRAVITY GRADIENT TENSOR COMPONENTS

*Mark Pilkington**
Geological Survey of Canada, Ottawa, Canada

Gravity gradiometry offers multiple single components and possible combinations of components to be used in interpretation. Knowledge of the information content of components and their combinations is therefore crucial to their effectiveness and so a quantitative rating of information level is needed to guide the choice. To this end we use linear inverse theory to examine the relationship between the different tensor components and combinations thereof and the model parameters to be determined. The model used is a simple prism, characterized by seven parameters: the prism location, xc, yc, its width w and breadth b, the density ρ, the depth to top z, and thickness t. Varying these values allows a wide variety of body shapes, e.g., blocks, plates, dykes, rods, to be considered. The Jacobian matrix, which relates parameters and their associated gravity response, clarifies the importance and stability of model parameters in the presence of data errors. In general, for single tensor components and combinations, the progression from well- to poorly-determined parameters follows the trend of ρ, xc, yc, w, b, z to t. Ranking the estimated model errors from a range of models shows that data sets consisting of concatenated components produce the smallest parameter errors. For data sets comprising combined tensor components, the invariants I1 and I2 produce the smallest model errors. Of the single tensor components, Tzz gives the best performance overall, but those single components with strong directional sensitivity can produce some individual parameters with smaller estimated errors (e.g., w and xc estimated from Txz).

GETTING THE BEST VALUE FROM GRAVITY GRADIOMETRY

Desmond FitzGerald and Rod Paterson*
Intrepid Geophysics, Melbourne, Australia

The critically important steps to get best value from your gravity gradiometry data, assuming your contractor has done his job well in designing and acquiring the data, is the preparation of the representation of the potential field gradients.

The ~200m resolving power of existing gradiometer systems approaches what is necessary for minerals applications. In particular, beyond the aircraft, the topographic surface represents the largest and most proximal density contrast encountered in an airborne survey. Hence terrain effects can have significant impact on AGG data.

The critical steps are:
Terrain correction and determining ‘best’ terrain density
Gridding, using all the measured gradients to constrain the interpolation
Smoothing while honouring the 3rd order tensor constraints
Anti-alias filtering of the gradient signals so that wave lengths are properly represented in all directories and no distortions exist along line
Transformation of the gradients by integration to estimate the gravity or magnetic field.

Terrain corrections are a necessary step in the processing of observed AGG data in rugged terrain, in order to highlight subsurface density variations with a minimal overprint from the terrain. We propose a simple and rapid AGG tensor-based method to estimate an optimum bulk terrain density for subsequent terrain-correction.

Each of the currently deployed systems for acquiring gradiometry is evolving driven by competition and the users’ needs. Mining applications of the technology to directly detect ore-bodies that are anomalies, can now be successful provided the dimensions are of the order of 200m or more.

EVALUATION OF AN UNMANNED AIRCRAFT FOR GEOPHYSICAL SURVEY

*Adam Kroll**
Shift Geophysics, Perth, Australia

UAV use in airborne geophysics is now a reality with companies such as Shift Geophysics, Universal Wing and TGS. There are many significant differences between an unmanned aircraft geophysical survey and a manned geophysical survey. Explorers wishing to conduct an airborne geophysics survey need to be aware of the differences as they affect data quality, safety, legality and logistics required.

Data quality can be affected either positively or negatively depending on the type of UAV used for the type of geophysics data acquisition. Magnetic data is negatively affected by electromagnetic noise. Due to the small size of a fixed wing UAV compared to a manned plane the magnetometer is placed much closer to noise interference, such as the electronic ignition of the engine, payload electronics and servomotors which move the control surfaces. If the separation can be achieved this will result in excellent magnetic data as the noise sources are of lesser amplitude.

Safety risks differ with UAV aircraft over manned aircraft. Many risks are mitigated, however other risks are introduced which are not present with manned aircraft and effective methods to mitigate those risks are required. Differences in regulation also produce differences in minimum safety standards a company can employ.

Regulation for UAV’s differ from manned aircraft and differ for regions around the world. Regulation differences also produce differences in the quality of geophysical data as aircraft operators can conduct the survey flying differently.

All of the factors mentioned need to be weighed up before choosing a contractor to carry out a geophysical survey for your company. Different companies will have different priorities on all of the items listed above and therefore no one company will suit all exploration terrains and targets.

CORRECTING FOR SPM EFFECTS IN AIRBORNE EM

Terence Kratzer[1], *James Macnae*[1]* *and Paul Mutton*[2]
[1]RMIT University, Melbourne, Australia
[2]Southern Geoscience Consultants, Perth, Australia

Recent noise reductions in AEM (airborne electromagnetic) systems have allowed detection of conductors at great depths, but systems now have also become sensitive to superparamagnetic (SPM) effects. We distinguish SPM effects in airborne electromagnetic survey data from the response of good conductors. In electromagnetic data processing, off-time data can be accurately represented as amplitudes of a set of basis functions that are comprised of decays that decrease exponentially as a function of time. The SPM impulse response can be approximated by a decay that is proportional to time to the inverse power, a time dependence associated with magnetic viscosity. We identify the presence of SPM effects, as distinct from the decay of good conductors, by using inverse power-law decays as additional basis functions in constrained least-squares fitting. Application of the method to airborne TEM (time-domain electromagnetic) surveys shows that the method allows correction of SPM and hence aids significantly in conductive target identification.

INTERGRATIVE GEOPHYSICAL APPROACH FOR ASSESSING THE PROSPECTIVITY OF THE IDELWILDE INTRUSION, NSW

Aurore Joly, David Maidment and Graham Miller*
St Barbara, West Perth, Australia

The Idlewilde Intrusion (IWI) sits below ca. 150 m-thick sediment overburden and consists of a Palaeozoic basement of presumed Ordovician Macquarie Arc volcanics and the Nyngan Intrusive Complex. The geological setting is similar to the gold-rich Cadia and Northparkes porphyry-style deposits. Geophysical data include ground gravity, airborne magnetic and electromagnetic.

Gravity data define a negative ovoid with an elevated gravity inner zone. Magnetic data show a central high surrounded by a circular low zone as part of a broader regional low. Electromagnetic data outline: (a) a ca. 150 m-thick dual conductor corresponding to the overburden; (b) a medium conductor associated with the volcanics; (c) a resistor linked to the intrusion and (d) a slightly conductive annulus around the resistor interpreted as alteration, but may instead reflect the lack of sensitivity below the conductive overburden. The central part of the intrusion associated to gravity and magnetic highs could conceivably correspond to: (1) a magnetite-altered potassic core characteristic of gold-rich porphyry, (2) eroded granite with volcanics close to the surface, (3) roof pendant volcanics above a barely-eroded granite, and (4) a late monzonite pulse.

From an exploration point of view, gravity data delineate the extent of the IWI. The regional low magnetisation suggests that the intrusion may be a later intrusive phase. Electromagnetic data identify the footprint of a granitic body which cannot be clearly associated with an alteration system because of conductive overburden. A mineralised system is yet to be identified, and one of the first company priorities is now to resolve the inner part of the IWI.

Day 2: Tuesday 13 August 2013

0830–1030
Day 2 Session 1 Stream 1

SEISMIC ACQUISITION – TECHNOLOGIES

KEYNOTE ADDRESS: MORE MEASUREMENTS, MORE SOURCES: IMPLICATIONS OF THE RECENT ADVANCES IN MARINE SEISMIC TECHNOLOGY

*Craig Beasley**
WESTERNGECO

Recent years have seen dramatic technical advances in both receiver and source technologies in marine acquisition. Multimeasurement receiver technology that measures not only the pressure wavefield but also pressure gradients enables both accurate removal of the 3D receiver ghost and higher resolution data. Similarly, the SimSource* simultaneous source acquisition and processing technique has now seen commercial application for both towed marine and ocean bottom cable acquisition providing higher fold, decreased shot interval and more shots in a give time frame . These two technologies promise a step change in the cost/quality relationship for marine acquisition. This talk gives a non-technical overview of these advances and focuses on results achieved.

SIMULTANEOUS SOURCES IN MARINE ACQUISITION: EXPERIENCES TO DATE

Roald Van Borselen, Andrew Long and Rolf Baardman**
PGS

A modified inversion approach is presented for the effective separation of sources in marine simultaneous shooting acquisition. The method aims to distribute all energy in the simultaneous shot records by reconstructing the individual shot records at their respective locations. The method is applied to a simulated simultaneous long offset data set, where two sources are used to acquire long offsets with conventional cables. In the second example, the performance is investigated on a data set from Western Australia, where two sources where located within close proximity, with only a small cross line distance between them. Results demonstrate that the individual sources can be separated satisfactory for both simultaneous source configurations.

SIMULTANEOUS SOURCES: RECENT ADVANCES IN MARINE ACQUISITION AND PROCESSING

*Ian Moore**
WesternGeco, Perth, Australia

Until recently, seismic data acquisition has been fundamentally limited by the requirement that the delay time between one shot and the next be sufficient to avoid significant contamination of data from one shot with energy from another. Acquisition with simultaneous sources drops this requirement, and therefore provides potential for enormous improvements in acquisition rates and source sampling. In order to realize this potential however, the way we acquire and process data must change.

The use of simultaneous sources is now a commercial reality for marine data. There is, however, significant scope for development both in the acquisition design and the data processing. Conventional processing based on ‘shot records’ ceases to apply in the general case that shots are taken at arbitrary times, and many of the conventional constraints on the acquisition design can be relaxed when shots are allowed to interfere. The recorded data become a continuous stream for each sensor, and new processing algorithms are required to handle the generalized interference.

This paper extends the current processing ideas used for the simple, marine simultaneous-source scenarios previously presented to the more general case, and illustrates the potential and the issues involved using simulated datasets for which the correct answer is known. The shot timing and sampling is, as might be expected, a critical factor in the survey design if processing is to be successful. Provided the survey is designed appropriately, it is shown that the use of simultaneous source technology can improve both acquisition efficiency and the quality of the final product.

0830–1030
Day 2 Session 1 Stream 2

ADVANCED SEISMIC INTERPRETATION

KEYNOTE ADDRESS: GLOBAL SEISMIC INTERPRETATION TECHNIQUES ARE COMING OF AGE

*Paul De Groot**
dGB Earth Sciences, Enschede, Netherlands

In recent years, a group of seismic interpretation techniques have emerged that aim to arrive at fully interpreted seismic

volumes. Collectively, these techniques are known as: 'global seismic interpretation techniques'. The classification 'fully interpreted seismic volume' is misleading as it suggests that no further interpretation is needed. In actual fact the fully interpreted volume marks the starting point for advanced interpretation workflows aimed at extracting more geologic information from seismic measurements. This paper gives an update on global seismic interpretation techniques and how they are used to add value to seismic data. Application domains include seismic sequence stratigraphy, model building & seismic inversion, geo-steering and geohazard interpretation.

DATA DRIVEN – INTERPRETER GUIDED GEOBODY INTERPRETATION

Nicholas McArdle and James Lowell*
ffA, Aberdeen, UK

Fully volumetric interpretation needs to encompass 3D delineation of geological features beyond the extraction of top and base horizons. To address this issue 3D geobody delineation techniques based on thresholding and voxel connectivity have been developed. Such techniques have limited applicability as there is often insufficient information to enable the discrimination of the constituent components of a geological system based on the seismic data alone.

Understanding how we perceive objects in images is central to the development of better interpretation tools. What we perceive in data is strongly influenced by geological knowledge, previous experience and analogues. These are subjective factors but to produce geologically realistic results we need to find a way of incorporating them within 3D geobody interpretation. A large step in this direction has been taken with a technology known as "adaptive geobody delineation". The adaptive geobodies technique combines an adaptive, classification based region growing method, with interactive 3D surface manipulation techniques. This enables delineation of 3D geobodies that are a best fit to the data whilst matching the interpreter's view of what is geologically realistic.

This paper will discuss how we perceive objects in images and, in the context of 3D geobody definition, how we can improve data analysis techniques for objectively delineating what we understand the image to represent.

We present the potential utility of these techniques applied to the delineation of a variety of geological elements from seismic data acquired from the North Carnarvon Basin, North-Western Australia. These include fluvial and deltaic systems, submarine canyons and fans, carbonate reefs and clinoform complexes through to sub-reservoir scale lithofacies variation.

The wide range of features of varying scale, morphology and depositional origin that have been successfully extracted within the sample sets demonstrates the broad applicability of the tool.

DIGITAL SURFACE ANALYSIS: A COMPLETELY NEW APPROACH USING DIFFERENTIAL GEOMETRY

James Dirstein[1], Stano Hroncek[2] and Paul Ihring[2]*
[1]Total Depth Pty Ltd, Subiaco, Australia
[2]GeoProxima Pty Ltd, Manly, Australia

After more than a decade of research and development our Eureka Moment is presented discussing a new differential geometry solution applied to the problem of digital surface analysis. The solution applies a completely different approach in mathematics without the use of existing techniques or algorithms. The process entails the calculation of a complete set of morphometric properties for the surface as it is defined by Differential Geometry. All processing of the data is automated, fast and accurately locates objects within the surface without the introduction of high frequency artefacts commonly associated with existing approaches. A number of objective evaluation methods are demonstrated offering comparative analysis with other published technologies on known mathematical models (with noise). Real data examples are provided showing the application of this technology on the analysis of data surfaces from seismic and potential fields surveys. The queryable database of accurate and high quality elements becomes and essential aspect to highly simplify and speed up the data mining process. While this new approach and philosophy is demonstrated here on specific types of surface data, it has application to problems related to the analysis of any digital signals, images, surfaces and volumes.

0830–1030
Day 2 Session 1 Stream 3

MINERALS – STATISTICAL METHODS IN AEM MAPPING

PROBABILISTIC INVERSION OF AIRBORNE ELECTROMAGNETIC DATA FOR A MULTIDIMENSIONAL EARTH

Juerg Hauser, David Annetts and James Gunning*
CSIRO ESRE, Australia

The inversion of airborne electromagnetic data is inherently non-unique, especially when data uncertainties are taken into account. If one model can be found that fits the data, then it is likely that there are alternative models that fit the data equally well. The probabilistic approach introduced in this work therefore aims at exploring the posterior distribution which is the distribution of models that are in agreement with both the prior information and the data. We quantify the prior information using geostatistics and use a Markov Chain Monte Carlo technique to sample the unknown posterior distribution. Data are predicted taking lateral changes in structure along the flight path into account by employing a 2.5D forward solver. A case study using the Harmony Ni-S deposit in Western Australia shows that our set of samples of the posterior distribution provides a more complete picture of solution space than what can be achieved by non-linear iterative inversion schemes that have previously been employed. Such a picture of the subsurface can ultimately be used to mitigate exploration risk.

CONDITIONAL AND MARGINAL PROBABILITIES IN AEM INVERSIONS USING MULTIVARIATE GAUSSIAN STATISTICS

Aaron Davis[1], Andrew King[1], Niels Christensen[2] and Tim Munday[1]*
[1]CSIRO, Perth, Australia
[2]Aarhus University, Aarhus, Denmark

AEM inversions often involve linearised approximations to the calculation of the Jacobian and Hessian matrices in the forward

solution. This results in a second order Taylor series expansion of the estimation of an error surface when calculating the misfit between forward model data and measured data. In the vicinity of a minimum in the error surface, the first-order terms drop out and only second-order terms are present. This guarantees that model parameters resulting from the inversion will be Gaussian distributed with mean model parameter values and model parameter variance terms. The first set is the output of the inversion that is most often used, and we produce conductivity-depth sections from the mean model parameters. However, we are then neglecting the fact that those parameters contain variances which are also of value. In reality, because of the way we have constructed the inversion scheme, the model variance terms contain information about how each model parameter interacts with each other model parameter for a given inversion output result. The collection of variances is most easily assembled in the posterior covariance matrix, where terms on the main diagonal are the autocorrelation values and terms off the diagonal are the cross-correlation or covariance terms.

We examine the posterior covariance matrix terms, and exploit the well known characteristics of Gaussian statistics to ask meaningful conditional and marginal probability questions from the inversion data. This is done so that we can ask questions such as: 'Given that the aquifer I am interested in has conductivity ranges between x_low and x_high, where, how deep and how thick is the aquifer?' The result is a probability map that shows the most likely location of the structure of interest given the conditional statements made when posing the question.

CORRELATING ERT WITH AEM IN A ROCK SLIDE MAPPING PROJECT, SAME SHAPE BUT DIFFERENT QUANTITIES

Andi A. Pfaffhuber[1]*, *Sara Bazin*[1], *Matt J. Lato*[1,2] *and Ulrik Domaas*[1]
[1]NGI, Oslo, Norway
[2]RockSense GeoSolutions Inc., Ottawa, Canada

We investigate an active rock slide in Western Norway with ground- and airborne resistivity mapping to ultimately find weakness zones & sliding planes embedded in crystalline bedrock. The study area comprises phyllite, a low grade metamorphic rock type that tends to be reworked to clay in disturbed zones. Mapping these electrically conductive clay zones was the aim of the survey. GPS measurements over the last 5 years indicate that precipitation drives rock slide movements. The role of ground water is thus a crucial factor to investigate for risk assessment in the area.

Based on a successful airborne electromagnetic (AEM) demonstration survey, we conducted a total of 1.600 profile meters of ground resistivity (ERT) measurements to confirm AEM anomalies, to gain precise 2D geometries and to link conductivity anomalies with geology.

All resistivity results confirm AEM anomalies and refine their lateral extent. In the East we find consistency between a strong conductor, dipping sub horizontal SW with an outcropping thrust fault, separating phyllite and gneiss. In the West a conductor dipping steeply NNW seems to be fed by surface water and may represent a formerly unknown sliding plane. While ERT and AEM anomaly shapes generally agree within their mutual resolution limitations, the resistivity values significantly deviate. It remains unclear whether anisotropy or strong 3D artefacts cause this disagreement.

FIXED WING VS. HELICOPTER AIRBORNE EM FOR MAPPING FINE SCALE CONDUCTIVITY VARIATIONS IN TRANSPORTED SEDIMENTARY COVER ASSOCIATED WITH SEDIMENTARY URANIUM MINERALISATION

Camillia Sorensen[1]*, *Tim Munday*[2] *and Jason Cherry*[3]
[1]University of Adelaide, Adelaide, Australia
[2]CSIRO, Perth, Australia
[3]Uranium1, Adelaide, Australia

The constant development and improvement of Airborne Electromagnetic (AEM) systems is not questionable. Contractors are constantly pushing their systems to see deeper, fly faster, output higher moment and to achieve a better resolution. Recording and archiving system parameters is becoming more standard practice than it used to be – making it easier to derive accurate conductivity-depth products from the acquired data. Appropriate processing and inversion of the data to achieve reliable conductivity-depth products becomes particularly important when trying to define finer scale conductivity variations. This variability may be relevant when determining aquifer bounds, groundwater quality differences, regolith discontinuities to assist geochemical sampling strategies and/or geological unit boundaries that have exploration significance.

In this paper, we examine the importance of understanding how a variable vertical constraint (or roughness) can influence the detail obtained from an inversion of AEM data within an alternating sequence of lacustrine and fluvial sediments in the southern Frome Embayment in South Australia. Specifically we compare results from the inversion of coincident fixed-wing (TEMPEST), helicopter time domain EM (SkyTEM508) data and ground EM data. We demonstrate how the manipulation of inversion parameters can significantly influence the detail obtained from an inversion of TEMPEST data when exploring through these transported sedimentary sequences. At local scales, vertical changes in conductivity can be resolved that better match those defined in the higher resolution SkyTEM data, borehole conductivity logs and ground TEM soundings. We also show how the use of both smooth and blocky model inversions can assist the understanding of the geometry and variability of these sediment packages that have associated uranium mineralisation. Our results emphasise the importance of carefully considering the output product being used and the processing employed, particularly when exploring through cover.

0830–1030
Day 2 Session 1 Stream 4

MINERALS – AEM INVERSION I

BIGGER, BETTER, SMARTER; HIGH PERFORMANCE COMPUTERS APPLIED TO GOVERNMENT GEOPHYSICS

*Ned Stolz**
Geoscience Australia, Canberra, Australia

Government Geological Surveys study the Earth at the regional, province or national scale, and acquire vast volumes of technically complex data. These data must be high quality, fit for purpose, durable, and readily accessible and usable by industry. Increasingly, users require the geological information contained

within the data as well as the data itself. High performance computers facilitate a step-change in advanced processing and modelling of large, complex data, and will help Government deliver more sophisticated products to industry. Data enhancement and manipulation are no-longer limited by the computational effort required, and there are no artificial limits to the size of the data or model, or the data resolution that can be processed.

Geoscience Australia is collaborating with the National Computational Infrastructure facility (NCI) at the Australian National University to develop advanced methods for extracting the maximum geological information from large data volumes. The new methods include: Modelling of potential-field data in spherical coordinates to create continental-scale reference models of density and magnetic susceptibility; Inversion of magnetotelluric tensor data to a full 3D mesh of resistivities, and; Monte Carlo inversions of AEM responses to assess the reliability and sensitivity of conductivity-depth images. These algorithms are being implemented in a new Virtual Geophysical Laboratory where Government data and advanced processing methods are brought together in a single high performance computer environment.

ULTRA-FAST 3D PARAMETERISED AEM INVERSION USING SPECTRAL METHODS

*James Macnae**
RMIT University, Melbourne, Australia

One of the first usages of spectral methods in EM was by Peter Annan in development of the algorithm for EM modelling program "PLATE", popular in the days of mainframe VAX computers. Using recent developments in spectral methodology and parallel computing on GPU boards, it is predicted to be possible on a desktop to run geologically plausible AEM forward models in microseconds, and inversions in milliseconds. In practice, the limitations of noise, imperfectly known waveforms, coupled with the effects of dielectric permittivity, viscous magnetism (superparamagnetism) and induced polarization conspire to limit the accuracy and speed of the process.

INVERSION OF SPECTREM AEM DATA FOR CONDUCTIVITY AND SYSTEM GEOMETRY

A. Yusen Ley-Cooper[1] and Ross C. Brodie[2]*
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[2]Geoscience Australia, Canberra, Australia

We evaluate the use of data from the fixed-wing Spectrem 2000 airborne electromagnetic (AEM) survey flown for ore body detection, regolith mapping and assessment of aquifers. Since the position and orientation of the receiver bird are not measured in the Spectrem system, the primary field at the bird cannot be known and removed precisely. In typical Spectrem data processing it is estimated and removed by subtracting out the last time window, relying on the assumption that the entire secondary field has decayed to zero by late-time. This is not generally a good assumption under the conductive regolith conditions and prevents the simultaneous fitting of both X- and Z-component data to within the noise envelope.

In order to successfully invert the AEM data, and produce conductivity's depth maps and sections, we first reinstate the removed primary field and convert the data from ppm units to Teslas. We then inverted the total (primary plus secondary) field data, to solve for a 1D conductivity model as well as the horizontal and vertical offsets and pitch of the receiver bird using Geoscience Australia's sample-by-sample inversion algorithm. High-altitude data and synthetic forward models were also analysed to better understand the system's noise.

Spectrem has flown many kilometres in other parts of the world but not that much in Australia. Our results highlight many similarities between Spectrem 2000 data and other systems previously flown over the same areas. Through our further processing and inversions we have resolved conductivity's depth structures very similar to those previously obtained from other well-established AEM systems flown under Australian conditions. We also present sections of AEM with project logged drilling core from both reverse circulation and diamond drill as means of cross validation of our derived inverted models with other data sets; which is always desirable.

HYBRID 1D/3D GEOLOGICALLY CONSTRAINED INVERSION OF AIRBORNE TEM DATA

Glenn Pears[1], Peter Fullagar[2] and James Reid[3]*
[1]Mira Geoscience Asia Pacific Pty Ltd, Brisbane, Australia
[2]Fullagar Geophysics Pty Ltd, Brisbane, Australia
[3]Mira Geoscience Asia Pacific Pty Ltd, Perth, Australia

TEM data are best interpreted in tight integration with geological data. A computer program, VPem1D, has been written to perform 1D TEM inversion in a 3D geological framework. The fact that VPem1D operates on a geological model facilitates a variety of inversion styles. For example, if one or more geological units are considered uniform in conductivity, the optimal conductivities can be determined for the entire survey area via homogeneous unit inversion. If geological units are variable in conductivity, heterogeneous unit inversion can be applied. Alternatively, because geological interfaces are captured in the model, geometry inversion can be used to adjust interfacial depths (e.g. depth to basement).

VPem1D inversion is directly applicable to data from variety of systems including (but not limited to) GEOTEM, TEMPEST, VTEM, Spectrem, SkyTEM, MegaTEM and Hoistem.

This paper will demonstrate the different inversion options as applied to a variety of case study data sets.

0830–1030
Day 2 Session 1 Stream 5

MINERALS CASE HISTORIES II

KEYNOTE ADDRESS: VISION FOR FUTURE EXPLORATION: GEOPHYSICS AND GOLD

*Barry Bourne**
Barrick Gold

GEOPHYSICAL SIGNATURE OF THE HOLLANDAIRE COPPER DEPOSIT, WESTERN AUSTRALIA

James Reid[1], David Price[2] and Ned Summerhayes[2]*
[1]Mira Geoscience, Perth, Australia
[2]Silver Lake Resources, Perth, Australia

In 2011 a review of an historical TEMPEST airborne electromagnetic survey in the Murchison Region of Western Australia identified a number of discrete bedrock conductor anomalies potentially associated with base metal mineralisation. One of the anomalies identified was in close proximity to a known gossan at Hollandaire, within rocks of the Archaean Mt Eelya Complex. The Hollandaire gossan had been previously investigated during the mid-late 1970's using a variety of geological, geochemical and geophysical methods, including ground magnetics, induced polarisation, magnetic induced polarisation and time-domain electromagnetics.

A single line of time-domain in-loop transient electromagnetic data was collected at Hollandaire during 2011, in order to follow up the TEMPEST bedrock conductor. A strong time-domain EM anomaly was identified, with a very high time-constant of 107 ms. Plate modelling of the in-loop data resulted in a target at depth-to-top 100 m, dipping at 45 degrees to the west-northwest, and with conductance 5000 S. The nine initial holes drilled to test the electromagnetic target all intersected sulphide mineralisation. The inferred resource now totals 2.8 million tonnes at 1.6% Cu, 0.4 g/t Au and 5 g/t Ag, with the supergene zone averaging 4.7% Cu. Subsequent downhole electromagnetic (DHEM) surveys have identified an off-hole electromagnetic conductor to the south of the known mineralisation, which has not yet been tested by drilling.

THE HOOD 10 VHMS DEPOSIT OF NUNAVUT, CANADA: A CASE HISTORY

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Hood 10 is a small polymetallic (Cu – Zn) VHMS mineral deposit located in the Archean aged Slave Craton in arctic Canada, and is 100% owned by MMG Ltd. The deposit is hosted in the Napaktulik volcanic belt, a bimodal greenstone belt of approximately 2.67Ga age. The deposit was initially discovered in the early 1970's by Texas Gulf, but the property has changed hands several times over the intervening years, with drill programs in the mid 1970's, early 1980's and early 1990's resulting in a non-JORC compliant resource of 1.2M tonnes of 4.4% Zn and 4.1% Cu. The ore body had been defined along a 250 m strike length and to a depth of 220m. The property was acquired by MMG Ltd in 2009.

The deposit was clearly visible as a small low apparent resistivity anomaly with a coincident magnetic high in a 1998 DigHEM survey and showed a small response in a 1993 in-loop fixed loop time domain EM (TDEM) survey. Axial component borehole TDEM measurements were undertaken on select holes during the 1992-1993 drilling campaign. MMG Ltd conducted significant geophysical exploration on the property for the first time in 2012 and acquired further surface and airborne TDEM over the deposit in conjunction with 3-component borehole TDEM on 11 of 12 holes drilled into the deposit that year. New geophysical modelling of the TDEM results, drilling results, recent surface geological mapping and structural studies have significantly increased the understanding of the deposit. The current non-JORC compliant resource stands at 2.4M tonnes of 3.52% zinc and 4.54% copper.

0830–1030
Day 2 Session 1 Stream 6

SURFACE WAVES IN HAZARD AND COVER STUDIES

THE GOOD, THE BAD AND THE UGLY – LESSONS FROM AND METHODOLOGIES FOR EXTRACTING SHEAR-WAVE VELOCITY PROFILES FROM MICROTREMOR ARRAY MEASUREMENTS IN URBAN NEWCASTLE

Michael Asten[1], Clive Collins[2], Theodora Volti[2] and Tatsunori Ikeda[3]*
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We report on our experience gained in applying the multiple-mode spatially-averaged coherency method (MMSPAC) at 25 sites in Newcastle (NSW) for the purpose of determining shear-wave velocity profiles as part of an earthquake hazard study.

The MMSPAC technique is logistically viable for use in urban and suburban areas, both on grass sports fields and parks, and on footpaths and roads. A set of seven recording systems designed for earthquake after-shock observations plus a team of three personnel is sufficient to survey three sites per day.

The uncertainties relating to local noise sources from adjacent road traffic or from service pipes contribute to loss of low-frequency SPAC data in a way which is difficult to predict in survey design. Coherencies between individual pairs of sensors should be studied as a quality-control measure with a view to excluding noise-affected sensors prior to interpretation; useful data can still be obtained at a sites one sensor is excluded.

The combined use of both SPAC data and horizontal:vertical spectral ratio (HVSR) data in inversion and interpretation is necessary in order to make effective use of low frequency data (typically 0.5 to 2 Hz at these sites) and thus resolve shear-wave velocities in bedrock below 20 to 50 m of unconsolidated sediments.

COVER DEPTH AND SEISMIC VELOCITY STRUCTURE ALONG A TRANSECT IN CENTRAL AUSTRALIA FROM PASSIVE SEISMIC SOUNDINGS

Nicholas Smith[1,2]*, *Anya Reading*[1], *Michael Asten*[3,4] *and Charles Funk*[2]
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The depth and seismic structure of stiff sediment cover overlying a prospective basement terrane were constrained with a passive seismic technique which uses surface wave energy from microtremor (also known as ambient seismic energy or seismic noise). Such constraints are very useful for mineral exploration under cover to decrease the inherent ambiguity in modelling potential field data for exploration targeting. We use data from small arrays of portable broadband seismometers, processed using both the Multimode Spatially Averaged Coherency (MMSPAC) method and the Horizontal to Vertical Spectral Ratio (HVSR) method, to produce profiles of seismic velocity structure along a 12 km transect. Wavefield conditions approaching the theoretical ideal for MMSPAC processing are created by combining the energy content of an off-road vehicle, driven around the seismometer array, and ambient sources. We find that this combination results in significantly higher quality MMSPAC waveforms in comparison to that obtained using ambient energy alone. Under ideal conditions a maximum depth of investigation of 500 m with a sensitivity to layer thicknesses of ± 5% can be achieved with a hexagonal sensor array with 50 m radius. A high velocity layer, if present in the sediment package, causes a reduction in the quality of the observed waveform frequency range which is sensitive to deeper structure. This can limit the model sensitivity for underlying layers but may be addressed by detailed analysis of the HVSR peaks. Microtremor recordings including off-road vehicle noise, combined with the MMSPAC and HVSR processing techniques, may therefore be used to constrain sediment structure and depth to basement in a cost effective and efficient method which could contribute greatly to future mineral exploration under cover.

DETERMINATION OF THE SITE CHARACTERIZATION PROPERTIES IN EASTERN SEGMENT OF THE NORTH ANATOLIAN FAULT ZONE IN TURKEY BASED ON THE MMSPAC METHOD

Fatma Nurten Sisman[1]*, *Michael Asten*[2] *and Aysegul Askan*[1]
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[2]Monash University, Victoria, Australia

Erzincan (a small city in Eastern Turkey) is located in the conjunction of three active faults: North Anatolian, North East Anatolian and East Anatolian Fault Zones. Erzincan city centre is in a pull-apart basin underlain by soft sediments which significantly amplify the ground motions. Combination of the tectonic and geological behaviour of the region have led to destructive earthquakes such as the 27 December 1939 (Ms=8.0) and the 13 March 1992 (Mw=6.6) events resulting in extensive losses. In this study, in order to perform site characterization in the region, we employ the passive microtremor survey technique at nine sites on three sides of the Erzincan city centre in order to gain quantitative estimates of 1D shear-wave velocity profiles for key parts of the basin. The sites are aligned as two profiles in the North-South and East-West directions allowing construction of approximate 2D profiles. At each site we performed surface wave dispersion curve analysis using the Multi-Mode Spatial Autocorrelation (MMSPAC) technique on either single or nested four-station arrays together with horizontal to vertical spectral ratio measurements at array centres. The combination allows resolution of Vs for typically the upper 4 m from high-frequency data, and as deep as 480 m using low-frequency SPAC and HVSR data in combination. The survey showed that a rate of production of two sites per day is achievable. We present our results in the form of one and two dimensional velocity structures and fundamental frequencies obtained from the HVSR spectra, a combination suitable for input to earthquake ground-motion prediction studies.

JOINT INVERSION OF SPATIAL AUTOCORRELATION CURVES WITH HVSR FOR SITE CHARACTERIZATION IN NEWCASTLE, AUSTRALIA

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[2]School of Geosciences, Monash University, Melbourne, Australia

In order to investigate site characterization of Newcastle affected by the 1989 Newcastle Earthquake (ML = 5.6), we conducted microtremor array measurements. The spatial autocorrelation (SPAC) method was applied to estimate the S-wave velocity structure from observed microtremor data. Although the inversion of spatial autocorrelation curves is effective for estimating shallow S-wave velocity structures within the sedimentary layer, it is usually difficult to estimate the boundary between the sedimentary layer and bedrock due to a lack of amplitude of vertical components of microtremors at low frequencies. On the other hands, it is well known that horizontal to vertical particle motion spectral ratios (HVSR) have information which assists in resolving the bedrock depth and velocity. Thus, we have applied joint inversion of the spatial autocorrelation curves with HVSR to observed microtremors. Since observed HVSR curves are subject to fluctuations due to unknown Love and body wave contributions or other noise effects, there is difficulty in fitting absolute values of observed

HVSR. Therefore, we evaluate observed HVSR and theoretical H/V spectra by zero-lag cross-correlation to fit the shapes of HVSR. The observed HVSR curve has accurate information for the deeper velocity structure and therefore, the estimated velocity model by joint inversion differs in velocity estimations at depth. It is concluded that the joint inversion of the spatial autocorrelation curves with HVSR is useful in practice for obtaining improved estimates of S-wave velocity models down to bedrock.

1100–1230
Day 2 Session 2 Stream 1

SEISMIC IMAGING

SUCCESSFUL APPLICATION OF JOINT REFLECTION/ REFRACTION TOMOGRAPHIC INVERSION IN A SHALLOW WATER MARINE ENVIRONMENT

Sergey Birdus[1]*, *Dean Criddle*[2], *Alexey Artyomov*[1] *and Qinghing Tang*[1]
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Standard depth-velocity modelling can be challenging for the upper part of the section in shallow water marine environments (water depth up to few hundred metres). Problems are caused by the limited number of offsets which are available for analysis and the wide-spread presence of strong multiples. Seismic acquisition that is designed for an optimal illumination of much deeper target intervals does not allow accurate velocity estimations in the shallow part of the section. However all deeper target reflections travel through the upper part of the model, so having an accurate velocity model right from the seafloor is important.

We show how refraction tomography (also called first arrival travel time tomography) helps to produce more accurate and detailed depth velocity models below a shallow seafloor. We do not use refractions by themselves to build a complete shallow velocity model. In our proposed workflow, refraction tomography complements standard reflection tomography and the priority remains with the reflections to guarantee stability of the solution and to avoid uncertainties associated with refracted or diving waves in complex media.

We show how this joint reflection/refraction velocity inversion works using a real 1000 sq.km 3D marine seismic dataset acquired in an area where the water depth varies from 20 m to 1100 m.

DEPTH VELOCITY MODEL BUILDING BEYOND REFLECTION TOMOGRAPHY, A CASE STUDY, OFFSHORE VIETNAM

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In the Southeast Asia offshore exploration, shallow reefs and channels, widely spread volcanic rocks and basement fracture system are some of the major challenges in seismic imaging. However, conventional reflection tomography has hard time to provide accurate and high resolution model to solve these challenges and other model building techniques are needed to introduce those velocity anomalies. First, reflection tomography has limited resolution at shallow (50-400m) because of limited number of offsets. So geo-mechanical modelling is used to put fast and slow velocity of reefs and channels. Second, the intrusive and extrusive volcanic rocks are too thin (around 50m-100m) to be resolved by tomography. Reflectivity inversion is used to derive the high resolution velocity of the volcanic rocks. Third, TTI/HTI anisotropy is used to simulate the situation, that image velocity is always much slower than well sonic velocity inside basement, and improve the image. Overall, geo-mechanical modelling, reflectivity inversion and TTI/HTI modelling in basement, together with the conventional reflection tomography, generate high resolution velocity model for PSDM thus provide much needed imaging uplift.

ADVANCES IN VELOCITY MODELING AND IMAGING TECHNIQUES IN THE TARANAKI BASIN

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[2]Todd Energy, Wellington, New Zealand

This paper demonstrates recent advances in grid-based reflection tomography model building in conjunction with anisotropic pre-stack depth migration. These advances significantly benefit the imaging and resolution of 3D seismic data in a number of structurally complex basins.

Using 3D seismic imaging examples from Petroleum Exploration Permit PEP 51558 in New Zealand's Taranaki Basin, this paper demonstrate how reflection tomography techniques can utilize implicit geological constraints to resolve complex velocity variations and, thereby, reduce structural and imaging uncertainty.

One challenge associated with velocity modelling in the Taranaki Basin is to adequately resolve the large lateral velocity contrasts across major faults. This work shows how the use of steering filters during the reflection tomography process significantly improves the resolution and delineation of these fault-constrained velocity contrasts. This approach is compared with the conventional gridded tomography approach of velocity model building.

Using a detailed velocity model from the Taranaki Basin, comparisons were made between time and depth migration, as well as alternate depth migration techniques.

1100–1230
Day 2 Session 2 Stream 2

SEISMIC INTERPRETATION – CASE STUDIES

THE ZEPPLIN 3D ROCKS THE VULCAN SUB-BASIN

*Jarrod Dunne**
MEO Australia Ltd

In January 2012, the storm clouds of Tropical Cyclone Iggy were gathering over the Timor Sea as production of the 500

km2 Zeppelin 3D seismic survey began in the Vulcan sub-basin permits AC/P 50 and AC/P 51. Despite the high seas and the adoption of a conventional approach towards acquisition, the Zeppelin 3D appears to have set a new benchmark for seismic data quality in the Vulcan sub-basin, which has traditionally been considered a 'difficult data area'. Reprocessing some of the overlapping legacy Onnia 3D seismic suggests that much of the imaging improvement stems from a similar approach to multiple suppression to that used successfully in other 'difficult' Australian basins. The combination of shallow water demultiple, SRME and gap deconvolution followed by a stratigraphically controlled velocity analysis appears to account for much of the improvement. Shooting in the (dominant) dip direction also appears to have helped although had we applied 3D SRME this might have been rendered less important.

Using the reprocessed Onnia 3D and the Zeppelin 3D, our seismic interpreters have been able to develop a detailed structural model, which underpins the distribution of fault bend fold related prospectivity. Enhanced resolution enables sequence stratigraphy to be delineated and low-stand fan leads identified. Seismic amplitudes also provide strong indications of reservoir sand geometries although porefill indications are expected to remain difficult to resolve. A series of structures within 3 separate plays (Triassic, Jurassic and Cretaceous) define a significant increase in the assessed oil and gas volumetric potential thereby justifying the early investment in seismic.

TEXAS IN AUSTRALIA? IMAGING CHANNEL SANDS IN THE COOPER BASIN

Anastasia Poole[1], *Peter van Baaren*[2], *John Quigley*[3], *Gabriele Busanello*[1]*, *Sharon Tan*[1], *Chester Hobbs*[1] *and Brendon Mitchell*[4]
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[2]WesternGeco, Sneek, Netherlands
[3]WesternGeco, Gatwik, UK
[4]Drillsearch Energy Limited, Sydney, Australia

This paper is inspired by a picture of a time slice from the prolific hydrocarbon state of Texas showing a stacked channel systems. Similar channel systems also exist in Australia's Cooper Basin but often difficult to see with typical sparse seismic acquisition. The desire is to see these channels, as in Texas. Due to reasons of cost and, environmental and cultural heritage protection relatively wide (sparse) line spacing gives the ability to cover larger areas than could otherwise be achieved. These sparse designs can provide a low environmental impact with reasonable images at target. Lack of traces at medium and near offset ranges may result in strong amplitude artefacts in the final image acquisition footprint. To reduce these artefacts, we deployed sources in a smooth 'wavy' sinusoidal pattern, modified as necessary to follow natural features in the terrain. This methodology results in acquisition with a minimal visual impact and provides significant benefits in reducing the acquisition footprint. This case study is from the 2012 acquisition. Innovative survey design and coordinate driven data processing techniques resulted in the dataset where channel features are now clearly visible on the migrated volumes. The acquisition technique features broad-band point-sources using a non-linear Maximum Displacement sweep of 2 to 100 Hz, broad-band point-receivers and dense sampling along both the source and receiver lines. In this paper we will demonstrate that even such relatively sparse 3D data can provide good signal-to-noise datasets suitable for extraction of seismic attributes, confirmed by identification of channel geobodies. Using the described technologies the acquired survey not only met, but by far exceeded, the initial expectations, and within the time frame. This survey has shown that exploration seismic surveys can be tailored to minimize environmental and acquisition foot print in Australia, high quality seismic dataset suitable for seismic attributes extraction.

BENEATH BASS STRAIT: LINKING TASMANIA AND MAINLAND AUSTRALIA USING AMBIENT SEISMIC NOISE

Simone Pilia[1]*, *Nicholas Rawlinson*[1], *Nicholas Direen*[1,3] *and Anya Reading*[2]
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[2]University of Tasmania, Hobart, Australia
[3]FrOG Tech LTD, Canberra, Australia

One of the most hotly debated topics in Australian geology pertains to the tectonic relationship between Tasmania and mainland Australia. Among the main difficulties in reconciling mainland Australian and Tasmanian tectonics is the lack of Precambrian exposure in the Lachlan Orogen (Victoria), which contrast with the West Tasmania Terrane that exhibits numerous outcrops of Proterozoic rocks, apparently excluding any tectonic affinity between them. Furthermore, the West Tasmania Terrane differs significantly from the East Tasmania Terrane in that the latter does not contain any evidence of Precambrian rocks and no evidence of a Proterozoic continental basement has been reported, either in outcrop nor inferred from geophysical surveys.

Furthermore, the presence of Bass Strait and the Mesozoic and Cainozoic sedimentary and volcanic sequences that mask the older terranes, makes the link between Tasmania and southeast mainland Australia even harder to decipher. This has significantly impeded the ability of conventional surface mapping to unravel the tectonic history of this area, which remains one of the great challenges of Australian Earth sciences. The focus of this study is ambient seismic noise data from 24 broadband stations, which span northern Tasmania, several islands in Bass Strait and southern Victoria, thus allowing a dense coverage of surface wave paths that can be exploited to image the 3-D structure of the crust joining Tasmania and Victoria in high detail. To produce the highest quality Greens functions, careful processing of the data has been performed, after which Group and Phase velocity dispersion measurements have been carried out using a frequency-time analysis method on the symmetric component (average of the casual and acasual signal) of the empirical Green functions. The next step is to invert the dispersion curves for maps of Group and Phase velocity, which is expected to shed new light on the structure beneath Bass Strait.

1100–1230
Day 2 Session 2 Stream 3

MINERALS – HARDROCK SEISMIC II

SEISMIC WHILE DRILLING EXPERIMENT WITH DIAMOND DRILL BIT AT BRUKUNGA, SOUTH AUSTRALIA

Baichun Sun[1], Andrej Bona[1], Binzhong Zhou[2], Christian Dupuis[1], Roman Pevzner[1] and Andrew King[2]*
[1]Curtin University
[2]CSIRO

Seismic-While-Drilling (SWD) utilises drill bit vibrations as a seismic source and receivers at the surface or in a borehole to acquire reverse VSP data. The basic processing technique is based on cross correlation to generate active shot-gather-like profiles. The successful implementation of SWD will yield time-depth information and image around the drill bit, which can aid drilling and geological understanding of the area.

To study the feasibility of using diamond impregnated drill bits for seismic-while-drilling, we conducted a small pseudo 3D SWD experiment at Brukunga, South Australia. It has been used to investigate the signals generated from diamond drilling, and study the potential to use a drill bit as a seismic source.

The drill bit energy for seismic imaging is influenced by the rig power setting, and the state of the drill bit (new or worn bit). The experiment shows that normally the diamond drilling frequency band is wide with strong discrete peaks, however sometimes due to changes in the drilling mode, e.g., increase or decrease the drilling power, the frequency spectrum can be smoothed. The strong peaks in the spectrum mean strong periodicity of the signal and as such, the signals do not lend themselves to standard cross correlation. Thus, we use a generalised cross correlation that produces results similar to an active shot gather-like profile.

OPTIMISING SEISMIC DATA ACQUISITION PARAMETERS FOR OPEN-CUT COAL EXPLORATION USING A SHALLOW HIGH RESOLUTION REFLECTION SEISMIC TEST SURVEY

*Kevin Wake-Dyster**
EcoSeis Brisbane, Australia

A shallow high-resolution seismic reflection test survey was conducted in the Maryborough Basin in an area near Gundiah, Queensland. The purpose of the seismic reflection test survey was to evaluate the application of using high resolution seismic data acquisition methods to detect thin coal seams at between 30 m to 150 m depth for open-cut coal exploration.

The seismic test survey tested three seismic sources which included a 50 kg weight-drop from 2 m height, a 7 kg sledgehammer, and a 12 g (blank cartridge) in-hole shotgun. Seismic forward modelling indicated that thin coal seams (1 to 2m thickness) should provide seismic reflections at shallow depths of 30 m, using 72 channel recording with 2 m geophone intervals. The seismic source tests showed that the 12 g in-hole shotgun produced the strongest seismic signal at the furthest geophone offsets. The seismic recording spread consisted of 96 seismic channels with single spiked 30 Hz geophones spaced at 2m geophone intervals. Based on the seismic source tests, the 12 g in-hole shotgun was used to record a seismic test line with shot-points recorded from one end of the 96 channel spread through to the other end of the spread. The recording arrangements provided seismic data to both test data quality with shot to receiver offset, and examine the optimum common depth point (CDP) fold coverage to use for a larger seismic survey. Based on the seismic data processing results, a larger seismic survey could be conducted using a 72 channel recording spread with 4 m geophone and shot-point intervals and achieve production rates of 400m per day with a 3-man crew.

COAL SEISMIC DIFFRACTION FAULT IMAGING: RESULTS FROM NUMERICAL MODELLING

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Faults are the most important structures which need to be detected for any modern underground coal mining projects. Even a fault with a throw of a few metres can create safety issues and lead to costly delays in mine production. While locating faults with throws greater than 5-10 m has been generally accepted for seismic surveys, techniques to resolve the more subtle faults, shears and features which exploration programs should also locate are needed.

Faults cause breaks in continuity of seismic horizons. These discontinuities generate diffraction patterns. Before the days of seismic migration and generation of very high fold data, diffraction patterns were what the seismic interpreter sought as an indication of faulting, especially for small faults where the discontinuities of the seismic reflections are less evident but most processing is now aimed at suppressing these diffractions. However, in recent years, techniques for diffraction imaging developed for petroleum seismic data processing, makes small fault detection possible by separating the diffraction events from the reflection seismic events. In this paper, we will develop new algorithms for extracting fault related diffractions from reflection seismic data and providing a new way to detect faults especially the small ones from coal seismic data and demonstrate the feasibility of the newly developed fault imaging algorithms with numerical examples in the coal mining environments.

1100–1230
Day 2 Session 2 Stream 4

MINERALS – AEM MAPPING I

GEOPHYSICS AND URANIUM IN THE CURNAMONA AND BILLAROO PALAEOCHANNELS, FROME EMBAYMENT, SOUTH AUSTRALIA

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[3]UraniumOne, Adelaide, Australia

Tectonism is believed to have exerted a strong control on the current disposition of sedimentary hosted uranium mineral deposits in the Frome Embayment. However the extent of this control has not been well understood, nor documented. Here, we examine the combined use of regional and finer-scale TEMPEST AEM data, linked to a structural interpretation of magnetic and gravity data airborne magnetics and ground gravity, to extend our understanding of the evolution, geometry and variability of sediment packages associated with sedimentary uranium mineralisation in the Curnamona and Billaroo Palaeochannel systems. Through the analysis of both smooth and blocky model LEI inversions of these AEM data, we contend that structural control was critical in determining the initial orientation of the palaeovalleys and the location of basal sequences of the Eyre Formation, the host to known uranium mineralisation.

The geophysical data suggest that NE orientated normal fault structures, and NW oriented transfer structures, initially developed in the Cambrian but reactivated with Cenozoic uplift caused by WNW ESE compression, were preferentially eroded by a series of braided stream systems flowing north. The inverted AEM data indicates that these streams cut wide channels, ranging from hundreds of metres to several kilometres wide in Cambrian Arrowie sediments before filling with Eyre Formation sediments which consist of sands with clay-rich interbeds sourced from the embryonic Flinders-Barrier ranges and Olary Spur during a period of tectonic upheaval and erosional. Understanding the variable geometry of this eroded channel system may assist in locating basal scours, bends, confluences or areas of channel-widening where uranium mineralisation is often located. It may also indicate sites which might have encouraged the accumulation of organic reductants (e.g. organic material) in the sediments, although the presence of reactivated basement faults in providing the loci for mobile reductants from underlying basins may also be significant.

UPDATED INVERSION OF SKYTEM DATA USING DOWNHOLE A-PRIORI FOR NEW CONCEPTUAL MODEL AND GW MANAGEMENT TARGETS AT TOOLIBIN LAKE

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Toolibin Lake is located southeast of Perth in the WA Wheatbelt.

Due to land clearing that altered the hydrologic balance depth to groundwater has risen from around ten metres below ground level to being at the land surface in the 1990s.

For vegetation to survive at Toolibin Lake pumping groundwater has become an important management tool, to reduce groundwater levels and if possible stored salt. To achieve this pumping bores need to be installed in aquifers that allow water (and salt) to be drawn down from the root zone. Different geological and hydrogeological information was available for drilling investigations in the late 1980s and 1990s and as a result not all bores are installed in aquifers that achieve the management goal.

A number of different AEM systems have acquired data over the lake and catchment. Results from the SkyTEM survey reported by Reid et al (2007) modelled a relatively homogeneous palaeochannel from 20 to 28 metres below ground level.

Recent data collected using the Javelin borehole NMR tool (VistaClara Inc) have allowed for the mapping of a more complex sequence of channels and valley fill deposits.

In this study we present updated geophysical results and groundwater conceptual model. They were obtained by i) reprocessing and re-inverting the SkyTEM data using borehole conductivity and hydrogeological surfaces as a-priori, and ii) inspecting again the correlation between AEM and MRS, and iii) producing new hydrogeological units to build a robust numerical model.

The updated conceptual and numerical allows the fine tuning of management targets.

1100–1230
Day 2 Session 2 Stream 5

MINERALS – EXPLORATION STRATEGIES II

KEYNOTE ADDRESS: DISCOVERING DEEPER PORPHYRY ORE BODIES – IS THERE A ROLE FOR GEOPHYSICS?

*Dan Wood**
W H Bryan Mining and Geology Research Centre, University of Queensland

The anticipated almost doubling of world mine Cu production by 2030 will require a substantially increased output from existing porphyry Cu mines, along with production from as yet undeveloped mines and the discovery of new porphyry ore bodies. Assisting the potential for increased output from existing and new mines, and partly in response to declining ore grade,

mass (large-scale) mining of porphyry Cu ore bodies is undergoing a major transformation, foreshadowing a significant increase in the size of some existing and future mining operations.

The discovery histories of two of the four Cadia, porphyry Au-Cu ore bodies in New South Wales, Australia offer insights into discovering deeper porphyry ore bodies. Induced polarisation geophysics (IP) contributed importantly to one of these discoveries (Ridgeway) by identifying the overlying 'sulphur' halo to the ore body.

It is proposed that IP, and possibly other geophysical methods, can play a greater role in discovering deeply-located porphyry ore bodies, when used as part of an 'ore-system' approach to discovery; particularly if the methods can be modified so as to 'see' much deeper than at present and used to identify a porphyry 'sulphur' halo, starting at a depth below surface of up to 1,000 m.

WHAT CAN SEISMIC IN HARD ROCKS DO FOR YOU?

*Milovan Urosevic**
Curtin University and Deep Exploration Technologies Corporative Research Centre, Perth, Australia

If potential field methods were sufficient for exploration of mineral resources at depth there would be no need for the application of seismic methods. The need to see deeper in the earth to find extensions of the existing ore shoots and to discover new reserves is of crucial importance in Australia where a constant decline of new discoveries is recorded over the last decade. The only geophysical method that can 'see' deep and at the same time resolve fine geological features is seismic. However it should be noted that if mineral prospecting with seismic methods was straightforward it would have been established as the primary exploration method many years ago. One of the reasons for seismic still being largely considered as an alternative or experimental method for mineral exploration is the lack of understanding of the variability of seismic responses in different geological settings. In some cases we have excellent seismic results in other very poor. Are they both useful? Several case histories will be shown and discussed which may help us to devise appropriate seismic exploration strategy according to a type of mineral deposit.

Seismic exploration of VMS (VHMS) deposits is relatively straightforward as seismic response of massive ore produces often clear signature, above the background trend. This is particularly the case in Canada, less so in Australia. Sediment hosted deposits are highly specific and could produce vastly different seismic signatures, while seismic response over IOCG f deposits is generally poorly understood. Recent seismic investigations over IOCG deposits show very promising results. As the number of seismic case histories grows it becomes clear that seismic can become a standard or even principal method for exploration of deep mineral deposits, providing that appropriate acquisition, processing and interpretation strategies are deployed.

1100–1230
Day 2 Session 2 Stream 6

MINERALS – REGIONAL STUDIES I

REGIONAL GEODYNAMIC STUDY OF THE YILGARN-OFFICER-MUSGRAVE REGION - INVESTIGATING THE DEEP CRUST USING FORWARD MODELLING AND 3D INVERSION

James Goodwin, Tim Jones, Russell Korsch and Terry Brennan*
Geoscience Australia, Canberra, Australia

The 11GA-YO1 deep seismic reflection survey reveals information on the crust down to ~66 km depth, imaging the crust-mantle boundary. The seismic survey traverses the Yilgarn Craton, Officer Basin and Musgrave Province yielding information on their key structures and boundaries.

Interpretation of the seismic reflection data was complimented with forward modelling and 3D inversion of gravity and magnetic data. This allowed the geological structures interpreted in the seismic data to be investigated and extended into 3D space.

The 3D gravity and magnetic inversions shown here reveal information on the geology and structure of the crust in the Yilgarn-Officer-Musgrave (YOM) region. In particular, information on the nature of dipping bodies beneath the Officer Basin and the boundary between the Yilgarn Craton and Musgrave Province.

NEXT GENERATION 3D GEOLOGICAL AND GEOPHYSICAL MODELLING, WEST TASMANIA

Mark Duffett[1], Daniel Bombardieri[1,2] and Tim Chalke[3]*
[1]Mineral Resources Tasmania, Rosny Park, Australia
[2]University of Tasmania, Hobart, Australia
[3]Mira Geoscience, Brisbane, Australia

Airborne magnetic and ground gravity data have been inverted to recover 3D distributions of magnetic susceptibility and density over an area (40 km × 35 km) in western Tasmania. Building on previous modelling and structural interpretation, the overall modelling strategy focused initially on the most magnetic units (Cambrian ultramafics), which are regionally associated with major tectonic features. Interpretation of their geometry via iterative 3D magnetic inversion and geometry adjustment thus outlines a structural framework capable of satisfying geologic and magnetic and gravity observations. Significant slabs of ultramafic material are demonstrated to underlie a considerable portion of the area, agreeing with previous 2D forward model investigations. This framework is effectively filled in with other major geological elements, including extensive low-density Devonian granites and magnetic Cambrian granites, such that geologic, magnetic and gravity constraints are all grossly satisfied. Magnetic and gravity residuals present at the conclusion of the modelling process are thus interpreted to indicate features such as alteration systems that are geologically as well as geophysically anomalous, and hence of exploration interest.

MAGNETIC DEPTHS TO BASALTS – EXTENSION OF SPECTOR GRANT METHOD

Roger Clifton[1,2]*
[1]The University of Western Australia, Perth, Australia
[2]Northern Territory Geological Survey, Darwin, Australia

Previously essentially manual, the Spector-Grant method requires inspection of the power spectrum to assign a single slope characterising the depth to a large flat body. In effect, there is only one subjectively chosen point on the spectrum to apply the SG formula. Using animations, the (oral) presentation demonstrates a fresh derivation of the formula for slopes extended to the entire length of the power spectrum, cutting off where the noise level rises.

By repeatedly taking grid samples 20 km wide, a depth spectrum can be drawn repeatedly across a landscape. The presentation thus demonstrates tracking the Antrim basalts across several hundred kilometres.

60,000 profiles for the entire Northern Territory have already been drawn up algorithmically, currently visible on the NTGS' Image Web Server, http://geoscience.nt.gov.au/giws/. Here, the base of the basalts can be tracked and a first estimate of their depths obtained. A degree of manual intervention reappears when fining up the depth estimates, because the different survey line spacings require separate calibrations, which change the apparent depths by 20%.

Whereas the original Spector Grant paper modelled a few prisms, the fresh derivation is NOVEL in that the power of modern computers allows the modelling of a thousand randomly-placed dipoles at each of 500 depths. The new method can be applied to flat magnetic bodies GLOBALLY.

The power of the technique has made UNDERSTANDABLE by demonstrating magnetic profiles of depths derived every 5 km across several hundred kilometres of the Northern Territory basalts.

By the time of the conference, the paper of the presentation will have been submitted to Exploration Geophysics for PEER REVIEW as part of my Ph.D..

1330–1500
Day 2 Session 3 Stream 1

SEISMIC PROCESSING – MULTIPLES

MODELLING AND REMOVING WAZ OBC INTERBED MULTIPLES

Todd Mojesky[1]*, *FongCheen Loh*[2] *and Robert Eliott-Lockhart*[3]
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[2]ASEG,SEG, CGGVeritas Australia
[3]ASEG, SEG, EAGE, Woodside Energy Ltd

Interbed multiples, caused by ringing between strong reflectors deeper within the section, have been historically difficult to remove. Conventional separation methods, based on multiple periodicity or residual moveout, will typically fail. As an example, interbed multiples from limestone packages can actually have a faster apparent velocity than the real primaries. Different techniques have to be used in these situations. Two different interbed demultiple methods have been tried successfully on a recent 3D Ocean Bottom Cable (OBC) seismic survey (Tridacna survey) over the North Scott Reef offshore Australia. In these data, strong events in the upper section do produce interbed multiples below, -and with very little normal moveout discrimination. This paper will present a new (and old) development to resolve our imaging problem.

Solution 1: Old method adapted to this: a horizon-based pattern-recognition algorithm is used pre-stack on migrated data. A robust algorithm. Assumptions, limitations, results, where-when will be discussed.

Solution 2: New method with new methodology and tools: 3D Interbed removal by (deterministic) wavefield modelling. Adapting a 3D SRME (surface multiple) approach to interbeds. Originally this uses one-way WE to model interbeds between the reflectors situated under and over a horizon. We now run this many times over many windows to make all possible multiples, and adaptively subtract in 3D all models at once. We hit upon a new constraint, -the amplitude spectra, to stabilize even more. Runs per-migration. Successful results (may be a first here) -requiring no interpretation. The new algorithms and ideas will be described/shared. Discussion results, limitations, etc.

HIGH-FIDELITY ADAPTIVE CURVELET DOMAIN PRIMARY-MULTIPLE SEPARATION

Xiang Wu and Barry Hung*
CGGVeritas, Singapore, Singapore

In this paper, we propose an adaptive implementation for separating multiples from primary events in seismic data and subsequently removing the embedded multiples from noisy seismic data using the curvelet transform. Because of the sparseness of the curvelet coefficients of seismic data, the optimization problem is formularized by incorporating L1- and L2-norms, based on the framework of Bayesian Probability Maximization. Iterative soft-thresholding can be used for solving the above optimization problem. By making use of least-square matching filtering, we precondition the multiple models to match the actual multiples in the seismic data prior to the separation step. We show that such an adaptive implementation is more robust than previous implementations and has superior performance than the conventional least-square separation method in attenuating multiples and noise, and preserving primary events.

Moreover, in order to meet the challenges faced by various types of data complications, we develop a frequency regularized adaptive curvelet domain separation approach/technique. This flexibility overcomes the varying effectiveness of separation methods for different frequency bands in responding to the noise and model inaccuracy control. For instance, it provides the opportunity to better preserve low frequency components of the primary, and to attenuate noise and less credible modelled multiples in high frequency bands. Accordingly, the high adaptability of this extension leads to its higher separation fidelity than existing curvelet domain separation implementations. We demonstrate the applications of our approach on synthetic and field data examples by comparing them with the results from the conventional least-square separation method.

SHALLOW WATER DEMULTIPLE USING HYBRID MULTICHANNEL PREDICTION

Kunlun Yang and Barry Hung*
Cggveritas Services (Singapore) Pte Ltd, Singapore, Singapore

This paper presents an extension of our previous effort on multiple attenuation in shallow water environment. While our previous workflow, termed as Shallow Water Demultiple (SWD), is robust in suppressing water-layer related multiples (WLRMs) with shallow seafloor, it faces difficulties when the seafloor is too shallow and complex because of the near offset gap related to acquisition. The wavelet stretch resulted from near offset extrapolation causes spectral distortion in multiple model from SWD which leads to sub-optimized subtraction result in shallow part of the data.

The new method is a hybrid approach in which shallow WLRMs are handled by using the Green's function of the seafloor primary reflections, while the rest of the multiples are handled by SWD. The Green's function in this case is derived from auto-picking the traveltime of the multichannel prediction operator estimated from SWD.

The approach combines the strengths of SWD and model-based methods. We show that the multichannel prediction operator estimated in SWD can be used as an accurate kinematic representation of seafloor reflection with high signal-to-noise (S/N) ratio. With this operator, the traveltime of the seafloor event can then be automatically estimated. Making use of this traveltime information, the Green's functions of the water-layer primary reflections can be modelled for tackling the shallow peg-lag multiples that have difficulty handled by SWD. We show the application of our hybrid method for suppressing shallow water multiples on field data acquired from offshore Australia

1330–1500
Day 2 Session 3 Stream 2

RESERVOIR CHARACTERISATION

KEYNOTE ADDRESS: RESERVOIR CHARACTERISATION USING CSEM, SEISMIC AND WELLS LOGS: CHALLENGES AND PITFALLS

*Lucy MacGregor**
RSI

Combining multiple geophysical data types using integrated interpretation or joint inversion approaches can provide information on earth properties that is either unreliable or simply unavailable when only a single data type is considered. In particular the combination of seismic, CSEM and well log data has the potential to improve the certainty with which reservoir lithology and fluid properties are constrained.

Although integrated interpretation brings many benefits, there are a number of challenges to be overcome before such approaches can be robustly applied. Firstly measurements made using very different physical processes (electric and elastic in the case of CSEM and seismic) must be combined and linked to the underlying rock and fluid properties in a consistent fashion. This requires a rock physics framework to be either numerically derived or empirically calibrated at well locations. In both cases such models are subject to uncertainty, which in turn leads to uncertainty in the resulting interpretation.

Secondly seismic, CSEM and well log techniques sample the earth at very different scales, varying from a few cm in the case of well logs, to hundreds of metres for CSEM. These different scales must be reconciled in an integrated interpretation or joint inversion approach.

Finally in order for an integrated interpretation approach to be successful, both seismic and CSEM methods must be sensitive to the interval of interest and changes in properties within it. Although this is perhaps an obvious statement, it is however a key consideration in determining where such approaches can be applied.

The solutions to these challenges are case dependent and must be considered with care. For any given geophysical question, the most robust answer will be obtained by using the tool, or combination of tools best suited to the task, and determining this combination is the first step in any analysis. The resulting choice of data must then be integrated within a rock physics framework, to provide a model that is geologically reasonable, and consistent with each of the geophysical data types available.

FINING UP THE SEISMIC STOCHASTICALLY ENOUGH FOR RESERVIOR CHARACTERIZATION OFFSHORE NORTH WEST AUSTRALIA

Vincent Kong[1], *Robert Cornect*[2], *Scott Alexander*[2], *Agathe Bucherie*[2] *and Chester Hobbs*[1]*
[1]WesternGeco Australia, Perth, Australia
[2]GDF SUEZ Bonaparte Pty Ltd, Perth, Australia

The vertical resolution of conventional seismic data limits the illumination and definition of thin sand reservoirs offshore North West Australia. With the availability of more wells within a field it is justified to use a well-centric stochastic seismic inversion approach to characterize the reservoirs. The stochastic AVO seismic inversion yields multiple triplet realizations of acoustic impedance, Poisson's ratio and density at the fine enough vertical sampling for a more relevant reservoir modelling procedure. The paper will discuss the stochastic seismic inversion approach, followed by a structured analysis workflow which condenses the generated multiple realizations to more interpretable data volumes.

1330–1500
Day 2 Session 3 Stream 3

MINERALS – HARDROCK SEISMIC III

3D VSP: A MINE OF INFORMATION FOR MINING EXPLORATION

Michel Denis[1], Charles Naville[2], Laurence Nicolettis[2], Quartus Snyman[3], Jean Claude Lecomte[2] and Eric Suaudeau[1]*
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[2]IFP, Rueil, France
[3]Anglo American, Johannesburg, South Africa

The 3DVSP technique becomes more popular with the emergence of multilevel 3 component borehole tools.

The value of the information derived from VSP is not always well understood.

In this paper we will present a case history of a joint surface and borehole seismic acquisition, with the goal to de-risk a shaft sinking location on a platinum mine. TD was about 650 m and the VSP tool was 110 m long.

On surface a dense grid of receivers and vibrator source points were laid out in 1.2 km radius circle centred on the well head. A 12 level 3C VSP digital tool was lowered in the borehole, in three successive depth positions.

The surface 3D cube was processed and interpreted independently from the 3D VSP data. On a near target reflector, the surface data structural interpretation showed mainly a clear E/W fault, and additional subseismic lineaments of differing azimuths, difficult to identify in terms of fault. The 3D VSP image limited to a short radius around the borehole confirmed the fault/dyke nature of these lineaments, separating monocline compartments.

As a consequence, the surface data was carefully re-interpreted and on the second structural images derived from two surface seismic reflectors and the near surface fault footprint from 3DVSP residual statics, a series of subtle faults were clearly assessed. Last, the few faults intersecting the borehole can be clearly recognized on the logs and the borehole radar logs.

This case study demonstrates the added value of a joint interpretation of surface and borehole data in a decision making process for shaft sinking.

ORE-BODY DELINEATION USING BOREHOLE SEISMIC TECHNIQUES FOR HARD ROCK EXPLORATION

Felix Menu, Andrew Greenwood and Christian Dupuis*
Curtin University, Perth, Australia

In recent years, seismic methods have emerged as a potential imaging technique for delineation of deep ore-bodies at the mine scale. The application of surface seismic methods in hard rock environments is however challenging due to various effects such as energy attenuation and scattering. Borehole seismic methods can be used to reduce these effects.

Ore bodies of economic importance are often only a few metres thick and the top and bottom are not resolvable by conventional geophysical techniques. In cross-hole geometry, higher seismic frequencies can be obtained as the source and the receivers are placed below the near-surface overburden which distorts and attenuates seismic wavefields. Resolution is dependent on borehole separation not depth. Higher frequencies result in higher resolution images. The resolution of seismic images is generally a few (tens of) metres, making it ideal for ore bodies delineation.

The potential of cross-hole methods to resolve ore-body's thickness and extent is explored in this Acoustic Seismic synthetic study.

IMAGING USING MINING MACHINERY AS A SOURCE

*Andrew King**
CSIRO, Perth, Australia

A mine is a difficult geophysical environment to work in because of the presence of large amounts of noise. For seismic techniques in particular, the presence of drilling, blasting, shearers cutting rock, pumping and other activities leads to high levels of background seismic noise. But this seismic noise interacts with the rock in the same way as energy from an active seismic source would do, so it could, in principle, be used to image the rock.

Most sources of noise – drills, shearers, pumps – are continuous, so there is no well defined "shot time" and no well-defined direct or reflected arrivals in measured traces. However, a process of coherence-weighted cross-correlation across an array of sensors can produce a set of relative travel times, which can be used for tomographic imaging.

Experiments have been done in a number of coal mines, using a coal shearer as a source of energy, and recording the signal on arrays of geophones, installed either in roadways underground, or on the ground surface above the mine. This data has been processed using various techniques to try to extract velocity and attenuation information. Results indicate that the technique is successful in extracting relative arrival times across an array from continuous noise.

1330–1500
Day 2 Session 3 Stream 4

MINERALS – AEM MAPPING II

MAPPING SUBSURFACE GEOLOGICAL STRUCTURE USING TEMPEST DATA, MCARTHUR BASIN, NORTHERN TERRITORY

Peter Kovac[1], Jacqueline Hope[1], Lynsey Brett[2] and Llyle Sawyer[3]*
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[2]Mira Geoscience Asia Pacific, Perth, WA
[3]Geos Mining, Milson Point, NSW

The airborne TEMPEST electromagnetic (EM) and magnetic survey is a proven tool for mapping geological structure for exploration. This technique was applied at the Bulman project area in the McArthur Basin to identify the geological environment of stratabound carbonate-hosted Pb-Zn mineralisation. The Late Palaeoproterozoic to Early

Mesoproterozoic sedimentary fill of the McArthur Basin in the Bulman project area consists of the Dook Creek and Limmen Formations. They are intruded by Early Mesoproterozoic dolerite sills and dykes. The location of the intrusive rocks was mapped using magnetic data while their depth was estimated from EM data. To find the top of the intrusives, depth to resistive basement was mapped using Conductivity Depth Images (CDIs) generated from the TEMPEST B-field Z-component data. Additionally, a voxel model was constructed from the CDIs to show the conductivity distribution in three dimensions. The conductivity pattern indicates that the dolomite sandstone and siltstone of the Dook Creek Formation are more conductive than the overlying coarse sandstone of the Limmen Formation. A disconformable boundary between the formations is shown as a distinct interface in the EM data. There is no marked conductivity contrast between intrusives and other rocks making up the resistive basement. As a result, the picked depth to resistive basement horizon corresponds to the bottom of a surface conductive unit that is interpreted to be the base of the Cenozoic unconsolidated deposits or part of the Dook Creek Formation. In places, the base of a sub-surface conductive zone is interpreted to be the top of the intrusives. The thickness of sediments above the resistive basement is variable, reaching up to 170 metres in the central – eastern part of the study area. Additionally, a 3D geological model has been constructed to image the distribution of the interpreted geological units and the tectonic pattern.

EUREKA! AEM UNCOVERS MORE THAN EXPECTED

Marina Costelloe, Ian Roach and Subhash Jaireth*
Geoscience Australia, Canberra, Australia

Precompetitive AEM data and associated scientific analysis assists exploration under cover by reducing risk; stimulating investment and promoting exploration for commodities. In recent years, Geoscience Australia has flown three regional Airborne Electromagnetic (AEM) surveys covering three percent of Australia. Data and associated interpretations from regional surveys in the Paterson, Pine Creek and Lake Frome regions have led to tenement take up, stimulated exploration for a number of commodities and have given rise to many Eureka moments.

This presentation highlights new results from the use of the regional AEM data and interpretations for commodities other than uranium; results that have been announced by industry via the Australian Stock exchange and other publications. A copper exploration company reported high-grade copper intercepts in target areas defined by data from the regional Paterson survey. A gold exploration company identified horizons associated with the gold-rich Cosmo-Howley corridor using the Pine Creek AEM data. The AEM data have also helped to identify Triassic coal measures at Leigh Creek.

3D CONDUCTIVITY MODEL OF THE LALOR LAKE VMS DEPOSIT USING GROUND AND AIRBORNE EM DATA

Dikun Yang and Doug Oldenburg*
University of British Columbia, Vancouver, Canada

Lalor Lake is a VMS deposit in central Manitoba, Canada. The deep ore body is buried under the cover rocks up to 1000 m. Multiple EM data sets were collected to delineate the compact and conductive alteration zones and two data sets are available to us. The first is HELITEM, an airborne time-domain EM survey that covers the entire exploration area. The second is a ground loop EM data measured by SQUID magnetometers that have high precision at late times. The two data sets map the conductivity structures at Lalor Lake in different ways: the airborne survey covers a broad area but has limited resolving power at depth; the ground survey provides information about the deep targets through very late times but the measurements were made in a smaller area. Individual 3D inversions were carried out for both data sets assuming little a prior information. Both are able to recover the trace of the expected ore body, but the airborne model is smooth and the ground model contains highly conductive anomalies. Then we invert the ground data again with the airborne model as the reference model. The new inversion again confirms the existence of the VMS ore body but also rearranges the conductive material according to the constraints from the reference model. The new model differs significantly from the blind inversion model at the deposit scale. Based on the information from the inversion so far, we conclude both surveys have picked up signals from the ore body in different levels of detail. More analysis and further data are still required to better delineate the target's geometry.

1330–1500
Day 2 Session 3 Stream 5

MINERALS – JOINT MT & SEISMIC

REGIONAL MINERAL EXPLORATION TARGETING FOR GOLD AND NICKEL DEPOSITS USING CRUSTAL ELECTRICAL CONDUCTIVITY VARIATIONS DETERMINED USING THE MAGNETOTELLURIC METHOD

Mike Dentith[1], Alan Aitken[1], Shane Evans[2] and Aurore Joly[1]*
[1]Centre for Exploration Targeting, Perth, Australia
[2]Mommbarriga Geoscience, Perth, Australia

Current ideas on regional prospectivity analysis emphasize the importance of major fault structures and in particular (palaeo) suture zones within and between cratonic blocks. These features represent deep penetrating zones of enhanced permeability encouraging the passage of potentially mineralizing brines and melts. Such features have been linked with the occurrence of several different types of deposit, notably nickel-sulphide and gold deposits. Detection of such geological features requires mapping variations in physical properties at lower crustal and mantle depths.

As part of a study on regional prospectivity, magnetotelluric (MT) surveys have been completed in several prospective Proterozoic and Archaean terrains in Western Australia (Kimberley Craton and surrounding orogenic belts, Musgrave Province, Capricorn Orogen, Yilgarn Craton). These data, which have been interpreted in association with potential field, seismic, geological and geochemical data, demonstrate that MT surveys can be used to identify features indicative of regional-scale prospectivity based on variations in the electrical conductivity of the crust and upper mantle. For example, a survey in the southern Yilgarn Craton has identified lateral changes in deep crust and upper mantle conductivity structure consistent with palaeo-cratonic boundaries inferred from studies using isotope geochemistry. The MT data allow the boundaries to be

accurately located; the isotopic results being limited by the spatial distribution of outcrops of suitable lithotypes.

The survey areas in Western Australia are geographically remote and often environmentally and culturally significant. MT surveys represent a comparatively cheap means of evaluating regional prospectivity, whilst causing minimal cultural and environmental disturbance. It is argued that MT data comprise useful pre-competitive data type and that Governments should consider this type of survey as a complement to the more common potential field surveys.

STRUCTURE-COUPLED JOINT INVERSION FOR MAGNETOTELLURIC, SEISMIC REFRACTION AND REFLECTION TRAVELTIME DATA

Xu Liu, Graham Heinson and Bing Zhou*
University of Adelaide, Adelaide, Australia

A method of joint inversion of Magnetotelluric, seismic refraction and seismic reflection (JIMRR) is developed especially for typical hydrocarbon or hard-rock mineral exploration. JIMRR includes two parts: jointed seismic refraction and seismic reflection; and its combination with Magnetotelluric (MT) method. The objective of the research is to enhance spatial resolution of the three model parameters: electrical resistivity, seismic velocity and reflector depth. Since horizontal coordinates of reflector are not treated as model parameters in existing travel time inversion algorithm, seismic forward modelling may loss the true reflection point locations at the side edges of reflector with limited extension. We developed the technology of extensible reflector to overcome this problem. JIMRR is completed by employing the cross-gradient function as constraints which enforces the structural similarity between the resistivity and the seismic velocities, so as to reduce velocity-depth ambiguity. The cross-gradient constraints are incorporated into the solution through least squares and Lagrange multiplier method. This method results in integrated symmetric square linear matrix that is solved by bi-conjugate gradient method (BiCG). Two example synthetic models show that our joint inversion can significantly enhance the spatial resolution of inversion; and also the velocity-depth ambiguity caused by reflection travel time inversion can be notably reduced by constraints from shallow lithologies.

1330–1500
Day 2 Session 3 Stream 6

MINERALS – REGIONAL STUDIES II

THE CURIE DEPTH OF AUSTRALIA, AND ITS UNCERTAINTY

Richard Chopping[1]** and Brian Kennett*[2]
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[2]Research School of Earth Sciences, ANU, Canberra, Australia

The Curie depth is the depth at which the crust or upper mantle ceases being magnetic due to temperature effects. Although there are several methods available to map this depth, magnetic methods are most often used. These methods, however, introduce uncertainty into the depth estimates and have not been adequately addressed in previous studies.

In this study, we have used magnetic data, at multiple scales, in combination with Monte Carlo techniques to evaluate both the Curie depth and its uncertainty for the Australian continent. Variations in the Curie depth for Australia is related to differences in mineralogy and thermal regimes across differing provinces of Australia, and may also be used to further our knowledge of crustal geothermal gradients. Increasing our knowledge in these areas will advance our understanding of uranium, geothermal and hydrocarbon systems in Australia.

DEPTH TO BASEMENT CALCULATION IN SOUTHERN THOMSON, QUEENSLAND

Janelle Simpson and Roger Cant*
Geological Survey of Queensland, Department of Natural Resources and Mines, Brisbane, Australia

Depth to crystalline basement is a major consideration when conducting minerals exploration. The thickness of sedimentary cover concealing mineralised basement rock is a primary factor in determining whether economic greenfields exploration is viable. A good knowledge of depth to basement is therefore critical for tenement selection and drill hole targeting. New airborne magnetic data released in 2012 allows the calculation of a depth to basement surface in the southern Thomson area adjacent to the Queensland – New South Wales border in south Queensland. Available drill hole data shows basement depths from about 100m to over 3km in the study area but is too sparse to create a reliable surface. A combination of different automatic depth to basement techniques, including Euler deconvolution and Naudy, were used. These techniques were preferred due to a regionally extensive high frequency, low amplitude magnetic signature attributed to shallow sources in one of the cover sequences in the study region. This signature created difficulties for depth to basement calculations which involved the use of higher order derivatives. Geosoft's Located Euler calculation was preferred in areas where remanence was evident as it uses the analytical signal grid. This technique was used in combination with standard Euler. Naudy depths were also compared to the Euler solutions, particularly in areas where the drill holes indicated the basement was relatively shallow (where smoothing associated gridding can cause overestimation of source depths). Seismic data available in the north of the study area was interpreted and used as a secondary (along with the drill hole data) quality control check on the basement surface. The calculated depth to basement surface was used to create voxet model for further analysis using gravity and magnetic inversion. The final depth to basement surface defines an area of shallow basement in the south-west of the study area.

MINERAL PROSPECTIVITY ANALYSIS OF THE WAGGA-OMEO BELT IN NSW

David Robson[1]**, Antony Mamuse*[2] *and Pietro Guj*[2]
[1]Geological Survey of New South Wales, Maitland, Australia
[2]Centre for Exploration Targeting, Perth, Australia

In preparation for a major geological mapping program within the mineral endowed Wagga-Omeo Belt in central-southern NSW, the Geological Survey of New South Wales, in

conjunction with the Centre for Exploration Targeting at the University of Western Australia, is undertaking a mineral resources assessment of the region.

The Wagga-Omeo Belt in NSW has been a significant tin, gold, silver and copper producer. This study has used predictive mineral endowment of the region by estimating the number of undiscovered deposits, estimating mineral endowment, and by predicting the likely locations of undiscovered deposits. Both spatial prediction (mineral prospectivity mapping -- MPM) and quantitative resource assessment (QRA) were undertaken for a study of tin mineralisation in the region.

This study has focused on the use of total magnetic intensity, gravity, radiometric and digital elevation data, together with geological and metallogenic data.

Where sufficient data existed, both internal data-driven analysis and external exemplar/analogue application were undertaken. It used local spatial analysis that incorporated the use of spatial models (e.g. Poisson, binomial) to directly predict deposit locations. To reconcile final estimates in some areas, Weights of Evidence (WofE), geographically weighted regression (GWR) and neural networks were used.

In areas of insufficient data, predictive estimation was knowledge driven and incorporated expert opinion, fuzzy and Boolean logic, fuzzy WofE and neuro-fuzzy operations. Using these processes/operations, we were able to better pin down positions where undiscovered deposits were likely to be found.

Although this study has just begun, preliminary results indicate several areas requiring further assessment and field mapping follow-up

1530–1730
Day 2 Session 4 Stream 1

SEISMIC INVERSION AND CO_2

A MULTI-OBJECTIVE STOCHASTIC OPTIMIZATION APPROACH FOR ESTIMATION OF SUBSURFACE GEOMODELS

Mohammad Emami Niri and David Lumley*
University of Western Australia, Perth, Australia

We present a multi-objective optimization approach to the subsurface geomodel updating problem using stochastic search techniques. This is a new approach to the geomodelling process for which a variety of direct and indirect measurements can be simultaneously fit to the geomodel. Due to the inherent uncertainties and noise in real data measurements, geological and geophysical datasets acquired in the same area may be in conflict with each other; and a realistic subsurface model can only be obtained by simultaneously integrating the combined datasets in a reasonable manner. One approach to this problem is to perform joint inversion of multiple geological and/or geophysical datasets, where an optimal model is achieved by optimization of a linear combination of several objective functions measuring the match of the simulated datasets with the observed datasets. In this paper, we consider joint inversion of multiple datasets for geomodel updating, as a Multi-Objective Optimization Problem (MOOP), where separate objective functions for each subset of the observed data are defined. Then, a stochastic optimization technique is employed to find the set of best-compromise model solutions that fit the defined objectives, which are found along the Pareto front (a set of non-dominated optimal solutions). We demonstrate that a customized initialization of the algorithm can speed up the convergence and result in a set of improved model solutions. An application of the methodology is presented using the example of a 3D reservoir lithofacies model that must honour a set of geological and geophysical attributes (e.g. log data and inverted seismic P- and S-wave impedances). Also, the sensitivity of the model inversion results to changes in the optimization parameters and the presence of seismic noise is analysed.

A GEOMORPHOLOGY-CENTRIC RANKING SCHEME FOR STOCHASTIC SEISMIC INVERSION REALIZATIONS

Vincent Kong[1]*, *Robert Cornect*[2], *Tim Dean*[1] *and Chester Hobbs*[1]
[1]WesternGeco Australia, Perth, Australia
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Advances in the acquisition and processing of 3D seismic data have led to significant improvements in our ability to image subsurface reservoirs. The limitations of conventional 3D seismic measurements for reservoir characterization include its band-limited vertical resolution as well as the non-uniqueness of inverting seismic amplitudes for reservoir properties. These limitations have an impact on our ability to accurately model thin reservoirs for volumetric computations. Stochastic seismic inversion addresses these concerns by producing multiple, equally likely realizations, consistent with the available well and seismic data, at the fine-scale vertical resolution required for such reservoirs. The nature of the algorithm results in a large number of realizations (typically in excess of 200). We, therefore, require a methodology to rank the realizations in a way that is meaningful for the problem at hand and identify models corresponding to the P10th, P50th, and P90th percentiles.

In the example presented here a feature recognized on a 3D deterministic seismic inversion result was interpreted as a mitten-shaped tidal bar using well-log data. The stochastic seismic inversion process generated realizations that showed a wide variation in the extent and geometry of the tidal bar. In this work we present an innovative ranking method used to classify the broad range of stochastic inversion results targeted at approximating this tidal bar geomorphological feature. From these results we were successful in identifying the various percentile models required for further analysis including input to reservoir simulation modelling.

INITIATION OF TIME LAPSE MEASUREMENT TO MONITOR THE CHANGE OF WATER TABLE IN WATER PUMPING AT AL WASEE FIELD, SAUDI ARABIA USING SEISMIC ACROSS SOURCE AND MULCH-RECEIVERS (PRELIMINARY REPORT)

Junzo Kasahara[1,3,5], *Khaled Aldamegh*[2]*, *Shinji Ito*[3], *Yoko Hasada*[4], *Khaled AlYousef*[2], *Ghunaim Al-Anezi*[2], *Omar Lafouz*[2], *Fahad Almalki*[2] *and Masamitsu Takano*[3]
[1]Tokyo University of Marine Science and Technology, Tokyo, Japan
[2]KACST, Riyadh, Saudi Arabia
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[4]Daiwa Exploration and Consulting Co. Ltd., Tokyo, Japan
[5]Shizuoka University, Shizuoka, Japan

We are developing a seismic technology for CCS, CO_2-EOR and permanent reservoir monitoring using ultra-stable and long duration seismic source. We use seismic-ACROSS (Accurately controlled and Rousingly Operated Signal System) developed in Japan and multi-seismometers for the above purpose. We carried out synthetic evaluations of reservoir change imaging assuming single seismic sources and field experiment of time-lapse related to underground air injection in Japan in 2011.

We are applying a seismic ACROSS in the context of carbonate rocks in Saudi Arabia. The Al Wasee water pumping site approximately 120 km east of Riyadh has been selected as a test-site. The intention is to observe the changes in aquifers induced by pumping operations. One ACROSS unit was installed at the Al Wasee site this December 2011. The instrument has been operated from 10 to 50 Hz with 40 ton-f at 50Hz. We use a device with a horizontal rotational axis. Using alternatively clockwise and counter-clockwise rotations we can synthesize vertical and horizontal forces, respectively. 31 three-components and 8 nearby geophones have been used to monitor the seismic changes from pumping the water.

Comparing the data during one and half month, we identified waveform changes and clear daily variations. These waveform changes might be caused by the change of water table. In this report, we will show the preliminary results obtained in this field. This experiment is conducted in the cooperation by Japan and KACST funded by JCCP (Japan Cooperation Center, Petroleum) and KACST.

LABORATORY MEASUREMENTS OF SEISMIC VELOCITIES OF CO2/BRINE MIXTURES AT ELEVATED TEMPERATURES UP TO 70°C AND PRESSURES UP TO 38 MPA

Olga Bilenko, Maxim Lebedev and Boris Gurevich*
Curtin University, Perth, Australia

Phase equilibrium of CO_2-brine fluids is important to studies related to CO_2 sequestration in deep saline aquifers and CO_2 enhanced oil recovery. Furthermore, the study of the seismic properties of CO_2 saturated and not saturated brines as pore fluids helps to understand their influence on the 4D seismic properties of rocks.

In this work we reported results of measurements of the acoustic velocities in brines with dissolved CO_2. We investigate the effects of pressure (from 2 MPa to 38 MPa), temperature (from 30°C to 70°C), and salinity (0, 10,000 ppm, 20,000 ppm, 40,000 ppm, 100,000 ppm) of KCl-NaCl brines on ultrasonic velocities. We also study the time lapse effect of CO_2 dissolution into the brine.

It has been found that CO_2 dissolution in brine has significantly changed acoustic properties of brine.

LOW FREQUENCY LABORATORY MEASUREMENTS OF THE ELASTIC AND ANELASTIC PROPERTIES OF THE SANDSTONE FLOODED WITH SUPERCRITICAL CO_2

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The results of the first low frequency experiments conducted on a sandstone sample (Donnybrook, Western Australia) flooded with supercritical CO_2 ($scCO_2$) are presented. The aim of the experiments was to investigate the effects of $scCO_2$ injection on the elastic and anelastic properties of the rock. The sandstone sample (porosity – 11.4%, permeability – 0.28 mD) was cut in the direction orthogonal to a formation bedding plane and tested in a Hoek's triaxial pressure cell equipped with the means for independent control of pore and confining pressures. The pore and confining pressures were set up at 10 and 31 MPa correspondingly. The low-frequency system and the pump comprising $scCO_2$ were held at a temperature of 42Â° C. Supercritical CO_2 was injected into the sample preliminary saturated with distilled water. The elastic parameters obtained for the sample with $scCO_2$ at frequencies from 0.1 to 100 Hz are very close to those for the dry sample. Some discrepancy in calculated acoustic velocities can result from the difference in water and $scCO_2$ densities. The increase of the extensional attenuation after $scCO_2$ injection into water saturated sandstone was insignificant. The applicability of Gassmann's fluid substitution theory for the interpretation of obtained results was also tested during the experiments.

EXPERIMENTAL LABORATORY STUDY ON THE ACOUSTIC RESPONSE DURING INJECTION OF SUPERCRITICAL CO_2 INTO BRINE SATURATED SANDSTONES

Maxim Lebedev[1]*, *Vassili Mikhaltsevitch*[1] *and Boris Gurevich*[1,2]
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[2]CSIRO, Perth, Australia

Quantitative knowledge of the acoustic response of rock from an injection site on supercritical CO_2 saturation is crucial for understanding the feasibility of time-lapse seismic monitoring of CO_2 plume migration. A suite of sandstones with similar composition but different petrophysical properties has been tested to reveal the effects on acoustic responses of supercritical CO_2 injection into brine saturated sandstones. CO_2 is first injected into dry samples, flushed out with brine and then injected again into brine saturated samples. Such experimental protocol allows us to obtain acoustic velocities of the samples for the wide range of CO_2 saturations from 0 to 100%. On injection of supercritical CO_2 ($scCO_2$) into brine-saturated samples, some of samples exhibit observable perturbation of ~10% of compressional velocities with the increase of CO_2 saturation form 0% to maximum (~50%). However for some sample effect of $scCO_2$ injection on acoustic properties is negligible.

1530–1730
Day 2 Session 4 Stream 2

MAG GRAV TECHNOLOGIES/DEEP EXPLORATION

GRAVILOG – BOREHOLE GRAVITY RESULTS IN MINING AND GEOTECHNICAL APPLICATIONS AND THE INTRODUCTION OF A DUAL SENSOR DENSITY PROBE

Chris Nind[1]*, *J. MacQueen*[2], *R. Wasylechko*[3], *M. Chemam*[3], *C. Nackers*[3] *and A. Black*[4]
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[2]Micro-g LaCoste, Inc, Lafayette, Colorado, USA
[3]Abitibi Geophysics, Val d'Or, Quebec, Canada
[4]Geoaviation LLC, Chandler, Arizona, USA

Scintrex GRAVILOG borehole gravity meters are now successfully deployed by Abitibi Geophysics crews in boreholes for mining exploration in Canada and USA and by Scintrex and Micro-g LaCoste crews in wells used for injection, sequestration and leaching in Canada, USA and Europe. In 2013, GRAVILOG systems and crews will be available in Russia, Brazil and Australia. Scintrex has developed and will be testing a dual sensor GRAVILOG probe in early 2013.

This talk will start with a brief review of the GRAVILOG development and specifications, followed by several recent case histories. The result from Donner Metals / Xstrata Zincs Bracemac KT Zone in the Abitibi region of Quebec is the first documented use in mining exploration of borehole gravity to measure excess mass coincident with a borehole EM conductor. Forward modeling and inversion of GRAVILOG data from multiple holes has proven effective to outline the body and estimate tonnage at Virginia Mines Coulon Lens 44 property in Quebec. Apparent bulk density measurements from four holes in Labrador Iron Mines James South Extension iron ore deposit near Schefferville, Quebec provide a quantitative estimate of tonnage, reducing drilling costs and time needed to obtain this information. GRAVILOG surveys are being conducted to establish baseline data in CO_2 sequestration wells in Michigan and Texas prior to commencing injection. The injected CO_2 will be monitored by future GRAVILOG surveys.

A major source of error in bulk density measurements of thin beds is minimized by the dual sensor GRAVILOG system. In addition to eliminating the error in the depth interval between the sensors, common mode noise rejection improves the gravity difference data.

NEW APPROACHES TO DEALING WITH REMANENCE: MAGNETIC MOMENT ANALYSIS USING TENSOR INVARIANTS AND REMOTE DETERMINATION OF IN SITU MAGNETISATION USING A STATIC TENSOR GRADIOMETER

David Clark[1,2]*
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[2]CSIRO Earth Science and Resource Engineering, North Ryde, NSW, Australia

Assuming without evidence that magnetic sources are magnetised parallel to the geomagnetic field can seriously mislead interpretation and can result in drill holes missing their targets. I present two new methods for providing information about magnetisation of anomaly sources, independent of the geometry of the causative bodies. The first method is based on analysis of magnetic gradient tensor data. Integral moments of tensor invariants locate the horizontal and vertical centres of magnetisation and estimate the magnetisation direction. The depth estimate allows correction of the integral moments for the finite range of integration, which can accordingly be restricted to the main part of the anomaly. This reduces interference from neighbouring sources. This method provides information on location, total magnetic moment (magnetisation X volume), and magnetisation direction of a compact source, without making any assumptions about its shape.

The second method employs a single combined gradiometer/magnetometer, operating in base station mode within a magnetic anomaly of interest. The response to geomagnetic time variations allows the contributions of induced magnetisation and remanence to the anomaly to be separated. This method allows remote estimation, prior to drilling of (i) the total magnetisation direction of the source, which is a key to accurate modelling (ii) the remanence direction, which can provide geological information such as age of intrusion or alteration, (iii) the Koenigsberger ratio Q, which is indicative of the magnetic mineralogy of the source. If the source is compact, the method also provides a direct indication of the direction to its centroid.

DEEP CRUSTAL STRUCTURES INTERPRETED FROM POTENTIAL FIELD DATA ALONG THE DEEP SEISMIC SOUNDING TRANSECT ACROSS OLYMPIC DAM, SOUTH AUSTRALIA

Irena Kivior[1], *David Boyd*[2], *David Tucker*[3]*, *Stephen Markham*[1], *Francis Vaughan*[1], *Fasil Hagos*[1] *and Leslie Mellon*[1]
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[3]Flinders Exploration

Energy spectral analysis techniques have been applied to magnetic and gravity data acquired over the Olympic Dam area of South Australia. Analysis has been conducted along two deep seismic lines previously acquired. There is a strong correlation between interfaces found in this analysis and structures interpreted from the seismic data. Lateral interpretation of the magnetic and gravity data allows for a valuable extension of the seismic interpretation. A bland zone apparent in the seismic data has been associated with the Olympic Dam ore-body by various authors. The top of this bland zone is strongly associated with density interface found from the gravity data, and this may be a significant correlation. Further deep crustal structures are evident, including the Moho, and indications of the Curie isotherm.

The results obtained from energy spectral analysis over this area suggest that a much wider application of this approach across the Australian continent could be highly valuable.

AIRBORNE MAGNETIC AND RADIOMETRIC GEOPHYSICAL MAPPING IN SOUTH AND CENTRAL RANGE MOUNTAINS, PAPUA INDONESIA

Katherine McKenna[1]*, *H. P. Siagian*[2], *I. Sobari*[2], *J. Nasution*[2], *B. S. Widijono*[2], *B. Setyanta*[2] *and Adrian Noetzli*[1]
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The Centre for Geological Survey (CGS) of Geological Agency, Indonesia, known as Pusat Survei Geologi, commissioned an airborne magnetic and radiometric survey covering the Indonesian Papuan Central Highlands Region and the southern side of the highlands during 2010 and 2011. The survey was funded by the State Revenue and Expenditure of the Ministry of Energy and Mineral Resources of The Republic of Indonesia and covered an area of 156,964 square kilometres. Geological mapping in this area is recognised as being difficult predominately due to the extreme terrain and weather. The objective of the survey was to map the surface geology as well as sub-surface geology, identify and map the structure of the region, to model new geophysical data along with previously collected ground gravity data, and integrate all the results with the previously known geology. The expected outcome would be a better understanding of the geology and structure in the region and an increase in mineral and oil and gas exploration for Indonesia. The survey consisted of a helicopter based magnetic and radiometric survey in the Central Highlands Region at 500 m spacing totalling 20,045 km and a fixed-wing aircraft based magnetic and radiometric survey over the south side of the highlands at 1,000 m spacing totalling 155,530 km. The results highlighted and extended the geological, structural, and tectonic evolution knowledge of the region and identified areas for further mineral and oil and gas exploration. The modelling of the magnetic and gravity data supported the interpretation and added further information to the depth analysis of the data.

LONG-WAVELENGTH MAGNETIC ANOMALIES AS A GUIDE TO THE DEEP CRUSTAL COMPOSITION AND STRUCTURE OF EASTERN AUSTRALIA

*Robert Musgrave**
Geological Survey of NSW, NSW Trade & Investment, Maitland, Australia

Aeromagnetic data over eastern Australia reveal a pattern of domains defined by systematic regional highs and lows, emphasised by low-pass filtering, over which are superimposed shorter (<20 km) wavelength anomalies related to mappable geology and its inferred subsurface continuation. Long-baseline levelling by Geoscience Australia has clarified the definition of these magnetic domains, and confirmed that they are not an artefact of grid merging. Geothermal and teleseismic data indicate that neither variation in Curie depth nor upper mantle magnetisation can produce the long-wavelength pattern. Hence, domain-wide variations in magnetisation at the middle to lower crustal level are presumably the cause of these long-wavelength features. Although reversed polarity remanence could contribute to deeply sourced negative magnetic anomalies, the correspondence of magnetic low domains with the Proterozoic Curnamona Craton and the Ordovician Macquarie Arc, and of a high domain with the western Lachlan Orogen floored by Cambrian ocean crust, suggests that the control may be simply stark contrasts in lower to middle crustal susceptibility. Moho thickness determined by the AusMoho model mimics the pattern of susceptibility domains, suggesting a relationship between tectonic history and mid to lower crustal composition. Implicit in this analysis is a division of the domains into two categories of deep crust type, continental and oceanic, with implications for the tectonic evolution of the Tasmanides and the distribution of mineral systems in eastern Australia. The mid to lower crust below the Macquarie Arc appears to be continental, and the Thomson Orogen is a compound feature, comprising both attenuated continental/arc crust and accreted oceanic crust.

DEFINING A DEEP FAULT NETWORK FOR AUSTRALIA, USING 3D 'WORMING'

Desmond FitzGerald[1]* *and Peter Milligan*[2]
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The original work on multi-scale edge detection ("worming") done by Hornby et al. in 1999 has become increasingly popular as a starting point for rapid interpretation using potential field data. Both gravity and magnetic grids are used. Several improvements have been made in the following years such that it is routine to capture points, "worms" and linear features in a form suitable for overlay in GIS packages.

There are important extensions which have recently been completed:
(a) support for gravity gradiometry using the measured gradients directly
(b) creation of interface and foliation data implying 3D surfaces that are geolocated
(c) adaption of Euler deconvolution techniques to both full tensor gravity gradiometry (FTG) and a best located method for scalar measures.

This paper reports on these new extensions applied to the Australian gravity grid and on issues arising from these efforts to improve/generalise the worming technology and get 3D contacts that can be interpreted.

This large scale gravity dataset, with a high density of near surface features, contains far too many gradients interpreted as faults, so a thinning strategy is required to find the significant deep crustal faults.

These deep crustal faults require proper attribution of depth, dip direction and dip, and also extent constraints.

For the FTG case, the largest 3-survey merge attempted to date has occurred with data acquired in Kenya. The new and improved 3D worming has been applied in the context of rapidly defining the horst/graben layouts in an active rift zone.

Some discussion and illustration of the present problems of how to build, merge and manage a 3D fault network, where the issues of faults terminating on other faults and which fault cuts which, will be shown and discussed.

1530–1730
Day 2 Session 4 Stream 3

HARD ROCK SEISMIC IV

INTERNAL COMBUSTION IMPULSE SOURCE VS. MINI-VIBRATOR VS. NOMAD65 VIBRATOR SHOT TEST

*Cliff Delaporte[1], Louis Polome[2], Charles Pretorius[3], Anna Leslie[4], Frederic Moinet[5], Jason Jurok[6], Eric Bathellier[4] and Michel Denis[4]**
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Over the last two decades 3D reflection seismic has been applied for mine planning in South Africa. For coal exploration, the mining targets are at shallower depths of less than 400 m. The challenge set by the mining companies is to obtain high-resolution seismic data with maximum vertical resolution at this depth of investigation. The cost of geophysics must also be more attractive than that of the "total drilling" alternative.

Seismic source trials were therefore conducted at one mine site. The ICIS (Internal Combustion Impulse Source) has been developed by CGG to provide a solution for shallow target surveys and for in-fills where access for conventional sources is restricted. The source is self-contained, powered by readily available propane gas and oxygen, capable of 3,000 impacts per 16 oz. standard propane canister. A GPS-driven high-accuracy clock and a specially developed impact sensor provide accurate time-stamping and recording of time-break information to better than 1 Î¼s. The shooting system integrates seamlessly with Sercel SN408 or SN428 recording systems, using an additional system process that allows the observer to switch rapidly from explosive or vibroseis mode to ICIS on a shot-by shot basis. The ICIS and Mini-vibrator performance were tested in shallow coal prospects, where existing 2D data have been acquired by Nomad 65 heavy vibrator.

The tests demonstrated that ICIS is well suited to image target depths less than 500m with frequencies up to 100 Hz. The comparison with the vibroseis sources showed that ICIS i) Delivered very good near offset data (> 50 m) and for up-hole/ low velocity layer survey ii) Required more shots per shot point in the medium offset range (1000 m) due to its low energy iii) Not designed for far offset data (3000 m). ICIS was found to be a viable geophysical and logistic solution for certain high-resolution mineral surveys.

ESTIMATION OF SEISMIC ATTENUATION FROM ZERO-OFFSET VSP ACQUIRED IN HARD ROCK ENVIRONMENTS

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Curtin University and CRCDET, Perth, Australia

Understanding of seismic attenuation plays an important role in successful application of seismic imaging and subsurface characterisation techniques based on amplitude analysis. Zero-offset vertical seismic profiling (VSP) is one of the principal tools which can be used to study seismic attenuation.

Apparent attenuation estimated from seismic data analyses comprises of scattering and intrinsic components. Scattering mechanism can play significant role in hard rock environments in areas associated with fracture zones or other complex structures. As such seismic attenuation can be an important seismic exploration attribute.

Meanwhile attenuation analyses from VSP data are almost routinely done in oil and gas industry they are still uncommon in mineral exploration.

In this study we analyse zero-offset VSP data acquired in Western Australia on one of CRC DET test sites using both hydrophones and 3C geophones as receivers. We compare several methods for apparent attenuation estimation and evaluate of their applicability to VSP data acquired in crystalline rocks. Extensive wire line log coverage for the well allows us to investigate relative contribution of different attenuation mechanisms.

VOLUMETRIC INTERPRETATION OF 3D HARD ROCK SEISMIC DATA

Muhammad Hossain, Milovan Urosevic and Anton Kepic*
Curtin University and Deep Exploration Technologies Corporative Research Centre

Seismic reflection method has been successfully used in the petroleum industry for the last few decades. Until recently, the mining industry has been reluctant to use seismic methods for mineral exploration because of its high cost, uncertain performance, and potentially ambiguous interpretation results. However, shallow mineral reserves are depleted and exploration is moving towards deeper targets in order to extend existing and find new mineral reserves. In that space it is perceptible that seismic method will become an important if not primary exploration tool to delineate subsurface structures hosting ore bodies. One of the outstanding issues along the application of seismic methods for mineral exploration is our ability to grasp and then interpret excessively complex seismic images.

Recently introduced volumetric interpretation technique has some advantages over the conventional interpretation technique where the interpretation is done by slicing the volume in X-Z or Y-Z planes. Volumetric interpretation is performed in 3D, in real time by applying various opacity and transparency filters to grasp the global structures and by rotating and viewing the seismic volume from different angles which allows in-depth understanding of the volume analysed. This, initial stage of volumetric interpretation is followed by more specific tasks aimed towards mapping the interfaces and associated structures of exploration interest. The ore shoots or occurrences are predicted by numerical modelling based on the a priori knowledge. The targeting strategy is constructed according to the numerical response and map of the main interfaces and structures. This, for hard rock, novel interpretation methodology is aimed towards direct targeting and estimates of the ore reserves. The implementation is demonstrated on a field data from Kambalda, WA.

A REPRODUCIBLE FRAMEWORK FOR 3D ACOUSTIC FORWARD MODELLING OF HARD ROCK GEOLOGICAL MODELS WITH MADAGASCAR

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A special challenge of hard rock exploration is to identify targets of interest within complex geological settings. Interpretation of the geology can be made from direct geological observations and knowledge of the area, and from 2D or 3D seismic surveys. These interpretations can be developed into 3D geological models that provide the basis for predictions as to likely targets for drilling and/or mining. To verify these predictions we need to simulate 3D seismic wave propagation in the proposed geological models and compare the simulation results to seismic survey data. To achieve this we convert geological surfaces created in an interpretation software package into discretised block models representing the different lithostratigraphic units, and segment these into discrete volumes to which appropriate density and seismic velocity values are assigned. This approach allows us to scale models appropriately for desired wave propagation parameters and to go from local to global geological models and vice versa. Then we use these digital models with forward modelling codes to undertake numerous 3D acoustic wave simulations. Simulations are performed with single shot and with exploding reflector (located on extracted geological surface) configurations.

NEW CONSTRAINTS ON AN EXISTING MINERAL RESOURCE THROUGH 3D SEISMIC

Chris Wijns[1,2]**, Alireza Malehmir and Emilia Koivisto*
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The Kevitsa nickel-copper deposit in northern Finland is a large, low-grade, mafic-hosted accumulation of disseminated sulphides with rare, spatially restricted occurrences of net-textured to semi-massive sulphides. The mineable limits of the resource grow or shrink with commodity prices, but it has also been recognised that subtle mafic layering in the intrusion controls subhorizontal layering of sulphides. The net-textured and semi-massive mineralisation styles occur near the base of the intrusion. Data from a 3D seismic survey demonstrate the unpredicted ability to image the sub-horizontal mafic layering, as well as the expected reflections at the base of the intrusion in contact with interlayered volcanic and sedimentary country rocks. The ability to trace the lateral extents of the mafic layering, backed up by analysis of borehole sonic and density logging, offers the possibility to predict the ultimate envelope of the resource. The interpretation of the base of the intrusion provides a horizon along which to target the net-textured to semi-massive contact sulphides.

CRS STACK BASED SEISMIC IMAGING – A CASE STUDY FROM ST IVES MINING CAMP, KAMBALDA, WESTERN AUSTRALIA

Liliya Malovichko and Milovan Urosevic*
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Seismic exploration in hard rock environments is challenging due to complex geological conditions that reduce the signal-to-noise (S/N) ratio of seismic data and, thus, an accurate velocity model recovery likelihood. This limits the application of conventional imaging methods, e.g., normal moveout (NMO), dip moveout (DMO) stacking or pre-stack migration.

The common reflection surface (CRS) stacking technique can be used in complex environments to increase the fold and therefore the signal quality and produces reliable stacked sections with high resolution. On the other hand, CRS stacking approach does not depend on a velocity model.

The CRS stacking approach was applied to 2D and 3D datasets acquired across the St Ives mining camp in Kambalda, Western Australia located within the core of a regional-scale Kambalda Dome. The main objective of this study is to review the application of the CRS approach at the St Ives mining camp in Kambalda, Western Australia.

Stacked 2D seismic sections and a 3D seismic volume obtained using the CRS approach are superior to those obtained by conventional DMO/NMO processing. They are characterized by a higher S/N ratio and improved continuity of seismic reflection events. Parameters (wavefield attributes) estimated using the CRS approach have a clear geophysical interpretation and will be used for building velocity models.

The target area and the existing faults and fractures were imaged clearly and the high grade of tectonic displacement necessary to ensure a sufficiently large production rate was verified. The CRS approach is now adopted as a part of the standard processing flow for hard rock seismic.

1530–1730
Day 2 Session 4 Stream 4

MINERALS – AEM INVERSION II

MONTE CARLO INVERSION OF SKYTEM AEM DATA FROM LAKE THETIS, WESTERN AUSTRALIA

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During 2011 Groundprobe Geophysics flew a SkyTEM airborne electromagnetic (AEM) survey in the vicinity of Lake Thetis near Cervantes in Western Australia. The survey was commissioned by the Western Australian Department of Water as part of the Mid West Groundwater Dependent Ecosystem Vulnerability Project. Groundprobe Geophysics processed and then initially inverted the dataset using the iTEM fast approximate inversion.

Subsequently the data were inverted using a reversible jump Markov chain Monte Carlo (rj-McMC) 1D inversion algorithm recently developed at Geoscience Australia. Both the high- and super-low-moment data were inverted simultaneously taking into account the tilts of the transmitter-receiver frame. In the inversion of each dual-moment AEM sounding an ensemble of 300,000 models were generated in a Markov Chain, about 290,000 of which fit the data within the estimated noise

envelope. The reversible jump aspect of the algorithm means that the number of layers in the 1D models varies, and the algorithm tends to favour models with the fewest number of layers that allow the data to be fitted, in essence providing a data-driven Occam's Razor.

The algorithm is considerably more computationally expensive than deterministic inversions. However its advantage is that a great deal of information can be extracted from the ensemble. For example, the most likely, mean, mode and median models were all extracted and made into conductivity depth slice maps and sections. We extract the 10th and 90th percentile models and use the spread between them as a measure of model uncertainty, which we convey on maps by making uncertain areas more transparent. Another output of the algorithm is a change-point histogram which provides information on the most probable depths of the layer interfaces. By extracting the peaks from this histogram we begin to be able to automatically interpret layer boundaries to be plotted onto conductivity sections.

CONSTRAINED INVERSION OF IP PARAMETERS FROM AIRBORNE EM DATA

Andrea Viezzoli[1]*, *Gianluca Fiandaca*[2], *Esben Auken*[2], *Anders Christiansen*[2] *and Simonetta Sergio*[1]
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[2]University of Aarhus, Aarhus C, Denmark

The possibility of extracting IP information from AEM data never stopped being of interest to the scientific community and industry.

We apply to this old problem the proven approach of the Laterally and Spatially Constrained Inversion. By applying constraints in the model space, we improve the resolvability of model parameters in the ill posed inversion problem. We present a synthetic study where the model the IP response over a layered earth using the Cole-Cole model. We simulate both an environmental and an exploration target.

Results show that, as expected, in some cases, some of the Cole-Cole parameters can be resolved better using the LCI-SCI than by using stitched together inversions. They also provide useful insight into different ranges/combinations of resolvable parameters. Limitations of the approach are those of the SCI-LCI; in presence of strong 3D variations, the dimensionality of the forward response produces inaccuracies in the recovered models. Nonetheless, we argue that this approach can be applied satisfactorily to a number of real cases. We aim at presenting at the conference results also from real dataset.

RECOVERY OF 3D IP DISTRIBUTION FROM AIRBORNE TIME-DOMAIN EM

*David Marchant**, *Eldad Haber and Douglas Oldenburg*
The University of British Columbia, Vancouver, Canada

A materials' chargeability is commonly considered to be the most diagnostic physical when exploring for disseminated mineralization. It is also useful in many environmental and engineering applications. Traditionally, the presence of chargeable material is detected using the induced polarization technique. While this technique has been successfully applied in the mineral exploration industry for a number of years, its application is not always practical. Exploring on a reconnaissance scale can be limited by the time required to place the transmitter and receiver electrodes. The technique can also fail in certain geologic environments. A highly resistive overburden may make it impossible to inject enough current to excite a measurable IP response.

Conventional IP is not the only technique that is sensitive to chargeable material. Any electromagnetic method applied in the presence of chargeable material will be affected. Unfortunately, the effects are often hard to recognize in the data. For the particular case of coincident loop time-domain EM data, negative transients – soundings with a reversal in sign of the received fields – are diagnostic of chargeable materials. This property can also be extended to centre loop systems, including many airborne systems. Negative transients are commonly observed in airborne TEM systems, such as Fugro's AeroTEM system or Geotech's VTEM system.

Despite the fact that negative transients can be directly related to the presence of chargeable material, relatively little has been done to try and interpret them directly. In this work, we develop a three dimensional inversion routine to recover the distribution of chargeable material from IP affected airborne time domain electromagnetic data. The technique is applied to a variety of synthetic examples in order to showcase when this approach should be expected to be successful. Finally, the technique is demonstrated on a field data set.

AEM SYSTEM TARGET RESOLVABILITY ANALYSIS USING A MONTE CARLO INVERSION ALGORITHM

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Geoscience Australia, Canberra, Australia

There are several factors that must be considered when choosing an airborne electromagnetic (AEM) system for a specific survey task. These factors always include cost, availability and logistics. However, the most important consideration is the ability of an AEM system to resolve the target(s) to be mapped.

To date Geoscience Australia has tackled this later consideration in terms of "detectability" rather than the "resolvability", which are two distinct concepts. We say that a target is detectable if the difference between the AEM response of the target and the background is sufficiently greater than the AEM system's noise levels. Resolvability not only requires that the target's data anomaly be detectable, but that we can also estimate, with sufficient confidence, via an inversion procedure, the cause of the anomaly.

Geoscience Australia is now addressing the resolvability question though a reversible jump Markov Chain Monte Carlo (rj-McMC) inversion algorithm. A 1D forward model code generates synthetic data for each AEM system under consideration, for a suite of type-model scenarios that represent the expected range of situations to be mapped, which may include actual downhole conductivity logs. The data are then inverted using the rj-McMC inversion, which, importantly, uses the expected AEM system noise levels.

The rj-McMC algorithm samples millions of models, possibly on independent parallel Markov Chains, that fit the data to within the AEM system's expected noise levels. Analysis of the ensemble of models yields a robust estimate of the uncertainty of resolving the model at any particular depth. It is a simple

matter to then compare and contrast the results for each AEM system under consideration. We also show how the method can be used to provide depth of investigation estimates.

3D INVERSION OF TIME DOMAIN ELECTROMAGNETIC DATA

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Airborne time-domain electromagnetic (EM) surveys are effective tools for mineral exploration, geologic mapping and environmental applications. These surveys can be an economical way to explore large prospective regions. Traditionally, the data from such surveys have been interpreted using time constant analysis, conductivity to depth imaging (CDI) or possibly 1D inversions. These methods assist in a simple interpretation of the data, however because they do not fully model the physics in 3D, they can fail to accurately represent environments such as real world structures and geological targets. Airborne EM datasets are characterized by large volumes of data, as each EM sounding implies a new transmitter location. As a result, inverting this data in 3D is a computationally difficult problem that until recently has not been possible for the exploration community. In this abstract we demonstrate a methodology for inverting large airborne EM surveys in 3D using multiple meshes, each spanning the full model domain. By using an adaptive meshing procedure during the forward modelling, each mesh is optimally designed for computational efficiency on the local domains defined by a subset of transmitters. This procedure allows the computational cost of each mesh to be dependent on the number of subset transmitters considered, rather than the total survey size. Since the forward modelling operation is the bottleneck for any inversion, this results in a highly parallel algorithm that can handle arbitrarily large datasets. In this abstract we outline our airborne electromagnetic inversion methodology and demonstrate it using synthetic and field data examples.

1530–1730
Day 2 Session 4 Stream 5

PASSIVE EM & REMOTE SENSING

PASSIVE AND ACTIVE HELICOPTER EM SURVEY COMPARISONS OVER THE 501 PROJECT CU-ZN VOLCANOGENIC MASSIVE SULPHIDE AT MCFAULD'S LAKE, NORTHERN ONTARIO

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The 501 project is a high grade Zn-Cu-Pb-Ag mineralized, Mattagami-Noranda style volcanogenic massive sulphide deposit that is situated in the Ring of Fire region of McFauld's Lake in Ontario. It hosts significant intersections of massive and semi-massive sulphide which have been delineated over a north-south strike length of 200 m and to a vertical depth of 275 m from surface.

The 501 zone was discovered in 2008 following drilling of AeroTEM airborne electromagnetic and follow-up ground magnetic and horizontal loop HLEM survey program in 2007. In fall 2008, the deposit and surrounding area were reflown with the VTEM helicopter EM system. And in summer 2009, the area was flown with the ZTEM passive helicopter EM system. The objectives of the VTEM survey was to provide greater depth of investigation, below the conductive alluvial and sedimentary cover, and for the ZTEM survey to provide indications of possible extensions of mineralized zones at depth.

Airborne EM, both passive and active, are known to be very useful tools for copper exploration – albeit respectively for disseminated copper porphyries and Cu-bearing volcanogenic & magmatic massive deposits. Although, in exploration settings, passive and active AEM surveys are rarely both flown over the same property, several joint ZTEM-VTEM test case studies for massive sulphides have been presented, notably the Axis Lake, Eagle's Nest, Nebo-Babel, Forrestania and Mayville magmatic Cu-Ni deposits, as well as the Lalor Lake Cu-Au VMS deposit. However, in nearly all instances these have all been relatively large/long strike-length orebodies, which are well-suited to ZTEM's large footprint and large depth of penetration. However, at approximately 200 × 250 m, the 501 zone is a relatively small VMS deposit that appears to respond well to all three active and passive airborne EM systems that have surveyed the property.

AN ASSESSMENT OF ZTEM AND TIME DOMAIN EM RESULTS OVER THREE MINERAL 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 survey, a helicopter time domain EM (HTEM) data set is available to compare with the ZTEM results. Overall, while similarities were noted between the ZTEM and HTEM results, there were also some significant differences that are not totally understood based on available geological information.

HELICOPTER EM (ZTEM-VTEM) SURVEY RESULTS OVER THE NUQRAH CU-PB-ZN-AU SEDEX MASSIVE SULPHIDE DEPOSIT IN THE WESTERN ARABIAN SHIELD

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Mineral exploration in the Precambrian Arabian Shield region of the Kingdom of Saudi Arabia has identified thousands of mineral occurrences in the last 40 years and has included airborne geophysics, primarily regional magnetics and radiometrics but, more recently, electromagnetics. As part of a larger survey campaign in the western Arabian Shield, helicopter

EM survey tests were flown for comparison purposes over the 1.4Mt Nuqrah sedex (sedimentary exhalative) copper-lead-zinc-gold massive sulphide deposit, using the VTEM and ZTEM systems. The Nuqrah deposit comprises mineralized bodies, Nuqrah North and Nuqrah South that are 4 km apart, each marked by a gossan, and hosted between beds of dolomitic marble and either volcanic tuffs or diabase intrusives.

The active source VTEM survey was able to characterize the regional geology and localized high conductivity signatures associated with known Nuqrah North and Nuqrah South sedex deposits. As well, new targets of low to moderate conductance have been identified that potentially represent massive to semi-massive sulphides. The passive source ZTEM survey also structurally mapped the Nuqrah survey area but penetrated more deeply. Both survey data indicate that the major controlling structures that host Nuqrah North and South also remain open to the northeast and south of the survey area. The active and passive EM anomalies generally coincide well with the North and South Nuqrah deposits, with the VTEM able to define the smaller, shorter strike-length and more massive sulphide mineralized vent portions of the sedex orebodies; whereas the ZTEM defined the larger, less mineralized but more clay-altered and less conductive distal portions of the sedex system. Interestingly, the passive EM survey appears to also have detected a deeper conductive feature lying further west of the South Nuqrah that potentially represents a down-dip extension of sedex deposit below 750 m depths.

3D INVERSION OF ZTEM DATA FOR URANIUM EXPLORATION

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We present a Gauss-Newton-based 3D inversion method for airborne ZTEM (Z-axis Tipper Electromagnetic) data to define resistivity structure relating to uranium deposits in Athabasca Basin of Saskatchewan, Canada. The geophysical targets in this region can be represented by conductive plunging dykes in a resistive basement beneath a thick, more resistive overburden. We demonstrate using synthetic examples the effectiveness of the inversion method for detecting and delineating the target dykes and discuss how the inversion results are affected by various factors. It is shown that the dykes can be well imaged to depths more than 2 km even for the data from 200-m receiver height, provided the flight line is oriented perpendicular to the strike, and that the inversion results are relatively robust to the choice of the starting model. It is also shown that topographic effects are not serious for detecting the dykes at depth, because topographic effects are more significant at higher frequencies, while the sensitivity to the dykes increases with decreasing frequencies. One important finding is that if the flight line is oblique to the strike, the dependence of the starting model increases and the overall resolution decreases, compared to the 2D case, due to 3D effects.

EXTRACTING MINERALOGICAL AND GEOMORPHOLOGICAL INFORMATION USING NEW ASTER MINERAL MAPS WITH AIRBORNE GEOPHYSICS

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[2]Geological Survey of New South Wales, Maitland, Australia
[3]Geological Survey of South Australia, Adelaide, Australia
[4]CSIRO Earth Science & Resource Engineering, Perth, Australia
[5]Geoscience Australia, Canberra, Australia

Australia wide maps have recently been generated and released by CSIRO and Geoscience Australia using the 14 band satellite-borne ASTER sensors. Seventeen map products related to surface composition have been developed, based on spectral absorption features representing either abundance of mineral groups, specific minerals and their chemistry, vegetation cover or regolith related characteristics. This study aims to test the geoscience mapping capabilities of these products, individually, and integrated with airborne geophysics and DEMs over the semi-arid Mt Fitton, South Australia, and within the agricultural Wagga Wagga region, New South Wales. The robustness of these techniques is further tested comparing the results from these two areas with different geological exposure and cultivation.

Various image processing, GIS and principal component analytical techniques were utilised. High resolution airborne hyperspectral imagery and published mapping provided control. ASTER map products: Ferric Oxide Content, Ferrous Iron Index, AlOH Group Content, FeOH Group Content, MgOH Group Content & Composition, Ferrous Iron Content in MgOH, and Silica Index products revealed surface mineral composition associated with previously mapped host or altered units of Mt Fitton. MgOH Group Composition and Ferrous Iron in MgOH products highlighted anomalies associated with Mt Fitton talc/tremolite metasomatism. The AlOH Group Content and Ferrous Iron Index products discriminated the radiometrically anomalous Terrapinna and Yerila Granites whilst DEM information enabled the discrimination between ASTER Silica Index defined quartz rich alluvium and outcrops.

These results showed that within the semi-arid Mt Fitton environment, ASTER map products were useful for the identification of the mineral (group) composition related to either the host rock units or altered mineralogy. Integration of ASTER products with airborne radiometric, magnetics and DEMs refined the interpretation of the surface geology and associated landforms.

UNSUPERVISED SOFT CLUSTERING OF HIGH RESOLUTION AIRBORNE GEOPHYSICAL AND SATELLITE DATA SUITES FROM THE SPERRGEBIET, KARAS REGION, SOUTHERN NAMIBIA, TO ENHANCE LITHOLOGY MAPPING

Detlef Eberle[1], *David Hutchins*[2]* *and Nortin Titus*[2]
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[2]Geological Survey of Namibia (GSN), Windhoek, Namibia

The Karas region is the southernmost region of Namibia extending between the Orange River in the south and latitude 25S in the north and from the South Atlantic Ocean in the west to the eastern border at longitude 20E. The geology of the Karas region

is characterized by the pan-African Gariep Fold Belt in the west, the Meso-Proterozoic Namaqua Metamorphic Belt in the central area and south, and the Kalahari Craton in the northeast.

The airborne magnetic and radiometric data were acquired with a flight line spacing of 200 m above ground and terrain clearance of 80 m. ASTER and Landsat imagery which completely cover the Karas Region were processed to match for integration with the airborne geophysical data.

A novel data integration and classification tool recently developed (e.g. Paasche and Eberle 2011) has been used for automated and objective information extraction. The integrated data, i.e. a large set of multi-element vector samples – each of them carrying magnetic, radiometric, satellite band/hyperspectral and positioning information - has been grouped into a number of classes to provide a pseudo-lithology map. Spatial resolution of the pseudo-lithology map is considerably higher than that of conventional geological maps. High resolution data are thus considered a pre-requisite to identify new mineral exploration targets from this innovative integration technology.

A few examples from different geological settings of the Karas region are discussed and compared with conventional mapping products, field trip evidence and geophysical ground-truthing.

1530–1730
Day 2 Session 4 Stream 6

MINERALS – REGIONAL STUDIES III

3D MODELLING OF MAGNETOTELLURIC DATA ACQUIRED ALONG THE YOUANMI DEEP SEISMIC REFLECTION TRANSECTS IN THE YILGARN, WESTERN AUSTRALIA

*Peter Milligan**
Geoscience Australia, Canberra, Australia

Geoscience Australia (GA) has been acquiring both broadband and long-period magnetotelluric (MT) data over the last few years along deep seismic reflection survey lines across Australia, often in collaboration with the States/Territory geological surveys and the University of Adelaide.

Recently, new three-dimensional (3D) inversion code has become available from Oregon State University. This code is parallelised and has been compiled on the NCI supercomputer at the Australian National University.

Much of the structure of the Earth in the regions of the seismic surveys is complex and 3D, and MT data acquired along profiles in such regions are better imaged by using 3D code rather than 1D or 2D code.

Preliminary conductivity models produced from the Youanmi MT survey in Western Australia correlate well with interpreted seismic structures and contain more geological information than previous 2D models. GA has commenced a program to re-model with the new code MT data previously acquired to provide more robust information on the conductivity structure of the shallow to deep Earth in the vicinity of the seismic transects

TARGETING FUTURE MINERAL DISCOVERIES UNDER COVER USING A MINERAL SYSTEMS APPROACH

Anthony Schofield and David Huston*
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Predictive mapping of mineral systems represents an important tool for assessing the potential for undiscovered mineral resources in Australia. Recently, assessments for a range of uranium mineralisation styles have been performed across three regional studies in Queensland, South Australia and the Northern Territory. These investigations have been undertaken using a mineral systems framework which considers key system components including sources, fluid-flow drivers and pathways, and depositional mechanisms.

The method which has been used places a strong emphasis on identifying important processes leading to ore formation, which are then translated into mappable geological proxies using a range of input datasets and derivatives. At relatively shallow depths, these may be mapped using geochemical and observational geological data. However, deeper-buried terranes, such as those dominating most of the Australian continent, require the use geophysical data to generate proxies for targeting the desired processes.

Importantly, and unlike other available techniques, the method employed does not rely on the locations of known mineralisation to generate maps of mineral potential. This allows assessment of mineral potential in Greenfield regions of Australia, including those beneath significant volumes of cover. Results from the regional studies completed to date successfully reproduce the locations of known mineralisation and highlight potential in areas not currently recognised as mineralised. Such mineral system analyses provide predictive models which may be the focus for follow-up investigation, including drilling.

AN ELECTRICAL RESISTIVITY MODEL OF THE SOUTHEAST AUSTRALIAN LITHOSPHERE

Kate Robertson[1]*, *Graham Heinson*[1], *Stephan Thiel*[1] *and David Taylor*[3]
[1]University of Adelaide, Adelaide, Australia
[2]Geological Survey of Victoria, Department of Primary Industries, California, USA

Data from 68 broadband magnetotelluric stations were inverted to obtain a 2D electrical resistivity model beneath the Delamerian Orogen in southeast Australia along a 150 km east-west transect. Station spacing of 5 km in the west and ~2 km in the east resolved structure with changes in resistivity from 10-10,000 m occurring laterally over several kilometres. To the west, the crust is generally resistive, with a more complex structure to the east involving narrow paths of low resistivity (10-300 m). These conductive regions extend from Moho depths up to the surface and align with fault structures. The narrow conductive pathways possibly track mineral alterations from reactions with mantle fluids moving upwards late in the Delamerian Orogeny.

REGIONAL AEM SURVEYS FOR NAMIBIAN GOVERNMENT

Gregory Street[1]*, *Geoffrey Peters*[1], *Ivor Kahimise*[2] *and David Hutchins*[2]
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[2]Namibian Geological Survey, Windhoek, Namibia

Regional surveys using the TEMPEST208 airborne electromagnetic system were acquired for the Geological Survey of Namibia in 2011. The TEMPEST208 is the lowest cost airborne electromagnetic system available currently worldwide and was selected to test a cost effective means of covering the country with AEM and particularly to map thickness of the Kalahari Sequence to open new areas for mineral exploration.

This review of the data acquired showed that:
• TEMPEST208 did have some noise problems but significant improvements could be achieved with minimal work by the contractor;
• TEMPEST208 can map areas of thin (0-60 m), to medium (~100 m) and thick cover (>150 m) Kalahari Sequence. In areas of thin cover conductors can be detected in the underlying basement. In areas of medium cover an estimate of thickness of the Kalahari (with LEI) is probably possible but in areas greater than 150 m the system generally did not detect the base of the Kalahari;
• Comparison with detailed surveys done with standard TEMPEST and VTEM shows that TEMPEST208 detected most of the features seen in surveys by the more sophisticated system; and
• The data will be useful for explorers selecting best areas for exploration particularly where the Kalahari Sequence is less than 60 m.

It is recommended that:
• Small upgrades to the TEMPEST208 system would assist in reducing noise particularly in relation to GPS position of the receiver bird;
• Water wells be logged with downhole conductivity to provide better modelling parameters, for input to Layered Earth Inversions; and
• The GSN should extend the survey with similar specifications to other parts of the country covered by Kalahari Sequence.

THE APPLICATION OF AEM AS A REGIONAL MAPPING AND TARGETING TOOL IN THE PATERSON PROVINCE OF WA

*Will Robinson**
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As part of the Onshore Energy Initiative GA flew the Paterson Province in WA for AEM using Tempest on east west flight lines ranging from 1-2 km line spacing in 2008.

Encounter Resources is an ASX listed, Greenfields exploration company run by a group of former WMC employees. The company's main project is the Yeneena Project, located 60km south west of the giant Telfer Gold/Copper deposit in the Proterozoic Paterson Province.

Prior exploration in this region has been minimal due to extensive sand cover and the ineffectiveness of magnetics as a regional mapping and targeting tool.

In what was a bold decision for the company at the time Encounter committed to infill the GA regional survey to a 500 m line spacing across its 1400km2 project.

The acquisition and application of this new data set was a seminal moment in the exploration project. The use of AEM to map structure and the geological units under sand cover in conjunction with regional aircore drilling has significantly improved the explorability of this highly prospective Paterson mineral province.

Following up on structural targets generated in the initial Tempest survey a series of helicopter based VTEM surveys have been completed by Encounter.

This use of the regional EM data has lead to a significant investment in ground geophysics, aircore, RC and diamond drilling and has been integral to the discovery of copper sulphides at three separate locations at the Yeneena project. This includes the BM1-BM7 copper mineral system which is now over 11 km long and still growing. Early intersections of 10m @ 6.8% Cu, 20 m @ 2% Cu and 73 m @ 0.4% Cu have demonstrated the prospectivity and the scale potential of this new copper discovery in WA.

THE LINK BETWEEN ELECTRICAL CONDUCTIVITY ANOMALIES AND RHEOLOGICAL BOUNDARIES

*Stephan Thiel** *and Graham Heinson*
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Interpreting magnetotelluric (MT) models requires solid modelling of the data as well as good knowledge from other geophysical data and geological constraint in the particular tectonic setting of the survey area. MT measurements, relating the natural variations of electric and magnetic field to obtain the electrical resistivity distribution of the crust and mantle appear to show that enhanced electrical conductivity zones are more abundant at certain depths. Models show that frequently enhanced conductivity zones are topping out in the upper crust at depths of about 10-15 km. These features are discrete and extend usually over a few km to tens of km laterally, and can be found across the Delamerian Orogeny, in zones of high heat flow east of the Northern Flinders Ranges and also in the central Eyre Peninsula. We interpret this to be related to recent findings on dynamic interactions between brittle and ductile layers leading to mid- to upper crustal detachment faults. A second zone of higher conductivity occasionally appears in the lower crust, as imaged east of the Flinders Ranges at depths of around 25-35 km. Geodynamic modelling indicates that permeable porosity is created through viscous grain boundary sliding, creep cavitation and precipitation. Irrespective of current of fossil fluid flow, these ductile shear zones and fluid pathways have a likely electromagnetic response to surface MT measurements. Thirdly, at 80 km depth mantle conductors appear in stable Archaean and Proterozoic terranes around the world, such as in the Slave Craton, Kaapvaal Craton and the Gawler Craton. In summary, information from geodynamic modelling helps to understand the processes in the earth in regards to fluid movement and potential mapping of heat flow and corresponding shift in depth of brittle-ductile boundaries.

Day 3: Wednesday 14 August 2013

0830–1030
Day 3 Session 1 Stream 1

SEISMIC ACQUISITION – TECHNOLOGIES II

KEYNOTE ADDRESS: ARE BROADBAND, WIDE AND MULTI-AZIMUTH THE NEW NORMALS FOR 3D MARINE SEISMIC?

*Dan Whitmore**
PGS

In the last decade the seismic industry has seen ever increasing application of wide, multi-azimuth, and rich azimuth surveys. Additionally, in last half decade the industry has seen a much greater emphasis on broadband acquisition and processing methods with the goal of achieving a seismic spectrum that spans both low and high frequencies. But are these technologies used only in specialized cases or are they the new normals in acquisition and processing?

There are significant costs associated with these acquisitions styles. So, value must be achieved by the use of technologies that provide improved subsurface images. The paper discusses some of the issues and highlights key technologies. This includes: imaging and velocity inversion in complex regimes, preservation of bandwidth for reservoir characterization, and estimation of the anisotropic and azimuthal properties of the subsurface.

MARINE TOWED STREAMER SEISMIC USING CONTINUOUS LINE ACQUISITION

Timothy Brice, Richard Patenall and Budi Priasati*
WesternGeco, Perth, Australia

The most cost-effective way to acquire 3D seismic data offshore is by towed-streamer survey; the majority of these surveys are acquired using a vessel shooting a series of parallel straight lines to cover the survey area. When each line is completed, the vessel turns and starts the next line until the survey area is covered. Normally, data are not acquired during the turns due to difficulty in maintaining streamer lateral separation and the extra noise generated in the data. This means that, depending on the survey size and shape, there may be significant non-production time.

Advances in marine acquisition technology have made it possible to acquire usable data as the vessel turns, which increases productivity because there is little or no non-productive time associated with line changes. Streamer steering systems allow spread shape to be maintained during line changes, and new streamer designs and processing schemes mean that noise no longer presents a barrier to utilising these data.

We present some background on this technique and discuss a recent survey in New Zealand. In this survey, the straight line sections were shortened and turn data were incorporated into the survey. This enabled data to be acquired in shallow water areas. In addition, the data were acquired using a fan shooting technique to improve coverage and a variable depth cable with a multilevel source to produce ghost-free data, and therefore extend the data bandwidth. These three streamer configurations were combined to efficiently acquire broadband data in a challenging area.

BROADBAND MARINE SEISMIC, HOW MUCH DIFFERENCE DOES ACQUISITION AND OR PROCESSING MAKE? A CASE STUDY FROM SOUTHEAST ASIA

Martin Bayly and Ng Swee Leng*
WesternGeco, Perth, Australia

Expanding the bandwidth of surface seismic data, particularly towards low frequencies, is essential for many exploration and production objectives. Broader band signal, both in land and marine environments have marked benefits for imaging deeper targets, imaging through absorptive overburdens, and especially useful for inversion to rock properties. Various methods have been proposed and implemented to expand seismic bandwidths which include both acquisition and signal processing methods. This paper describes a series of tests run to evaluate and analyse the bandwidth response of different acquisition and processing techniques.

We present a Southeast Asia offshore case study of an experimental dataset. A single multi-cable boat pass of data was collected with several different cable depths, including shallow, deep and slanted configurations. These data were then processed with their appropriate deghosting methods and results compared against a conventional “flat” eight metre tow acquisition and processing approach. In addition, we examine methods for evaluating the success of these methods and their potential pitfalls.

The tests demonstrate the processing techniques used to overcome the phase, datum and frequency response issues for both a single slanted cable and also those used for twin paired cables (over-under technique). Comparisons of final images, amplitude spectra and “spectral split” displays will be shown to analyse the final results. Conclusions are drawn as to the relative geophysical success of differing methods and their logistical implementation.

0830–1030
Day 3 Session 1 Stream 2

KEYNOTE ADDRESS: CAN WE USE CONVENTIONAL SEISMICS IN UNCONVENTIONAL RESOURCE PLAYS?

*Leon Thomsen**
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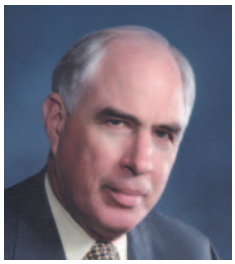
UH Department of Earth and Atmospheric Sciences, Houston, Texas, USA



Unconventional resource plays are currently driven by advances in drilling and completion technology, rather than in exploration technology. In order to increase the efficiency of operations in these fields, it is necessary to actually explore for the best places, the "sweet spots", to drill and frac. This will require unconventional geophysics, to match these unconventional rock formations. In particular, the exploration techniques of acquisition, processing, and interpretation will recognize the fact that these formations are anisotropic, both seismically and electromagnetically.

UNEXPECTED HTI VELOCITY ANISOTROPY: A WIDE-AZIMUTH, LOW FOLD, 3D SEISMIC PROCESSING CASE STUDY

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[2]Velseis Processing Pty Ltd, Brisbane, Australia

This case-study demonstrates seismic processing in the presence of Horizontal Transverse Isotropic (HTI) velocity anisotropy encountered in a low-fold land 3D survey in New Zealand. The HTI velocity anisotropy was unexpected, being suspected only after the initial poor stack response compared to vintage 2D sections in the area, and the sparse 3D design made it difficult to identify. The paper shows how anisotropy was singled out from other possible causes, such as geometry errors. We discuss the key steps of the processing flow incorporated to deal with the HTI anisotropy to attain a high quality final processed volume. In particular we show data examples after the application of azimuthally dependant NMO velocities, along with pre-stack HTI migration. Examples are shown which demonstrate the preservation of the HTI anisotropy before and after 5D trace interpolation.

Maps and vertical profiles of 3D attributes are used to demonstrate the magnitude and direction of the HTI velocity field, which varies 5% to 10% between the fast and slow horizontal directions. These observations coincide with the local stress state deduced from borehole break-out studies. We conclude that the fast velocity direction corresponds to the present maximum horizontal stress direction. Finally the paper summarises the implications for processing wide azimuth 3D data in this area and suggests improvements for future 3D survey design.

SPATIAL VARIATION IN AZIMUTHAL ANISOTROPY DUE TO SAND-SHALE DISTRIBUTION: STYBARROW FIELD CASE STUDY

Lisa Gavin and David Lumley*
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Anomalous horizontal stress conditions within reservoir rock can result in azimuthally anisotropic elastic properties, the effects of which can be observed in borehole and 3D seismic data. The amount of stress-induced anisotropy can vary depending on sedimentary rock type and on subsurface stress conditions. There is currently no methodology we are aware of to quantify the relationship between azimuthal anisotropy and sand-shale content in unconsolidated sediments. We use data from the Stybarrow Field, located offshore NW Australia in the Carnarvon Sedimentary Basin, which is an area where strong anomalous horizontal stress conditions are present and have induced azimuthal anisotropy. We model azimuthally anisotropic gathers from logs and spatially correlate azimuthal AVO variations with sand-shale content. We derive a relationship that predicts the Thomsen parameter gamma as a function of the shale volume (for volume ratios greater than 0.3), and use this relationship to predict spatial variations in the azimuthal anisotropic AVO observed in the seismic data at Stybarrow. Implications from this work are that azimuthal anisotropy can be a strong function of sand-shale content, and that spatial variations in the sand-shale ratio can be estimated from azimuthal AVO.

0830–1030
Day 3 Session 1 Stream 3

GEOPHYSICS IN HYDROLOGY

IS NUCLEAR MAGNETIC RESONANCE THE FUTURE OF HYDROGEOPHYSICS?

*Jared D. Abraham**
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Over the past 15 years, Nuclear Magnetic Resonance (NMR) has become much more accessible for use in hydrogeologic characterisations. With the development of Surface NMR (SNMR) systems by Iris Instruments, Radic Research, and Vista Clara Incorporated; the research and commercial industries have

access to a geophysical system that can directly detect water. The petroleum industry has long been using NMR in boreholes and some of those systems have been used in groundwater investigations. For many groundwater projects the logistics and costs associated with implementing petroleum industry tools have been prohibitive. In 2010 Vista Clara released a smaller NMR borehole system called the Javelin. This system is considerably smaller than the petroleum industry version making it useable in small diameter wells and less expensive to operate. Logistically the system is small in size, light in weight and short in length and does not require a large draw works and drill rig to deploy. So currently as there are several surface NMR systems and several choices of borehole systems, is NMR solely a hydrogeophysics industry? The fact is it is not. Geologists and hydrologists are using NMR more and more often, but it is still not used in every hydrogeophysical study.

To understand the details of NMR we need to look at what parameters we observe with the NMR technique. The three key parameters are longitudinal relaxation (T1), transverse relaxation (T2), and the free induction decay envelope (T2*). The important question is how do these parameters relate to what we want; which includes total water content, mobile water content, bound water content, and hydraulic conductivity. The petroleum industry has spent many millions of dollars giving us some important clues as to how these parameters related to aquifer parameters in porous media. One of the big challenges remaining is how do NMR parameters behave in unconsolidated sediment? Often in many groundwater environments the aquifers are unconsolidated. Ultimately all NMR soundings and logs need some form of calibration to understand how to correlate the NMR signal to a parameter that we desire (hydraulic conductivity and mobile versus bound water).

Currently both surface NMR and the new slim-hole Borehole NMR tools are being used more and more around the world. Use of SNMR ranges from applications of locating drilling targets in Africa to detecting water filled karst in France. SNMR and borehole NMR are also beginning to be used in understanding aquifer parameters in the high plains of Nebraska and the Murray and Darling Rivers in Australia. Another user of this technology is the mining industry where they are applying NMR in the detection of water in and around active mining operations.

NMR has the potential to change the way hydrologists perform aquifer tests. Academic institutions and government organizations around the world are actively pursuing research projects to better understand and utilise the information that is provided by NMR. One of the critical links in the research into NMR phenomena is the understanding of the impact of magnetic minerals and the complexity of the relaxation in unconsolidated sediments.

Is NMR the "Silver Bullet" in hydrogeophysics that will replace all other techniques? No, but NMR has an important and a critical role in the future of Hydrogeophysics, hydrogeology and water management activities.

THE ROLE OF AIRBORNE GEOPHYSICS IN FACILITATING LONG-TERM OUTBACK WATER SOLUTIONS TO SUPPORT MINING IN SOUTH AUSTRALIA

*Timothy Munday**
CSIRO Earth Science and Resource Engineering, Perth, Australia

Mining and energy development in South Australia's far north is set to have significant consequences for the water resources of the region. These sectors generate significant economic value to the State and their support remains a priority for the government. The scale of the planned developments and the potential from current exploration programs facilitated by the South Australian Government through PACE Program will result in a substantial increase in infrastructure requirements, including access to water resources and Aboriginal lands for potential mine developments. Increased demand for water and in particular groundwater is compromised by the limited knowledge we have about these resources. This includes information about their character, variability, sustainability and their relationship to environmental and cultural assets, which is most notable in the priority areas for development. There is a recognised need to develop this knowledge so that water is not a limiting factor to development. In this paper results from the Goyder Institute's Long-Term Outback Water Solutions (G-FLOWS) Project are presented. Particular reference is made to work completed in the Musgrave Province. It illustrates the role of local scale AEM, acquired for exploration, and regional scale airborne magnetics in helping develop a hydrogeological conceptual model for the Province. The AEM data reveal a complex, extensive inset palaeovalley system which contains groundwater of variable quality (2000–4500 mg/L TDS). Examination of their location against the regional magnetics indicates a strong lithostructural control on their orientation and distribution. If mineral resources were to be developed in the area, these groundwater systems would represent the best option for water supply. A regional scale water resource map, based on information gleaned from the geophysics, existing hydrogeological and digital elevation data, is presented that provides a framework for groundwater resource determination when/if mineral deposits were to be mined in the region.

INTERGRATION OF THE SURFACE AND LOGGING NMR DATA TO MAP HYDRAULIC CONDUCTIVITY

Elliot Grunewald[1]*, *David Walsh*[1], *Rosemary Knight*[2], *Katherine Dlubac*[2], *Andrew Parsekian*[2], *James Butler*[3], *Steve Knobbe*[3], *Ed Reboulet*[3] *and Mercer Barrows*[1]
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Geophysical NMR measurements yield direct detection of groundwater and provide sensitivity to hydraulic conductivity (K) via the measured NMR water content and relaxation times. The aim of this work is to map hydraulic conductivity over wide areas by leveraging complementary aspects of surface and logging NMR measurements. Surface NMR measurements have the advantage of being non-invasive and can image the basic NMR response of the subsurface over wide areas. NMR logging measurements, on the other hand, provide data at higher resolution and detail, but can only be acquired at sparse locations where boreholes are available. In practice, deriving robust estimates of K from either of these measurements is improved using site-specific calibration and comparison with hydrogeologic K measurements. We have developed a framework for calibrating and integrating these measurements, and this framework has been tested at three field sites in the United States. The framework can be divided into three components: (1) establishing the relationship between the logging NMR measurement and hydrogeologic measured K; (2)

establishing the relationship between the logging NMR and surface NMR measurement; and (3) relating the surface NMR measurement to K and extending surface acquisition over a wide area. The data include an extensive collection of slug-tests, NMR logs, and surface NMR measurements, supplemented further by (DP) technologies, including a pressure/flow sensor DP-K tool and novel DP-NMR tool. Our results demonstrate the viability of this approach as well as the need for appropriate site- or region-specific calibration. Specifically, the relationship between the NMR logging measurement and surface NMR measurement can vary significantly in the presence of magnetic geology. We have also established that the method of well installation and logging can influence the estimated relationship between the NMR log and K measurement.

0830–1030
Day 3 Session 1 Stream 4

ADVANCES IN DATA VISUALISATION I

KEYNOTE ADDRESS: GEOLOGICAL INTERPRETATION OF POTENTIAL FIELD DATA

*John McGaughey**
Mira Geoscience

Potential field methods have a distinguished history of contribution to mineral discovery. The role of gravity and magnetics is necessarily evolving as modern exploration addresses the challenge of finding significant new deposits at depth, under cover, or in brownfields settings. The exploration problem is increasingly one of multi-disciplinary data integration, guided by expectation of the characteristics of ore deposit settings across a range of scales. In this context potential field data is increasingly playing more of a supporting role in recognition and investigation of ore systems, and less of a direct discovery role through recognition of anomalies in data.

Beyond the more traditional roles of aid to geological mapping and direct anomaly detection, potential field data have a clear role to play in supporting or directly driving the geological interpretation required for recognising and interpreting complex ore system environments. Key contributions are:
1) structural mapping, as the structural architecture both defines the volumetric geometry of the geological setting as well as typically providing a direct control on ore emplacement;
2) inversion for geometry of geological units across which a density or magnetic susceptibility contrast is known or assumed;
3) inversion for establishing the existence of particular geological units, or understanding the 3D distribution of physical properties within such units for interpretation in terms of alteration or other geological characteristics that exert a control on density or magnetic susceptibility.

In practice these roles imply a requirement of advanced 3D structural interpretation of potential field data, geologically-constrained and structurally-constrained 3D inversion, and understanding the statistics of density and magnetic susceptibility within the geological setting at hand. Significant advances have occurred in each of these areas over the past several years, and are highlighted through several examples.

Virtually all ore deposits are structurally controlled at some level, and structural interpretation of potential field data remains a potent tool. Case studies are presented highlighting recent advances in developing structural models from magnetic and gravity data, as well as developing 3D structural vector field models for use as inversion constraints.

The techniques of constrained inversion for interpreting geological settings have proven extremely valuable and are in relatively wide use. Case study examples demonstrate inversion guided by interpretive control of the relative contribution of physical property heterogeneity and the geometry of geological unit boundaries. Understanding physical properties is widely accepted as critical to geological interpretation of potential field data but, in spite of significant progress, challenging problems remain. Understanding the relationship between physical properties and geological description remains inadequate, although recent case studies have clearly demonstrated that what often constitutes a coherent unit to the geologist may not be so to the geophysicist. Natural physical property units, as seen through both density and susceptibility properties, may cut across natural geological units, whether on the basis of formation, lithology, or alteration zone. This is particularly true of magnetic susceptibility, which is not only controlled by magnetic mineral content, but also its form, texture, and relevant geological history. The long-promised value of joint inversion of potential field data is even more hobbled by inadequacy of physical property understanding, as it requires understanding of joint physical property distributions if its promise is to be realised.

In spite of challenges, particularly in connecting potential field data to geological interpretation through the physical property model, there have been many important advances in using potential field to directly contribute to geological interpretation, in geological terms. The role of both gravity and magnetic data in directly supporting exploration at depth, under cover, and in brownfields settings is assured by the new and developing methods of geological interpretation of potential field data.

COMPUTING, BRAINS AND GEOPHYSICS?

Andrew Pethick[1]*, *Karen Lam*[2] *and Brett Harris*[1]
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Brain computer interface (BCI) systems are emerging as a breakthrough technology of the 21st century. As is the case with other developing technologies, proof of concept must be demonstrated before advanced methods are pursued. This article presents the first published case study of a brain controlled geophysical software package. We show how brain computer interface systems can facilitate accelerated learning in the geoscience community. Our results show that processed

brainwaves from the NeuroSky MindWave electroencephalography (EEG) device can be used to control various geophysical survey parameters with an acceptable degree of accuracy and to model the corresponding data in real-time.

TOWARDS UNDERSTANDING AND IMPROVING GEOSCIENTIFIC DATA INTERPRETATION

Yathunanthan Sivarajah[1], Eun-Jung Holden[1], Roberto Togneri[2] and Mike Dentith[1]*
[1]Centre for Exploration Targeting, University of Western Australia, Perth, Australia
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Geoscientific data interpretation is a highly subjective and complex task as human intuition and biases play a significant role. Based on these interpretations, however, mining and petroleum industries make decisions with paramount of financial implications. As a first step towards understanding and improving the interpretation process, we carried out two experiments to monitor the human-data interactions during the process of identifying targets (porphyry-style intrusive systems) within the aeromagnetic imagery. This is achieved by capturing the eye gaze position using an eye tracker system and the brain responses using electroencephalography (EEG).

The first experiment was intended to analyse the target spotting performance and the data observation patterns. For this experiment participants performed exercises, where the same magnetic image was presented in different orientations.

Some key findings include: inconsistencies in target spotting performance within and between the interpreters; an improvement performance when the data were viewed in multiple orientations; and a strong correlation between the target spotting performance and efficient (systematic) data observation pattern. There was no correlation between success in identifying targets and the participant's perception of their expertise.

The second experiment was designed to identify the characteristics of the targets that are easier to detect using EEG. For this experiment images with targets and without targets were presented in a rapid visual display. The analysis on the image characteristics based on the human visual attention model show a strong correlation between target spotting difficulty and dispersion of the visual attention.

0830–1030
Day 3 Session 1 Stream 5

MINERALS – POTENTIAL FIELDS – CONSTRAINED GEOLOGICAL INVERSION I

3D GEOLOGICAL MODEL FOR KING SOUND, CANNING OFFSHORE BASIN, WESTERN AUSTRALIA USING FALCON HIGH RESOLUTION AIRBORNE GRAVITY GRADIOMETRY

Peter Kovac[1], Sharon Lowe[1], Tony Rudge[2], Carlos Cevallos[1], Jurriaan Feijth[1] and Lynsey Brett[3]*
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A 3D geological model for King Sound, in the offshore Canning Basin, Western Australia, was produced by interpretation of FALCON high resolution airborne gravity gradiometry and magnetic data, aided by 2D gravity models, 2D seismic data and well logs. Pseudo-depth slices of the vertical gravity gradient (GDD) and magnetic data and interpreted seismic horizons were used to constrain the vertical distribution of sedimentary sequences, intrasedimentary intrusives and basement rocks. Basement depth was determined from the magnetic data using traditional profile-based automated magnetic depth estimation techniques with well control.

The 3D model indicates an elevated, fault-bounded platform of Archaean to Proterozoic basement in the north. The platform is rimmed by Late Devonian and Early Carboniferous carbonate reefs and carbonate breccias and in the south, contemporaneous siliciclastic submarine fans and turbidite deposits occur in a deep marine environment.

Density values derived from published literature and measured in wells at King Sound were assigned to units in the geological model. A forward model was calculated and compared to the observed GDD data. The assigned density values were then modified, within the expected range for each rock type, using property inversions until a good fit between the modelled and observed data was obtained.

Models derived from potential field data can be beneficial for petroleum exploration in frontier basins worldwide, where only limited well and seismic data are available. The 3D geological model provides a good framework for use in designing future exploration programs in the area and it aids data visualisation and interpretation.

APPLICATION OF CURVATURES AND POISSON'S RELATION TO AIRBORNE GRAVITY GRADIENT DATA IN OIL EXPLORATION

Carlos Cevallos, Peter Kovac and Sharon Lowe*
Fugro Airborne Surveys Pty Ltd

The application of equipotential surface curvatures and Poisson's relation to airborne gravity gradient data is presented. The mean and differential curvature of the equipotential surface, the curvature of the gravity field line, the shape index, the zero contour of the Gaussian curvature of the equipotential surface and the zero contour of the determinant of the gravity gradient tensor should improve the understanding and geological interpretation of gravity gradient data. Their use is illustrated in model data and applied to FALCON airborne gravity gradiometer data from the Canning Basin, Australia.

KEYNOTE ADDRESS: 3D POTENTIAL-FIELD INVERSIONS: RECENT ADVANCES AND ROAD AHEAD

*Yaoguo Li**
Center for Gravity, Electrical, and Magnetic Studies (CGEM)
Colorado School of Mines

With the breathtakingly rapid development of quantitative data interpretation techniques in potential-field methods, it might be beneficial to look back at the advances achieved in recent years and to look ahead on some of the leading-edge research that will likely transpire in the next few years and lead to a new generation of interpretation tools.

Towards these goals, we will first provide a review of new developments in 3D potential-field inversions achieved during the last six years. We will focus on the advances in three areas associated with the physical property inversions: (1) inversion of complex magnetic data sets affected by strong remanent magnetisation and self-demagnetisation effect, (2) inversion of multiple-component gravity gradiometry, magnetic gradiometry, and borehole gravity data, and the requisite processing techniques for these new data types; and (3) algorithmic and computational techniques for enabling and accelerating the solution of super-large scale problems on district scales with high-resolution data, and on regional and global scales with extensive data areas.

Several current research directions are poised to bring about dramatic changes to potential-field inversions and their applications. We will highlight a limited number of such directions and venture a prediction of their roles as the next generation interpretation tools. These include: (1) rapid solution on super-large scales using differential-equation solutions; (2) inversion in spherical coordinates on a global scale, and (3) joint inversion of potential-field data of themselves, and with other geophysical and petrophysical data.

This review will be structured primarily from a mineral exploration perspective, but advances are being made in a wide range of disciplines that utilise the potential-field methods such as environmental clean up, mineral exploration, and oil and gas exploration and production. It is hoped, therefore, that such a review will be beneficial to a broad audience of practicing geophysicists in the mineral and petroleum industry as well as other allied disciplines.

1100–1230
Day 3 Session 2 Stream 1

SEISMIC PROCESSING – CASE STUDIES

MULTI-AZIMUTH PSDM PROCESSING IN THE PRESENCE OF ORTHORHOMBIC ANISOTROPY – A CASE HISTORY OFFSHORE NORTH WEST AUSTRALIA

Sergey Birdus[1], Jason Sun[2], Wenting Sun[2], Yi Xie[2], Marco Gazzoli[3], Marco Andreolli[3] and Alex Ursulic[4]*
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[4]Eni Australia Limited, Perth, Australia

In this paper we present a case history of multi-azimuth 3D PSDM processing. The datasets show strong HTI as well as VTI anisotropy. We show the processing workflow with emphasis on the construction of an imaging velocity model that correctly represents the orthorhombic anisotropy and short-wavelength velocity variations. The PSDM image is improved over earlier processings.

HORIZON BASED TARGET ORIENTATED BEAM DEMULTIPLE WITH EXAMPLES FROM THE NORTH WEST SHELF, AUSTRALIA

*Edward Lewis and Andrew Long**
Petroleum Geo-Services, Perth, Australia

Complex inter-bed multiple in the North West Shelf, Australia, is a problem for depth velocity modelling and imaging of Jurassic reservoirs. Traditional Radon & 3D-SRME (3D Surface Related Multiple Elimination) demultiple techniques are now standard processes for removing long period and waterbottom related multiples. However, throughout the Browse Basin, deeper multiple generators and the small velocity discrimination between primary have rendered these techniques ineffective against inter-bed multiples.

Beam Migration has specific advantages in its speed and high signal-to-noise levels that make it suitable for depth velocity modelling and final imaging. Wavelets can, based upon a combination of criteria, be weighted down or excluded from reconstruction.

It is possible to reject wavelets that match a multi-dimensional multiple model. This model is based upon a combination of interpretation, normal moveout and spatial & temporal location.

Data examples from the North West Shelf, Australia, illustrate the flexibility of this approach and demonstrate its effectiveness in the complex inter-bed multiple area of Browse Basin.

Close interaction and good understanding of the objectives, especially between the imagers and the asset team is required for the project' success. Interactive or quick testing of multiple model scenarios (through combined depth velocity model building software) is necessary to aid this interaction.

AN IMAGING CASE STUDY OF RAGAY SC-43, PHILIPPINES: FROM 2D TO 3D PSDM PROCESSING

Xiaodong Wu[1]*, *Keat Huat Teng*[1], *Joe Zhou*[1], *Edgar Benedict Cutiongco*[2] *and Jimmy Bacud*[3]
[1]CGGVeritas, Singapore, Singapore
[2]Mubadala Petroleum, Singapore, Singapore
[3]Philippine National Oil Company, Manila, Philippines

Ragay SC-43 Block was located off the southern tip of Bondoc Peninsula, between the Ragay Gulf and the Sibuyan Sea. Huge carbonate reef was developed and complex faulting system dominated in the shallow sediment in this area. This resulted in a very complex subsurface geology with strong lateral velocity contrast, which made high resolution PSDM processing essential for the successful structure imaging in this area. With dense model representation and optimized inversion regularization, high resolution tomography update can provide detailed velocity modelling. Together with high fidelity controlled beam migration technology, it provided a solution for structural imaging in such a complex area.

1100–1230
Day 3 Session 2 Stream 2

SEISMIC VELOCITIES AND APPLICATIONS

KEYNOTE ADDRESS: THE CHALLENGE OF DRILLING IN HIGH PRESSURE AREAS SUCH AS THE NORTH WEST AUSTRALIAN SHELF

*Richard Swarbrick**
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The North West Australian Shelf documents Mesozoic continental break-up, generating a series of structures with trapping geometries for Jurassic and Triassic reservoirs, often sealed beneath Cretaceous shales. The Tertiary section is dominated by carbonates which document continental margin collapse. Many of the wells have found near-normal pressure reservoirs at all depths drilled, but some deep drilling has proven very high-pressure reservoirs. The combination of older, deeper and hotter reservoirs (where long periods of exposure to elevated temperatures has modified rock properties used in conventional pressure prediction) and thick carbonate-rich Tertiary overburden lead to many challenges to predicting overpressure. The paper will help to explain the mechanisms which create overpressure and its preservation, and what methods are available for pressure prediction, including the development of geological models to complement traditional porosity-based solutions, using seismic velocity and other geophysical methods applied to petrophysical logs. The context for the overpressure, the implications for top seal failure and hydrocarbon leakage, as well as indications of lateral pressure escape will also be reviewed. Analogues of other Mesozoic continental break-up margins such as Norway and east coast of Canada provide insights into the challenges of drilling high pressure reservoirs and offer some possible solutions.

HIGH RESOLUTION TIME-TO-DEPTH CONVERSION USING 3D GRID TOMOGRAPHY

*Fabio Mancini**
Woodside, Perth, Australia

Time-to-depth conversion is the process where seismic velocities are scaled accordingly to check shots and well logs so that geological markers and seismic horizons match in depth. Seismic data, if in depth, are stretched to time with the migration velocity before re-depthing with the calibrated velocity model. There are many different techniques that are routinely used in the industry either by scaling average velocities or interval velocities with some derived correction functions. These functions can be simple scalars, depth variant scalars or more complex time and space variant functions which need to be interpolated between wells. In any case the depthing process is quite laborious since the derivation of correction function for each well is time consuming. The application of these correction functions may produce results that look somehow discontinuous, with jumps in velocity at the horizons where the corrections have been applied, and, when working on average velocities, they could produce unrealistic interval velocity in the presence of thin layers. Since most of today seismic projects are run through PSDM, an elegant way to derive the velocity volume for time-to-depth conversion is to use the same tool used for PSDM velocity model building, the 3D Grid Tomography.

In this paper I show how this technique greatly simplify the depthing process producing a velocity model that ties all the markers for all wells within a velocity depth sample.

1100–1230
Day 3 Session 2 Stream 3

ENVIROMENTAL AND ENGINEERING I

APPLICATION OF NEAR-SURFACE GEOPHYSICS WHERE NO-ONE THOUGHT YOU COULD, OR SHOULD

*Phil Sirles**
Zonge International Inc.

For about a decade, engineers and environmental scientists have utilised geophysical investigations with an increasing regularity.

This is attributed to three separate, but equally important, items: 1) use of laptop computers in-the-field to produce on-site, (preliminary) interpreted results; 2) use of software and hardware that is easier to produce results in a format that mates with their industry software (e.g., ArcInfo, ArcView, Acad3D); and, 3) the visualisation techniques of geophysical results, particularly in 3D. When complex, integrated, and multiple geophysical data sets can be displayed in common user-friendly formats the results GET USED for design and analysis. Further development of field instrumentation and software that lessens the trepidation of engineers, hydrologists and environmental scientists will create an ever-increasing need for- and the application of- geophysical tools. Because of ever-increasing training opportunities, field experiences and knowledge of the value of geophysical data, the presentation will demonstrate, through several examples of near-surface engineering and environmental geophysical investigations, that these three important items promulgate the use of appropriate geophysical methods. Ultimately, we need clients to understand why they should utilise subsurface imaging, scope the work, fund and contract the often esoteric investigation, and then incorporate quality geophysical results acquired in urban settings into their analyses.

APPLICATION OF GEOPHYSICAL METHODS TO DAM SAFETY ASSESSMENT IN KOREA

Sung Keun Lim[1], *Ki Yeon Park*[1], *Young Soo Song*[2], *Sung Ho Song* [1] *and Chi Ho Ahn*[1]
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[2]Chonbuk National University, Korea

Electrical resistivity methods were applied to delineate leakage pathways and to investigate the condition of core material in earth fill dams. In other to evaluate the engineering geological properties of the soil deposits, two boreholes a dam were drilled to the bedrock that exceeds the height of the dam. A large set of field tests including standard penetration test (SPT) and in-situ permeability tests were carried out along the boreholes.

A series of laboratory tests were also conducted on the undisturbed soil samples obtained using the split-spoon sampler and thin wall tube sampler to determine their engineering characters. The resistivity values which were estimated from the previous inversion result for each depth were compared with the N values from SPT for each borehole. It could be classified in two groups where were not showed in general trend and most of the sites had some seepage problem and decrepit facilities need to be improved.

We have also measured resistivity values of undisturbed soil samples obtained from boreholes at 311 different dam sites. We confirmed low resistivity values of soil in core material were distributed at the Gyeongsang basin and some regions in Korean peninsula. As a result of these studies, it was possible to get more quantitative interpretation of seepage problem.

1100–1230
Day 3 Session 2 Stream 4

ADVANCES IN DATA VISUALISATION II

MASS ANOMALY VISUALISATION AND DEPTH ESTIMATION FROM FULL TENSOR GRADIENT GRAVITY DATA

Daniel Wedge[1]*, *Yathunanthan Sivarajah*[1], *Eun-Jung Holden*[1], *Peter Kovesi*[1], *Chris Wijns*[1,2] *and Paul Johnston*[3]
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[3]School of Physics, The University of Western Australia, Perth, Australia

Full Tensor Gradient (FTG) gravity data measures the derivatives of the Earth's gravitational field. Such variations in the gravitational field may be due to the presence of bodies of higher or lower density relative to the surrounding rock. Recent technological advances have made airborne measurement of FTG data possible, resulting in the rapid collection of vast quantities of data particularly for mineral, oil and gas exploration purposes.

As the gravity tensor contains 5 independent components, effective visualisation of this high-dimensional dataset is advantageous for efficient processing of the FTG data. We present two aspects of visualising mass anomalies in FTG gravity datasets. First, we create a textured image where the orientations of the resulting texture reflect local lateral orientations encoded in the FTG data. It uses a colour map to highlight geologically significant structures such as linear features and radially symmetric points by identifying different geological features and using colour components to represent different feature types. This visualisation method is shown to be robust to significant levels of modelled noise, and we demonstrate its applicability to a field FTG survey.

Second, we present an algorithm for estimating the depths of mass anomalies in FTG data. A voxel representation of the subsurface is created and voxels are voted for according to gravitational curvature properties encoded in the FTG tensor. A visualisation of the volume at successive depths highlights locations of mass anomalies at each depth, with mass anomalies located at local maxima of the volume. The algorithm is evaluated on a forward-modelled FTG dataset where the depths of mass anomalies are known. The depths of mass anomalies are shown to be accurately located in the presence of noise.

INTERACTIVE MULTI-IMAGE BLENDING FOR DATA VISUALISATION AND INTERPRETATION

*Peter Kovesi**, *Eun-Jung Holden and Jason Wong*
Centre for Exploration Targeting, Perth, Australia

The ability to integrate data from a range of different images is often a crucial requirement for successful interpretation. Interactive multi-image blending is presented as a tool for facilitating the interpretation of complex information from multiple data sources. Traditionally, image blending has only been considered for cross-dissolving effects between two images. However, it is common for there to be more than just two images of interest in an interpretation task. We have developed a family of different multi-image blending tools to fill this need. These have been designed to support a number of different interpretation tasks and image types. For image blending to be a useful tool for multiple image interpretation it is important that the association between features and individual

input images remain identifiable and distinct within the blend. We argue that interactivity of the blend is an important component for achieving this. Blending can also be usefully employed to interactively explore parameter variations for enhancement techniques. Often the best parameter values to use cannot be known beforehand, and it is common for different regions of an image to require different parameter values for best enhancement. By preparing a set of images processed over a sequence of scales and parameter values, and then interactively blending between these images, the interpretation of a data set can be greatly facilitated.

A GEOLOGICAL STRUCTURE MAPPING TOOL USING PHOTOGRAMMETRIC DATA

Yathunanthan Vasuki, Eun-Jung Holden, Peter Kovesi and Steven Micklethwaite*
Centre for Exploration Targeting, The University of Western Australia, Perth, Australia

Accurate and efficient identification and mapping of geological structures has broad application across the minerals industry. Recent advances in data acquisition technologies using Unmanned Aerial Vehicles (UAV), have led to a growing interest in capturing high-resolution rock surface images and analysing those datasets remotely. However due to the large volumes of data that can be captured in a short flight, efficient analyses of these data brings new challenges.

We propose a semi-automated method that allows efficient mapping of geological structures using photogrammetry of rock surface data collected by UAV. Our method harnesses advanced automated image analysis techniques and human data interactions to identify structures and calculate dip and dip angles of structures. Geological features were detected in two dimensional (2D) images and the corresponding three dimensional (3D) features were automatically identified from 3D surface models. The location, dip and dip angle of geological features were then calculated.

A feature map generated by our semi-automated method correlates well with a fault map resulting from visual interpretation by an expert. Some advantages of our semi-automatic method include the following: Firstly; it generates results in few minutes whilst manual interpretation took around an hour, thus contributing significantly in time saving. Secondly; unlike manual interpretation, our software technology provides objective and consistent results that can be reproduced.

1100–1230
Day 3 Session 2 Stream 5

MINERALS – POTENTIAL FIELDS – CONSTRAINED GEOLOGICAL INVERSION II

THREE-DIMENSIONAL POTENTIAL FIELD MODELLING OF THE SUBSURFACE MORPHOLOGY OF COMPLEX MAAR VOLCANOES – EXAMPLES FROM THE NEWER VOLCANICS PROVINCE, WESTERN VICTORIA

Teagan Blaikie, Laurent Ailleres, Peter Betts and Ray Cas*
Monash University, Clayton, Australia

Potential field geophysical modelling techniques can be applied to better understand the subsurface morphology of volcanoes, and when linked with observations of surface geology can be used to develop a more complete understanding of the volcanic centres eruptive history.

High resolution ground gravity and magnetic data was acquired across several maar volcanoes located within the Newer Volcanics Province (NVP) of Western Victoria. The maar volcanoes surveyed represent a range of the different sizes and styles of eruptions observed within maar volcanoes of the NVP. Maar volcanoes form as ascending magma comes into contact with ground water, resulting in phreatomagmatic explosions that excavate a deep crater which is infilled by pyroclastic debris during and after the eruption. This crater is known as a diatreme and has a high petrophysical contrast (lower density and higher magnetic susceptibility) with the surrounding host rock, making maar volcanoes ideal for gravity and magnetic modelling.

Gravity and magnetic data was subject to 2D forward and 3D inverse modelling in order to reveal details on the depth, geometry and petrophysical property distributions of the volcanoes diatreme and feeder dykes. Gravity lows with corresponding magnetic highs are observed across the maar craters and were reproduced during modelling with the presence of a diatreme. Smaller wavelength gravity and magnetic anomalies detected in the centre of the more complex volcanic craters can be explained by the presence of intrusive dykes or vents filled with a higher proportion of denser volcanic debris.

Modelling suggests that multiple coalescing diatreme structures exist below the volcanic edifices, some containing intrusive dykes or a denser central vent filled in with volcanic debris. Multiple diatreme structures suggest a complex eruption history involving vent migration, while preserved dykes within the diatreme suggest short-lived fluctuations between phreatomagmatic and magmatic eruption styles.

RECOVERY OF RESULTANT MAGNETISATION VECTORS FROM MAGNETIC ANOMALIES

Dean Hillan, Clive Foss and Phil Schmidt*
CSIRO Earth Science and Resource Engineering, Sydney, Australia

A magnetic body has a resultant magnetisation that is the vector sum of its induced and remanent components. Ignoring the role of remanence may lead to erroneous resultant magnetisation direction and hence inaccurate geophysical models. Determination of this resultant magnetisation direction may be obtained from total magnetic intensity data for a well separated magnetic anomaly. We present a new method to recover the resultant magnetisation direction that proceeds by iteratively calculating an approximate source layer, and cross correlating trial magnetisation directions. This method is tested with a number of remanent component directions for compact and elongate sources. For a compact source, the accuracy to which the correct resultant magnetisation direction can be recovered is generally found to be less than 5Â°. The method retains accuracy for low inclination resultant magnetisation directions, however, begins to lose sensitivity as the direction approaches the pole. Application of the method to the case study of the Black Hill Norite recovers resultant magnetisation directions in agreement with palaeomagnetic results. Here the resultant directions from the two methods are found to be consistent, with minor differences possibly due to limited palaeomagnetic

sampling of magnetisation directions that changed as the intrusion cooled. A higher bulk Q value, than found from the limited sampling, is suggested for one of the three anomalies studied, as supported by the results of other authors.

GEOLOGICAL UNCERTAINTY AND GEOPHYSICAL MISFIT: HOW WRONG CAN WE BE?

Mark Lindsay[1]*, *Stephane Perrouty*[2,3], *Laurent Ailleres*[4] *and Mark Jessell*[2,3]
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[3]Institut de Recherche pour le Développement, Toulouse, France
[4]Monash University, Melbourne, Australia

Geophysical inversion employs numerical methods to minimise the misfit between three-dimensional petrophysical distributions and geophysical datasets. Inversion techniques rely on many subjective inputs to provide a solution to a non-unique problem, including use of an a priori input model or model elements (a contiguous volume of the same litho-stratigraphic package) and inversion constraints. Inversions may produce a result that perfectly matches the observed geophysical data but still misrepresents the geological system. A workflow is presented that offers objective methods to provide inputs to inversion. First, simulations are performed to create a model suite that contains a range of geologically possible models. Next, uncertainty analysis is performed using stratigraphic variability to identify low certainty model regions and elements. Geodiversity analysis is then conducted to determine the geometrical and geophysical extremes within the model space. Next, geodiversity metrics are then simultaneously analysed using principal component analysis to identify the geometrical and geophysical aspects that contribute most toward model suite variability. Principal component analysis determines which models exhibit common or diverse geological and geophysical characteristics, facilitating selection of models subjected to geophysical inversion.

We apply this workflow to the Ashanti Greenstone Belt, southwestern Ghana in West Africa. The workflow described in this manuscript reduces the subjectivity during decision making, explores the range of geologically possible models and provides geological constraints to the inversion process with the aim of producing geologically and geophysically robust suites of models associated with an uncertainty grid.

1330–1530
Day 3 Session 3 Stream 1

4D MONITORING

KEYNOTE ADDRESS: THE STYBARROW FIELD – A 4D CASE STUDY

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The Stybarrow oil field was discovered in 2003 in the Exmouth Sub Basin, offshore Western Australia. Production started at Stybarrow in November 2007. A 4D seismic modelling study conducted early in the field's life indicated that Stybarrow would be a good candidate for reservoir monitoring using the 4D seismic technique. The modelling indicated that changes in reservoir pressure produced by the water injectors and changes in water saturation due to reservoir depletion should be observable on 4D seismic data. The first monitor survey at Stybarrow was recorded in November 2008, 12 months after the start of production and a second monitor in May, 2011.

There were a number of geophysical challenges that needed to be overcome for the 4D seismic technique to be successful at Stybarrow. These included very strong azimuthal anisotropy, orthogonal acquisition directions and strong currents. Azimuthal anisotropy produced large artefacts in the data and degraded the strength of the 4D signal. Two methods were used to overcome the effect of azimuthal anisotropy. The first was a conditioning step based on azimuthal NMO prior to prestack time migration and the second method was orthorhombic prestack depth migration. Both methods produced good results.

The results of the surveys were in agreement with the 4D modelling and a development well was drilled on the basis of the first monitor survey. The 4D surveys have proven to be an important tool at Stybarrow for facilitating optimal reservoir management.

ENHANCED RESERVOIR MONITORING USING COUPLED ELECTROMAGNETICS AND FLOW MODELING

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Remote time lapse monitoring of reservoirs can provide valuable information to meet production goals such as enhanced oil recovery and CO_2 sequestration. Remote monitoring requires technology that can reliably detect movement and changes in the reservoir during production and flooding events. An injection event can be modelled and monitored using flow simulation software and electromagnetic (EM) data. First the injection event is simulated to predict the fluid flow. The modelling simulates multiphase flow in porous media and is based on a fully implicit solution of the pressure saturation formulation. The code is able to simulate any fluid flow, such as water, CO_2 and/or oil within the reservoir given an injection rate and hydraulic parameters. While EM geophysical data can be inverted on their own, due to the non-uniqueness of the problem, adding additional information to the inversion can greatly improve results. To enhance the inversion model, the outputs of the flow simulation software are used as constraints for the electromagnetic inversions. Once the constraint model has been constructed, the EM data are then inverted in 3D. The changes in the inverted conductivity models image the injection event over time. The final product is a remote monitoring system for reservoirs and injection events that can reliably assess real-time reservoir conditions to meet production goals.

ADVANCED CONCEPTS IN ACTIVE AND PASSIVE SEISMIC MONITORING USING FULL WAVEFIELD TECHNIQUES

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Time-lapse seismic monitoring of reservoir fluid flow and other time-variant subsurface phenomena can be achieved with active and/or passive source seismology. Conventionally, active-source 4D seismic monitoring of reservoir production changes in saturation, pressure, and geomechanical effects is conventionally done via prestack time migration analysis of the time-lapse wavefields. Instead, we present new developments that demonstrate the benefits of using the full time-lapse wavefields more accurately, for example via 4D prestack depth migration (4D PSDM), 4D wave-equation migration velocity analysis (4D WEMVA) and 4D full waveform inversion (4D FWI). These new developments provide an opportunity for more accurate imaging of complex scattered 4D wavefields, and also the possibility to monitor very weak signals using 4D coda waves such as in gas depletion reservoirs.

Passive-source monitoring of induced seismicity in the subsurface typically involves seismic data recorded from a few sparse sensor locations, picked event arrival times, and triangulation to determine microseismic event source locations. This conventional approach to passive seismic monitoring has remained relatively unchanged for the past 100 years. Instead, we present new developments that demonstrate an opportunity for significant improvements in passive seismic imaging and monitoring by using dense (possibly permanent) buried receiver arrays that record the full induced seismicity wavefields, and by using full wavefield imaging techniques applied to passive array seismic data and scattered noise fields.

1330–1530
Day 3 Session 3 Stream 2

SEISMIC VELOCITIES AND APPLICATIONS II

EVIDENCE FOR OVERPRESSURE IN THE BELFAST FORMATION, SHIPWRECK TROUGH, OTWAY BASIN

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The Late Cretaceous Belfast Formation is the regional seal for many gas reservoirs in the Otway Basin. Analysis of this formation within the Shipwreck Trough has revealed several lines of evidence characteristic of over-pressure, which can be correlated over a significant area of the basin. A distinct decrease in sonic velocity and resistivity, relative to expected compaction trends, is observed in wells on the western (down thrown) side of the Sorell Transform. Increased drilling mud weights through this section in some wells supports this conclusion. The overpressure is interpreted to be a consequence of disequilibrium compaction due to rapid sedimentation during the Late Cretaceous rifting event and development of the Sorell Transform.

Using the Eaton Method and sonic log data a maximum pore-pressure of approximately 30% higher than hydrostatic is calculated in the shale. This prediction, however, cannot be made without an implicit assumption regarding a "normal" compaction trend; we utilise a Gardner density-derived velocity prediction in addition to a standard depth trend extrapolation method. Observations are consistent with recently published evidence for overpressure in Otway Basin west of the Shipwreck Trough.

Implications for the interpreted overpressure will also be discussed, primarily focused on the impact of velocity analysis and depth conversion. The overpressure is not readily observable during velocity analysis of CMP gathers. This is partly due to the lack of reflectivity through the Belfast Formation and partly as the velocity of any reflector in this shale section will have a slower than expected velocity and can be potentially dismissed as multiple energy. This results in stacking velocities that are over predicted through the shale, which can limit their use in detecting overpressure and cause depth conversion errors.

REGIONAL VELOCITY MODELLING METHODOLOGY IN THE GIPPSLAND BASIN

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A new velocity volume has been constructed across the Gippsland Basin to enable regional scale depth conversion of seismic interpretations. The velocity model covers a region 210 km x 150 km and a vertical extent of 5500 ms, and has cell dimensions of 500 m x 500 m x 10 ms. Average stacking velocities from 17 seismic surveys (14 3D surveys and 3 2D) were used to inform the 3D velocity volume. These datasets collectively totalled ~12.2 million separate velocity points. Check-shot velocity data was also used to constrain and guide the velocity distribution throughout the 3D grid. A total of 263 wells were used totalling ~14000 data points.

Seismic stacking velocities were broken up into 8 separate intervals using time horizons derived from seismic interpretation. This provided a typical distribution of velocities to sample from during simulation in data-poor areas. A semi-variogram analysis was performed for each velocity interval to characterise the spatial variation of the velocity data, and determine how far velocities can be statistically interpolated. This process produced a search ellipse which facilitated distribution of the data. The ellipse was UVW transformed with the seismic time surfaces so that the geometry of the ellipse was aligned to stratigraphy. Velocities were therefore distributed along stratigraphic horizons preserving the geological integrity during the gridding process. Velocities were kriged close to data points, and simulated away from data points. The final step was to integrate check-shot velocities into the velocity volume. This was done by kriging primary data (check-shot velocities) alongside secondary data (stacking velocities) using a locally varying mean approach.

This velocity model has applications not only for depth estimation, but also calculating layer thickness from interval velocities, density estimation, fluid overpressure, assessing compaction / porosity and burial history. The model will be freely available on the Department of Primary Industries' online store.

INTEGRATION OF SEISMIC VELOCITY MEASUREMENTS IN THE CONTEXT OF THE CO2 STORAGE PROJECT IN THE BONAPARTE BASIN, OFFSHORE NW AUSTRALIA

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An accurate seismic velocity model is essential for depth conversion and rock property determination in the context of fluid flow modelling to support site selection for secure storage of carbon dioxide in the study area. Three types of seismic velocity measurements are available within the study area: velocities derived from stacking of multi-channel reflection seismic data; velocities determined in the process of ray tracing modelling of large offset refraction data acquired by the ocean bottom seismographs (OBS) along the coincident reflection/refraction transect, and velocities from well log measurements. Comparison of interval velocities calculated independently from refraction and reflection data for the key geological horizons shows good correlation for a large part of the area. However, local discrepancies in depths to these horizons calculated using these two alternative velocity models can exceed 10%. Large discrepancies are observed in the eastern part of the study area where the OBS velocity model is faster than the stacking velocity model. This region of high velocities in the OBS velocity model is consistent with elevated seismic velocities measured by well logs in the Newby 1 and Flat Top 1 exploration wells in the northeast of the Petrel Sub-basin.

Discrepancy between two types of velocity models can be due to geological reasons or to differences in methodology of velocity determination in reflection and refraction data processing and interpretation. Accurate measures of uncertainty of both types of velocity need to be developed. However, time-depth functions constructed for individual horizons on the basis of the OBS derived velocity models are acceptable for a first pass depth conversion for a large part of the study area. The accuracy of the first pass depth conversion is further improved by calibration against wells.

TIME-LAPSE VELOCITY INVERSION THROUGH IMAGE-DOMAIN TOMOGRAPHY

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Adjoint-state methods (ASMs) are effective for calculating the gradients of the functionals commonly found in geophysical inverse problems. The image-domain ASM formulation of the 3D seismic velocity estimation problem leads to an objective function related to imperfections in 3D migrated images, which sets up an inverse problem that can be solved through standard optimisation approaches. Even though more the kinematic image-domain approaches afford lower resolution than their data-domain counterparts (because they do not directly match modelled amplitudes with measured data), they remain a powerful tool for the early iterations of velocity model building owing to their greater immunity to errors in starting velocity models. For time-lapse (4D) seismic scenarios, we show that the ASM approach can be extended to multiple datasets and recover high-resolution estimates of subsurface velocity perturbations. We discuss an absolute 4D inversion strategy that uses the difference between two independent 3D inversions to estimate 4D perturbations. We then present a relative 4D inversion approach that incorporates baseline image constraints into the monitor inversion to accentuate where the baseline and monitor images are different, and then recovers the velocity perturbation that caused the 4D image discrepancy. Both techniques yield very good 4D velocity estimates on synthetic data; however, we argue that the relative approach is more robust and preferable to the absolute strategy in the presence of 4D field noise because it represents a less-demanding inversion goal.

HIGH FREQUENCY ENHANCEMENT OF SPARKER SUB BOTTOM PROFILES WITH MULTICHANNEL REFLECTION PROCESSING

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The Petrel Sub-basin Marine Survey was undertaken in May 2012 by Geoscience Australia and the Australian Institute of Marine Science to support assessment of CO_2 storage potential in the Bonaparte Basin. The aim of sub bottom profiling was high resolution data to investigate regional seal breaches and potential fluid pathways.

The sub bottom profiler data were acquired aboard the AIMS RV Solander, a total of 51 lines and 654 line km. Acquisition employed a Squid 2000 sparker and a 24 channel GeoEel streamer. Group interval of 3.125 m and shot interval of 6.25 m resulted in 6 fold stacked data. Record length was 500 ms, sampled every 0.25 ms. Rough sea conditions during the trade winds resulted in obvious relative motion between source and streamer.

Multichannel seismic reflection processing compensated for most of the limitations of sparker acquisition. Front end mute and band pass filter removed low frequency noise. Non surface consistent trim statics corrected for the relative motion of sparker and streamer, aligning reflections pre stack and improving signal to noise. Post stack minimum entropy deconvolution both suppressed ghosting and enhanced high frequencies (>1000 Hz). Vertical resolution of better than 1 m allowed delineation of multiple episodes of channelling in the top 100 m of sediment. Imaging of small channels was improved by collapsing diffractions with finite difference migration.

SHALLOW SUBSURFACE IMAGING USING HIGH RESOLUTION SEISMIC REFLECTION METHODS

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King Abdulaziz City For Science and Technology

In order to evaluate the use of shallow seismic technique to map the bedrock up to the depth of 20-25 metres, three high resolution seismic reflection profiles were carried out. The data were acquired using a Strata Visor with 48-channel, 40 Hz geophones and a weight drop system as seismic source. Seismic reflection data were recorded using a CMP (common mid-point) acquisition method. The results show that the bedrock lies at about 18-25 metres depth. The bedrock related horizon observed here is of low frequency, its depth is almost similar in all three seismic lines and thus giving us the enough confidence in results and also following the subsurface structure. Reflection line 3 is been crossed by reflection line 1 and reflection line 2. To confirm the structure and same statics, I did tie these lines to confirm and the reflectors are exactly matching, hence no need to give any shifting. There is high frequency loss due to high

attenuation in near surface. A good structural image of subsurface is visible from the seismic sections and for interpreter it's easy to mark structure and integrate it with other methods. With the proper equipment, field parameters and particularly great care in data collection and processing, we can image reflections from layers as shallow as 25 metres.

1330–1530
Day 3 Session 3 Stream 3

ENVIRONMENTAL AND ENGINEERING II

APPLICATION OF SURFACE AND BOREHOLE SEISMIC METHODS TO TRENCHLESS CONSTRUCTION PROBLEMS

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Within cities and urban areas trenchless construction and tunnelling are preferred methods for providing new infrastructure mainly because of their social and environmental benefits. However, problems can occur when unexpected subsurface conditions are encountered or when relatively 'minor' geotechnical factors interact with the construction process in unexpected ways that create adverse outcomes. These can cause extensive project delays, major cost over-runs and legal disputation.

Advanced geophysical technologies using combinations of marine, land and borehole seismic methods can assist with identifying and overcoming geotechnical problems encountered during trenchless construction. Case studies from recent civil infrastructure projects in Australia and China demonstrate the application of various seismic methods to a range of trenchless construction problems. These projects involve horizontal directional boring, pipe-jacking and micro-tunnelling in soils, mixed material and rock for pipeline and buried power cable installations.

The case studies clearly show that appropriate seismic methods can assist in the solution of construction problems of a geological or geotechnical nature. This provides a new application area for engineering geophysics.

ENGINEERING GEOPHYSICS FOR GEOTECHNICAL CHARACTERISATION OF LNG PROCESSING PLANT SITES

*Tariq Rahiman**
Golder Associates

New Liquefied Natural Gas (LNG) processing plants are being developed and constructed along the eastern and western seaboards of Australia. In support of tendering processes for engineering design and construction, geotechnical site investigations are required over these large construction site foot print areas. The foot print areas often span across remote and inaccessible onshore and nearshore marine environments. Previously the domain of the resource exploration industry, geophysical technology is now being increasing used to support traditional site investigation techniques in order to provide complete and accurate geotechnical characterisation of large LNG construction sites. High resolution and near-surface geophysical techniques, when integrated with intrusive sampling and testing, are proving to be a cost effective and reliable way to image and test large volumes of onshore and nearshore footprint areas. Geophysical techniques are particularly helpful where borings and intrusive testing are limited for reasons that may include investigation budget limitations, inaccessibility and environmental disturbance constraints. Integration of geophysics with geotechnical investigative techniques offers the potential to improve management of project risks and costs, as well as enhance understanding of site conditions. This article describes some proven geophysical techniques in geotechnical investigations of large footprint LNG construction sites.

AN MASW SURVEY FOR GEOTECHNICAL ENGINEERING IN AN URBAN SETTING – AN APPLICATION TO PRE-TUNNELLING INVESTIGATION

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Terra Australis Geophysica Pty Ltd, Brisbane, Australia

As a part of the Airport Tunnel project, an MASW survey was carried out to investigate the nature of the fill site of an old rock quarry. The site is currently used as a shopping centre car park in an inner suburb of Brisbane along one of the main roads. To avoid excessive noise, the survey took place at night.

The MASW is a surface wave seismic method, particularly suited to characterisation of the near-surface. Some part of the seismic data presented an unusual but consistent noise pattern.

The analysis of the seismic data outlined the depth and shape of the quarry. The noisy area was identified as a shallow hard rock left in the quarry, perhaps as an access ramp. This was verified a historic photography of the old quarry.

The depth of the quarry was found shallower than the proposed depth of the tunnel to ensure the safety of boring.

GEOPHYSICAL MONITORING FOR INSPECTING THE STABILITY OF THE SEA DIKE IN SOUTH KOREA

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Geophysical methods including electrical resistivity and MASW are used for delineating seawater inflow through sea dike and detecting the abnormal compactness region that could affect the structure of dike. To identify the part of anomalous seawater inflow through the sea dike, we periodically carried out 3D resistivity survey along the dike including anomalous regions. 3D resistivity survey and monitoring for the dike can define effectively the low resistivity zones lower than 1 ohm-m, which may indicate seawater inflow through the dike. For detailed analysis of 3D resistivity monitoring data, time-lapse inversion method was adopted in this study. Time-lapse inversion is effective for identifying the subtle changes over time and for suppressing inversion artefact. The results of time-lapse inversion method show no significant changes in the sea dike with time. Shear wave velocity profiles obtained by MASW periodically indicate less compacted layer that could be originated by the loss of dredge sand or the bad compactness

condition during the construction and would be predicted the possibilities of subsidence. From this study, 3D electrical resistivity surveys using time-lapse inversion approach and periodic MASW surveys are revealed to be effective for identifying seawater inflow pathway through the sea dike and investigating its safety, respectively.

VALIDATING VERTICAL VELOCITY GRADIENTS IN NEAR-SURFACE REFRACTION SEISMOLOGY

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Wavepath eikonal traveltime (WET) refraction tomograms are generated with the generalised reciprocal method (GRM), a novel medium resolution common offset gather (COG) implementation of the GRM, using uniform velocities and vertical velocity gradients, and the low resolution default starting model consisting of smooth vertical velocity gradients. All tomograms have comparable misfit errors, which illustrates the ubiquity of non-uniqueness and the necessity for validating all starting models.

Nevertheless, the use of even the maximum vertical velocity gradients in the weathered region does not produce any improvement in the spatial resolution of the seismic velocities in the sub-weathered region with either the default or the COG GRM starting models. Therefore, if a low resolution starting model is used, then the most likely outcome will be a low resolution WET tomogram, irrespective of whether or not vertical velocity gradients are employed.

Vertical velocity gradients can be represented as part of a continuum of seismic velocities in the weathered layer, which range from uniform to hyperbolic velocities, and which are consistent with the traveltime data. Acceptable models employ seismic velocities in the weathered and sub-weathered regions computed with the same XY value. In this study, the optimum XY value is representative of uniform seismic velocities, whereas the maximum XY value, which is the average cross-over distance, is representative of default and hyperbolic velocities. Intermediate XY values indicate more moderate vertical velocity gradients and/or undetected layers.

WET tomography is largely a smoothing operation which does not improve the spatial resolution of either medium resolution or detailed starting models. A limited number of iterations, usually a maximum of five, can improve the cosmetics of refraction tomograms, whereas repeated applications can result in considerable reductions in spatial resolution, and eventually, low resolution tomograms consisting of essentially featureless parallel quasi horizontal layers.

ULTRASONIC SOUNDING AND MONITORING OF THE EXCAVATION DAMAGED ZONE IN RELATION WITH DRIFT SUPPORT

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Under high in situ stresses, the excavation of underground openings generally causes the creation of a disturbed (EdZ: Excavation disturbed Zone) and/or damaged (EDZ: Excavation Damaged Zone) zone, resulting from the initiation and growth of cracks and fractures and from the initial stress redistribution and rearrangement of. The EdZ or EDZ changes the mechanical and hydromechanical properties which in return, constitute a potential risk for the efficiency of the geologic and/or engineered structures in the context of underground storage. Ultrasonic experiments have been implemented to characterize the EDZ extension around drifts and its evolution in time according to the structural support type (soft or rigid) and the environmental conditions. Those studies consist of two experimental components: (1) the prior auscultation of the floor and sidewalls of the gallery by ultrasonic transmission tomography, (2) the monitoring of the time-dependant evolution of EDZ and the analysis of measurable changes in the propagation of ultrasonic waves in the medium term. A code for inversion of these continuous in situ measurements of five elastic wave velocities has been developed. Then, the five dynamic elastic constants for the assumed transverse isotropic character of the rock are derived as a function of time and the distance from the drift wall. Performed a few months after the excavation of the galleries, the tomography shows that ultrasonic velocities are higher in the orthoradial direction (both in the concrete support and rock). This velocity field highlights the damaged zone and arrangement of the new stress field.

1330–1530
Day 3 Session 3 Stream 4

MINERALS – GEOPHYSICAL INVERSION

AN ASSESSMENT OF THE PERFORMANCE OF DERIVATIVE BASED DATA ENHANCEMENT TECHNIQUES IN THE PRESENCE OF COHERENT NOISE

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Enhancement of potential field datasets using operators based on one or more of the spatial derivatives is common practice. The performance of these methods in the presence of noise is poorly understood; other than a general acceptance that they can be significantly affected, especially when higher order derivatives are used. Most published descriptions which involve noise tests use random noise and a dense and uniform sampling of the test region. More realistic tests of the effects of noise should account for the incomplete and anisotropic sampling comprising most datasets and also correlated noise such as due to incorrect levelling. An understanding of the effects of noise on the different methods of enhancement is particularly important when working with lower quality (older) and lower resolution datasets.

Interpretation of geophysical data from West Africa, as part of a major project on the prospectivity of the region, is being undertaken. Much of the data available is of relatively low quality and resolution. An important component of the work will involve determining how best to enhance the gravity and magnetic datasets. For the aeromagnetic datasets with wider line spacing, the calculation of dy proved especially challenging with

the resulting noise propagating in to enhancement products which rely on this parameter, e.g. tilt derivative. Significantly better results are obtained when dy is calculated from the two other spatial derivatives using Hilbert transform. Our results suggest that line, rather than grid based, processing is most effective for magnetics with grids being created as late as possible during the processing sequence.

LARGE-SCALE MAGNETIC INVERSION USING DIFFERENTIAL EQUATIONS AND OCTREES

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The inversion of large-scale magnetic data sets has historically been successfully achieved through integral transforms of the large, dense sensitivity matrix. Two well-known transforms, the discrete Fourier and multi-dimensional wavelet, reduce the required storage and ultimately speed of the inversion by storing only the necessary transform coefficients without losing accuracy. The main drawback of the approaches is the required calculation of the entire dense sensitivity matrix prior to the transform. This process can be much more costly than the inversion itself. We solve the magnetostatic Maxwell's equation using a finite volume technique on an ocTree-based mesh. The ocTree mesh greatly reduces the time required for the inversion process. When working in the differential equation domain it is not necessary to explicitly form the sensitivity matrix; this decreases the storage requirement of the problem and increases the overall speed of the inversion. The principal mesh is broken up into sub-domain ocTree grids to further enable parallelization of the forward problem. These grids extend the entire domain of the principal mesh to include large regional features that may influence the data. We present the discretisation of the equations and verify the accuracy of the modelling both with the principal mesh and with multiple sub-domains. We show a synthetic example and a large field example consisting of over 4 million data and 5 million model cells that was inverted on a desktop computer.

3-D INVERSION OF THE REGIONAL MAGNETIC DATA IN SPHERICAL COORDINATES AND ITS PRELIMINARY APPLICATION IN AUSTRALIA

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[3]Geoscience Australia, Canberra, Australia

To properly construct broad features of lithospheric magnetisation structure derived through inversion of the regional magnetic anomaly data, the curvature of the Earth should be taken into consideration. A method for inverting large-scale magnetic anomaly data in spherical coordinates has been developed. The recovered model is in the form of a 3D spherical orthogonal mesh. The inversion uses a classical Tikhonov regularization approach by incorporating a specially formed model objective function in spherical coordinates. We illustrate the algorithm using a synthetic example and then apply it to the satellite magnetic data over Australia. The results from the synthetic data example show that the inversion method in spherical coordinates is able to recover large-scale magnetisation distributions. The inverted model in the field example is consistent with independent geological, heat flow, and Curie depth features published in the literature.

LARGE SCALE JOINT INVERSION OF GEOPHYSICAL DATA USING THE FINITE ELEMENT METHOD IN ESCRIPT

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Inversion is finding the minimum value of a cost function measuring data defect and physical property variation subject to constraints defined by a partial differential equation (PDE). In general, this problem is equivalent to the solution of a system for coupled PDEs for three unknowns -- the physical property, the observation and a Lagrangian multiplier. Therefore it is appropriate to use established PDE solution methods such as the finite element method (FEM) and solver software systems such as escript (see https://launchpad.net/escript-finley) to tackle inversion problems.

Besides the ability to handle non-linearity in the physical model (e.g. required for high susceptibility) as well as in the regularisation term or in the cross-gradient terms the PDE approach provides a number of computational advantages in comparison to traditional, linear algebra based solution approaches. The method is data sparse by nature and does not require compression or sparsification on the sensitivity matrix when solving large scale inversion problems. Moreover, domain decomposition can be applied to run the inversion across processors in a parallel computer. In contrast to traditional tiling, domain decomposition is not imposed on the inversion from the outside but applied on the lowest level which makes the approach more computationally efficient.

In the presentation we will introduce the concept of PDE based, joint inversion of gravity and magnetic data. We will outline the appropriate solution methods when using the finite element method, outline the implementation strategy using the PDE solver escript and show results from joint inversion runs of field data using massive parallel computer.

CONSTRAINED VOXEL INVERSION USING THE CARTESIAN CUT CELL METHOD

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Cartesian voxel inversion of geophysical data has proven to be a useful aid to mineral exploration, particularly over the last two decades. Using Cartesian voxel models is appealing because of the simplicity of the representation: computationally it is straight forward to implement a Cartesian representation, to visualise it, and to perform mathematical operations on it. However Cartesian representations have the shortcoming of forcing a regular Cartesian representation on the earth which they are trying to represent and as such introduce modelling errors into forward modelling and inversion processes. This is particularly apparent when the Cartesian voxel representation is used to simulate topography where continuous topography must be represented in a step-stair, or piecewise constant fashion, dependent on the size of the voxels in the model. Likewise geologic features such as faults, or abrupt changes in lithology or mineralization from drilling results, must all be superimposed onto a piecewise constant voxel representation. Two emerging

model representations used to overcome these modelling errors are the octree mesh and the unstructured mesh, both of which significantly increase computational and visualisation complexity. In this work we present a third alternative, the Cartesian Cut Cell method, as a way to rather simply extend the regular Cartesian representation to accurately include continuous geologic features in the model. We apply this method to significantly improve the representation of topography and also demonstrate how it can be applied to allow natural implementation of abrupt lithology changes deduced from drill results. Not only does the Cartesian Cut Cell method allow us to more accurately represent geology, but it also imposes only a minor computational complexity into existing simple Cartesian voxel representations. We demonstrate the method on constrained inversion of synthetic and field data.

FLEXIBLE APPROACHES TO GRAV/MAG INVERSION AT REGIONAL AND CONTINENTAL SCALES

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Magnetic and gravity data have great potential to inform us about regional-scale features. Major fault zones, basin geometries, basement character, Moho, intra-crustal boundaries etc can all be imaged. However, modelling results are inherently non-unique and often highly uncertain. This feeds into the reliability of the method and its usefulness in resource exploration. Following Occam's razor, traditional methods have usually sought to find the simplest model possible, through use of maximum smoothness regularization (e.g. UBC-GIF), or through simplifying the model to an analytically unique problem (e.g. Parker-Oldenburg). More recent software packages allow the process to be constrained by the explicit incorporation of geological knowledge into the process, through a lithological model including property constraints. There are now two variables: lithology and the property within that lithology. This increased degree of freedom leads to greater flexibility, but also greater ambiguity in results, and a single result is clearly not adequate in these cases. Here we present some examples at regional and continental scales where the inclusion of variability measures has greatly increased the usefulness of the inversion process to understand 1) the architecture and properties of the features of interest and 2) the robustness of the solution.

1330–1530
Day 3 Session 3 Stream 4

MINERALS – POTENTIAL FIELDS – CONSTRAINED GEOLOGICAL INVERSION

3D MAGNETIC MODELLING AND INVERSION INCORPORATING SELF – DEMAGNETISATION AND INTERACTIONS

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Self-demagnetisation can significantly reduce the amplitude and modify the shape of the magnetic response from highly magnetic bodies. For quasi-planar bodies, only the transverse component of magnetisation is reduced, with the result that the direction of magnetisation rotates towards the plane of the body.

Furthermore, when highly magnetic bodies are in close proximity, the assumption of uniform inducing field is violated. Rather, highly magnetic bodies can modify the local magnetic field appreciably, with the result that the magnetisation induced in one body is affected by the magnetisations induced in all the others. It is important to take such interactions between highly magnetic bodies into account.

Potential field modelling and inversion software "VPmg" has been upgraded to account for self demagnetisation and interaction between magnetic bodies. The algorithm computes H-field perturbations at the model cell centres in two stages: initialisation and optimisation. During initialisation, a demagnetisation tensor is estimated for each cell, from which a first estimate for the H-field perturbation is derived. During optimisation, the H-field field estimate is refined iteratively via an inversion procedure. Remanence can be taken into account.

The algorithm has been validated for homogeneous spheres, spheroids, slabs, and cylinders. It has also reproduced magnetic interactions between two horizontal cylinders for the case published by Hjelt (1973). Explicit verification for complex heterogeneous bodies requires a suitable independent algorithm for benchmarking.

The application to inversion in highly magnetic environments is illustrated on field data examples.

A NEW TECHNIQUE FOR LOW MAGNETIC LATITUDE TRANSFORMATION: SYNTHETIC MODEL RESULTS & EXAMPLES

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Traditional methods for processing low magnetic latitude data below ±25° magnetic latitude are notoriously unstable. Existing methods such as Reduction to the Pole (RTP), and Equator (RTE), and Analytical Signal (AS), do not fully resolve anomaly location and may distort the anomaly shape leading to misinterpretation of the data, as well as loss of certain directional anomalies. These methods contain some limitations such that satisfactory results are not always achievable, and interpretation of geology from magnetic data can be difficult.

The main difficulties are to do with anomaly shape and location, negative anomalies over induced magnetised source bodies, elongated anomalies perpendicular to the declination direction and weak or barely detectable anomalies for source bodies with a strike parallel to the declination direction. Combined, these difficulties lead to unsatisfactory processing, enhancement and interpretation of low magnetic latitude data.

We have developed a new filter, Modulus of Total Component at Low Magnetic Latitude (MTC-LML Filter) based on the calculation of the Modulus of three magnetic components of the main field (one vertical and two orthogonal horizontal). The filter is designed to better position anomalies, reduce anomaly distortion and provide good anomaly shape. Positive anomalies

are derived from both induced and remanently magnetised bodies and structures parallel to the declination direction are better recovered.

We present the results of the MTC-LML Filter for synthetic models, composed of complicated bodies each with different strike directions and depths. We then present applications of the Filter to survey datasets from Peru and Niger, and compare the results with traditional low magnetic latitude transformation methods.

Preliminary results show strong spatial correlation of geologic features between the MTC-LML Filter, radiometric (showing surface geology) and DEM datasets providing confidence that this technique can be used for geological interpretation.

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY (AMS) AND PALEOMAGNETISM APPLIED TO THE DIFFERENTIATION OF STRUCTURAL AND METALLOGENIC CONTROLS ON IRON OXIDE COPPER-GOLD (IOCG) MINERALIZATION: A CASE STUDY FROM MONAKOFF, NW QUEENSLAND

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The temporal and metallogenic relationships between BIFs and IOCGs in the Mt Isa Block are controversial and difficult to assess quantitatively. In this study we examine new magnetic data, anisotropy of magnetic susceptibility (AMS) and remanent magnetisation to define potential structural controls on mineralisation, and try to determine temporal relationships between a barren hematite-magnetite BIF and a carbonate-hosted IOCG, Monakoff. The results showed that the BIF was magnetically isotropic, but that it had a high remanent component (Q=13). The remanent magnetisation has Dec= 238.4°, and Inc= -38.6°, which is offset from the present field and previous data from Cloncurry, so it likely formed during deposition, or early in the deformation history e.g., D1, D2. Conversely, the ore has very low remanent magnetisation (Q<0.2) but significant AMS, oriented Azimuth=225°, Plunge=75°, which is consistent with NE-SW (D3) shortening. 3-D magnetic modelling, constrained by magnetic property data and geophysical enhancements, showed that the BIF horizon formed a tight synform. However, modelling of the ore body showed it to be sub vertical. Based on the recognition that the ore body formed during D3 shortening, we infer that the ore formed in a zone of dilation sub-perpendicular to the shortening direction, rather than in a layer sub-parallel jog. The results suggest that the intersection of NW-oriented, sub-vertical faults with stratiform BIF horizons, adjacent to mafic volcanics are prospective for Monakoff-style IOCGs.

EQUIVALENT SOURCES: RAPID CALCULATION IN THE FREQUENCY DOMAIN AND APPLICATION TO LEVELING CORRECTION

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The equivalent source is usually calculated by an iterative method, designed to converge on the observed potential field, magnetic or gravitational. Each iteration involves two Fourier transforms, one forward and one inverse. As the number of grid point increases the time penalty may become prohibitive. However, the number of transforms can be dramatically reduced by the a priori transformation of the observed potential field to the frequency domain. We describe this method which reduces the number of Fourier transforms from n to two, and demonstrate its use on a simple magnetic anomaly. An extension of this equivalent source technique is also given for the case of a draped magnetic survey that requires levelling correction. The observed data is separated into layers according to the height changes, and the equivalent source is iteratively calculated via comparisons of the upward continued data. Whilst this process is computationally intensive, it is designed to scale with the complexity, and hence the discretisation, of the topographical changes. This gives the method a speed advantage compared with similar Taylor series approaches. A synthetic example containing multiple dipole sources is used to test the method, and to illustrate the advantages and differences of draped surveys and the need to reduce the data to a common datum.

SUPERVISED AND UNSUPERVISED CLASSIFICATION OF NEAR-MINE SOIL GEOCHEMISTRY AND GEOPHYSICS DATA

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Remotely sensed geoscience data can assist detailed geological field mapping in areas of thick vegetation and poor outcrop. However, the potentially high dimensionality of these data makes it difficult to visually interpret and fully comprehend. Machine learning algorithms provide an efficient semi-automated means of recognising and identifying patterns in data. We use Random Forests for supervised classification of geologic units from airborne geophysical and soil geochemical data in the economically significant Hellyer – Mt Charter region of western Tasmania. A backward-recursive variable selection method is used to select the most relevant and useful data for this problem. This reduces computation cost and enhances interpretation of results without significantly affecting prediction accuracy. Random Forests generates accurate predictions of the spatial distribution of surface geologic units from these data. An example is provided regarding the use of Self-Organising Maps, an unsupervised clustering algorithm, to identify distinct but spatially contiguous clusters within a geologic unit. By visualising cluster spatial distribution and identifying key variable contributions to cluster differences, we interpret the geological significance of intra-class variability.

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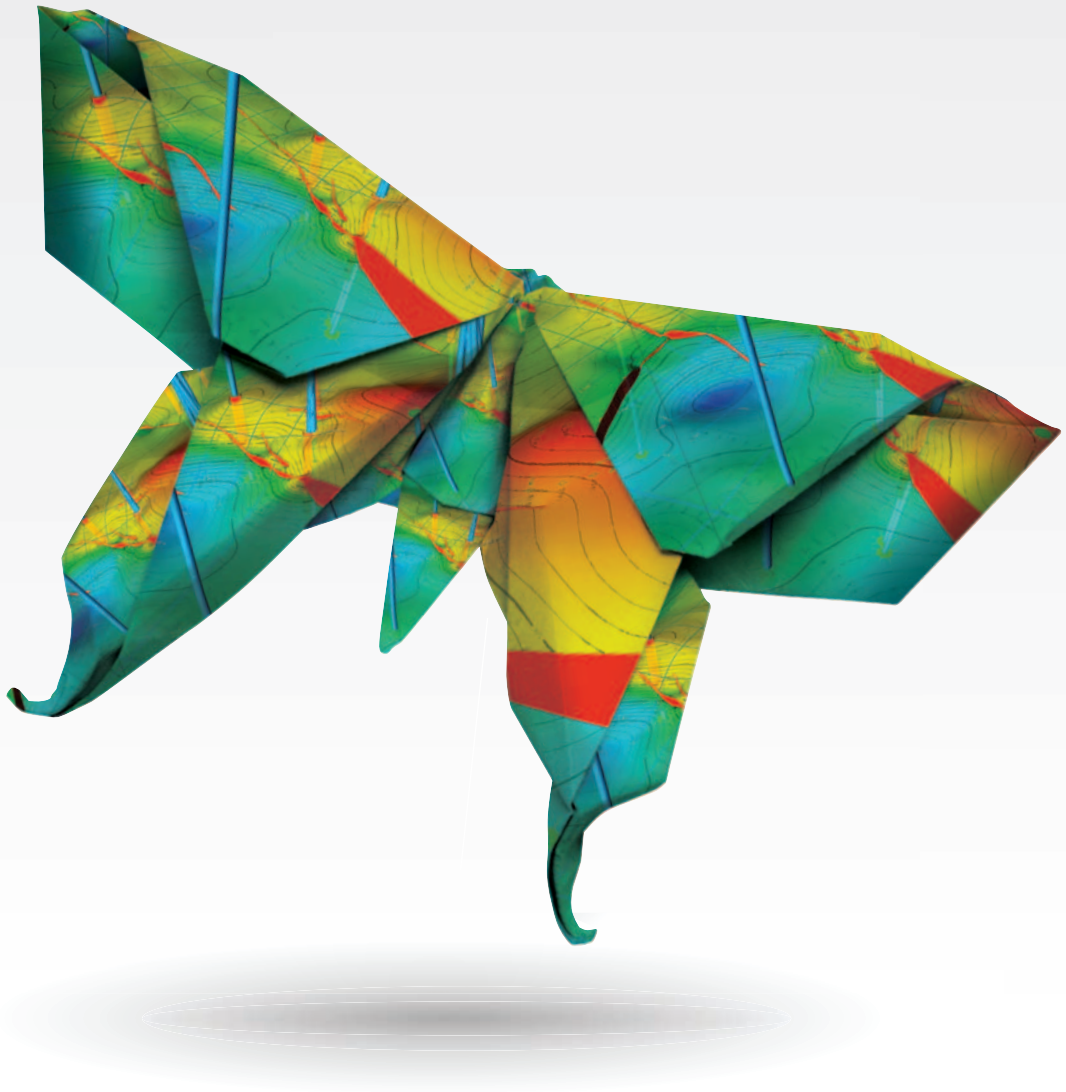

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