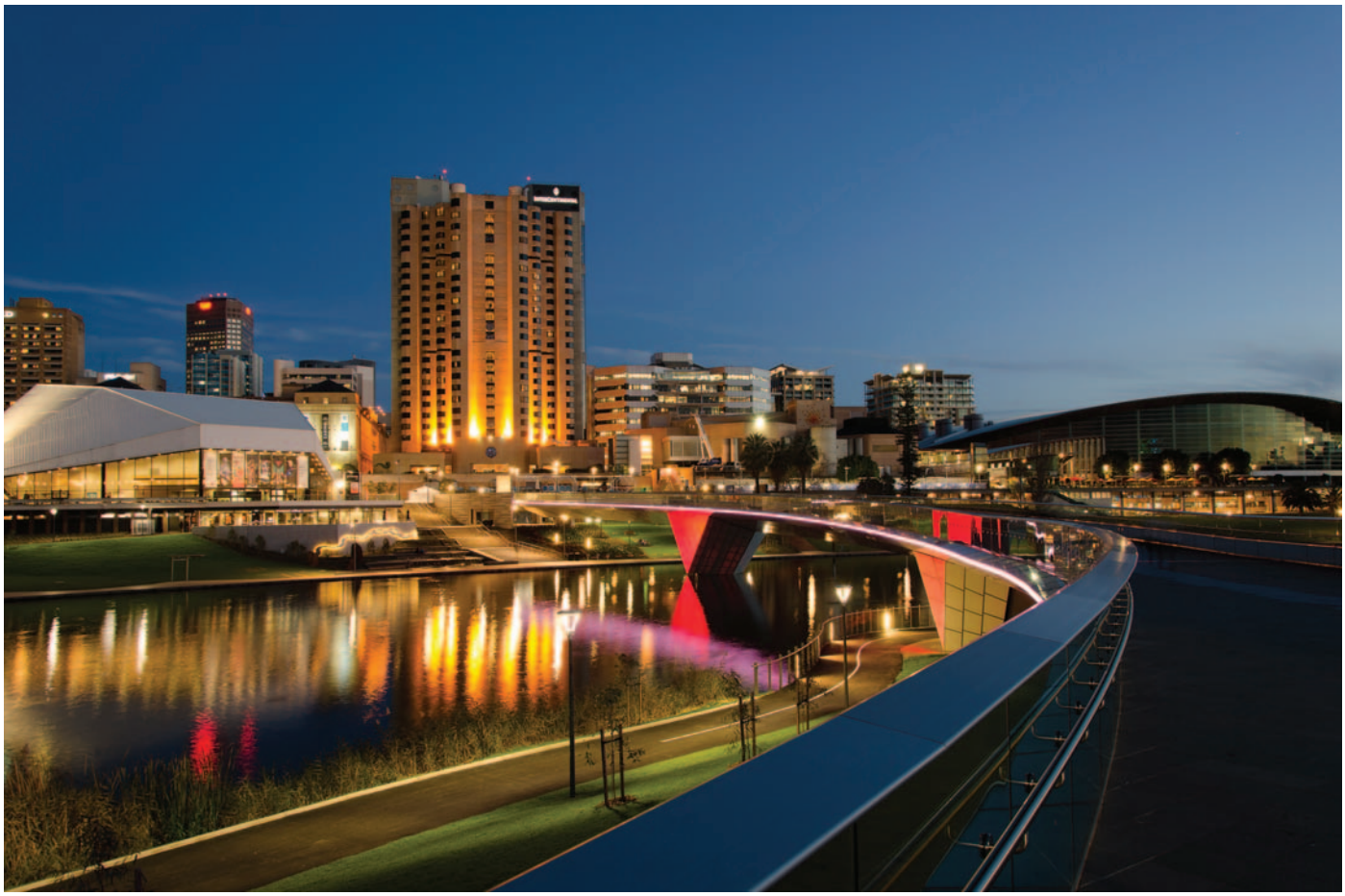
10.1071/PVv2016n183p83

ASEG-PESA-AIG 2016
25TH GEOPHYSICAL CONFERENCE & EXHIBITION

Interpreting the Past, Discovering the Future

SECTION 3
ABSTRACTS



Australian Society of Exploration Geophysicists

PESA Petroleum Exploration Society of Australia

AUSTRALIAN INSTITUTE OF GEOSCIENTISTS

Monday 22 August 2016

1040–1220
Monday 22 August 2016

Petroleum 1.A – Offshore Case Studies

BASEMENT INFLUENCES ON STRUCTURAL STYLES IN THE BREMER AND EYRE SUB-BASINS, SOUTHERN AUSTRALIA

Jane Cunneen, Fletcher Pym and Chris Elders*
Curtin University, Australia

The Bight Basin on the southern margin of Australia is nearly 2000 km wide from west to east and overlies a number of different basement terranes (Figure 1). Major basement terrane divisions occur between the basement of the Ceduna delta and the Eyre and Bremer sub-basins, resulting in changes in structural styles in the overlying basin successions.

The Eyre Sub-Basin overlies the boundaries of the Proterozoic Madura and Coompana basement provinces, which are separated by the Mundrabilla shear zone. The shear zone is a N-S trending, continent-wide structure visible in magnetic data which appears to extend offshore in the Eyre Sub-Basin and is also visible as a north-trending present-day fault scarp in the onshore Eucla Basin. Seismic data interpretation suggests that the shear zone steps to the east in the region of the Jerboa-1 well. Differential movement across the shear zone during Jurassic-Cretaceous rifting may have influenced the location of depocentres within the Eyre Sub-Basin.

Overlying the Albany Fraser Orogen's northern foreland, the Bremer Sub-Basin is dominated by WSW-ENE trending half graben structures and large rollover anticlines associated with Jurassic-Cretaceous rifting. The basin is divided by a N-S trending basement structure, visible in gravity data, and in the overlying sedimentary succession as a broad zone of subsidence with several periods of reactivation. Similarities between this structure and the shear zone in the Eyre Sub-Basin suggest they may have a similar origin.

KRAKEN 3D – ACQUISITION TO INTERPRETATION ON THE EDGE OF THE BROWSE

*Jarrod Dunne**
Karoon Gas Australia, Australia

The broadband Kraken 3D Marine Seismic Survey was acquired during 2013 in the outer Browse Basin exploration permit WA-314-P with the specific goal of assessing risk and volumes at the Elvie prospect. The survey was acquired over a highly rugose sea floor, comprised of deep slump canyons that overlie a steeply prograding Miocene carbonate sequence.

Multiple attempts at processing the seismic data have already been made; including a post-stack time migration (a fast-track volume), pre-stack time and pre-stack depth migration. Conventional processing and pre-stack depth migration approaches were unable to fully resolve short-wavelength velocity anomalies below the sea floor that cause obvious residual imaging problems and impact upon depth conversion and seismic amplitude interpretation. A geomechanical pre-stack depth migration now underway to hopefully address the remaining imaging concerns.

Overall, the Kraken 3D is considered to be a significant improvement over the pre-existing 2D seismic. Interpretation was performed largely in the depth domain, although ties to nearby wells were made in the time domain using legacy 2D and 3D seismic. Mapping has further matured the Elvie prospect, which is a robust 4-way dip closure located on the divide between the Caswell and Seringapatam Sub-basins. The survey provides strong evidence for a thick top seal in the form of deep-marine muds of Miocene age, although there is evidence of minor seepage through a thin flank of the sealing unit. These shallow amplitude indicators, nearby surface seeps and pockmarks near the sea floor provide additional support for a working petroleum system. The Elvie structure appears to be draped by potentially high quality turbidite reservoirs of most-likely Paleocene age.

MULTI-SOURCE DESIGN AND PENTA SOURCE CASE STUDY FROM THE NWS AUSTRALIA

Edward Hager[1] and Phil Fontana[2]*
[1]Polarcus, Singapore
[2]Polarcus, UAE

Marine towed streamer acquisition has been largely restricted to just a few geometries which are determined by the streamer separation and number of sources. Most acquisition uses two sources with 100m streamer separations, or sometimes 75m and 50m for higher resolution surveys. Greater flexibility can be gained by using more than two sources and this leads to a range of design options more commonly associated with land acquisition. The aim here is to allow greater tuning of the acquisition to meet efficiency, quality or time restraints of the survey so that so a better match is obtained between the actual and desired survey.

The use of multiple sources is in part enabled by the commercialisation of interfering shot energy removal which has long been practiced in land seismic, but is much more challenging with marine streamer data due to the lack of azimuthal and offset variation of the source positions relative to the receivers. The ability to remove interfering shot energy means shotpoint intervals can be reduced, enabling multi-source designs by increasing inline fold, which is needed for successful processing of the data in domains such as 2D CMP and common-trace.

With triple sources we show that the options are greatly increased to either improve efficiency or quality and sometimes both, but we can also consider 5 or penta sources with which we obtain very high density data – 6.25m cross-line cells – with acquisition efficiency.

A 400km^2 survey was acquired on behalf of Quadrant Energy using the 5 source method and in addition a smaller 50km^2 using a conventional geometry. Direct comparisons can be made between the geometries and the simple fast-track processing shows the benefits of decreasing the cross-line sampling to fully realise the benefits of broadband data as high-frequencies are fully sampled in the cross-line domain.

FIRST RESULTS OF INAUGURAL DEPLOYMENTS OF THE AUSTRALIAN NATIONAL OCEAN BOTTOM SEISMOGRAPH FLEET

Alexey Goncharov[1], Ashby Cooper[2], Peter Chia[3] and Michal Malinowski[4]*
[1]Geoscience Australia, Australia
[2]University of Tasmania, Australia
[3]Shell Australia, Australia
[4]Polish Academy of Sciences, Poland

The Australian National Ocean Bottom Seismograph Fleet is part of AuScope's Australian Geophysical Observing System (AGOS) – an initiative of the Australian Government funded through the Education Investment Fund. These instruments will greatly contribute to the understanding of the crust beneath oceanic basins surrounding Australia. In 2014–15 the Australian National OBS Fleet was utilised by the petroleum industry on a number of seismic surveys. High-quality data were recorded at all OBS deployment sites, often to offsets sufficiently large to detect Pn phases – refractions from the upper mantle. Analysis of earthquake data recorded during marine seismic surveys suggests strong interaction between anthropogenic signals (airgun source, vessel noise) and the natural environment, and allows arguing that in some instances earthquake energy contaminates marine reflection data in the frequency pass-band needed for petroleum exploration. Recording earthquake and airgun signals at fixed locations opens up a completely new possibility for calibration and comparison of those signal strengths and spectral compositions.

1040–1220
Monday 22 August 2016

Petroleum 1.B – Gravity & Applications

COMPARISON OF SATELLITE ALTIMETRIC GRAVITY AND SHIP-BORNE GRAVITY – OFFSHORE WESTERN AUSTRALIA

Asbjorn Norlund Christensen[1] and Ole B. Andersen[2]*
[1]Nordic Geoscience, Australia
[2]DTU Space, Denmark

Since 2010 several new satellite altimetry missions have commenced delivering altimetry-derived gravity data with a global offshore coverage and with a quality in many regions nearing that of ship-borne gravity observations. This is resulting in greatly improved global offshore high resolution gravity fields.

The DTU13 and Sandwell and Smith's v23.1 grids of altimetric gravity anomalies from offshore Western Australia are compared with ship-track gravity anomalies computed from the Geoscience Australia marine gravity database. The standard deviation of the difference between the ship-borne gravity data and the satellite altimetric gravity data is 3.1mGal for the DTU13 data and 3.3 mGal for Sandwell and Smith's v23.1 grid. In water depths less than 20m we observed significant differences between ship-borne gravity and altimetric gravity. Over the sampled wavelengths, the DTU13 altimetric gravity data appears to have the best resemblance to the reference marine gravity data, exhibiting the overall least difference amplitude over most wavelengths.

INTERPRETING THE DIRECTION OF THE GRAVITY GRADIENT TENSOR EIGENVECTORS: THE MAIN TIDAL FORCE AND ITS RELATION TO THE CURVATURE PARAMETERS OF THE EQUIPOTENTIAL SURFACE

*Carlos Cevallos**
CGG, Australia

Rotating the gravity gradient tensor about a vertical axis by an appropriate angle allows one to express its components as functions of the curvatures of the equipotential surface. The description permits the identification of the gravity gradient tensor as the Newtonian tidal tensor and part of the tidal potential. The identification improves the understanding and interpretation of gravity gradient data. With the use of the plunge of the eigenvector associated with the largest eigenvalue or plunge of the main tidal force, it is possible to estimate the location and depth of buried gravity sources; this is illustrated in model data and applied to FALCON airborne gravity gradiometer data from the Canning Basin, Australia.

FULL SPECTRUM GRAVITY – IMPROVING AGG DATA QUALITY AT BOTH ENDS OF THE SPECTRUM

Chris van Galder and Mark Dransfield*
CGG, Australia

Three major developments provide improvements in the spatial resolution, long wavelength response and noise reduction in airborne gravity gradiometer data. The world's first commercial strap down gravimeter, sGrav, has achieved the same levels of data quality at long wavelengths as stabilized platform systems. With a repeatability of 0.71 mGal RMS at 300 s filtering, it is ideally suited to augment the long wavelength airborne gravity gradiometer data. The sGrav data is incorporated into the airborne gravity gradiometer processing stream by a modified conforming technique that first converts the gravity data to gravity gradients and then merges the result with the gradients from the gravity gradiometer. This improved process has advantages for conforming gravity gradiometer data to any regional gravity data.

Processing gravity gradient data routinely involves low-pass filtering which limits the spatial resolution. A new processing method increases this resolution by splitting the acquisition noise from the geologic noise and then removing the acquisition noise. This method has reduced noise amplitude densities, in some cases by 50%.

1040–1220
Monday 22 August 2016

Minerals 1.C – Characterising Cover (1) – Passive Seismic

PASSIVE SEISMIC SURVEYING FOR DEPTH TO BASE OF PALEOCHANNEL MAPPING AT LAKE WELLS, WESTERN AUSTRALIA

Matthew C. Owers[1]*, *Jayson Meyers*[1], *Brenton Siggs*[2] *and Matt Shackleton*[2]
[1]Resource Potentials, Australia
[2]Goldphyre Resources, Australia

Goldphyre Resources Limited (Goldphyre) undertook a passive seismic survey over parts of the Lake Wells project using Tromino 3G seismometers. Modelling of the passive seismic survey data has defined the depth to bedrock and location of a deep, E-W trending paleochannel system occurring beneath a broad salt lake playa, where underlying Cainozoic paleochannel deposits likely form a reservoir system for potash brines. Drilling by Goldphyre supports these findings. A total of 180 readings were acquired along six survey line traverses over the salt lake, spaced 1,200 m to 2,100m apart on average, using four Tromino seismometers and 20 minute recording times. The passive seismic data were analysed using the H/V spectral ratio (HVSR) method, whereby the spectral ratio of the horizontal and vertical component data are assessed to determine a resonant frequency of an upper softer layer having low S-wave velocity sitting above a high S-wave velocity bedrock. The depth of the upper layer is related to the resonant frequency and S-wave velocity by a simple formula: $f_0 = V_s/(4h)$, where f_0 = peak frequency in Hz, V_s = shear wave velocity in m/s and h = thickness in m.

The modelled passive seismic survey depth to bedrock estimation has delineated a paleochannel system over 20 km long, up to 4 km wide and up to 170 m deep. In addition, the paleochannel system was found to branch to the northwest and southwest, and remains open in these directions. A paleochannel of these dimensions can potentially provide significant high-grade sulphate of potash (SPO) mineralisation hosted in the paleochannel brines.

The passive seismic method is commonly used for seismic hazard mapping, and has not been used extensively for mineral exploration up to now, as very broadband seismometers have typically been used in array configurations that take significant time to setup and record data. The Tromino seismometers are self-contained, lightweight, portable and very simple to use. The HVSR method of analysis allows the user to quickly estimate the thickness of softer sediment cover over hard basement rocks ranging from 0 to 500m. This method has many applications for mineral exploration, and it may become a standard survey tool to predict thickness of cover deposits and reduce drilling costs.

BENCHMARKING PASSIVE SEISMIC COVER DEPTH ASSESSMENTS

Sarah Buckerfield, Karol Czarnota and Alexei Gorbatov*
Geoscience Australia, Australia

Passive seismic techniques utilise the properties of ambient seismic waves to infer information about the structure of the subsurface, namely the depth(s) at which significant impedance contrasts occur. Geoscience Australia has recently conducted three passive seismic surveys to assess the suitability of two passive seismic methods, the horizontal over vertical spectral ratio (HVSR) and spatial autocorrelation (SPAC) techniques, for estimating cover depth over crystalline basement. Both techniques rely on ambient seismic noise in the form of surface waves. The HVSR technique involves measurement of the horizontal and vertical components of ambient seismic noise at an individual site. Where an impedance contrast exists, a maximum is observed in the HVSR value at a frequency directly dependent on the interface depth. The SPAC technique utilises dispersion observed in surface waves, which is also dependent on interface depth. Shear wave subsurface velocity profiles are constructed through inversion of the HVSR and/or SPAC curves.

The logistically simpler HVSR method, requiring only one seismometer, was found to produce estimates with significantly lower error than estimates from SPAC for depths up to 300 m in the Murray Basin, where unconsolidated to semi-consolidated Cenozoic sediments overly Paleozoic crystalline basement. Both HVSR and SPAC methods failed to resolve the target interface with the exception of one site in the Gawler Craton, located at a depth of 900m. Further work is planned for these data with different processing techniques. The HVSR technique produced estimates consistent with other geophysical techniques (airborne electromagnetic, refraction seismic, and magnetotelluric methods) for the majority of sites in the Thomson Orogen, where the Mesozoic Eromanga Basin, Cenozoic cover, and regolith associated with both these stratigraphic groups overly crystalline basement to a depth of up to 550 m. The accuracy of these profiles will be verified with stratigraphic drilling.

Results from these three surveys provide strong support for the passive seismic technique, in particular the single station HVSR method, as a highly effective and logistically low-cost and simple tool suitable for mapping cover depth in many regions of interest across Australia.

EFFECTIVE MINERAL EXPLORATION UNDER COVER: ADDRESSING THE CHALLENGE USING PASSIVE SEISMIC METHODOLOGY

*Nicholas R.A. Smith**
PassiveX, Australia

Passive seismic methodology is becoming a popular tool for estimation of cover depth, cover velocity structure and basement topography for mineral exploration applications. Analysis of passive seismic array data gives information on wavefield characteristics and constrains shear-wave velocity structure. Single station techniques are useful as a tool to rapidly estimate cover thickness but require further information from drill holes or array techniques for robust interpretation. The combined use of array and single station techniques provides an effective cover depth mapping methodology and allows for highly flexible survey design, adaptable for a range of applications. This paper

provides a summary of relevant passive seismic techniques and overview of their effective use with several example mineral exploration scenarios.

1040–1220
Monday 22 August 2016

Minerals 1.D – Distal Footprints (1) – Case Studies

UNDERSTANDING THE 3D STRUCTURE OF THE GILMORE FAULT ZONE THROUGH GEOPHYSICAL MODELLING: IMPLICATIONS FOR LACHLAN TECTONIC RECONSTRUCTIONS

Deepika Venkataramani[1]*, *Robert Musgrave*[2] *and David Boutelier*[1]
[1]University of Newcastle, Australia
[2]Geological Survey of New South Wales, Australia

This study aims to clarify the tectonic evolution of the Lachlan Orogen by modelling the subsurface morphology of the Gilmore Fault Zone (GFZ). The GFZ marks a distinct geophysical contrast between (high gravity, low magnetic intensity) high-grade metamorphic rocks found in the Wagga metamorphic belt (WMB), to the west, and the (low gravity, uniformly high magnetic intensity) low-grade volcanic rocks found in the Macquarie Arc and Silurian rift basins to the east. Understanding the structure of this fault at depth should provide constraints on existing models for the tectonic evolution of the Lachlan Orogen.

Subsurface structure around the GFZ in the vicinity of Barmedman has been inverted by iterative 2.5D potential-field modelling of gravity and magnetics, constrained by pre-existing reflection seismic profiles, potential-field interpretations by previous workers, and physical properties data collected on representative lithologies.

Preliminary findings show that the surface structure mapped as the Gilmore Fault is an east-dipping, shallow thrust fault, and doesn't correspond to the major crustal 'suture' envisaged in regional tectonic studies. It is a secondary antithetic structure off the main west-dipping, crustal penetrating fault that separates the Macquarie arc and the WMB. Another, steeper west-dipping fault cuts these structures and separates the WMB from the Silurian Tumut Trough. This larger structure defines the regionally extensive tectonic feature of the GFZ. The trace of the mappable Gilmore Fault (as opposed to the GFZ) is curved, and terminates abruptly to the north, indicating the Gilmore Fault is the base of a series of thrust flakes imposed on the pre-existing main fault in the GFZ.

West-dipping crustal-penetrating thrust faults east of the GFZ are indicative of successive collision, accretion and extension events. Thus far the modelled structure of the GFZ is not consistent with the terrane accretion model but is consistent with the accretionary orogen and orocline model.

2½-D INVERSION CONSTRAINTS ON THE PALINSPASTIC RETRO-DEFORMATION OF SILURO-DEVONIAN STRUCTURES IN THE BLACK RANGE REGION, WESTERN VICTORIA – THE 'CRAB NEBULA' UNTANGLED

Phil Skladzien, *Ross Cayley, David Taylor and Mark McLean*
Geological Survey of Victoria, Australia

The Stavely Arc developed during the Cambrian above a continent (west) dipping subduction zone within the Grampians-Stavely Zone in present-day western Victoria. Siluro-Devonian regional dextral trans-tensional strike-slip faults recently mapped by the Geological Survey of Victoria in Cambrian basement, previously only recognised in Grampians Group cover, have segmented what was a relatively simple Cambrian configuration of Stavely Arc volcanic fault slices into a complex array of segmented and variably rotated arc fragments, including the until now enigmatic 'Crab Nebula' in the Black Range.

Inversion of magnetic data has provided an understanding of the 3D geometries of the three volcanic belts in the Black Range. Applying this understanding, together with over-printing criteria evident in filtered potential field data, within the context of a trans-tensional strike-slip stress regime, has enabled a retro-deformation of the Black Range belts into a single, west dipping belt of arc volcanics – an untangled, pre-Silurian 'Crab Nebula'. The proven prospectivity of the Black Range Belt (by the presence of the McRaes/Eclipse prospect) can now be extended to all three of the Black Range belts.

THE DISCOVERY OF THE ARTEMIS POLYMETALLIC DEPOSIT

A.D. Thompson and R.B. Flint*
Minotaur Exploration, Australia

The Artemis Cu-Au-Zn-Ag deposit is located approximately 43 km southeast of Cloncurry and 19 km west of Eloise in northwest Queensland. The deposit, hosted within the Paleoproterozoic Mount Norna Quartzite unit which is part of the Lower Soldiers Cap Group, is a steeply-dipping massive sulphide body. The Artemis deposit was discovered by Minotaur in July 2014, only 9 months after taking possession of the project. The deposit is a new type of mineralisation that has previously not been identified in the Cloncurry district. The discovery was made by meticulously piecing together the historical geophysical and geological data, complimented by new geophysical data sets including airborne EM and ground EM to improve the understanding of prospective targets throughout the area. The dominant sulphide within the deposit is pyrrhotite, hence the deposit is highly conductive. Airborne and ground EM techniques were therefore the main tools in resolving the mineralisation. The pyrrhotite is non-magnetic and therefore the deposit has no discernible magnetic signature and magnetics played no part in the discovery process. The deposit had no associated surface geochemical anomalism and very little alteration, making this deposit geologically difficult to find and essentially reliant on EM techniques in making the discovery.

APPLICATION OF VERTICAL ELECTRICAL SOUNDING METHOD TO IDENTIFY DISTRIBUTION OF HOT GROUNDWATER AROUND THE HOTSPRINGS IN GEOTHERMAL PROSPECT AREA

Mariyanto and Has Priahadena*
Institut Teknologi Bandung, Indonesia

Field survey with geoelectric method has been conducted in the Songgoriti geothermal prospect area, Malang, Indonesia. This area is located between Mount Arjuno and Mount Welirang. The aim of this study is to identify the distribution of hot groundwater. Subsurface resistivity data acquisition is done by using Vertical Electrical Sounding (VES) in the four sounding points around the hotsprings with a maximum path length of 160 meters. Data from this measurement is the apparent resistivity that be a response model of the subsurface rock model parameters at each depth. The true resistivity of the subsurface model parameters is determined by inversion modeling. Result of data processing generates a resistivity model of each layer of rock at depth. This study successfully estimate the hot groundwater aquifer layer in the study area. The layer of hot groundwater aquifer is identified by low resistivity in the VES-1 point, VES-2 point and VES-3 point with different depth and thickness. Resistivity of hot groundwater layer is about 19.5–43.1 ohmmeter with the largest thickness in VES-3 point with the direction of orientation from Mount Welirang to southeast.

1040–1220
Monday 22 August 2016

Near Surface/Engineering 1.E – Hazards and Engineering

FINDING BEDROCK IN UNCONTROLLED CLAYEY FILL – SUCCESS WITH GPR PROFILING

*Cara Danis and Roderick Lawrence**
Macquarie University, Australia

GPR in clay rich environments is often assumed to yield poor results due to signal attenuation, however it can still be possible to penetrate deep enough to reflect off targets of interest. Finding the bedrock level in an old quarry filled with clay and building rubble was successful using GPR reflection image profiling primarily due to the fact the fill material had previously been dewatered. Distinctive layers were observed in the fill material which when drilled corresponded to specific dominant material types. It appears the compaction level of the clay and the moisture content of the fill were important factors in the success of the GPR profile.

AN INTEGRATED GEOPHYSICAL SURVEY AT A LANDSLIDE-PRONE AREA

Koya Suto[1], Milovan Urosevic[2], Sinisa Arsenovic[3] and Jun Sugawara[4]*
[1]Terra Australis Geophysica, Australia
[2]Curtin University, Australia
[3]CTU-IPKIN, Bosnia and Herzegovina
[4]WorleyParsons, Australia

A heavy rainfall of May 2014, caused an extensive disaster to the catchment of River Sava in Serbia and Bosnia and Herzegovina (BiH). The number of landslides exceeded 2000 in Serbia and BiH. This prompted an urgent investigation of the areas which have potential of further landslide.

Association of Geoscientists and Environmentalists of Serbia (AGES) initiated a project of geophysical investigation of these areas supported by Geoscientists without Borders (GwB) of Society of Exploration Geophysicists (SEG). Over twenty students participated from three countries and more than ten technical professionals from six countries joined in the project.

Reflection seismic, MASW and resistivity surveys were carried out in the Vrazici area in BiH in June 2015. Two survey lines were surveyed totaling about 120 meters along a slope of grassland and orchard.

A clear increase of S-wave velocity from 250 to 350m/s at about 3 to 5m below the ground surface is observed by the MASW analysis, which is consistent with the reflection profile at the same area. This depth roughly corresponds to the resistivity boundary at 80 ohm m. It is interpreted the interface between soft soils and relatively competent rock. The depth profiles of these boundaries show that the soft soils are thicker toward the lower part of the slope. This landslide can be classified as Varnes's classification 'earth slide or earth flow'.

3D AEROMAGNETIC IMAGING OF IWATE VOLCANO, NORTHEAST JAPAN

Shigeo Okuma[1], Tadashi Nakatsuka[1] and Ryota Kageura[2]*
[1]Geological Survey of Japan, Japan
[2]Nippon Engineering Consultants, Japan

Iwate volcano, northeast Japan is an active Quaternary volcano and is comprised of two parts: West-Iwate and East-Iwate. These bodies are underlain by early–middle Pleistocene volcanic rocks. In 1999, fumarolic areas were newly emerged along the ridge between Ubakura and Kurokura Mountains in West-Iwate and Iwate volcano was thought that an eruption was impending in 2000. However, the fumarolic activity has decreased since its peak in July 2001, and the disaster seems to have passed.

In late 2000, a helicopter-borne EM and magnetic survey was conducted over Iwate volcano to better understand the subsurface structure of the volcano related to the ongoing volcanic activity. Recently we have conducted three-dimensional (3D) imaging of Iwate volcano to constrain its subsurface structure. Our model indicates that magnetization highs occupy the main edifice of East-Iwate, which reflects the surface and/or subsurface distribution of basaltic lavas. Meanwhile, magnetization lows are dominant inside the summit caldera of West-Iwate except for a magnetic high over the Onashiro lava flow. Magnetization highs are also distributed on the northern and southern slopes of West-Iwate but local magnetization lows lie on the heads of narrow valleys, corresponding to hydrothermal altered areas. These hydrothermal altered areas are also characterized by resistivity lows observed by the Airborne EM survey.

Although the imaging improved our understanding of the surface and subsurface distribution of volcanic rocks in Iwate volcano, some limitations exist. No information about the magmas which should have intruded during the recent eruptive crisis was obtained by the imaging. The small magnetic contrast between the intruded magmas and their host rocks is the most probable reason.

DELINEATION OF TUNNEL VALLEYS ACROSS THE NORTH SEA COASTLINE, DENMARK BASED ON REFLECTION SEISMIC DATA, BOREHOLES, TEM AND SCHLUMBERGER SOUNDINGS

Theis Raaschou Andersen[1], Flemming Jørgensen[2] and Steen Christensen[3]*
[1]VIA University College, Denmark
[2]Geological Survey of Denmark, Denmark
[3]University of Aarhus, Denmark

Buried tunnel valleys are elongated depressions eroded into the substratum during the Pleistocene glaciations. Nine such valleys are mapped on- and offshore in a 300 km^2 area located at the Danish North Sea coast. The delineation of the buried valleys is based on an extensive data set consisting of on- and offshore 2D seismic data, TEM (Transient Electro-Magnetic) soundings, Schlumberger soundings, and boreholes. The valleys are observed as discrete incisions with three overall orientations: SSE–NNW, ESE–WNW, and SSW–NNE. They have depths between 75 and 185 m, widths up to 1.8 km, and lengths from 7 to 25 km. The infill comprises till, glaciofluvial sand, and glaciolacustrine clay and silt. Younger tunnel valleys are found to often re-use pre-established valleys generating cut-and-fill structures which are clearly revealed on the reflection seismic profiles. Cross-cutting relations, preferred orientations, and morphology support that three of the tunnel valleys cross the North Sea coastline. It is suggested that the nine valleys were formed during at least six events that occurred through one or more pre-Weichselian glaciations.

1345–1500
Monday 22 August 2016

Petroleum 2.A – Onshore Case Studies

NEW INSIGHTS INTO THE PETROLEUM POTENTIAL OF THE ONSHORE OTWAY BASIN, VICTORIA AUSTRALIA

Lucas McLean-Hodgson and Bruce McConachie*
SRK Consulting, Australia

A seismic attribute study was conducted over a subset of data located in the onshore area of the Otway Basin, Victoria. Attributes were developed from the original legacy processed seismic data including energy and frequency attributes. With investigation and analysis it was possible to identify an amplitude anomaly with multiple stacked attribute anomalies directly related to reservoir levels with observed hydrocarbon shows from legacy well data close to the structure. This study combined with a new independent evaluation of the exploration potential revealing thickening and extension of an excellent reservoir and indications of trapped hydrocarbons that have previously gone unnoticed on data acquired in the 1980's.

Evaluation of the well data identified a thick sequence of stacked sandstones representing a facies change of the lower Eumeralla Fm. Identification of anomalous energy and frequency and combined with a neural network chimney model that demonstrates a gas cloud overlying the reservoir interval; presents a clear target for further evaluation.

Seismic mapping identified potential closure from a coarse 2D seismic grid. The nearby Greenslopes-1 well, located in a highly structured zone, represents high risk leak potential from migrated hydrocarbons and was drilled in a zone of low seal potential. This well however, provides an excellent test of the good quality reservoir potential at the level of the interpreted anomalous energy and frequency attributes.

Deterministic volumetrics of the prospect assuming a 70% recovery factor estimate recoverable gas volumes of 108 BCF. If a 10 barrel/MMCF ratio is assumed for condensate then the estimated recoverable condensate volume is estimated at 1.08 MMBBL. The overlying gas cloud potentially indicates significant liquids enrichment and it is likely the reservoir contains a fully saturated hydrocarbon charge.

Due to the current moratorium for onshore oil and gas drilling in Victoria the target will undergo further evaluation to assess the oil potential.

EXPLORING THE SUB-SALT PLAY IN THE FRONTIER AMADEUS BASIN – INSIGHTS FROM REGIONAL 2D SEISMIC AND POTENTIAL FIELD DATA

Emma Hissey[1], Jennifer Clifford[1] and Tim Debacker[2]*
[1]Santos, Australia
[2]FROGTECH, Australia

Early exploration of the frontier Amadeus Basin in the Northern Territory has been limited due to its size and remoteness, along with complexity of structuring and limited early success. The primary exploration targets of the southern Amadeus are the sub-salt and intra-salt plays of the Neoproterozoic lower Gillen-Heavitree petroleum system. Two wells have tested the sub-salt play, both flowing gas with high helium content, confirming the sealing capacity of the Gillen evaporates despite two significant orogenic events.

In 2013, the first regional framework of 2D seismic was acquired over the southern Amadeus. In areas where seismic coverage is sparse, or of poor quality due to halotectonics, higher spatial density magnetic and gravity surveys have been used to interpolate trends between seismic and well control and create a high resolution depth-to-basement model. Alternate methods of seismic processing have also been trialled to improve sub-salt imaging.

The newly acquired seismic and depth-to-basement model are revealing the architecture of the basin and provide a regional perspective of the sub-salt and intra-salt plays. With improved seismic imaging large sub-salt structures are emerging beneath the complex folds resulting from thin-skinned deformation.

Learnings from the challenges associated with acquisition and processing, along with a better understanding of the complex halotectonics, will have significant implications for future exploration in the region.

WAVEFORM CLASSIFICATION AS A PSEUDO FOR RESERVOIR THICKNESS

Bonnie Lodwick and Lawrence Grant-Woolley*
Santos, Australia

In an incised channel lacustrine shoreface environment the thickness of the incised channels is unknown away from well control. The thickness often varies over short distances and is the predominant control on reservoir quality, as the best

reservoir is in the channels and not the shoreface. A common practice in reservoir modelling is to use an empirical relationship between channel thicknesses to derive width ratios. However, this cannot indicate where other channel bodies are in the area of interest. This study created a relationship between waveform classifications and thickness. The absence of an upper peak-trough within the seismic trace was considered to be indicative of where the upper reservoir unit, incised channels, were present. A relationship was defined whereby the more prominent the upper peak-trough, the more shoreface preserved. Using this method, it is proposed that erosion, and subsequent channel fill, controls the presence of the upper peak-trough. Therefore, waveform classification schemes can be used as a probability map in the static model to control the channel thickness and distribution. The resultant models matched thickness of the upper incised channels at the wells and provide realistically geological models which are able to predict thickness away from well control. At the present, work is ongoing to understand what the waveform represents at wells with a poorer match.

1345–1500
Monday 22 August 2016

Petroleum 2.B – Exploration Techniques

EXPLORATION CHANCE OF SUCCESS PREDICTIONS – STATISTICAL CONCEPTS AND REALITIES

*Balakrishnan Kunjan**
Cue Energy, Australia

There is much confusion in the conceptualisation and application of Chance of Success (COS) Predictions in oil and gas exploration. Although the basic statistical underpinnings of COS predictions are not mathematically complicated, in practice, there appear to be significant difficulties. The consequences of this in many cases include misplaced expectations and hence morale problems from results of exploration which fall outside expectations. In reality, commercial exploration success rates worldwide range from 30–40%. So, there is more pain than not in our industry with the unfolding of expectations. As a result of this, companies have many times reacted in a knee jerk fashion to 'correct' their course which sometimes results in restructuring exploration teams and also changing the course of exploration. Much of the misunderstandings appear to arise from the fact that most small companies are involved in limited trials campaigns where budgets allow the drilling of only a handful of wells over 1–5 years. Realistic COS' can only be based on expectations related to drilling a statistically significant large number of wells. In this paper the vagaries of the actual unfolding of exploration results are simulated using MS Excel software's Random Number Generator function. Despite the intrinsic difficulty of not being able to guarantee any specific success, it will be shown how companies can choose the COS range they should be involved in to enable sustainable growth over the longer term.

IMPROVING PREDICTION OF TOTAL ORGANIC CARBON IN PROSPECTIVE AUSTRALIAN BASINS BY EMPLOYING MACHINE LEARNING

Irina Emelyanova, Marina Pervukhina, M. Ben Clennell and David N. Dewhurst*
CSIRO, Australia

Total organic carbon (TOC) is directly associated with total porosity and gas content and is a critical factor in assessing the potential of unconventional reservoirs. TOC content is only known at the depths where the laboratory measurements on recovered core samples are performed. However, reliable estimation of potential resources can only be based on information about vertical and lateral distribution of organic matter throughout the prospective gas shale reservoir. This information is commonly obtained from conventional wireline logs, such as gamma ray, density, transit time and resistivity. Due to the complexity of unconventional reservoirs, traditional methods based on distinct differences of resistivity, density and sonic velocity of organic matter from those of the inorganic matrix are not always successful. We investigate the best way to predict the TOC using gamma-ray, density, porosity, resistivity and sonic transit time log responses by applying machine learning methods such as Artificial Neural Network (ANN) and Support Vector Machine (SVM). The analysis is done on the data from seven wells drilled through onshore unconventional reservoirs in the McArthur Basin (Northern Territory) and Georgina Basin (Northern Territory and Queensland), Australia. The prediction quality of traditional, multiple liner regression (MLR) and machine learning methods was compared. The most accurate TOC estimates were generated by ANN- and SVM-based nonlinear predictors, followed by the MLR and traditional models. This indicates that geologic complexity affects the relationship between the log response and TOC in the area of interest.

X-RAY COMPUTED TOMOGRAPHY OF STRUCTURES IN OPALINUS CLAY FROM LARGE SCALE TO SMALL SCALE AFTER MECHANICAL TESTING

Gerhard Zacher[1], Annette Kaufhold[2] and Matthias Halisch[3]*
[1]GE, Germany
[2]BGR, Germany
[3]LIAG, Germany

In recent years use of X-ray Computed Tomography (CT) has become more common for geoscientific applications and is used from the µm-scale (e.g. for investigations of micro-fossils or pore scale structures) up to the dm-scale (full drill cores or soil columns). In this paper we present results from CT imaging and mineralogical investigations of an Opalinus Clay core on different scales and different regions of interest, emphasizing especially the 3D evaluation and distribution of cracks and fractures and their impact upon mechanical testing of such material. Enhanced knowledge of the behaviour of the Opalinus Clay as a result of these tests is of great interest, especially since this material is considered for a long term radioactive waste disposal and storage facility in Switzerland. Hence, results are compared regarding the mineral (i.e. phase) contrast resolution, the spatial resolution, and the overall scanning speed.

With this extensive interdisciplinary top-down approach it has been possible to characterize the general fracture propagation in comparison to mineralogical and textural features of the

Opalinus Clay. Additionally, and to the best of our knowledge, a so called mylonitic zone has been observed for the first time in an experimentally deformed Opalinus sample. The multi-scale results are in good accordance with data from naturally deformed Opalinus Clay samples, which allows systematic analysis under controlled laboratory conditions. Accompanying 3D imaging greatly enhances the capability of data interpretation and assessment of such material.

1345–1500
Monday 22 August 2016

Minerals 2.C – Characterising Cover (2) – Potential Fields

LARGE SCALE MAGNETOTELLURIC SOUNDING AT THE PERIPHERY OF THE SONGLIAO BASIN, NE CHINA

Weijun Zhao, Heng Zhu and Qiuhong Ding*
Shenyang Institute of Geology and Mineral Resources, China

Recently, China Geological Survey (CGS) has launched 3D geological mapping programs from regional to local scales. The project Deep geological survey at the periphery of the Songliao Basin funded by CGS was implemented from 2012 to 2014. Its main goals are to reveal the tectonic framework of the Jarud Basin (JB) as well as to identify the strata distribution of Permian Linxi Formation by integrating new electromagnetic data with existing geophysical and geological data since black mudstones in the Linxi Formation have shown the potential of shale gas. The study area is situated in Jarud Banner and Ar Horqin Banner, Inner Mongolia, China. It is covered dominantly with Cretaceous-Jurassic igneous rocks with exception of the small southeastern part. It is tectonically located in the southern Great Khingan Range, western margin of the Songliao Basin, north of Xar Moron Fault.

Over years of 2012 to 2014, a magnetotelluric survey was carried out at the west of the Songliao Basin. A total of 1559 stations including existing MT data on eight NW and five NE profiles were obtained, covering area that exceeds 10,000 km^2. After dimensionality analysis and static shift removal, the nonlinear conjugate algorithm was used to conduct 2D inversion for TM and TE modes. Inversion results revealed numerous large faults, some of which constitute the boundaries of the Jarud Basin, and modified the tectonic framework. Integrated with well logging and geological data, two Paleozoic fault depressions (Gadasu and Hunnitu) and one Meoszoic depression was discovered. Two Paleozoic sag were inferred to be presence of Linxi Fms. One Mesozoic sag was inferred to be hydrocarbon potential. Attention should be paid to Gadasu sag with area of around 500 km^2 since it contains reasonably thick conductive sediments exceeding 4 km in depth which might be black mudstones pertaining to shale gas.

REVISING GRAVITY TERRAIN CORRECTIONS IN TASMANIA

*Mark Duffett**
Mineral Resources Tasmania, Australia

Terrain corrections for determination of the complete Bouguer anomaly are empirically evaluated with respect to a number of different techniques, parameters and digital terrain model data sets, for areas in western and northern Tasmania.

For the most part, while terrain corrections calculated from very high resolution terrain models (1.2 metres or better) are presumed to deliver the most accurate results, those computed for the same area using only a Statewide 25 metre-cell digital terrain model to within two metres of gravity stations correspond remarkably well. Internally consistent comprehensive terrain correction of acceptable yet maximal accuracy can therefore be calculated for all Tasmanian gravity stations, even if very high resolution DTMs are unavailable.

Fully automatic terrain correction computation from two metres to 167 kilometres from gravity stations will result in significantly improved removal of topographic effects over extant manual corrections, which were limited to 22 kilometres.

INVERSE MODELING OF INSAR AND GROUND LEVELING DATA FOR 3D VOLUMETRIC STRAIN DISTRIBUTION

L.A. Gallardo, O. Sarychikhina and E. Glowacka*
CICESE, Mexico

Wide availability of modern InSAR data have made possible the extensive observation of differential surface displacements and are becoming an efficient tool for the detailed monitoring of terrain subsidence associated to reservoir dynamics, volcanic deformation and active tectonism. Unfortunately, this increasing popularity has not been matched by the availability of automated codes to estimate underground deformation, since many of them still rely on trial-error subsurface model building strategies. We posit that an efficient algorithm for the volumetric modeling of differential surface displacements should match the availability of current leveling and InSAR data and have developed an algorithm for the joint inversion of ground leveling and DInSAR data in 3D. We assume the ground displacements are originated by a stress free-volume strain distribution in a homogeneous elastic media and determined the displacement field associated to an ensemble of rectangular prisms. This formulation is then used to develop a 3D conjugate gradient inversion code that searches for the three-dimensional distribution of the volumetric strains that predict InSAR and leveling surface displacements simultaneously. The algorithm is regularized applying discontinuous first and zero order Thikonov constraints. For efficiency, the resulting computational code takes advantage of the convolution integral associated to the deformation field and some basic tools for multithreading parallelization. We test our algorithm on leveling and InSAR field data of the Northwest of Mexico.

1345–1500
Monday 22 August 2016

Minerals 2.D – Distal Footprints (2) – Heat Flow

HEAT FLOW: THE NEGLECTED POTENTIAL FIELD FOR MINERAL EXPLORATION

*Graeme Beardsmore**
Hot Dry Rocks, Australia

This paper argues that heat flow is a valid 'potential field method' for mineral exploration. Certain ore deposits, most notably iron oxide copper gold uranium (IOCG-U) deposits, demonstrably affect the local heat flow and ground temperature conditions. The physics of steady state conductive heat flow is mathematically the same as gravitational acceleration, with buried heat sources analogous to buried masses. Detecting the surface signature of a buried heat source can therefore yield direct evidence of an ore body. The physics is robust, appropriate tools exist for the collection of heat flow data for exploration, and some simple strategies could yield valuable additional information about the subsurface for small marginal cost.

NUMERICAL MODELLING OF THE SYDNEY BASIN USING TEMPERATURE DEPENDENT THERMAL CONDUCTIVITY MEASUREMENTS

Alexandre Lemenager, Craig O'Neill and Siqi Zhang*
Macquarie University, Australia

The Thermal structure of continental crust is a critical factor for geothermal exploration, hydrocarbon maturation and crustal strength, and yet our understanding of it is limited by our incomplete knowledge of its geological structure and thermal properties. One of the most critical parameters in modelling upper crustal temperature is thermal conductivity, which itself exhibits strong temperature dependence. In this study, finite-element geothermal models of the Sydney Basin are generated through the use of deal.II finite element libraries. Basin geometry and structure is adapted from Danis, et al. (2011), which quantified the extent of Triassic sediment, Permian coal measure, Carboniferous volcanics and Basement thickness. We find that temperature-dependent thermal conductivity result in lower lateral variation in temperature compared to constant thermal conductivity models. However, the average temperatures at depth are significantly higher when temperature-dependent thermal conductivity effects are included. A number of regions within the Sydney Basin demonstrate temperature above 150C at depths of less than 2000m in these models, for instance NW of Singleton exhibits a strong thermal anomaly, demonstrating the potential for geothermal prospectivity of the region from experimentally-constrained thermal parameters. Future work will address the repeatability and application of this type of thermal model in areas of varying geology and stratigraphy, as well as refining the model by adding new variables, such as pressure or fine tuning existing variables.

1345–1500
Monday 22 August 2016

Minerals 2.E – 4D Geodynamics (1)

NEXT GENERATION RESOURCE DISCOVERY LINKING GEOPHYSICAL SENSING, MODELLING AND INTERPRETATION

Klaus Regenauer-Lieb, Thomas Poulet and Manolis Veveakis*
University of New South Wales, Australia

We present a status report on the next generation data assimilation techniques for Resource Discovery using a new multidisciplinary fundamental science approach. We combine a recent multiphysics, multiscale geodynamic theory with laboratory and modern computational assisted petrophysics and material science concepts with the aim of linking it 'on the fly' to geological and geophysical field data acquisition. This solid science base is designed to build the platform for enabling a data intensive paradigm for the resource industry. Such a physics-based big data interpretation opportunity has not yet been exploited in current geoscience applications. In other disciplines the approach is, however, fully realized. Owing to its major impact it has been hailed by the US National Research Council [ICME, 2008] as a transformational discipline for improved competitiveness and national security. The approach has been pioneered in polymer sciences, the automotive and aerospace engineering as well as in computational biomechanics, via a so-called 'Integrated Computational Materials Engineering' (ICME) cyber-infrastructure. An ICME system unifies materials information into a multi-scale system that is linked by means of software integration tools to a designer knowledge base containing tools and models from different scales and different disciplines.

MICROSEISMIC CHARACTERIZATION OF BRITTLE FRACTURE MECHANISM IN HIGHLY STRESSED SURROUNDING ROCK MASS

Chunchi Ma[1], *Yupeng Jiang*[2]*, *Tianbin Li*[1] *and Guoqing Chen*[1]
[1]Chengdu University of Technology, China
[2]University of Queensland, Australia

Brittle fracturing of rock mass is a major problem for deep tunnelling or mining in highly stressed rock mass, which could evolve into rockburst hazard and severely undermine the safety of engineering project. In this paper, an advanced microseismic approach is proposed to analyse the mechanism clearly. The results suggest that brittle fracturing contains three energy development stages (i.e. energy accumulation, energy transfer and energy release). Therefore, based on the seismic energy moment and the apparent stress criteria, microseismic events can be classified into six categories that corresponding to the three major categories of stress-adjustment event, deformation-driven event and bursting event. The Energy index develops steadily at first, then followed by a drastic drop and finally ends with a large increment. Cumulative apparent volume grows slowly before a sudden increase. For brittle fracturing development, tensile cracks appear firstly, then the shear cracks and finally the mixed types of cracks.

1530–1710
Monday 22 August 2016

Petroleum 3.A – Seismic Acquisition

MAKING WAVES – TOWARDS A NEW ERA OF SEISMIC RECORDING EQUIPMENT

Andy Bull[1]* *and C.J. Criss*[2]
[1]INOVA Geophysical, UK
[2]INOVA Geophysical, USA

Seismic recording equipment engineering and manufacturing has experienced an evolutionary change in the past 20 years. In addition to great strides in channel count and flexibility, the cost

per channel has also dropped steadily. Seismic contractors utilizing modern equipment can economically shoot in virtually any region that can be accessed with little or no lasting impact on the land and at the same time the quality and utility of the recorded data has increased inversely to the cost.

These evolutionary strides are supported by higher channel counts; lighter more flexible equipment and advances in source technology including operational strategies which produce 20,000 or more source points in a single day of shooting. The growing trend of high density single point sources combined with single point sensors is yielding high fold data of unprecedented quality.

This presentation will explore the more recent advances in seismic equipment development and the operational changes they have enabled to deliver this evolutionary change in the quality and cost of seismic data.

LOW-FOLD 3D SEISMIC: A KEY TO UNLOCKING EXPLORATION POTENTIAL COST-EFFECTIVELY IN THE EROMANGA BASIN

Jennifer Clifford, Alison Goedecke, Michael Giles and Malcolm Horton*
Santos, Australia

ATP 636 is a lightly explored permit on the eastern margin of the Cooper-Eromanga Basin, more than 60km northeast of the Jackson Oil Field in South-West Queensland. Prior to award of the permit, heritage seismic data was very limited and no wells had been drilled within the permit area.

Low-fold 3D seismic was acquired (the 'Gumbo 3D') in place of a more conventional program of 2D seismic followed by 3D seismic. The location of the low-fold 3D seismic survey within the permit was determined using play-based exploration principles.

The seismic data quality compares favourably with full-fold 3D seismic from a structural perspective and provides good imaging of faults and key stratigraphic units. The result is a robust interpretation and a well-defined inventory of prospects and leads.

APPLICATION OF INTERFEROMETRIC MASW TO A 3D-3C SEISMIC SURVEY

Shaun Strong and Steve Hearn*
Velseis, Australia

Multichannel analysis of seismic surface waves (MASW) is well developed for shallow geotechnical applications. The technique has received much less attention in 3D reflection. The primary goal of this investigation is to develop an improved methodology for extracting S-wave receiver statics in 3D converted-wave (PS) reflection surveys.

The main challenge of using MASW in this context is the increased receiver spacing. To overcome this we need to include multiple sources in each dispersion analysis. Unfortunately, adding more sources increases the chance that the dispersion image will be degraded due to lateral near-surface variations. We present a methodology which incorporates interferometry into the MASW method (IMASW). This effectively repositions sources at receiver locations, reducing the region over which lateral variations can contribute to the data.

Application of this approach to a 3D-3C trial dataset provides an alternate approach for determining the S-wave receiver statics solution for converted-wave reflection surveys.

1530–1710
Monday 22 August 2016

Petroleum 3.B – Alternative Technologies

BLACK SWAN AIRBORNE GEOPHYSICAL SURVEY STRUCTURAL INTERPRETATION FOR HYDROCARBONS TARGETING IN THE PERTH BASIN

Peter Kovac[1], *Carlos Cevallos*[1]*, *Jurriaan Feijth*[1] *and Matus Kovac*[2]
[1]CGG, USA
[2]University of Western Australia, Australia

The integrated interpretation of the airborne FALCON® Airborne Gravity Gradiometer (AGG) survey was designed to assist oil and gas producer Empire Oil and Gas in identifying target areas for hydrocarbon exploration in the Perth Basin. It was developed as a synthesis of the geological structure, tectonic evolution and principles of gravity and magnetic data behaviour. The survey identified areas containing large structural leads and trends as the target of future gas exploration activities, including infill 2D seismic acquisition. The prospectivity of some identified leads has been significantly increased by the gas discovery at wells Red Gully North-1 and Gingin-1, located in EP 389 in central Perth Basin.

POTENTIAL FIELD DATA GUIDED SEISMIC FORWARD MODELLING OF BASEMENT STRUCTURES: A CASE STUDY FROM OFFSHORE NILE DELTA BASIN

Said Hanafy[1], *Shastri L. Nimmagadda*[2]* *and Sharaf Eldin Mahmoud*[3]
[1]Tharwa Petroleum, Egypt
[2]Curtin University, Australia
[3]Cairo University, Egypt

The offshore Nile Delta region has huge exploration potential, keeping in view the existing commercial oil and gas fields in and around this basin. The majority of the offshore Nile Delta basin is underexplored. Sparsity of geophysical data coverage and ambiguity in the interpretation of existing geophysical data have held back the exploration for many decades. In order to assess and evaluate the exploration potential, it is important to estimate the depth to the basement, the nature of basement and its topography. Identifying the basement reflector based on the current seismic data is challenging, because of limitations of the resolution and record length of the seismic data. Moreover, an estimation of sedimentary column is paramount for further detailed geological and geophysical investigations. The objective of the research is to perform seismic forward modelling of the basement reflector, guided by gravity and magnetic field data, and minimize the ambiguity involved in a single geophysical method of interpretation. The geophysical properties and their contrasts derived from seismic, gravity and magnetic methods of exploration are various criteria used in the integration and modelling process. Seismic stacking velocity data and depth values interpreted from gravity and magnetic field data are used in the modelling process. The uncertainty in modelling the

basement character is assessed based on the stacking velocities and seismo-geological cross-sections interpreted from 2D seismic data, instead of cross-sections obtained from unreliable seismically derived depth data. The analysis of errors observed in the seismic data due to younger layer-cake reflections interfering with the basement reflector are analysed and the observed errors in the velocity models are accordingly reconciled based on the potential field data. The potential field data interpretation guiding the seismic forward modelling facilitates the redesign process of seismic data acquisition and processing in the hugely unexplored offshore Nile Delta basin in Egypt.

HIGH RESOLUTION MAGNETIC ANOMALY MODELLING AND ITS IMPLICATION FOR PETROLEUM PROSPECTIVELY ON SERAM ISLAND, MALUKU, INDONESIA

H.P. Siagian[1], B.S. Widijono[1], J. Nasution[1], B. Setyanta[1], Nurmaliah[1], Katherine McKenna[2] and Adrian Noetzli[2]*
[1]Center for Geological Survey, Indonesia
[2]GPX Surveys, Australia

An airborne magnetic survey was conducted over Seram Island in 2012. The Total Magnetic Intensity ranged from 41,565.7 nT to 41,715.2 nT. High anomaly were observed with a range between 41,665.7 nT and 41,715.2 nT. These anomalies were predominately located in western part of the survey area with some small high frequencies and a long wave length anomalies present in the southeastern part of the island. The high anomalies have been interpreted as Paleozoic rocks of Taunusa Formation. Medium anomaly range from 41,618.9 nT to 41,665.7 nT are present in the east, northeast and west northwest of Seram Island. This magnetic response has been interpreted to reflects the occurence of Mesozoic rocks from Kanikeh Formation. The low magnetic anomalies which range from 41,565.7 nT to 41,618.9 nT are present in the centre and northeast of the island, and reflects the occurence of Jurassic Manusela Formation. Modelling of the high resolution magnetic anomalies, constrained by well data information, confirms the rock stratigraphy while also indicates folds, thrust fault structures and basement fractures being present over the survey area. The occurence of hydrocarbons in the area have been interpreted to be associated with traps in basement fractures. Areas with similar tectonic structure, as interpreted from the high resolution magnetic data, represent a high potential for the presence of further hydrocarbons. The recommended areas are dominated by basement fractures and thrust fault structures. The modelling shows that the source rock, the Jurassic Kanikeh Formation, has thickness of about 2,623.5 metres. The Kanikeh Formation is estimated to have high porosity because it consists of fractured sandstone (Tjokrosaputro et. al., 1993). From the modelling it is also observed that the cap-rock, the Jurassic sedimentary rocks, have thickness reached of about 1,166 metres.

ANALYSIS OF ELECTROMAGNETIC DEPTH SOUNDING RESPONSES OVER A LAYERED EARTH: INVESTIGATING OIL & GAS SEEPS IN THE PETROLEUM PROVINCES

Shastri L. Nimmagadda[1] and Andrew Ochan[2]*
[1]Curtin University, Australia
[2]Petroleum Exploration & Production Department, Uganda

The present work embodies the results of theoretical and practical investigations of electromagnetic depth sounding using central frequency sounding (CFS) system over a layered earth. Failure of conventional electrical resistivity sounding in the study of geological conditions under resistive overburden calls for variable frequency sounding techniques. Electromagnetic depth sounding which involves the measurement of variation in conductivity with depth is used for solving various geoengineering, hydrogeological and shallow cases of oil & gas seeps associated with stratified earth. The CFS, which is one of the depth sounding techniques involving the measurement of vertical component of magnetic field induced at the centre of a circular or square loop, is considered in the present study for obtaining theoretical responses over a layered earth and its interpretation with shallow oil and gas seeps.

Because of some limitations of contour integration and numerical integration approaches, used earlier, a more rapid digital linear filter technique is adopted for evaluation of the integral involved in the CFS theoretical expressions. Theoretical expressions for frequency-domain soundings written for layered earth models are suitably transformed for evaluation through digital linear filter. Dimensionless normalized vertical magnetic field is computed for different frequencies and loop radii for layered earth models with different layer conductivities and thicknesses. The responses computed for these cases are analysed in terms of resolution characteristics and detectability effects. In frequency-domain sounding, amplitude response curves of layer-sequences show the effect of layer conductivity, layer thickness and loop radius. Separation between individual curves on the sets for amplitude responses normally gives sufficient indications for subsurface conductivity variations of the layered earth cases. The author explores the CFS applicability and feasibility in investigating shallow oil & gas seeps in oil & gas provinces, in particular on the flanks of the rifted grabens and basin margin areas, where sediment-basement contact areas are interpreted.

1530–1710
Monday 22 August 2016

Minerals 3.C – Characterising Cover (3)

MAPPING COVER-THICKNESS TO UNCOVER BASEMENT AND DEEP EARTH ARCHITECTURE AND PROCESSES

Karol Czarnota, Tony Meixner, John Wilford and Alexei Gorbatov*
Geoscience Australia, Australia

Under the UNCOVER initiative it is generally accepted that construction of accurate cover-thickness maps is the most tractable and urgent means of facilitating resource exploration under cover. To meet this goal we have been undertaking benchmarking of various geophysical techniques, constructing a national database of Estimates of Geological and Geophysical Surfaces (EGGS) to store legacy estimates and developing machine learning algorithms to interpolate between these estimates. Benchmarking magnetic top estimates to ~700 drill sites across the Murray Basin highlights the importance of performing estimates using profile data as opposed to grids. Inversion of horizontal to vertical spectral ratio data, derived

from single broadband seismometers, reveals surprisingly robust cover-thickness estimates. While these insights are directly relevant in supporting drilling programs they can also be used to constrain deep Earth architecture and processes. We show that inversion of basin subsidence data can be used to constrain lithospheric thickness and mapped chrono-stratigraphic surfaces can be used to test models of uplift of the Australian continent related to convective flow within the Earth's mantle.

GEOLOGICAL AND COVER THICKNESS MAPPING USING AIRBORNE ELECTROMAGNETIC DATA IN AN UNCOVER APPLICATION

*Ian C. Roach**
Geoscience Australia, Australia

Airborne electromagnetic (AEM) data are an immensely useful tool for mapping cover thickness and under cover geology in Australia. The regional AEM surveys conducted by Geoscience Australia (GA) and other agencies are an ideal starting point for integrating legacy AEM datasets across a range of scales with other information, e.g. borehole stratigraphy and shallow seismic data, as part of a national cover thickness map. Geoscience Australia is working towards this end as part of the UNCOVER Initiative.

NEOTECTONIC INTRA-PLATE FAULT ZONE MAPPING AND HYDROGEOLOGY IN FLOODPLAIN SEDIMENTS: AN INTER-DISCIPLINARY APPROACH

Ken Lawrie[1], Ross S. Brodie[1], Niels B. Christensen[2], David Gibson[3], Larysa Halas[1], Neil Symington[1], Kokpiang Tan[1], Mike Sandiford[4], Sasha Ziramov[5], Milovan Urosevic[5], Elliot Grunewald[6] and Phil Hayes[7]*
[1]Geoscience Australia, Australia
[2]Aarhus University, Denmark
[3]David Gibson Geological Services, Australia
[4]University of Melbourne, Australia
[5]WA School of Mines, Australia
[6]Vista Clara, USA
[7]Jacobs, Australia

Over the past decade, a relatively rich record of neotectonics has been revealed in continental Australia, however very few investigations into the hydrogeological implications have been undertaken. While the most active intra-plate deformation zones are readily identified by seismicity monitoring and satellite and airborne terrain mapping, advances in airborne electromagnetic (AEM) technology and data optimization have made it possible to map numerous, more subtle 'blind' intra-plate fault systems concealed in near-surface floodplain landscapes. To date, fault geometries, displacements, and fault zone properties remain ambiguous due to the combination of AEM footprint resolution, the non-uniqueness of the conductivity models and derived hydrostratigraphy and fault geometry solutions produced by AEM equivalent inversion models, and the inherent uncertainty of stitched 1D AEM inversion models. The resultant uncertainty in fault zone characterisation inhibits investigations into the permeability heterogeneity and anisotropy introduced by these faults, making it difficult to resolve the significance of these structures for groundwater processes.

In this study, a novel, inter-disciplinary approach has been developed that helps characterise the hydrogeology of one such intra-plate fault zone in unconsolidated, near-surface floodplain sediments. The approach integrates the mapping of tectonic geomorphology, with mapping of sub-surface hydrostratigraphy and 'blind' intra-plate fault systems using AEM. Validation of fault zone geometry and displacement at local scales is provided by ground geophysics (e.g. seismic reflection, resistivity and surface nuclear magnetic resonance (SNMR)) and drilling. Fault zone hydrogeology, including permeability variability, has been assessed through the integration of geophysics with hydrochemistry, hydrodynamics, and studies of vegetation response to water availability (using Landsat time-series analysis). A combination of deterministic and stochastic approaches is then used to unravel complex fault zone conduit-barrier system behaviour that determines lateral and vertical groundwater flow, inter-aquifer leakage and recharge. This inter-disciplinary methodology has been used to parameterise numerical groundwater flow models and target potential groundwater resources.

1530–1710
Monday 22 August 2016

Minerals 3.D – Distal Footprints (3) – Case Studies

MAPPING THE PUNT HILL IOCG SYSTEM USING GEOPHYSICAL, GEOCHEMICAL AND SPECTRAL METHODS – AN INTEGRATED APPROACH

Adrian Fabris[1], Laszlo Katona[1]*, Gary Reed[1], Tim Keeping[1], Georgina Gordon[1], George Gouthas[1] and Greg Swain[2]*
[1]Geological Survey of South Australia, Australia
[2]Monax Mining, Australia

Integrated data sourced from drill core geochemistry, spectral logs, petrophysical logs from available holes and geophysical data in and around the Punt Hill Copper-Gold prospect was used to characterise and map an IOCG system and predict prospective areas using a multi-disciplinary approach. Mineral assemblages associated with copper mineralisation were identified from geochemical analysis and spectral logs; density ranges associated with favourable mineral assemblages were noted and density inversions were fitted to these ranges in an attempt to predict similar densities in untested parts of the study area.

Mineral assemblages associated with both prograde- and retrograde-dominated assemblages were found to be associated with copper mineralisation at Punt Hill. Densities associated with the prograde mineralising event were generally higher than those associated with the retrograde mineralising event; both are higher than background density. This provided a basis for fitting the results of density inversions to the known data to map inferred prograde and retrograde alteration within the study area. Inversions were performed at both the regional and deposit scale and were used to identify as yet untested regions with density values that are consistent with known zones of mineralisation and therefore showing high potential for further copper mineralisation.

LOOKING INTO A 'BLUE HOLE' – RESOLVING MAGNETIZATION AND STRUCTURE FROM THE COMPLEX NEGATIVE COOMPANA ANOMALY, SOUTH AUSTRALIA

Clive Foss[1], Gary Reed[2], Tim Keeping[2], Tom Wise[2] and Rian A. Dutch[2]*
[1]CSIRO, Australia
[2]Geological Survey of South Australia, Australia

A large (c. 2000nT amplitude, 50 km diameter) negative amplitude TMI anomaly under the Eucla Basin in southwestern South Australia, long known and referred to as the 'Coompana Anomaly' has been well resolved by a new high resolution (200 metre line spaced, 80 metre ground clearance) survey flown for the Geological Survey of South Australia. We use parametric inversion to simultaneously derive magnetization direction and spatial distribution of magnetizations giving rise to satellite anomalies both above and around the main anomaly. For the two most prominent satellite anomalies these magnetization estimates agree well with estimates derived from the historic data, but the new survey data provides greater confidence, and reliable mapping of many smaller bodies. The improvement in resolution has allowed us to attempt isolation of the anomaly due to the more voluminous, deeper magnetization, but to date we have not yet been able to recover repeatable results for that deeper magnetization. Magnetization intensity estimates for all investigated anomalies are very high, ranging from about 5 A/m to over 20 A/m (equivalent in intensity to magnetizations from susceptibilities of 0.1 to 0.5 SI). The deeper magnetization is well correlated with a negative gravity anomaly, suggesting that the material generating the main magnetic anomaly has a relatively low density.

INTEGRATED GEOLOGICAL AND GEOPHYSICAL INTERPRETATION FOR THE KOODAIDERI DETRITAL IRON DEPOSITS, FORTESCUE VALLEY, WESTERN AUSTRALIA

James Reid[1], James Farrell[1], Glenn Pears[1], Andrew Jaunzems[2], Mike Enright[2] and Mike Haederle[2]*
[1]Mira Geoscience, Australia
[2]Rio Tinto Exploration, Australia

This paper presents a review of integrated interpretation of geophysical surveys with geological data for interpretation and exploration targeting for detrital iron deposits at the Koodaideri Project, Western Australia. Significant previous exploration has been conducted in the area and this has identified a number of detrital iron deposits. The aim of this project has been to integrate all available geoscientific data in order to assess remaining prospectivity of the area and provide a framework for future exploration and evaluation projects.

Previous exploration at Koodaideri has used a variety of techniques including drilling, downhole geophysical logs, sparse refraction seismic, airborne and ground gravity, airborne magnetics and time-domain airborne electromagnetics. Spatial coverage of the individual exploration datasets is irregular, and the first stage of this project has focussed on an area of approximately 42 km × 12 km within which there is reasonably good coverage of all data types. The relatively high data density has allowed the relationships between the various data types to be assessed and effective exploration parameters to be defined.

The larger detrital iron deposits at Koodaideri occur within palaeochannels or depressions within the basement, which is mainly comprised of units of the Wittenoom Formation. The detrital iron deposits are considered to have been sourced from erosion of bedded iron deposits of the Brockman Iron Formation which outcrops on the high ground both upstream and immediately to the southwest of the area of interest. The known deposits generally occur beneath cover of variable thickness of up to 50 m. The detrital deposits themselves may have thicknesses in excess of 100 m in major palaeochannels and sinkholes. The detrital deposits have a higher density than other cover units due to their high iron content (>50% Fe). However, gravity alone is not an effective exploration technique because the gravity signature is complicated by significant variability in the depth to higher density Wittenoom Formation bedrock. A more recent development is use of a modified seismic refraction method (Sparse Refraction Seismic) to constrain the basement topography, and then to model and remove the basement response from the observed gravity data to identify areas of anomalous excess mass. This approach has allowed cost-effective semi-regional exploration and has been successful in identifying all known major detrital iron deposits.

This study extended the excess mass approach by constructing revised basement models from the sparse refraction seismic and drilling and from interpretation of the SkyTEM airborne electromagnetic and drilling. The results show that the basement interface can be interpreted from either the seismic or airborne electromagnetic datasets, although the airborne electromagnetic interpretation is complicated by highly saline groundwater in the northeastern quadrant of the area and by conductive shale units within the Wittenoom Formation bedrock. Almost all of the known detrital and channel iron deposits are spatially associated with an overlying pisolite unit, which can be identified from the magnetic data via its characteristic magnetic texture.

These studies have shown that the derived excess mass is spatially associated with the known detrital and channel iron mineralisation. Significantly, almost all of the known deposits were also successfully identified from the simple geological model, in the absence of drill hole constraints. A number of untested areas of possible mineralisation have been identified, as well as potential extensions or alternate trends to known mineralisation.

The modelling scenarios tested confirmed that the minimum elements for exploration targeting at Koodaideri are a geological model incorporating basement topography, interpreted magnetic domains and geologically constrained inversion of the gravity data.

APPLICATION OF THE AIRBORNE ELECTROMAGNETIC METHOD FOR BANDED IRON-FORMATION MAPPING IN THE HAMERSLEY PROVINCE, WESTERN AUSTRALIA

Regis Neroni, Rory Murray and Doug Kepert*
Fortescue Metals Group, Australia

Stratigraphy of the Hamersley Province in Western Australia, featuring alternating units of banded iron-formations and shales with contrasting electrical properties in a mostly gently undulating shallow dipping layered geometry, is particularly favourable to airborne time-domain electromagnetic mapping techniques. Manipulated vertical cross-sections of modelled conductivity obtained from laterally constrained 1D inversion of SkyTEM^{304} data enable the exploration geologist to interpret weathering profiles, shallow dipping stratigraphy and steep structures, all of which are crucial aspects of bedded iron ore

deposits genesis models. Five potential interpretation pitfalls have nevertheless been encountered. Occasional obvious artefacts can be present in inverted models but their causative sources should be easily identifiable in the measured channel data. The inverted models coherence is generally compromised when acquisition system terrain clearance cannot be maintained below approximately 80 m. The in-loop setup and processing routines have inherent limitations over steep stratigraphy. Complex stratigraphy geometries can result in off line responses to be artificially incorporated in the 1D inverted conductivity cross-sections. Lastly, lateral interfaces between fresh and altered rocks could easily be misinterpreted as fault contacts.

1530–1710
Monday 22 August 2016

Near Surface/Engineering 3.E – New Technologies

EXTRACTING IP INFORMATION FROM AEM DATA TO IMPROVE THE HYDROGEOLOGICAL INTERPRETATION

Andrea Viezzoli[1], Vlad Kaminski[1], Nicholas Ebner[2] and Antonio Menghini[3]*
[1]Aarhus Geophysics, Denmark
[2]Newexco Services, Australia
[3]Aarhus Geophysics, Italy

IP measurements in airborne EM data have not been previously considered for mapping groundwater distribution. IP modelling can be applied to discriminate between co-existing salty aquifers (conductive and non-chargeable) and extensive clay layers (conductive and chargeable); typical in both coastal areas and regions affected by dry-land salinity. The current case study presents the field results from a gold and metal project that had a hydrogeological mapping component to it in central Western Australia. Accounting for IP signal in the forward response was necessary to fit the data in localised areas, which were then interpreted as clay filled (conductive and chargeable) palaeochannels. The synthetic experiments that followed confirm that in favourable conditions, clay derived IP signal can affect the measured AEM response. Conversely, IP information can be recovered from these data, providing an extra physical parameter of value to the hydrogeological interpretation.

TRANSIENT SURFACE IMPEDANCE (TRANSIM) MEASUREMENTS USING DISCRETE LIGHTNING FOR ELECTROMAGNETIC MAPPING AT AUDIO FREQUENCIES

Artyom Emelyanenko and David V. Thiel*
Griffith University, Australia

The paper describes the first field measurements using recently developed TranSIM instrumentation. The method is based on registering horizontal components of electric and magnetic field of distant lightning strokes (sferics). In fact it is an expansion of classical MT method in the VLF frequency range of 3 to 30 kHz thus providing information about conductivity distribution at the depths of approximately 50 to 300 meters.

Measurements are conducted atop basalt body in the vicinity of Ipswich (Queensland) over 16 sites on 2 parallel profiles. From 20 to 50 sferics were registered at every site. Data was processed using short time Fourier transform obtaining spectrograms of electric and magnetic field. Apparent resistivity was calculated and frequency pseudo sections are presented.

The apparent resistivity sections were matched with geological scheme of the site. Highly resistive zones correlate with high thickness of a basalt layer and conductive zones show where the underlying basalt sandstone is closest to the surface.

RAPID ACQUISITION OF AUDIO FREQUENCY MAGNETOTELLURICS

Barrett Cameron[1] and Peter Wolfgram[2]*
[1]Rapid Geophysics, Australia
[2]Retiree, Australia

We illustrate that rapid acquisition of audio magnetotellurics (RAMT) is an alternative methodology to construct the impedance tensor. A solenoid is used as the magnetic sensor and a capacitively coupled, long wire antenna (LWA) as the electrical sensor. Recent improvements in data quality, automated processing flows and apparent resistivity to depth transforms resulted in a cost effective and practical alternative for quickly acquiring audio magnetotelluric 1D soundings. Case studies for groundwater, engineering and mining illustrate how the method may be useful for decision making, and hopefully enable more widespread adoption of low cost resistivity measurements.

MAPPING GROUNDWATER AND SOIL MOISTURE USING MULTI-DEPTH ELECTRICAL CONDUCTIVITY DATA FROM TOWED TEM CARTS

*David Allen**
Groundwater Imaging, Australia

Groundwater presence and salinity both correlate with electrical conductivity, a property readily mapped over a swath of depths by various geophysical instruments. Thus, it would seem then that exploration for groundwater could be a simple matter, however, for most groundwater investigations the level of detail of geological complexity demands detailed acquisition and multi-dataset interpretation.

Towed or airborne electromagnetic survey permits multi-layer map coverage of a site as is necessary for revealing geological detail that would make little sense when viewed as individual transects. Further, because electrical conductivity responds to so many natural variables related to groundwater, multi-disciplinary information must be included in the interpretation. In many cases, the footprint of an airborne system will be too large to sufficiently resolve complexity of geology and cultural interference to successfully site bores. In other cases the mobilization cost of an airborne system will, on its own, exceed the exploration budget. In these cases, towed electromagnetic devices including AgTEM$_4$^{TM} cart have a niche.

Exploration depth and resolution of practical towed devices is very limited by their practical size constraints so great care must be taken in other design aspects including effective, robust primary field nulling and maximizing of transmitter loop – receiver loop separation.

Case studies of groundwater exploration demonstrate these geological interpretation and physical design challenges and limitations.

Tuesday 23 August 2016

0830–1010
Tuesday 23 August 2016

Petroleum 4.A – Seismic Facies

SEISMIC FACIES MAPPING – GETTING MORE GEOLOGY INTO YOUR PLAY

*Rob Kirk**
Consultant, Australia

Seismic facies mapping is an underutilized tool for getting extra geology in to your exploration, or development. It is a key component of palaeogeography mapping that help show different types and locations of seals and reservoirs.

Both manual and automated facies mapping, on 2D and 3D seismic, when calibrated to local wells, can help de-risk crucial components of a play.

In many areas today where deep water or new frontier exploration is undertaken, there is often little or no well control and seismic facies mapping, allied to analogues, may be your only tool for getting at the geology in your palaeogeography maps.

This talk will apply geological models to, and discuss, the construction of manual seismic facies maps which are then used to guide automated facies map work.

Manual facies mapping is undertaken once sequence boundaries have been mapped and named. Each different facies identified is given the name of upper and lower boundaries and the facies name and then the horizon is picked so that the facies extent is shown on a base map. Once completed, polygons encompass this facies. The final map uses all polygons constructed, along with well logs for that sequence.

Automated facies maps start with RMS and maximum amplitude maps of the sequence, then possibly of proportional slices within the sequence and then we may construct waveform facies maps or spectral decomposition maps of the interval.

All these maps are considered with the interval's isochron map and at least gamma log windows at wells, with appropriate geology transcribed to finally construct the palaeogeography map of the interval.

CONTROL ON PLEISTOCENE SHELF DRAINAGE BY POST-EOCENE STRATIGRAPHY OF THE GIPPSLAND BASIN

*Mark Bunch**
University of Adelaide, Australia

The Jemmys Point Formation – uppermost member of the cool-water carbonate Seaspray Group – records a terrestrial drainage system that traversed the now submerged continental shelf of the Gippsland Basin during the latest ice age. A partial network of large sinuous channels that includes a few diffuse areas of arced broadening (probably recording local slack-water lacustrine conditions), has been imaged by aeromagnetic survey data and now large-scale 3D exploration seismic data. Channels are well resolved in narrow-band quadrature phase exploration seismic data by a surface probe that runs along the first zero crossing of the seismic wavetrain. This corresponds closely with the modern-day bathymetric surface when assuming a seawater acoustic velocity of 1,500 m/s.

The stratigraphy of these channel features has not been ground-truthed despite the basin being a highly mature and productive petroleum province. In fact, it seems that their distribution is a 'negative' of the distribution of petroleum field areas. This fact leads to the consideration of two hypotheses: ongoing structural inversion of existing trapping structures at depth pushes channels away; or intervening zones of relatively high differential compaction subsidence pull channels towards them. No evidence was found to confirm the former hypothesis but this may be because the rate of local uplift does not outpace shelf-wide sedimentation (so cannot be resolved in seismic or seabed bathymetry data). By contrast, the loci of drainage channels appear to correspond well with regions of the thickest post-Eocene stratigraphy. This suggests that differential compaction subsidence has continued to hold the lowstand drainage system in place since a pre-cursor canyon head network was developed by the Mid-Miocene inversion maximum.

SPATIAL MAPPING OF SEISMIC FACIES VARIATIONS TO MITIGATE RESERVOIR RISK IN COAL PRONE FLUVIAL-DELTAIC SETTINGS

Dylan Cremasco, Yahya Villareal Basman II and Judith Travers*
Santos, Australia

Seismic facies classification has been used to reduce risk in laterally heterogeneous reservoir prediction. Studies were focused on the Barrolka/Coolah/Durham Downs Trend in the south-west Queensland sector of the Cooper Basin. The primary reservoir targets are the fluvial channel sediments of the Toolachee Formation. Historically, well success rates across the area have been low, with highly variable reservoir development and connectivity identified as the limiting factors influencing well performance.

Conventional seismic attribute analysis has typically yielded inconclusive results, often associated to the presence of thick coals that dominate the seismic response. However, recent drilling campaigns utilised seismic waveform classification mapping, which resulted in an increase in technical success rate of wells. This study aims to investigate the concepts behind the success of the waveform classification method and to determine alternate techniques to further delineate reservoir presence.

Key outcomes from rock physics studies indicate subtle variances in the seismic wave shape could be attributed to changing reservoir thickness underlying coal formations. Cross correlation of the wave shape against well results confirmed the concept of dimming seismic amplitude response to be related to increased reservoir thickness. In an attempt to capture the lateral extent of these variances, three adjacent 3D seismic volumes, covering majority of the complex, were subject to a variety of attribute analysis methods. Unsupervised waveform classification was found to be the most efficient and effective method for capturing the dimming seismic reflector, and thus defining the channel trends. The strong correlation between waveform class and reservoir thickness measured in wells enabled the generation of risk-segment maps for the reservoir units.

Observed changes in wave shape on full stack seismic data have been related to lithological variations based on rock physics studies. These learnings have been used to select attribute extraction techniques that can best highlight the wave shape variations. Using seismic facies mapping to enhance reservoir prediction capabilities has reduced reservoir risk and improved the technical success rate of drill targets. The output maps from this study have been used to locate future opportunities in the region.

0830–1010
Tuesday 23 August 2016

Petroleum 4.B – Rock Physics

EFFECTS OF ROCK POROSITY ON ACOUSTIC WAVE VELOCITIES ESTIMATION FROM SONIC LOGS

*M. Farrokhrouz**
University of Adelaide, Australia

Estimation of S-wave velocity from P-wave velocity has been widely used in geomechanical applications as both velocity measurements are not always available. In present study, some of previously suggested equations for estimation of shear velocity have been presented. These equations have local validity and new calibration of constants is needed if used in new region. On the other hand, theoretical background in geomechanics shows linear relationship between the squares of these velocities. Measured data points were tested in this linear equation and it was found that good matching is observed only in clean sandstone samples. The idea that alteration in linearity is mainly due to porosity effect, motivated the authors to make a new regression considering porosity as one of input parameters. The results highly confirmed this method and new correlations with previously published data showed correlation coefficient nearly equal to unity.

INTEGRATING CORE AND WIRELINE LOG DATASETS – A PATHWAY TO PERMEABILITY FROM AVO SEISMIC?

Lahra Lanigan and Jarrod Dunne*
Karoon Gas Australia, Australia

Improved reservoir modelling and simulation is sought by assigning permeability using AvO seismic. The integration of sidewall-core porosity and permeability with wireline logs represents one possible pathway for differentiating the seismic amplitude responses of different reservoir flow-unit facies.

Two sand facies with differing porosity-permeability trends were defined in the reservoir interval of a Paleocene oil field in a shallow offshore clastic setting. Available sidewall-core data from several wells were added to their respective log datasets as discrete, depth-matched points and used to pinpoint the extraction of relevant log values corresponding to each point. The extracted Vp, Vs and density values enabled calculation of AI and Vp/Vs for each sample. Fluid substitutions using the Gassmann equations were then performed on points within the two sand facies.

A statistical comparison of brine and oil porefill cases for each sand facies in this study showed a clear shift due to the hydrocarbon effect. However, only minor differences were observed in an AI-Vp/Vs cross-plot when the two sand facies with common porefill were overlain. Compositional similarity between the sand facies appears the most likely cause for the lack of significant difference in AvO response. Thin carbonates with high AI are also present in the reservoir interval and lateral variation in carbonate volume of as little as 5–10% would overprint the small differences observed between the sand facies. This method should be revisited for sand facies possessing greater compositional differences or where a larger porosity-permeability distinction between facies exists.

LABORATORY EXPERIMENTS AND NUMERICAL SIMULATION ON BITUMEN SATURATED CARBONATES: A ROCK PHYSICS STUDY FOR 4D SEISMOLOGY

Arif Rabbani[1], Jason Nycz[2], Zizhen Wong[3], Doug Schmitt[1] and Ken Gray[4]*
[1]University of Alberta, Canada
[2]Laricina Energy, Canada
[3]China University of Petroleum, China
[4]Osum Oil Sands, Canada

The change in seismic reflectivity from a reservoir – during in situ bitumen recovery processes such as SAGD – can be substantial due to the combined effects of increased temperature, pore pressure and effective stress changes, and the substitution of bitumen with water and steam. These physical property changes can be observed with time lapse seismic monitoring e.g. 4D seismology. The proper interpretation of geophysical observations, however, requires a solid understanding of the saturated reservoir rock's behavior and pore fluid's properties under changing conditions. Our first suite of ultrasonic measurements with bitumen saturated carbonate show the P- and S-wave velocities decrease by ~11.5% and ~8.5% for a temperature increase from 10°C to 102°C, respectively at a constant effective pressure of 5 MPa. In the next effort, direct measurements with bitumen show ~29% decrease of P-wave velocity for 10°C to 130°C change in temperature. Different slopes in velocity versus temperature plot may also indicate the possible states of quasi solid and liquid in bitumen. The change in fluid bulk modulus with temperature drives the drop in the P-wave velocities. We may also infer that the decline in S-velocity in core sample is due to greatly lowered viscosity of the fluid with temperature.

We also attempt to simulate numerically the ultrasonic pulse-transmission through rock saturated with viscous fluid, which exhibits similar trends of P-wave velocity drop with temperature. However, the decrease in velocity is not quite large as experimental studies with bitumen saturated carbonates; may be due to the difference in pore structure and fluid properties. In addition, the dynamic moduli of saturated rocks at seismic frequencies on core scale using the strain-stress method indicate its strong dependency on viscosity of pore fluid and (or) the frequency.

ULTRASONIC MEASUREMENTS ON THIN SAMPLES: NUMERICAL MODELLING

Alexey Yurikov[1], Maxim Lebedev[1] and Marina Pervukhina[2]*
[1]Curtin University, Australia
[2]CSIRO, Australia

Ultrasonic pulse velocity method is a standard method for measuring elastic properties of rock cores in laboratories.

Cylindrical plugs of 40–100 mm length are usually used for such measurements. It was recently shown that thin disc samples (~15 mm in length) were suitable for such measurements in the case of an advanced experimental set-up. Here we present results of numerical simulations to support the outcome of the previous work and to improve the understanding of wave propagation in the samples during laboratory ultrasonic measurements. The finite element method within Abaqus/Explicit (Dassault Systemes, Simulia) is used to simulate wave propagation along the experimental rig and the rock sample caused by transmitted ultrasonic pulse. The computational domain mimics the real geometry. The results of the numerical modelling prove that an S-wave transducer also produces a compressional wave that propagates along the sample and can be recorded by a receiver. Simulations are performed for three configurations used in real laboratory experiments. The numerically simulated waveforms are compared with the signals, recorded during laboratory experiments. Simulated travel times of elastic waves are in a good agreement with experimentally obtained results.

0830–1010
Tuesday 23 August 2016

Minerals 4.C – Characterising Cover (4) – Electromagnetics

INTEGRATED INVERSION OF ELECTROMAGNETIC AND GEOLOGICAL DATA FOR REGOLITH CHARACTERISATION

Andrew King and Ignacio González-Álvarez*
CSIRO, Australia

An increase in demand for commodities coupled with a decrease in world-class ore deposit discoveries in the last three decades is the driving force for exploring for a new generation of world-class ore deposits at depth. Exploration through cover is becoming one of the critical challenges for the mineral exploration industry.

This paper explores methods of integrating geophysical, geological and landscape data so as to reduce uncertainty in landscape evolution models interpreted from inversion of electromagnetic (EM) data. Inversion of EM data is, in general, non-unique: many different models will be able to fit the EM data equally well, resulting in large uncertainty. However, EM model uncertainty can be significantly constrained when geological and landscape context are taken into account. This study aims to characterise the regolith (weathered and transported cover), and understand how its conductivity varies with the landscape and with the regolith architecture. This is assisted by logging information from 104 boreholes penetrating through the regolith and into the basement rocks. The study area is associated with the DeGrussa Cu-Au deposit located in the Capricorn Orogen of Western Australia, a regolith-dominated terrain where the regolith varies in thickness between <5 and ~150m.

We first select EM decay curves, extracted from an airborne EM survey, whose locations are close to those of the boreholes. We then use a layered-earth (1D) forward model, and invert those data for the electrical resistivities of each of the lithologies identified on the geological borehole logs. Layer boundary depths are fixed to the borehole depths. We show how the non-uniqueness associated with EM inversion can be reduced by the inclusion of decay curves from geology with different layer thickness ratios.

Lithological models derived from the integration of electromagnetic, geological and landscape data show less uncertainty and are therefore more reliable for mineral exploration targeting.

TOWARDS 3D INVERSION OF GROUND BASED TEM DATA

Kristoffer R. Andersen, Casper Kirkegaard, Esben Auken and Anders Vest Christiansen*
Aarhus University, Denmark

We describe the setup for inversion of ground based TEM data using a 3D modelling code and a full description of the measurement system using the system response. The response is calculated using a finite volume method where we solve for the electric field on the edges of a staggered grid and time step solutions using backward Euler steps. For the forward calculation we use an iterative solver and a preconditioner which solves the Helmholtz decomposed E-fields. In the iterative process we take advantage of the similarity between different time steps and always use the previous result as the starting point of the next iteration. To compare the calculated fields with measured data we interpolate the fields to the receiver positions and convolute the calculated fields with the system response. In this way we include all system related effects in the calculation and this is in particular relevant for the early time signal. We show that the forward code is in good agreement with the analytic response from a half space and sketch the layout of survey setup with a large, centrally positioned transmitter and many receivers located around the transmitter. We demonstrate that the code can be used to invert data from a single loop system with multiple receivers as commonly used in ground follow-up surveys in mineral exploration.

AN INTER-DISCIPLINARY APPROACH TO AIRBORNE ELECTROMAGNETICS (AEM) SURVEY DESIGN FOR GROUNDWATER EXPLORATION USING THE AUSTRALIAN GEOSCIENCE DATA CUBE AND MORPHOTECTONICS

Ken Lawrie[1], Ross S. Brodie[1], John Magee[1], Kokpiang Tan[1], Larysa Halas[1], Norman Mueller[1], Leo Lymburner[1] and Niels B. Christensen[2]*
[1]Geoscience Australia, Australia
[2]Aarhus University, Denmark

Over the past decade, advances in new satellite and airborne sensor technologies provide an opportunity for rapid multi-scale mapping, measurement and monitoring of the physical state of the crust, including resolution of key elements of surface and sub-surface hydrological systems. These advances have been mirrored by the development in advanced computational research infrastructure which is now giving the groundwater research community access to high-resolution (spatial and temporal) biophysical datasets (e.g. climate, ecology, geoscience and geospatial) relevant to broader hydrological systems understanding. This infrastructure facilitates integration of multiple datasets and rapid and improved signal processing,

inversion, and sophisticated analysis. These datasets provide a catalyst for collaboration, with inter-disciplinary approaches enabling new discovery science in a 'big data' environment, and enabling the qualitative and quantitative analysis and modelling of landscape and hydrological system processes.

In Australian landscapes, airborne electromagnetics (AEM) is widely used in near-surface (<200m) groundwater investigations due to the ability to acquire consistent, spatially coherent information of high quality using calibrated systems, in very short timeframes. This study reports on an evolving inter-disciplinary approach to AEM survey design for groundwater exploration. Recent investigations have employed time series analysis of surface water availability (using the Australian Geoscience Data Cube (AGDC)) combined with morphotectonic analysis of digital elevation datasets, tectonic analysis, and geomorphic analysis of satellite optical data, to help predict preferential recharge zones and shallow groundwater resources. This novel approach has been used successfully for groundwater exploration in the western Murray Basin and Kimberley Region of northern Australia.

ACHIEVING ACCURATE INTERPRETATION RESULTS FROM FULL-WAVEFORM STREAMED DATA AEM SURVEYS

Magdel Combrinck[1] and Richard Wright[2]*
[1]Tau Geophysical Consultants, Canada
[2]New Resolution Geophysics, South Africa

Successful interpretation of airborne electromagnetic (AEM) data depends strongly, but not exclusively, on the quality of data. The ability to accurately describe the system, knowledge of the data processing procedures as well as an understanding of the geological targets all contribute to derive accurate models. Xcite™ is a recently developed helicopter time domain electromagnetic system featuring an inflatable frame and full-waveform recording of streamed data. Working with the streamed data allows for re-structuring of traditional data processing routines to customize data sets for specific applications. It also allows for a better understanding of the corrections that are required to isolate the secondary field response from measurements acquired on a helicopter platform. An accurate system description as well as transparency in the data processing phase allows interpreters to get the most value from airborne electromagnetic data.

0830–1010
Tuesday 23 August 2016

Minerals 4.D – Distal Footprints (4) – Airborne Geophysics

RESULTS OF AN INTEGRATED HELICOPTER ZTEM-GRAVITY-MAGNETIC SYSTEM TEST SURVEY OVER THE VREDEFORT DOME STRUCTURE, SOUTH AFRICA

Thomas Wade, Jean M. Legault, Geoffrey Plastow, Carlos Izarra and Andrei Bagrianski*
Geotech, Canada

In 2016, Geotech completed a test of a helicopter-borne GT-2A gravimeter combined with ZTEM™ (Z-Axis Tipper Electromagnetics) and aeromagnetic towed bird system over the Vredefort Dome impact structure in South Africa. The survey consisted of nine (9) approx. 70 km long NW-SE oriented flight lines, totalling 640 km, acquired at a nominal spacing of 500 m over an area of approximately 650 km^2. The successful test demonstrates the feasibility of integrating density measurements using airborne gravimetry on a helicopter platform while combining the superior depth of investigation of ZTEM™ and aeromagnetics for regional geophysical survey applications.

EXTENDING GEOBANDWIDTH USING THE MULTIPULSE CONFIGURATION

*Adam Smiarowski and Tianyou Chen**
CGG, Canada

Measurement bandwidth is an important feature of a geophysical system. Bandwidth allows detection of very resistive features (such as some kimberlites) and very conductive targets (like massive sulphides). In electromagnetic systems, bandwidth is not simply the sample rate of the data acquisition system or the earliest time channel, but also depends on transmitter spectrum, distance to target and processing. Optimising a system to detect a feature or measure a specific signal requires design considerations and trade-offs for different targets. The choice of excitation waveform in electromagnetic systems is one such trade-off. A square-pulse allows high-frequency energy to be excited, but, because of electronic limitations, has only limited dipole moment. A half-sine waveform efficiently generates energy at the base frequency and first few odd harmonics (low-frequency energy) and less high-frequency energy. Here, we describe the Multipulse configuration, an option on the Helitem system which employs both a half-sine and a trapezoid waveform to efficiently generate high- and low-frequency energy. Using survey data, we show the resolution power of the combined system compared to a single waveform. The combined data is better able to resolve near-surface features and deep structure than data from either waveform alone.

THE BALBOA ZTEM CU-MO-AU PORPHYRY DISCOVERY AT COBRE PANAMA

Jean M. Legault[1], Chris Wijns[2], Carlos Izarra[1] and Geoffrey Plastow[1]*
[1]Geotech, Canada
[2]First Quantum Minerals, Australia

This paper describes the ZTEM airborne EM and magnetic results over the porphyry copper-gold camp at Cobre Panama, with a focus on the discovery of the blind Balboa deposit in 2010, the first documented case attributed to the ZTEM system. Balboa is the westernmost of six porphyry copper-gold deposits that make up Cobre Panama and it escaped detection in 40 years of exploration that relied primarily on soil geochemistry, airborne magnetics and drilling. ZTEM was flown in summer 2010 to detect resistivity variations related to hidden porphyry systems in a region of dense jungle, difficult access and thick (20–30 m) conductive saprolite cover. The ZTEM survey detected all the known porphyry systems, including Balboa, based on anomalous conductive response. Our study presents the geophysical survey results at Cobre Panama and is supported by 2D-3D ZTEM and magnetic inversions that appear to validate the survey evidence. 2D synthetic modeling appears to confirm the detectability of the weakly conductive Balboa orebody below 30 m of saprolite cover.

AIRBORNE IP DETECTS ONLY FINE-GRAINED MINERALS WHEN COMPARED TO CONVENTIONAL IP

*James Macnae**
RMIT University, Australia

Using a thin-sheet model, it is possible to predict Cole-Cole parameters of polarizable materials in the near-surface from airborne EM data. With the high frequency of AEM systems, typically more than 100 times higher than ground IP systems, most conventional IP targets will often not show an AIP response. Very fine-grained minerals, around 0.1 mm in average dimension, are however good sources for AIP responses. In 6 examples from Tasmania and NSW comparing AIP with ground IP, 5 have AIP responses that are not coincident with ground responses, but may detect finer grained minerals in the periphery of the alteration system associated with a mineral deposit.

0830–1010
Tuesday 23 August 2016

Near Surface/Engineering 4.E – Acquisition Approaches

THE PARETO PRINCIPLE – SOMETHING FOR HYDROGEOPHYSICAL PRACTITIONERS TO REMEMBER WHEN EMPLOYING GEOPHYSICAL DATA IN GROUNDWATER RESOURCE ASSESSMENT?

*Tim Munday**
CSIRO, Australia

The Pareto principle, named after the Italian engineer, economist, and sociologist Vilfredo Pareto, (also known as the 80:20 rule) states that, for many events, roughly 80% of the effects come from 20% of the causes. A variation of that principle might be to suggest that to achieve 80% of what is needed, only 20% of effort is required, whereas to deliver the final 20% requires 80% of the effort. I'd like to argue that in the application of geophysical methods to hydrogeology, particularly where airborne electromagnetic techniques are employed, it is perhaps worth remembering that principle when considering their application for groundwater resource assessments in data poor areas. Practitioners of hydrogeophysical investigations, myself included, are sometimes guilty of making the case for analysing and interpreting geophysical data without being necessarily cognisant as to how, at what cost, and to what extent groundwater resource assessments can be improved through their incorporation.

Most applications of AEM for groundwater resource assessment in remote parts of Australia only require limited effort on the processing and analysis of the data once acquired. Examples abound on the use of AEM in defining palaeovalleys across the Australian outback to aid the location of groundwater resources for mining purposes. More often than not, their relatively simple transformation using CDI's, rather than their full inversion, is adequate for determining where to drill, and to then progress conventional hydrogeological investigations that might result in a bore field. Often the products supplied by the contractors are adequate for such needs. Our collective challenge is to understand at what point there is value in going beyond this step.

Of course there are also examples which demonstrate the relevance of a more considered approach to geophysical data analysis and interpretation, including studies linked to managed aquifer recharge, to drill targeting which requires water of a certain quality in a particular aquifer, or where the accurate definition of an aquifer bound or salt water interface may be required in the absence of drill hole data. We are well placed to deliver into these areas benefiting from the emergence of practical and robust data inversion techniques. However in many of these studies even the extra effort employed is sometimes not without fault. For example, while the geophysics community regularly deal with measurement and model uncertainty, arising from issues such as equivalence, we seem to gloss over these matters and rarely transfer of them into hydrogeological domain. Similarly, we sometimes appear to ignore the limits of groundwater models. We may expend considerable effort in using geophysical data to help conceptualise an aquifer and its variability, and then argue till we are blue in the face that the detail in the geophysics needs to be incorporated into a 'groundwater model', conveniently forgetting that most models have low absolute accuracy, but good resolution and some predictive capability with the latter being determined by (limited) data other than that from geophysics. The limited data tends to lead to a generalized representation of the aquifer system which is then calibrated to measured data, usually water levels, to enhance model utility.

In summary, while acknowledging that geophysics can offer much to improve groundwater resource assessment, it's appropriate to question the worth of data during the survey design stage, and to consider whether, if and when, the Pareto principle might be enacted.

THE EMPEROR'S NEW CLOTHES – OPPORTUNITIES AND LIMITATIONS APPLYING AEM TO GEOTECHNICAL DESIGN WORK

Andi A. Pfaffhuber[1], Helgard Anschütz[2] and Kristoffer Kåsin[2]*
[1]NGI, Australia
[2]NGI, Norway

In summer 2015, we acquired close to 6.000 km of Helicopter, time-domain airborne electromagnetic (AEM) data for regional geotechnical mapping for the Norwegian National Rail Administration. This survey and further experience from related Norwegian road planning projects demonstrated the unprecedented accuracy of modern AEM data. The extent of geotechnical site investigations can be drastically reduced, both in terms of time schedule, and costs if AEM derived bedrock models are included when soil investigations are planned. Geotechnical projects demand high resolution (meter scale) and AEM data is to some extent capable of delivering that. Some of our data matched the resolution of corresponding ground geophysics data. Here we present the way in which AEM can be used as bedrock models, sensitive clay delineation and to determine bedrock types. Our discussion leads us to the missing link between high vertical resolution in the first tens of meters for geotechnical work and the focus on simple, sub-vertical structures in exploration AEM. Ultimately, we should strive for the best of both worlds, shouldn't we?

1040–1220
Tuesday 23 August 2016

Petroleum 5.A – Seismic Interpretation

STRUCTURAL INTERPRETATION OF SEISMIC, GEOLOGICAL REALISM AND 3D THINKING

Pete Boult[1]*, *Brett Freeman*[2] *and Graham Yielding*[2]
[1]Santos, Australia
[2]Badley Geoscience, UK

Our notion of reality in seismic interpretation and structural geology usually follows a series of careful observations and ideas that eventually crystallize into a best-case model. In most other branches of science the strength or reality of such models (or hypotheses) is increased by the number of robust tests that either refine or fail to disprove the original idea. However, geological models in the Exploration and Production (E&P) sector differ because the starting point for testing is usually an interpretation of seismic or other remote measurements, rather than the direct observation of an effect. This means that whatever tests we are able to apply have, in themselves, significant margins for error and are further compounded by the intellectual issue of constructing a 3D view or model of the perceived geologic reality. This model building is an early stage of the E&P process, but errors and uncertainty at this point propagate throughout the subsequent workflow and arguably, amount to the single biggest factor affecting perceived value and in particular drilling risk.

THE GEOLOGY AND STRUCTURAL STYLE OF THE JUHA GAS FIELD, PAPUA NEW GUINEA

Amanda Hanani[1]*, *Paul Lennox*[2] *and Kevin Hill*[1]
[1]Papuan Oil Search, Australia
[2]University of New South Wales, Australia

The Juha Anticline in the jungle-covered highlands of Papua New Guinea was drilled by three crestal wells in the 1980's and discovered gas-condensate in a Lower Cretaceous clean quartz sandstone reservoir. The Juha-4 and Juha-5 wells drilled in 2007 further delineated the structure and defined a separate North Juha compartment. The Juha structure is 25 km long and up to 8 km wide and is traversed by a number of seismic lines, some of which are of moderate to good quality allowing the structure to be interpreted. Unlike most structures in PNG the seismic lines reveal the nature of the overlying Pliocene-Pleistocene sediment which help to define the depth of burial and timing of deformation. The wells and seismic data suggest that the Lower Cretaceous sandstone reservoir was buried by 1.5 km of Cretaceous shale, the regional seal, and 1.5 km of Miocene limestone as well as more than 1.6 km of Pliocene-Pleistocene sediment prior to uplift and erosion. To constrain the timing and style of extensional and compressional deformation, 25 2D seismic lines were interpreted aided by forward modelling of the structure. The seismic interpretation revealed basement-involved structures that were predominantly influenced by two major events, rifting in the Triassic-Jurassic and compression in the late Pliocene-Pleistocene. The deep structure remains uncertain, but gravity data indicate a very deep underlying graben a concept that has recently been investigated and validated by 3D analogue modelling. A key seismic section indicates inverted basement faults beneath Juha flattening upwards into a detachment horizon creating triangle zones in the Cretaceous mudstones such that the overlying Miocene Limestone in part deforms independently. The Juha Anticline is part of the PNGLNG project operated by ExxonMobil which commenced production in 2014, 32 years after drilling of the Juha-1 discovery.

FAULT GEOMETRY AND DEFORMATION HISTORY, NORTHERN CARNARVON BASIN

Chris Elders[1]*, *Sam McHarg*[1] *and Amy l'Anson*[2]
[1]Curtin University, Australia
[2]University of Sydney, Australia

The Carnarvon Basin has experienced three distinct phases of extension – in the Carboniferous-Permian, in the Upper Triassic to Middle Jurassic and in the Lower Cretaceous. Detailed mapping of fault patterns associated with each event is possible at a regional scale using widespread, publically available 3D seismic data sets.

The complex interaction between NNE and NE-SW oriented Carboniferous and Permian age faults provides the structural framework for subsequent rift events. Both sets of faults show evidence of oblique reactivation under a WNW oriented extensional regime in the Jurassic, somewhat at odds with the general perception of NW oriented extension associated with separation of Argoland from the NW shelf at this time.

Lower Cretaceous extension is much shorter lived, is primarily confined to the SW part of the Northern Carnarvon Basin and is associated with significant uplift and erosion. The relationship of this event to the separation of Greater India from Australia is less clear, but a proposed mantle plume goes some way to addressing some of the observed structural and stratigraphic relationships.

1040–1220
Tuesday 23 August 2016

Minerals 5.B – Electromagnetic Inversion (1)

FAST 3D INVERSION OF 'TOTAL FIELD' RESISTIVE LIMIT TEM DATA

Peter K. Fullagar[1]* *and Dennis Woods*[2]
[1]Fullagar Geophysics, Canada
[2]Discovery International Geophysics, Canada

Rapid interpretation of transient electromagnetic (TEM) data sets is highly desirable for timely decision-making in exploration. However, full solution 3D inversion of TEM data sets is often impractically slow. Therefore, a fast approximate 3D TEM inversion scheme has been developed for time-integrated (resistive limit) data. The resistive limits are amenable to linear 3D magnetic inversion, which is up to 100 times faster than 'rigorous' 3D TEM inversion. The resistive limit inversion scheme is suitable for airborne, ground, and downhole TEM, both dB/dt and B-field. Its efficacy is illustrated here via application to a heli-borne sub-audio magnetic (HeliSAM) data

set recorded over the Lalor Zn-Cu-Au VMS deposit in Manitoba, Canada. The response from the deposit is clear in the 'total field' EM (TFEM) data even though the mineralisation is very deep, extending from depth 575m to over 1100m. A three-stage inversion of resistive limits derived from the TFEM rapidly defined a 3D conductor below the uppermost pyrite-sphalerite lenses, enclosing a volume containing mainly pyrrhotite-chalcopyrite stringer sulphides. Total inversion time was less than one minute on a notebook PC.

GEOLOGICALLY CONSTRAINED 2D AND 3D AIRBORNE EM INVERSION THROUGH CROSS-GRADIENT REGULARIZATION AND MULTI-GRID EFFICIENCY

C. Scholl[1], *J. Neumann*[1], *M.D. Watts*[2], *S. Hallinan*[2] *and Shane Mulè*[3]*
[1]CGG, Germany
[2]CGG, Italy
[3]CGG, Australia

With a goal of increasing the geological reliability of single and joint domain inversion, including those set in rugged terrain, we present an expanded scope for cross-gradient regularized inversion. The basic application covers the usual structural similarity objective – comparing the gradient fields of distinct property volumes derived from different geophysical domains – but a particular advantage comes when including gradients derived a priori, from geology or any ancillary property set, providing reference gradient control during single or joint inversions.

In the first example, straightforward cross-gradient joint inversion of synthetic datasets of airborne EM (AEM) and airborne gravity-gradiometry (AGG) improves both the lateral and vertical definition of closely adjacent but distinct bodies.

Two further AEM examples include surface and subsurface geology in the cross-gradient inversion; a) complex foothills setting, and b) buried massive sulphide. Both outputs demonstrate a marked improvement in interpretability over the standard smooth model approach.

EFFECTIVE AND ACCURATE PROCESSING AND INVERSION OF AIRBORNE ELECTROMAGNETIC DATA

Esben Auken, Anders Vest Christiansen, Kristoffer R. Andersen and Gianluca Fiandaca*
Aarhus University, Denmark

Airborne electromagnetic (AEM) data is used throughout the world for mapping of mineral targets and groundwater resources. The development of technology and inversion algorithms has been tremendously over the last decade and results from these surveys are high-resolution images of the subsurface.

In this keynote talk, we discuss an effective inversion algorithm, which is both subjected to intense research and development as well as production. This is the well know Laterally Constrained Inversion (LCI) and Spatial Constrained Inversion algorithm. The same algorithm is also used in a voxel setup (3D model) and for sheet inversions. An integral part of these different model discretization is an accurate modelling of the system transfer function and of auxiliary parameters like flight altitude, bird pitch, etc.

1040–1220
Tuesday 23 August 2016

Minerals 5.C – Characterising Cover (5) – AEM and MT Methods

MAGNETOTELLURICS: IMAGING BASEMENT THROUGH DEEP AND CONDUCTIVE COVER

Tristan Kemp, Jingming Duan, Liejun Wang and Richard Chopping*
Geoscience Australia, Australia

The audio magnetotelluric (AMT) technique has been applied by Geoscience Australia to determine the nature and thickness of cover, plus the basement architecture in regions around Australia. The depth of cover derived from AMT data agrees with results obtained by other geophysical techniques and known information.

IMPROVED STRUCTURAL MAPPING AND CONDUCTIVE TARGETING DELIVERED BY A NEW 2.5D AEM INVERSION SOLVER

Rod Paterson[1]*, *Jovan Silic*[2] *and Des FitzGerald*[1]
[1]Intrepid Geophysics, Australia
[2]Jovan Silic and Associates, Australia

The advantages of 2.5D (2D geology, 3D source) airborne electromagnetic inversion in 3D geological mapping applications and the identification of conductive drilling targets compared to the more commonly used CDI transforms or simple 1D inversions are demonstrated using examples from different geological settings.

The 2.5D inversion application used in this work and described in Silic et al, 2015 is a substantially changed version of ArjunAir, Wilson et al., 2006, a product of CSIRO/AMIRA project P223F. The changes include a new forward model algorithm and a new inversion solver. The application enables the accurate simulation of 3D source excitation for full domain models inclusive of topography, non-conforming boundaries and very high resistivity contrasts. Solution is accurate for a geoelectrical cross-section which is relatively constant along a strike length that exceeds the AEM system footprint.

The major innovation includes a new inversion solver with adaptive regularisation which allows the incorporation of a misfit to the reference model and the model smoothness function. The regularisation parameter is chosen automatically and changed adaptively at each iteration, as the model, the sensitivity and the roughness matrices are changing, Silic et al, 2015.

Memory usage has been dramatically reduced and provides a usage estimate prior to execution. For speed the software has been parallelised using Intel MPI and can be used on standard computing hardware or computing clusters. Data from survey lines with lengths exceeding 30 kilometres can be inverted on high end laptop computers. The integrated software design allows the user to prepare a full survey inversion then execute this simply in a batch process. The user can visualise inversion progress at any time during process execution.

We allow flexibility in the selection of components and in the estimation of noise. A non-specialist can obtain a high value result from our 2.5D AEM inversion in terms of it achieving a more realistic geological section.

We show inversion examples from groundwater, minerals (VMS) and geological mapping AEM surveys projects and compare the results with known geology and drilling. We demonstrate the much improved mapping and target definition delivered by this inversion method when compared with the other more common transforms or inversion methods used on these projects.

SUMMARISING AEM DATA FOR MAPPING APPLICATIONS

David Annetts and Juerg Hauser*
CSIRO, Australia

AEM Geophysical surveys are excellent tools for mapping conductivity variation over large areas. Common workflows involve inverting data using 1D models on a per-station basis, then gridding those results over lines to produce maps. In the absence of other filtering, gridding operations must combine finely-sampled along-line data with sparsely-sampled between-line data. Independent of the choice of gridding technique and map cell dimension, such maps will obscure the two scales. Obtaining a spatially coherent map will often involve reducing the resolution along the survey lines. Indeed, it could be argued that if the goal of an AEM survey is mapping, then inverting the data on a station by station basis is not necessary.

We show that large-scale structures are preserved when data are summarised using the arithmetic mean over a number of stations. This allows practitioners to objectively determine map cell dimensions since it provides an indication of the distance over which 1D models which are typically used to process large data sets are valid. Practically, it makes little difference whether this summary takes place before data are inverted or after. Summarising data before inversion may provide a practical estimate of spatial and temporal variation of the data at a particular scale. In contrast, summarising inverted models may provide an estimate of model variability at a particular scale.

MAGNETOTELLURIC MONITORING OF HYDRAULIC FRACTURE STIMULATION AT THE HABANERO ENHANCED GEOTHERMAL SYSTEM, COOPER BASIN, SOUTH AUSTRALIA

Yohannes L. Didana[1]*, *Stephan Thiel*[2], *Graham Heinson*[1] *and Goren Boran*[1]
[1]University of Adelaide, Australia
[2]Geological Survey of South Australia, Australia

Magnetotelluric (MT) data were collected across the Habanero Enhanced Geothermal System project in the Cooper Basin, South Australia. A baseline regional MT survey consisting of two profiles was collected to delineate the pre-injection resistivity structure. Two dimensional inversions of the MT data reveal three main resistivity structures to a depth of 5 km. The low resistivity surface layer (about 1.5 km thick) is interpreted as poorly consolidated sediments of Lake Eyre and Eromanga Basins. Below the conductive layer, a zone with relatively high resistivity with thickness of 2 km can be correlated to consolidated Cooper Basin sediments. A high resistivity zone below depths of 3.5 km is interpreted as the hot intrusive granodiorite (granite) of the Big Lake Suite with low porosity and permeability. This deep structure is also related to the Habanero EGS reservoir.

The second MT survey was conducted during stimulation of Habanero-4 well by Geodynamics Ltd, where 36.5 ML of water with a resistivity of 13 m (at 25°C) was injected at a relatively continuous rate of between 27–53 L/s over 14 days at a depth of almost 4 km. Analysis of pre- and post-injection residual phase tensors for periods greater than 10 s indicate conductive fractures oriented in a N/NNE direction. Apparent resistivity maps also revealed that injected fluids possibly propagated towards N/NNE direction. This result is in agreement with the micro-seismic events with an area of 4 km^2 observed during fluid injection, as well as orientation of pre-existing N-S striking sub-horizontal fractures susceptible to slip due to stimulation. The MT responses close to injection show on average 5% decrease in apparent resistivity at periods greater than 10 s. The main reasons for observing subtle changes in resistivity at Habanero EGS is the screening effect of the conductive thick sedimentary cover (about 3.6 km thick) and the presence of pre-existing saline fluids with resistivity of 0.1 m (equivalent to salinity of 16.1 g/L at 240°C) in the natural fractures. Overall, the MT monitoring at Habanero EGS highlights the need for favourable geological settings to measure significant changes in resistivity in EGS reservoirs.

1040–1220
Tuesday 23 August 2016

Minerals 5.D – Distal Footprints (5) – Potential Field Inversion

APPLYING ADVANCED GRAVITY AND MAGNETIC INVERSION METHODS TO EXPAND THE PLATREEF PGE-NI-CU RESOURCE IN THE BUSHVELD COMPLEX

Nicholas Williams[1]*, *Barry de Wet*[1], *Sello Kekana*[2], *Shane Nielsen*[3] *and David Broughton*[4]
[1]High Power Exploration, Canada
[2]Ivanhoe Mines, South Africa
[3]Nielsen Exploration & Development, New Zealand
[4]Ivanhoe Mines, Canada

There are many potential field inversion algorithms available, and all are sufficiently capable of generating a model that explains supplied geophysical observations. The challenge is extracting a model that provides real geological insight. Here we present applications of two different styles of advanced inversions to a deep exploration program at the Platreef PGE-Ni-Cu deposit in the Bushveld Igneous Complex of South Africa. The initial approach was to apply generalised focussing constraints to a 3D magnetic vector inversion, an approach chosen to manage the effect of expected strong remanent magnetisation. This resulted in successful prediction and drill definition of inferred resources within a deep, west-dipping extension to the shallow-dipping 'Flatreef' deposit. Later, a detailed 3D model of geological constraints based on drilling and mapping was constructed and used to tightly constrain inversions of gravity data derived from a FALCON airborne gravity gradiometer survey. The resulting 3D density model

accurately predicted a continuation of the Flatreef host rocks to shallower levels than previously anticipated. This facilitated further drill-definition of additional inferred resources within a southern extension of the Flatreef deposit. Key to the success of the inversions at accurately targeting mineralisation at depths of 700–1300 m depth, was the inclusion and integration of all available information to ensure that predictions were consistent with prior observations.

VK1™ – A NEXT-GENERATION AIRBORNE GRAVITY GRADIOMETER

Theo Aravanis[1], Jon Chen[2], Martin Fuechsle[2], Mark Grujic[1], Paul Johnston[2], Yitping Kok[2], Rhet Magaraggia[2], Anthony Mann[2], Laurence Mann[2], Stephen McIntosh[1], Gerard Rheinberger[1], David Saxey[3], Mark Smalley[2], Frank van Kann[1], Grant Walker[1] and John Winterflood[2]*
[1]Rio Tinto Exploration, Australia
[2]University of Western Australia, Australia
[3]Curtin University, Australia

The minerals exploration industry's demand for a highly precise airborne gravity gradiometer has driven development of the VK1™ Airborne Gravity Gradiometer, a collaborative effort by Rio Tinto and the University of Western Australia. VK1™ aims to provide gravity gradient data with lower uncertainty and higher spatial resolution than current commercial systems.

In the recent years of VK1™ development, there have been significant improvements in hardware, signal processing and data processing which have combined to result in a complete AGG system that is approaching competitive survey-ready status. This paper focuses on recent improvements. Milestone-achieving data from recent lab-based and moving-platform trials will be presented and discussed, along with details of some advanced data processing techniques that are required to make the most use of the data.

APPLICABILITY OF STANDARD EULER DECONVOLUTION, MODELING AND AMPLITUDE MAGNETIC DATA INVERSION IN GREENFIELD PROGRAMS: THE LEITE TARGET CASE STUDY – CARAJÁS MINERAL PROVINCE – BRAZIL

João Paulo Souza[1], Marcelo H.L. dos Santos[2] and Cantidiano O. Freitas[3]*
[1]Universidade de Brasília, Brazil
[2]Universidade Federal de Goiás, Brazil
[3]Vale, Brazil

The Leite target is located in Carajás Mineral Province and has a magnetic anomaly with 140 nT of amplitude, elongated in the northwest-southeast direction. Four exploratory drillholes were performed to test the magnetic anomaly. The test showed that the source of the anomaly is a narrow magnetite hydrothermal alteration zone bearing copper mineralization up to 2%. In addition, geologic and geochemical data, magnetic susceptibility (MS) measurements were collected to identify the lithotypes with ferromagnetic minerals. We use three different techniques to estimate the depth and geometry of the magnetic source: standard Euler deconvolution, total field magnetic anomaly modeling, and magnetic amplitude inversion. When visualized in 3D, the depth of solutions from Euler deconvolution crossed the real magnetic layer with less inclination. The modeling, using the solutions from Euler deconvolution, was performed, and the magnetic anomaly produced by the body modelled achieved a low misfit. The body used in the forward modeling is geometrically similar to the geologic magnetic layer. The magnetic amplitude inversion successfully recovered the MS distribution. Finally, we carried out a borehole magnetic survey in two drillholes to validate the obtained models and investigate the magnetic source. This survey confirmed that the models were intercepted and the magnetic anomaly was associated, a hydrothermal alteration zone, with magnetite intercepted by drillholes. In this study, we demonstrated that the use of those techniques was effective in Greenfield exploration programs.

1040–1220
Tuesday 23 August 2016

Near Surface/Engineering 5.E – Groundwater

THE EAST KIMBERLEY ORD BONAPARTE PLAINS PROJECT: DE-RISKING INVESTMENT IN AGRICULTURE AND WATER INFRASTRUCTURE THROUGH AIRBORNE AND GROUND GEOPHYSICAL INVESTIGATIONS

Neil Symington[1], Ken Lawrie[1], Ross S. Brodie[1], Kokpiang Tan[1], Larysa Halas[1], Ross C. Brodie[1], John Magee[1], Don Bennett[2] and Richard George[2]*
[1]Geoscience Australia, Australia
[2]DAFWA, Australia

The Ord Bonaparte Plains area is a priority area for irrigated agriculture development as part of the Ord Stage 3 development in the East Kimberley region of Western Australia. Irrigated agriculture in this area will depend on access to groundwater resources in underlying bedrock aquifers. A program of airborne electromagnetics (AEM), drilling, ground and borehole geophysics and hydrogeological investigations is being undertaken to confirm the presence of suitable groundwater resources, map the connectivity between surface and groundwater systems, and identify potential risks to agriculture and water infrastructure including salt stores, groundwater salinity and seawater intrusion.

Preliminary analysis shows that the AEM survey has successfully mapped key elements of the groundwater system, including aquifer and aquitard extent, groundwater quality (salinity) distribution, hydraulic properties, compartmentalisation and inter-connectivity, the seawater intrusion (SWI) interface in coastal zones, and key tectonic elements of regional hydrogeological significance. The survey has mapped significant faulting within the Cockatoo Sandstone and Point Springs Sandstone aquifers, while conductivity distributions suggest that faults within and bounding major stratigraphic units display both fault barrier and conduit behaviour. The survey has also found that fresh groundwater in the aquifer system continues offshore as discontinuous lenses.

Initial inversions have been used to target drilling, hydrochemical investigations, and a program of ground geophysics (including Surface Nuclear Magnetic Resonance (SNMR)). Further analysis and groundwater modelling is required to determine appropriate development and management of any groundwater resource and the potential risks to agricultural development.

UNCOVERING THE GROUNDWATER RESOURCE POTENTIAL OF MURCHISON REGION IN WESTERN AUSTRALIA THROUGH TARGETED APPLICATION OF AIRBORNE ELECTROMAGNETICS

Aaron Davis[1], *Scott Macaulay*[2], *Tim Munday*[1]*, *Camilla Sorensen*[1], *John Shudra*[2] *and Tania Ibrahimi*[1]
[1]CSIRO, Australia
[2]WA Department of Water, Australia

Access to water is identified a key infrastructure need for mining, energy and industry development. In Western Australia, the scale of planned developments linked to current mineral exploration and mining is set to generate significant economic value for the State, but its realisation is dependent on ensuring access to groundwater. To address these issues, The WA Government Department of Water (DoW) has embarked on a series of groundwater investigations to identify and establish long-term water resources in regional areas where agriculture and mining opportunities have the potential for development. The Murchison in northern WA was identified as one of six key priority areas for this initiative. With numerous known mineral deposits having potential for development, locating and securing an adequate, sustainable long-term water supply is a critical consideration if these mineral resources are to be developed further. While it is known that there are significant groundwater resources in the region, at present these are generally poorly understood.

Of particular importance are the palaeovalley aquifers which are known (locally) to contain a significant resource, but which are relatively poorly characterised. To aid an understanding of their extent an airborne electromagnetic (AEM) survey was commissioned and flown in the Murchison extending over an area in excess of ~106 000 km^2. Prior studies at a local scale had indicated that airborne EM would be very effective at defining the location and thickness of palaeovalleys in the region. Pilot investigations also determined the most appropriate AEM system to use for acquisition. These studies suggested that the buried palaeovalleys were most likely to be near-coincident with contemporary valley systems developed in a granite/gneiss-greenstone basement. Covering such a large region required a novel approach to survey design to maximize the information relating to their expected spatial variability. Therefore a terrain index (MrVBF) was used with the SRTM 1sec DEM to define the extent of contemporary valleys, and the extent of the AEM survey area. This approach allowed survey acquisition costs to be kept to less than half that of flying a more 'traditional' survey over the entire area. It also allowed for the acquisition of data with a closer line spacing than would have been possible otherwise, therefore capturing more of the spatial variability associated with the palaeovalley systems. The results have demonstrated the validity of the strategy adopted and have shown that in the absence of conventional hydrogeological information, geophysical methods are demonstrably a cost and time effective approach to upscaling local hydrogeological information, thereby fast tracking groundwater resource assessments that would otherwise take decades to complete.

FRONTIER GROUNDWATER INVESTIGATIONS IN THE WEST KIMBERLEY (FITZROY) REGION: PRELIMINARY ASSESSMENT OF GROUNDWATER RESOURCE POTENTIAL AND THE SALINITY HAZARD TO PROPOSED IRRIGATION DEVELOPMENTS

Alastair Hoare[1]*, *Ken Lawrie*[2], *Neil Symington*[2], *Ross S. Brodie*[2], *Kokpiang Tan*[2], *Larysa Halas*[2], *Ross C. Brodie*[2], *John Magee*[2], *Celine Stocker*[1], *Norman Mueller*[2] *and Wayne Tingey*[1]
[1]WA Water for Food, Australia
[2]Geoscience Australia, Australia

A regional reconnaissance AEM survey in the west Kimberley region (lower Fitzroy River valley and May-Meda Catchments) has successfully mapped the extent of regional Canning Basin aquifers (e.g. Pool Sandstone, Grant Group and Erskine Sandstone) confirming these as significant potential groundwater resources. The survey has successfully mapped a multi-layered hydrostratigraphy to depths of ~400m (in resistive areas), also revealing significant tectonics manifested as large scale basin-scale tilting of stratigraphy and more localised folding and faulting.

The survey also mapped other key objectives including: the seawater intrusion (SWI) interface for the lower Fitzroy River valley and the May and Meda River Catchments; river flush zones along the Fitzroy, May and Meda Rivers; groundwater salinity variations and potential salt stores in the shallow alluvium of these rivers and proposed irrigation areas. River-parallel surveys also identified reaches of the May and Meda Rivers with direct contact between the rivers and underlying regional aquifers of the Pool Sandstone and Grant Group. These reaches are areas of potential recharge, and/or groundwater discharge, with the AEM used to target hydrochemical investigations, drilling and aquifer testing. The AEM data reveal more complex relationships between perennial in-stream pools along the Fitzroy River, underlying aquifers, tectonics, and river alluvium.

AEM survey design incorporated time series analysis of surface water availability through time (Water Observations from Space (WOfS)) derived using the Australian Geoscience Data Cube (AGDC). This has facilitated investigations of surface-groundwater interaction through ensuring the AEM transects coincide with permanent water holes and river reaches considered to be potentially sustained by groundwater discharge. The AEM data provide a framework for hydrogeological process understanding, while the knowledge generated in this project will inform water resource allocation planning, help assess risks to culturally and environmentally sensitive riverine ecosystems, and de-risk investment in agriculture and water infrastructure more broadly.

1345–1500
Tuesday 23 August 2016

Petroleum 6.A – VSP

MAPPING OF FRACTURE ZONES AND SMALL FAULTS USING VSP AND CROSS DIPOLE SONIC IN EASTERN SIBERIA CARBONATE RESERVOIRS, YURUBCHANSKY FIELD, RUSSIA

Sergey Shevchenko[1]*, *Sergei Tcherkashnev*[2], *Maxim Kuznetsov*[3] *and Tagir Mamleef*[4]
[1]SIS Exploration, Australia
[2]ASTO Geophysical Consulting, Australia
[3]Rosneft ESOGC, Russia
[4]CJSC SPF GITAS, Russia

Zero offset VSP, two Walkaway lines, ultra sonic and cross dipole sonic were used to interpret fracture zones and small faults in the vicinity of a deviated well drilled through carbonate reservoirs of the Yurubchansky giant oil and gas field, Russia. The fractures and small faults are the main flow conduits and storage of the hydrocarbons within mainly low porosity carbonate reservoir of the Proterozoic age. The wells are only successful if they intersect these 'sweet spots' in the reservoir. This is a challenge in developing the Yurubchansky field. The 3D seismic over the field has low resolution, strong heterogeneous reservoirs, varying degrees of anisotropy, multiples contamination and therefore cannot be used to map the 'sweet spots' reliably.

An incoherency attribute was used to guide fracture and fault interpretation. Two major fault zones and small faults were interpreted from VSPs. One of the fault zones within the reservoir corresponds to fractured core, intensive fracture zones interpreted from the logs and hydrocarbon shows. This demonstrates the effectiveness of high resolution VSP data in mapping fractured zones. Other geological features including unconformity at the top of the reservoir were also interpreted from VSPs.

MULTI-AZIMUTHAL WALKWAY VSP FOR FULL AZIMUTH SEISMIC CALIBRATION

Konstantin Galybin[1]*, *Anastasia Poole*[2] *and Michael Giles*[3]
[1]Schlumberger, Australia
[2]Schlumberger, UK
[3]Santos, Australia

Comprehensive borehole seismic surveys hold the key to unlocking the knowledge contained within the long-offset full-azimuth surface seismic surveys that are fast becoming common in land exploration. This paper presents a case study of acquisition, processing and use of such survey for validation and calibration of processing parameters and inversion results of a recent point-source/point-receiver 3D surface seismic dataset acquired in the Cooper Basin.

The 3D surface seismic data have been initially processed without significant borehole seismic data input. However, as the processing revealed gaps in knowledge, the need for borehole calibration was realised. This led to acquisition of a complex borehole seismic survey in a gas-discovery well comprising Multi-Azimuthal Walkaway (MAZ WVSP), Walkaround and Zero Offset Vertical Seismic Profiles (ZVSP). The acquired dataset shed light into the peg-leg multiple mechanisms as well as the VTI and azimuthal anisotropy. Advanced processing techniques such as calibrated piece-wise VTI inversion and azimuthal travel time fitting were applied to the MAZ WVSP data to validate the processing steps of the 3D surface seismic data and calibrate the results of its AVOaz inversion.

Apart from showing some of the results of this study, this paper documents the various contact points between VSP and surface seismic datasets and how the results of processing complement each other. The final result comprised a calibrated seismic map of drilling targets.

APPLICATION OF FULLWAVEFORM TOMOGRAPHY TO VSP WALKAWAY DATA

*Eric Takam Takougang** *and Youcef Bouzidi*
Petroleum Institute, UAE

VSP walkaway data were collected in an oil field in the United Arab Emirates. 2D frequency domain fullwaveform tomography was used to obtain high resolution rock properties (P-wave), and structural information near and away from the borehole, following a specific data preconditioning and inversion strategy. The field data were inverted between 4 and 50 Hz, and the starting model was obtained from traveltime tomography. The results of the inversion show zones with anomalous low velocities that correlate in places with known presence of hydrocarbons, and highlight their possible extensions. A comparison of the results at the borehole location with the sonic log shows a generally good match. However, some mismatches are evident and can be explained by possible anisotropy and out of the plane structures not taken into account during the inversion.

1345–1500
Tuesday 23 August 2016

Petroleum 6.B – Depth Conversion and Interpretation

A STATISTICAL APPROACH TO ASSESSING DEPTH CONVERSION UNCERTAINTY ON A REGIONAL DATASET: COOPER-EROMANGA BASIN, AUSTRALIA

David Kulikowski[1]*, *Catherine Hochwald*[2], *Dennis Cooke*[1] *and Khalid Amrouch*[1]
[1]University of Adelaide, Australia
[2]Santos, Australia

Deciding on the most accurate grid based depth conversion method can often be an arbitrary choice made by geophysicists, particularly if previous research is limited. The importance of accurate depth conversion is particularly crucial in the Cooper-Eromanga Basin, where the presence of oil rich, low relief structural traps are questionable depending on the method used. Previous depth conversion studies are limited to local scales, limited well control and a focus on select horizons. To investigate the depth conversion uncertainty on a regional scale,

this research performs a comprehensive and regionally extensive depth conversion analysis utilising 13 3D seismic surveys with 73 interpreted TWT grids and 657 wells. Depth conversions were performed using the 4 most commonly used methods; average (pseudo) velocity, time-depth trend, kriging with external drift using TWT, and kriging with external drift to tie stacking velocities to average well velocities. To manage the large volume of data, a looping script was written to automate the depth conversion process and utilise the cross-validation, or blind-well method (use n wells to predict the n^th +1 well). Statistics on several variables were captured after each loop, with cluster analysis performed on the final data set to test variable significance on depth conversion accuracy. A database of approximately 10000 error calculations found that although the average velocity method is the most accurate at a high level (average absolute error ~24.9 feet), the best method and the expected error changes significantly (tens of feet) depending on the combination and value of the most significant variables. The variables which impacted uncertainty the most were; location (3d survey), formation, distance to the nearest well, and the spatial location of the predicted well relative to the existing well data envelope.

NORTH WEST SHELF 3D VELOCITY MODELING

Laureline Monteignies[1], Cédric Magneron[2] and Natalia Gritsajuk[2]*
[1]ESTIMAGES, Australia
[2]ESTIMAGES, France

The NWS is a major Oil&Gas area in Australia where regional velocity models exist for all the basins located in the province. Using an innovative 3D approach, a model covering the entire NWS has been built and is presented in this paper. The major challenge of the project was to honour as much as possible the resolution of the geological features and to ensure a global consistency of the model in a non-stationary environment at such a wide scale. Another one has been to work with more than 200 surveys and nearly 900 wells as input. The Estimage's 3D approach associated with advanced geostatistical techniques allowed us to build a geologically consistent model with a depth uncertainty far from the wells below +/-100m (at more than 100km from the wells).

NEW INTERPRETATION AND MODELLING RESULTS FOR A LATE TRIASSIC ISOLATED PINNACLE REEF COMPLEX ON THE EXMOUTH PLATEAU, WESTERN AUSTRALIA

*Jarrad Grahame**
CGG, Australia

The West Foxhound 3D survey is located approximately 200km from the north-west coast of Australia within the Exmouth Plateau, which represents the outermost structural element of the Northern Carnarvon Basin. The survey covers one of two known, isolated, Rhaetian pinnacle reef complexes that exist within the Exmouth Plateau making it of particular interest to enhance understanding of a new and under-explored exploration play. The results presented herein are derived from the focused interpretation and analysis of the West Foxhound 3D, which makes up part of a larger, comprehensive regional Triassic study, covering the entire North West Shelf including the Northern Carnarvon, Browse and Bonaparte basins. Results of the interpretation and analysis confirm that the Late Triassic interval within Foxhound hosts a significant number of isolated pinnacle reefs with potential access to charge from underlying Triassic source rocks. The pinnacle reefs represent a new and emerging play with only one reef to date drilled as a primary target.

1345–1500
Tuesday 23 August 2016

Minerals 6.C – Uncertainty & Big Data (1)

TAMING UNCERTAINTY IN GEOPHYSICAL INVERSION

Malcolm Sambridge, Rhys Hawkins and Jan Dettmer*
Australian National University, Australia

The concept of uncertainty in geophysical inversion is often confined to quantification of errors in parameters estimated from some data. A broader definition is to include uncertainty arising from the assumptions made in posing the inverse problem in the first place. These may include assumptions about the physics of the relationship between observations and unknowns, the class of parameterisation assumed for the unknowns, and guesses about the statistical character of random noise contaminating the data. Typically these assumptions are required to arrive at a tractable mathematical problem to solve using geophysical inversion methods. In this paper we outline an inversion approach that allows a broader definition of uncertainty which includes each of these classes of assumption. Including uncertainty in the model parametrization or in the nature of the noise statistics can lead to more realistic inversion results, but not always with increased error bars on the model parameters. For example, relaxing rigid assumptions in the nature of the parametrisation, even in simple problems can result in smaller and more realistic model error estimation. Using the data to decide between different classes of parameterization, physical assumptions or observational noise process is often called 'model choice' in statistics, an area that is often overlooked in the geosciences. Over the past 5 years the trans-dimensional inversion approach has increasingly found applications across a variety of inference problems in the geosciences, with new applications appearing regularly.

A BAYESIAN INFERENCE TOOL FOR GEOPHYSICAL JOINT INVERSIONS

Graeme Beardsmore, Lachlan McCalman and Alistair Reid*
Data61, Australia

Geophysical joint inversions seek to exploit the statistical fact that a model that simultaneously satisfies two or more independent data sets is more likely to represent geological 'reality' than a model that only satisfies a single data set. Interpreting geophysical data directly rapidly exceeds the capacity of a human as more data are added, so some form of machine assistance is usually required. Conventional inversion techniques can produce a 'best fit' model but this might only be one of a large range of possible models that fit the data. Bayesian inference provides a tool to evaluate the relative probability of all possible geological models in a given set, thereby quantifying the amount of information the data is actually providing.

Over 2012–2014, National ICT Australia (NICTA; now Data 61) worked with a number of university, government and industry partners, with support from the Australian Renewable Energy Agency, to build a Bayesian inference software tool for geophysical joint inversions. The tool was initially directed at geothermal energy exploration but is equally applicable to investigating other geological problems. For one geothermal exploration problem, Bayesian inference allowed us to jointly invert gravity, magnetics, magnetotelluric soundings and borehole temperature records to map in three dimensions the probability of encountering granite >270°C beneath the Moomba region of South Australia. The results correlated well with an independent deterministic inversion carried out by Geoscience Australia, but provided a much richer interpretation in probability space.

NICTA released the software tools as open source code on the GitHib platform.

1345–1500
Tuesday 23 August 2016

Minerals 6.D – Distal Footprints (6) – Case Studies

PRELIMINARY INTERPRETATIONS FROM THE 2015 COOMPANA AEROMAGNETIC SURVEY

Tom Wise, Mark J. Pawley and Rian A. Dutch*
Geological Survey of South Australia, Australia

The Coompana airborne survey is a large-scale pre-competitive aeromagnetic and radiometric survey in western South Australia flown in 2015. The survey was undertaken in order to provide greater geological controls on the basement geology in this area, which lies beneath the cover sequences of the Eucla, Bight, Denman and Officer Basins. This survey covers much of the South Australian part of the Coompana Province, which includes the Coompana Magnetic Anomaly. In this preliminary interpretation of the aeromagnetic survey, we have distinguished five basement domains based on the magnetic data and attempted to differentiate where domain boundaries are structural or intrusive. Integrating the aeromagnetic interpretation with existing drillhole and outcrop constraints suggests that the western part of South Australia had a long-lived, dynamic geological history with at least four major rock-forming events identified in the Coompana Province: c. 1610 Ma, c. 1500 Ma, c. 1180 Ma and c. 860 Ma.

Detailed interpretation of the 200 m line-spaced infill region has enabled contact and relative age relationships of the intrusive bodies causing the Coompana Magnetic Anomaly. We suggest a multi-phase intrusive complex, with an early deep disc-like intrusion, followed by pipe-like satellite bodies intruding higher into the crust. The relative age of this intrusive complex is interpreted to be between c. 1120 Ma and c. 860 Ma.

MAGNETOTELLURIC INVERSION, CARBONACEOUS PHYLLITES AND AN ORE ZONE: KEVITSA, FINLAND

Cuong V.A. Le, Brett D. Harris and Andrew M. Pethick*
Curtin University, Australia

We invert seven densely sampled magnetotelluric transects at the Kevitsa Ni-Cu-PGE (platinum group elements) deposit in Finland. The geology at the deposit presents at least two high electrical conductivity rock types within a resistive host. We consider the extent to which highly conductive phyllite and an ore zone can be separated through inversion of magnetotelluric data. Multiple inversions were completed with 312 magnetotelluric (MT) stations. It was possible to generate a three-dimensional conductivity volume from the 2D MT derived conductivities sections via volumetric interpolation. We compare the resulting 3D conductivity volume with co-located 2D and 3D seismic data. Comparisons show that an impression of the Ni-Cu-PGE ore-body could be observed in both seismic reflection and conductivity volumes. We discuss methods for constraining MT inversions and the impact they may have in separating proximal but highly conductive units. The inversions were complete as a precursor to full 3D cooperative inversion of the seismic and magnetotelluric data at this site.

INTERPRETING THE EROMANGA AND GEORGINA BASINS FROM MAGNETOTELLURIC DATA

Janelle Simpson[1] and Graham Heinson[2]*
[1]Geological Survey of Queensland, Australia
[2]University of Adelaide, Australia

This study uses broadband magnetotelluric (BBMT) and audio magnetotelluric (AMT) data to model the Eromanga and Georgina Basins in the Boulia region of western Queensland. Extensive data analysis to establish dimensionality, strike and the presence of galvanic distortion was conducted before inversion. The OCCAM 2D MT inversion code was used to produce conductivity sections for interpretation. The results of OCCAM inversions were compared the results of other inversion codes to ascertain the presence of any inconsistencies in the results. Several inversions were run for each profile to optimise inversion parameters with detailed inspection of data fit at each site to establish any systematic data misfits. Inversions were run on the full frequency of AMT data first as the resolution of the data was better. The broadband data was subset to frequencies above 0.4 Hz to focus the inversion on resolving the shallow features. A priori knowledge from the AMT inversions was very useful in interpreting the lower resolution BBMT data. Independent constraint in the form of drillhole and seismic data was used to aid interpretation of the inversions profiles. The BBMT inversions allowed the two-layer Georgina Basin signature evident in the south of the project area to be traced further north. They also delineated more complicated basin morphology in the west of the project area.

1345–1500
Tuesday 23 August 2016

Minerals 6.E – 4D Geodynamics (2)

GEOPHYSICAL RESPONSES FROM MINERAL SYSTEM COMPONENTS IN THE DEEP CRUST AND UPPER MANTLE

*Michael Dentith**
University of Western Australia, Australia

The concept of a mineral deposit forming via a mineral system that operates across areas of perhaps 1000s of squares kilometres and to mantle depths has important implications for greenfields

mineral exploration. Geographically widespread datasets and deep penetrating geophysical methods are required to map key mineral system elements such as fluid/metal source zones and migration paths. Developed primarily for academic studies of the deep crust, there are several established geophysical techniques that can potentially be used to identify elements of mineral systems in the deep crust and upper mantle. Although the seismic reflection method produces the highest quality images, it is prohibitively expensive and the recommended approach is a combination of MT surveys and receiver function recordings with CCP stacking. Mineral system elements that can be detected in this fashion include major structures and geological boundaries which are potential controls on fluid flow and also areas of crust and mantle that have been altered by one or both of fluid creation and migration.

IMAGING FRACTURE PERMEABILITY USING MAGNETOTELLURICS

Alison Kirkby, Graham Heinson and Simon Holford*
University of Adelaide, Australia

We present 1D anisotropic inversions of magnetotelluric data in two regions of the Otway Basin; Koroit, Victoria, and Penola, South Australia. In the Koroit region we have delineated an electrically anisotropic layer at approximately 2.5 to 3.5 km depth; this corresponds to the upper part of the Lower Cretaceous Crayfish Group, a known reservoir unit. The anisotropy strike is consistent between stations at approximately 160° east of north. We interpret the anisotropy at Koroit as resulting from pervasive NNW oriented, fluid-filled fractures, resulting in enhanced bulk electrical and hydraulic conductivity. This interpretation is consistent with permeability data from well formation tests. It is also consistent with the orientation of mapped faults in the area, which are favourably oriented for reactivation in the current stress field. In Penola, no persistent anisotropic layer has been defined even though the areas are geologically similar. The difference in the resistivity structure may reflect differences in the density of fractures or their fill material. Alternatively, it may reflect small differences in the amount by which the fractures are open, resulting from differences in the stress field and fracture orientation in each area.

1530–1710
Tuesday 23 August 2016

Petroleum 7.A – Acquisition & Processing

A ROBUST GRADIENT FOR LONG WAVELENGTH FWI UPDATES

Jaime Ramos-Martinez[1], *Sean Crawley*[1], *Kathy Zou*[1], *Alejandro Valenciano*[1], *Lingyun Qiu*[1], *Nizar Chemingui*[1] *and Andrew Long*[2]*
[1]Petroleum Geo-Services, USA
[2]PGS Australia, Australia

We introduce a robust method to produce long wavelength updates in gradient-based Full Waveform Inversion (FWI). The solution introduces dynamic weights in the velocity sensitivity kernel derived from impedance and velocity parameterization of the classical objective function. The new kernel implementation effectively eliminates the migration isochrones produced by the specular reflections, enhances the low wavenumber components in the gradient in heterogeneous media, and is able to deliver velocity updates beyond the penetration depth of diving waves. We use synthetic examples to illustrate how this dynamic weighted FWI gradient successfully recovers the velocity from pre-critical reflections. We also show with dual-sensor streamer data from deep-water Gulf of Mexico how the dynamic weighted FWI gradient can combine both transmitted and reflected energy in a global FWI scheme.

ADVANCED REPROCESSING AND IMAGING: ENHANCING LEGACY SURVEYS

Dominic Fell[1]*, *Shane Westlake*[2], *Richard Patenall*[1] *and Jennifer Badry*[1]
[1]WesternGeco, Australia
[2]Finder Exploration, Australia

This work demonstrates how fully utilizing a modern reprocessing and depth imaging sequence significantly enhances seismic data quality, thereby extracting additional value from older seismic datasets. Using an example from the northern Browse basin, a case study is presented in which the combination of broadband processing, advanced demultiple techniques and anisotropic earth model building produce significant uplift in the imaging results from what is a historically challenging basin for successful seismic data.

The reprocessing sequence was undertaken in two phases. The first phase focused on lowering the noise levels and extending the useful bandwidth of the conventionally acquired seismic data using deghosting techniques. This was combined with 2D and 3D surface demultiple techniques to produce a dataset with low noise levels and a broad signal spectrum for migration. These data were subsequently input to the second phase of the reprocessing which focused on deriving a detailed and accurate earth model. Further anisotropy analysis and well calibration routines were performed to calibrate the earth model to the well data.

The final imaging was performed using TTI Kirchhoff prestack depth migration and comparisons were made to the previous time domain imaging results undertaken in 2010.

HYBRIDISED WEIGHTED BOOT-STRAP DIFFERENTIAL SEMBLANCE

Hamish Wilson and Lutz Gross*
University of Queensland, Australia

Velocity analysis is often necessary in pre-stack seismic processing to produce a good estimate of subsurface velocities. It requires the picking of moveout velocities on the semblance spectra. The semblance spectra is hampered with noise and lack of resolution around the peak representing the best move out velocity approximation. In this paper we introduce a new semblance scheme to reduce spectral noise and increase resolution in the semblance domain. The new scheme is based on a simple amalgamation of previously developed semblance enhancement methods. These methods are; the local-similarity weighted semblance, velocity-sensitivity weighted semblance and boot-strapped differential semblance. Velocity sensitivity semblance weights all traces based on sensitivity in the semblance spectra to changes in velocity, the local similarity weighting accounts for correlation between the stacked gather

trace and all traces within the gather on a temporally localised scale and the boot-strapped differential semblance scheme weights the semblance spectra based on enhancing sensitivity to lateral differences in amplitudes. We test the proposed scheme on synthetic and real trace gathers. The test results show that our approach significantly improves the resolution and noise attenuation in the semblance spectra albeit to other semblance schemes.

ADVANCED DEBLENDING SCHEME FOR INDEPENDENT SIMULTANEOUS SOURCE DATA

M. Wang[1]*, *Z.H. Chen*[1], *C. Chen*[1], *F.C. Loh*[1], *T. Manning*[2] *and S. Wolfarth*[2]
[1]CGG, Singapore
[2]BP, Indonesia

Independent Simultaneous Source (ISS®) technology is an attractive way to provide high acquisition production rates and affordable higher density seismic imaging. In this paper, we propose an advanced deblending scheme to address the source separation requirement of ISS® data. The deblending scheme includes a) 3D low-rank decomposition based iterative noise modelling, and subtraction, b) signal-to-noise ratio map guided residual denoise and c) erratic noise attenuation. The application is tested on actual shallow water OBC dataset, which was pseudo-blended using a realistic dual vessel acquisition plan. The result shows that this advanced deblending scheme can successfully recover individual source responses. The deblended data have a minimal difference compared with the actual unblended data.

1530–1710
Tuesday 23 August 2016

Petroleum 7.B – Unconventional

APPLICATION OF NUCLEAR MAGNETIC RESONANCE (NMR) LOGS IN TIGHT GAS SANDSTONE RESERVOIR PORE STRUCTURE EVALUATION

Liang Xiao[1]*, *Zhi-qiang Mao*[2] *and Xiu-hong Xie*[3]
[1]China University of Geoscience Beijing, China
[2]China University of Petroleum Beijing, China
[3]BrightStars Hi-Tech Development, China

Based on the simultaneously applied mercury injection capillary pressure (MICP) and nuclear magnetic resonance (NMR) laboratory experimental results for 20 core samples from tight gas sandstone reservoirs of the Sichuan basin, the relationships of the piecewise power function between nuclear magnetic resonance (NMR) transverse relaxation T_2 time and capillary pressure (P_c) are established. A novel method, which is used to transform NMR reverse cumulative curve as pseudo capillary pressure (P_c) curve is proposed, and the corresponding model is established based on formation classification. By using this model, formation pseudo P_c curves can be consecutively synthesized. The pore throat radius distribution, and pore structure evaluation parameters, such as the average pore throat radius (Rm), the threshold pressure (Pd), the maximum pore throat radius (Rmax) and so on, can also be precisely extracted. After this method is extended to field applications, several tight gas sandstone reservoirs are processed, and the predicted results are compared with core derived results. Good consistency between evaluated results with core derived results illustrates the dependability of the proposed method. Comparing with the previous methods, this presented model is much more theoretical, and the applicability is much improved.

A NEW METHOD OF EVALUATING TIGHT SANDSTONE RESERVOIR PORE STRUCTURE FROM CONVENTIONAL LOGS

Liang Xiao[1]*, *Chang-chun Zou*[1] *and Xiu-hong Xie*[2]
[1]China University of Geoscience Beijing, China
[2]BrightStars Hi-Tech Development, China

The identification and evaluation of tight gas sandstone reservoirs faces a great challenge due to the characteristics of ultra-low porosity, ultra-low permeability, complicated pore structure and strong heterogeneity. To improve tight gas sandstone reservoir evaluation, the pore structure should be first quantitatively evaluated. NMR logs are advantageous in formation pore structure evaluation, but may not always be practicable as they are only acquired in limited wells. This study is based on the analysis of morphological characteristics of experimental mercury injection capillary pressure (MICP) curves for 54 core samples from tight gas sandstone reservoirs of central Sichuan Basin, southwest China. A new method is proposed to construct pseudo capillary pressure curves from conventional porosity and permeability. The corresponding models of predicting pseudo P_c curves from conventional logs are established. The reliability of this technique is verified by comparing constructed capillary pressure curves with laboratory measured results. After this technique is extended to field application, consecutive pseudo capillary pressure curves are constructed, and the parameters associated with reservoir pore structure evaluation, such as pore throat radius distribution, the average pore throat radius, the threshold pressure, and so on, are estimated. Combining with these parameters, tight gas sandstone reservoirs pore structures are quantitatively evaluated, and effective formations can be easily identified. The proposed technique is more universally applicable in tight gas sandstone reservoir pore structure evaluation as it does not require the acquisition of field NMR logs.

1530–1710
Tuesday 23 August 2016

Minerals 7.C – Uncertainty & Big Data (2)

BIG DATA TECHNIQUES FOR APPLIED GEOSCIENCE: COMPUTE AND COMMUNICATE

Anya M. Reading, Matthew J. Cracknell and Stephen Kuhn*
University of Tasmania, Australia

Big Data techniques have the potential to be paradigm-changing for applied geoscience if they are used widely. A significant number of such techniques, under the umbrella of Earth informatics, involve Machine Learning applied to high dimensional data to create new forms of value. This contribution

presents two case studies of successful Earth informatics computation and the communication of the value of results, which provide insight into the uptake of 'Big Data' in geosciences.

Machine Learning techniques split naturally into either supervised or unsupervised approaches. Supervised algorithms, such as Random Forests™ (RF), support vector machines or neural networks, share the concept of training a classifier using an initial (training) dataset. They are generally applied to predictive tasks, such as our first case study, predicting lithology from remote sensing and airborne geophysical data. Unsupervised algorithms, such as Self-Organising Maps (SOM), allow patterns inherent in the data to emerge without the use of a training dataset. They are generally applied to tasks which seek to explore patterns in data, such as our second case study, which identifies new potentially prospective river catchments. We find that calculating and presenting explicitly the newly extracted value, of the result obtained through computation, is an essential component of the post-compute evaluation.

As strong advocates for the use of a range of Big Data techniques in applied geosciences, we conclude that the benefits to be gained from the way that we 'compute' can be lost if we do not also take considerable care with the ways that we 'communicate'.

QUANTIFYING THE ERRORS IN GRAVITY REDUCTION

*Philip Heath**
Geological Survey of South Australia, Australia

Mistakes in processing gravity data lead to errors in the final product. This can mean that overlapping gravity surveys are often incompatible, and can lead to incorrect geological interpretations. In this paper I demonstrate the magnitude of the errors introduced at various stages of the gravity reduction process. I have focussed on errors relating to calibration factors, time zones and time changes, height, geodetic datums, gravity datums, and the equations involved therein. The errors range from below the level of detection, to many milligals.

The results highlight the need to not only be diligent and thorough in processing gravity data, but also how it is necessity to document the steps taken when processing data. Without properly documented gravity surveys they cannot be reprocessed should an error be identified.

RESOURCE MANAGEMENT THROUGH MACHINE LEARNING

Justin Granek[1], *Eldad Haber*[1]* *and Elliot Holtham*[2]
[1]University of British Columbia, Canada
[2]NEXT Exploration, Canada

In the modern era of diminishing returns on fixed exploration budgets, challenging targets, and ever-increasing numbers of multi-parameter datasets, proper management and integration of available data is a crucial component of any resource exploration program. Machine learning algorithms have successfully been used for years by the technology sector to accomplish just this task on their databases, and recent developments aim at appropriating these successes to the field of natural resource exploration. Numerous algorithms have been attempted for resource prospectivity mapping in the past, and in this paper we apply a modified support-vector machine algorithm to a test dataset from the QUEST region in central British Columbia, Canada, to target undiscovered Cu-Au porphyry districts. The modified algorithm is designed to properly handle the highly variable uncertainty associated with both the training data (ie: geophysics, geochemistry, geological mapping) as well as the training labels (known Cu-Au porphyry targets in the region). Support vector machines are introduced, the challenges of working with geoscientific datasets are discussed, and finally results from applying the modified algorithm to the QUEST dataset are presented.

1530–1710
Tuesday 23 August 2016

Minerals 7.D – Distal Footprints (7) – Hard Rock Seismics

INTRODUCING 3RD DIMENSION INTO 2D REFLECTIVE SEISMIC EXPLORATION IN THE COMPLEX HARD ROCK ENVIRONMENT

*Aleksandar M. Dzunic**, *Pouya Ahmadi, Mahyar Madadi and Andrej Bona*
Curtin University, Australia

In this paper, we are proposing a new methodology of 2D seismic acquisition and processing that aims to improve imaging of complex 3D geological environments. The method requires a simultaneous acquisition along two parallel receiver lines. The adapted processing highlights locations of the reflectors that are out of vertical plane by filtering the data by the apparent angle of incidence. This filtering also produces static and residual corrections as a function of this angle. Another benefit of the proposed pre-stack plane filtering is producing 3D velocity model as well as set of individually filtered and migrated sections that can be distributed in 3D volume for the visualisation proposes and interpretation free of conflicting events that would be present in conventional 2D imaging.

INTERPRETATION OF HARD ROCK SEISMIC DATA USING 3D PRESTACK DIFFRACTION IMAGING

*M. Javad Khoshnavaz**, *Andrej Bona, M. Shahadat Hossain and Milovan Urosevic*
Curtin University, Australia

Mineral deposits are associated with geological settings characterized by discontinuities and complex structural heterogeneities such as fracture zones, small-scale objects, intrusive and steeply dipping structures. Therefore, detecting such heterogeneities is of primary interest in mineral exploration. Usually, the scale and shape of such heterogeneities cause the seismic energy to diffract rather than reflect. Despite the natural lack of reflectors and potentially abundant number of diffrators, there are only few case studies of diffraction imaging in hard rock environments with almost no examples of diffraction imaging in prestack domain. Herein, we fill this gap by implementing a 3D prestack diffraction imaging technique to detect point diffractors in hard rock environment. The technique includes computation of diffraction traveltime curves followed by semblance analysis along the curves, with high value of

semblance corresponding to high diffractivity.

The performance of the method is demonstrated on a 3D synthetic seismic data and applied to a 3D field seismic data set recorded over Kevitsa mineral deposit in the northern Finland. The results of the 3D prestack diffraction imaging method suggest that diffractivity is a powerful attribute that can be used with other seismic attributes for the interpretation of seismic data in hard rock environments.

OLYMPIC DAM SEISMIC REVISITED: REPROCESSING OF DEEP CRUSTAL SEISMIC DATA USING PARTIALLY PRESERVED AMPLITUDE PROCESSING

Tom Wise[1], Anthony Reid[1], Sara Jakica[2], Adrian Fabris[1], Simon van der Wielen[1], Sasha Ziramov[3], Don Pridmore[2], Graham Heinson[4] and Paul Soeffky[4]*
[1]Geological Survey of South Australia, Australia
[2]HiSeis, Australia
[3]Curtin University, Australia
[4]University of Adelaide, Australia

Two deep crustal seismic profiles, centred on the Olympic Dam Cu-Au-U deposit, were reprocessed by HiSeis Pty Ltd. using a proprietary method. This processing method aimed to enhance subtle variations in signal strength and highlight upper crustal discontinuities. The resulting images enable interpretation of steep structures and regions of enhanced/reduced reflectivity possibly associated with large-scale alteration zones. This work highlights additional information within these deep crustal seismic lines that illuminate different aspects of the geology.

AN EXAMPLE OF IMAGING DEEPER USING EXTENDED VIBROSEIS CROSS-CORRELATION

*Ross D. Costelloe**
Geoscience Australia, Australia

Geoscience Australia has been collecting Vibroseis deep crustal reflection seismic data since 1999. Since 2013, Geoscience Australia has also collected the uncorrelated single sweep data for each VP of each survey. For a typical survey using three 12 s sweeps, each with 20 s listening time, this means collecting 96 s + 20 s = 116 s of data per VP, instead of 20 s of data per VP. This is nearly a 6-fold increase in data volume, and has been made possible by the availability of high capacity USB data disks. Using extended cross-correlation on the uncorrelated record data, it is possible to image deeper into the earth than using standard vibroseis cross-correlation. Geoscience Australia applied the method of truncated cross-correlation to a deep crustal reflection seismic survey collected over the Yathong Trough section of the Darling Basin in central NSW in 2013. This area showed unusual reflectivity below the Moho in the mantle, stimulating this study. The extended correlation stack showed some faint reflectivity visible from 18s to 24 s which may link to a region of higher reflectivity visible at about 18s in the mantle. Also, the truncated extended cross-correlation method appeared to show improved reflectivity in the mid to lower crustal areas.

1530–1710
Tuesday 23 August 2016

Minerals 7.E – Inversion (2)

QUANTITATIVE MAGNETIZATION VECTOR INVERSION

Ian N. MacLeod and Robert G. Ellis*
Geosoft, Canada

Modelling of magnetic rock properties from magnetic field observations has been an important practice in resource exploration for decades. However, the application of this practice has been limited by conventional thinking that assumes rock magnetization is dominated by induced magnetization such that magnetization direction is aligned with the geomagnetic field. Convention has also accepted that we are unable to model for magnetic remanence without a-priori knowledge of remanence direction and strength.

Recent practical successes in directly modelling magnetization vector direction and strength using Magnetization Vector Inversion (MVI) have challenged these conventions, and MVI modelling is proving useful in practical exploration scenarios. The addition of new information, namely the direction and amplitude of magnetization, demands new thinking and approaches to understanding what this information means, and how to use the modelled direction of magnetization in practical situations.

This paper presents a new statistical and quantitative approach to define and discriminate different magnetization domains within a full 3D MVI voxel model. Our studies show that modelled vector direction is meaningful even without prior knowledge of remanence (and other) magnetization characteristics. We also demonstrate that reasonable magnetization direction can be recovered from both weakly and strongly magnetized source rocks.

AEM CROSS-GRADIENT CONSTRAINED INVERSION OF GRAVITY AND MAGNETIC DATA

Adrián M. León-Sánchez[1], L.A. Gallardo[1] and A. Yusen Ley-Cooper[2]*
[1]CICESE, Mexico
[2]CSIRO, Australia

Nowadays magnetics, electromagnetics and gravity are among the most abundant airborne surveys. Traditionally they aim at specific depth targets. For instance, Airborne Electromagnetic (AEM) data are known to provide reliable models of a few hundred meters deep; whereas, gravity and magnetic data can reveal geological features below few thousand meters depth. This depth-resolution difference has historically limited the combined interpretation of these data. We, however, hypothesize that there is a commonly sensed depth interval, which could be used to harness the joint inversion of the data and increase the reliability of the models in the wider depth extent. To demonstrate this we designed three inversion experiments using potential and AEM field data acquired in Western Australia. Firstly, we inverted each data set separately using a conventional 2D inversion strategy. Secondly, we jointly inverted the gravity and magnetic data using the cross-gradient constraint. Thirdly, we added a preliminary AEM resistivity model as a cross-

gradient constraint for the 2D cross-gradient joint inversion of the gravity and magnetic datasets. Our results show that the three data sets sense a common area of the subsurface and that the vertical resolution of each data set influences in the shallow and deep structures of the joint models.

INVERSE AND FORWARD MODELLING USING RANDOM DIPOLES – CASE STUDY

*Roger Clifton**
Northern Territory Geological Survey, Australia

A recently published method of automatically finding magnetic depths to magnetic layers is demonstrated, finding depths to significant details in the magnetic basement under Melville Island, Northern Territory.

By using a method that simulates a magnetic basement as a series of layers of random dipoles, the depths to basement are satisfactorily obtained. Multiple layers appear in the results. However the inversion method used has coarse horizontal resolution, and the layers may be separated horizontally within the sample.

To resolve the ambiguity a forward model, also composed of layers of dipoles, is built on the information obtained from the inversions. Forward modelling requires Fourier convolution for speed. The cycle of analysis is logically completed by comparing the synthetic depth profile with the depth profile obtained by inverting the survey data.

THE 3D RESOLUTION POWER OF THE FULL TENSOR GRAVITY GRADIENT

José P. Calderón-Magallón and L.A. Gallardo*
CICESE, Mexico

Airborne gravity tensor (or gravity gradient) surveying is one of the newest techniques for geophysical exploration. The rise in the acquisition of this data type is partially due to the fact that these data provide much more complete, extensive and higher resolution information of rock density distribution than conventional land gravity data. This has positioned Airborne Gravity Gradient (AGG) surveys among the geophysical services requested by mining companies, alongside aeromagnetic and radiometric surveys. The use of these data has been primarily to support geological mapping given the limited access to commercial software for quantitative depth interpretation. In particular, there has been a scarce development of AGG data inversion software, which has limited our understanding of the significance of these data for resolving three-dimensional subsurface targets. In this work we hypothesize that AGG data can provide more detailed information of the multidirectional variations of subsurface density. To prove this hypothesis, we developed conjugate gradient AGG-data inversion software for three-dimensional targets. This software was applied to synthetic data generated by several test assemblages of three-dimensional bodies and used to perform a Singular Value Decomposition (SVD) sensitive analysis to explore the actual resolution power of the different tensor data components and whether they are indeed superior to the conventional vertical gravity.

Wednesday 24 August 2016

0830–1010
Wednesday 24 August 2016

Petroleum 8.A – Inversion

WHAT'S NEW AND EXCITING IN SEISMIC INVERSION?

*Dennis Cooke**
ZDAC Geophysical Technologies, Australia

Consider an oil and gas exploration team that has been successfully using seismic attributes such as gradient & intercept or fluid & lithology indicators. Why might this team want to switch from those tried-and-true seismic attributes to seismic inversion? And which type of seismic inversion should they use? We now have access to azimuthal inversion, facies inversion, Bayesian probabilistic inversion and full waveform acoustic and (emerging) full waveform elastic inversion. The evolution and pace of seismic inversion technologies is exciting but present some difficult choices to the uninitiated interpreter. This talk aims to give seismic interpreters an overview of these 'new' technologies and how they compare. Topics covered will include: the advantages and challenges of azimuthal AVO inversion in Australia's high stress environment, Bayesian (probabilistic) inversion and how inverting for facies improves it, synergies and challenges of combining new broad-band/long cable seismic acquisition with AVO inversion, and full waveform seismic inversion – can it replace AVO inversion? A minimum of equations will be shown – and only then to as a guide to illustrate what the different inversion techniques are doing.

OBTAINING LOW FREQUENCIES FOR FULL WAVEFORM INVERSION BY USING AUGMENTED PHYSICS

Eldad Haber[1]*, *Eran Treister*[1] *and Elliot Holtham*[2]
[1]University of British Columbia, Canada
[2]Kyma Geosciences/Computational Geosciences, Canada

Full waveform inversion (FWI) is a process in which seismic data in the frequency or time domain are being fitted by changing the velocity of the media under investigation. The problem is nonlinear, and therefore, optimization techniques have been used to attempt and find a geological solution to the problem. The main problem in fitting the data is the lack of low special frequencies. This deficiency often leads to a local minimum and to non-geologic solutions. In this work we discuss how to obtain low frequency information that can augment FWI. We explore two techniques, the first, travel time tomography and the second, controlled-source electromagnetics. We then discuss a framework for joint inversion and show that by considering these problems jointly we are able to steer the direction of FWI towards the global minimum.

ESTIMATION OF RESERVOIR FLUID SATURATION FROM 4D SEISMIC DATA: EFFECTS OF NOISE ON SEISMIC AMPLITUDE AND IMPEDANCE ATTRIBUTES

*Rafael Souza**, *David Lumley and Jeffrey Shragge*
University of Western Australia, Australia

Time-lapse (4D) seismic data sets have proven to be extremely useful for reservoir monitoring. Seismic-derived impedance estimates are commonly used as a 4D attribute to constrain updates to reservoir fluid flow models. However, 4D seismic estimates of P-wave impedance can contain significant errors associated with the effects of seismic noise and the inherent instability of inverse methods. These errors may compromise the geological accuracy of the reservoir model leading to incorrect reservoir model property updates and reservoir fluid-flow predictions. To evaluate such errors and uncertainties we present a time-lapse study based on a 3D reservoir model example, thereby exploring a number of inverse theory concepts associated with the instability and error of coloured inversion operators and their dependence on seismic noise levels. In this example, we use an oilfield benchmark case based on the Namorado Field in Campos Basin, Brazil. We introduce a histogram similarity measure to quantify the impact of seismic noise on maps of 4D seismic amplitude and impedance changes as a function of S/N levels, which indicate that amplitudes are less sensitive to 4D seismic noise than inverted impedances. The root-mean-square errors in the estimates of water saturation changes derived from 4D seismic amplitudes are also smaller than for 4D seismic impedances, over a wide range of typical seismic noise levels. These results quantitatively demonstrate that seismic amplitudes can be more accurate and robust than inverted seismic impedances for quantifying water saturation changes from 4D seismic data, and emphasize that seismic amplitudes may be more reliable to update fluid-flow model properties in the presence of realistic 4D seismic noise.

0830–1010
Wednesday 24 August 2016

Petroleum 8.B – Unconventional/Monitoring

USING FLUID-INDUCED SEISMICITY TO INFER PERMEABILITY

*Andrew King** *and Tobias Müller*
CSIRO, Australia

For engineering applications involving fluid flow through porous rocks underground, the permeability of a rock mass is an important parameter. Imaging of the 3D permeability distribution is generally done by a history-matching approach: fluid pressure due to injection in a well with known pressure and flow rates is numerically simulated, and the rock permeability is adjusted so as to match predicted pressure values to measured observations. These pressure observations are made at producing wells. Because there will normally be few wells, the observations, while being dense in time, are spatially sparse. The idea of this paper is to augment these downhole pressure measurements by using microseismic data to infer pressure at seismic event locations.

The mechanism of pressure-induced seismicity is the reduction of effective normal stress across a plane of weakness. The rock strength can be represented as a critical pressure – the pore pressure above which the rock will fail. The rock strength is highly heterogeneous, because of the existence of weaknesses such as joints, bedding planes, and clay bands, and stronger regions such as sandstone channels. So the rock strength will be random. We model the rock strength as a Weibull-distributed

critical field. A microseismic event occurs where pressure exceeds this critical field, and so is effectively a point pressure measurement, with an uncertainty given by this Weibull distribution. The idea is to augment the well-pressure observations with these 'virtual' pressure measurements at seismic event locations.

We model pressure diffusion using a finite volume approach, and examine the inversion, for permeability, of two different types of data, (1) pressure measurements in boreholes, and (2) virtual pressure measurements at seismic event locations. We show that the two types of data provide complementary information.

RELATING ELECTRICAL RESISTIVITY TO PERMEABILITY USING RESISTOR NETWORKS

Alison Kirkby, Graham Heinson and Lars Krieger*
University of Adelaide, Australia

We use resistor network models to explore the relationship between electrical resistivity and permeability in fractures filled with an electrically conductive fluid. The fracture aperture distribution is determined by generating fracture surface pairs that are constructed based on characteristics measured on rock samples. We use these to generate and solve resistor networks with variable hydraulic and electrical resistance. The aperture is incrementally increased, to analyse the changes in both properties as a fault is opened. At small apertures, electrical conductivity and permeability increase moderately with aperture until the fault reaches its percolation threshold. Above this point, the permeability increases by four orders of magnitude over a change in mean aperture of less than 0.1 mm, while the resistivity decreases by up to a factor of 10. The permeability increases at a greater rate than the conductivity, and therefore the percolation threshold can be defined in terms of the matrix to fracture resistivity ratio, M. The value of M at the percolation threshold, M_{PT}, varies with the ratio of rock to fluid resistivity, the fault spacing, and the fault offset but is always less than 10. Greater M values are associated with fractures above their percolation threshold and therefore open for fluid flow.

MAGNETOTELLURIC MONITORING OF UNCONVENTIONAL ENERGY RESOURCE DEVELOPMENT: DISRUPTIVE TECHNOLOGY OR DAMP SQUIB?

*Graham Heinson**
University of Adelaide, Australia

A significant scientific and engineering challenge for the energy resources industry is to monitor injected or produced fluid at depths of hundreds or thousands of metres, and over time-scales of hours to years. A new approach using surface magnetotelluric (MT) methods has been developed over the last five years to map deep-fluid pathways by virtue of their electrical resistivity changes, both spatially and temporally. This is a cheap technology as it uses natural electromagnetic source-fields and does not require drilling. However, is this method really effective for industry for economic reasons and for social and environmental compliance? In other words, is it a disruptive technology or a damp squib?

This paper reviews the physics of the approach, and demonstrates the feasibility of the MT method for monitoring unconventional energy resource development. A number of case studies will be shown, including shallow coal seam gas de-pressurisation, deep hydraulic stimulation of a shale gas reservoir, and enhanced geothermal system development.

0830–1010
Wednesday 24 August 2016

Minerals 8.C – Lithospheric Architecture (1) – Seismology & Potential Fields

3D IMAGING OF THE EARTH'S LITHOSPHERE USING NOISE FROM OCEAN WAVES

Yingjie Yang, Jun Xie and Kaifeng Zhao*
Macquarie University, Australia

The lithosphere is the rigid outer shell of the Earth, composed of the crust and the rigid uppermost mantle. The lateral variation of lithosphere is believed to be closely related to the foci of intraplate earthquakes and volcanism, the location of large ore deposits and diamond-bearing kimberlites, and the formation of oil/gas-bearing sedimentary basins. Understanding the fine-scale structure of the lithosphere is therefore one of the most fundamental tasks in Earth sciences, and has important implications for society in terms of economic prosperity and hazard mitigation.

Seismic tomography is the main technique available to image the subsurface structure of the Earth across a range of scales. Conventional seismic tomography exploits the seismic waves emitted by earthquakes. However, because most large earthquakes occur at plate boundaries and most continents, including Australia, are not seismically active, earthquake-based tomography suffers from uneven distributions of earthquakes and has difficulties in deciphering fine-scale structures of the Earth in seismically quiet continents.

In the past decade, the advent of ambient noise tomography (ANT) has revolutionized seismic tomography because it can overcome the limitations of conventional earthquake surface wave tomography. This technique uses diffuse background seismic energy, mostly comes from the interaction of ocean waves with the crust. Empirical Green's functions of surface waves passing between a pair of stations are extracted by cross-correlating continuous time series of ambient noise. Within a regional seismic array, all inter-station measurements of surface-wave dispersion can be measured and tomography can be performed to image the underling lithospheric structure. In this study, we demonstrate the applications of broadband ANT in mapping fine-scale lithosphere structures around the world using continuous seismic data.

PASSIVE SEISMIC STUDIES SHOW CONFIGURATION OF PALEOPROTEROZOIC SUBDUCTION ZONES AND THEIR ROLE IN CRATON ASSEMBLY IN WESTERN AUSTRALIA

Ruth E. Murdie[1], Huaiyu Yuan[1], Michael Dentith[2], Simon P. Johnson[1] and Klaus Gessner[1]*
[1]Geological Survey of Western Australia, Australia
[2]University of Western Australia, Australia

The Capricorn Orogen Passive source Array (COPA) is the passive source seismic component of a major Science and Industry Endowment Fund (SIEF) project, 'The distal footprints of giant ore systems: Capricorn case study'. COPA focuses on the deep crustal and shallow lithospheric structure in the Capricorn Orogen with the aim to better understand the tectonic amalgamation of the Western Australian Craton. The objective of COPA is to produce 3D multiple scale seismic images across the orogeny, that together with other geological and geophysical datasets help constrain the timing and kinematic evolution of Capricorn Orogen's fault zones, and their role in the metallogenic history.

POTENTIAL FIELD STUDIES ALONG THE 13GA-EG1 EUCLA-GAWLER DEEP CRUSTAL SEISMIC REFLECTION LINE

Ruth E. Murdie[1], Lucy Brisbout[1], John Brett[1], Catherine V. Spaggiari[1], Klaus Gessner[1], Rian A. Dutch[2], Stephan Thiel[2], Tom Wise[2] and Mark J. Pawley[2]*
[1]Geological Survey of Western Australia, Australia
[2]Geological Survey of South Australia, Australia

This paper highlights the complimentary potential field studies that have been done in parallel to the interpretation of the 13GA-EG1 Eucla-Gawler deep crustal reflection seismic line. Gravity and magnetic images have been interpreted and potential field data has been modelled using edge detection, forward modelling and inversions to pick out the main domains and structures. Seismic, MT and drill core analysis has been progressing in parallel to the potential field investigations. The different approach taken here was to allow more freedom and independence in the interpretations originating from the potential field studies, rather than constraining them with a predefined architecture from the seismic interpretation. Initial results show gravity and magnetic worms correlating with interpreted structures and domain boundaries. Inversions show the 3D distribution of magnetic susceptibility and densities associated with major features such as the Mundrabilla Shear Zone and folded feature seen in the Nawa Domain. This paper summarises the main findings from the potential field studies, which, in conjunction with the parallel studies, allows for a more robust understanding of the crustal architecture and assessment of the mineral potential of the region.

0830–1010
Wednesday 24 August 2016

Minerals 8.D – Distal Footprints (8) – Hard Rock Seismics

EXAMPLES OF THE USE OF SEISMIC REFLECTION TO RE-INVIGORATE A MATURE FIELD: TENNANT CREEK

G. Turner[1], J. Kinkela[1], G. Hird[1], S. Zulic[1], G. Osborne[2], R. Bills[2], A. Cuison[2], J. Cook[3] and R. Smith[3]*
[1]HiSeis, Australia
[2]Emmerson Resources, Australia
[3]Evolution Mining, Australia

Recently seismic reflection has been gaining prominence as a tool for the minerals industry for orebody delineation and exploration in known mineralised terrains particularly where mineralisation extends to depths beyond a few hundred metres. We believe it can also play an important role in establishing the structural architecture of an area due to its unrivalled ability to map the orientation of structures at depth. In this paper we present recent results from an exploration program in the Tennant Creek Mineral Field (TCMF) in the Northern Territory of Australia for both of these objectives.

The program included the completion of 2 × 4km seismic lines close to the Gecko mine and a 60km N-S seismic line centred on Tennant Creek together with borehole full waveform sonic and vertical seismic profile data.

The borehole measurements confirm that the ironstone bodies and associated alteration that host the mineralisation provide a strong acoustic impedance contrast within the Warramunga sediments that otherwise show relatively little acoustic impedance variation.

The 4km seismic lines have generated two targets both at approximately 1km depth. Shallow imaging was hampered by strong surface wave noise but it is the targets that are not detectable by gravity and magnetics that motivated the use of seismic at Gecko and Chariot.

The regional survey was acquired to improve the understanding of the mineralising systems and underlying structural architecture around Tennant Creek. The survey mapped major structures that control mineralisation, such as the Southern Shear Zone, Mary Lane Fault and Gecko Fault. The seismic survey also showed that these structures were north verging and identified similar structural positions that lack surface expression but show many of the characteristics of the mineralised structures.

SHOOT FIRST, ASK QUESTIONS LATER: APPLICATION OF SEISMIC REFLECTION TO A GREENFIELDS ZINC EXPLORATION PROJECT

Darren Hunt and Daniel Sully*
Teck Australia, Australia

As exposed portions of premier Zn belts reach exploration maturity, targets become deeper and more challenging to explore. Explorationists are faced with having limited methods for effective deep exploration.

Seismic reflection is one method which can be used effectively to characterise geological targets at depth. Teck has applied seismic reflection at an early stage on several zinc exploration projects, including the greenfields Yalco Zn project.

Geophysical methods have been used to assess the structural architecture of the remote Yalco area, located within the highly prospective Emu Fault corridor. 2D Seismic reflection lines have been used in addition to potential field methods and magnetotellurics. The superior resolution of seismic reflection has allowed us to characterise the stratigraphy and map key structures in detail in order to validate a conceptual geological target. The preliminary interpretation of the seismic sections has confirmed favourable depths to host, and resulted in a re-evaluation of target locations.

Use of seismic reflection surveys at an early stage has the potential to reduce technical risk and increase the effectiveness of target testing.

YATHONG TROUGH DEEP 2D REFLECTION SEISMIC SURVEY – IDENTIFYING MAJOR STRUCTURES FOR THE SOUTHERN COBAR BASIN, NSW

Rosemary Hegarty[1], Astrid Carlton[1] and Karol Czarnota[2]*
[1]Geological Survey of New South Wales, Australia
[2]Geoscience Australia, Australia

Two 2D deep seismic reflection survey lines totalling 229 km in length were completed in western NSW by the Geological Survey of New South Wales (GSNSW) under the New Frontiers initiative. Contract management for seismic acquisition and data processing were conducted by Geoscience Australia (GA), with funding for data processing contributed by Coal Innovation, NSW Industry. The survey aimed to detail the stratigraphy of thick Devonian sequences within the Yathong Trough in the eastern Darling Basin.

Survey line YT2 was extended eastwards across the southern Cobar Basin over rift-phase volcanic sequences of the Cobar Supergroup in the Mount Hope and Rast Troughs. The objective of acquiring 20 s two-way time data was to identify major structural elements, crustal architecture, and to improve understanding of this mineralised region. Preliminary interpretation of the deep 2D seismic data by GSNSW and GA has recognised reflector domains and discontinuities below the surface outcrops (in the east) and also within basement rocks beneath the basin sequences. These were considered in the context of regional aeromagnetic and gravity data, and previous deep seismic profile interpretations for the Cobar region. The key results are definition of crustal thickness and interpretation of prominent fault structures in the upper and middle crust. In particular, good correlation was found between near-surface fault zones (from geological mapping or interpreted from potential field data) and faulting related to a major west-dipping high-angle seismic discontinuity that penetrates to the middle levels of the lower crust.

This presentation describes the interpretation of major reflective horizons and structures, identifying upper, middle and lower crustal features. The profiles and interpretations will provide valuable input for regional geodynamic studies. Increased structural understanding may assist the search for additional gold and copper deposits in the southern Cobar Basin.

DEVELOPMENT AND IMPLEMENTATION OF THE SPARSE REFRACTION METHOD TO EXPLORATION FOR DETRITAL FE DEPOSITS

Mike Haederle[1], Leon Mathews[2] and Mike Enright[1]*
[1]Rio Tinto Exploration, Australia
[2]Atlas Geophysics, Australia

The need for a more effective tool to explore for channel hosted detrital iron ore deposits under post mineral cover has led to the development of a novel minimalistic seismic refraction survey method we call 'Sparse Refraction', to map the depth of cover over basement. The survey configuration employs a single source and a single receiver, at a fixed offset. The source-receiver pair are moved progressively along a traverse, and at each station a first break reading is recorded. Gravity data is also acquired. Combining the two datasets allows the target response to be isolated from the gravitational effects of palaeotopography – we call this residual gravity field the 'Excess Mass'. The method allows large areas to be screened quickly and effectively, with low environmental impact.

This paper describes the journey from understanding the exploration problem, finding a solution, and the successful implementation of the new approach.

0830–1010
Wednesday 24 August 2016

Minerals 8.E – Uncertainty & Big Data (3)

DEALING WITH UNCERTAINTY IN AEM MODELS (AND LEARNING TO LIVE WITH IT)

*A. Yusen Ley-Cooper**
CSIRO, Australia

Interpreting inversions and modelling airborne electromagnetic (AEM) data is ambiguous. Assessment on the degree of certainty of how representative a selected model is, always reassuring. Geophysicists assessing AEM models are often faced with the conundrum of determining a single 'best', 'right' and geologically sensible model from of all the possible solutions. This paper explores the characteristics of several acceptable models, without being concerned with details of any particular one.

Geoscience Australia's reversible jump (trans-dimensional) Markov chain Monte Carlo (rj-MCMC) is a stochastic algorithm which has enabled the sampling of thousands of plausible models that fit the data at each individual location. Through the statistical analysis of these ensembles of models, a measure of uncertainty and a probable distribution of conductivities at that depth can be derived.

On most occasions, single 'best' solutions fromm deterministic inversions are found to be reasonable representations of the whole suite of models recovered by the MCMC. But the importance of exploring multiples models and their limitations resides on trying to extract what information can actually be determined from the data, information which often cannot be given by a single best model.

QUANTIFYING THE EFFECT OF PRIMARY FIELD MODELLING ON TEMPEST DATA – THE IMPORTANCE OF UNCERTAINTY

Anders Vest Christiansen[1], Esben Auken[1], A. Yusen Ley-Cooper[2] and Kristoffer R. Andersen[1]*
[1]Aarhus University, Denmark
[2]CSIRO, Australia

The TEMEPST system is used widely for large-scale mapping. It is a fixed-wing time-domain system with the transmitter strung around the aircraft and the receiver coils towed in a bird behind and below the aircraft. The TEMPEST data are special in the sense that the data are presented as B-field, 100% duty cycle data. In this process the system self-response is removed, which means that one needs to compute and reinstate the primary field that was removed to accurately model the measured data.

In this paper we show that it is crucial to assign uncertainty to the reinstating of the primary field because it can be several orders of magnitude larger than the secondary field especially over resistive grounds and at late times. To quantify the effect

of the uncertainty we have produced a number of inversions of a line in the Capricorn survey where we have added different levels of uncertainty when reinstating the primary field. The results have all been produced with the Aarhus Workbench which uses the AarhusInv algorithm and compared with results from the GA-LEI algorithm.

We show that reinstating the primary field into the forward calculations is necessary for accurate modelling of TEMPEST responses. Though, to achieve realistic and fitting inversion models (particularly over resistive ground when less signal is measured) it is crucial to allow for a small uncertainty on the primary field when this is reinstated to the forward response. This balances the inversion and allows for misfits in the range of the assumed data noise, which is not possible for the resistive areas without the assumed noise on the primary.

GRAVITY GRIDDING IN SOUTH AUSTRALIA

Philip Heath and Laszlo Katona*
Geological Survey of South Australia, Australia

Creating an image of the acceleration due to gravity over a large area (in this case a large portion of South Australia) is not a trivial process. This paper examines some of the issues involved with creating such an image, and presents some examples. Treating the state gravity as a single dataset highlights outliers and results in 'dimples'. These are short wavelength features around single points. Treating the data as a compilation of grids and then levelling the grids results in linear artefacts where the survey boundaries meet.

Two new approaches have been implemented, involving removing selected data points (based on proximity to adjacent points) and implementing variable density gridding techniques. The resulting grids still have artefacts (notable when viewing a first vertical derivative of the grid), but are smoother and more geologically plausible.

1040–1220
Wednesday 24 August 2016

Petroleum 9.A – Anisotropy

P- AND PS-WAVE VECTOR WAVEFIELDS FOR ANISOTROPIC PETROPHYSICS

*James Gaiser**
GGC, USA

Predicting petrophysical properties of lithology, density and fractures using seismic data is an essential part of reservoir evaluation. In addition to lithology characterization, 'frackability' has become a very important area of investigation for high-grading locations for drilling and hydraulic fracture stimulation. Most seismic studies that estimate P- and S-wave impedance, density and brittleness or formation strength use conventional P-wave data and isotropic elastic inversion methods. However, converted-wave (PS-wave) joint inversion and S-wave splitting methods have successfully been used to improve determination of seismic properties for shale plays as well as other unconventional resource plays.

Anisotropic behaviour related to layered media (VTI), fracture properties, stress direction and the geomechanics of shales are increasingly more important for seismic analysis, imaging and reservoir characterization. Vector wavefields are sensitive to these properties and can help identify optimal drilling and stimulation locations. Also, it has been shown that use of conventional elastic parameters for characterizing 'brittleness' should include anisotropic corrections to obtain a more accurate response. Including PS-wave seismic data is beneficial for isotropic elastic inversion and should improve anisotropy estimates for identification of potential fracture locations.

Elastic inversion of azimuthally anisotropic amplitude variations (AVAz) is also becoming more important. When layered media are fractured, orthorhombic symmetry of P-wave amplitude depends on S-wave birefringence. PS-waves are ideal for determining this S-wave splitting information from layerstripping and their reflectivity provides additional equations for joint inversion with P-waves. Two coefficients, a radial R_{PSV} and transverse R_{PSH} reinforce anisotropic signatures similar to P-wave reflectivity R_P. Vector wavefields contain all the necessary information for S-wave anisotropy from short wavelength AVAz as well as from long wavelength moveout behaviour.

CHARACTERIZING HETEROGENEITIES IN A CLASTIC RESERVOIR USING JOINT/SIMULTANEOUS PP/PS INVERSION, 4D TIMELAPSE, MULTI ATTRIBUTE ANALYSIS, AND PSDM

*Jason Nycz**
Synterra Technologies, Australia

In the relatively mature Western Canadian Sedimentary Basin, the primary objective of the geophysics discipline is transitioning from the traditional interpretation of reservoir morphology to include reservoir characterization through the determination of rock and fluid properties. Increasing competition, eroding rates of return, and a decreased tolerance for risk have driven operators to strive to gain as much robust information from their data as possible.

Between 2011 and 2015, Laricina Energy, a privately held bitumen extraction company, acquired both PP/PS 3D and 4D timelapse seismic data over its producing areas. Prestack joint/simultaneous PP/PS inversion, combined with multi attribute analysis allowed for the investigation of both the static and dynamic reservoir. An inability to reconcile the PSTM inversion data to the laterally changing geology of the lower reservoir (and therefore velocities determined during PSTM) warranted processing the data to PSDM.

Ongoing results demonstrate that combining geologic data with compelling analysis products from optimally acquired seismic data can be used to gain meaningful insight as to the physical conditions of both the reservoir and its fluids. As this information is obtained through the life cycle of an E&P project, continual integration and utilization will result in decisions having a higher NPV and could result in more favourable economic results.

UNCOVERING SEISMIC HTI ANISOTROPY OF THE COOPER BASIN

Stephanie Tyiasning and Dennis Cooke*
University of Adelaide, Australia

3D seismic data from the Cooper Basin exhibit horizontal transverse isotropy (HTI) anisotropy in amplitude versus offset (AVO) and interval migration velocity. Theoretically, vertical fractures and in-situ stress can induce HTI anisotropy. The main objective is to determine if the HTI anisotropy is caused by fractures or by the Cooper Basin's large difference between minimum and maximum horizontal stress. We compare migration velocity anisotropy and seismic AVO anisotropy extracted from a high-quality 3D survey with a 'ground truth' of dipole sonic logs, borehole breakout, and fractures interpreted from image logs. The AVO anisotropy is inverted using Rüger AVO algorithm and Fourier Coefficient algorithm that give similar results. Fractures interpreted from image logs are primarily oriented approximately 30° from S_H.

Our work suggests that stress is the dominant cause of the HTI anisotropy observed in the seismic data. The fact that seismic anisotropy is parallel with current S_H and not aligned with the observed fractures suggests that Cooper Basin large differential stress causes the anisotropy observed on seismic.

1040–1220
Wednesday 24 August 2016

Petroleum 9.B – Broadband

BACK TO BASICS ON BROADBAND SEISMIC AMPLITUDES, PHASE AND RESOLUTION

*Andrew Long**
PGS Australia, Australia

Marine broadband seismic results typically have observed amplitude spectra that are inconsistent with the earth reflectivity spectra measured from spatially coincident well data. The most notable inconsistency is a visual bias towards stronger ultra-low frequency amplitudes in the 0–10 Hz range on seismic data. Whilst useful in principle for more accurate elastic seismic inversion with less dependence upon low frequency model (LFM) building and for more stable full waveform inversion (FWI), the low frequency bias will degrade seismic resolution if not balanced properly during processing. Furthermore, the observed seismic amplitude spectra on pre-stack data vary with increasing offset and the phase can strongly vary in a frequency-dependent manner. These variations are attributed to three first-order processes: 1. Progressive attenuation of higher frequencies with longer travel paths, 2. NMO stretch, and 3. Offset-dependent tuning, and may easily be compounded by inappropriate parameterization of various processing and imaging steps. A key component of elastic seismic inversion is the extraction and scaling of several angle-dependent and depth-dependent wavelets. These wavelets are ideally independent of the aforementioned processes but inevitably they are not, and the angle ranges used in the inversion impact the significance of NMO stretch and offset-dependent tuning. Even if these various considerations can all be accommodated during processing, the resolution of seismic images is limited by the resolution of the velocity model, the scattering assumptions of the imaging algorithms used, and the a priori information used to constrain imaging and inversion.

After reviewing the principles of seismic wavefield propagation in the contemporary context of broadband seismic methods, largely pursued with the ambition of removing sea surface-related ghost effects, I discuss the additional uncertainties introduced into seismic signal processing by broader bandwidth data – notably at the low frequency end. I consider two rather different 'broadband seismic' perspectives: 1. The industry must progress towards higher fidelity and resource-consuming measurements of every source event and every receiver measurement in order to effectively deconvolve the 'system response' from the data, or, 2. High-end imaging solutions can automatically eliminate the 'source term' without requiring detailed source information – assuming that wavefield separation has robustly accounted for dynamic variations in receiver geometry. A longer term consideration of imaging suggests that the classical sequential processing paradigm is in fact dead, that the definition of 'noise' is changing, and that advances in hardware are enabling solutions to long-standing challenges with cross-talk artifacts and irregular illumination. The addition of appropriate a priori information into joint migration and inversion allows historical assumptions about the unknown velocity model having a smooth background to be dismissed, and step changes in velocity model resolution may be achievable. I conclude by discussing how higher resolution velocity models will translate to less non-physical efforts in processing that can corrupt pre-stack amplitude, pre-stack phase and (elastic) image resolution.

IMPROVED SUBSURFACE IMAGING AND INTERPRETABILITY THROUGH BROADBAND REPROCESSING OF LEGACY SEISMIC DATA: EXAMPLES FROM NORTH WEST SHELF AUSTRALIA

Stephen Malajczuk[1], Rajesh Saklani[2], Dean Clark[2] and David Eastwell[3]*
[1]Geotrace Technologies, Australia
[2]Geotrace Technologies, Malaysia
[3]Spectrum, Australia

The reprocessing of legacy seismic data can be a time and cost effective means of obtaining an improved image of the subsurface, particularly when compared to the acquisition of new seismic data. The investment that has been made over the years in acquiring the many thousands of kilometres of seismic data offshore Australia has been preserved by Geoscience Australia, which houses an extensive collection of petroleum data including seismic survey data. Much of this data is available to the petroleum industry for reprocessing, facilitating the potential to enhance the data's value for regional reconnaissance and interpretation.

Two marine examples are shown from North West Shelf Australia where reprocessing was performed on seismic data from two different surveys acquired in 1993. The first example is from the Northern Carnarvon Basin, and the second example is from the Browse Basin.

These two examples demonstrate how the uplift attained from a modern broadband processing flow can yield a vastly improved subsurface image, which in turn can assist with interpretation. The reprocessing workflow (which was similar for both surveys)

is discussed, as well as some insights into how the improved data benefit the interpretation and understanding of subsurface geology.

DEMULTIPLE FOR WIDE-TOW BROADBAND ACQUISITION IN A SHALLOW WATER ENVIRONMENT: A CASE STUDY FROM THE NW SHELF, AUSTRALIA

*Mike Hartley, Shuo Ji and Alex Browne**
CGG, Australia

Given its importance, shallow water demultiple has been under constant investigation for many years. Significant progress has been made, effective processing flows have been established, and excellent results have been achieved in different basins across the world. There remain however significant challenges with demultiple in shallow water environments, especially when it comes to broadband acquisition with a wide tow configuration. In this paper, we discuss a shallow water demultiple processing flow used on a recently acquired wide tow broadband dataset in the Northern Carnarvon basin, North West shelf Australia. We demonstrate that the removal of shallow water multiples can be optimized in data acquired in this manner by using a combination of demultiple techniques.

1040–1220
Wednesday 24 August 2016

Minerals 9.C – Lithospheric Architecture (2) – AusLAMP MT

INSIGHTS INTO LITHOSPHERIC ARCHITECTURE, FERTILISATION AND FLUID PATHWAYS FROM AUSLAMP MT

Stephan Thiel[1]*, *Graham Heinson*[2], *Anthony Reid*[1] *and Kate Robertson*[2]
[1]Geological Survey of South Australia, Australia
[2]University of Adelaide, Australia

The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) has the goal to map the electrical resistivity of the Australian lithosphere to constrain the geodynamic framework of the continent. Data acquisition in South Australia has covered two-thirds of the state to date. Three-dimensional resistivity models of subsets of the AusLAMP grid across the Gawler Craton show a generally electrically resistive crust and lithosphere, but an area of low resistivity between depths of 100 km and 200 km beneath the Gawler Range Volcanics exists. A possible explanation is a fertilised mantle signature as a result of metasomatic events in the Proterozoic. The continuous low resistivity connection along the margins of the Gawler Craton core to the surface coincides with the prospective IOCG belt along the eastern margin of the Gawler Craton. The results support the importance of the AusLAMP project to define the lithospheric architecture of the continent and the value of primary lithospheric architecture for mineral exploration.

AUSLAMP MT OVER VICTORIA: NEW INSIGHT FROM 3D MODELLING HIGHLIGHTS REGIONS OF ANOMALOUSLY CONDUCTIVE MANTLE AND UNEXPECTED LINEAR TRENDS IN THE CRUST

Jingming Duan[1], *David Taylor*[2]*, *Karol Czarnota*[1], *Ross Cayley*[2] *and Richard Chopping*[1]
[1]Geoscience Australia, Australia
[2]Geological Survey of Victoria, Australia

The Australian Lithospheric Architecture Magnetotelluric Program (AusLAMP) is a multi-year collaborative project aimed at resolving the first order electrical structure of the Australian continental lithosphere through the acquisition of long-period magnetotelluric data at ~55×55 km spacing. Here we present the results of the first deployment of AusLAMP which was in Victoria in 2014. Previous MT coverage over Victoria comprised limited 2D profiles in the western portion of the State. Three-dimensional inversion of AusLAMP data provides a context for these isolated profiles while revealing interesting and unexpected results with evident correlations with the mapped geology and well established seismic tomography trends. Along the eastern and southern edge of Victoria, the resistivity structure is resolvable into the asthenosphere, in contrast beneath the central and western part the State the base of the thicker lithosphere is not resolved. Resistivity of the asthenosphere beneath the Victorian eastern highlands conforms with global values (~1,000 Ωm) and becomes more conductive (~200 Ωm) beneath the Newer Volcanic province. The seismologically defined lithospheric mantle beneath the central and western part of the State is relatively resistive (~200 Ωm) compare to the east (~20 Ωm). This anomalously conductive lithospheric mantle we tentatively attribute to metasomatism during Palaeozoic accretion of oceanic terranes. Vertically, this conductive lithospheric mantle merges upwards into a series of northeast trending conductive anomalies within the mid to lower crust. These trends correspond with the surficial distribution of Devonian granite intrusions suggesting they represent fossil metasomatised ascent pathways of the granitic melts, which cross cut the older dominant north-south structural trend. The western limit of these linear conductive trends maps out the boundary of the Delamerian and Lachlan Orogens.

THE FLINDERS CONDUCTIVITY ANOMAL(IES) REVISITED USING AUSLAMP MAGNETOTELLURIC DATA

Kate Robertson[1]*, *Stephan Thiel*[2] *and Graham Heinson*[1]
[1]University of Adelaide, Australia
[2]Geological Survey of South Australia, Australia

We use 74 stations from the long period eventual-Australia-wide AusLAMP (Australian Lithospheric Architecture Magnetotelluric Project) dataset to image the electrical resistivity beneath the Neoproterozoic Ikara-Flinders Ranges and adjacent Paleo-Mesoproterozoic Curnamona Province. Results from 3D inversions using ModEM software show a relatively resistive Ikara-Flinders Ranges, with two parallel arcuate conductors at 20 to 80 km depth in the Nackara Arc. There is a good correlation of diamondiferous kimberlites occurring over conductors, which we interpret as evidence for these conductors to be residing on large lithospheric structures that have been conduits for partial melt and volatile movement in the Jurassic period. The Curnamona Province is remarkably conductive for a region that is thought to have a cratonic core, with Delamerian reworking only at its edges. We see an enriched crust that

covers most of the province at depths of 10–40 km. The presence of the conductor at lower crustal depths suggests that conductive sediments cannot entirely explain the conductor. We suggest that fluids associated with subduction have pervasively modified the crust in the past, resulting in an enrichment of carbon and sulphides, enhancing conductivity. Additionally, we conclude that the notion of a single continuous arcuate Flinders Conductivity Anomaly is unlikely and that the anomalous response observed is instead a result of the combined response of three separate anomalies; the Curnamona Province Conductor and the two Nackara Arc Conductors.

1040–1220 Wednesday 24 August 2016

Minerals 9.D – Distal Footprints (9) – Constrained Modelling

APPLICATION OF PETROLOGY & GEOLOGY TO THE INTERPRETATION OF GEOPHYSICAL DATA IN DEFINING ECONOMIC PORPHYRY-RELATED CU-AU MINERALISATION ALONG THE EKUTI RANGE, MOROBE PROVINCE, PNG

Anthony Coote[1]* *and Mike Erceg*[2]
[1]Applied Petrologic Services & Research, New Zealand
[2]Canterbury Resources, Australia

Detailed petrologic and petrophysic data obtained from surface rock chip and diamond core of the Mt Leahy Tenement, Ekuti Range porphyry copper-gold exploration project area, Morobe Province, Papua New Guinea have been applied to interpretations of geologic setting and hydrothermal environment of mineralisation, and interpretations of airborne magnetic field data in defining a causative intrusion framework for mineralisation. Petrologic data confirm and refine a model of magmatic hydrothermal fluid sources for structurally confined mesothermal to epithermal style Cu, Au, Mo, Ag, Pb, Zn and Bi mineralisation within eroded composite granodiorite, quartz monzodiorite and diorite/andesite intrusion centres and hornfelsed metasedimentary rock, with potential for delineation of 'disseminated' porphyry and hornfels styles of mineralisation. The application of petrophysic data, derived from petrology, to the interpretation of airborne magnetic field data defines three intrusion centres within the Leahy tenement: a northern and relatively deeply eroded Otibanda-Weke/Waikanda composite intrusion zone, and higher-level Kopekio and Ekoato intrusion domains, the latter with greater potential for discovery of low-grade high-tonnage style copper-gold mineralisation.

GETTING THE MOST OUT OF EXISTING EXPLORATION DATA: A NEW INTERPRETATION OF THE MT MAGNET GOLD CAMP, WESTERN AUSTRALIA

Sarah Monoury, Ben Jupp and Matthew Greentree*
SRK Consulting, Australia

The Mt Magnet is one of Western Australia's oldest gold mining districts with numerous mine workings and extensive past exploration. The extent of historic exploration has made developing new exploration concepts and targets increasing difficult. The aim of the study was to better understand the subsurface architecture of the region as well as identify previously unrecognised geological units which are considered prospective for gold mineralisation, namely banded iron formations or porphyry granite bodies. To achieve this aim a regional 3D geological model was constructed using geological interpretations and a constrained gravity inversion. The geological model was refined using the gravity inversion to create a model consistent with both geophysics and geological understandings. Ultimately from this work greater confidence was provided for drill targets in areas where previous exploration had not effectively tested these areas.

GEOPHYSICS FOR NI-CU – WHERE ARE WE AT AND WHERE ARE WE GOING?

*W.S. Peters**
Southern Geoscience Consultants, Australia

Exploration for Ni-Cu sulphide deposits has been possibly the most significant factor in the development of modern minerals geophysical technology. The strong response of Ni-Cu sulphides to multiple geophysical methods has resulted in a heavy reliance on geophysics for exploration. This has, in turn, spurred researchers, instrument manufacturers and contractors to continually develop new and/or improved technology.

As discovery of outcropping and near-surface deposits is becoming rarer, the challenge is moving into covered areas and exploring deeper. Historical technology has proven effective in the 0–250m depths; current technology has extended this to more than 500m; new developments are pushing this towards 1000m.

Significant advances in acquisition have been facilitated by factors such as faster processors, large data storage, faster A-D convertors, miniaturisation of sensors, UAVs, integrated GPS and communications. Key developments, particularly in electrical and EM technology include high power transmitters, full waveform recording, and distributed arrays. Interpretation advances include small and large scale 3D inversion, integrated 3D visualisation, and advanced flexible modelling.

1040–1220 Wednesday 24 August 2016

Minerals 9.E – Inversion (3)

INVERSION OF MAGNETOTELLURIC DATA WITH FUZZY CLUSTER PETROPHYSICAL AND BOUNDARY CONSTRAINTS

Duy Thong Kieu, Anton Kepic and Andrew M. Pethick*
Curtin University, Australia

Inverse magnetotelluric (MT) problems are naturally ill-posed and smoothing criteria are typically added to stabilize the process. Smoothing and geo-electrical equivalency tend to produce unrealistic geological models. In reality the subsurface geology is differentiated by distinct rock units that are often better defined by boundaries rather diffuse or smooth boundaries. We present the application of fuzzy clustering as an

added constraint within the inversion process to guide model updates toward earth models that resemble geological units. Fuzzy clustering divides the simulated model into clusters based on the similarity of model features. Moreover, fuzzy clustering enables the inclusion of additional prior information in the inversion process such as structural and/or petrophysical information. The inclusion of this information produces geo-electrical distributions that more closely reflect the true rock units and unit boundaries. This is demonstrated through several synthetic examples. The simulations show that by including prior petrophysical and/or boundary location information within the inversion the original conductivity distribution is well resolved.

GEOLOGICAL AND GEOPHYSICAL INTEGRATED INTERPRETATION AND MODELLING TECHNIQUES

Glenn Pears and Tim Chalke*
Mira Geoscience, Australia

Exploration is becoming harder, at depth or under cover and decisions need to be made in model rather than data space; supported by multiple data sets. Geophysics plays an ever increasing role and integration of information from various geophysical data sets in tight collaboration with geological control is required to maximise the return from the individual data sets.

In terms of integrating geological and geophysical data, the essential goal is to interpret the available geophysical data in terms of geological domains. The process requires a common sense approach to interpretation that is flexible, adaptive and objective driven. It is not an exact formula or procedure; particularly when multiple geophysical surveys are involved. Understanding the relationships between geology, geophysical responses and rock properties is the key to develop a geological basis for your integrated interpretation. Following this, rapid 3D geological modelling and geologically based forward modelling and inversion are essential for model validation and quantitative integration of data. An integrated interpretation is not necessarily the simplest approach, but does provide answers to geoscientific questions that are stronger than individual elements interpreted on their own.

This paper presents a review of the mechanics involved in integrated interpretation and demonstrates the results with selected case study examples.

GEOPHYSICAL JOINT INVERSION USING STATISTICAL PETROPHYSICAL CONSTRAINTS AND PRIOR INFORMATION

Jérémie Giraud[1], Mark Jessell[1], Mark Lindsay[1], Roland Martin[2], Evren Pakyuz-Charrier[1] and Vitaliy Ogarko[1]*
[1]University of Western Australia, Australia
[2]GET (UMR 5563), France

We introduce and test a workflow that integrates petrophysical constraints and geological data in joint geophysical inversion in order to decrease the uncertainty of the results. This workflow uses statistical petrophysical properties to constrain the values retrieved by the geophysical inversion and geological prior information to decrease the effect of non-uniqueness. We integrate the different sources of information in a Bayesian framework, which takes into account the state of information. This permits us to quantify the posterior state of knowledge, the reduction of the uncertainty and to calculate the influence of prior information using quality indicators based on fixed-point statistics. This workflow was first tested using simple synthetic datasets to validate the method and assess the robustness of the workflow. As a result, the use of petrophysical constraints permits us to retrieve sharper boundaries, while prior structural information from geology permits to retrieve the geometry more accurately. Overall, the integration of the different constraints provides a model, with reduced uncertainties and better resolved parameters.

3-D RESISTIVITY INVERSION WITH ELECTRODES DISPLACEMENTS

M.H. Loke[1], P.B. Wilkinson[2] and J.E. Chambers[2]*
[1]Geotomosoft Solutions, Malaysia
[2]British Geological Survey, UK

3-D resistivity monitoring surveys are used to detect temporal changes in the subsurface using the measurements repeated over the same site. The positions of the electrodes are measured at the start of the survey program and perhaps at occasional intervals. In areas with unstable ground, the positions of the electrodes can be displaced by ground movements. If this occurs at times when the positions of the electrodes are not measured, they have to be estimated from the resistivity data. The smoothness-constrained least-squares optimisation method can be modified to include the electrodes positions as additional unknown parameters. 3-D resistivity surveys present a special challenge due to the greater computational requirements for the forward modelling routine and the possible movements of the electrodes in three directions. To reduce the calculation time, a fast adjoint-equation method is used to calculate the Jacobian matrices required by the least-squares method. It is several orders of magnitude faster than the simpler perturbation method previously used for 2-D problems. In areas with large near-surface resistivity contrasts, the inversion routine sometimes cannot accurately distinguish between electrodes displacements and subsurface resistivity variations. To overcome this problem, the model for the initial time-lapse data set (with accurately known electrodes positions) is used as the starting model for the inversion of the later-time data set. This greatly improves the accuracy of the estimated electrode positions compared to the use of a homogeneous half-space starting model.

1345–1510
Wednesday 24 August 2016

Petroleum 10.A – Coal

ENHANCING COAL QUALITY ESTIMATION THROUGH MULTIPLE GEOPHYSICAL LOG ANALYSIS

Binzhong Zhou and Graham O'Brien*
CSIRO, Australia

Coal quality information such as ash content, density, volatile matter and specific energy are important to the coal mining industry for mine planning, design, extraction, beneficiation and

utilisation. These parameters are traditionally obtained through laboratory analyses conducted on drill-core samples from exploration drill holes. This process is expensive and time consuming. In this paper, we use a multi-variable data analysis algorithm based on the Radial Basis Function (RBF) neural network methods to estimate coal quality parameters from routinely-acquired multiple geophysical logs such as density, gamma ray and sonic logs. The performance of this RBF-based approach was demonstrated using both self-controlled training data sets and an independent data set from a mine. It was observed that although the density logs play a key role in coal parameter estimation, the use of multiple types of geophysical logs, including logs with different resolutions such as short spaced density log DENB and long spaced density log DENL, improves the estimation accuracy. It is therefore expected that the use of additional geophysical logs such as photoelectric factor (PEF), SIROLOG and PGNAA, which provide data of geochemical constituents, should improve estimates of coal quality parameters.

THICKNESS PREDICTION OF TECTONICALLY DEFORMED COAL USING CALIBRATED SEISMIC ATTRIBUTES: A CASE STUDY

Tongjun Chen and Xin Wang*
China University of Mining and Technology, China

Tectonically deformed coal is a key factor affecting the phenomena of gas outbursts in coal mines. Seismic attributes associated with coal-bed reflections can represent this kind of coal, but the representation is indirect and ambiguous since both coal-bed thickness and lithology can affect the attributes. We propose a model-based function to calibrate seismic attributes from thin coal-bed reflections, and use the calibrated attributes to estimate the distribution of tectonically deformed coal. To eliminate the influence of coal-bed thickness on seismic attributes, we first build a synthetic model to simulate true geological condition of the coal bed. Then, we extract seismic attributes from the synthetic section and cross plotted the correlations between attributes and thickness. After the fitting of cross-plotted correlations with a Fourier series, we estimate the calibration functions of the attributes. Finally, true attributes of a mining zone are calibrated with those functions. The results presented here show much more observable correlation with the thickness of tectonically deformed coal than uncalibrated attributes.

IMAGING OF SHALLOW COAL STRUCTURES USING 2D6C MINI-SOSIE

Shaun Strong[1]**, James Alderman*[2] *and Steve Hearn*[1]
[1]Velseis, Australia
[2]Rio Tinto Exploration, Australia

At a trial field site in the Bowen Basin previous seismic surveys had difficulty imaging the coal seams near the base of weathering. It was suspected that these may be highly structured which could complicate future open-cut mining.

To improve the understanding of the geology a multicomponent 2D trial was conducted. This used the Mini-SOSIE technique to simultaneously generate P-wave and transverse S-wave energy. This allowed for the processing and interpretation of three separate datasets (P, S, and PS).

In this case, the PS image provided the best structural interpretation. This was achieved using information (e.g. statics and velocities) gained from processing the pure P and S datasets.

1345–1510
Wednesday 24 August 2016

Petroleum 10.B – Regional

TIME SLICING THE COOPER BASIN

Witold Seweryn, Dave Cockshell, Peter Hough and Steve Fabjancic*
SA Department of State Development, Australia

An efficient and practical method of generating composite time slices using all available, non-confidential 3D seismic data recorded in the South Australian sector of the Cooper Basin has been developed. Twenty georeferenced tiff images of time slices between 1000 ms and 2900 ms at 100 ms intervals have been prepared and are intended to be made publicly available through the Department of State Development SARIG website. 2D seismic data has also been used in this project in an attempt to 'fill in' some of the gaps between 3D datasets. Forty eight 3D and 5076 2D seg-y data files were utilised in this project. All 3D and 2D segy files were scaled to normalise amplitude levels for gridding and imaging.

The ability to time slice 3D volumes of seismic seg-y data is a basic method employed in seismic interpretation. This method is usually applied to a single survey as commonly used software packages are not designed to view and analyse multiple 3D surveys at the same time or such functionality is not yet well implemented. For large scale regional interpretation, such constraint limits interpreting potential, especially in terms of basin wide correlation of main structural features.

Whilst the methodology developed in this project retains the quality and resolution inherent in the variety of surveys used, it provides a cost effective method of generating basin wide time slice images, compared to costly reprocessing required in merging of 3D data sets into one 3D volume.

The time slice data suite prepared complements other value-added regional datasets prepared by the Department of State Development to stimulate petroleum exploration in South Australia.

PATTERN AND ORIGIN OF THE PRESENT-DAY TECTONIC STRESS IN THE AUSTRALIAN SEDIMENTARY BASINS

Mojtaba Rajabi and Mark Tingay*
University of Adelaide, Australia

The present-day stress field of Australia has been the subject of great interest in the three past decades because it shows a variable pattern for the orientation of maximum horizontal stress (S_{Hmax}) that is not parallel to absolute plate motion. The last prior release of the Australian Stress Map (ASM) project, published in 2003, contained 549 data records in 16 stress provinces and highlighted the role of plate boundary forces on the regional stress pattern of continental Australia. However, smaller scale rotations of the S_{Hmax} orientation in Australian

sedimentary basins were not investigated in great detail in previous studies. Herein, we present the latest release of the ASM with 2140 data records in 30 stress provinces, with a particular emphasis on newly compiled data in eastern Australian basins. The new release of the ASM has stress data from 20 Australian sedimentary basins, which further confirms the regional variability of S_{Hmax} orientations in the Australian continent, and reveals four major trends for the orientation of S_{Hmax} including NE-SW in northern, northwestern and northeastern Australia, E-W in southern half of Western Australia and South Australia, ENE-WSW in most parts of eastern Australia and NW-SE in southeastern Australia. In addition, the 2016 ASM reveals significant rotation of stress within various sedimentary basins due to different geological structures, including basement structures, faults, fractures and lithological contrasts. Understanding and predicting local stress perturbations has major implications for determining the most productive fractures in petroleum and geothermal systems, and for modelling the propagation direction and vertical height growth of induced hydraulic fractures in unconventional reservoirs.

MONITORING OF UNCONVENTIONAL RESOURCES USING MAGNETOTELLURICS

Nigel Rees[1]*, *Graham Heinson*[1], *Simon Carter*[2] *and Lars Krieger*[3]
[1]University of Adelaide, Australia
[2]Wuhan University, China
[3]Institute for Geothermal Resource Management, Germany

The success of unconventional gas extraction is dependent on establishing sufficient permeability in otherwise low-porosity and low-permeability formations. In the case of shale gas, permeability can be established through hydraulic stimulation of deep formations, either through existing fracture networks or by creating new pathways for fluids to flow. Coal seam gas (CSG) permeability can be established through de-pressurisation of coal beds by extracting existing sub-surface fluids.

The primary geophysical technique for the monitoring of hydraulic stimulation and de-pressurisation has been microseismic, which measures small seismic events associated with rock fractures. The magnetotelluric method (MT) presents itself as an alternative geophysical approach for monitoring unconventional resource development. MT is directly sensitive to electrical resistivity with depth and orientation and could be used to infer fracture orientation, fluid migration and hydraulic conductivity.

We report on the first industrial MT field surveys for the spatial and temporal monitoring of fluid movement resulting from both hydraulic fracturing of a shale gas reservoir and de-pressurisation of a CSG formation. We show that increasing permeability enables conductive fluids to connect resulting in small drops in bulk resistivity. Such changes in resistivity can be mapped through modelling and inversion allowing a determination of areas with greater permeability and hence production capacity.

1345–1510
Wednesday 24 August 2016

Minerals 10.C – Lithospheric Architecture (3) – Joint Inversion

MULTI-OBSERVABLE THERMOCHEMICAL TOMOGRAPHY: A NEW APPROACH TO AN OLD PROBLEM

*Juan Carlos Afonso**
Macquarie University, Australia

The past ten years have been marked by dramatic advances in four seemingly isolated research fields: Thermodynamic modelling of minerals and rocks at high PT conditions, numerical simulation of the thermomechanical behaviour of the Earth's interior, efficient decomposition techniques to solve complex simulation-based problems, and probabilistic data analysis and inversion methods. All these disciplines/techniques have individually created true 'revolutions' in the way we understand and model natural systems, including the interior of the Earth. Nevertheless, a more profound understanding is still ahead of us from the formal combination of these disciplines/techniques into a single operational framework to study the physical state of the Earth's interior.

In this contribution, I will present and discuss the concept of multi-observable probabilistic tomography or 'thermochemical tomography'. This new kind of tomography is particularly designed for studies of the fundamental thermodynamic variables of the Earth's lithosphere, namely temperature, pressure and chemical composition. Once these variables are known, all physical parameters of interest (e.g. seismic velocities, density, viscosity, conductivity, etc), as well as traditional tomography images, are also retrieved in a thermodynamically-consistent way. The method is built on a simulation-based inversion technique where multiple satellite (e.g. gravity gradients, geoid height, etc) and land-based (e.g. seismic, plate motions, heat flow, etc) datasets can be jointly inverted to maximize the physical consistency of the resulting Earth model. Assembling this large problem required a collaborative effort between thermodynamicists, mineral physicists, geophysicists and geochemists, and marks the first step towards a full coupling between geophysics, geodynamics, thermodynamics, and geochemistry. I will present results for both synthetic and real case studies, which serve to highlight the advantages and limitations of this approach.

INTEGRATING GRAVITY, SEISMIC, AEM AND MT DATA TO INVESTIGATE CRUSTAL ARCHITECTURE AND COVER THICKNESS: MODELLING NEW GEOPHYSICAL DATA FROM THE SOUTHERN THOMSON REGION

*Chris Folkes**
Geoscience Australia, Australia

New geophysical data, including gravity, airborne electromagnetic (AEM), and both audio frequency and broadband magnetotelluric (AMT, BBMT) were collected along a series of traverses in the southern Thomson Orogen region of north-western New South Wales and southwestern Queensland in 2014 as part of the Southern Thomson Project. Comparing

and integrating these data over the same spatial extents aimed to provide a better understanding of the crustal architecture of this region, and help estimate cover thicknesses above basement rocks. When comparing all available datasets, AEM cannot be reliably used when cover thickness is > ~150 m because of limitations in Depth of Investigation (DOI), and BBMT tends to overestimate cover thickness where it is less than 50 m. AMT likely provides the best resolution for estimating cover thicknesses of 0–1000 m on this regional scale. Forward modelling of the gravity data along selected traverses tested the interpreted crustal architecture and cover thicknesses inferred from available seismic images and the new AEM and MT conductivity models. The variable cover thicknesses interpreted from this combined approach produces a closer match with the observed gravity response when compared to a uniform, average cover thickness. The most accurate crustal-scale forward model is a thickened crust north of the Olepoloko Fault (the proposed southern boundary of the southern Thomson), split into simplified lower, middle and upper layers with basement lithologies immediately beneath cover based on the most recent basement interpretation map. Resistive bodies shown in the MT models were included in the gravity modelling, producing a good match between the observed and calculated gravity responses. These results demonstrate the utility in using a combination of different geophysical techniques to understand crustal architecture and estimations of basement depths in regions of Australia with little surface outcrop and thick cover sequences.

1345–1510
Wednesday 24 August 2016

Minerals 10.D – Distal Footprints (10) – Airborne Geophysics

TOWARDS RESOLVING DIPPING CONTACTS UNDERCOVER IN THE CAPRICORN OROGEN USING AEM

Sasha Banaszczyk[1]*, *David Annetts*[2] *and Michael Dentith*[1]
[1]University of Western Australia, Australia
[2]CSIRO, Australia

The Capricorn Orogen is located in central Western Australia and includes several Proterozoic sedimentary basins. The Yerrida and Earaheedy basins are located in the south-east of the orogen and were formed, and deformed, over multiple orogenic events. The complexity and thickness of these basins and presence of conductive regolith has hindered minerals exploration within the region. A recently acquired TEMPEST AEM survey across the Capricorn provides an extensive dataset to aid in the mapping of the basin lithologies and assessment of the potential for mineralisation within these basins. Before detailed interpretations can be made from 1D inversions of these data, an understanding of the reliability of TEMPEST AEM inversions is desirable.

1D time-domain inversion algorithms are useful for interpreting TEMPEST AEM data. However, it is important to understand the limitations of using such codes in geologically complex regions such as the Capricorn Orogen. The response from three simple scenarios involving a dipping conductive contact within a resistive basement, and a dipping conductive contact under a varying conductive regolith have been inverted using a 1D layered earth algorithm. Results show that conductive units in a resistive host dipping steeper than 25° are poorly resolved. When moderately conductive to resistive cover is present, the dip and thickness of dipping features can be defined, however, this is dependent on the depth of the conductive unit. Knowledge of the limitations of 1D AEM modelling provides some confidence for making geological interpretations from 1D inversions, as falsely resolved dipping features can be eliminated from the interpretation process.

AIRBORNE IP: DRYBONES KIMBERLITE VTEM DATA COLE-COLE INVERSION

Domenico Di Massa[1], *Vlad Kaminski*[2] *and Andrea Viezzoli*[2]*
[1]Università di Napoli Federico II, Italy
[2]Aarhus Geophysics, Denmark

A VTEM survey was flown over the Drybones kimberlite in 2005, followed by a ZTEM survey in 2009. These data sets were inverted on multiple previous occasions using various 1D, 2D, 3D and plate modelling algorithms. VTEM data showed AIP effects, manifested as negative voltages and otherwise skewed transients. This created artefacts in conventional inversions of VTEM data, which showed some inconsistencies with ZTEM inversions, as well as with the known geology. In 2015 the VTEM data were transferred to Aarhus Geophysics, reprocessed and reinverted using the modified 'AarhusINV' code with Cole-Cole modelling. The results are presented in current abstract, they appear to be more interpretable and provide better data fit, than previous inversion attempts.

IDENTIFYING POTENTIAL MINERALISATION TARGETS THROUGH AIRBORNE GEOPHYSICS – THE WESTERN PAPUA NEW GUINEA CASE STUDY

Nathan Mosusu[1]*, *Katherine McKenna*[2] *and Dulcie Saroa*[1]
[1]Mineral Resources Authority, Papua New Guinea
[2]GPX Surveys, Australia

Over the last few years exploration activity in Papua New Guinea (PNG) has declined to alarming lows that the Mineral Resources Authority (MRA) has introduced initiatives to acquire new geo-scientific datasets to enhance exploration in the country. One such initiative has been the 30,000 plus line kilometre airborne magnetic and radiometric survey over the western part of the country. The airborne survey was strategically located between the large Ok Tedi porphyry copper-gold mine and the advanced Frieda River porphyry copper-molybdenum prospect. The airborne datasets were acquired at a north-south line spacing of 500m with a Tie-line spacing of 5km and at nominal terrain clearance of 100m.

The main aim of the airborne geophysical survey was to identify magnetic and radiometric anomalies that may be further investigated for their mineral potential. Preliminary results of the airborne survey show large deep-seated NW-trending fault systems cross-cut by north-east trending transfer structures that may have contributed to mineral deposition in the region. Several magnetic and radiometric anomalies located within the periphery of existing prospects also have the potential to substantially increase resource values, while isolated anomalies may indicate new targets for further exploration.

While this paper highlights some of the interesting magnetic and radiometric features defined from the WPAGS, the release of the

datasets now ensures investors have an extra layer of information to build on the mineral potential of the surveyed area. It is anticipated that the results from the survey will not only boost interest to explore in the area, but also drive exploration activities in the area to new heights, hopefully resulting in the identification of new mineral prospects.

1345–1510
Wednesday 24 August 2016

Near Surface/Engineering 10.E – NMR

DETERMINATION OF FORMATION SPECIFIC NMR CALIBRATIONS FOR WATER WELL EVALUATION IN A SEMI-CONSOLIDATED AQUIFER

P.J. Hawke[1], A. Harrild[1] and Elliot Grunewald[2]*
[1]Wireline Services Group, Australia
[2]Vista Clara, USA

Downhole NMR data was collected through a fibreglass cased section of water well NG3A that intersected the semi-consolidated sediments of the Yaragadee Formation which is one of the main aquifers supplying domestic water for the city of Perth. The main purpose of this work was to empirically derive formation specific NMR processing parameters to match the hydraulic property estimates to a direct core measurements, to calibrate the system to deliver a more detailed log of porosity and permeability in the hole as well as other holes logged in a similar geologic environment.

Equations for NMR permeability estimation generally include lithology specific calibration coefficients. We show that application of 'generic' calibration coefficients derived for unconsolidated aquifer materials overestimate permeability in the Yaragadee Formation when compared to core permeability measurements. This result is expected given that the Yaragadee formation is not unconsolidated but is partially consolidated/cemented. More appropriate site specific coefficients were derived by scaling the calibration coefficients to produce NMR permeability estimates that match the measurements derived from the core samples. The site specific coefficients determined for the Yaragadee are consistent with those derived in previous studies for partially consolidated aquifers in the United States.

The NMR T_2 distribution is very sensitive to pore size changes which often reflect subtle changes in the sedimentary geology of the formation. This can provide additional geological information which may not always be apparent in mud or core logging. Detailed knowledge of both the sedimentary geology as well as the hydraulic properties of the formation that can be obtained by NMR are likely to be useful in identifying the best place to place screens during the design of a production water well to generate the best possible yield.

DESIGNING ADIABATIC PULSES FOR SURFACE NMR

Denys Grombacher and Esben Auken*
Aarhus University, Denmark

Surface nuclear magnetic resonance (NMR) is a powerful technique providing non-invasive imaging of groundwater. One challenge with the method is that it commonly suffers from low signal to noise ratios (SNR). Two methods to increase SNR are to either develop noise cancellation approaches to reduce the noise level, or to perform the experiment in a manner capable of increasing the signal amplitude. A recent study adopted the latter approach by employing a novel transmit strategy. An adiabatic pulse was employed and observed to produce significant signal improvements compared to the standard transmit method in surface NMR. The advantage of an adiabatic pulse is that it is capable of producing a uniform excitation in the presence of a heterogeneous magnetic field, which describes exactly the transmit conditions in surface NMR.

Given the great potential of adiabatic pulses for surface NMR, we explore several factors related to the design of adiabatic pulses intended for application in surface NMR conditions. We investigate how various adiabatic pulses perform in a heterogeneous magnetic field given the limitation that current instrumentation couples the modulation of the current amplitude during the pulse to the instantaneous transmit frequency. That is, only the duration of the adiabatic sweep, the bandwidth through which the pulse sweeps, and frequency modulation throughout the pulse can be directly controlled. A numerical sensitivity analysis of each of these parameters is performed to gain insight into how to design optimal adiabatic pulses for surface NMR. Additionally, a numerically optimized modulation (NOM) approach is implemented to optimize the frequency sweep. The spatial resolution and depth penetration provided by an example adiabatic pulse is also investigated. A trade off between signal amplitude and spatial resolution is observed to be present when employing adiabatic pulses.

DEVELOPMENT OF RAPID SCANNING SURFACE-NMR FOR WIDE AREA HYDROGEOLOGIC MAPPING

Elliot Grunewald and David O. Walsh*
Vista Clara, USA

Surface nuclear magnetic resonance (Surface-NMR) measurements hold the valuable capability to directly image groundwater and to characterize aquifer flow and storage properties. Historically, implementations of surface-NMR have been limited by long stacking times and slow survey deployment, restricting applications primarily to 1D soundings and short 2D profiles. Through advancements in acquisition schemes, hardware, and deployment platforms, we demonstrate the ability to deploy surface-NMR as an efficient wide-area mapping technique. To increase measurement efficiency, we have developed acquisition schemes to improve the inherently low signal-to-noise-ratio of Earth's field NMR. Adiabatic pulse sequences are used to increase the detected NMR signal amplitude and to reduce requirements to scan over a wide range of pulse moments. Newly developed wireless noise-reference coil stations are used to cancel environmental noise without increasing the size or footprint of the signal-detection array. Smaller footprint wired signal-detection arrays are transported efficiently using mobile platforms, including towed coil mats and elevated coil forms. The detection array can be moved along a profile line and left in a static position for short time intervals to acquire measurements before being moved to the next position. These newly developed rapid scanning NMR technologies are demonstrated at a collection of sites in the Western United States.