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SECTION 3 ABSTRACTS

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Day 1: Monday 16 February 2015

1030–1210
Day 1 Session 1 Stream A

PETROLEUM – MARINE SEISMIC ACQUISITION

EVOLUTION OF MARINE ACQUISITION TECHNOLOGY AFTER WIDE AZIMUTH

Nick Moldoveanu[1]*
[1]Schlumberger

Seismic exploration in the deep-water Gulf of Mexico was based for many years on the 3D acquisition method and, as a result, significant oil discoveries were made and most of the plays were found below salt or in intra-salt-body basins. The quality of the seismic data acquired in deep-water subsalt environments was occasionally satisfactory for exploration purposes, but, in most cases, it was not good enough to support an accurate earth model for reservoir development. The main challenges for data interpretation are: incomplete reservoir illumination, poor signal-to-noise ratio of the subsalt events and poor seismic resolution. Developments in the last decade in marine seismic acquisition and data processing were driven to solve these challenges.

One reference point in the evolution of marine seismic technology in the last decade was the introduction of wide azimuth acquisition (WAZ). Introduced in 2006 by British Petroleum in the Gulf of Mexico, the method was quickly adopted by the industry as a seismic technology to explore the complex subsalt geologic structures where improved subsurface illumination and signal-to-noise ratio are required. The introduction of WAZ started a period of several innovations in the seismic industry: dual-sensor streamer acquisition, full-azimuth towed streamer acquisition, broadband seismic measurements on both the source and receiver sides, long-offset marine acquisition, simultaneous shooting, and multimeasurement streamers. Challenges in processing wide-azimuth data lead to new developments in velocity model building based on tomography and full-waveform inversion, 3D demultiple methods, 3D anisotropic imaging with reverse time migration, and other improvements in computational methods.

The presentation will review the latest innovations in marine seismic acquisitions with examples of applications, and will discuss the geophysical benefits and limitations, as well as specific survey design and processing aspects related to each method.

FAST CYCLE TIME BROADBAND SEISMIC FOR EXPLORATION

Peter Chia[1]*, *Adam Smith*[1] *and Cameron Dinning*[2]
[1]Shell Australia
[2]Shell Deep Water, Borneo

As commitment seismic for exploration permit WA-477P, Shell acquired a 3D broadband seismic survey utilising variable depth streamers and a multi-level airgun source. The application of this combined technology for the first time in Australian waters was intended to attenuate seismic ghosts inherent in conventional seismic surveys. The successful deployment of the method has brought new insights into the processing and interpretation of broadband seismic that raise challenges in providing the deliverables necessary for exploration turnaround cycle time. By tailoring the processing workflow, while investigating and testing new algorithms, products were available to meet exploration requirements to mature prospects for early decisions.

NEW INSIGHTS INTO THE NORTH TARANAKI BASIN FROM NEW ZEALAND'S FIRST BROADBAND 3D SURVEY

Marjosbet Uzcategui Salazar[1]*, *Malcolm Francis*[1] *and Tristan Allen*[1]
[1]Schlumberger

For decades, the Taranaki basin has been New Zealand's only producing basin whilst exploration for large new hydrocarbon discoveries has moved to more frontier basins. Statistically speaking, the Taranaki basin should still hold numerous large fields; however, the information currently available is not sufficient to solve the challenges in understanding the petroleum system. The North Taranaki basin has widespread 2D seismic coverage and numerous wells that have not encountered commercial accumulations. This is attributed to the structural complexity in the basin and the absence of necessary information to help understand the basin evolution. An oilfield services company identified the North Taranaki graben as one area that has huge potential yet to be understood. A modern broadband, long-offset 3D survey was modelled and expected to provide the necessary information to finally understand the petroleum system and provide evidence for material hydrocarbon accumulations. In this investigation we assess the hydrocarbon potential of the basin using the newly acquired data. Advanced acquisition techniques were implemented for increased coverage and bandwith, including continuous line acquisition, sliding-notch broadband acquisition and imaging techniques, and delta source, resulting in a full broadband acquisition. Raypath distortions and depth uncertainty are significantly reduced processing through vertical transverse isotropy (VTI) anisotropic Kirchhoff prestack depth migration with a geologically constrained velocity model. Resolution of the deepest sections in the central graben have identified structures never before seen, as well as fault definition critical to understand charge. Here, we demonstrate the potential of the basin that has been unlocked thanks to the technology advances in acquisition and processing. 3D seismic interpretation and amplitude-versus-offset (AVO) analysis support the renewed potential of the basin.

1030–1210
Day 1 Session 1 Stream B

PETROLEUM – 4D SEISMIC MONITORING 1

OVERBURDEN HETEROGENEITIES INFLUENCE ON TIME-LAPSE SEISMIC REPEATABILITY: A FINITE DIFFERENCE MODELLING STUDY

Lisa Gavin[1]* *and Gary Hampson*[1]
[1]Chevron ETC

One of the aims of time-lapse seismic feasibility studies is to determine whether a desired time-lapse signal is distinguishable from incoherent noise. Acquisition parameters play a key role in repeatability, with source-receiver positioning errors commonly being regarded as the most important issue. A normalised root-mean-square (N RMS) variogram analysis measures the effect of source-receiver geometry differences on observed non-repeatability of traces. The overall trend of the variogram is strongly controlled by the heterogeneous characteristics of the overburden. We investigate the influence of heterogeneity on seismic repeatability using a NRMS variogram on synthetic data. We generate synthetic seismic data (with no incoherent noise) from velocity models with a variety of overburden characteristics and run finite-difference simulations over them. Variograms are generated from the synthetic data and show similar trends to those observed in real seismic data. We demonstrate that the length of the coherent signal of a target reflector (derived from the variogram) is directly related to the size and position in depth of the heterogeneity.

4D SEISMIC OVER THE PYRENEES FIELDS

Guy Duncan[1]*, *Kon Kostas*[1], *Mauricio Florez*[1], *James Cai*[1], *Tom Perrett*[1], *James Stewart*[1] *and Stas Kuzmin*[1]
[1]BHP Billiton

In this paper we present a case study of 4D seismic acquired over the Pyrenees Fields, offshore Western Australia. The Pyrenees trend was discovered with the drilling of the West Muiron-5 discovery well in 1993 which found oil and gas within the Pyrenees member sandstones. Production at Pyrenees started in 2010.

Before the start of production, a dedicated 4D baseline survey was recorded over the fields in 2006. A detailed modelling study concluded that a 4D monitor survey would provide useful information for reservoir surveillance and infill drilling decisions. The monitor survey was acquired in 2013, and the overall quality of the 4D was excellent with high 4D signal strength and low 4D noise.

The 4D response at Pyrenees is broadly consistent with the modelling. The main response is softening of the reservoir caused by gas coming out of solution produced by a pressure drop within the reservoir. The 4D response to changes in oil saturation is small. Incorporating the 4D interpretation into field development is ongoing, and so far it has been useful for refining the stratigraphic model, determining fault seal integrity, and determining the sealing capacity of intra-field faults.

ESTIMATION OF RESERVOIR FLUID SATURATION FROM SEISMIC DATA: AMPLITUDE ANALYSIS AND IMPEDANCE INVERSION AS A FUNCTION OF NOISE

Rafael Souza[1]* *and David Lumley*[1]
[1]The University of Western Australia

Noise in seismic data can create significant challenges for the integration of 4D information into seismic history matching procedures. Impedances derived from a seismic inversion are usually compared to impedances provided by the coupling between a fluid flow and a petro-elastic model. The problem is that uncertainties associated with noise in seismic data are rarely carried though all the seismic inversion steps. And the noise in seismic data can alter the correlation between acoustic impedance and fluid saturation, resulting in erroneous estimates of reservoir properties.

We hypothesize that the amplitude domain could be a better option than the impedance domain for seismic history matching, considering seismic noise. To verify this hypothesis we analyse amplitude and impedance changes as a function of water saturation and seismic noise. We demonstrate that the noise in seismic data causes higher variations on seismic inversion results than on amplitudes. A cross-domain comparison suggests that these impedance variations can be as high as their values derived from the seismic baseline survey.

These results indicate that matching time-lapse seismic and fluid flow data in the amplitude domain may be more reliable than using the impedance domain – in the presence of strong seismic noise. Errors in seismic data, such as noise, need to be considered when undertaking seismic history matching, and proper uncertainty analysis is required for accurate reservoir predictions.

4D INVERSION OF BOREHOLE GRAVITY DATA FOR MONITORING FLUID FRONTS

Hyoungrea Rim[1]* *and Yaoguo Li*[2]
[1]KIGAM
[2]Colorado School of Mines

Monitoring fluid movement is an important component in enhanced oil recovery (EOR) and CO2 sequestration. The newly available slim-hole gravimeter operating at high temperature offers a new avenue for such monitoring efforts because of the direct sensitivity to the change in the density distribution. We present a time-lapse gravity inversion algorithm for recovering the front of injected fluid using borehole gravity measurements. We assume that the horizontal extent of the fluid can be represented by a polygon with known but variable thickness and density contrast due to fluid substitution. We represent the evolution of the front as a 4D function of the spatial position and time since the initiation of the injection. The inversion can be carried out either independently at discrete time points or as a single inversion simultaneously over all time points. We demonstrate that the latter approach is superior in that it is more stable and offers improved capability in detecting break-through events at later times. In this paper, we will describe the details of the two inversion approaches, including two different model objective functions in polar coordinates and the nonlinear solution strategies. We will illustrate the advantages and drawbacks of independent and simultaneous 4D inversions using numerical examples.

1030–1210
Day 1 Session 1 Stream C

PETROLEUM – SEISMIC SIGNAL PROCESSING

TRUE-AZIMUTH 3D INVERSE SCATTERING SERIES METHOD FOR INTERNAL MULTIPLE ATTENUATION

Min Wang[1]* *and Barry Hung*[1]
[1]CGG

Removal of internal multiples is a long-standing problem and is still very challenging for the industry. The inverse scattering series (ISS) method is one of the advanced approaches addressing this issue. It is a data-driven approach that can predict all internal multiples without any prior knowledge of subsurface information.

In this paper, we discuss the implementation of a true-azimuth 3D ISS method which takes into account the 3D nature of the earth. It is applicable to both wide-azimuth data (land or marine) and conventional marine streamer data. We apply the approach on a synthetic example as well as real data acquired from the Santos Basin, offshore Brazil. The results show that the 3D approach predicts the multiples well because it takes into account the out-of-plane contributions of the internal multiples. As a result, all the internal multiples are strongly attenuated from the data while primaries are well preserved.

ADAPTIVE PRIMARY-MULTIPLE SEPARATION USING 3D CURVELET TRANSFORM

Xiang Wu[1]* *and Barry Hung*[1]
[1]CGG

In this paper, we propose a method to enhance the separation of primaries and multiples by utilizing the ultra-sparseness property of the 3D curvelet transform. By extending our earlier work on the 2D method, our current 3D primary-multiple separation method takes into account the coherence between neighbouring gathers, and extends the Bayesian Probability Maximization (BPM) based separation mechanism into the 3D curvelet domain. The primaries and multiples are differentiated by utilizing the traces of neighbouring gathers in an additional dimension; this further promotes their separation compared to the 2D curvelet domain method. Moreover, this 3D curvelet domain separation method produces robust results regardless of the ordering of data as long as they are organized in a volumetric manner. Additionally, we have also introduced a 3D spatiotemporal constraint for handling the deviation from linearity or planarity of the seismic events. We demonstrate the improvement of the 3D curvelet domain primary-multiple separation method on synthetic and field data examples, by comparing the results with those produced by existing separation methods.

IMPROVING IMAGING THROUGH SPECULAR AMPLITUDE ENHANCEMENT IN THE LOCAL ANGLE DOMAIN

Karl Hosgood[1]*, *Masako Robb*[1], *Zvi Koren*[1] *and Duane Dopkin*[1]
[1]Paradigm Geophysical

We present a method to improve imaging in the local angle domain (LAD) decomposition and imaging system. This system uses the entire recorded data to generate true-amplitude, angle-dependent or angle and azimuth dependent imaging gathers (Koren and Ravve 2011). These gathers have the ability to distinguish the wavefields by their directional components: Specular (continuous structural surfaces) and diffraction (discontinuous objects such as small-scale fractures and faults). The high-energy values associated with the specular directions can be used to enhance the continuous objects to obtain a diffraction-free, sharpened image of highly complex areas. We propose that the specular enhancement in the LAD system be used to re-evaluate existing land and marine (including narrow-azimuth legacy) seismic data to obtain more detailed high-resolution images without the need to acquire additional 3D data about existing assets.

INTERFEROMETRIC OBC SURFACE RELATED MULTIPLE ATTENUATION

Kunlun Yang[1]*, *Lubo Liu*[1], *Barry Hung*[1] *and Joe Zhou*[1]
[1]CGG Singapore

Surface-related multiples in Ocean Bottom Cable (OBC) data cannot be removed by directly applying standard SRME, which requires sources and receivers that are surface consistent. The ray paths needed for a complete surface-multiple prediction can be achieved by combining streamer and OBC data. The combination allows fully data driven SRME to be extended to OBC data. However, streamer data is not always available.

In this paper, we demonstrate that the required data to predict surface-related multiples in OBC data can be constructed using inter-source and inter-receiver interferometry, and the multiples can then be predicted similarly as in SRME. The work flow does not require knowing any subsurface information.

1030–1210
Day 1 Session 1 Stream D

MINERALS – EXPLORATION CASE STUDIES 1

+40 YEARS OF GEOPHYSICS IN PILBARA AND BEYOND

Asmita Mahanta[1]*
[1]BHP Billiton

The Pilbara region of North West Australia is one of the world's major iron ore provinces. Geophysical techniques have been applied routinely for exploration of iron ore. The first known application of a geophysical technique in mineral exploration was, in fact, the use of a magnetic method in the search for iron.

This presentation summarises the use of geophysical techniques in iron ore exploration over the last half century. Magnetic methods have been the most favoured, followed by gravity. EM has been applied in niche areas, such as in the exploration for CID. However it is time to venture beyond conventional techniques and start focusing on future developments in geophysics that promise yet greater benefits to mining generally and iron ore exploration in particular.

GEOPHYSICAL RESPONSES OVER THE CANNINGTON AG-ZN-PB DEPOSIT-QUEENSLAND

Ken Witherly[1]* *and I Graeme Mackee*[2]
[1]Condor Consulting
[2]Geo Discovery Group

The Cannington Deposit is high grade Ag-Zn-Pb deposit found in 1990 by BHP Minerals drilling in isolated 1000 nT aeromagnetic feature. Following the discovery of Cannington, numerous airborne, ground and borehole surveys have been carried out which overall, provided some assistance at better defining the ore system but did not lead to the discovery of new major deposit in the area.

While Cannington possessed a clear magnetic response, the presence of a thick conductive cover made the use of EM and electrical techniques challenging. BHP used Cannington as a test ground for a variety of new techniques including a ground SQUID EM sensor, modified airborne EM technology (higher power and lower base frequency) and over 10 years after discovery, the first ever Falcon airborne gravity gradiometer survey in Australia.

THE CAMELWOOD AND MUSKET NICKEL DEPOSITS – DISCOVERY OF A NEW NICKEL SULPHIDE CAMP IN THE NORTH-EASTERN GOLDFIELDS OF WESTERN AUSTRALIA

Antonio Huizi[1]*, *Ian Mulholland*[2] *and William Belbin*[2]
[1]Southern Geoscince Consultants
[2]Rox Resources

The Camelwood and Musket nickel sulphide deposits are significant recent discoveries, located within the Mt Fisher Greenstone Belt, in the northern goldfields region of Western Australia. Camelwood was the first deposit to be discovered, in December 2012, from a reverse circulation (RC) drilling campaign designed to test a coincident airborne electromagnetic (AEM) and geochemical anomaly.

The original objective of the AEM surveys was to detect massive sulphides known to be associated with gold mineralization at the old Mt Fisher gold mine. However, a number of discrete, late-time EM anomalies were identified along an interpreted ultramafic sequence on the eastern boundary of the greenstone belt. The EM anomalies represented classic nickel sulphide mineralisation targets.

Ground time-domain electromagnetic (TEM) surveys, down-hole TEM (DHTEM) surveys, and extensive drilling have been carried out since then, resulting in a JORC compliant resource at Camelwood (1.6Mt @ 2.2% Ni) and the discovery of the Musket deposit.

The application of the AEM method was instrumental in the discovery of the Camelwood nickel deposit. Systematic use of ground and down hole geophysical methods has been valuable in delineating the resource at Camelwood and in the discovery of the Musket deposit. The discovery of Camelwood and Musket proves the potential of the Mt Fisher Greenstone belt to host significant nickel sulphide mineralisation.

1030–1210
Day 1 Session 1 Stream E

MINERALS – GRAVITY AND MAGNETICS 1

MAGNETIC MAPPING OF RIVER CHANNEL AND PALAEOCHANNEL DEPOSITS – AN EXAMPLE FROM TEETULPA, SOUTH AUSTRALIA

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

High-resolution, low-level aeromagnetic surveys of the Teetulpa gold field in the Nackara Arc, South Australia, map the distribution of magnetic minerals in the alluvial cover, in the form of linear anomalies with a dendritic pattern typical of drainage systems. These anomalies are not evident in the regional aeromagnetic data flown at wider line spacing and higher elevation. Combination of the high resolution magnetic field data with mapping of present day drainage is an important input to gold exploration of the area. The magnetic anomalies can be modelled and inverted, and this might provide quantitative information to indirectly target and evaluate gold resources. Sampling and statistical analysis of relationships between the gold and magnetic minerals within the alluvium are required to form the basis for any such study.

AUTOMATED ESTIMATION OF UNCERTAINTIES IN A 3D GEOLOGICAL MODEL OF THE SANDSTONE GREENSTONE BELT, YILGARN CRATON, WESTERN AUSTRALIA

Ruth Murdie[1]*, *Florian Wellman*[2] *and Klaus Gessner*[1]
[1]Geological Survey of Western Australia
[2]University of Aachen

Geological models that represent the structure of the subsurface, are becoming a regular product of geological surveys. It is widely accepted that the sparse data at depth and the ambiguity of structural interpretations of geophysical data lead to inherent model uncertainties . The analysis and visualisation of model uncertainties is therefore the scope of current research.

We here apply a recently developed method to estimate uncertainties to a 3D model of the Sandstone Greenstone Belt in the Archean Yilgarn Craton in Western Australia. On the basis of errors in geological parameters, a suite of probable models is generated and analysed. Our results show that visualisations of unit probability and information entropy provide suitable methods analyse uncertainties in this geological model.

3D JOINT GRAVITY AND MAGNETIC INVERSION AT REGIONAL SCALE – WHAT CAN IT TELL US ABOUT GEOLOGY?

Alan Aitken[1]*, *Mark Lindsay*[1], *Lutz Gross*[2] *and Cihan Altinay*[2]
[1]University of Western Australia
[2]University of Queensland

No abstract available.

PALEO-DRAINAGE AND STRUCTURAL DEFORMATION DURING GONDWANA BREAKUP: INSIGHTS FROM THE 3D GEOMETRY OF THE BUNBURY BASALT

Hugo Olierook[1], Nicholas Timms[1], Renaud Merle[1] and Fred Jourdan[1]*
[1]Curtin University

The Cambrian Miga Arc developed above a continent-dipping subduction zone active along the east Gondwanaland margin. At the end of the Cambrian, the arc-complex was accreted to the margin in an Andean-like convergent scenario – important for understanding base metals prospectivity in western Victoria. Understanding the Miga Arc is challenging. The geology is complex, the arc fragmented and poorly exposed – mostly buried by Grampians Group, the Murray Basin, or young lava flows. An exposed arc fragment at Mt Stavely has a characteristic magnetic character, can be interpreted beneath younger cover rocks and, in combination with other geological constraints, can be used to infer several additional arc fragments in far western Victoria. Explaining the complex present-day arc fragment configuration has required advanced understanding of Tasmanides tectonics. A key breakthrough is the realisation that a template for Siluro-Devonian deformation developed for the adjacent Lachlan Fold Belt can also be applied to retro-deform Miga Arc aeromagnetic data. Once restored, a pre-Silurian Miga Arc configuration comprises two sub-parallel fault slices, each quite continuous along-strike – a greatly simplified template for mineral exploration and target selection, and a start-point for understanding the Cambrian deformation that originally accreted the Miga Arc and the metallic mineralisation developed within it.

1030–1210
Day 1 Session 1 Stream F

NEAR-SURFACE – GROUNDWATER GEOPHYSICS 1

COMPILATION OF A RESISTIVITY ATLAS OF DANISH LITHOLOGIES BASED ON DIRECT RESISTIVITY MEASUREMENTS AND WIRELINE LOGGING DATA

Ingelise Møller[1] Flemming Jorgensen[1], Verner H. Sondergaard[1], Claus Ditlefsen[1] and Anders V. Christiansen[2]*
[1]*Geological Survey of Denmark*
[2]*Aarhus University*

Electrical conductivity, or its inverse, the resistivity, is an important geophysical property within groundwater mapping. It is known to correlate empirically to lithology, primarily through clay minerals and pore water ions. Although, in Denmark, geoelectric and electromagnetic surveys have been carried out for decades, no systematic, nationwide study on the relationship between resistivity and lithology has been carried out.

We present a procedure for generating a resistivity atlas based on resistivity measurements, which can be related directly to specific and well described soil samples. Data are obtained from archives, literature and the Danish national databases. The procedure implies a restricted use of wireline logging data in combination with direct measurements on samples, resulting in resistivity distributions for specific lithologies or geological formations. The use of documented high-quality data ensures reliable results, reflecting actual resistivity of a specific lithology.

This procedure is illustrated on clay till. The resistivity variations obtained for this lithology seems to be related to real compositional variations, which reflect the process of forming the clay till.

Our procedure is likely to provide equally reliable results for other main lithologies. Future detailed studies, in particular on sediments with low clay content, should consider resistivity differences related to the degree of saturation and variations in the formation water resistivity.

OPTIMIZING AIRBORNE ELECTROMAGNETIC (AEM) INVERSIONS FOR HYDROGEOLOGICAL INVESTIGATIONS USING A TRANSDISCIPLINARY APPROACH

Ken Lawrie[1], Niels B. Christensen[2], Ross S. Brodie[1], Jared Abraham[3], Larysa Halas[1], Kokpiang Tan[1], Ross C. Brodie[1] and John Magee[1]*
[1]Geoscience Australia
[2]Aarhus University
[3]XRI International

High-resolution hydrogeophysical data are increasingly acquired as part of investigations to underpin groundwater mapping. However, optimization of AEM data requires careful consideration of AEM system suitability, calibration, validation and inversion methods.

In modern laterally-correlated inversions of AEM data, the usefulness of the resulting inversion models depends critically on an optimal choice of the vertical and horizontal regularization of the inversion. Set the constraints too tight, and the resulting models will become overly smooth and potential resolution is lost. Set the constraints too loose, and spurious model details will appear that have no bearing on the hydrogeology. There are several approaches to an automatic choice of the regularization level in AEM inversion based predominantly on obtaining a certain pre-defined data misfit with the smoothest possible model.

However, we advocate a pragmatic approach to optimizing the constraints by an iterative procedure involving all available geological, hydrogeological, geochemical, hydraulic and morphological data and understanding. In this approach, in a process of both confirming and negating established interpretations and underlying assumptions, the inversion results are judged by their ability to support a coherent conceptual model based on all available information. This approach has been essential to the identification and assessment of MAR and groundwater extraction options in the Broken Hill Managed Aquifer Recharge project.

ADVANCING GEOPHYSICAL METHODS FOR GROUNDWATER EVALUATION AND MANAGEMENT

Rosemary Knight[1]*
[1]Stanford University

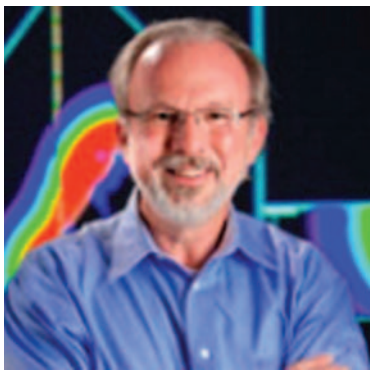
There is increasing use, throughout the world, of groundwater as the primary source of freshwater. The evaluation and management of this resource requires information about the extent and connectivity of groundwater aquifers, the contained volume of producible water, the changes in stored water, and the processes that can impact the quantity and/or quality of the water. Such information is required at a density of spatial and temporal sampling best provided by various forms of geophysical data. For the past decade, we have been working in partnerships with groundwater districts and managers to advance the use of geophysical methods as a central component of groundwater evaluation and management. Examples include the use of surface and logging nuclear magnetic resonance to estimate water content and hydraulic conductivity, electrical resistivity tomography for imaging saltwater intrusion along the California coast, and satellite InSAR data for estimating changing hydraulic head levels in confined aquifers in the San Luis Valley, Colorado. Such examples illustrate the tremendous potential for – and need for – geophysical methods to ensure the long-term health of our groundwater resources.

1330–1510
Day 1 Session 2 Stream A

PETROLEUM – PASSIVE SEISMIC

MICROSEISMIC FRAC MONITORING: YESTERDAY, TODAY AND TOMORROW

Peter Duncan[1]*
[1]MicroSeismic



Horizontal drilling and hydraulic fracturing have fathered a rebirth in the North American oil and gas business. Microseismic monitoring of the frac's has led to a new and more complete understanding of what really happens during pumping, leading to better frac design. This talk will focus on the technology of frac monitoring, past, present and future, and what it means to the industry. Case histories will be used to illustrate the state of the art in data analysis and interpretation.

VELOCITY MODEL ESTIMATION BY FULL WAVEFORM INVERSION OF TIME-LAPSE 4D PASSIVE SEISMIC ARRAY DATA

Rie Kamei[1]* *and David Lumley*[1]
[1]University of Western

In passive-source monitoring, an accurate velocity model is important to precisely estimate microseismic source locations, and to understand changes in reservoir properties. In this study, we employ frequency-domain full waveform inversion in order to obtain a high-resolution velocity model by exploiting full wavefields. We demonstrate the feasibility of the method for a surface geophone array by inverting for time-lapse 4D velocity changes in a realistic subsurface model. Our method successfully estimates the small velocity changes of a few percent within layers of 10s of meters, even for a single passive seismic source event. The analysis of wavepaths and gradients suggests that keys for the successful inversion are the use of full wavefields (both first and scattered arrivals), the vicinity of velocity changes to the source, and the wide-aperture surface array.

PASSIVE SEISMIC IMAGING AT DEPTH USING AMBIENT NOISE FIELDS RECORDED IN A SHALLOW BURIED SENSOR ARRAY

Nader Issa[1]* *and David Lumley*[1]
[1]University of Western Australia

A small scale field trial of a buried receiver array is used to generate passive recordings during a period of minimal human activity at the site of the array. We carefully analyse the data to reveal a number of valuable insights. In particular, we find that shallow burial of the geophones improves noise levels significantly and in a strongly frequency dependent manner. By isolating ambient seismic noise, which is a significant noise contribution in the frequency range from 3Hz to 30Hz, we show it is possible to utilize this seismic energy for the purpose of deep imaging. We successfully use advanced techniques of seismic interferometry to produce images to reservoir depth (~2km) and below, which show very good agreement with 3D seismic images taken on site.

1330–1510
Day 1 Session 2 Stream B

PETROLEUM – 4D SEISMIC MONITORING 2

STOCHASTIC TIME-LAPSE INVERSION OF A CO2 SEQUESTRATION SYNTHETIC SEISMIC DATA

Mateus Meira[1]* *Boris Gurevich*[1,2], *James Gunning*[2] and *Roman Pevzner*[1,3]
[1]Petrobras/Curtin University
[2]CSIRO
[3]CO2CRC

The objective of this work is to assess the effect of noise and parameterisation on the performance of the stochastic time lapse inversion. To do so, a noise-free synthetic dataset created for a feasibility study of an actual CO2 sequestration project (CO2CRC Otway Project) was inverted and used as a baseline. Noise (random and coherent) was added to the seismic data, input parameters changed and the results were compared with the baseline case.

The findings for wrong parameterisation cases were very encouraging and consistent with the theory.

When random noise was added to the input seismic data the algorithm was able to recover the true model within an acceptable margin of error. However, addition of coherent noise affected the inversion result significantly. Only when the root-mean-square (RMS) amplitude level was comparable to the one in the difference volume the algorithm was able to actually differentiate the noise from the signal.

These findings support the idea of a careful processing to avoid coherent noise and a judicious interpretation when it is unavoidable. Finally a new indicator was developed to calculate the improvement in detectability after the input of new data using the stochastic time lapse inversion.

INTEGRATING 3D SEISMIC AND HYDRAULIC UNITS TO IMPROVE RESERVOIR PROPERTY MODELS

Mohammad Emami Niri[1]* *and David Lumley*[1]
[1]University of Western Australia

We present a new method for reservoir property modeling based on integration of 3D seismic data and hydraulic flow units, and apply it to an example of a producing reservoir offshore Western Australia. Our method combines hydraulic unit analysis with a set of techniques for seismic reservoir characterization including: rock physics analysis, Bayesian inference, pre-stack seismic inversion and geostatistical simulation of reservoir properties.

Hydraulic units characterize regions and properties of fluid flow in porous permeable media, and are defined at well locations. However, usually the number of wells and their lateral coverage is extremely limited. In contrast, the lateral resolution of 3D seismic data is excellent, and this can be used to extend hydraulic unit analysis away from well locations into the 3D reservoir volume. We develop a probabilistic relationship between each of the hydraulic units defined at well locations, and the 3D seismic information. Reservoir models jointly constrained by 3D seismic and hydraulic unit analysis can therefore be useful to improve the production history matching process.

USING TIME-LAPSE VSP DATA TO CONSTRAIN VELOCITY-SATURATION RELATIONS

Boris Gurevich[1,3]*, *Mohammed Al Hosni*[1], *Roman Pevzner*[1], *Thomas Daley*[2] and *Eva Caspari*[1]
[1]Curtin University
[2]LBNL
[3]CSIRO

Quantitative interpretation of time-lapse seismic data is an ongoing challenge. Understanding the velocity-saturation relations and changes caused by CO_2 injection play an important role for the application of seismic monitoring techniques to carbon dioxide storage projects.

High uncertainties associated with well log measurements affected by borehole conditions can affect our ability to constrain a rock physics model. Seismic measurements, such as Vertical Seismic Profile (VSP), that span both the near-well region and far beyond the borehole can provide good control for correcting these measurements and reducing the uncertainties thereafter.

In this paper, we analyse the observed time delays in time-lapse VSP data from the Frio CO_2 injection test site by employing an integrated approach of rock physics and seismic forward modelling to reduce uncertainties in the choice of the dry frame modulus and velocity-saturation relations. First, we confirmed the quality of pre-injection well logs velocities with VSP data. Afterwards, we use inverse Gassmann relations to calculate the dry frame properties of the reservoir with different input parameters for the grain moduli with fluid substitution applied for uniform saturation of brine and CO_2. Finally, forward modelling of the results is implemented to compare the response with field VSP data.

Our investigation shows that VSP data can help constrain the choice of dry frame modulus, and thus the velocity-saturation relation. The rock physics model best matches the VSP results using large grain moduli and uniform saturation for fluid substitution.

MULTI-OBJECTIVE OPTIMIZATION FOR RESERVOIR MODELLING AND SEISMIC DATA MATCHING: PROOF OF CONCEPT AND FIELD APPLICATION

Mohammad Emami Niri[1]* *and David Lumley*[1]
[1]University of Western Australia

We present a new method to generate reservoir models by combining geostatistical simulation and optimization of multiple objective functions; including seismic data matching (i.e. a reservoir model seismic matching loop). Our method is used to estimate static reservoir models by simultaneously integrating several datasets including well logs, geologic information and various seismic attributes. The key advantage of our proposed method is that we can define multiple objective functions for a variety of data types and constraints, and simultaneously minimize the data misfits. Using our optimization method, the resulting models converge towards Pareto fronts, which represent the sets of best compromise model solutions for the defined objectives. We test our new approach on a 3D object-oriented reservoir model, where variogram-based simulation techniques typically fail to produce realistic models. Our results indicate that improved reservoir facies and porosity models and flow-unit connectivity can be obtained with this new multi-objective optimization approach.

1330–1510
Day 1 Session 2 Stream C

PETROLEUM – POTENTIAL FIELDS + SEISMIC

ESTIMATION OF A PETROPHYSICAL MODEL VIA JOINT INVERSION OF SEISMIC AND EM DATASETS

Fabio Miotti[1], *Ivan Guerra*[1], *Federico Ceci*[1], *Andrea Lovatini*[1], *Mehdi Paydayesh*[1], *Graham Milne*[1], *Margaret Leathard*[1], *Ajai Sharma*[1] *and Garrett Kramer*[1]*
[1]Schlumberger

Reservoir characterization objectives are to estimate the petrophysical properties of the prospective hydrocarbon traps and to reduce the uncertainty of the interpretation. In this framework, we present a workflow for petrophysical joint inversion of seismic and EM attributes to estimate the petrophysical model in terms of porosity and water saturation. This study realizes the joint inversion within the probabilistic structure provided by the Bayesian theory. The algorithm is applied to a real hydrocarbon exploration scenario to evaluate its contribution to the interpretation phase. 3D volumes of estimated porosity and saturation, show how the joint inversion of acoustic impedance and electrical resistivity can provide a quantitative description of the reservoir properties and with it a measure of uncertainty, which is consistent with the petrophysical model and observations.

AIRBORNE GRAVITY GRADIOMETER SURVEYING OF PETROLEUM SYSTEMS UNDER LAKE TANGANYIKA, TANZANIA

Douglas Roberts[1]*, *Priyanka R. Chowdhury*[2], *Sharon J. Lowe*[2] *and Asbjorn Norlund Christensen*[2]
[1]Beach Energy
[2]CGG

Beach Energy has been the sole interest holder and operator of the 7200 km^2 Lake Tanganyika South block since 2010. The block is located within the western arm of the East African Rift System. The prospectivity of the lake sequence was enhanced by large oil discoveries in the similar geological environment of Lake Albert in Uganda and in the eastern part of the rift in Kenya. The lack of wells drilled in the lake to date make predicting sedimentary sections difficult. In 2010 Beach Energy commissioned CGG to fly a FALCON® Airborne Gravity Gradiometer (AGG) and a high-resolution airborne magnetic (HRAM) survey over the Lake Tanganyika South block in order to map the basin structural framework and the depth to magnetic basement. The AGG survey facilitated the imaging of the architecture of the rift zone and the interpreted sediment thickness provided an indication of prospective petroleum target areas. This information was used to plan a subsequent 2D marine seismic survey, which was shot in 2012. The preliminary results from the 2D marine seismic survey has confirmed a rifting structure similar to that encountered further north at Lake Albert in Uganda. A number of targets over tilted fault blocks, low-side rollovers and mounded features, have been identified for follow-up from the seismic sections. Natural oil seeps evident on the surface of Lake Tanganyika, which have been sampled and analyzed by Beach Energy, also indicate that a working petroleum system is present in the sedimentary section of the rift beneath the lake.

NEW GEOLOGICAL INSIGHTS FROM THE BARBWIRE TERRACE USING FALCON DATA, CANNING BASIN

Tony Rudge[1]*, *Jurriaan Feijth*[2], *James Dirstein*[3] *and Stano Hroncek*[4]
[1]Buru Energy
[2]CGG Airborne
[3]Total Depth
[4]Geoproxima

The Barbwire Terrace in the Canning Basin has always presented explorers with an enigma. It has long held interest for hydrocarbon explorers and also mineral explorers looking for 'Mississippi Valley Type' sulphide mineralisation, being on the opposite side of the Fitzroy Trough to the Lennard Shelf (host to multiple oil fields and MVT's in the Cadjebut/Kapok area) (Copp, 2008).

Seismic interpretation on the Barbwire Terrace has been difficult, not only due to the paucity of modern reflection seismic data, but also due to the difficulty in imaging through the carbonate/dolomites of the Pillara and Nullara sections.

The Airborne Gravity Gradiometry (AGG) survey was designed to capture a large comprehensive grid of geophysical information about the southern margin of the Fitzroy Trough. The survey is instrumental in providing a greater understanding of an area of the Canning Basin that is poorly understood, yet has had many hydrocarbon shows and indications.

While CGG undertook a more traditional workflow of interpreting the AGG, aeromagnetics and seismic data, a parallel approach, using Geoproxima processing technology (differential geometric analysis for digital data) provided additional insights on features and objects not readily recognisable using traditional colour bar stretches and sun illumination.

INTEGRATED INTERPRETATION AND SIMULTANEOUS JOINT INVERSION OF 3D MARINE CSEM AND SEISMIC DATASETS

Federico Ceci[1]*, *Massimo Clementi*[1], *Ivan Guerra*[1], *Marco Mantovani*[1], *Andrea Lovatini*[1] *and Garrett Kramer*[1]*
[1]Schlumberger

One of the most complex seismic challenges is the imaging of thick salt bodies, the detection of their base and flanks, and imaging underlying units. To achieve good seismic imaging, the complementary use of non-seismic methods is one of the recommended solutions. Electromagnetic (EM) methods, such as magnetotellurics (MT) and controlled source electromagnetics (CSEM) are sensitive to the presence of salt bodies thanks to the high resistivity contrast with respect to sedimentary units. We present an integrated workflow applied to re-image wide azimuth (WAZ) seismic data acquired by Schlumberger using EM data acquired by EMGS over 35 blocks in the Keathley Canyon, in the Gulf of Mexico to reduce risk in exploration decisions and improve seismic deliverables. Seismic and EM data are utilized first in a cooperative workflow through localized seismic imaging reverse time migration (LSI RTM) to validate new salt structures highlighted by the single domain 3D anisotropic CSEM and MT inversions. They are then fed into a simultaneous joint inversion (SJI) to update a multi-property earth model (velocity and resistivity) by jointly minimizing the CSEM data misfit, the seismic residual move-outs and a relationship between the two properties.

1330–1510
Day 1 Session 2 Stream D

MINERALS – EXPLORATION CASE STUDIES 2

GEOPHYSICAL RESPONSE OF THE TROPICANA GOLD DEPOSIT

Keith Martin[1]*
[1]AngloGold Ashanti Limited

The Tropicana Gold Mine is located 330 km east-northeast of Kalgoorlie, Western Australia. Discovered in August 2005 the deposit is the first world-class gold resource discovered in high-metamorphic grade gneissic rocks, in an Archean terrane not previously thought to be prospective for gold.

The contrast in petrophysical properties of host rocks observed across the Tropicana gold mine enable geophysical methods to assist in mapping the deposit. Geophysical methods applied at Tropicana include; regional aeromagnetics and gravity, high-resolution airborne magnetics, gradient array Induced Polarisation (IP), pole-dipole IP, detailed gravity, MIMDAS IP, 2D seismic reflection, 3D seismic reflection, helicopter TEM, and SPECTREM.

Initial gradient array IP combined with geochemical analysis of aircore drilling samples provided the most cost effective method to direct early diamond and RC drill testing of auger and soil anomalies. Integration of all available data within a 3D Common Earth Model (CEM) facilitates lithology constrained 3D potential field and 3D IP inversions. When combined with the lithological packages, structural architecture, alteration assemblages and zonation, and geochemical signatures the 3D CEM provides a powerful means of delineating ore positions and exploration targets.

GEOPHYSICAL RESPONSE OF THE ATLÁNTIDA CU-AU PORPHYRY DEPOSIT, CHILE – AN UNDERCOVER DISCOVERY IN AN OLD DISTRICT

Matthew Hope[1]* *and Steve Andersson*[1]
[1]First Quantum Minerals

The discovery of the Atlántida Cu-Au-Mo porphyry deposit is a recent example of exploration success under cover in a traditional mining jurisdiction. Early acquisition of geophysics was a key tool in the discovery, and in guiding resource definition drilling, throughout the lifecycle of the project. Review of the geophysical response of the deposit with respect to its lithological distribution and petrophysical properties has allowed it to be fully characterised despite no mineralisation being exposed at surface. Data acquired over the project includes induced polarisation, ground and airborne magnetics, gravimetry, and petrophysics.

The distribution of the key lithologies is demonstrated to be readily defined, via a combined application of susceptibility and density properties, which agree well with geophysical data acquired at surface. This is in contrast to the electrical properties, which instead map the extent of mineralisation associated with the hydrothermal system, via chargeability, and the location of copper bearing sulphides via resistivity.

In combination these characteristics can be used to infer depth to exploration targets and potential for high grade mineralisation in a geological context. Future exploration will be increasingly reliant on the understanding of the surface manifestations of buried deposits in remotely acquired data. This review summarises the application and results of these principles at the Atlántida project.

PASSIVE AIRBORNE EM AND GROUND IP\RESISTIVITY RESULTS OVER THE ROMERO INTERMEDIATE SULPHIDATION EPITHERMAL GOLD DEPOSITS, DOMINICAN REPUBLIC

Jean Legault[1]*, *Jeremy Niemi*[2], *Jeremy Brett*[3], *Shengkai Zhao*[1], *Zihao Han*[1] *and Geoffrey Plastow*[1]
[1]Geotech Ltd.
[2]GoldQuest Mining Corp.
[3]MPH Consulting Inc.

The Romero gold copper zinc silver deposits are located in the Province of San Juan, Dominican Republic, approximately 165 km west-northwest of Santo Domingo. Romero and Romero South orebodies contain stratabound gold mineralization with copper, silver and zinc of intermediate sulphidation epithermal style. The gold mineralization is associated with disseminated to semi-massive sulphides, sulphide veinlets and quartz-sulphides within quartz-pyrite, quartz-illite-pyrite and illite-chlorite-pyrite alteration.

Ground DC resistivity and induced polarization (DCIP) supported by ground magnetics remain the main targeting tools for drill follow-up along with geologic mapping and geochemistry. However ZTEM passive airborne electromagnetics have recently also been applied with success for reconnaissance mapping of deep alteration and increased porosity regionally.

Our case-study compares ground DCIP and airborne EM-magnetic geophysical responses, supported by 3D inversions, over the known Romero and Romero South Au-Cu-Zn-Ag intermediate sulphidation deposit area.

1330–1510
Day 1 Session 2 Stream E

MINERALS – GRAVITY AND MAGNETICS 2

CONSTRAINING REGIONAL SCALE FAULT ARCHITECTURE IN THE SOUTHERN NEW ENGLAND OROGEN: INTEGRATION OF SEISMIC, MULTISCALE EDGES AND SURFACE MAPPING

Jamie A. Robinson[1*], *Glen Phillips*[1] *and Lisa Nix*[1]
[1]Geological Survey of New South Wales

Regional scale fault structures are considered a first order control on hydrothermal ore systems. Recognition and delineation of such features is essential for search space reduction and project selection in exploration. The New England Orogen in northeastern New South Wales has significant potential for the discovery of new hydrothermal ore systems. However, limits to interpretation of broad scale geophysics in the region and limited exposure for ground-based mapping have hampered the recognition of the first order fault architecture in many areas.

As part of the Geological Survey of New South Wales 3D mapping program, we aim to further the understanding of strike extensive and depth penetrative regional scale fault architecture in the southern New England Orogen. The workflow for constraining the regional 3D fault architecture involves integrating a limited number of deep seismic lines with broader gravity and magnetic wavelet-based multiscale edges. All the geophysical data sets are further constrained by the Geological Survey of New South Wales' seamless geology mapping and surface structural orientation data. The work to date demonstrates correlation between the lateral position of multiscale edges and their dip inferred from upward continuation, with steeper dipping structures interpreted in seismic lines. Strike orientations of edges, or systematic breaks in edges, are broadly consistent with structural orientations previously recognised in mapping, but often not at the true regional scale as suggested by edge continuity. Known hydrothermal ore systems in the southern New England Orogen display a strong correlation with the deeply penetrating edges.

A NEW INTERPRETATION OF CAMBRIAN BASEMENT GEOLOGY INCREASES THE PROSPECTIVITY FOR CU PORPHYRIES IN WESTERN VICTORIA

Phil Skladzien[1*], *Ross Cayley*[1], *David Taylor*[1] *and Mark McLean*[1]
[1]Geological Survey of Victoria

Recent Geological Survey of Victoria work has confirmed the presence of the Miga Arc, a buried Andean-type Cambrian arc system in western Victoria.

Geophysical data sets, particularly magnetics and gravity, were interpreted to characterise the regional tectonic setting, and to gain a deeper understanding of poorly exposed bedrock of the southern Miga Arc, within the Geological Survey of Victoria's Willaura Cu Porphyry project area.

Geophysical interpretation and modelling, and field mapping of Cambrian bedrock has identified new regional Late Silurian dextral faults which are important in understanding the distribution of Miga Arc rocks in western Victoria. The updated bedrock interpretation together with new geochemical results has significantly expanded the potential exploration fairway for Cu porphyries in rocks associated with the buried Miga Arc.

Key words: Miga Arc; Mount Stavely Volcanic Complex; Lachlan; Delamerian; geophysical modelling; Cu porphyry; dextral strike-slip faults.

3D GRAVITY AND MAGNETIC MODELING – ITS PAST AND FUTURE CONTRIBUTION TO UNDERSTANDING THE GEOLOGY OF AUSTRALIA

Richard Lane[1*]
[1]Geoscience Australia

Geoscience Australia (a.k.a. BMR and AGSO) pioneered the acquisition of regional gravity and magnetic data to aid geological mapping. These data revealed for the first time the extent and nature of the major tectonic elements of the Australian continent. In the 1980's, airborne survey and major exploration companies extended this concept to higher resolution at the province scale, further bringing the geology into focus. Qualitative interpretation of this type of information in 2D plan view has proved invaluable. Thoughts turned to 3D modeling and interpretation. Despite an array of software tools to perform the modeling, we are yet to feel that it has really met expectations. As we move into the future, the grand challenge for us all will be to inject more geological knowledge ("prior information") into the modeling. Technology in the form of better geophysical data acquisition capabilities, improved software tools, High Performance Computing facilities, and novel ways to integrate interpretations and visualize 3D spaces will all contribute to the solution. However, user input will remain the key ingredient for success. Injecting geological knowledge into the modeling process and understanding the results that modeling provides will enable us to reveal more detail of the 3D subsurface structure and to identify and manage the resources that are hidden therein.

1330–1510
Day 1 Session 2 Stream F

NEAR-SURFACE – GROUNDWATER GEOPHYSICS 2

AN INVESTIGATION OF THE HIDDEN PRECIOUS WATER RESOURCES OF DAMPIER PENINSULA USING AIRBORNE ELECTROMAGNETIC METHOD

John Joseph[1]* *and Josephine Searle*[2]
[1]Geophysical Consultany Services
[2]Department of Water Western Australia

An airborne electromagnetic (AEM) survey was carried out over the Dampier Peninsula, North of Broome, WA during September-October, 2012. The key objectives of this geophysical survey funded by the Department of Water was (i) to obtain a better understanding of the nature of the contact between the base of the Broome Sandstone and the underlying siltstone; (ii) to identify areas of water retentive clay layers in the near surface, (iii) to create a map of the water table; (iv) to study the detailed geometry of the near shore saline intrusion; and thus (v) assist the conceptualisation of the hydrogeology and determine the quantity and quality of available groundwater resources for the benefit of local communities, government and industry. The survey was conducted using SkyTEM, a helicopter-borne time domain AEM system.

The processed AEM data for each of the survey lines were examined and inverted using the industry standard inversion techniques. The results were then compared with available bore-hole geophysical logging as well as the regional geophysical, geological and hydrogeological data. Apart from successfully mapping the depth to water table for the whole project area, this survey has clearly delineated the thickness of Broome Sandstone, shallow impermeable layers within the Broome Sandstone and areas of possible saline sea water intrusions. The survey has also successfully identified a WNW-ESE trending lineament (a basement high) and couple of NW-SE trending structural features (such as fault structures) from the central part of the survey region. The regional geophysical data images obtained from Department of Mines & Petroleum supports this finding.

ADIABATIC PULSES ENHANCE SPEED AND SENSITIVITY OF GEOPHYSICAL SURFACE NMR MEASUREMENTS FOR GROUNDWATER INVESTIGATIONS

Elliot Grunewald[1]*, *Denys Grombacher*[2] *and David Walsh*[1]
[1]Vista Clara, Inc.
[2]Stanford University

We present a new approach to improve the sensitivity and efficiency of geophysical surface nuclear magnetic resonance (NMR) measurements. An extremely powerful tool in groundwater investigations, surface NMR inherently has a relatively low signal-to-noise ratio (SNR), which sometimes necessitates long survey times for signal averaging. In pursuit of faster survey speeds, we show that replacing the standard on-resonance excitation pulse with an adiabatic, frequency-swept pulse can provide significant increases in the NMR signal amplitude. This increase results from the fact that adiabatic pulses can excite larger volumes of groundwater more efficiently than conventional pulses. Using numerical simulations and full-scale field experiments, we show that adiabatic pulses can provide a factor of ~3 increase in signal, and suggest other advantages for groundwater imaging. The signal increase alone allows for data of equivalent SNR to be acquired in a fraction of the time required for conventional on-resonance pulses. Ultimately these improvements can allow surface NMR to be exploited in an expanding range of applications.

USING AIRBORNE EM AND BOREHOLE NMR DATA TO MAP THE TRANSMISSIVITY OF A SHALLOW SEMI-CONFINED AQUIFER, WESTERN NSW

Ko Piang Tan[1]*, *Ross S. Brodie*[1], *Larysa Halas*[1] *and Ken Lawrie*[1]
[1]Geoscience Australia

The Broken Hill Managed Aquifer Recharge (BHMAR) project aimed to define key groundwater resources and aquifer storage options in the lower Darling River floodplain of western NSW. The project was multi-disciplinary and utilised airborne electromagnetics (AEM), borehole nuclear magnetic resonance (NMR) and LiDAR DEM data and lithological, hydrostratigraphic and hydrochemical information to develop a suite of hydrogeological and groundwater property maps and products.

This abstract discusses the methods and results of estimating the transmissivity of the semi-confined target aquifer. Hydrostratigraphy and hydraulic texture classes were mapped by interpreting the AEM data in conjunction with borehole geophysics and lithological information. Aquifer transmissivity was statistically derived by combining borehole NMR hydraulic conductivity estimates with the mapped 3D distribution of texture classes and hydrostratigraphic units. Using a statistical and GIS approach, the derived aquifer thicknesses in the key areas ranged from 20 to 40 m and the lower and upper transmissivity bounds ranged from 1 to 10 m^2/d, and 10 m^2/d to 1000 m^2/d, respectively.

AN EFFICIENT AND AUTOMATIC PROCEDURE FOR INTEGRATING RESISTIVITY AND BOREHOLE INFORMATION FOR LARGE SCALE GROUNDWATER MODELLING

Anders Vest Christiansen[1]*, *Nikolaj Foged*[1], *Pernille Marker*[2], *Peter Bauer-Gottwein*[2] *and Esben Auken*[1]
[1]Aarhus University
[2]Technical University of Denmark

We present an automatic method for parameterization of a 3D model of the subsurface, integrating lithological information from boreholes with resistivity models through an inverse optimization, with the objective of creating a direct input to groundwater models. The parameter of interest is the clay fraction, expressed as the relative length of clay-units in a depth interval. The clay fraction is obtained from lithological logs and the clay fraction from the resistivity is obtained by establishing a simple petrophysical relationship, a translator function, between resistivity and the clay fraction. Through inversion we use the lithological data and the resistivity data to determine the optimum spatially distributed translator function. Applying the translator function we get a 3D clay fraction model, which holds information from the resistivity dataset and the borehole dataset

in one variable. Finally, we use k-means clustering to generate a 3D model of the subsurface structures, which we then use as direct input in a groundwater model. We apply the concept to the Norsminde survey in Denmark integrating approximately 700 boreholes and more than 100 000 resistivity models from an airborne survey in the parameterization of the 3D model covering 156 km^2. The final five-cluster 3D model is input to a groundwater model and it performs equally well or slightly better than traditional groundwater models from the area.

1530–1710
Day 1 Session 3 Stream A

PETROLEUM – FULL WAVEFORM INVERSION 1

FULL MODEL WAVENUMBER INVERSION

Tariq Alkhalifah[1]*
[1]KAUST

The promise of full waveform inversion (FWI), granted we could (completely) simulate the conditions in which our field data were acquired, including an accurate representation of the physics involved, is a model of the Earth capable of generating synthetic data that resembles (fits) our field data; No deghosting, no filtering, in fact, no processing is theoretically required as the goal in this case is a model of the Earth, not a seismic section. However, we still have a long way to go, as we usually resort to approximate physics and many assumptions, and yet, we still fail to converge to that promise. The high nonlinearity of the inversion problem with the large number of model points necessary to properly represent the resolution of interest (or need) in our model are prime reasons for the ill convergence.

The long wavelength components of the velocity model usually constrain the general geometrical behavior of the wavefield (the kinematics), observed in our data, while the short wavelength components are responsible for the scattering (the reflections themselves as events in our data). Since FWI is based on comparing the observed and modeled data, free of wavefield geometrical utilization, it usually requires that the long (and at depth and with complex media, the middle) wavelength components of the model be accurate enough to provide modeled data that is within a half cycle of the observed data. These long wavelength components are usually estimated from tomography or migration velocity analysis (MVA) methods. They, however, usually contain too low of a wavelength to fit the cycle skip criteria for all reflections in the data, especially those reflections corresponding to deeper reflectors. We are, specifically, missing the "middle" model wavenumbers necessary to help us transition from the geometrical features of the wavefield to the scattering ones. The analysis of the sensitivity of our conventional (and even FWI-in-mind enhanced) data to the model points show that such lack of middle wavenumbers is a serious problem at depth, and specifically the depths we tend care about in our industry.

In this presentation, we investigate two potential solutions to this problem, beyond requiring low frequency to be acquired. To combat this problem we shift our focus from the data domain to the model domain in which we devise an approach to explicitly control the wavenumbers that we introduce to the model at different stages of the inversion. Such controls are admitted naturally by scattering angle filters. An explicit control on the model wavenumbers provided by the scattering angle of the FWI gradients can help us maneuver model wavenumber gap. This is especially true in anisotropic media where such filters are applicable to the individual parameter models necessary to represent such the anisotropic model; A feature not accessible though data domain decimation and data hierarchical implementations, as all parameters share the same data. Though the physics involved in creating the data and the obvious acquisition limitations will eventually impose bounds on the model wavenumbers we may be able to extract, a proper integration of image domain analysis to the FWI objective will help us widen the model wavenumber spectrum that we can extract from the data. Thus, the combination of scattering angle filtering and an objective that utilizes MVA and FWI are at the heart of making FWI work, and hopefully help us converge to it's promise. During this presentation, I will share many examples that demonstrate the assertions made in this summary.

HIGH RESOLUTION ANISOTROPIC EARTH MODEL BUILDING ON CONVENTIONAL SEISMIC DATA USING FULL WAVEFORM INVERSION: A CASE STUDY OFFSHORE AUSTRALIA

Bee Jik Lim[1]*, *Denes Vigh*[1], *Stephen Alwon*[1], *Saeeda Hydal*[1], *Martin Bayly*[1], *Chris Manuel*[2], *Dimitri Chagalov*[2], *Gary Hampson*[3] *and Dimitri Bevc*[3]
[1]Schlumberger
[2]Chevron ETC APGC
[3]Chevron ETC RnD

We present a case study from the North West Shelf of Australia where the complexity of the overburden consists of several thin multi-level channel systems filled with a combination of anomalously high or low velocity sediments. Not accounting for these strong velocity variations accurately, can lead to subtle image distortions affecting the underlying section down to and including the reservoir level. This can have significant impact on the volumetric estimates of reserves in place. To resolve these complexities in the overburden, full waveform inversion (FWI) was utilized to generate an updated earth model exploiting both early arrivals and reflection events. One caveat to using full waveform inversion is the need for low frequencies to be present in the seismic data, or, the initial starting velocity model must contain the correct low wavenumber components. However, conventional seismic data acquired at shallow tow depths are usually band limited particularly at the very low frequencies. Our case study will discuss these issues along with other limitations that this "conventional data" presented along with the

workflows and quality control methods adapted to this data in order to converge to a plausible, high resolution earth model.

MAKING ANISOTROPY IN PSDM DEPTH-VELOCITY MODELS CONFORMAL WITH GEOLOGY AND VELOCITY. CASE STUDY FROM THE NW AUSTRALIAN SHELF

Sergey Birdus[1]*, *Llew Vincent*[2], *Alexey Artemov*[1] *and Li Li*[1]
[1]CGG
[2]Hess Exploration Aus

We propose and successfully apply on a real 3D seismic dataset from the North-West Australian shelf a new technique that uses well information to correlate anisotropy with velocity for localized lithology driven anomalies. We assume that localized variations in both velocity and anisotropy are caused by changes in the lithology (shale vs carbonate vs sandstone etc). This should result in some correlation between anisotropy anomalies and velocity anomalies. We use well information to establish such a correlation. Our technique produces geology conformal PSDM anisotropic velocity models and reduces depth misties.

1530–1710
Day 1 Session 3 Stream B

PETROLEUM – BOREHOLE GEOPHYSICS

INSTANTANEOUS FREQUENCY-SLOWNESS ANALYSIS APPLIED TO BOREHOLE ACOUSTIC DATA

Marek Kozak[1]* *and Jefferson Williams*[1]
[1]SuperSonic Geophysic

The methods most frequently used to process borehole acoustic data are based on semblance analysis. Two most commonly utilized semblance implementations are: slowness-time coherence and slowness-frequency coherence. Both of them are relatively robust under noisy well conditions. They deliver slowness value across the receiver array, and, as the quality control measures, coherence peak value and frequency dispersion curve.

Semblance processing might be substituted by instantaneous frequency-slowness method based on complex wave form analysis. Instantaneous frequency -slowness delivers rich set of quality control measures. Among them are the velocities, the goodness and standard deviation across the receiver array, and instantaneous frequency and slowness wave forms computed between adjacent receiver pairs. Furthermore, since computations are performed across adjacent receivers, the vertical resolution is limited to the offset between receivers. Thus the effect of multiple semblance peaks observed while the receiver array is passing through the high acoustic impedance contrast is eliminated. Also, the method is capable to detect underperforming receivers. Finally it can help to control mixed acoustic mode conditions.

Instantaneous frequency-slowness method delivers robust results under good to moderately noisy well data. The set of quality measures it delivers is much broader than the one generated by the semblance method.

LOOK AHEAD RIG SOURCE VERTICAL SEISMIC PROFILE (VSP) APPLICATIONS – CASE STUDIES

Muhammad Shafiq[1]*, *Konstantin Galybin*[1] *and Mehdi Asgharzadeh*[1]
[1]Schlumberger

Borehole Seismic has played vital role in aiding the better understandings of the conventional and unconventional reservoirs around the world in the last few decades. In VSP technique we have an advantage of listening and measuring the formation velocities at seismic scale in the vicinity of the formations while on contrary in surface seismic measurements, it is done from surface.

In vertical seismic profile (VSP) technique, the direct arrivals are recorded in addition to the reflections below current sensor depth, which makes it feasible to use the reflections to predict ahead of current depth, detailed methodology will be discussed in the paper.

In this paper, we will discuss a case history where look-ahead VSP have been successfully employed by reducing the pre-drill depth uncertainty of reservoirs from tens of meters to within a meter. Schlumberger's down-hole seismic tool was used to acquire intermediate look-ahead VSP. The data was acquired in open hole, few hundred meters above the target intervals. Fast-track processing of the field data and timely delivery of a high quality product allowed a rapid interpretation, which resulted in significant savings in relatively high cost offshore environment.

AUTOMATED STRUCTURE DETECTION AND ANALYSIS IN TELEVIEWER IMAGES

Daniel Wedge[1]*, *Eun-Jung Holden*[1], *Mike Dentith*[1] *and Nick Spadaccini*[2]
[1]Centre for Exploration Targeting
[2]The University of Western Australia

Borehole televiewer data is an important source of data on structural and stratigraphic discontinuities in both the mining and petroleum industries. Manually picking features in downhole image logs is a labour-intensive and hence expensive task and as such is a significant bottleneck in data processing. It is also a subjective process. We present a new algorithm and workflow for automatically detecting and analysing planar structures in downhole acoustic and optical televiewer images. First, an image complexity measure highlights areas most suitable for automated structure detection. Changes in the image complexity can be used to locate geological boundaries. Second, structures are automatically detected, with each structure having an associated confidence level; users can apply a threshold to the confidence values to adjust the quality and quantity of the detected structures based on the image quality and geological complexity. Third, structures that have been detected but that do not meet the structure confidence threshold can be interactively assessed and if necessary selected. We also provide tools for rapidly picking sets of equivalent structures and reducing structures to a set of representative picks.

IMAGING BY MULTIPLES: A CASE STUDY IN THE CARNARVON BASIN

Konstantin Galybin[1], Fargana Exton[1] and Efthymious Efthymiou[2]*
[1]Schlumberger
[2]Chevron Australia

Vertical Seismic Profiling (VSP) is renowned for its high resolution images of the subsurface. By and large, the images derived are beneath the well. Now a new technique allows imaging above the borehole by utilizing free surface multiples as a secondary source. A number of conditions need to be met for this technique to successfully meet its objectives. This paper presents a case study of data acquired recently in the Carnarvon basin and processed to derive an image above the well. The high-resolution, multiple-free VSP image allows verification of the shallow part of the subsurface. This information can be used to identify drilling hazards, faults and generally improve subsurface interpretation. The result can also be used to overcome the limitations of poor cementing which often causes casing ringing noise, which in itself is detrimental to VSP imaging. Subsequently, the size of the VSP image for this survey was increased by a factor of 2, thus greatly improving the value of acquisition.

1530–1710
Day 1 Session 3 Stream C

PETROLEUM – ROCK PHYSICS 1

CHANGES IN MICROSTRUCTURE AND MINERALOGY OF ORGANIC-RICH SHALES CAUSED BY HEATING

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Understanding of microstructural changes in gas shales caused by their thermal maturation is of practical importance for evaluation of extractability of hydrocarbons from these low permeability reservoirs through methods such as sweet spot mapping from surface seismic.

Two organic-rich shales (ORS), one with extremely high total organic carbon (TOC) and the other extremely low TOC are chosen for this study. The Upper Jurassic Kimmeridge Shale from and the Upper Cretaceous Mancos Shale contain around 23% and 1% TOC, respectively. Samples are subjected to temperatures in the range of 300 to 510°C. Changes in their mineralogical composition, TOC, weight and microstructure with temperature increase are monitored.

The Kimmeridge Shale shows rapid decomposition of the organic matter at the temperatures of 370–390°C. This process is accompanied by fracture development and propagation. The Mancos Shale exhibits shrinkage of the solid organic matter with mobile bitumen expulsion and relocation. No fracture development is directly observed in microtomograms. Further work has to be done to understand whether the ability of shale to develop a fracture network depends on its TOC content, the mineralogical composition of its inorganic matrix or on other parameters.

EFFECTIVE MEDIUM MODELLING THE EFFECTS OF SATURATION ON THE JOINT ELASTIC-DIELECTRIC PROPERTIES OF CARBONATES

Tongcheng Han[1], Michael Ben Clennell[1], Marina Pervukhina[1] and Matthew Josh[1]*
[1]CSIRO

The effects of saturation on the joint elastic-dielectric properties of porous medium is important for the understanding of elastic and electromagnetic wave propagation phenomena as well as quantifying hydrocarbon content in partially saturated reservoir rocks. We studied theoretically for the first time the cross-property relations between elastic velocity and dielectric permittivity (the joint elastic-dielectric properties) of carbonates with a unified microstructure. The effects of porosity and water saturation on the joint elastic-dielectric properties were also studied using validated self-consistent effective medium models for elastic velocity and dielectric permittivity. The results offered an important new possibility for estimating in situ carbonate porosity and hydrocarbon saturation using joint velocity-permittivity crossplots from co-located sonic and dielectric surveys.

JOINT EFFECT OF CAPILLARY FORCE AND FLUID DISTRIBUTION ON ACOUSTIC SIGNATURES IN ROCKS SATURATED WITH TWO IMMISCIBLE FLUIDS

Qiaomu Qi[1] and Tobias Müller[2]*
[1]Curtin University
[2]Mineral Resources Flagship, CSIRO

Capillary forces control the spatial distribution of pore fluids during two phase flow. Capillarity and fluid distribution are known to influence seismic signatures. By comparing recently developed capillarity-patchy saturation models for different fluid-patch distributions, we obtain an understanding of the underlying connection between capillarity and velocity and attenuation in patchy-saturated reservoir rocks. Our results show that, for the same gas saturation and patch size, P-wave velocity as well as attenuation manifest differently for various fluid distributions. The key parameter in controlling these characteristics is the specific surface area of the fluid patches. This work provides further insights into the relation between the seismic signatures and the two phase flow underpinning saturation information.

INTEGRATION OF STRATIGRAPHIC & ROCK PHYSICS MODELS TO GENERATE SYNTHETIC SEISMIC DATA

Mohammed Alkaff[1], Boris Gurevich[1], Cedric Griffiths[1] and Mahyar Madadi[1]*
[1]Curtin University

Stratigraphic forward modelling (SFM) is an important subsurface modelling method. A numerical SFM program, such as the Sedsim software used in this study, is able to quantitatively model the sedimentation process with time in order to predict rock properties away from well data.

Although numerical SFM is a powerful technique, it is important to quantify and minimise the uncertainty in the resultant

stratigraphic model. This uncertainty can be reduced by producing synthetic seismic traces from the results of the stratigraphic model. This simulated seismic may then be compared to observed seismic over the same area and the parameters of the stratigraphic model modified based on the results of the comparison.

In order to generate synthetic seismic from the results of a stratigraphic model, sediment properties from the stratigraphic model must be converted to acoustic properties. This becomes challenging at inter-well locations, or locations with little or no well control. Fortunately, such conversion can be achieved by the application of a suitable rock physics model even at those challenging locations.

The integration of a Sedsim stratigraphic model and the Velocity-Porosity-Clay (VPC) rock physics model in the Cornea field, Browse Basin, Australia shows the importance of integrating geological and geophysical methods in order to reduce uncertainty when predicting subsurface properties.

1530–1710
Day 1 Session 3 Stream D

MINERALS – EXPLORATION CASE STUDIES 3

DISCOVERY OF THE EUREKA VOLCANOGENIC MASSIVE SULPHIDE LENS USING DOWN-HOLE ELECTROMAGNETICS

Mike Whitford[1]*, *Jacob Paggi*[1] *and Daniel Macklin*[1]
[1]Independence Group NL

The Eureka massive sulphide lens is the first new discovery of VMS mineralisation at the Stockman Project since 1979. The discovery was made in early 2013 through the integration of geophysical techniques, particularly down-hole electromagnetics, with a robust geological interpretation.

The lens is located approximately 350 m northeast of the Currawong deposit, immediately along strike and beneath the Bigfoot lens at a depth of 360m. Though surface EM methods played key roles in the discovery of the main deposits at Currawong and Wilga, airborne and fixedloop EM surveys failed to detect the Eureka lens due to its moderate conductance and increased depth. Interpretation of subtle DHTEM responses in two exploration drill holes was a key component of the discovery. Additional geological input, including short wavelength infrared modelling and structural reinterpretation, presented a compelling drill target, which led to the discovery of the Eureka massive sulphide lens.

HELICOPTER AFMAG (ZTEM) EM AND MAGNETIC RESULTS OVER SEDIMENTARY EXHALATIVE (SEDEX) LEAD-ZINC DEPOSITS AT HOWARD'S PASS IN SELWYN BASIN, YUKON

Jean M. Legault[1]*, *Ali Latrous*[1], *Shengkai Zhao*[1], *Nasreddine Bournas*[1], *Geoffrey Plastow*[1] *and J.J. O'Donnell*[2]
[1]Geotech Ltd
[2]Selwyn Chihong Mining Ltd

In 2008 Geotech flew a regional scale 24 675 line-km survey covering a 25 000 km^2 area (1 km line spacing) in the Selwyn Basin. The survey footprint straddles eastcentral Yukon and overlaps into the western Northwest Territories. In March 2013 Yukon Geological Survey purchased the survey data, and in November 2013, released the data publicly. The Selwyn Basin area is prospective for SEDEX-style Pb-Zn-Ag mineralization and the ZTEM survey data provide insights into regional structures and plutons in the region. The Howard's Pass SEDEX deposits at the southeastern edge of the Selwyn Basin survey area host a combined ~250 million tonne resource with ~4.5% Zn and ~1.5% Pb. Major NW-SE to ESE and minor NNW-SSE linear conductive trends correlate with known regional geologic, structural and inferred mineral trends. Circular conductive anomalies surrounding resistivity highs reflect porich hornfels surrounding intrusive plutons. 2D-3D computer inversions reveal a correlation between enhanced conductivity along strike and the clustering of deposits at Howard's Pass.

IDENTIFICATION OF MASSIVE SULPHIDE TARGETS USING THE GALVANIC SOURCE EM (GSEM) SIGNAL FROM A SUB-AUDIO MAGNETIC (SAM) SURVEY AT THE FAR SOUTH PROJECT, WESTERN AUSTRALIA

William Peters[1]*, *Yvonne Wallace*[1], *Daniel Card*[1], *Keith Gates*[2], *Mal Cattach*[3] *and Bill Peters*[1]
[1]Southern Geoscience Consultants
[2]Saracen Mineral Holdings Ltd
[3]Gap Geophysics Australia

The Far South project is located five kilometres along strike from the Deep South mine, where gold mineralisation is commonly associated with semi-massive pyrrhotite and pyrite. Data from a Sub-Audio Magnetic (SAM) survey set up in galvanic configuration were acquired over the project principally to map stratigraphy and structure using the on-time Magnetometric Conductivity (MMC) and Total Magnetic Intensity (TMI) responses. The off-time Galvanic Source EM (GSEM) data were subsequently extracted from the raw data and examined. Four late time anomalous responses were identified. Two of these responses are strong late-time (>45 ms) anomalies up to 350 m in strike length, and the remaining two are weaker mid-time, more subtle and less diagnostic responses. Follow-up Moving Loop Transient Electromagnetics (MLEM) and Fixed Loop Transient Electromagnetics (FLEM) surveys confirmed well defined conductive responses over all four follow-up areas. Modelling of the GSEM data over the two strongest anomalies is in good agreement with modelling of the MLEM/FLEM data, confirming the ability to identify and model conductive targets from SAM GSEM data. The two weaker GSEM responses could not be reliably modelled and use of the MLEM/FLEM data was necessary to produce robust models. The identified conductors were all interpreted as having good exploration potential, and a subsequent drill program intersected the source of all four as sulphide zones of varying widths and types.

FOLLOW-UP DRILL HOLE SURVEYING TO DETERMINE UNIDENTIFIED EM TARGETS

Paul Mutton[1]*
[1]Touchstone Geophysics

In these two case histories, drill hole surveying using down-hole electromagnetic surveys and wireline conductivity probes are used to determine the source of geophysical targets that remained unidentified after initial drill testing.

In the first example, after drilling the identification of the geophysical target remained uncertain, despite surface EM surveys determining it had a high conductance. Subsequent DHEM and conductivity surveys were clearly able to locate and define the targeted conductor.

In the second example, deep AMT targets could not be identified after drill testing. Using data from an AEM survey over the same area, and after subsequent DHEM surveying, it appears that the targets are probably artefacts of complex (frequency dependent) conductivity in the near surface soils and regolith.

Targeting errors are very costly. These examples emphasise how critical follow-up drill hole surveying can be to resolving unidentified geophysical targets and ensuring that exploration practices are sound and efficient.

1530–1710
Day 1 Session 3 Stream E

MINERALS – GRAVITY AND MAGNETICS 3

CONSTRAINTS ON INTERPRETING MAGNETIC SPECTRAL DEPTHS

Roger Clifton[1]*
[1]NT Geological Survey

It is now possible to automate the extraction of magnetic depths over large areas as depth profiles. A depth profile is a graph of the probability of a layer at each depth. Presented in the form of a transect, depth profiles allow layers to be traced across significant distances. The appearance of discontinuous layers, and multiple layers, raises questions for interpretation, here addressed with modelling. Modelling of layers requires simulating the heterogeneity of the material. Accordingly, a method of modelling is demonstrated where flat prisms are populated with very large numbers of dipoles and their fields accumulated for spectral analysis.

Thick layers give a depth signal in the transects about 20 m below their top surface. The distinction is minor given that the layer is assumed to extend across a 20 km square.

In general, only one depth signal credibly represents the depth of its source. Multiple layers can be picked out ontraverses when the deeper layer is sufficiently more magnetised than the layer above it. A weaker depth signal appears closer to a stronger signal. Signals within 100 m of each other tend to merge. The sensitivity of the method is significantly better when the survey has been flown north-south rather than east-west. Near-surface layers are not picked up by the method. The sampling frequency of the original survey dictates how close to the surface estimates can be provided. A rough rule of thumb is that no reliable depth estimates can be expected for sources shallower than half the flight line spacing.

CONSTRAINING GRAVITY GRADIENT INVERSION WITH A SOURCE DEPTH VOLUME

Cericia Martinez[1]*, *Daniel Wedge*[2], *Yaoguo Li*[1] *and Eun-Jung Holden*[2]
[1]Center for Gravity, Electrical, and Magnetic Studies, Department of Geophysics, Colorado School of Mines
[2]Centre for Exploration Targeting, The University of Western Australia

Efficiently extracting the maximum amount of information from gravity gradient data is challenging. Interpretation often takes place in either the data domain or model domain. Here, we present a workflow that utilizes two interpretation techniques that can result in better characterization of the subsurface. Using a method that estimates depth to source, we obtain a depth volume of estimated source locations. The depth volume is then used to constrain inversion of gravity gradient data in the form of a reference model and 3D model weighting. We demonstrate that this combined approach improves the ability to recover sources at depth.

REMANENT MAGNETISATION INVERSION

Peter Fullagar[1]* *and Glenn Pears*[2]
[1]Fullagar Geophysics
[2]Mira Geoscience Asia

Remanent magnetisation is an important consideration in magnetic interpretation. In some cases failure to properly account for remanence can lead to completely erroneous interpretations. In general the strength and orientation of remanence are unknown. Two main strategies have been pursued for “unconstrained” inversion of large data sets. One strategy is to invert quantities, such as total magnetic gradient (3D analytic signal), which are insensitive to magnetisation direction. The inverted property is then magnetisation amplitude. Another strategy is to invert for the magnetisation vector, allowing its three components to vary freely. These approaches are useful, but the resulting magnetisation models are highly non-unique.

When interpreting magnetic data in tandem with geological modelling there is greater potential to infer remanence parameters. Non-uniqueness is reduced if the shape of magnetic domains is constrained, especially if the susceptibility is known and if remanence can be assumed uniform. Accordingly, inverting for the remanent magnetisation of individual homogeneous geological units of arbitrary 3D shape is the subject of this paper. Our remanent magnetisation inversion (RMI) approach can be regarded as a generalisation of parametric inversion of simple geometric bodies.

If susceptibility is known, the optimal remanent magnetisation vector within each selected unit is determined via iterative inversion. Sensitivity to change in magnetisation is determined in the x-, y-, and z-directions, and the perturbation vector is found via the method of steepest descent. If the susceptibility is unknown, the optimal susceptibility of each unit (subject to bounds) can be determined via a similar inversion procedure.

The geological units can carry remanent magnetisation, but it is fixed during this stage. The susceptibility and/or remanence inversions can be repeated, if necessary, to refine the magnetic parameters. Self-demagnetisation and interactions are taken into account when susceptibilities are high.

THE APPLICATION OF THE SIGNUM TRANSFORM TO THE INTERPRETATION OF MAGNETIC ANOMALIES DUE TO PRISMATIC BODIES

Jeferson de Souza[1]* *and Francisco J.F.F. Ferreira*[1]
[1]Laboratorio de Pesquisas em Geofisica Aplicada

The Signum transform is a simple derivative-based method for qualitative and quantitative interpretation of magnetic anomalies from discrete sources. The methodology is based on the normalization of a filtering function, which is a derivative of the anomalous field or function of this, by its absolute value. The filtered anomalies have only two values (+1 or –1) and the causative sources are represented by the positive values. The transform has been applied to three different functions, namely the first order vertical derivative of the magnetic anomaly, the first-order vertical derivative minus total horizontal derivative and second-order vertical derivative

For a vertical magnetisation the edges of the sources can be recognised from the locations where one or more of the spatial derivatives change its sign: the zero crossover point. The zero cross over point and actual source edge are separated by an amount which depends on the dykes depth and the type of data being transformed. Thus, actual edge locations are easily computed from the Signum transformed data.

The method performs well when closely spaced sources cause anomalies to overlap. Imagery based on the Signum transformation of first and second-order derivative based transforms of the magnetic data combines the advantages of the resolution of the second-order transform with the greater stability of the first-order transform.

1530–1710
Day 1 Session 3 Stream F

NEAR-SURFACE – GROUNDWATER GEOPHYSICS 3

DERIVATIVE ANALYSIS OF GEOPHYSICAL BOREHOLE TRACES

Aaron Davis[1]* *and Niels Christensen*[2]
[1]CSIRO
[2]Aarhus University

We present a derivative analysis method that automatically detects and selects layers in any geophysical borehole trace. Using a wavelet analysis, we delineate relevant boundaries from inflection points. This allows for the automatic, objective detection of layers.

Our software classifies layers based on importance in the geophysical data, and allows a user to select blocked layers based on total number of layers detected, a portion of the total layers, minimum layer thickness or the number of layers detected using a minimum operator width.

We demonstrate the effectiveness of the layer blocking technique with some field examples in Western Australia and New South Wales for aquifer detection and soil classification.

THE APPLICATION OF AEM TO MAPPING SEA-WATER INTRUSION AT LA GRANGE, WA

David Annetts[1]*, *Richard George*[2], *Tim Munday*[1], *Tania Ibrahimi*[1], *Kevin Cahill*[1], *Robert Paul*[2] *and Aaron Davis*[1]
[1]CSIRO MRF
[2]DAFWA

We describe interpretation of an AEM survey around the La Grange allocation area, WA. This survey was designed to map aquifer bounds and the sea water intrusion, and then to assess groundwater in the region, and to facilitate planning water use.

The simple, stratified nature of sediments of the western onshore Canning Basin allowed us to use blocky layered earth models and we found that five-layer models were the most parsimonious. After deriving surfaces representing the top of the Jarlemai siltstone and the top of the sea water ingress, we were able to effectively characterise the spatial characteristics of the sea water intrusion.

We found that in places, sea water intruded 40 km inland, and could be found at a depth of over 250 m.

AIRBORNE ELECTROMAGNETIC SURVEY FOR WATER SUPPLY PLANNING – CANE RIVER, WESTERN AUSTRALIA

James Reid[1]* *and Geoff Peters*[2]
[1]Mira Geoscience
[2]International Geoscience

A SkyTEM airborne electromagnetic survey was flown in the Cane River area near Onslow, Western Australia in 2011, in order to assist groundwater investigation and borefield development. The survey yielded a range of information relevant to future groundwater investigations.

The detailed geometry of the nearshore saline intrusion has been successfully defined in three dimensions. The intrusion occurs in the unconfined aquifer above the impermeable Muderong Shale.

A broad zone of low conductivity has been mapped within the alluvium and Trealla Limestone, which has been interpreted to indicate the extent of relatively fresh groundwater. The low conductivity zone has greatest extent in the 10–20 m depth slice. Between 20–50 m depth, the low conductivities are confined to the downstream part of the Cane River. At these depths, the low conductivities extend further to the eastern side of the river than to the west. This result suggest that it may be possible to expand the existing borefield to the east in areas without clay cover, while retaining a reasonable buffer from the nearshore saline intrusion.

A number of shallow granite bedrock highs have been identified in the northern and central parts of the survey area, many of which have not been intersected by existing drilling. The upper weathered and/or fractured parts of the granite may have potential as aquifers where they are not overlain by impermeable clays. However the margins of the granite should be avoided where they are in contact with the onlapping Muderong Shale, which is associated with poor water quality.

3D GEOLOGICAL MODELLING OF A BURIED-VALLEY NETWORK BASED ON AEM AND BOREHOLE DATA

Anne-Sophie Høyer[1]*, *Flemming Jørgensen*[1], *Peter Sandersen*[1] *and Ingelise Møller*[1]
[1]Geological Survey of Denmark

In former glaciated areas buried tunnel valleys can often be found. These buried erosional structures can be highly decisive for groundwater recharge and groundwater flow. Delineation of the architecture and infill of the structures are therefore very important in relation to groundwater mapping. The dense data coverage offered by airborne electromagnetic methods makes it possible to map and model the buried valley structures with a high degree of detail. The delineation of the individual valleys and the mapping of the internal cross-cutting relationships are dependent on the geological interpretation, which is founded on the knowledge about geological processes and the regional geology.

In this study, we have investigated a relatively small study area in Denmark with SkyTEM and lithological log data as the main data sources. The area is characterised by a network of cross-cutting buried tunnel valleys, which have been incised into impermeable Paleogene clay deposits. The geological interpretation of the SkyTEM data resulted in modelling of 21 buried valleys belonging to at least 7 different generations. Manual voxel modelling of the infill of these valleys, as well as the surroundings, resulted in a geological 3D model consisting of 43 different units. Most of the valleys show heterogeneous infill, characterized by a predominant lithology (for instance meltwater sand) with local occurrences of secondary lithologies (for instance clay till). In the majority of the valleys, meltwater sand is the main lithology, but clay till and meltwater clay deposits are also commonly found. Due to the heterogeneity of the infill, proper modelling of this type of geology requires voxel modelling instead of layer modelling.

Day 2: Tuesday 17 February 2015

0830–1010
Day 2 Session 1 Stream A

PETROLEUM – FULL WAVEFORM INVERSION 2

RANDOMIZED ALGORITHMS IN EXPLORATION SEISMOLOGY

Felix Herrmann[1]*
[1]UBC

As in several other industries, progress in exploration seismology relies on the collection and processing of massive data volumes that grow exponentially in size as the survey area and desired resolution increase. This exponential growth – in combination with the increased complexity of the next generation of iterative wave equation-based inversion algorithms – puts strain on our acquisition systems and computational back ends, impeding progress in our field. During this talk, I will review how recent randomized algorithms from Compressive Sensing and Machine Learning can be used to overcome some of these challenges by fundamentally rethinking how we sample and process seismic data. The key idea here is to reduce acquisition and computational costs by deliberately working on small randomized subsets of the data at a desired accuracy. I will illustrate these concepts using a variety of compelling examples on realistic synthetics and field data

FULL WAVEFORM INVERSION COMPARISON OF CONVENTIONAL AND BROADBAND MARINE SEISMIC STREAMER DATA, NW SHELF AUSTRALIA

U. Geun Jang[1]* *and David Lumley*[1]
[1]University of Western Australia

The lack of low-frequency information in conventional marine seismic streamer data inhibits the success of frequency-domain full waveform inversion (FWI). Low frequencies are typically absent in marine seismic data due to the low-cut spectral responses of airgun sources and hydrophone receivers, and the fact that the air-water interface produces source and receiver ghost reflections which create notch frequencies in the data amplitude spectrum. Advances in broadband streamer acquisition, such as the variable depth towed streamer, allow us to extend the low and high bounds of the useful frequency bandwidth in the seismic data spectrum. We illustrate the application of frequency-domain FWI to two 2D seismic data sets acquired simultaneously offshore North West Australia. Both data sets were acquired together, one with a conventional streamer, and the other with a variable depth streamer configuration. Our examples demonstrate that the FWI results are clearly superior when using the broadband variable depth streamer data, compared to using the conventional streamer data.

DO WE REALLY NEED A VERY ACCURATE STARTING VELOCITY MODEL FOR FULL WAVEFORM INVERSION?

Fabio Mancini[1]*, *Kenton Prindle*[1] *and Tom Ridsdill-Smith*[1]
[1]Woodside

Full Waveform Inversion (FWI) has recently emerged as one of the most exciting new techniques in the seismic industry, with the potential to deliver incredibly detailed velocity models. We applied FWI to 2D lines from the Exmouth basin, Western Australia. Results showed that FWI can produce excellent high resolution velocity models even if the starting velocity model is far from perfect providing that the input data is rich in low frequencies.

0830–1010
Day 2 Session 1 Stream B

PETROLEUM – FAULTS AND STRUCTURES

3D SEISMIC ANALYSIS OF NORMAL FAULT GROWTH AND INTERACTION WITHIN A GRAVITATIONAL DETACHMENT DELTA SYSTEM IN THE CEDUNA SUB-BASIN, GREAT AUSTRALIAN BIGHT

Alexander Robson[1]*, *Rosalind King*[1] *and Simon Holford*[1]
[1]University of Adelaide

We use three-dimensional (3D) seismic reflection data to determine the structural evolution of thin-skinned listric fault growth, at the extensional top of a gravitationally driven delta system, in the central Ceduna Sub-Basin. We present analysis of a strike and dip-linked extensional fault system, which is decoupled at the base of a marine mud interval of late Albian age. The fault system is oriented NW-SE with strike-linkage of fault segments and dip-linkage through the Santonian interval which connects a Cenomanian-Santonian period of kilometre scale fault growth and post-Santonian normal faulting. Understanding the growth of listric faulting requires quantifying heave and throw, which involves simplistic depth conversion of fault plane time measurements to establish a fault plane model to translate throw into fault plane displacement. Our analysis constrains fault growth into six evolutionary stages: [1] early Cenomanian nucleation and isolated radial propagation of fault segments; [2] substantial segment linkage established by the latest Cenomanian; [3] late Santonian cessation of a majority of fault growth; [4] heavy erosion at continental breakup of Australia and Antarctica (c. 83 Ma); [5] early Campanian independent nucleation of the post-Santonian fault system; and [6] fault assemblages fully linked by the Cenozoic, with continued accumulation of displacement. The structural evolution of this fault system is compatible with the ‘isolated fault model’.

In particular, we emphasise the importance of dip-linkage in this fault system, which controls the present day geometry of the fault array.

KINEMATIC RECONSTRUCTION OF THE HASTINGS BLOCK, SOUTHERN NEW ENGLAND OROGEN, AUSTRALIA

Paul Lennox[1]*, *Jie Yan Paul Lennox*[1], *Bryce Kelly*[1] *and Robin Offler*[2]
[1]University of New South Wales
[2]University of Newcastle

This research project uses 3D geological modeling software to build a 3D structural surface model of the Permo-Carboniferous rocks in the northern Hastings Block (NHB). The model is being built using comprehensive strike and dip structural data and a digital elevation model. It is designed to unravel a comprehensively mapped, complexly folded, extensively faulted geological sequence where there are no well-log data. The new 3D model will enable testing of the validity of existing tectonic models, which will assist in constraining the relative timing of fault development, testing fault emplacement of the block, and verification of the number and orientation of folding events in the NHB.

Fault-block analysis has highlighted shortcomings with the existing geological map of the NHB. Fault movement history shows early movement south of the NHB and later initial movement around the northern and northeastern margins of the NHB. Fault movement termination was probably during the Hunter-Bowen Orogeny after folding of the NHB. Preliminary 2D restoration indicated the NHB was compressed (folded) and then extensively faulted.

QUANTITATIVE SONIC TRANSIT TIME ANALYSIS DEFINES MULTIPLE PERMIAN–CRETACEOUS EXHUMATION EVENTS DURING THE BREAKUP OF GONDWANA

Hugo Olierook[1]* *and Nicholas Timms*[1]
[1]Curtin University

The Perth Basin in southwestern Australia has an extended history involving multiple regional unconformity-forming events from the Permian to Cretaceous. The central and southern Perth Basin is the closest basin to the relict triple junction of eastern Gondwana and comprises a complete Permian to Recent stratigraphy, thus recording the full history of the breakup events. We use sonic transit time analysis to quantify the magnitudes of net exhumation and the minimum differences in net exhumation across different time intervals (here called 'interval exhumation') for four stratigraphic periods from 37 wells. We were able to quantify the minimum interval exhumation of the Permian–Triassic, Triassic–Jurassic, Early Cretaceous breakup and post-Early Cretaceous events. The Permian–Triassic and Triassic–Jurassic events recorded spatially varied exhumation, up to 1000 m, across sub-basins. These localized variations are caused primarily by reverse (re-) activation of NW- and N-striking faults in the Permian–Triassic and Triassic–Jurassic events, respectively. The Valanginian breakup unconformity (~133 Ma) records approximately 400 m of basin-wide interval exhumation during the breakup of Gondwana, which implies a change to relatively uniform exhumation on a regional scale. Using published uplift rates for volcanic and non-volcanic passive margins, estimates of the time required for 400 m of exhumation vary from 6 to 20 Ma, respectively. A volcanic margin is far more likely given that post-breakup sedimentation commenced 2–7 Ma after breakup. Lastly, post-breakup interval exhumation ranges from 0 to 800 m. The highest values are in the hangingwall blocks of faults. Up to 200 m may be locally caused by reverse fault re-activation due to the present-day compressional stress state of Australia. The remainder is attributed to regional exhumation caused by dynamic topography in the last 50 Ma.

A PROSPECTIVE DEEP BASIN IN SOUTHERN PAPUA NEW GUINEA?

Michael Alexander[1]*, *Robert Marksteiner*[2] *and Corine Prieto*[1]
[1]Integrated Geophysics Corporation
[2]Consultant for BP

ExxonMobil's development of the Hides area to the northwest, and Inter Oil's giant gas discoveries at Elk and Antelope to the east, have revitalized exploration in the intervening area of PPL 319-PRL 13, southern Papuan Basin. With only limited seismic and well data available, the most time- and cost-efficient exploration option for the permit holder was to fly and interpret an airborne gravity and magnetic survey covering the permits and the adjacent surround.

After completion of acquisition and processing, the gravity/magnetic data were analysed both qualitatively and quantitatively. Existing seismic data were reprocessed and reinterpreted. We then integrated the results by means of 2D structural models incorporating surface geology, seismic, and subsurface data in order to reach solutions compatible with all data sets.

The final interpretation revealed what appeared to be a large, deep Jurassic basin which we have named Kikori Basin. If confirmed, it could be a hydrocarbon kitchen feeding both internal and surrounding prospective fold and fault structures. Several target leads in and around the deep basin were selected for detailing by a new seismic program which is not yet completed.

0830–1010
Day 2 Session 1 Stream C

MINERALS – MT METHODS 1

3D MAGNETOTELLURICS FOR MINERAL EXPLORATION BENEATH COVER

Graham Heinson[1]*, *James Komenza*[1,2] *and Dennis Conway*[1]
[1]University of Adelaide
[2]Santos

As a consequence of diminishing shallow mineral resources, the exploration industry has turned its focus to deeper targets. For this reason, the magnetotelluric (MT) method has gained much attention due to its unique penetration in regions of thick cover sequences. As the setting and geometries of mineral deposits are often complex, 3D models are required for their interpretation.

However, there has been little critical analysis of the ability of 3D MT surveys to recover structural geometry. A comparison of

synthetic model responses demonstrate that while MT is greatly sensitive to conductive and symmetrical bodies at depth, its resolution for detecting finite 3D bodies is significantly reduced under conductive regolith cover. Although 2D inversions can recover the geometry of finite conductive bodies, it is possible to successfully interpret 2D survey data using 3D inversion algorithms. Utilising all components of the impedance tensor, off-profile 3D conductive structure can be obtained from 2D survey data alone.

THE 3D JOINT INVERSION OF MT AND ZTEM DATA

Daniel Sattel[1]* *and Ken Witherly*[2]
[1]EM Solutions LLC
[2]Condor Consulting, Inc.

MT and ZTEM data were inverted with a number of 2D and 3D algorithms to recover the subsurface conductivity structure of an area of interest. A 2D inversion algorithm was used to model the magnetotelluric TM and TE mode impedances and the ZTEM tipper data, separately. The derived conductivity-depth sections don't show much agreement, possibly indicating the conductivity structure of the area to be highly three-dimensional.

A 3D inversion algorithm was used to invert the MT and ZTEM data, separately and jointly. Overall, there is good agreement between the derived conductivity structures. This suggests that a joint inversion can extract successfully the combined subsurface conductivity information from the two data sets.

NATURAL FIELD ELECTROMAGNETICS USING A PARTIALLY KNOWN SOURCE: IMPROVEMENTS TO SIGNAL TO NOISE RATIOS

Lachlan Hennessy[1]* *and James Macnae*[1]
[1]RMIT University

We aim to provide a novel approach to processing and interpretation of natural fields electromagnetic (EM) data through automated interpretation of sferic source parameters provided by the World Wide Lightning Location Network (WWLLN). Accurate sferic time stamps obtained from WWLLN are hypothesised to improve signal to noise ratios (SNR) through precisely controlled extraction of sferics with amplitudes both above and below observed noise levels in time series audio-magnetotelluric (AMT) measurements. Averaging of extracted data of equal source moment increases signal in proportion to the square root of the number of averages whilst decreasing noise since data between sferic events is inconsequential and can be discarded. Knowledge of source characteristics allows further improvements to data quality to be achieved through discrimination of sferic sources that do not meet the required assumptions of AMT. Since sferic propagation occurs primarily along great circle paths, antipodal sferics propagating around the reverse side of the earth can in principle be extracted for inclusion as additional signal. These increases in SNR afford reduced measurement time and an increase in data quality, leading to more cost effective exploration. Use of source information is unique amongst existing approaches to time domain AMT. The existing approaches are often limited in application to signals with amplitudes well above the noise level.

ARMIT sensors developed at RMIT are sensitive to natural EM fields generated by worldwide lightning activity and can measure up to 40 sferics per second. We collected AMT data using one such sensor in order to carry out an initial feasibility study on our hypothesis. Preliminary results are encouraging and demonstrate that WWLLN data are accurate and efficient enough to predict useful sferic arrival times. Future efforts will be applied to characterizing waveform similarity and investigating the relationship between stacking techniques and data reliability. This may improve SNR and hence the prediction of subsurface geological structure.

THE EFFECT OF HIGHLY MAGNETIC MATERIAL ON ZTEM DATA

Daniel Sattel[1]* *and Ken Witherly*[2]
[1]EM Solutions
[2]Condor Consulting

ZTEM data acquired across the Humble magnetic anomaly of almost 30 000 nT were analyzed for the presence of a magnetic gradient response and the effects from elevated magnetic susceptibilities.

The response of moving the receiver coil through the magnetic-field gradient peaks at 0.01 Hz and drops off strongly with frequency. Lacking information about the field strength at the base station precludes the comparison of amplitudes between computed gradient responses and the survey data, but the comparison of response shapes suggests that the gradient responses are too small to have a noticeable effect on the survey data.

The 3D inversion of the magnetic survey data indicates magnetic susceptibility values as high as 2.0 (SI). Forward-modeling the ZTEM response for these κ–values combined with resistive half-spaces indicates that the response amplitudes and shapes strongly depend on the background resistivities. Ignoring the elevated κ-values during an inversion can result in the underestimation of conductivities and other artifacts, such as the mapping of patterns that resemble crop circles. For an environment such as Humble, with deep-seated zones of elevated κ-values, the shallow inverted conductivity structure appears to be reliable, but the deeper structure should be interpreted with caution.

0830–1010
Day 2 Session 1 Stream D

MINERALS – MINE SCALE GEOPHYSICS 1

STEP-CHANGES IN GEOSCIENTIFIC INPUTS TO MINING VALUE CHAIN CONFIGURATION

John Vann[1]*
[1]Anglo American PLC

The revolution in computational power and integrated geoscience modelling approaches over the past decade is set to accelerate. Geoscientists (collectively; geologists, geometallurgists, mineralogists, geochemists and importantly geophysicists) will lead a transformation in the way the mining value chain can be conceived, evaluated and operated. The emerging capability to process large numbers of stochastic images of the mineralised system – each characterised by rich multivariate information – will allow better decision-making about alternative value chain configurations in the face of uncertainty. While this decision making has obvious implications for capital decisions in project evaluation, it has equally dramatic possibilities for real-time optimisation of existing operations. The advent of more flexible, highly configurable and in many instances automated and intelligent approaches to mining and mineral processing is perfectly timed to enable these inputs to deliver step-changes in value.

IMPROVING RESOURCE DENSITY MODELS VIA SURFACE GRAVITY INVERSION

Chris Wijns[1]*
[1]First Quantum Minerals Ltd

Density is one of the fundamental physical properties required in a mining operation, underpinning the calculation of ore tonnages and thus metal produced. The resource density model captures this information, but is often based on a relatively sparse collection of density measurements. Gravity data are a direct reflection of the true distribution of subsurface density, and can be used to improve the resource model. The example of the Ravensthorpe nickel laterite mine illustrates the improvement in the resource density model that results from combining high resolution surface gravity with the set of borehole logged density readings.

SEISMIC RESONANCE MODES FOR MINE ROOF STABILITY MONITORING

Andrew King[1]*
[1]CSIRO

This work aims at the detection of instabilities in underground mine roadway roof, with the goal of predicting and preventing roof failure and collapse.

Openings in the rock have their own resonances, due to the propagation of seismic waves in the rock around the opening. If the surrounding rock is damaged or fractured, this would result in the resonant frequencies decreasing. An experiment was set up in an underground mine to detect these resonances and see how they change in the process of rock degradation leading up to collapse.

Accelerometers were grouted into a mine roadway roof, along with displacement and stress sensors. Waveforms from mining-induced microseismic events were recorded. The spectra of the coda of these events were used to search for resonances. Strong resonance modes were indeed seen, which were stable over time. The resonance frequencies did decrease in the days prior to roof collapse, in parallel with measured stress changes. At the time when significant movement was detected in the roof rocks, the resonance modes changed completely, probably due to delamination of the rock causing seismic decoupling. This means that resonance modes could be used for roof stability monitoring.

0830–1010
Day 2 Session 1 Stream E

MINERALS – PETROPHYSICS

A MOVING 3 COMPONENT FLUXGATE MAGNETOMETER TO MEASURE REMANENT AND INDUCED MAGNETIZATIONS IN DRILL CORE

Clive Foss[1]*, *Keith Leslie*[1] *and Wayne Stuart*[1]
[1]CSIRO

We have developed a 3 component magnetometer which can be drawn along a track to produce a detailed 3 component mapping of a traverse of up to 3 metres length. One of the main applications for this instrument is to rapidly map both remanent and induced magnetizations within drill-core. Continuous sections of up to 2.5 metres of drill core are logged by running the magnetometer along the side of the core. Multiple runs following successive rotations of the core enable separation of fields arising from remanent magnetization (which rotates with the core) from induced magnetization (which does not). A first-pass interpretation of the multi-track data is made using a string of dipoles as equivalent sources. More detailed model inversions are applied if required. Broken sections of core are logged with sufficient gaps between sections that the anomalies from each are well separated.

EVALUATION OF BANDED IRON FORMATION USING MAGNETIC SUSCEPTIBILITY

Robert Howard[1]*
[1]Case Consulting Pty

In a banded magnetite deposit where assays gave no indication of concentrate yield, information required for process plant design was derived from downhole magnetic susceptibility logs.

Early analysis showed poor correlation between Davis Tube Recovery (DTR) and downhole magnetic susceptibility. The role of anisotropy in this relationship was identified and a correction factor applied to bring all data to an equivalent core to bedding angle. The result was a very high definition measure of in-situ magnetite distribution from which product yield estimates could be made.

The definition of ore type according to magnetic susceptibility profile enabled the content of potential Run of Mine ore to be characterised. Information required for front end plant design relating to economic cut-off grade, magnetic separator configuration and waste rock volumes could be estimated at an early stage of project development.

The use of geophysical data has now been applied successfully to other banded formations where conventional mining block models fail to deliver the resolution of data required by process engineers.

A METHODOLOGY FOR DENSITY DETERMINATION FROM CORE IMAGERY AND ASSAYS

Adel Vatandoost[1]* *and Peter Fullagar*[2]
[1] *CODES, University of Tasmania*
[2] Fullagar Geophysics Pty Ltd

Density is an important physical parameter due to its influence on ore resource and reserve estimation. The most efficient form of density measurement is gamma-gamma logging. However, downhole density logging is rarely conducted in non-ferrous metalliferous mines. Accurate prediction of density from core images could provide an alternative means for continuous density estimation.

A Geotek Multi-Sensor Core Logging system has been used to record petrophysical properties and also core imagery on archival drill core from Ernest Henry mine, Queensland, Australia for geometallurgical studies. Mineral grades estimated from the classified core images were not sufficiently reliable for density prediction. However, the fractional volumes can be adjusted to ensure consistency with assay data.

A linear programming algorithm was developed for this purpose. Given corrected volumes and mineral densities, it was then possible to predict density continuously along the drill hole. At Ernest Henry the average relative error between image-based density and Geotek gamma-gamma density was 3.5%.

CASING CORRECTION OF SLIMLINE DENSITY LOGS FOR IRON ORE EXPLORATION

James Wordsworth[1]*, *Fredy Giraldo*[1] *and Julian Morales*[1]
[1]Weatherford

Slimline geophysical logs are frequently used worldwide in iron ore exploration because they provide key data for ore evaluation. Application can be limited by the fact that many formations associated with iron ore deposits are friable, increasing the occurrence of borehole collapse before geophysical logs can be obtained. A cased-hole correction scheme for density logs based on an existing technique developed for oil and gas (C–thru) has been developed. The technique enables accurate and reliable near-spaced density measurements in a cased-hole (or through-rods) environment by recharacterising the response equations of the density tool to account for the casing or rods. The method effectively treats the casing or rods as part of a "modified" density tool. The method means that it is possible to obtain quantitative data when the logging tools are run inside the drilling rods. The application of this technique minimizes the risks associated with logging unstable open holes in iron ores, and can reduce costs and operation times.

0830–1010
Day 2 Session 1 Stream F

NEAR-SURFACE – ARCHAEOLOGICAL GEOPHYSICS

AN OVERVIEW OF AUSTRALIAN ARCHAEOLOGY: A NEAR SURFACE GUIDE

Fiona Hook[1]*
[1]Archae-Aus Pty Ltd

As a topic "Australian archaeology" is immensely vast and covers close to 60 000 years of history with initial colonisation by the ancestors of Aboriginal Australians through to the maritime and industrial archaeology of more recent immigrants. During this keynote I will delve into the history and prehistory of Western Australia as evidenced through the results of exiting new research projects ranging from the enigmatic rock art of the Kimberley through the Pleistocene use of dusty caves in the Pilbara to the shipwrecks in the depths of the Roaring Forties.

GEOPHYSICAL REMOTE SENSING OF A HISTORICAL ABORIGINAL GRAVESITE IN QUAIRADING, WESTERN AUSTRALIA

Lisa J. Gavin[1]*, *Thomas Hoskin*[1], *Ben Witten*[1], *Jeffrey Shragge*[1], *Adrian Petersen*[1] *and James Deeks*[1]
[1]The University of Western Australia

Burial sites have extreme cultural significance to societies around the world. Until recently, insufficient recognition of Aboriginal heritage in Australia has led to a very poor

understanding and documentation of many culturally significant locations, including burial sites. In some cases, sites have been preserved through the efforts of local people; however, others were subsequently redeveloped or even completely destroyed. Local Aboriginal people are usually the best source of information regarding these locations and can identify broad regions with historical significance, but seldom do they provide precise details about individual grave locations. There are still many Aboriginal gravesites throughout Australia where the exact burial locations are unknown. Locating gravesites – and doing so in a way that minimises site disturbance – is paramount to any investigation and preservation program. For efficient investigation of large areas, geophysical remote sensing provides practical and non-invasive tools for investigation of large poorly documented burial areas.

The UWA Society of Exploration Geophysicists Student Chapter, in conjunction with the South West Aboriginal Land and Sea Council, acquired several near-surface geophysical surveys over a known aboriginal burial site near Quairading, Western Australia. Multiple techniques were used to delineate possible grave locations, including ground penetrating radar (GPR), magnetics and conductivity. While work is ongoing with the data processing and integration, and future surveys are planned, early indications show anomalies that may be related to burial locations.

GEOPHYSICAL SURVEY RESULT OF ANCIENT TURKISH TOMBS

Tseedulam Khuut[1]*, *Ichinkhorloo Bayanmunkh*[1] *and Takayuki Kawai Niigata*[2]
[1]*Mongolian University of Science and Technology*
[2]Niigata University, Japan

Archaeological methods involve excavation, which is time consuming. Sometimes, this effort may not be very cost-effective since there are risks of damaging or missing the archaeological remains. On the other hand, information about the location, depth, size and extent of buried archaeological remains may be determined by means of geophysical investigation, which is carried out easily and quickly on the surface without disturbing or damaging the buried archaeological structures. Mining activity associated with increased, small-scale miners using metal detectors to plunder and to damage archaeological objects in Mongolia. In order to protect archaeological objects and remains, we carried out archaeo-geophysical research work in Bulgan province, central Mongolia. Archaeologists believe ancient remains' history related to seventh century. We carried out magnetic survey, GPR measurement, and resistivity tomography in ancient remains, and successfully detected in buried objects.

1030–1210
Day 2 Session 2 Stream A

PETROLEUM – STRATIGRAPHY AND FACIES 1

INTEGRATION OF SEISMIC STRATIGRAPHY AND SEISMIC GEOMORPHOLOGY FOR PREDICTION OF LITHOLOGY; APPLICATIONS AND WORKFLOWS

Henry Posamentier[1]*
[1]Independent Consultant and ex-Chevron

As high-quality 3D seismic data has become widely available, stratigraphic interpretation has significantly improved our ability to predict the subsurface distribution of lithologies. Stratigraphic interpretation of seismic data involves the integration of stratigraphy and geomorphology, with integrated section and plan view images yielding robust interpretations of stratigraphic architecture and associated lithology. Key aspects of successful application of seismic stratigraphic analysis are: (1) integrating section and plan views in an iterative workflow, (2) understanding and recognizing geologically-meaningful patterns both in section and plan view, and (3) having efficient and creative workflows to quickly analyze geophysical data.

Seismically-derived geologic interpretations can have significant impact on exploration and production in the following ways:

Geology: (1) prediction of lithology, (2) prediction of compartmentalization, (3) development of depositional analogs, (4) Enhanced understanding of geologic processes.

Geophysics: (1) provides depositional context for geophysical analyses (e.g., DHI analysis, reservoir properties from seismic), and (2) quality control for geophysical processing.

Numerous examples from a variety of different depositional settings will be shown and key workflows will be illustrated.

GEOPHYSICS OF STRATIGRAPHIC FACIES IDENTIFICATION: EMERGENT PHASES OF SELF ORGANIZATION AND THE MALLAT SCATTERING TRANSFORMATION

Michael Glinsky[1]*
[1]Halliburton

A framework for the analysis of stratigraphic facies as emergent phases of self organization will be presented. An example will be given of turbidite deposition that is governed by a system of partial differential equations. It will be shown how the boundary

conditions and coefficients of the PDEs parameterize a phase space that is divided into distinct phases, or what is more commonly called facies. A method of renormalization of the texture of geologic outcrops, seismic data, and well logs will be presented that gives the scale dependance of the PDE coefficients and boundary conditions. This specification of the running coupling coefficients or S-matrix of the physics gives the form of the PDE as well as the coefficients and boundary conditions. Practically this gives a unique fingerprint, or "attribute" (technically a metric) of the geologic facies. The mathematical framework is based on the Mallat Scattering Transformation – an iterative wavelet transformation.

1030–1210
Day 2 Session 2 Stream B

PETROLEUM – LABORATORY MEASUREMENTS

JOINT INVERSION OF P-, AND S-WAVE TRAVEL TIMES FOR CHARACTERISATION OF ANISOTROPIC MATERIALS USING LASER DOPPLER INTERFEROMETRY MEASUREMENTS

Andrej Bóna[1]*, *Boris Gurevich*[1], *Roman Pevzner*[1], *Maxim Lebedev*[1] *and Mahyar Madadi*[1]
[1]Curtin University

We used laser Doppler interferometer for measuring the displacement on the sample surface. These measurements allow us to clearly separate different wave types, whose picked travel times are used for estimation of VTI anisotropy parameters. One of the observations in this study is the very strong amplitude of critically refracted SP wave at the measurement surface. We confirmed the characteristics of this wave by numerical modelling. We used this wave to improve the estimates of the anisotropy. The observed strong amplitude of this wave can have strong implications for the interpretation of ultrasonic measurements.

BROADBAND LABORATORY MEASUREMENTS OF DISPERSION IN THERMALLY CRACKED AND FLUID-SATURATED SODA-LIME-SILICA GLASS

Yang Li[1]*, *Emmanuel David*[1], *Ian Jackson*[1] *and Douglas Schmitt*[1]
[1]Australian National University

To better understand the dispersion of seismic velocities arising from stress-induced fluid flow, broadband laboratory measurements have been conducted on a range of synthetic samples. Forced oscillation methods providing access to low frequencies (mHz – Hz) were combined with measurements at MHz frequencies with ultrasonic methods. Either fully dense soda-lime-silica glass or aggregates of sintered glass beads were subject to broadband tests before and after thermal cracking under dry, argon- and water-saturated conditions in sequence. Crack closure effects under pressure are observed on all samples. A systematic increase in shear modulus, attributed to the suppression of 'squirt' flow, has been monitored on the low-porosity (approximately 2%) cracked glass-bead specimen with both argon and water saturation at ultrasonic frequency. The use of samples with different porosities varying from 0 to 6% promises to distinguish the roles of pores and cracks in fluid-flow-induced dispersion.

STRESS-ASSOCIATED SCATTERING ATTENUATION AND INTRINSIC ATTENUATION FROM ULTRASONIC MEASUREMENTS

Li-Yun Fu[1]*, *Yan Zhang*[1], *Wei Wei*[1], *Bing Zhang*[1] *and Zhenxing Yao*[1]
[1]Institute of Geology and Geophysics, Chinese Academy of Sciences

Acoustic attenuation has been proved to be an indicator of stress changes in solid structures. Acoustic coda, as a superposition of incoherent scattered waves, reflects small-scale random heterogeneities in solids. Acoustic coda attenuation, as a combination of intrinsic attenuation and scattering attenuation, contains information on stress changes as a result of changes in the physical state of small-scale heterogeneous structures. Based on the ultrasonic measurements of a rock sample with intra-grain pores and fractures under different pore-pressure induced effective stresses, we compute the stress-associated coda attenuation quality factors QPC and QSC as a function of frequencies. Based on the digital heterogeneous cores of the sample, the experimental results are validated and corrected with numerical results by the finite-difference simulation of Biot's poroelastic equations and the Monte Carlo simulation of multiple scatterings, respectively. The quality factors characterize its scale dependence of scattering attenuation on stress variations in rocks. We compare them with the intrinsic attenuation quality factors QP and QS calculated by the spectral ratio method and BISQ model, respectively, from ultrasonic measurements. Comparisons demonstrate that the scattering attenuation is much stronger, particularly when ultrasonic wavelengths are comparable to the scale of pores and grains. The intrinsic and coda attenuations versus increasing effective stresses present quite different nonlinear features, where QPC and QSC show a greater sensitivity to pore pressure than QP and QS.

X-RAY COMPUTED TOMOGRAPHY INVESTIGATION OF STRUCTURES IN CLAYSTONE AT LARGE SCALE AND HIGH SPEED

Gerhard Zacher[1]*, *Thomas Paul*[1], *Annette Kaufhold*[2] *and Werner Graesle*[2]
[1]GE Sensing & Inspection Technologies
[2]Federal Institute for Geosciences and Natural Resources

In the past years X-ray Computed Tomography (CT) became more and more common in geo-scientific applications and is used from the µ-scale (microfossils) up to the dm-scale (cores or soil columns). Hence a variety of different systems was adapted to these applications.

In the present paper we investigate CT results from an Opalinus Clay core (diameter ~100 mm) considering the 3D distribution of cracks. Two CT systems are compared both, with specific ad- and disadvantages: the large and flexible phoenix v|tome|x L300 high energy CT scanner and the high throughput speed|scan CT 64 helix CT system (both GE Measurement & Control).

The results are compared regarding the contrast resolution, spatial resolution, and scanning speed. The fast medical scanners provided a quick overview whereas the microfocus tube provided a more detailed view on cracks.

1030–1210
Day 2 Session 2 Stream C

MINERALS – MT METHODS 2

INTERPRETATION OF RESISTIVITY AND MAGNETIC ANOMALIES FROM THE FOX RIVER SILL, TRANS HUDSON OROGEN, CANADA

Ian Ferguson[1], Darrell Epp[1], Thamara Saturnino[1], Marcelo Orellana[1], Jim Craven[2] and Alan Jones[3]*
[1]University of Manitoba
[2]Geological Survey of Canada
[3]Dublin Institute for Advanced Studies

The Fox River Belt is a sequence of rocks at the margin of the Proterozoic Trans Hudson Orogen in Canada that have been intruded by the Fox River Sill, a stratiform ultramafic–mafic sill. An earlier 2D magnetotelluric (MT) study of the sill revealed a conductor that is spatially correlated with a sheared serpentinite unit in the Lower Central Layered Zone of the sill. Re-analysis of the data from 10 MT sites lying on a 1.4 km north–south profile, approximately perpendicular to geological strike, across a 1 km wide portion of the sill produced a resistivity model containing a conductor with an average resistivity of <1 ohm.m.

Using aeromagnetic data from a profile subparallel to the MT profile, a geologically constrained magnetic model of the sill was constructed. Empirical susceptibility-magnetic mineral content relationships were used to estimate the magnetite content of the different geological units from the magnetic model. The results indicated a susceptibility of 0.2 SI for the sheared serpentinite unit, suggesting a magnetite content of ~5% which compares with petrological estimates of up to 10%.

The bulk resistivity of geological units in the resistivity model was interpreted in terms of metallic mineral content using published resistivity relationships and a range of connectivity models. Integration of these results with magnetic and geological analyses suggests the enhanced conductivity in the sheared serpentinite is a result of a higher degree of magnetite interconnectivity due to the shear fabric. The analysis also reveals that although portions of the adjacent Marginal Zone in the sill contain concentrations of magnetite similar to those in the sheared serpentinite, the significantly higher resistivity of the Marginal Zone can be explained by a lower degree of magnetite interconnectivity.

DEEP CONDUCTIVITY ANOMALY OF THE DARLING FAULT ZONE – IMPLICATIONS FOR FLUID TRANSPORT IN THE PERTH BASIN

Thomas Hoskin[1], Klaus Regenauer-lieb[2] and Alan Jones Dias[3]*
[1]University of Western Australia
[2]CSIRO
[3]Dublin Institute for Advanced Studies

The Darling Fault Zone (DFZ) is one of the largest lineaments in the world, mapped over approximately 1000 km. It is a long-lived feature with imprints of multiple deformation phases with multiple orientations since the Archean. Although it is still topography forming in some areas, and therefore must have recent activity, its seismic quiescence reduces the perceived need for scientific investigation into the extent and physical properties of this crustal scale fault. Seismic activity is common in the south west of Western Australia and evidence suggests these are located on faults that communicate with the DFZ. It is therefore paramount to have more detailed understanding on the fault architecture and the role of fluids in lubricating aseismic slip.

Magnetotelluric (MT) data are acquired along transects across the Perth Basin and the western margin of the Yilgarn Craton providing deep, high resolution data about the electrical structure of the DFZ. In this contribution we focus on the interpretation of the data, details on the acquisition and analysis are presented in the poster session.

Using impedance tensor analysis and 2D modelling techniques, we map the DFZ to the base of the crust, confirming it as a lithospheric feature. We reveal a complex pattern of deep-seated conductivity associated with the foot wall of the DFZ that persists to depth. Resistivity models are used to estimate porosity on the DFZ, identifying a more complex internal structure for the DFZ than generally considered, with important implications for fluid transport in the basin.

RESISTIVITY STRUCTURES OF WESTERN VICTORIA, AUSTRALIA FROM 2D AND 3D MODELLING OF MAGNETOTELLURIC DATA

Sahereh Aivazpourporgou[1], Stephan Thiel[1], Patrick Hayman[2], Naser Meqbel[3], Louis Moresi[4] and Graham Heinson[1]*
[1]University of Adelaide
[2]Monash University
[3]Helmholtz Centre Potsdam
[4]Melbourne University

A long period magnetotelluric (MT) survey, comprising 39 sites over an area of 270 by 150 km, has identified partial melt within the thinned lithosphere of Quaternary Newer Volcanics Province (NVP) in southeast Australia. MT inversion models reveal several important tectonic features and unravel critical information about the tectonics of the area. The models have imaged a conductive anomaly beneath the NVP at ~40-80 km depth, which is consistent with the presence of 1.5–4% partial-melt in the lithosphere. The conductive zone is located within thin juvenile oceanic lithospheric mantle, which was accreted onto thicker Proterozoic continental lithospheric mantle, suggesting that the NVP origin is due to decompression melting within the asthenosphere, promoted by lithospheric thickness variations in conjunction with rapid shear. In addition, inversion modelling shows that there is a conductivity contrast across the Moyston Fault that suggests the transition from Proterozoic continental lithospheric mantle under the Delamerian Orogen to the Phanerozoic lithospheric mantle under the Lachlan Orogen.

CARPENTARIA CONDUCTIVITY ANOMALY REVISITED WITH PRELIMINARY MAGNETOTELLURIC RESULTS FROM THE SE MT ISA SURVEY 2014

Millicent Crowe[1] and Peter Milligan[1]*
[1]Geoscience Australia

The region to the east of Mt Isa has complex electrical conductivity, with conductive basin sediments overlying the deeper Carpentaria Conductivity Anomaly (CCA). Early magnetotelluric (MT) model results show alignment of the CCA with aeromagnetic, gravity and seismic features, together

implying that they define the major structural edge of the Mt Isa Block. Profile MT data acquired during the previous 20 years have helped refine the position and depth of the CCA. New MT and deep seismic reflection data have recently been acquired in 2014 along a NW to SE profile, funded by the Geological Survey of Queensland's Greenfields 2020 Program in conjunction with Geoscience Australia. These new data provide further evidence of the complex nature of the crustal conductivity in this region. Induction vectors indicate that the CCA itself is braided into several zones which may define deep-seated fracture systems.

1030–1210
Day 2 Session 2 Stream D

MINERALS – MINE SCALE GEOPHYSICS 2

GEOSTATISTICALLY AND DRILLING CONSTRAINED MAGNETIC INVERSION FOR PREDICTING MINERALISATION AT THE BASIL CU-CO DEPOSIT

Matthew Zengerer[1]*
[1]Intrepid Geophysics

The Basil Cu/Co deposit comprises a 26.5 Mt JORCcompliant inferred resource of copper and cobalt, grading 0.57% Cu and 0.05% Co. It lies in the Harts Range, central Australia, within the Riddock Amphibolite of the Irindina Province. The deposit coincides with a prominent anomaly in aeromagnetic data. Intersections of mineralisation at depth follow the magnetic anomaly trend. Analysis of drilling within the mineralised zone determined a spatial association between pyrrhotite with high magnetic susceptibility and chalcopyrite, with no other significant magnetic mineralisation present.

A study was commissioned to examine if geophysical inversion could predict the distribution of mineralisation, using pyrrhotite as a proxy for chalcopyrite, from the surface to the drillhole intersections, as well as predicting further mineralisation at depth or in the vicinity of the deposit. Commercial software was chosen for performing geostatistical analysis, 3D geological modelling, forward modelling and stochastic inversion.

Petrophysical data from core and information on mineralisation from drilling were used to constrain 3D geological modelling of mineralisation based on domain kriging of susceptibility data and sulphur assays. Magnetic data was conditioned for inversion in Intrepid software. Sensitivity testing of results to source depth and distribution was performed using 3D forward modelling. Alternative 3D geological models were tested during inversion for their behaviour and adherence to observed drilling data and the limitations imposed by the sulphide distribution in the geostatistics.

The resulting initial geological model had known property voxels from drilling fixed and surrounding property voxels locally interpolated from kriging. Using these as a seed, geophysical inversion was performed alternating property and lithology inversion, until a desired minimum misfit with the observed magnetics signal was reached.

The new predicted mineralisation distribution was compared with estimated mineralisation shells from conventional geostatistical modelling and found to be in good agreement, with reliability increasing closer to the surface.

MAGNETIC MODELLING AND GEOLOGICAL MODELLING COME TOGETHER AT THE KINTYRE URANIUM DEPOSIT

Andrew Fitzpatrick[1]* *and Penny Large*[1]
[1]Cameco Corporation

We present a case study whereby unconstrained magnetic modelling accurately defined the altered host lithology of the Kintyre Uranium deposits, verified by detailed geological modelling. The Kintyre Uranium deposits are hosted by a sequence of iron and carbonate rich meta-pelites, which makes it an ideal target for magnetic prospecting. As part of the resource definition, magnetic modelling and geological modelling were performed over the Kintyre deposit independently. In the process of further refinement of the magnetic model through incorporation of geological constraints it was determined the two models were already highly complementary and further modelling was not warranted, particularly at the resolution of the magnetic data. This case study demonstrates that in some geological environments, unconstrained geophysical models can adequately map stratigraphy and structure for drillhole target generation.

MINE SCALE CONSTRAINED GEOPHYSICAL INVERSION; A CASE STUDY AT THE DARLOT-CENTENARY GOLD MINE

Sarah Monoury[1]*, *Ben Jupp*[1] *and Andrew Foley*[2]
[1]SRK Consulting
[2]Gold Fields

SRK Consulting (SRK) conducted a geological and geophysical modelling study of the Darlot-Centenary Gold Mine, Western Australia. This study defined geological boundaries in areas where drilling was limited, allowing for targeting of potential extensions to the gold mineralisation. 3D geological modelling of the structural setting and geometry of gold mineralisation within the deposit has shown a strong relationship between gold grade and a magnetic sub-domain within the Mount Pickering Dolerite. The magnetic dolerite domain is considered as a more prospective unit and a target for exploration drilling.

To define the boundaries of the dolerite multiple unconstrained magnetic inversion, models were conducted. This was followed by geologically constrained inversions. The resulting models were consistent and both methods are capable of resolving the prospective magnetic dolerite domain. However, the constrained inversion model ultimately provided a better representation of the geometry of the folded dolerite units. Using the inversion modelling, SRK was able to provide greater certainty in the subsurface geometry of the prospective Mount Pickering Dolerite, providing greater accuracy for the potential near mine exploration targets.

BLIND TEST OF MUON GEOTOMOGRAPHY FOR MINERAL EXPLORATION

Joel Jansen[3]*, *Douglas Bryman*[1] *and James Bueno*[2]
[1]University of British Columbia
[2]CRM GeoTomography Technologies Inc.
[3]Teck Resources Limited

Muon geotomography is a new geophysical imaging technology that creates 3D images of subsurface density distributions. Similar in concept to computed tomography scanning, muon geotomography uses naturally occurring cosmic radiation that gets attenuated when traversing matter. Cosmic ray muon data were acquired in the Pend Oreille Zn-Pb mine in Metaline Falls, Washington State, USA without prior knowledge of the presence or absence of ore bodies. The resulting 3D density distribution indicated a substantial volume of rock with higher density than the host stratigraphy above the survey location. Subsequently, a model of existing ore shells based on drill core data was provided and a simulation of the expected muon tomography data was found to be consistent with the muon geotomography measurements. This is the first blind test demonstration of muon geotomography applied to mineral exploration.

1030–1210
Day 2 Session 2 Stream E

NEAR-SURFACE – ENGINEERING GEOPHYSICS

DEVELOPING URBAN AND MINING GEOPHYSICAL INSTRUMENTS AND METHODS: PUSHING THE BOUNDARIES

Alireza Malehmir[1]*
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It is becoming increasingly evident that our understanding of the geological conditions in the shallow subsurface is limited. This is especially apparent in large cities and areas covered by lakes where underground infrastructure such as tunnels, subways and train stations have to be constantly developed or expanded to facilitate the daily life and transportation. The degree to which we can understand geological conditions such as these also has great economical and environmental effects for mine planning. What makes these environments similar and challenging targets for geophysical investigations are the various sources of noise and restriction (both in time and space), which require the equipment to be versatile and to produce minimal disruption as well as fast to set up and pack. Direct observations of the subsurface are cumbersome, expensive and sometimes impossible. However, if properly designed and implemented, geophysical methods are capable of imaging detailed subsurface structures and can successfully be used to provide crucial information for site characterizations, infrastructure planning, brown- and near-field exploration and mine planning. To illustrate the potential of geophysical methods in these environments, I will show prototype seismic and EM instrumentation and their applications that are especially geared for noisy environments and areas where high-resolution images of the subsurface are needed. The presentation will be supported by several examples from these two areas.

MULTICHANNEL 3D GROUND PENETRATING RADAR – ADVANCES IN CIVIL INFRASTRUCTURE SCANNING

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The scope of this paper is to highlight improvements in Ground Penetrating Radar (GPR) as an infrastructure condition assessment tool, in particular through the use of multichannel 3D GPR.

Multichannel 3D GPR is a relatively new and alternative infrastructure scanning tool which can assist geophysicists and engineers in providing 100% sub-surface coverage of an investigation area, where site access is possible. Advantages of an increased level of subsurface coverage using multichannel 3D GPR includes providing the user with improved accuracy in highlighting and quantifying regions that may require further invasive testing for future maintenance programs and also possible long-term monitoring.

This paper briefly discusses current applications of standard GPR for infrastructure condition assessments and how multichannel 3D GPR can improve knowledge of the sub-surface in these application areas.

Visualisations of multichannel 3D GPR data outputs with interpretations have been presented to illustrate the improved subsurface information made available from this method. The example presented is an approximately 4 m long section of multichannel 3D GPR data acquired along the surface of a reinforced concrete-lined tunnel.

DETECTION OF DEEP BURIED METAL OBJECTS WITH THE ULTRATEM

Stephen Billings[1]*, *Malcolm Cattach*[1] *and Michael Laneville*[2]
[1]Gap Geophysics Australia
[2]MMG LXML Sepon

The UltraTEM Deep metal detection system combines a rugged, fast-switching transmitter with a powerful custom designed generator and one to ten three-component receiver coils that collect time-domain electromagnetic induction data across a wide time-range. The roving receiver is operated inside a fixed loop of copper cable, typically 30–150 m long and 5–50 m wide. The large size of the loop results in a slow falloff in primary field with depth and effective excitation of deep buried unexploded ordnance as well as other metal objects such as Ground Engaging Tools (GET). We describe the results of an extensive trial of the UltraTEM system at a magnetically challenging site in Laos. The UltraTEM was able to detect all seeded items buried at depths down to 5 m across a wide range of site conditions. Subsequent work with the system at a different site demonstrated an ability to detect GET to depths of at least 3.0 m in a magnetite stockpile.

1330–1510
Day 2 Session 3 Stream A

PETROLEUM – STRATIGRAPHY AND FACIES 2

SEISMIC GEOMORPHOLOGY OF MIXED-INFLUENCE COASTAL-DELTAIC SYSTEMS

Simon Lang[1]*
[1]Chevron

Recognition of mixed processes on coastal-deltaic systems end members (relative power of W- wave, T -tide and F-fluvial processes) is important for both exploration and reservoir characterization. Mixed-influence systems impart asymmetry and heterogeneity that impact prediction of subsurface lithology (facies), static modelling of various connectivity scenarios, and ultimately exploration to development well planning. Numerous detailed studies of these mixed-influence systems from modern analogs, outcrop and core, and log data requires calibration with high resolution seismic visualisation.

Although typical stacking of genetic units (5–25 m parasequence-scale) is at or below the resolution limits of most 3D seismic data, focused seismic stratigraphic workflows can image detailed geomorphic plan-forms, which reflect features at the limits of detection (<10 m).

A range of seismic stratigraphic workflows are illustrated (single and multiple datums, horizon slicing, flattening, optical stacking, channel/feature chasing, and attribute calculations) with a variety of example seismic datasets. These workflows can produce detailed images of complex facies juxtapositions at or near the detection limit. Specifically, we show examples of varying degrees of wave, fluvial and tidal influence, recognized by characteristic plan-form features at element to complex scales including (but not limited) to the following:

1. High to low reflectivity, continuous elongate arcuate, divergent to subparallel reflections (either convex or concave in a basinward direction), indicative of wave-dominated (W), to wave-dominated, but tide-influenced (Wt) strand-plains and associated down-drift chenier-plains (Tw).

2. High reflectivity, continuous and sinuous channel-form reflection features adjacent to sets of recurved-lineations (convex-basinward), interpreted as the trace of tide-influenced estuarine channels (Tf) or distributary channels (F, Ft).

3. Transparent seismic reflections with internal channel-forms, and dendritic or reticulate planforms, indicative of tide-dominated shorelines including tidal flats and associated tidal creeks (T, Tw, Twf).

4. High to low reflectivity, continuous or discontinuous, low- to high-sinuosity channel-form reflections, either isolated or amalgamated, indicative of fluvial-dominated channel belts, and associated abandoned meander loops (F, Ft), associated with a background of transparent to highly reflective continuous to discontinuous reflections, representing the alluvial or coast-deltaic floodplain.

This approach can assist prediction of reservoir connectivity in wave-dominated systems, with the recognition of internal baffles and local barriers associated with shale-prone parts of the depositional system, both within and between parasequences.

QUATERNARY ISOLATED CARBONATE BUILD-UPS IN THE TIMOR SEA (NW AUSTRALIA) – UNDERSTANDINGS AND IMPLICATIONS

Muhammad Mudasar Saqab[1]* *and Julien Bourget*[2]
[1]Centre for Petroleum Geoscience and CO_2 Sequestration
[2]University of Western Australia

Distribution and growth history of isolated carbonate build-ups (ICBs) is controlled by complex interplay between various tectonic, eustatic, and oceanographic parameters. Quaternary ICBs in the Timor Sea (NW Australia) are located in tropical waters, and at present they form clusters of ~150 build-ups, developing 2 to 85 km from the edge of a wide continental shelf. The tectonic evolution of the Timor Sea lead to regional changes in the oceanography and flexural deformation of the NW Bonaparte Basin, which in turn had a major impact on the evolution of ICBs. Flexure-induced fault activity produced structural topography for the growth of ICBs over 'highs', while oceanic current through Timor Trough provided warm and nutrient-rich water. Our results demonstrate that, despite potentially good conditions for carbonate production, ICBs did not form until the Mid Pleistocene (ca. 0.582–0.8 Ma BP). This age corresponds to the onset of repeated, high-amplitude (+120 m) sea level fluctuations with rapid deglacial rises and slow falls. Thus, we infer that the NW Australia ICBs formed due to: (1) structural shaping of the margin; (2) oceanographic changes, and; most importantly, (3) onset of repeated short-term transgressions reactivating the carbonate production along isolated highs. The distribution and growth of ICBs could be useful to understand the evolution of ancient ICBs that formed along very wide shelves and epeiric seas.

GEOMORPHOLOGY AND SEISMIC STRATIGRAPHY OF THE EARLY CRETACEOUS DELTA IN THE VLAMING SUB-BASIN AND IMPLICATIONS FOR SEAL QUALITY

Chris Southby[1]*, *Megan Lech*[1], *Liuqi Wang*[1] *and Irina Borissova*[1]
[1]Geoscience Australia

The early Cretaceous South Perth Shale has been previously identified as the regional seal in the offshore Vlaming Sub-basin. The South Perth Shale is a deltaic succession, which infilled a large palaeotopographic low in the Early Cretaceous through a series of transgressive and regressive events. A study undertaken at Geoscience Australia has shown that the seal quality varies greatly throughout the basin and in places has very poor sealing properties. A re-evaluation of the regional seal based on seismic mapping determined the extent of the pro-delta

shale facies within the South Perth Shale succession, which provides effective sealing capacity.

New sequence stratigraphic interpretation, seismic facies mapping, new and revised biostratigraphic data and well log analysis were used to produce palaeogeographic reconstructions which document the distribution of depositional facies within the South Perth Shale and reveal the evolution of the early Cretaceous deltas.

Our study documents spatial variations in the seal quality and re-defines the extent and thickness of the regional seal in the offshore central Vlaming Sub-basin. It provides an explanation for the lack of exploration success at some structural closures and defines constraints on the possible location of valid plays.

1330–1510
Day 2 Session 3 Stream B

PETROLEUM – THEORETICAL STUDIES

BROADBAND DATA FROM FLAT STREAMERS: CONSIDERATIONS FOR ACQUISITION AND PROCESSING

Edward Hager[1]* *and Phil Fontana*[1]
[1]Polarcus

Broadband acquisition aims to improve the bandwidth of seismic data, which in practice means extending the low-frequency end of the spectrum without limiting the high-frequencies beyond the natural earth response (Q-factor). These "unconventional" techniques focus on the receiver-side ghost, and commonly used are co-located velocity and pressure sensors and dual-depth hydrophone or variable depth hydrophones, which either capture phase or timing differences respectively of the receiver ghost. All these methods rely on processing to achieve the final receiver side de-ghosted data as the "dumb sum" of the measurements will lead to poor results, or post-stack broadband data in the case of slant streamer. With sufficient signal-to-noise in the data it is possible to de-ghost the receivers towed at a moderate single depth by tuning the acquisition design, with consideration of the source emission response in combination with the streamer reception response. A test line was acquired that shows the equivalency of slant streamer and flat depth streamers in terms of post-stack amplitude spectra, showing that the acquisition design and pre-stack deghosting processing methodology is effective in providing broadband data.

LINKING ELECTRICAL AND HYDRAULIC CONDUCTIVITY THROUGH MODELS OF RANDOM RESISTOR NETWORKS

Alison Kirkby[1]* *and Graham Heinson*[1]
[1]University of Adelaide

We present models of random resistor networks to relate electrical resistivity to fracture permeability in the upper crust. In this approach, the upper crust is modelled as a network of resistors that are randomly assigned to be either electrically and hydraulically conductive or resistive based on a network-wide probability of connection. In the models presented here, the conductive resistors are assigned resistance values based on a constant fracture diameter of 1 mm and a fluid resistivity of 0.1 Ωm, with variable fault length distributions and probabilities of connection. We have found that the permeability is very sensitive to both of these parameters, increasing to 8.33×108 times the matrix permeability in the fully connected case. The resistivity is less sensitive, increasing by a factor of 1000.

LAYER-INDUCED SCATTERING ATTENUATION AND VTI ANISOTROPY – NW SHELF AUSTRALIA SYNTHETIC STUDY

Roman Pevzner[1], *Tobias Muller*[2], *Andrej Bona*[2] *and Boris Gurevich*[1,2]*
[1]CSIRO
[2]Curtin University

Seismic attenuation and anisotropy in the overburden can significantly affect seismic image quality, including amplitudes of the target horizons. Therefore, understanding magnitudes, causes and spatial distribution of attenuation and anisotropy is important for seismic imaging and reservoir characterization. Thin layering can cause both scattering attenuation and anisotropy. These phenomena can only be significant, if there is a strong contrast in elastic properties between the layers. We present a case study from North-West Shelf of Australia, where presence of shallow stiff carbonate layers can be responsible for deterioration of seismic data quality through both attenuation and anisotropy.

PRESTACK TIME MIGRATION IN COMMON SOURCE DOMAIN WITHOUT VELOCITY MODEL

Mohammad Javad Khoshnavaz[1]*, *Andrej Bona*[1] *and Milovan Urosevic*[1]
[1]Curtin University

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

1330–1510
Day 2 Session 3 Stream C

MINERALS – ELECTRICAL-ELECTROMAGNETIC METHODS

CORRECTING EM SYSTEM BANDWIDTH LIMITATIONS

James Macnae[1]*
[1]RMIT University

All EM transmitters, sensors and data acquisition systems have bandwidth limitations. Transmitters have upper bandwidth limitations due to finite slew rate issues, and systems have a lower bandwidth set by the base frequency used.

Receivers and data acquisition systems ideally should have a flat bandwidth response that spans the transmitted signal bandwidth. The data acquisition system should sample fast enough to capture the highest frequencies of interest, with anti-alias filters to prevent data contamination from unwanted signals. Sensors however may have physical bandwidth limitations, for example fluxgates and feedback MT sensors may have an upper corner frequency of a few kHz, and ARMIT and feedback MT sensors have lower corner frequencies in the sub 1 Hz range. In many cases, the sensor corner frequency can be mathematically described as a single- or multi-pole response. In this case, it is possible to exactly deconvolve the data to exactly correct for the sensor imperfection. A limitation of this process is that noise as well as signal may be amplified in this correction process.

Without correction, data may be incorrectly modelled or interpreted. This paper illustrates the correction of fluxgate (mostly a time delay of hundred or more microseconds), ARMIT 2 (where a significant but exact correction is required), ANT23 feedback and 3D3 dBdt data.

USING INDUCTION COIL SENSOR OPTIMIZATION TECHNIQUES FOR DESIGNING COMPACT GEOPHYSICAL TRANSMITTERS

Joseph Hamad[1]* *and James Macnae*[1]
[1]RMIT University

We have developed and tested code to optimise electromagnetic (EM) sensors to improve performance of the ARMIT B field induction coil sensor at desired frequencies. We aim to use the optimised parameters to develop a compact air core transmitter, which will form the basis for developing a compact ferromagnetic core transmitter. Techniques for optimising induction coil sensors are well established in literature and use analytical equations for the objective and constraint functions. Alternatives for EM sensor design are also well documented. In contrast, the design of compact transmitter systems needed for portability or in boreholes have limited discussion in the literature and have many more design constraints than sensors. Our ultimate intention is to use established sensor optimisation techniques to build a compact transmitter with sufficient magnetic dipole moment.

PARETO EFFICIENT MULTI-OBJECTIVE JOINT OPTIMISATION OF EM DATA

Sebastian Schnaidt[1]* *and Graham Heinson*[1]
[1]University of Adelaide, Electrical Earth Imaging Group

Jointly inverting different data sets can greatly improve model results, provided that the data sets are sensitive to similar features. Such a joint inversion requires assumed connections between the different geophysical data sets, which can either be of analytical or structural nature. Classically, the joint problem is expressed as a scalar objective function that combines the misfit functions of all involved data sets and a joint term accounting for the assumed connection. This approach has two major disadvantages: Firstly, by aggregating all misfit terms a weighting of the data sets is enforced, and secondly, false models are produced, if the connection between data sets differs from the assumed one. We present a Pareto efficient multi-objective evolutionary algorithm, which treats each data set as a separate objective, avoiding forced weighting. The algorithm jointly inverts one-dimensional datasets from different electromagnetic techniques and also treats any additional information as separate objectives, rather than imposing them as a fixed constraint. Additional information can include, for example a priori models, seismic constraints, or well log data. Statistical analysis of the final solution ensemble yields an average one-dimensional model with associated uncertainties. Furthermore, the shape and evolution of the Pareto fronts is analysed to evaluate dataset compatibility and to judge if the assumed connection between datasets was valid.

DETERMINATION OF MODEL RELIABILITY IN 3-D RESISTIVITY AND I.P. INVERSION

M. H. Loke[1]*
[1]Geotomo Software

Mineral deposits frequently have complex structures that can only be resolved by 3-D inversion of resistivity and I.P. data. A nonlinear optimisation routine is commonly used to create a 3-D model from the measured apparent resistivity and I.P. data. It is particularly important to be able to assess the reliability of the anomalies seen in the inversion model before further tests are conducted. In this paper, we examine the model resolution (MR) and volume of investigation (VOI) approaches in determining model reliability. The MR method produces sections that are easier to interpret but more computationally intensive that puts practical limitations for models with more than 50000 cells. The VOI method can be used for any data set where an inversion can be carried out, but produces sections with more complex patterns and prone to local artefacts. Either method should be used for any interpretation to discern anomalies that are likely to be supported by the data.

1330–1510
Day 2 Session 3 Stream D

MINERALS – NEW WAYS TO ANALYSE DATA

COMBINING MACHINE LEARNING AND GEOPHYSICAL INVERSION FOR APPLIED GEOPHYSICS

Anya Reading[1]*, *Matthew J. Cracknell*[1], *Daniel J. Bombardieri*[2] *and Tim Chalke*[3]
[1]University of Tasmania
[2]Mineral Resources Tasmania
[3]Mira Geosciences

Machine learning and geophysical inversion both represent ways that the applied geophysicist might gain knowledge from field observations and remote sensed data. The two approaches represent contrasting philosophies based respectively on statistics and physics. Both potentially add insights which might help constrain 3D geology by geophysical means. Machine learning uses patterns in data to provide statistically controlled predictions, e.g. of lithology. In contrast, geophysical inversion relies on modelling the physical response of 3D geological block geometry in a deterministic manner. Although both approaches are widely used, it is not currently commonplace in applied geosciences to make use of a combined approach.

We present an example which aims to refine the 3D geology in a prospective region of west Tasmania. Although the region is geologically well-mapped, thick vegetation and significant topography present a challenging set of conditions under which to refine the lithology and block geometry to a level of detail which will support the next generation of exploration. We use multiple layers of remote sensed geophysical data to provide probabilistic information on near-surface lithology extent using the Random Forests classifier.

We show how the statistical, robust, output from the machine learning exercise can be used to guide the construction of improved volume geometry within a 3D GOCAD geological and geophysical modelling environment. This enables better constraints to be supplied to the geophysical inversion with resulting improvements in the detail of the 3D geology.

COMPARISON BETWEEN MANUAL AND AUTOMATED TARGETING FOR NOLANS BORE-STYLE RARE EARTH ELEMENT (REE) DEPOSITS

Sharon Lowe[1]*, *Lisa Vella*[1], *Richard Brescianini*[2] *and Kelvin Hussey*[2]
[1]Southern Geoscience
[2]Arafura Resources Ltd

A manual litho-structural interpretation of airborne magnetic, radiometric and digital elevation model (DEM) data over the Nolans Bore rare earth element (REE) deposit, in northern Australia, has identified additional REE targets in the area. These targets were compared to automated targets generated using a Levenberg-Marquardt neural network (LMNN) analysis of the data.

A number of different quantitative analyses were performed: one with only the geophysical data as an input and one that included the structural interpretation. The geophysical data needed modification for use in the LMNN algorithm, as the known deposit is anomalous in its absence of magnetite and a corresponding magnetic anomaly. Therefore, a shallow depth slice was extracted from a 3D inversion model of the magnetic data and the magnetic susceptibility values were inverted to form anomalies over non-magnetic regions. A Th/U ratio was calculated from the measured single radioelement responses. The structural interpretation was modified to incorporate only those faults oriented in the direction of the controlling structures at the known deposit. DEM data were used as a mask to ensure that targets were found in low-lying areas where the radiometric data is influenced less by topography or masks the underlying bedrock.

It was found that the interpreted targets closely match the predicted targets, but that the predicted targets yielded smaller, more specific locations for follow-up work.

THE FUTURE OF MINERAL EXPLORATION – AND WHAT IT MEANS FOR GEOPHYSICS

Jon Hronsky[1]*
[1]Western Mining Services

The global mineral exploration industry is currently perhaps a decade or two into the most important transition in its several thousand year history – the move from a world where discovery was primarily about surface prospecting (in various form) to a world where important future discoveries will be blind, with little or no surface expression. This transition is, and will continue, profoundly influencing all aspects of our industry, from financing and government policy through to targeting methods and detection technologies. Geophysics will play an increasingly central role in the exploration industry as this transition progresses, as it did in the analogous transition in the history of the petroleum exploration industry about a century ago. However, this future for geophysics will not simply be doing more of the same – the relationship of geophysics to the exploration industry will need to evolve significantly to enable cost-effective exploration performance in this future world. Some of the required key areas of development include; (a) better characterisation of mineral systems at multiple scales from the continental to the deposit, (b) improved integration between geological and multi-parametric geophysical observations at multiple scales, (c) improved capabilities to image critical deep-seated ore-controlling structures and perhaps metal-enriched deep source regions which are cryptic in near-surface data and (d) more specific rather than just more sensitive detection technologies, which reduce the usually high false-positive rate of geophysical targets. An important strategic enabler for these required advances will be ever increasing access to supercomputing capability. However, the potential of

entirely new physical techniques cannot be overlooked either, with Muon tomography having recently been applied to mineral exploration for the first time.

1330–1510
Day 2 Session 3 Stream E

NEAR- SURFACE – SHALLOW SEISMIC 1

ADVANCES IN SEISMIC SURFACE WAVE ANALYSIS AND INTEGRATION WITH BODY WAVES DATA

Laura Valentina Socco[1]*
[1]Politecnico di Torino

In the last decade the analysis of surface wave dispersion has become a standardly applied technique in near surface seismic exploration. The method has evolved from the local estimation of 1D VS profiles, based on the inversion of surface wave fundamental mode, to more sophisticated approaches that can provide reliable velocity models in complex geological settings presenting 2D/3D velocity distributions, with the inversion including higher modes and other guided waves. To retrieve comprehensive velocity models, surface wave and body wave data can be extracted from the same seismic records and inverted jointly, imposing structural and petrophysical constraints and overcoming the inherent limitations of both body and surface wave techniques. More recent developments of surface wave methods are aimed at adapting tomographic techniques used in earthquake seismology to small scale exploration data.

INTEGRATED REFLECTION AND REFRACTION PROCESSING OF AN ULTRA-SHALLOW SEISMIC SURVEY

Alan Meulenbroek[1]*
[1]Velseis & University of Queensland

Velseis Pty Ltd acquired and processed an ultra-shallow seismic reflection survey designed to image targets with a depth of less than 50m, including the structure of the weathering layer. Several experimental sources were implemented, each with unique frequency and amplitude characteristics.

Reflection processing was not routine since the target of interest was the weathering zone itself. Due to this, a combination of reflection and refraction processing was used in order to develop an integrated image and interpretation of the near-surface.

The results from the different processing techniques, including refraction (reciprocal method and tomography), reflection, and a depth converted stack, provide an internally consistent interpretation of the base of weathering and layering within the weathering.

IS IT TIME TO MODERNIZE NEAR-SURFACE REFRACTION SEISMOLOGY WITH FULL WAVEFORM METHODS?

Derecke Palmer[1]*
[1]University of New South Wales

Historically, near surface refraction seismology has focused almost exclusively on inverting first arrival traveltimes to generate spatially varying models of the seismic velocities in the weathered and sub-weathered regions. This study describes two approaches to full waveform near surface refraction seismology, using common offset gathers (COG) and the refraction convolution section (RCS). Full waveform refraction methods can improve the resolution and characterization of the routine mapping of the base of the weathering, through stacking, flattening and spectral analysis.

Full waveform refraction methods can usually reveal first and later events wherever reflection events are recorded within the refraction Fresnel zone. In most cases, full waveform refraction methods can provide more detailed images of the sub-surface structure than can be obtained with low resolution 1D refraction traveltime tomography.

The amplitudes of first and later events are related to the head coefficient, which in turn, is a simple ratio of the specific acoustic impedances. Both the density and the P-wave modulus models of the near surface, which are derived from the head coefficient and the seismic velocities, can be employed for more comprehensive characterization of the regolith for geotechnical and groundwater investigations, as well as for starting models for full waveform inversion.

Full waveform methods represent a new frontier for the modernization of near surface refraction seismology. They offer the opportunity for more effective implementation of exploration refraction seismology through extracting greater value from the data.

1530–1710
Day 2 Session 4 Stream A

PETROLEUM – STRESS & SEALS

INTEGRATING GEOLOGY & GEOPHYSICS TO ASSESS SEAL RISK – AN EXAMPLE OF SEISMIC INTERPRETATION TO ADDRESS SAND JUXTAPOSITION ACROSS FAULTS

Leonardo Molinari[1]*, *Vickie Foster*[1] *and Efthymios Efthymiou*[1]
[1]Chevron Australia

Understanding the geological risks is an essential process while exploring for hydrocarbons and seal risk is considered the

primary reason for unsuccessful wells around the world. This paper focuses on a simple seismic interpretation workflow to address fault-seal sand juxtaposition risk in a structurally complex area. The geological nature of the fluvial reservoirs in the study area, combined with tilted fault blocks provides an effective sealing mechanism to trap hydrocarbons but also enhances leak points. The workflow uses 3D seismic data to analyse juxtaposition of sand bodies across faults, with some geophysical limitations. The presented method has been successfully applied to the study area and has significant implications in exploration pre-drill risks and post-drill evaluations. The results of this study reinforce the necessity to integrate a multidisciplinary evaluation with latest technology to obtain reliable subsurface assessments that effectively translates to better business decisions and improved exploratory success rates.

THE ROLE OF SEAL INTEGRITY IN THE VLAMING SUB-BASIN (PERTH BASIN) FOR PRESERVATION OF HYDROCARBON ACCUMULATIONS

Irina Borissova[1]*, *George Bernardel*[1], *Chris Southby*[1] *and Megan Lech*[1]
[1]Geoscience Australia

The offshore Vlaming Sub-basin, located in the southern part of the Perth Basin, is a Mesozoic depocentre estimated to contain over 12 km of sediments. It has several potential source rock intervals, good reservoir and seal pairs and an active petroleum system. The reasons for a lack of exploration success in this basin have been re-assessed by analysing fault reactivation and signs of hydrocarbon seepage. A recently completed study integrated structural mapping with analysis of fluid inclusion results. New data and interpretations show that a number of synrift faults with signs of reactivation in seismic data also have Fluid Inclusion Stratigraphy (FIS) anomalies above the regional seal. Many previously identified plays rely on the post-rift South Perth Shale for a seal. Our analysis suggests that many faults were reactivated after the deposition of the South Perth Shale, with some showing signs of present-day reactivation. Reactivated faults provided migration pathways for generated hydrocarbons; therefore, no accumulations were formed at these locations. The study provides insight into the location of leaky structures and areas with potentially valid plays in the Vlaming Sub-basin.

OBLIQUE REACTIVATION OF INHERITED FABRICS IN RIFT BASINS: APPLICATIONS TO THE NORTHERN CARNARVON BASIN

Chris Elders[1]*
[1]Curtin University

Rift basins are typically developed on heterogeneous continental crust. Inherited basement fabrics exert a fundamental control rift basin geometry, and on the geometry of individual faults. Many rift basins are also the result of multiple rift episodes and early formed structures will exert further control on the way in which faults evolve in subsequent rift events.

Inherited fabrics and fault reactivation are often invoked to explain rift orientation and segmentation, often with little independent evidence for their existence. However analogue models of orthogonal and oblique rifts show that predictable fault patterns result from the partitioning of stress between pre-existing structures and superimposed extension directions. The Northern Carnarvon Basin provides an ideal laboratory in which to test these models. High resolution 3D seismic data allows detailed imaging of fault patterns developed during separate Lower-Middle Jurassic and Lower Cretaceous rift events. Fault patterns clearly reveal the influence of older structures, most likely related to Carboniferous and Permian rifting, enabling contemporaneous stress patterns to be revealed.

EVOLUTION OF DETACHED LISTRIC FAULT SYSTEMS IN THE CEDUNA DELTA, BIGHT BASIN: INSIGHTS FROM 3D SEISMIC DATA

Jane Cunneen[1], *Matthew Kovacevic*[1]* *and Chris Elders*[1]

Deformation of the Cretaceous Ceduna Delta system is dominated by gravitationally driven listric extensional faults. They were initiated as strongly listric faults during deposition of the Cenomanian White Pointer deltaic sequence, coincident with the final stages of rifting and break up between Australia and Antarctica. The faults were progressively reactivated during deposition of the post break up Santonian to Maastrichtian Hammerhead deltaic sequence, propagating upwards as relatively planar sequences associated with narrow zones of downward converging secondary faults.

Individual faults segments maintain a characteristic curved geometry in map view which link together to form relatively long continuous NW-SE trending faults which rotate to a NNW orientation in the west of the study area (towards the break of slope at the edge of the delta top). Previously unrecognised N-S trending faults that are confined to the lower part of the sequence control some of the segmentation of the NW-SE trending faults.

Understanding the evolution of these fault systems will help to better define the risks associated with Cretaceous plays in this highly prospective frontier petroleum province.

1530–1710
Day 2 Session 4 Stream B

PETROLEUM – SEISMIC IMAGING THEORY

SOLVING THE 3D ACOUSTIC WAVE-EQUATION ON GENERALIZED STRUCTURED MESHES: A FDTD APPROACH

Jeffrey Shragge[1]*
[1]University of Western Australia

The key computational kernels of most advanced 3D exploration seismic imaging and inversion algorithms involve calculating solutions of the 3D acoustic wave equation, most commonly with a finite-difference time-domain (FDTD) methodology. While well suited for regularly sampled rectilinear computational domains, FDTD methods seemingly have limited applicability in scenarios involving irregular 3D domain boundaries and mesh interiors best described by non-Cartesian geometry (e.g., surface topography). Using coordinate mappings and differential geometry, I specify a FDTD approach for generating numerical solutions to the acoustic wave equation that is applicable to generalized 3D coordinate systems and (hexahedral) structured meshes. I validate the method on different computational meshes

and demonstrate the viability of the modelling approach for 3D non-Cartesian imaging and inversion scenarios.

Key words: Finite difference, reverse-time migration, 3D acoustic wave propagation, seismic modelling.

PERFORMANCE OF THE DOUBLE ABSORBING BOUNDARY METHOD WHEN APPLIED TO THE 3D ACOUSTIC WAVE EQUATION

Toby Potter[1]*, *Jeffrey Shragge*[1] *and David Lumley*[1]
[1]University of Western Australia

The double absorbing boundary (DAB) is a new high-order absorbing boundary condition for the scalar acoustic wave equation. It suppresses scattered waves at the edge of a boundary layer in computational domain boundary by using destructive interference analogous to a noise-cancelling headphone. This method has advantages in that it addresses some of the shortfalls in existing boundary conditions, such as the need for tuning in Perfectly Matched Layers or complex formulations at corners such as in high-order absorbing boundary conditions. We extend the original formulation of the DAB to three dimensions and higher-order stencils. Through numerical simulation we test the performance of the DAB by comparison with a reflecting boundary. We find that the DABC is a broadband attenuator with a power attenuation of 20–30 dB using only six boundary cells. Increasing the order of the method improves accuracy for wavelengths less than 10 cells, whereas increasing the layer width does not improve accuracy. The method shows promise as a robust and computationally efficient boundary condition for seismic applications.

CROSS-CORRELATIVE LEAST-SQUARES REVERSE TIME MIGRATION – THEORY AND FIELD APPLICATIONS

Yi Xie[1]*, *Lian Duan*[1], *Yi Xie*[1] *and Graham Roberts*[1]
[1]CGG

We introduce a new practical least-squares reverse-time migration (LSRTM) scheme and derive a steepest descent method for optimal imaging by adapting reverse-time migration (RTM) and demigration (RTDM) as the migration and modelling operators to maximize the cross-correlation between simulated and acquired seismic data. Through real data experiments, we demonstrate that the proposed LSRTM provides high quality images with balanced amplitudes, improved focusing and enhanced resolution. The method is also capable of removing the free surface ghosts generated in towed streamer acquisition and filling holes in the imaged structures due to imperfect acquisition.

Together with impedance perturbation technique, the proposed method is a useful tool for both seismic imaging and inversion.

SEISMIC PRISM WAVES GENERATED BY SEAFLOOR CANYONS AND THEIR EFFECTS ON SUBSURFACE IMAGING

James Deeks[1]* *and David Lumley*[1]
[1]University of Western Australia

Complex seafloor bathymetry can create significant challenges for subsurface imaging and geologic interpretation of seismic exploration and monitoring data. Steep seafloor canyons that cut through continental shelf areas can produce very strong seismic wavefield distortions. Neglecting such wavefield complexity can result in inaccurate velocity models, significant imaging errors, misleading amplitudes and uncertain geologic interpretations. In this paper we investigate the kinematic and dynamic effects of seismic "prism waves" generated by seafloor canyons. Prism waves are waves that undergo multiple primary reflections at scattering interfaces before propagating to the recording sensor array. We demonstrate that strong prism waves can be generated for realistic seafloor canyon geometries, and show how their adverse effects can contaminate the seismic imaging process.

1530–1710
Day 2 Session 4 Stream C

MINERALS – ATOMIC DIELECTRIC RESONANCE

LARGE DEPTH EXPLORATION USING PULSED RADAR

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[1]ADROK
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We present an overview of the Adrok radar scanning technology and describe experimental results that suggest that ground penetrating radar can be utilized to much greater depths in selected environments than commonly assumed. High frequencies were found to penetrate very little, but the low frequency component had very low losses. Results were analysed to estimate the skin depth and interpreted in terms of a constitutive model incorporating Maxwell's equations with conductivity and polarization losses. To explain these results we hypothesize that moisture penetrates limestone only relatively superficially and once the outer wet layer is penetrated the conductivity and therefore the losses are greatly reduced. In a second experiment we successfully detected the reflection of the radar pulse from a body of water through 350 m of rock. A numerical simulation of the model confirmed that these results do not contradict theoretical expectations for dry limestone.

GOLD AND SULFIDE TARGETING USING ATOMIC DIELECTRIC RESONANCE (ADR)

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[2]ADROK
[3]Rapid Geophysics

The lack of modern mining in Charters Towers is linked to the difficulties associated with accurately pinpointing high-grade gold-bearing lodes on host fractures. A geophysical survey of the Charters Towers area has been carried out by ADROK using a non-destructive, non-invasive surface-based technique termed Atomic Dielectric Resonance (ADR). A vertical log is generated for selected sites and the resonance energy (E-ADR) used to pinpoint sulphide-bearing lodes within granitic host rocks below the site. Preliminary results show that the technique can successfully pinpoint sulfide and associated gold mineralisation to a depth of up to 1000 m. A total of nine scans or "Virtual Boreholes" over three main ore-bearing fractures in Charters Towers have correctly identified the depth and presence of known sulfide ore zones with a maximum depth error of 13 m. In some scans, the presence of anomalies at unexpected depths is interpreted to represent potential sulfide targets. The ADR technique is particularly useful in Charters Towers, for example,

where other techniques such as TEM, magnetics, gravity or seismic reflection surveying cannot be used due to access or other anthropogenic factors. Results so far indicate that the technique represents a significant advance in the pre-drilling identification of target sulfides.

1530–1710
Day 2 Session 4 Stream D

MINERALS – CRC DET DOWNHOLE TECHNOLOGIES

COILED TUBING DRILLING AND REAL-TIME SENSING – ENABLING 'PROSPECTING DRILLING' IN THE 21ST CENTURY?

Richard Hillis[1]*
[1]Deep Exploration Technologies CRC

New Tier 1 discoveries are critical to maintaining Australia's mineral resource inventory without continuing decline in the grade of mined resources. Such discoveries are becoming less common because, increasingly, remaining prospective, under-explored areas are obscured by deep, barren cover. Improving the rate of Tier 1 discoveries requires a step change in mineral exploration techniques that may be provided by 'prospecting drilling', i.e. extensive drilling programs that map mineral systems beneath cover, enabling geophysical and geochemical vectoring towards deposits during a single drilling campaign. The rationale for 'prospecting drilling' is provided (i) a dataset of antimony from the Kalgoorlie district of Western Australia, and; (ii) analysis of hypogene alteration systems of IOCG deposits in South Australia. The technological platform for 'prospecting drilling' must include low cost drilling due to the dense subsurface sampling required. This may be provided by transferring coiled tubing (CT) drilling technology, with its continuous drill pipe on a reel, from the oil and gas sector. CT drilling can be complemented by real-time downhole and top-of-hole sensing providing petrophysics, structure/rock fabric, geochemistry and mineralogy. The first manifestation of real-time, downhole sensing is DET CRC's newly developed autonomous sonde that is deployed by the driller and logs natural gamma radiation as the dill rods are pulled. Experimentation on real-time, top-of-hole sensing (on drill cuttings from diamond cored holes) has successfully demonstrated geochemistry and mineralogy determination with the necessary depth-fidelity. At the target cost of $50/metre, CT drilling could cost-effectively undertake 'prospecting drilling' in large, covered provinces such as the IOCG-prospective Gawler Carton of South Australia.

LOGGING DURING DIAMOND DRILLING – AUTONOMOUS LOGGING INTEGRATED INTO THE BOTTOM HOLE ASSEMBLY

Andrew Greenwood[1]*, *Anton Kepic*[1], *Anna Podolska*[1], *Christian Dupuis*[2] *and Gordon GlobalTech*[3]
[1]Curtin University
[2]Université Laval
[3]Global Tech Corporation

Logging total count gamma data while diamond drilling an HQ borehole has been achieved using an autonomous shuttle. The shuttle is integrated into the Bottom Hole Assembly (BHA) prior to drilling. Logging is initiated at the beginning of each core run and the shuttle unit continuously logs at 1 second intervals. Continuous logging combined with the relatively slow rate of penetration of diamond drilling results in high fidelity logs at 1–5 cm intervals. The data is collected by the drilling crew, who download and email the data at the end of each core run for near real time analysis. Little to no interruption to the normal drilling process is experienced once the Shuttle has been integrated into the BHA. Autonomous logging while diamond drilling enables the collection of in-situ rock property measurements, without the risks and costs associated with later wireline logging. This value is added to the drilling process at little expense.

EVALUATION OF THE LOOKING AHEAD CAPABILITY OF CONVENTIONAL BOREHOLE RADAR

Binzhong Zhou[1]* *and Matthew van de Werken*[1]
[1]CSIRO Energy Flagship

There is a strong need to develop real-time imaging technologies to enable the driller to 'see' the subsurface structures ahead of the drill-bit and around the borehole during borehole drilling. One of the ways to realise such imaging while drilling is to use borehole radar (BHR) techniques. In this paper, a conventional non-directional mono-static BHR will be evaluated for its forward-looking capability by using the data collected at an abandoned mine site at Brukunga, South Australia. Here we demonstrate that the conventional BHR can be electrically coupled on to a conductive wire or drill-rod whilst a guided wave is induced along the axial wire or drill string making it possible for imaging ahead of the drill-bit by integrating the BHR with the steel drill string. The drill-rod ahead of the BHR acts as a forward-looking antenna. When the guided wave travels to the end of the drill-bit, part of the energy is reflected by the drill-bit and the remaining energy radiates in front of the drill-bit, and is reflected by the geological/electrical discontinuities, recorded by the BHR. The forward-looking capability of the BHR is about 2-6m in the tested borehole section.

1530–1710
Day 2 Session 4 Stream E

NEAR-SURFACE – SHALLOW SEISMIC 2

THE APPLICATION OF GEOPHYSICS TO THE SPORT OF CRICKET

Timothy Dean[1], *Ben McCarthy*[1]*, *Pieter Claassen*[1] *and Raquibul Hassan*[2]
[1]Curtin University
[2]The University of Sydney

Over the years interest in sports science has boomed with current research in using technology to monitor athlete performance and the motion of balls or other equipment during a game. The contributions of Geophysics to sport are, as far as we have found, only indirect until now. We used the seismic method, specifically a 48-channel seismic acquisition system, coupled with basic processing, to locate the position at which a cricket ball impacted the pitch with an accuracy of ±10 cm. Previously this could only be done using expensive television-based systems.

AN ONSHORE AND OFFSHORE SEISMIC INVESTIGATION ACROSS A CREEK

Koya Suto[1]*, *David King*[2] *and Nadia Vellar*[3]
[1]Terra Australis Geophysica Pty Ltd
[2]Marine & Earth Sciences Pty Ltd
[3]Jacobs Group (Australia)

A seismic survey across a river with refraction and multichannel analysis of surface waves (MASW) methods was carried out to investigate the ground condition for design of a bridge across Iron Creek near Hobart, Tasmania.

The survey had onshore and offshore components. Therefore it was necessary to use a hydrophone cable as well as land geophones. A sledge hammer was used as an onshore seismic source and a small airgun across the creek.

The result is presented as P-wave velocity section from the refraction analysis and S-wave velocity section from MASW. Two boreholes onshore indicated the depth of basalt with very high strength at 8 metres on west bank and 3 metres on east bank. These depths correspond to P-wave velocity about 1400 m/s and S-wave velocity about 600 m/s. The sections showed the depth of this strong basalt increases in the creek up to about 10 metres, and it is the deepest in the eastern side of the creek. With this information, necessity of expensive offshore drilling was eliminated.

CAN NEAR-SURFACE VELOCITY STRUCTURE BE IMPROVED VIA DISPERSION ANALYSIS OF CONVENTIONAL REFLECTION DATA?

Shaun Strong[1]* *and Uni Steve Hearn*[1,2]
[1]Velseis Pty Ltd
[2]University of Queensland

A recent ultra-shallow 3C survey provides an attractive dataset for evaluation of surface-wave dispersion analysis, for improving knowledge of the near-surface. The primary motivation is for S-wave reflection processing, but with potential for P-wave static control. Finite-difference modelling and real data analysis suggests maximum-offset should be set at several times the investigation depth. This study suggests the geophone interval should be less than 10m, and single phones are preferred. An inverted near-surface S-wave section provides structural information complementary to that available from P-wave refraction.

Day 3: Wednesday 18 February 2015

0830–1010
Day 3 Session 1 Stream A

PETROLEUM - ROCK PHYSICS 2

SEISMIC SCREENING FOR HYDROCARBON PROSPECTS USING ROCK-PHYSICS ATTRIBUTES

Per Avseth[1]*
[1]Norwegian University of Science & Technology

Rock-physics templates (RPT), in combination with seismic AVO inversion data, can be used to screen for hydrocarbon prospects during exploration. With the improved quality and increased use of elastic seismic inversion, there has recently been a paradigm change in prospect mapping in the oil industry, and quantitative interpretation has become a widely used jargon. Rock-physics models are essential in that they help in converting elastic parameters from inversion data to reservoir parameters. Rock physics models plays an important role in many of the stages of seismic AVO inversions; including the petrophysical log evaluations, well ties and wavelet estimation, the setting of parameter constraints during the inversion, and the interpretation of the inversion results in terms of reservoir properties. Rock-physics models can also be used to quality check and modify the low-frequency model used in seismic AVO inversion, and to assess the quality and uncertainties of inverted elastic parameters. In this presentation we will demonstrate the use of rock-physics models during the different stages of seismic inversion, and how these can improve our ability to reveal hydrocarbon-associated anomalies.

RELATIONSHIP BETWEEN SHEAR WAVE AZIMUTHAL ANISOTROPY, SAND-SHALE CONTENT AND DEPTH IN THE EXMOUTH SUB-BASIN, WESTERN AUSTRALIA

Lisa J. Gavin[1]* *and David Lumley*[2]
[1]Chevron, ETC
[2]The University of Western Australia

Anisotropy characterisation from surface seismic, VSP and borehole measurements is notoriously difficult. This is mostly due to limitations in parameterising the stiffness tensor constants required give an accurate representation of the anisotropic material. The Exmouth Sub-Basin has very strong anomalous horizontal stress conditions; in some areas the maximum horizontal stress (σhmax) can exceed the vertical stress (σv). There are many data examples across the Sub-Basin showing the influence of strong azimuthal anisotropy (AA). Qualitative observations of log data demonstrate that there is greater amounts s-wave anisotropy (γ) in the sand dominated sediments than in the shale dominated and the AA is greater in shallower clastic sediments than deeper. In this paper we compare data observations of AA fast and σhmax azimuths in the Exmouth Sub-Basin, which show consistent trends when plotted geographically. We then outline a methodology to determine a relationship between γ and Vshale (shale volume ratio versus sand and shale volume) from logs with existing γ and Vshale data and then extend the method to incorporate the total vertical depth (subsea) of the log (TVDss). We test this methodology on a well taking a "blind test" approach, predicting Vsslow, γ and Vshale. We also test the methodology on original logs and ones upscaled using Backus averaging to a typical seismic resolution. Our results show that we can accurately predict AA and Vshale, especially when the logs depth is incorporated, removing depth trends.

ROCK PHYSICS AND QUANTITATIVE INTERPRETATION USING LAMBDA-MU-RHO IN THE SHIPWRECK TROUGH, OTWAY BASIN

David Close[1]*, *Randall Taylor*[1] *and Sebastian Nixon*[1]
[1]Origin Energy

A rock physics study and AVO modelling study has been completed to assist in the interpretation of seismic amplitude and AVO anomalies in the Shipwreck Trough of the offshore Otway Basin of southeastern Australia. Elastic log data, core data (both full and sidewall) and associated thin section analysis of composition and texture were available on a number of wells; and these data are important in calibrating proposed rock physics models that suggest incorporating cement is critical to understanding anomalies in seismic inversion volumes and measured log data.

Lithoprobability volumes based on conventional interpretation paradigms, such as low Vp:Vs values indicating gas presence, that do not incorporate an understanding of the rock physics lead to biased interpretations. Ratios in particular can be misleading as there is ambiguity about whether an anomalous ratio is driven by the numerator or denominator. As a classic gas indicator low Vp:Vs values are interpreted to be driven by a decrease in Vp associated with gas replacing brine in a rock. Using Lamé Impedance terms λρ and μρ, however, provides an alternative interpretation template that does not utilise ratios and can improve insight into rock properties. As in this case study, using LMR can be an important tool when shear velocity has increased relative to the compressional velocity irrespective of any pore-fluid change.

We propose that due to quartz cement in the reservoir rocks of the Shipwreck Trough both gas and brine sandstones exhibit very low Vp:Vs, creating substantial challenges to the use of a standard rock physics template. In LMR space, however, the low Vp:Vs data points are clearly characterized by a high shear rigidity – an important point to recognize and incorporate into AVO interpretation workflows.

0830–1010
Day 3 Session 1 Stream B

PETROLEUM – BROADBAND SEISMIC PROCESSING

UNLOCKING THE FULL POTENTIAL OF BROADBAND DATA WITH ADVANCED PROCESSING AND IMAGING TECHNOLOGY, A CASE STUDY FROM NWS AUSTRALIA

Jingyu Li[1]*, *Joe Zhou*[1], *Peter Chia*[2], *Henry Ng*[1], *Sergey Birdus*[1], *Keat Huat Teng*[1], *Ying Peng Phan*[1], *Jason Sun and Yi He*[1]
[1]CGG
[2]Shell

The high costs associated with hydrocarbon exploration in deepwater have led to an increased business demand for acquisition and processing of high-resolution broadband seismic data. In this paper, we review our experience of working on the Shell Sandman 3D survey, which was acquired using variable-depth streamers and synchronized multi-level sources. We focus on the key factors that influence the surface seismic temporal resolution and the technologies that provide solutions to these challenges: (1) source deghosting using source designature with near-field hydrophone data; (2) receiver deghosting using the 3D deghosting algorithm; and (3) compensation for the Earth absorption using centroid frequency shift Q tomography (FS-QTOMO) and QPSDM. The extra-wide bandwidth obtained from these processes provides a final image with detailed resolution that enhances quantitative characterization, not only for shallow geo-hazards but also for resolving relatively thin reservoirs in the deep section. Therefore, we can conclude that broadband seismic methodologies coupled with advanced seismic processing techniques, provide an effective solution for generating high-resolution seismic images, especially in challenging areas.

PRE-STACK DEGHOSTING: BRINGING OUT THE SEISMIC BANDWIDTH IN LEGACY MARINE DATA

Jun Zhou[1]*, *Peter Chia*[2], *Hassan Masoomazdeh*[1], *Xuening Ma*[1] *and Teck Goh*[1]
[1]TGS
[2]Shell

Broadband seismic processing has been proven in marine seismic data obtained with new acquisition techniques. However, we are challenged with what can be achieved towards improving the bandwidth of many legacy seismic data in our library, of which the acquisition configuration and parameters were lacking of information for proper broadband processing requirements, such as accurate receiver depths.

This paper demonstrates some of the broadband processing techniques we applied on legacy 3D and 2D data to bring out the bandwidth and improve the quality of the signal of legacy seismic data.

IMAGING THROUGH SHALLOW GAS: INTEGRATING BROADBAND ACQUISITION, PROCESSING AND HIGH-END MODEL BUILDING FOR IMPROVED IMAGING OF DEEPER TARGETS

Gavin Menzel-Jones[1]*, *Jan Rindschwentner*[2], *Chui Huah Lim*[2], *Bee Jik Lim*[1] *and Saeeda Hydal*[1]
[1]Schlumberger
[2]Petrofac

We present a case study offshore Malaysia, shallow gas features in the overburden distort the seismic imaging at the target level. While a multifaceted approach involving a combination of seismic acquisition and processing strategies were used to improve the bandwidth of the seismic data, particularly for the low-frequency content of the seismic image, several distortions still existed at the target level. The prominent structural sag evident at the reservoir level is a typical indication that the overlying shallow gas velocity model needed to be resolved and incorporated into a depth migration algorithm.

To resolve the transversally and laterally variant velocity features in the shallow gas areas, a solution that consisted of full waveform inversion (FWI) and high-resolution reflection traveltime tomography was utilized to produce an accurate compressional velocity model. To further resolve the amplitude and phase distortions at the reservoir level due to shallow gas effects, Q tomography was incorporated into the model building phase to derive a space-variant 1/Qmodel and Q compensation was integrated within depth migration.

The integrated approach of broadband receiver acquisition, data processing strategies and high-end Earth model building has cumulatively improved the imaging of the reservoir below the shallow gas anomalies.

INNOVATIVE PROCESSING APPROACHES TO OVERCOME SAMPLING SPARSENESS AND IRREGULARITY IN 3D OBC SEISMIC DATA OFFSHORE ABU DHABI

Shotaro Nakayama[1]*, *Mark Benson*[1], *Tarek Matarid*[1], *Kamal Belaid*[1], *Mikael Garden*[2] *and Dmitry Zarubov*[2]
[1]ADMA-OPCO
[2]Schlumberger Geosolutions Abu Dhabi

Due mainly to commercial and operational constraints, seismic data are often sparsely and irregularly sampled, leading to several challenges in processing of 3D OBC seismic data offshore Abu Dhabi.

Conventional linear noise attenuation techniques are not effective with Scholte waves as they are usually aliased with typical sampling interval in 3D OBC seismic data, and sometimes scattered because of near-surface heterogeneity. To address this, we apply model-based surface wave attenuation, Surface Wave Analysis Modeling and Inversion (SWAMI), which enables an estimate of local near-surface properties by analysing dispersion curves. Thus, both direct and scattered Scholte waves are effectively modelled and attenuated without suffering a lack of spatial sampling. We also highlight the shortcomings of the application of interferometry to scattered noise attenuation for sparse acquisition geometry.

Matching Pursuit Fourier Interpolation (MPFI) is then implemented to deal with insufficient sampling in crossline direction caused by acquisition geometry. MPFI employs anti-aliasing capability so optimum data reconstruction can be performed for any frequency ranges. In addition to regularization aspect, MPFI with 5D implementation (4 spatial coordinates and time) is targeted to densify receiver line interval and extend source lines, which consequently enhances fold, offset and azimuth distributions of the data.

0830–1010
Day 3 Session 1 Stream C

MINERALS – AIRBORNE ELECTROMAGNETICS 1

QUASI3D INVERSION OF AIRBORNE EM DATA

Robert Ellis[1]* *and Ian MacLeod*[1]
[1]Geosoft Inc.

Full 3D inversion of AEM data is not generally available to minerals explorers because of limitations in current algorithms

and computer resources. Consequently we must resort to approximations to full 3D AEM inversion to support today's exploration projects. One form of approximation is to reduce the dimensionality of the inverse problem from 3D to 1D and while layered earth inversion has proven fast and effective in practice, it has limitations in 3D environments. To address these limitations we propose a physically motivated approximate 3D AEM inversion: Quasi3D inversion. Full 3D EM inversion requires calculation of the 3D induced current in the earth whereas the Quasi3D approximation is based on a full 3D inversion but with a simplified, approximate, induced current flow in the earth. We demonstrate the Quasi3D approximation by comparing its response over the interface of a quarter-space model with the full AEM response, and then demonstrate Quasi3D inversion on a challenging synthetic model and on field data. From our work we conclude that the Quasi3D approximation is an effective and efficient approximation which should aid in the interpretation of AEM data for today's exploration projects.

PARAMETRIC 3D INVERSION OF AIRBORNE TIME DOMAIN ELECTROMAGNETICS

Michael McMillan[1]*, *Douglas Oldenburg*[1], *Eldad Haber*[1] *and Christoph Schwarzbach*[1]
[1]University of British Columbia

Conventional voxel-based inversion algorithms can encounter difficulties when inverting airborne time-domain electromagnetic data in three dimensions. In certain environments with these codes, it can be challenging to delineate sharp boundaries between geologic units with large conductivity contrasts and to accurately image thin conductive targets. Furthermore, spurious circular inversion artifacts, known as ringing, can occur around conductive targets.

To address these issues we have developed a parametric inversion code that can be used to find the optimal location, shape and conductivity value of a single anomaly in a homogeneous or heterogeneous background. The algorithm incorporates a Gauss-Newton optimization scheme in conjunction with a level set formulation to outline the anomaly of interest, and can be combined with a conventional voxel-based algorithm in more complicated geologic settings.

The code is shown to be successful with a synthetic data set over a thin dipping plate, and two field data sets. For the synthetic scenario, the parametric inversion recovers the true dip and size of a conductive target with no a priori information. The algorithm also accurately defines the extent of a diamondiferous kimberlite pipe and a dipping massive sulphide deposit beneath a conductive overburden.

RAPID 3D INVERSION OF AIRBORNE TEM DATA FROM FORRESTANIA, WESTERN AUSTRALIA

Peter Fullagar[1]*, *James Reid*[2] *and Glenn Pears*[2]
[1]Fullagar Geophysics Pty Ltd
[2]Mira Geoscience

VPem3D performs 3D inversion on time-integrated (resistive limit) data. Conversion to resistive limits delivers a massive increase in speed since the TEM inverse problem reduces to a quasi-magnetic problem. The time evolution of the decay is lost during the conversion, but the information can be largely recovered by constructing a starting model from CDIs or 1D inversions.

We have carried out preliminary inversion of VTEM dBz/dt data from the Forrestania EM test range. The inversion places a weak conductor at a depth and location consistent with the known target. Run time is a few minutes, a fraction of that required by a full 3D EM inversion.

AUTOMATED AIRBORNE EM ANOMALY PICKING AND 3D MODEL FITTING

James Macnae[1]*
[1]RMIT University

A number of algorithms for the transformation of airborne EM data to 3D conductivity distributions have been developed in the past few years. This paper describes a MATLAB implementation of the Annan spectral method to permit the automatic detection and fitting of vortex and current gathering responses from discrete targets.

The method used consists of (1) AEM System definition, (2) pre-calculation of a large number of system specific AEM responses for target geometries of interest, (3) Conversion of data to stitched 1D CDI through EMFlow with conversion to equivalent step response data, (4) response – background separation, (5) successive brute force fitting of every "possible" anomaly to every successive line segment of data, (6) selection and refinement of acceptable models based on error criteria.

This paper presents results of the application of the method to fixed-wing Geotem data from Queensland and Sweden.

0830–1010
Day 3 Session 1 Stream D

MINERALS – GEOLOGY FROM GEOPHYSICS 1

STRUCTURE AND STRATIGRAPHY FROM AEROMAGNETICS IN SEDIMENTARY BASINS

David Isles[1]*
[1]Southern Geoscience Consultants

Sedimentary rocks commonly contain sufficient magnetic mineral to yield coherent signal in modern aeromagnetic surveys. Careful acquisition procedures and astute application of conventional processing methodology allow the signal from the

sedimentary section to be recognised and isolated from that of 'basement', facilitating focused interpretations of each these geological domains.

Spectral separation filtering underpins this process, providing imagery of magnetic sources that lie at differing depths. The integration and interpretation of the resulting 'spectral depth windows' follows the steps used to integrate aeromagnetics with geology in 'hard-rock' domains. A substantial phase of basic observations on the aeromagnetic imagery is the fundamental first step, and commitment to the integration of the best available geology to yield lithostratigraphic and structural framework interpretations completes the initial task. Forward and inverse modelling constrains the qualitative geological interpretation, and enables hypotheses formed during that interpretation to be tested.

The two examples presented show the virtues of separation filtering and the style of geological interpretation that can be derived using the aeromagnetic data as the driver. The Amadeus Basin example presents a 'feast' of shallow magnetic rock units, many of which are probably magnetic stratigraphic marker horizons. These yield a thought-provoking interpretation of structure and stratigraphy in the upper sedimentary section. The discordance between the geometries of the shallow and deep magnetic rock units raises the likelihood of a major detachment structure between the two geological domains.

The aeromagnetic data from the second example, in the Galmoy Pb-Zb district in Ireland, presents major challenges. Separation filtering yields a set of very low amplitude but strongly coherent spectral depth windows which, when interpreted, provide a range of structural and stratigraphic features that relate directly to the mineralised environment. The successful application of aeromagnetics in this erstwhile 'non-magnetic' geological domain is testimony to the value of the technique in most, if not all sedimentary basins.

STRUCTURAL GEOPHYSICS – GEOLOGICAL PRINCIPLES APPLIED TO GEOPHYSICAL DATA

Peter Betts[1]*
[1]Monash University

The fundamental precept of structural analysis is that descriptions of geometry lead to interpretations of kinematics and the dynamics of geological systems. Controls of the formation of structures at all scales depend on the starting material heterogeneity, and the anisotropy and time dependence mechanical response of the materials. Processes that control mechanical response at the small scale (~1 cm) may be quite different to those at the regional scale (>1 km), the flow fields and structures that develop can be similar and therefore can be interpreted in similar ways. This approach is second nature in structural geology but is also easily applicable to analysis of regional geophysical datasets such as aeromagnetic and gravity data. Structural geophysics is a discipline defined by Jessell and Valenta (1996), where structural methodology and interpretation could be applied to regional geophysical datasets to unravel 3D architecture and overprinting relationships. Geophysical datasets are increasingly used in conjunction with structural analysis, and as a stand-alone tool, to resolve regional crustal architecture and geological evolutions, particularly in remote regions and areas of limited outcrop, or where there is some ambiguity in how structure can be determined in the third dimension. Importantly, aeromagnetic data is also effective interpret regional kinematics of major shear zones and high strain zones at different scales. Applying structural kinematic analysis to regional geophysical datasets informs a broad range of disciplines including, but not limited to structural analysis, plate reconstruction, tectonic analysis, and prediction of mineral systems in exploration. In the context of resource exploration 3D and kinematic analysis allows you to predict Earth structuring that controls mineralisation, but more importantly allows prediction of favourable sites of dilation and fluid flow. In this presentation will highlight many of the principles of 3D geometry and kinematic analysis and illustrate how they improve our understanding of geological architecture and dynamic processes of the Earth.

0830–1010
Day 3 Session 1 Stream E

MINERALS – HARD ROCK SEISMIC 1

SEISMIC EXPLORATION OF THE WORLD'S DEEPEST GOLD AND PLATINUM OREBODIES IN SOUTH AFRICA – OVERVIEW OF THE PAST, PRESENT AND A LOOK INTO THE FUTURE

Musa Manzi[1]*
[1]University of the Witwatersrand

Without doubt, the geologically complex Witwatersrand Basin in South Africa is by far the most important known gold-producing province. It has produced about one-third of the gold ever mined, worldwide. Gold mining in the goldfields takes place at depths ranging from 500 to 4200 m below surface. Many call

the underground workings the 'devil's workplace'. This means that there are an increasing number of technical challenges in exploration and optimizing new resources, with rising costs and reduced effective mine designs. There are about 20 or more gold ore bodies (quartz pebble conglomerates) that have been mined, or are currently in production. Furthermore, the Bushveld Complex of South Africa is estimated to contain about 70% of the world's reserves of platinum group elements. The most important platinum ore bodies are the Merensky Reef and the UG2.

This paper presents the past and current research activities on the use and implementations of seismic methods for gold and platinum exploration and deep mine planning and designs. It, particularly, presents a state-of-the-art in seismic design and acquisition, processing, interpretation of the seismic data as well as modelling of strato-structural complexies of the basin using advance techniques. The current challenges and possible future solutions are further discussed with special emphasis on the reflection seismic imaging limitations. For example, reflection seismic data acquired on the surface in the Witwatersrand Basin and Bushveld Complex have wavelengths of approximately 60–100 m, providing vertical seismic resolution of approx. 20 m. Consequently, it is difficult to resolve the top and bottom of thin reefs (~1 m in thickness) due to seismic wave interference as well as to detect faults with throws less than 20 m. However, gold reefs as thin as 20 cm to 1 m are currently the main targets for deep mining and faults that crosscut these reefs with throws as small two meters may present difficulties to deep future mining operations. Recent research work has further demonstrated that some of these minor faults may act as conduits for ingress of water and flammable gas into underground workings.

There has been more of hard-rock reflection seismics undertaken in South Africa than anywhere else in the world. Therefore, this paper attempts to answer the following trickier question: Will seismic application in the mining industry in South Africa accelerate or decline in the coming years?

USING SEISMIC REFLECTION PROFILES TO MODEL 3D GEOLOGY OF VMS DISTRICTS IN THE RAAHE-LADOGA BELT, FINLAND

Suvi Heinonen[1], Pekka J. Heikkinen[2], Ilmo T. Kukkonen[2] and David B. Snyder[3]*
[1]Geological Survey of Finland
[2]University of Helsinki
[3]Geological Survey of Canada

Volcanogenic massive sulphide (VMS) deposits of Pyhäsalmi, Vihanti and Outokumpu in Finland belong to the same mineralized belt but are different in terms of age and detailed deformation history. Results of sonic and density logging show that in these mining camps rock formations hosting the known ore deposits are reflective which encourages the use of seismic reflection method for mapping the subsurface geological structures. A network of seismic reflection profiles was acquired in each study site and these data are utilized in the geological 3D-modeling and deep mineral exploration.

SEISMIC EXPLORATION FOR VOLCANOGENIC MASSIVE SULPHIDES: THE DEGRUSSA COPPER-GOLD MINE, WESTERN AUSTRALIA

Jai Kinkela[1], Sasha Ziramov[2], Aleksandar Dzunic[1] and Paul Hilliard[3]*
[1]HiSeis Pty Ltd
[2]Curtin University
[3]Sandfire Resources NL

Traditional geophysical prospecting techniques used for mineral exploration rarely provide either the depth of penetration or resolution required to accurately target orebodies at depth. Based on this, the seismic reflection method was trialled over a known VMS orebody at the DeGrussa copper-gold mine, Western Australia, in the hope of providing a viable exploration tool for deeper depths of investigation. However, a structurally complex geologic setting and a thick, highly variable regolith caused significant challenges in the processing of the seismic data.

An initial 3D survey was not successful in imaging the orebody, so a follow-up downhole and 2D survey was acquired to address the potential issues. After verifying the in-situ seismic properties of the orebody through zero-offset Vertical Seismic Profiling (VSP) and increasing the down-dip offset range in the follow-up 2D survey it was found that the target provided a clear and unambiguous seismic response. However, a deep and variable regolith continued to cause significant issues during the imaging phase. This was overcome by applying a tomography-derived velocity field to a Kirchhoff migration, which produced outstanding results.

Numerous tests and extensive data analyses eventually verified the seismic technique as a viable exploration tool for the region, with the direct detection of the target orebody.

1030–1210
Day 3 Session 2 Stream A

PETROLEUM – SEISMIC IMAGING PRACTICE

INCORPORATING NEAR-SURFACE VELOCITY ANOMALIES IN PRE-STACK DEPTH MIGRATION MODELS

*Ian Jones[1]**
[1]ION GX Technology

Unresolved velocity anomalies in the near-surface degrade deeper imaging. As a consequence, great care needs to be taken to ensure that all significant near-surface effects have been dealt

with before attempting to build the deeper parts of a velocity depth model. All ray paths that pass through a near-surface velocity anomaly will be affected by it, distorting the subsurface response about half a cable length to either side of the anomaly. The distorted region actually extends beyond a half cable length due to the influence of the Fresnel zone: in other words, we are really dealing with wavefronts rather than hypothetical rays.

In the context of this review, by "near surface" I refer to features whose fold of coverage in CRP gathers is either too low or near the practical limit for autopickers to be able to determine residual moveout, and/or whose lateral extent is too small for ray-based methods to perform reliably (i.e. features with lateral velocity changes occurring over distances less than several times the dominant wavelength of the seismic wavefronts reflected from them).

Here, I'll describe current industrial practice for building complex near-surface models, which is based on a range of approximate techniques (depending on whether just the geobody geometry alone is discernible, or whether its velocity distribution as well is known), as well as the more complete solution offered by the emerging technology of waveform inversion. It will be shown that, although usually painstaking, a suitable near-surface velocity model can often be obtained.

ANISOTROPIC DEPTH IMAGING IN PRESENCE OF STRESS: TRANSVERSELY ISOTROPIC OR ORTHORHOMBIC?

Olga Zdraveva[1]*, *Robert Bloor*[1] *and Dave Nichols*[1]
[1]Schlumberger

Presence of oriented stresses and fractures in the subsurface can pose significant challenge when imaging wide-azimuth and multi-azimuth data using transverse isotropy as an approximation to describe the medium. We describe the key components of an orthorhombic model-building and updating workflow for depth imaging in areas affected by stress. We discuss several different options for deriving the initial parameters describing orthorhombic medium and their dependencies on the geometry of the available seismic data.

We demonstrate the effectiveness of the workflow on real data from the Gulf of Mexico. Compared to transversely isotropic imaging, the orthorhombic imaging flattens the common-image-point gathers in all azimuths and results in improvements of image focussing.

A STABLE TOMOGRAPHIC SOLUTION FOR ANISOTROPIC EPSILON – A TOOL TO AID IN EXPLORING FOR OIL IN THE NORTHERN CARNARVON BASIN

Ed Lewis[1]* *and Shane Westlake*[2]
[1]ION-GXT
[2]Finder Exploration

AVO studies have typically been used in the search for gas on the North-West Shelf for decades, but its use for identifying oil filled reservoirs has been limited by the effective meaningful angle range obtainable from the seismic data.

We have performed tomographic updates of the anisotropic parameter epsilon to obtain flatter and cleaner gathers out to a much higher angle range than traditional anisotropic assumptions. This then gives the ability to use the data for AVO much more effectively.

1030–1210
Day 3 Session 2 Stream B

PETROLEUM – RESERVOIR CHARACTERIZATION 1

USING AVO TO MAP COOPER BASIN PERMIAN SANDS IN THE PRESENCE OF COAL

Stephanie Tyiasning[1]* *and Dennis Cooke*[1]
[1]The University of Adelaide

Cooper basin Toolachee and Patchawarra sands are difficult to map due to strong seismic reflections from Permian coals. Seismic amplitudes are mainly driven by coal thickness instead of lithology (sand vs shale). We proposed a method for obtaining better sand prediction. This method uses AVO intercept (I) and gradient (G) and the Extended Elastic Impedance (EEI) to highlight the subtle differences between coal-shale and coal-sand interfaces. We test this method by creating several wedge models to understand the effect of coal thickness and lithology on seismic amplitudes. Results are compared with a more traditional method that recognizes a 'channel' pattern on stacked seismic and uses a geologic facies model to locate sand with respect to that channel. For the 3D survey used here, our EEI-AVO method 'finds' sand in locations predicted by the traditional facies model method as well as in new locations.

TARGETED INTERPRETATIVE REPROCESSING FOR RESERVOIR CHARACTERISATION – A CASE STUDY USING THE SATYR FIELD

Dan Gillam[1]*, *Gavin Ward*[1] *and Matthew Waugh*[1]
[1]Chevron Australia Pty Ltd

The large isolated gas bearing channel belts of the Mungaroo Formation are for the most part easily identified on marine surface seismic (MSS). However a more quantitative interpretation of the reservoirs is often impeded by a combination of seismic noise and complex reservoir characteristics. Many sands are at or below tuning thickness and their amplitude response is affected by varying degrees of diagenesis. The presence of acoustically soft carbonaceous siltstones further compromise any quantitative interpretation.

Using the Satyr field as a case study, this paper illustrates how recent advances in seismic processing are able to help mitigate some of the issues affecting MSS, such as free-surface multiple contamination. The paper then explores ways in which the resulting seismic products can be enhanced and manipulated to better discriminate lithologies, such as organic siltstones and cemented intervals. Wells within the Satyr seismic volume are used to demonstrate the improved reliability of reservoir quality estimates in support of field development planning. It is concluded that in certain instances targeted reprocessing of conventional MSS data using modern processing flows can go a long way towards delivering what might otherwise only hope to be achieved through a dedicated broadband acquisition.

PROSPECT VALIDATION USING GEOLOGICAL EXPRESSION IN A GAS DISCOVERY, OFFSHORE MOZAMBIQUE

Adrien Bisset[1], *Gaynor Paton*[1]*, *Nicholas Cooke*[1], *Peter Szafian*[1] *and Roger Gruenwald*[2]
[1]Foster Findlay Associates Australia Pty Ltd
[2]SASOL Petroleum International

This study attempts to gain a better insight into the controls on an under-saturated gas discovery, offshore Mozambique, using Geological Expression techniques such as High Definition Frequency Decomposition (HDFD) and multi-attribute classifications with synthetic wedge modelling being used to better understand the results. HDFD highlights known hydrocarbon bearing sands as high magnitudes and shows that structural processes are dominant in controlling their distribution. Observations from the Chaos divided by Envelope attribute lead to gas chimney interpretations and show that faults may be acting as migration pathways for hydrocarbons into and out of the reservoir. The Interactive Facies Classification tool confirms preconceived ideas of a later stage inversion, shows potential deposition fairways and sand-sand juxtaposition across faults confirming that faults are not acting as baffles to fluid flow. Finally synthetic wedge modelling of the reservoir provides an explanation for similar colour responses of the HDFD RGB blend above and below the gas-water contact. We observe that, even though thickness is a dominant controlling factor on the colours in the RGB blend, pore fill plays a role and allows a single stratigraphic layer to be divided based on it. These techniques aided in better understanding and risking the reservoir.

VOLCANIC ROCK CHARACTERISATION USING THE CONCEPT OF EXTENDED ELASTIC IMPEDANCE: A CASE STUDY FROM MIDDLE JURASSIC GAS RESERVOIR IN OFFSHORE WESTERN AUSTRALIA

Syed Iftikhar Arsalan[1]*, *Kapil Seth*[1] *and Keiichi Furuya*[1]
[1]INPEX

Successful identification of volcanic rocks is critical in reservoirs where they have been previously intersected. This is because they impact on reserve estimates and influence fluid flow behaviour. Various studies using seismic inversion data were performed to try to characterise volcanic rocks in a sandstone reservoir in the Plover Formation. We noted that traditional techniques such as cross-plots between P-Impedance (Ip) and Vp/Vs was not very effective in this reservoir due to significant facies overlap at seismic resolution and inversion data quality. Therefore volcanic rock identification was attempted using advanced seismic attribute analysis. This involved testing and evaluating other elastic attributes, either individually or in combinations, to try and segregate volcanic rocks from other lithofacies.

Two approaches were adopted to find out a suitable single attribute to identify the volcanic rock: (i) scaling of elastic logs with a non-elastic trend; (ii) generating a single attribute using Ip, Is and LMR cross-plots. Log and seismic scale analysis proved the suitability of both methods in volcanic rock identification. Subsequently, Extended Elastic Impedance (EEI) was applied to generate the EEI equivalent of those single attribute yielding positive results.

1030–1210
Day 3 Session 2 Stream C

MINERALS – AIRBORNE ELECTROMAGNETICS 2

UTILIZING MASSIVELY PARALLEL CO-PROCESSORS IN THE AARHUSINV 1D FORWARD AND INVERSE AEM MODELLING CODE

Casper Kirkegaard[1]*, *Kristoffer Andersen*[1], *Tue Boesen*[1], *Anders Vest Kristiansen*[1], *Esben Auken*[1] *and Gianluca Fiandaca*[1]
[1]Aarhus University

While the forefront of AEM research is focusing on the challenges of 3D modelling, the wide AEM community still rely on less sophisticated computational techniques for their calculations. Inversion of large time domain AEM surveys still prove a computational challenge within a 1D formulation, and require much more computational resources than can be delivered by an office workstation. Emerging Monte-Carlo based 1D Bayesian inversion schemes provide another example of applications that are currently limited by the 1D forward modelling rate.

In this abstract we describe our research in modifying the AarhusInv AEM inversion code to utilize next generation massively parallel co-processors. While our results are early and based on very little optimization, we still achieve comparable levels of performance (>80%) from a single co-processor and a 48 cpu core server. We estimate that performance on the co-processor can be speeded up by approximately another 4x with a limited amount of code restructuring/rewriting.

SHARP SCI: A NEW PRACTICAL TOOL FOR BLOCKY MODELS RECONSTRUCTION

Andrea Viezzoli[1]*, *Giulio Vignoli*[2], *Anne-Sophie Høyer*[2] *and Ahmad Behroozmand*[3]
[1]Aarhus Geophysics Ap
[2]GEUS
[3]Stanfor University

In general, a priori information and assumptions are necessary to invert geophysical data. The problem is to formalize this knowledge in the appropriate way. The Sharp Spatially Constrained Inversion (sSCI) approach presented in this paper represents a contribution in this sense. Using the gradient support, it extracts from multilayer inversion the minimum number of -relatively homogeneous- resistivity domains needed to fit the AEM data, retrieving in this way their sharp boundaries. The sharp transitions are, to some extent, similar to those normally achieved with few-layer inversion -which however requires prior determination of the number of layers and may generate artefact in case of unexpected complex geologies. Results obtained from synthetic and experimental data illustrate the concept and prove that the sSCI can be superior to standard multilayer inversions in mapping sharp spatial resistivity transitions.

ARTIFICIAL NEURAL NETWORKS FOR EFFICIENT REMOVAL OF COUPLED AIRBORNE TRANSIENT ELECTROMAGNETIC DATA

Casper Kirkegaard[1]*, *Kristoffer Andersen*[1], *Casper Kirkegaard*[1], *Nikolaj Foged*[1] *and Esben Auken*[1]
[1]Aarhus University

Modern airborne transient electromagnetic (ATEM) surveys typically span thousands of line kilometres requiring careful data processing. When surveys are flown in populated areas data processing becomes particularly time consuming, since the acquired data is contaminated by couplings to manmade conductors (power lines, fences, pipes, etc.). Coupled soundings must be removed from the dataset prior to inversion, but since the signature of couplings can be subtle and difficult to describe in general terms it has so far remained mostly a manual task.

Here we train an artificial neural network (ANN) to recognize coupled soundings in previously processed data and use this network to identify couplings in other data. The approach provides a dramatic reduction in the time required for data processing, since one can directly apply the network to the raw data. We describe the neural network we use and present the inputs and normalizations required for maximizing the effectiveness of the network. We present the training state and performance of the network and finally compare inversions based on manually processed data and ANN processed data. The results show that a well trained network can produce a high quality processing of ATEM data, which is either ready for inversion or in need of minimal manual processing. The results are very promising and can significantly reduce the processing time and cost of large ATEM surveys.

QUASI-3D INVERSION OF FULL SIZE AEM DATASETS

Esben Auken[1]*, *Gianluca Fiandaca*[1], *Casper Kirkegaard*[1] *and Anders V. Christiansen*[1]
[1]Aarhus University

We present a new algorithm for quasi-3D inversion of airborne transient electromagnetic data (AEM). The algorithm uses a 3D voxel grid for the model domain while the forward response and derivatives are calculated using interpolated "virtual" 1D models collocated at the AEM measurement points. The algorithm efficiently decouples the model domain from the practical spatial sampling, which is often dictated by the landscape, ground installations etc., rather than the optimal model resolution. The algorithm uses sparse storage with efficient solvers and it scales linearly with both the number of CPU's and with the survey size. This means that it can be used to invert entire surveys of thousands of kilometres on small multiprocessor servers priced at less than 5000 Euro. The algorithm allows inputting a-priori information from boreholes, joint inversion with ground based electrical/electromagnetic data and modelling of flight altitude and shift parameters.

1030–1210
Day 3 Session 2 Stream D

MINERALS – GEOLOGY FROM GEOPHYSICS 2

GEOCHEMISTRY, THE NEW GEOPHYSICS?

Scott Halley[1]*
[1]Minerals Mapping Pty Ltd

Both geochemical and geophysical responses of earth materials are governed by mineralogy. It should therefore come as no surprise that geochemical and geophysical patterns are strongly correlated. Using a strong acid digest and a combined ICP MS/AES analytical package, we can now analyse half of the periodic table with very low detection limits, for around the same real dollar cost that Au plus base metals would have cost 30 years ago. With the new analysis methods, we can classify rock types, quantify the intensity of alteration, as well as map pathfinder metals. Integrating chemistry with geophysical data adds a new level of understanding to the meaning of the geophysical patterns. An example from Zambia shows a district-scale alteration map. Correlation with airborne radiometrics and magnetics allows interpolation between sample points, and extrapolation across a whole province. The hydrology of an entire sedimentary basin can be mapped from the combination of data.

PRACTICAL GEOLOGICAL MAPPING UNDER COVER USING ELECTROMAGNETIC DATA

Gavin Selfe[1]*
[1]GRS Consulting

As the world's 'easy' mineral deposits on surface are increasingly discovered, it becomes more and more necessary

for geo-scientists to explore under cover. Southern Africa has vast expanses of young cover in the form of Kalahari sands and the Karoo sequence, and this cover is ignored at one's peril. The big challenge is to map the geology beneath these young sequences, using a variety of techniques to increase the validity of the interpretation. Instead of relying purely on magnetics and gravity, various electromagnetic (EM) techniques are discussed, ranging from airborne EM surveys to 2.5D audio magneto-telluric (AMT) surveys and high-temperature SQUID EM surveys. Datasets are presented from current base metal exploration projects in Botswana, South Africa and Zambia, and the innovative use of these in some cases is demonstrated. The emphasis is on interpreting the general structure and geology, using all available datasets, in ways that benefit the overall exploration strategy. The important role of understanding physical rock properties by using downhole geophysical logging (petrophysics) is also discussed, and related to the geological interpretation. The varying levels of success of some of these methods at a prospect scale are highlighted.

1030–1210
Day 3 Session 2 Stream E

MINERALS – HARD ROCK SEISMIC 2

KEVITSA NI-CU-PGE DEPOSIT, NORTH FINLAND – A SEISMIC CASE STUDY

Sasha Ziramov[1]*, *Aleksandar Dzunic*[2] *and Milovan Urosevic*[1]
[1]Curtin University
[2]HiSeis

A 3D seismic survey was designed, acquired and processed by HiSeis Pty Ltd in 2010 at the Kevitsa NiCu-PGE deposit. The objectives of the survey were the definition of sub-vertical structures (knowledge of which could assist in the design and characterisation of the slopes of the proposed open pit), and mapping out the general structural setting of the mafic intrusive. The 2010 processing of the Kevitsa 3D seismic data was accelerated to meet engineering design deadlines. Although this phase of work was restricted to processing sequences that were not amplitude consistent and to the post stack migration algorithm, never-the-less the resultant product achieved good resolution of the complex structural setting. The dataset was re-processed in 2014 with the goal of preserving relative signal amplitudes, in order that the volume could be inverted into an acoustic impedance cube. Another reason for re-processing was to improve imaging in shallow depth, by improving the static solution and velocity model used for imaging. Both of these processes are considered to be crucial steps in hard rock seismic data processing. Considerable improvement was achieved through the application of a pre-stack time migration (PSTM) algorithm. Conventional 3D deepmove out corrections (DMO), followed by a post-stack migration algorithm proved to be insufficient to handle the lateral changes of velocities. Consequently, pre-stack time imaging was attempted to aid in handling the highly complex velocity field. The goal was to derive a velocity model appropriate to the geologic environment in order to place events in their correct positions, to properly focus the energy, to avoid introduction of false structures and to flatten the image gathers. The Kevitsa 3D seismic dataset is considered as being of high quality and as the data volume contains a statistically significant number of log measurements, it is deemed suitable for the seismic inversion.

SEISMIC VOLUMETRIC INTERPRETATION OF STEEPLY DIPPING FAULTS IN A DISSEMINATED COPPER SYSTEM IN KEVITSA, NORTHERN FINLAND

Muhammad Shahadat Hossain[1]*, *Milovan Urosevic*[2] *and Chris Wijns*[2]
[1]Curtin University
[2]First Quantum Minerals

Improved mining technology and scarcity of near–surface deposits is forcing the mining industry to explore deeper in the search for economic mineralisation. Reflection seismic is one of the few geophysical methods that have sufficient resolution at depth to constrain geological information of an ore deposit at the drilling scale. Reflection seismic methods can be used to reduce drilling costs by focusing the drilling in strategically important areas. Seismic volumetric interpretation techniques have advantages over conventional interpretation techniques, where the interpretation is done by slicing the volume in 2D planes. Volumetric interpretation is performed in 3D and in real time, by applying various opacity and transparency filters to the seismic volume from different angles, which enables in–depth understanding of the volume. This initial stage of volumetric interpretation is followed by mapping the interfaces and associated structures of exploration interest.

A 3D high–resolution seismic dataset was collected to investigate steeply dipping to sub–vertical structures in Kevitsa, northern Finland. Automatic fault extraction using a modified ant–tracking workflow was performed on the seismic volume. The faults extracted using ant–tracking have acceptable correlation with the currently available geological interpretation.

SEISMIC IMPEDANCE INVERSION WITH PETROPHYSICAL CONSTRAINTS VIA THE FUZZY CLUSTER METHOD

Duy Thong Kieu[1]* *and Anton Kepic*[1]
[1]Curtin University

Seismic impedance inversion produces results that should be better for geological interpretation. However, seismic impedance inversion in mineral exploration normally suffers from poor signal-to-noise, and a lack of well control normally assumed for the process. To counter these problems we have developed an approach that exploits the fact that the geology in these environments often has fewer distinct geological units so we can restrict the number of physical parameters possible. A model-based seismic impedance inversion method using fuzzy c-means clustering to constrain inversion with petrophysical information has been developed. Using synthetic examples, we show that our method effectively recovers the true model even when the data is strongly contaminated by noise. This method is applied to seismic data from a US gold mining district and the results are reasonably consistent with well log data. The impedance images provide a better basis for geological interpretation than reflection images alone.

LASER DOPPLER INTERFEROMETRY (LDI) TO OBTAIN FULL STIFFNESS TENSOR: A CASE STUDY ON A DEFORMATION ZONE IN SWEDEN

Pouya Ahmadi[1]* *and Alireza Malehmir*[1]
[1]Uppsala University

Estimation of elastic anisotropy, which is usually caused by rock fabrics and mineral orientations, has an important role in exploration seismology and a better understanding of crustal seismic reflections. If not properly taken care of during data processing steps, it leads to wrong interpretation and/or distorted seismic image. In this work, a state-of-the-art under the development Laser Doppler Interferometer (LDI) device is used to measure phase velocities on the surface of rock samples from a major poly-phase crustal scale deformation zone (Österbybruk Deformation Zone) in the Bergslagen region of eastern Sweden. Then, a general inversion code is deployed to invert the measured phase velocities to obtain full elastic stiffness tensors of two samples from the deformation zone.

At the end, results are used to correct for the anisotropy effects using three dimensionless Tsvankin's parameters and a non-hyperbolic moveout equation. The resulting stacked section shows partial reflection improvement of the deformation zone compared with the traditional isotropic processing approach. This illustrates that rock anisotropy contributes to the generation of the reflections from the deformation zones in the study area although they do not show significant density contrast with their surrounding rocks.

ABSTRACTS

1330–1510
Day 3 Session 3 Stream A

PETROLEUM – UNCONVENTIONAL OIL AND GAS

CULTURAL AND TECHNICAL ISSUES WITH DEVELOPMENT OF UNCONVENTIONAL RESERVOIRS IN AUSTRALIA

Dennis Cooke[1]*
[1]University of Adelaide

Will development of unconventional reservoirs (tight gas, shale gas and CSG) in Australian proceed as in North America? What aspects of Australian development are more favorable? And what aspects will make development in Australia more difficult or expensive?

Australia currently has a more challenging cost structure than North America, but there are some distinct hidden advantages in Australia's oil and gas permitting laws. Australia's gas market appears to be much more attractive, at least for the short to mid-term. And the environmental issues are playing out in Australia in a very similar manner to North America.

Inside Australian companies developing unconventional resources, there is a debate over competing development philosophies that is largely hidden from public view; this is the debate between a low cost factory-like pattern drilling program versus an expensive up-front investment in geoscience data that will hopefully lead to a more economic drilling and completion solution.

Within the subsurface technical realm, a common mantra in North America now is "every shale gas play is different" – meaning that a technical solution for shale gas development in one basin may not work in another basin. With this view, shale gas development in Australia will not be any more or less challenging than trying to adapt Barnett shale gas solutions to the Eagle Ford shale (which is highly successful) or to the largely disappointing Woodford Shale. But there is one significant development challenge common to Australian basins that has not been experienced in North American: higher tectonic stress and higher differential stress. These higher stresses can lead to horizontal fracture stimulation treatments instead of the expected and more favorable vertical frac treatments.

While it is still too soon to pick the successful and unsuccessful unconventional plays in Australia, this talk will attempt to highlight the critical drivers in that success.

VALUABLE LESSONS FROM ACQUIRING 3D SEISMIC FOR COAL SEAM GAS

Andrew Aouad[1]*, *Randall Taylor*[1], *Neil Millar*[1] *and David Dorling*[1]
[1]Origin energy

A land 3D seismic survey was carried out in the Surat and Bowen Basins with the specific objective of imaging Coal Seam Gas reservoirs. Use of nodal acquisition technology allowed the survey to be designed around numerous obstacles while collecting a full range of azimuths and offsets. These were maintained through processing to provide well imaged structures and pre-stack data for quantitative interpretation.

UNCONVENTIONAL RESOURCE EVALUATION AND APPLIED GEOPHYSICS UTILISING LMR

David Close[1]* *and Marco Perez*[2]
[1]Origin Energy
[2]Apache Canada

Over the last decade the oil and gas industry has delivered conceptual and technical changes that have entirely changed the fundamentals of natural gas supply in North America. Underpinning the step change in natural gas reserves and market ready supplies has been the change in the perception of fine-grained, organic rich rocks (i.e. shales – although of course not all shales are organic rich). No longer are such rocks viewed only as source and seal candidates, but also as source rock reservoirs or shale gas plays.

Although the geological continuity of shale gas plays have led to the production-line style operations seen across North America

in mature unconventional plays, it is not "factory-style" efficiency improvements in isolation that allow the economic exploitation of shale gas. The large number of fit-for-purpose technologies, introduced by operators and service companies, has been critical in increasing production while keeping costs flat and/or reducing costs and time to production.

3D seismic data play a key role in unconventional developments as a unique look-ahead dataset. The role of seismic, however, has evolved to be far more than simply a tool for mapping major structures. For example, through AVO inversion we are able to make predictions regarding elastic properties of the formations of interest. The integration of AVO inversion data with engineering and rock physics data is providing new avenues of data exploitation. Seismic data are also being used to predict closure stress and stress anisotropy, which can be calibrated with data and analysis from hydraulic fracturing. Additionally, the integration of surface seismic data with microseismic provides a means of fine-tuning the estimation of stimulated rock volume.

1330–1510
Day 3 Session 3 Stream B

PETROLEUM – REGIONAL BASIN STUDIES

INTERPRETATION AND MODELLING OF NEW BROWSE BASIN AIRBORNE MAGNETIC DATA FOR IGNEOUS ROCKS AND BASEMENT

Ron Hackney[1]*, *Rowan Romeyn*[1] *and Claire Orlov*[1]
[1]Geoscience Australia

The Browse Basin on Australia's North West Shelf is a NE-trending Paleozoic to Cenozoic depocentre that contains more than 15 km of sediments. These sediments host significant hydrocarbon reserves, some of which are currently under development. The basin also has the potential to store large volumes of carbon dioxide. Recently-acquired aeromagnetic data over the Browse Basin provide new impetus for studies of the nature of basement, the role of structural inheritance and controls on the distribution of volcanic rocks.

Initial interpretation of the new magnetic data has utilised magnetic source polygons and depth estimates derived from the tilt-angle filter. Exploration wells that intersect mainly volcanic flows or tuffaceous rocks tend to lie on or adjacent to source polygons. Computed tilt depths show that these sources tend to coincide with the depth to the top of volcanics in wells and that tilt depths extend deep into the basin (up to ~10 km). The magnetic susceptibility distribution inferred from minimally-constrained, regional-scale inversion models also indicates that magnetic anomalies arise from features deep in the basin and within basement. These results highlight the importance of understanding the role of volcanic rocks in basin evolution and their influence on reservoirs that may host hydrocarbons or that may be suitable for CO2 storage.

USING POTENTIAL FIELD DATA TO MAP SALT DISTRIBUTION IN THE WESTERN OFFICER BASIN, WESTERN AUSTRALIA

Jane Cunneen[1]*, *Warick Crowe*[2] *and Geoff Peters*[2]
[1]Curtin University
[2]International Geoscience

The Neoproterozoic western Officer Basin has a total fill of up to 8 km and a depositional history with similarities to other Australian basins, particularly the Amadeus Basin. Exploration has been limited due to the size and remoteness of the basin; therefore potential field data can be a useful and cost-effective tool to assess petroleum prospectivity.

Salt distribution and mobilisation in the Officer Basin has been significantly underestimated due to a lack of quality seismic data. This study uses satellite, digital terrain, magnetic, gravity and seismic data to show the existence of mobilised salt much further west than previously suggested, with significant implications for future exploration in the region.

SCIENTIFIC OCEAN DRILLING AND THE CAPABILITIES OF THE IODP DRILLSHIP JOIDES RESOLUTION

Neville Exon[1]* *and Mitchell Malone*[2]
[1]Australian IODP Office, Australian National University
[2]US IODP Office, Texas A&M University

Scientific ocean drilling uses several drill ships to work on global scientific problems. These include changes over various time scales in climate, biology and oceanography, extreme life forms beneath the sea bed, planetary dynamics and geological hazards. The International Ocean Discovery Program (IODP) involves 27 countries, including Australia and New Zealand, and is the world's largest scientific geoscience program. One IODP drill ship, JOIDES Resolution, is working in our general region at present and for several years to come. Although the primary aim of the work is purely scientific, deep stratigraphic wells are always of interest to the petroleum exploration industry. This talk will cover IODP in general, ocean drilling in our region, and the capabilities of the JOIDES Resolution.

3D GEOPHYSICAL MODEL OF THE GLYDE BASIN, NORTHERN TERRITORY, BASED ON CURVATURES DERIVED FROM AIRBORNE GRAVITY GRADIENT DATA

Carlos Cevallos[1]* *and Peter Kovac*[1]
[1]CGG

This paper presents automatic 3D geophysical model generation based on equivalent pseudodepth slicing of the shape index of the equipotential surfaces derived from airborne gravity gradient data. The method is carried out in three steps. First, the pseudodepth slices of the vertical gravity gradient and the magnitude of the differential curvature components are generated. Second, the equivalent pseudodepth slices of the shape index are generated. Finally, 3D interpolation is carried out to obtain the final model.

The method is applied to FALCON airborne gravity gradiometer data from the Glyde Basin, Northern Territory and compared to an independently interpreted, integrated 3D geological Earth model.

1330–1510
Day 3 Session 3 Stream C

MINERALS – AIRBORNE ELECTROMAGNETICS 3

THE SUPERPARAMAGNETIC RESPONSE OF TRANSIENT AEM DATA

Daniel Sattel[1]* *and Paul Mutton*[2]
[1]EM Solutions LLC
[2]Touchstone Geophysic

Several lines of VTEM data flown at different system elevations across a known sulphide body and surface cover with elevated superparamagnetic (SPM) properties were analysed with MAXWELL, layered-earth inversions, LEROIAIR and LEROI. The SPM material was modelled with frequency-dependent magnetic susceptibilities at shallow depth.

Due to their slow late-time decay, SPM responses can be confused with responses of deep conductors and vice versa. Depending on the parameter weighting used, 1D inversions model all late-time responses as deep conductive material or as surficial SPM material. However, the joint 1D inversion of data acquired at different system elevations manages to recover a deep conductor from the sulphide anomaly and elevated SPM values at the location of the SPM response. For the modelled parameters, the VTEM data sets from two elevations (at 70 and 80 m) require a vertical separation of about 10 m to allow for the discrimination between the SPM and sulphide responses. For lower system elevations, less sensor separation is necessary due to the strong gradient of the SPM response.

We suggest that two vertically separated receivers could be used to measure the AEM gradient and depending on the flying height of the transmitter, the vertical offset of the receivers should be between 2 and 40 m.

RESTORATION OF DISTRIBUTED IP INFORMATION IN AIRBORNE-TIME DOMAIN ELECTOMAGNETIC DATA

Seogi Kang[1]* *and Douglas W. Oldenburg*[1]
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We propose a methodology to generate a 3D distribution of pseudo-chargeability from airborne time domain electromagnetic data. The processing flow is as follows: (a) Apply 3D inversion to TEM data to restore a background conductivity. This might involve omitting responses that are obviously contaminated with IP signals, such as negative transients in coincident loop surveys. The recovered background conductivity is assumed to be uncontaminated by IP signals. (b) Compute the TEM response from the background conductivity and subtract it from the observations. This yields the dIP data, and reduces the EM coupling. (c) The background conductivity is likely not exactly the earth conductivity, but we assume that the major effects of this inaccuracy will lead to a large scale, smoothly varying perturbation to the dIP data. If this correct, then these can be recognized and removed. (d) The final data are linearly related to a pseudo-chargeability through a sensitivity function that is analogous to that employed in usual DC-IP ground surveys. (e) The dIP data at various time channels can be inverted individually. The pseudo-chargeability models may be useful in themselves or they may be further processed to estimate Cole-Cole, or equivalent, parameters. We demonstrate our procedure on a field data set from Mt. Milligan. In the field example, we identify chargeable targets that show no indication of negative transients in the raw data. From the images we can make inferences about the relative strength and geometries of the chargeable bodies.

AIRBORNE INDUCTIVE INDUCED POLARIZATION CHARGEABILITY MAPPING OF VTEM DATA

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[3]Geotech Airborne Ltd

Airborne inductive induced polarisation (AIIP) effect has been widely recognized in airborne time domain EM system data. AIIP chargeability mapping opens new and exciting areas in mineral exploration for airborne time domain EM systems in the search for sulphides and clay minerals. An AIIP chargeability mapping tool based on CSIRO/AMIRA Airbeo is created for VTEM data, with examples from Mt Milligan, British Columbia, Canada and Tullah, Tasmania. Using the Cole-Cole frequency dependent resistivity, the tool examines the VTEM decay data spectrally and selects the decay associated with the lowest RMS error from a set of decays generated by varying chargeability m and time constant within specific ranges, giving a constant frequency factor c, while the background resistivity is inverted. The parameter mo used to generate the decay is the AIIP apparent chargeability.

DETERMINING COVER VARIABILITY IN THE CAPRICORN OROGEN WITH AIRBORNE EM

Yusen Ley-Cooper[1]*, *Tim Munday*[1] *and Tania Ibrahimi*[1]
[1]CSIRO

This paper focuses on elucidating cover variability throughout the Capricorn Orogen in Western Australia. We use, as a baseline, data from a widely spaced airborne electromagnetic (AEM) fixed-wing survey acquired for the Geological Survey of Western Australia in 2014. The Capricorn 2013 AEM survey is the largest AEM survey by area flown in Australia to date, covering over 146 300 km2. The Capricorn Orogen is a highly mineral prospective under explored orogeny located between the Pilbara and the Yilgarn Craton. Whilst the western part of the Orogen is particularly well exposed, and as a result the surface geology, geological history tectonic setting is well understood, the north west and eastern regions are characterised by a variably thick and complex regolith. The region is relatively under-explored, although host to significant mineralisation, including mesothermal orogenic gold, copper–gold volcanogenic massive sulphides, and channel iron ore deposits. In a region of variable cover, geophysical (aeromagnetic, electromagnetic and gravity) and geochemical techniques are critical aids to the mapping of lithostratigraphic units that are covered by regolith materials, but also in providing an understanding of the regional geological factors that control the mineralisation. Here we discuss some initial results from the smooth model layered earth inversion of 30,119 line km of AEM data. We consider sections from geologically contrasting parts of the Orogen. The results show the complexity and variability of conductive cover in the region and suggest some areas in the orogen could be beneath

200m of transported and in-situ regolith cover. The regional regolith framework that is being developed from the AEM data will provide a basis for better understanding and interpreting regolith geochemistry that has been acquired across a region, particularly where outcrop is limited.

1330–1510
Day 3 Session 3 Stream D

MINERALS – GEOLOGY FROM GEOPHYSICS 3

GEOSCIENCE DATA INTEGRATION: INSIGHTS INTO MAPPING LITHOSPHERIC ARCHITECTURE

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In order to develop a 4D understanding of the architecture of the entire lithosphere, it is necessary to embrace integration of multi-disciplinary, multi-scale data in a GIS environment. An holistic understanding has evolved whereby geologic, geochemical and geophysical signals are consistent with a subcontinental lithospheric mantle (SCLM) dominated by a mosaic of domains of Archean ancestry, variably overprinted by subsequent tectonothermal events. Pristine Archean SCLM is mostly highly depleted (high Mg#), low density, high velocity and highly resistive, and preserves intact Archean crust. There is a first order relationship between changes to these signals and the degree of tectonothermal overprint (by melts, fluids). Continental crust is comprised largely of reconstituted Archean components, variably diluted by juvenile addition, symptomatic of the various overprinting events. These events impart crustal fabrics and patterns dictated by SCLM architecture, influenced by the free surface and crust-mantle decoupling.

BUILDING EFFECTIVE MINERAL SYSTEM MODELS; THE IMPORTANCE OF MERGING GEOPHYSICAL OBSERVATION WITH GEOLOGICAL INFERENCE

Ken Witherly[1]*
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As the discovery of shallow, high grade deposits for essentially all commodities continues to decline, explorers have to increasingly search for deposits at greater depth and with increased amounts of cover material. As a result, the direct detection of deposits becomes problematic and there needs to be a much greater reliance on secondary or tertiary signatures or halos of deposits to define the likely presence of the target. The mineral system approach is a means by which the overall environment in the earth which has been changed due to emplacement of a deposit in both space and time is characterized at a variety of scales. If we are able to understand the reasons for these changes and then systematically track them in the earth, explorers have a powerful new tool to identify deposits at depth. For this approach to be successful it will require a degree of integration between geology, geophysics and geochemistry not previously undertaken.

1330–1510
Day 3 Session 3 Stream E

MINERALS – MISCELLANEOUS 1

GEOPHYSICS IN GREENFIELDS REGIONS TO DETERMINE COVER THICKNESS: PRE-COMPETITIVE DRILLING IN THE STAVELY REGION OF VICTORIA

Anthony Meixner[1]*, *Aki Nakamura*[1], *Malcolm Nicoll*[1] *and Sarlae McAlpine*[1]
[1]Geoscience Australia

Fifteen pre-competitive stratigraphic holes have been drilled to test geological and mineral system models in the 'greenfields' Stavely region of western Victoria. Prior to drilling, seismic reflection and refraction, gravity, and airborne magnetic data were used to estimate the thickness of cover at the selected drill sites. This analysis also tested the reliability of the geophysical techniques in a range of geological conditions.

Comparisons with preliminary drilling data indicate that seismic refraction data successfully predicted cover thickness at six out of seven sites. Estimates of depth to magnetic source at the top of basement, derived from airborne magnetic data successfully predicted cover thickness at eight of ten sites. Seismic reflection

was the least reliable technique with one out of four successful predictions. However, despite their success rate, neither the refraction nor the magnetic data gave reliable cover thickness estimates where cover materials were highly magnetic or had high seismic velocities.

PROCESSING GRAVITY GRADIENTS TO DETECT KIMBERLITE PIPES

Thomas Meyer[1]*
[1]Lockheed Martin MST, New Ventures - Gravity Systems

A modelling and pattern recognition-based approach is applied to processing airborne gravity gradient data for kimberlite exploration. The carrot-like bodies with low density crater facies that typify kimberlite pipes are particularly amenable to this treatment. Results for small and medium-sized pipes buried deeply beneath nominal geologic clutter are promising. Details regarding various error rates provide valuable input to exploration programs and the framework can include any data type. A three-class problem is formulated to address the case of false positives. A first example is worked for low density shallow depressions that closely mimic gravity images of pipes, providing insight to what is needed from a survey fidelity standpoint to effectively mitigate false positives.

HIGH PRECISION TERRAIN CORRECTIONS FOR NEXT GENERATION AIRBORNE GRAVITY DATA

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[1]Rio Tinto Exploration
[2]Scientific Computing
[3]Greenfields Geophysics

This paper describes a method of improving the estimation of terrain effects in airborne gravity or gravity gradient data by closer sampling of the terrain and flight path in areas of steep topography and integrating spot estimates over the actual flight path measurement interval. Simulated estimates of terrain effect over an actual flight path in rough terrain are used to demonstrate the expected improvement in terrain corrections and target recognition. Integrating the gravity gradient of the terrain along the flight path of an airborne gravity gradiometry survey is a necessary part of terrain corrections for the upcoming generation of highly accurate gravity gradiometers. The effect of spatial integration does not generally need to be considered in the data processing workflow of current instruments.

THE VALUE OF A COMBINED APPROACH: INNOVATIVE MINERAL EXPLORATION TECHNIQUES IN THE IRISH ZN-PB OREFIELD

Simone De Morton[1]*, *Malcolm Wallace*[1], *Christopher Reed*[2], *Chad Hewson*[2], *Patrick Redmond*[2], *Eoin Cross*[2] *and Conor Moynihan*[2]
[1]University of Melbourne
[2]Teck Namibia

The Early Carboniferous stratigraphy of the Irish Midlands contains one of the world's major Carbonate-hosted zinc-lead orefields covering a region of approximately 8000 km^2. The large-scale nature of the sedimentary fluid flow systems that produce these ore deposits suggest it is necessary to understand not only the nature of mineralisation, but also the nature of the basin in which it is hosted. In this study we integrate typical methods of stratigraphic analysis (core and outcrop logging) with recently acquired seismic reflection data and gamma ray logs to ascertain the relationship between the stratigraphic and structural setting of the Ballinalack Zn-Pb deposit and the wider host basin (Dublin Basin).

Geometric relationships between layers as revealed by seismic reflection, in conjunction with detailed lithological analysis has shown extensional tectonism was the main driving force of sedimentation in the Dublin Basin. A period of significant extensional tectonism first occurred in the late Tournaisian (Moathill Event, ~348 Ma) and was accompanied by faulting and regional subsidence. This was followed by a period of relative tectonic quiescence, before a second period of tectonism during the lower Viséan (Tober Colleen Event, ~345 Ma) resulted in regional subsidence, but without significant faulting. Major subsidence associated with these events produced strong transgressions in the Dublin Basin, interspersed with periods of regression. This view of the tectonic history of the Irish Carboniferous basin contrasts with previous interpretations that suggest the Lower Carboniferous represents an overall deepening sequence. The suggested earlier timing of fault movement has implications for arguments about the origin of Irish-type Zn-Pb deposits and the necessity (or not) for having active faulting during mineralisation. These novel results reveal the value of a combined approach to sedimentary basin analysis.

1530–1710
Day 3 Session 4 Stream A

PETROLEUM – RESERVOIR CHARACTERIZATION 2

INSIGHTS OF DIELECTRIC MEASUREMENTS FROM CUTTINGS RECOVERED ALONG THE DEEPEST OFFSHORE WELL IN THE WORLD (NANKAI TROUGH ACCRETIONARY PRISM): IODP EXPEDITION 338, SITE C0002F

Lionel Esteban[1]*, *Matthieu Cauchefert*[1] *and Matthew Josh*[1]
[1]CSIRO-ESRE

A total of 109 cuttings were recovered during the IODP expedition 338 in site C0002F down to 2005 mbsf. A special dielectric end-load probe was designed and used for the first time at sea on this sample collection to measure dielectric and electrical conductivity from 10 kHz to 6 GHz. The whole dataset was compared to specific surface area (SSA), mineralogy from XRD measurements and resistivity log while drilling acquired during the expedition to understand the relationship between fluid, clays and lithologies. The dielectric results revealed to be very powerful to: (i) understand the clay composition and content; (ii) re-calibrate cutting depths; (iii) detect unit boundaries and (iv) detect conductive and not-conductive fault systems.

USING MULTIVARIATE DATA CLASSIFICATION ON FRONTIER EXPLORATION BASINS TO ENHANCE THE INFORMATION VALUE OF SUBOPTIMAL 2D SEISMIC SURVEYS FOR UNCONVENTIONAL RESERVOIR CHARACTERIZATION

Andrea Paxton[1]*, *David Handwerger*[1], *Roberto Castaneda-Aguilar*[1], *Don Stachiw*[2] *and Roberto Suarez-Rivera*[1]
[1]Schlumberger
[2]Northern Cross Yukon

We developed a workflow that allows integrating legacy 2D seismic surveys with modern log and core data, validating their consistency, classifying them into rock classes with consistent properties, propagating material properties across each of these rock classes, and using this information to improve reservoir characterization and the assessment of their hydrocarbon resource potential. As proof of concept, we analyzed two intersecting 2D seismic lines shot in 2001 in a frontier basin in Canada to determine the distribution of reservoir quality. Each of these had been separately prestack inverted, but have modern core and log data (as well as legacy log data) which were integrated with the inverted attributes.

Results identify a most prospective class for reservoir quality within the zone of interest, and show that it increases in thickness to the south in the seismic section.

1530–1710
Day 3 Session 4 Stream B

PETROLEUM – RESERVOIR CHARACTERIZATION 3

ENHANCED DELINEATION OF RESERVOIR COMPARTMENTALIZATION FROM ADVANCED PRE AND POST-STACK SEISMIC ATTRIBUTE ANALYSIS

Mauricio Herrera Volccan[1]*, *Clark Chahine*[1] *and Leigh TrueLove*[1]
[1]Schlumberger

Reservoir compartmentalization has a huge bearing on fluid flow within hydrocarbon reservoirs, and can impact overall recovery during field development. Small and sub-seismic faults can have a dramatic effect on the compartmentalization within a reservoir, but until recently they have not typically been incorporated into fault interpretations. This can be due to data fidelity and the amount of time needed to manually pick them. Their omission from the interpretation – and ultimately reservoir models – means the understanding of reservoir compartmentalization is incomplete, hence solving this problem is critical to improve production. Approaches that automatically identify and extract faults from seismic volumes are available. These automated methods aim to emphasize discontinuities within seismic volumes and are usually focused on poststack data. However, they need preconditioned inputs that are often based around a coherence algorithm. This preconditioning aims to suppress noise but can inflict data degradation, which may diminish smaller features in the seismic volumes. This article proposes an enhanced approach using a new combination of preconditioning steps designed to avoid these degradation problems. It also proposes the use of prestack seismic data, which has not traditionally been used for this purpose. Analysis of various pre-stack elements is displayed to show it can delineate more features than poststack data alone in certain noisy areas, such as gas effects or low frequencies. Finally, it demonstrates that the best approach combines results from pre- and poststack analysis to produce a more complete picture of reservoir compartmentalization.

SEISMIC WAVEFORM CLASSIFICATION: RENEWING THE INTEREST IN BARROLKA FIELD, SW QUEENSLAND, COOPER BASIN

Yahya Il Basman[1]*
[1]Santos

Seismic wave form classification techniques have been used to significantly improve the efficiency of the interpretation of the Barrolka field 3D seismic survey. Pattern recognition of seismic shape based on a neutral network has proven to be powerful approach in reducing risk associated with characterising and predicting the extent of the Barrolka field's historically elusive PC30 reservoir. This technique resulted in recent drilling success with development wells intersecting predicted reservoir and resulting in exceptional initial gas rates, a contrast to the field complex's 30 years low drilling success. This study has rejuvenated interest to convert the field's large contingent resource to reserves.

1530–1710
Day 3 Session 4 Stream C

MINERALS – RADIOMETRICS

MONITORING AIRBORNE GAMMA RAY SPECTROMETER SENSITIVITIES USING THE NATURAL BACKGROUND

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[2]Sander Geophysics

In many airborne gamma-ray surveys, uranium and thorium sources are required to verify that the airborne system maintains the same sensitivity for each survey flight. Recently, due to radioactive material regulations, it has become increasingly difficult to transport these radioactive sources around the world. Measurements of the natural radioactivity of the ground, recorded as part of source tests carried out in Tanzania were analysed. These data involved three different aircraft at two bases of operation. The results have shown that in all cases the potassium and thorium background measurements were more consistent than the measurements from the uranium and thorium sources. In addition, the variations in the potassium and thorium measurements could be reduced even further by removing the effect of airborne radon daughter fluctuations using stripping ratios derived from measurements on concrete calibration pads.

THE 3D INVERSION OF AIRBORNE GAMMA-RAY SPECTROMETRIC DATA

Brian Minty[1]* *and Ross Brodie*[2]
[1]Minty Geophysics
[2]Geoscience Australia

We present a new method for the inversion of airborne gamma-ray spectrometric line data to a regular grid of radioelement concentration estimates on the ground. The method incorporates the height of the aircraft, the 3D terrain within the field of view of the spectrometer, the directional sensitivity of rectangular detectors, and a source model comprising vertical rectangular prisms with the same horizontal dimensions as the required grid cell size. The top of each prism is a plane surface derived from a best-fit plane to the digital elevation model of the earth's surface within each grid cell area.

The method is a significant improvement on current methods, and gives superior interpolation between flight lines. It also eliminates terrain effects that would normally remain in the data with the use of conventional gridding methods.

1530–1710
Day 3 Session 4 Stream D

MINERALS – GEOLOGY FROM GEOPHYSICS 4

GEOLOGICAL UNCERTAINTY AND GEOPHYSICAL INVERSION

Mark Jessell[1]*
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One of the major challenges for geophysical inversion schemes is to retain geological meaning during the inversion process. In voxel-based methods based on prior geological models we are typically forced into a manual reinterpretation of smooth petrophysical images in terms of discrete structures and lithostratigraphy.

Recent work in the characterisation of geological uncertainty has demonstrated the inherent weaknesses in classical 3D geological model building strategies. The analysis of 3D geological uncertainty provides several pathways to improved geophysical inversion. The uncertainty can be characterised at the local scale to provide constraints on petrophysical inversions, and at the global scale to provide end-member geologically and topologically distinct prior models. Although in its infancy, geological uncertainty analysis shows promise in workflows aimed at integrating geological and geophysical constraints in 3D.

1530–1710
Day 3 Session 4 Stream E

MINERALS – MISCELLANEOUS 2

BAD COLOUR MAPS HIDE BIG FEATURES AND CREATE FALSE ANOMALIES

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Many colour maps provided by vendors have highly uneven perceptual contrast over their range. It is not un-common for colour maps to have perceptual flat spots that can hide a feature as large as one tenth of the total data range. The opposite can also occur whereby perceptual discontinuities in the colour map can induce the appearance of false anomalies. This paper presents a set of design techniques that allow colour maps to be constructed with uniform perceptual contrast across their full range. The most important factor in designing a colour map is to ensure that the magnitude of the incremental change in perceptual lightness of the colours across the map is uniform. The rate of incremental change in hue or saturation of the colours in the map prove to be relatively unimportant when one is seeking to discern features at fine spatial frequencies. Accordingly, the colour maps pre-sented here are designed in CIELAB colour space. In contrast to RGB this colour space provides a perceptual organization of colours in terms of their lightness, hue and chroma/saturation which facilitates the design process. The utility of the colour maps presented here is demonstrated using a simple test image that allows the perceptual uniformity of colour maps to be readily evaluated.

QUANTIFYING MODEL STRUCTURAL UNCERTAINTY AND FACIES PREDICTION FOR LOCATING GROUNDWATER SUPPLIES IN TIMOR-LESTE USING AEM DATA

Burke Minsley[1]* *and Yusen Ley-Cooper*[2]
[1]U.S. Geological Survey
[2]CSIRO

Geological structures key to understanding groundwater resources in Timor-Leste's Baucau Plateau are mapped using an airborne electromagnetic (AEM) survey. A comprehensive assessment of model structural uncertainty is conducted using a Bayesian Markov chain Monte Carlo algorithm, and an approach for translating geophysical to geological model uncertainty is introduced. A prominent feature of the Baucau survey is a very high-contrast transition from resistive limestone materials to conductive clays, which is well-resolved from the AEM analysis. The inferred 3D geometry of potentially water-bearing limestone units that overly relatively impermeable clays is a key outcome of this analysis, and will be the focus of future ground-truthing efforts.