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Education matters

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Lightning strikes at ASEG (Vic branch) Student Night

RMIT PhD student Lachlan Hennessy gained first prize at the Victorian Branch Student Night presentations, with a talk on 'Magneto-tellurics with lightning source information'. The method promises improvements in audio-magneto-telluric studies investigating depths to 500 m, by reducing recording time and increasing signal to noise ratios for the AMT method.

ASEG Branch President Seda Rouxel presents a cheque for first prize to Lachlan Hennessy.

Other presentations were given by:

Elizabeth Grange (MSc – University of Melbourne): 'A new interpretation of the Lachlan fold belt', Jesse Keegan-Osborne (Hons – Monash University): 'Emplacement of the Stawell granite', Andrew Pearson (MSc – University of Melbourne): 'The structural evolution of the Wentworth trough', Hamish Stein (MSc – University of Melbourne): 'Shallow elastic property models for the North-west Shelf', with Jesse and Hamish sharing the runner-up prize.

Asbjorn Christenson, speaking for the judging panel, said 'We were very impressed with the breadth of the presentations, and it's obvious that a lot of work has gone into the preparation of these talks'.

Contestants at the Victorian ASEG Student Night; from left, Jesse Keegan-Osborne, Hamish Stein, Elizabeth Grange, Andrew Pearson and Lachlan Hennessy.

Student projects in geophysics completed in 2016

Queensland

PhD

Shaun Strong, University of Queensland: 'Resolution Enhancement in Shallow 3D-PS Seismic Reflection'.

This thesis aims to advance methodology for acquiring and processing 3D multicomponent seismic data for shallow (<300m) exploration targets. The primary focus is to improve seismic resolution, and hence geological interpretation, for coal-scale targets.

The coal industry is a significant contributor to the energy security and economy of Australia and the world. Conventional P-wave seismic methods are widely used in this industry, providing economic, safety and environmental benefits. There is potential for expanding these benefits by including multicomponent procedures. In this thesis, the primary focus is on converted-wave (PS) reflection, which is a logical extension to the standard approach. This has theoretical potential to provide extra geological information. It has also been proposed that there may be resolution advantages for shallower targets such as coal.

A valuable starting point for understanding resolution in shallow P and PS reflection is via visco-elastic finite-difference simulation. This provides a useful indication of the reflection response of different targets, and can include the influence of different processing flows. For typical coal-scale environments, modelling with reasonable anelasticity assumptions suggests that PS resolution is unlikely to be superior to P resolution, even with idealised acquisition and processing. In real-world situations, achieving good PS resolution may be even more challenging. There are a number of factors across the acquisition and processing flow which incrementally influence resolution.

Survey design is intrinsically more complex for PS surveys than for P, primarily because of ray-path asymmetry. In addition, phase and amplitude effects require careful analysis, and finite-difference modelling provides a useful tool. Such modelling suggests that for shallow surveys in particular, it may be possible to incorporate longer relative offsets, compared to the petroleum scale. An examination of bin fold, and offset/azimuth distribution, suggests that the natural bin size of a PS survey is mostly dependant on the receiver spacing, and is generally larger than for P waves. This favours the use of higher receiver densities for multicomponent surveys. These observations can be more important at the shallow scale, again because of greater ray-path asymmetry and potentially higher VP/VS ratios.

One of the most critical steps in shallow PS processing sequence is correcting for the S-wave receiver statics. Three relatively conventional approaches have been evaluated. A surface-consistent inversion approach has been shown to fail for shallow targets, or in the presence of strong noise. For our 3D data set, PPS refraction analysis provided the preferred solution. In other cases where PPS refractions are poorly defined, our robust statistical approach may be useful for determining short-wavelength statics, although additional long-wavelength control would then be needed.

In exploration seismology, surface waves are commonly considered to be noise. However, the dispersive nature of surface waves is strongly dependent on the S-wave properties of the near surface. These properties can be estimated using the so-called MASW technique. Most commonly, MASW has been applied in an engineering context. Using modelling, and a high-resolution 2D dataset, we have evaluated the viability of extracting surface-wave dispersion information from shallow exploration data, where parameters are not necessarily ideally suited to the task. This suggests that viable S-wave velocities (and potentially S-wave statics) can be derived using exploration equipment provided receiver intervals are less than about 10 m. It has also been demonstrated that this method can be used with a Vibroseis source, and that use of uncorrelated data provides improved low-frequency response.

Application of the same approach to a real, coal-scale 3D dataset has been more difficult, partly due to the coarser geophone spacing (15 m). However, incorporation of an interferometric approach shows potential for providing broad-scale shallow S-wave velocities. In particular, for our trial 3D dataset, a combination of robust statistics (short-wavelength) and dispersion (long-wavelength) provides a useful alternative to the preferred PPS refraction statics approach.

Analysis of our high-fold 3D multicomponent dataset has included a preliminary investigation of azimuthal anisotropy. A pragmatic assessment of the PS stacking velocity for the target reflector indicates significant azimuthal variation in an 'effective' VP/VS ratio. In the vicinity of major faults, anisotropy of about 5% is indicated. The observations are consistent with azimuthally varying VP, along with S-wave splitting effects, with higher velocities in the direction perpendicular to fault planes. This could be an indication of fracturing associated with local stress fields. More detailed research is required to validate these preliminary results, and to assess the degree to which correction for azimuthal velocities can improve stack resolution.

A significant proportion of usable PS energy can be on far offsets. This may be particularly so for shallow surveys. These far offsets tend to be susceptible to NMO stretch during conventional processing, and this has a significant impact on the resolution of shallow PS data. Use of a non-stretch moveout method, including higher-order polar-anisotropy terms, greatly improves the resolution of the stack data in coal-scale environments.

Imagery of coal-scale targets can benefit by integrating PS reflection with the standard P-wave product. This research has demonstrated that achieving good PS resolution is challenging, and requires careful consideration of multiple factors in the design, acquisition and processing chain. The range of methodologies demonstrated here will further advance the practical application of PS reflection at the coal scale.

M.Phil

Alan Meulenbroek, University of Queensland: 'Inversion of Seismic Refraction Amplitudes for Near-Surface Velocity Control'.

Analysis of seismic refraction amplitudes has the potential to produce a richer geological interpretation than if only travel-times are considered. In theory, the amplitude of a seismic head-wave is dependent on the strength of the shot and the offset at which it is measured. A constant of proportionality, called the head-wave coefficient, is a function of the elastic properties either side of the refracting interface. As the velocity contrast between the two media decreases, the head-wave coefficient increases.

A detailed examination of refraction amplitude theory reveals that the head-wave coefficient is a product of two Zoeppritz transmission coefficients, a downgoing one at the source end and an upgoing one at the receiver end. The bulk amplitude of the head-wave coefficient is mainly due to the transmission coefficient at the receiver end. However, the receiver component is relatively insensitive to lateral changes. On the other hand, the transmission coefficient at the source end is sensitive to lateral changes.

Theoretical models, which simulate laterally inhomogeneous geologies, are used to forward-model refraction amplitudes. The head-wave coefficient is then estimated via non-linear inversion of refraction amplitudes. Inverted shot and receiver terms are shown to be related to the transmission coefficients at the shot and receiver ends. The product of the inverted shot and receiver terms are related to the full head-wave coefficient. The inversion cannot separate the effect of velocity contrast from short-wavelength shot/geophone coupling effects. Smoothing of the inverted solution is suggested as a means of reducing coupling effects.

For laterally inhomogeneous models, offset limiting is required prior to inversion in order to achieve successful separation of constituent amplitude components. For offset-limited model data, the estimated model parameters exhibit consistency with the true model parameters in a relative sense. Non-uniqueness between parameter groups prohibits successful estimation of model parameters in an absolute sense. Calibration is therefore required to adjust the relative results obtained from inversion to results which are consistent with geology. This calibration uses independent estimates of weathering-layer velocity at several points along the seismic line. Calibration can be performed on the inverted shot terms alone, or the product of the inverted shot and receiver terms.

The inversion methodology is evaluated on three real data sets. For the first Vibroseis dataset, the relative head-wave coefficient profile is consistent with that derived using an alternative approach (the Refraction Convolution Section). However, the implied weathering-layer velocity profile differs from that estimated by analysis of direct arrivals.

For the second Vibroseis dataset, the derived weathering-layer velocity is reasonably consistent with the long-wavelength velocity profile derived from analysis of hammer shot records, acquired as part of the original survey. The CMP stack, incorporating the velocity profile from refraction amplitudes, shows subtle structural differences when compared to the conventional stack.

The third dataset, which uses dynamite as a source, exhibits large variations in source strength. A velocity profile is not derived because these large source effects swamp any amplitude changes related to velocity changes at the refractor.

For these real-data tests, offset limiting does not assist separation of the shot and receiver terms (as was the case for the model data). Independent statistical analysis of average shot and receiver amplitudes suggests that the inversion process itself is working correctly.

However, it appears that in practice, observed refraction amplitudes are strongly influenced by factors not included in theoretical models. Further work is required before this technique can provide a reliable tool for near-surface characterisation.

Honours

Shakira Heffner, University of Queensland: 'Analysis of azimuthal anisotropy in coal-scale 3D seismic reflection'.

Azimuthal anisotropy in seismic velocity is a well-known phenomenon, although it is often ignored in conventional reflection processing. Such anisotropy can result from sub-vertical fracturing often related to orientation of horizontal stress. It can also be an artifact of dipping interfaces in an isotropic system.

Some understanding of the likely contributions can be obtained from simple numerical models. If dips are less than 10 degrees, then spurious azimuthal effects are likely to be less than 2%. If reasonable values of Thompson parameters are assumed, true velocity anisotropy can be well in excess of 10%. If this is ignored in the NMO process, then smearing is expected, particularly at the coal scale where dominant frequencies in excess of 100 Hz can be expected.

A robust algorithm has been implemented to invert reflection travel times in terms of an azimuthally anisotropic velocity model. The inversion yields the fast azimuth (major axis of best-fit ellipse) and the degree of anisotropy (derived from the ellipticity). The algorithm performs well on a high-fold 3D P-wave survey from the Bowen Basin. A very consistent pattern of azimuthal anisotropy is observed across the survey area, with largest magnitude approaching 10%. The observations cannot be explained in terms of known dip and are believed to represent true azimuthal effects. A preliminary analysis of an associated converted-wave survey suggests anisotropy parameters (magnitude, direction) which are consistent with the P-wave results. When the detected anisotropy is allowed for in the NMO correction, the improvement in stack quality is not as significant as expected based on modelling. For these shallow data, factors such as NMO stretch and statics are significant and it is possible that such effects are overriding improvement achieved via anisotropic NMO.

Christopher Mathews, University of Queensland: 'Near-Surface Characterization from Dispersion of Rayleigh and Love Waves'.

Surface wave dispersion has been exploited in earthquake seismology since the 1920s, and for several decades in engineering seismology. Until very recently, seismic reflection surveys have treated surface waves as noise, to be attenuated by acquisition design and in processing. This study investigates the properties and underlying characteristics of surface-wave dispersion, and assesses practical potential in various exploration-scale scenarios. In the engineering and exploration contexts, most studies of dispersion have exploited Rayleigh waves, because of the ready availability of vertical-component recording equipment. This study focusses on the possible advantages of combined analysis of Rayleigh and Love waves, using 3C recording.

Propagator-matrix algorithms have been implemented for both Rayleigh- and Love-wave dispersion. Theoretical dispersion curves illustrate sensitivity to various physical properties of near-surface earth models. While Rayleigh-wave dispersion is primarily influenced by S-wave velocities, it can also depend significantly on P velocity. Love waves have the advantage that dispersion is totally independent of P velocities. This theoretical analysis also demonstrates that interpretation of higher modes is likely to be much simpler in the case of Love waves.

This study examines different approaches to extracting dispersion curves, and performing inversion, for real exploration-scale data. One important limitation is the attenuation of low frequencies due to geophone response and short recording time. This reduces the reliability of inverted earth models at sub-weathering depths. The study also demonstrates the problems arising from stacking of dispersion curves in situations where geology varies laterally. Where it is feasible to acquire 3-component data, best results are obtained by performing joint inversion using both Love and Rayleigh dispersion curves. Although reflection acquisition parameters may not be ideal for dispersion analysis, it is nevertheless possible to extract meaningful near-surface velocity information. This may have direct geological value, and provide additional control in statics solutions.

Tasmania

Honours

Brady Gower, University of Tasmania: 'Structural and Sedimentological Analysis of the Adele Trend – Browse Basin'.

The Adele 3D seismic survey in the Caswell Sub basin of the Browse Basin, offshore northwest Western Australia, depicts a sequence of sediments above Proterozoic basement that range from late Palaeozoic rift sequences to passive margin sediments of the Pliocene-Recent Barracouta Formation. This study evaluates the structural and sedimentological architecture of the region, with a particular emphasis on the stratigraphy above the Callovian unconformity.

Faults in lower stratigraphic units are predominantly oriented NE-SW but in upper stratigraphic units the dominant trend is E-W. This observation is consistent with stress orientations previously inferred for major basin forming events that have affected the northwest shelf of Australia since the Late Palaeozoic. An archetypical example of strata-bound polygonal fault systems is developed within fine grained strata of the Upper and Lower Heywood Formations. A prograding deltaic sequence characterised by the presence of clear clinoform reflectors has been identified and mapped beneath the Puffin Formation throughout the survey area. The isochron map of the deltaic interval suggests that this sequence potentially provided a control on the deposition of the overlying Puffin Formation. The Puffin Formation is an important petroleum exploration target formation within the Caswell Sub Basin which is delineated on the basis of time-structure and isochron maps that illustrate exploration targets associated with existing petroleum wells. Sedimentary units deposited during the mid to late Miocene were deposited in a tropical carbonate system, and are associated with widespread karstification features developed during sea-level lowstands.

The fine grained sediments of the Heywood Formation can form a regional seal but recognition of complex polygonal fault systems within this interval has implications for the integrity of underlying petroleum systems, as significant small displacement faults could dramatically increase the permeability of normally impermeable sediments. Sand packages within the deltaic sediments of the Fenelon Formation have potential as hydrocarbon reservoirs. Palaeokarst features in the Bassett Formation pose a significant risk when drilling exploration wells. The increased porosity and permeability of karstified formations can lead to drilling mud losses, as well as borehole collapse.

Declan D. G. Radford, University of Tasmania: ‘Geological mapping from radar imagery with machine learning’.

Mineral exploration and geological mapping in the highly prospective region of western Tasmania is difficult due to the combined effects of steep topography, dense vegetation and limited outcrop. The potential for imaging radar to be beneficial for geological mapping in this region is significant as the microwave signal is able to penetrate vegetation canopies and image the surface. When radar is analysed in combination with other sources, such as geophysical and Light Detection and Ranging (LiDAR) data, a wider range of lithological related signals are captured allowing a more comprehensive geological interpretation to be created. Machine learning algorithms are well suited to integrating and classifying data such as these for the production of objective geological maps.

Analysis of the radar imagery highlighted the importance of image texture and the identification of boundaries for geological classifications. Field work showed that the majority of anomalous geological features identified within the radar imagery related to geobotanical and geomorphological relationships. The inconsistent nature of these relationships limits the reliability of the radar method to determine lithology.

The supervised machine learning Random Forests (RF) classifications, based on geophysical data, were accurate (~ 90%) even when using a very limited training data input size (~ 0.25% of the total data). RF successfully identified a new region of the Tasmanian mafic-ultramafic complexes that was validated through targeted field work. This discovery has significant tectonic implications with respect to western Tasmanian geology, providing insight into the Cambrian subduction zones, Tyennan Orogeny as well as the relationship between Gondwana and the Cambrian Tasmanian.

Ultimately the results from the RF classifications and field observations have been efficiently combined with geophysical and radar data to produce a new geological interpretation of the Heazlewood region. This research further validates the growing application of machine learning to solve geoscience problems, particularly in remote and difficult terrain.

Tyler Williams, University of Tasmania: ‘Seismic Evaluation of the Integrity of the Henty Tailings Storage Facility, Henty, Tasmania’.

Traditional geotechnical methods such as the Cone Penetration Test (CPTu) measure shear-wave velocity (V_s) which provides a proxy for material strength. These invasive methods are costly and time consuming, and thus inefficient for characterisation of large areas. The Multi-Channel Analysis of Surface Waves (MASW) technique can be utilised to rapidly evaluate the geotechnical properties of near-surface materials to non-invasively estimate vertical variations in V_s. V_s correlates directly with liquefaction resistance, and hence it is possible to estimate the potential for soil liquefaction through the analysis of surface waves. This study applies the MASW method to assess the geotechnical properties and liquefaction potential of the Henty Mine tailings dam in western Tasmania prior to a planned upstream raise of the dam embankment. The results of MASW assessment are compared to limited data acquired using CPTu testing.

Five MASW traverses were conducted at the Henty Tailings Storage Facility (TSF) and 1D vertical estimates of V_s derived from inversion of surface wave dispersion were used to produce 2D V_s sections for each traverse. Four traverses were conducted perpendicular to the embankment to highlight V_s variations within the dam construction materials and tailings. A single long traverse was undertaken parallel to the embankment to highlight lateral variations in the tailings that will partially act as the foundation for the proposed upstream raise. MASW V_s estimates were compared to CPTu V_s values to assess the accuracy of V_s values derived from the inversion of surface wave dispersion data.

MASW provides layered 1D V_s profiles which integrate the response over the length of the seismic spread (78 m). The MASW V_s profiles have low vertical resolution when compared to CPTu data but effectively capture the general variations in V_s. MASW V_s data were used to calculate values for the probability of liquefaction (P_L%), which were used to generate 2D profiles of a deterministic Factor of Safety (FS). These FS profiles suggest that the tailings material beneath the proposed upstream lift will provide a suitable foundation for construction and will require only a small amount of additional preparation. Near surface zones of high P_L % and low FS are present further into the TSF and these zones will acquire additional investigation if later upstream lifts are intended.

The MASW technique is a cost-effective method for lateral imaging of V_s in mine tailings dam environments. MASW estimates cannot provide the high-resolution V_s data obtained using CPTu but does provide continuous measurements between CPTu locations that can reduce uncertainty and be used to provide probabilistic assessment of liquefaction potential.

Victoria

Honours

Josephine Bailey, Monash University: ‘The structure and emplacement of the Two-Eyed Creek granodiorite and Bulgana diorite’.

In this study, Anisotropy of Magnetic Susceptibility (AMS) and the gravity surveying and forward modelling methods are used in conjunction with field observations and petrography to define the structural, petrological, petrophysical and geophysical characteristics of the eastern half of the composite Stawell pluton (Stawell Zone, Western Lachlan Orogen). This half of the pluton, consisting of the Two-Eyed Creek Granodiorite and Bulgana Diorite, is characterized by a tail-shaped map pattern. This multi-disciplinary approach has characterized the structure of the two intrusions, and provided insights on their mode of emplacement. Magnetic directional data from the AMS study reveal magnetic foliation and lineation patterns, which are confirmed by petrological observations to represent a primary emplacement-related magmatic fabric. This fabric indicates NE-directed magma flow along the ‘tail’, originating from a feeder zone underneath the center of the composite pluton, the location of which is inferred via the interpretation of gravity data. Forward modelling suggests the 3D geometry of the intrusions is that of a tongue-shaped lobe. The orientations of fractures and syn-plutonic dykes suggest a potential structural control on intrusion by NW-SE extensional reactivation of the Early South Faults in the early Devonian.

Jesse Keegan-Osborne, Monash University: ‘Emplacement of the Stawell Granite as determined by combined use of gravity and AMS’.

A hybrid laccolithic and lopolithic geometry is inferred from geological and geophyisical data for the Stawell granite. Nearly circular in shape, the 13 km diameter Stawell granite is the youngest of three phases of the teardrop shaped, E-W trending Stawell pluton, and lies 2 km east of the Western boundary of the Lachlan Fold Belt. Magnetic fabric determined by anisotropy of magnetic susceptibility has been inferred to correlate with the magmatic fabric by use of microstructural observations and mineral orientation analysis. Magnetic foliations are concentric around a central feeder zone and dip outwards. Magnetic lineations radiate away from the central feeder zone and plunge outwards. Gravity data suggest that the granite is roughly tabular with a deeper zone in the southern part of the granite with a maximum thickness of 4 km, and a central northern root zone. The granite is interpreted as post kinematic and as being emplaced differently to the earlier phases of the pluton.

Adriana Traviati, Monash University: ‘The Evolution and Development of the Barracouta Region, Gippsland Basin, Australia’.

The Barracouta field, discovered in 1965, is one of the most significant gas fields in Australia. It is located in the offshore Gippsland Basin, one of Australia’s most prolific hydrocarbon provinces. This study aims to determine the structural and stratigraphic evolution of the Barracouta region, assess major stratigraphic packages, interpret major fault sets, analyse the major N-1 gas and M-1 oil reservoir and seal characteristics and finally assess the remaining hydrocarbon potential of the Barracouta field. This involves interpreting stratigraphic units and biostratigraphic seismic marker horizons in three dimensions across the field area, as well as undertaking a regional fault analysis at depth, correlating well log responses and mapping the movement of the gas–water contact to its position at 2001. It also involves investigating key characteristics of the N-1 and M-1 reservoirs and their seal properties, constructing a burial history plot to determine the depositional history of the field, performing a depth conversion across the 3D dataset and finally undertaking a volumetric analysis of remaining reserves. This study draws upon the G01a 3D seismic volume acquired in 2001, well logs across 13 wells, government data and well completion report data.

The research demonstrates how post-Latrobe Group sediments have been deposited syn to post compressionally over the Barracouta anticline. It highlights the presence of two major Early and Late Cretaceous fault sets and shows that the Barracouta field's anticlinal structure was formed by the preferential re-activation of an ~E–W trending Early Cretaceous normal fault set caused by an Early Miocene compressional event that led to structural inversion. The major reservoir–seal couple relationships and properties change across the field in their thickness and lateral distribution, with most reservoir–seal couples being thickest at the centre west of Barracouta.

The study shows that the 2001 gas–water contact can be imaged via amplitude extraction and spectral decomposition methodology, showing a movement of ~42 m over 36 years of production from a position of 1151 m TVDSS at first production in 1965 to 1109 m TVDSS as at 2001. Finally, the volumetric analysis indicates that ~1.15 Tcf has been produced in this interval, with ~0.7 to 0.9 Tcf remaining to be produced as at 2006, according to deterministic and estimated volumetric calculations.

South Australia

Honours

Hugh Merrett, University of Adelaide: '2D Lithospheric Imaging of the Delamerian and Lachlan Orogens, Southwestern Victoria, Australia from Broadband Magnetotellurics'.

A geophysical study utilising the method of magnetotellurics (MT) was carried out across southwestern Victoria, Australia, imaging the electrical resistivity structure of the lithosphere beneath the Delamerian and Lachlan Orogens. Broadband MT (0.001–1000 Hz) data were collected along a 160 km west-southwest to east-northeast transect adjacent to crustal seismic profiling.

Phase tensor analyses from MT responses reveal a distinct change in electrical resistivity structure and continuation further southwards of the Glenelg and Grampians-Stavely geological zones defined by the Yarramyljup Fault, marking the western limit of exploration interest for the Stavely Copper Porphyries. The Stawell and Bendigo Zones also show change across the Moyston and Avoca faults, respectively.

Results of 2D modelling reveal a more conductive lower crust (10-30 Ωm) and upper mantle beneath the Lachlan Orogen compared to the Delamerian Orogen. This significant resistivity gradient coincides with the Mortlake discontinuity and location of the Moyston fault. Broad-scale fluid alteration zones were observed through joint analysis with seismic profiling, leaving behind a signature of low-reflectivity, correlating to higher conductivities of the altered host rocks. Isotopic analysis of xenoliths from western Victoria reveal the lithospheric mantle has undergone discrete episodes of modal metasomatism. This may relate to near-surface Devonian granite intrusions constrained to the Lachlan Orogen where we attribute the mid to lower crustal conductivity anomaly (below the Stawell Zone) as fossil metasomatised ascent paths of these granitic melts. This conductivity enhancement may have served to overprint an already conductive lithosphere, enriched in hydrogen from subduction related processes during the Cambrian. A predominately reflective upper crust exhibits high resistivity owing to turbidite and metasedimentary rock sequences of the Lachlan Orogen, representative of low porosity and permeability. Conductive sediments of the Otway Basin have also been imaged down to 3 km depth southwest of Hamilton.

NSW

Honours

Bailey Payten, The University of Sydney: 'Modelling the fragmentation of cordilleran orogens: Applications to the Lord Howe Rise'.

The fragmentation of Eastern Gondwana led to the formation of the world's largest continental ribbon, the Lord Howe Rise. This fragmentation occurred through west-dipping subduction of the Pacific plate and subsequent back-arc extension in the Eastern Gondwana Cordillera; the mechanisms of which are not well constrained. Through thermo-mechanical numerical modelling, this study explored the impacts of the Cordillera itself, a buoyant mantle wedge and kinematic plate movement on back-arc extension and subduction.

A palinspastic reconstruction of the Lord Howe Rise and Eastern Australian margin was performed, with reconstructed extensional velocities, crustal thicknesses and crustal geometries derived for comparison to the numerical model output. Presence of a Cordillera introduces a gravitational potential energy anomaly resulting in orogenic collapse which then promotes trench retreat. Removal of this orogen caused a ~60 km decrease in continental extension. Introducing a buoyant mantle increases continental extension by ~70 km through development of higher stresses promoting lateral extension in the overriding continental crust. Most importantly, the study found that removing horizontal oceanic plate velocity to develop increased extension by ~90 km, with continental crust hyperextension and asymmetry matching the narrow Eastern Australian margin and hyperextended Lord Howe Rise. Rift migration is proposed to be the primary factor that controlled the formation of this crustal geometry.

Western Australia

MSc

Adouley Guirou, Curtin University: 'Extraction of Induced Polarisation from Magnetotelluric measurements, case study from Atlántida Copper-Gold deposit, Atacama Desert, Northern Chile'.

Retrieving induced polarisation effects from natural source magnetotelluric or natural field induced polarisation (NFIP) surveying continues to be a subject of considerable interest to the geophysics community. The complex electromagnetic response of a finite body is caused of induction and polarisation in the body and by the distorted inductive current of the background medium. At low enough frequencies (below the 'DC limit'), the induction currents are negligible and the polarisation effect is dominant. Since the dc response is not frequency dependent, any frequency dependent conductivity change at low frequencies is due to polarisation effect. The frequency dependent conductivity (or resistivity) changes at low frequencies (below 'dc limit') can be expressed by the percent frequency effect (PFE). Normalised phase and imaginary component of electric field with respect to a reference field measurement are used to express the polarisation effect.

The NFIP technique was applied on the induced polarisation (IP) anomalous Atlántida copper-gold deposit in Chile. The resulting NFIP laterally correlates with conventional induced polarisation. The possibility to retrieve induced polarisation from magnetotelluric brings two significant advantages: firstly, the possibility of using magnetotelluric measurement in difficult terrain to observe resistivity and chargeability distribution and secondly, the possibility to explore for deep seated targets where conventional IP systems have limitations.

Abdulaziz Aljaroudi, Curtin University: 'Optimal Seismic Acquisition Parameters Design, Data Processing and Imaging, using 2D Finite Difference Modelling of the Complex Geological Structures'.

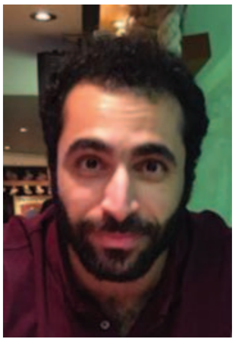
The project consists of the two-dimensional complex structure(s) embedded within the different geological environment created in painting software in grayscale mode. These geological environments are varying from simple to complex one. Then, four different standalone programming codes are used to convert the painted model from raw picture format to field format disk (SEG-Y) that is readable by Promax. The SEG-Y tape that contains the model is transferred into an interval velocity in-depth model for modelling and migration analysis.

The finite-difference method has been effectively applied to a better understanding of the seismic wave propagation through the created models. This has been accomplished by generating synthetic zero-offset seismic sections using exploding reflector and source point modelling. Later, various migration algorithms on these seismic sections provided different outcomes, and their performance depends on many factors. The main difficulty of the seismic imaging is the target of a complex structure (2D selfie) in created models, with distance (x) of 1000–3000 meter and a depth of 1200–3000 meter. This thesis addresses three issues in seismic imaging: (1) The stability of various migration approaches in handling laterally varying velocities; (2) Speed and accuracy of migration algorithms; and (3) Computational time comparative analysis of various migration algorithms.

This thesis describes the implementation of four different migration algorithms on the exploded reflector models and normal source models: Kirchhoff time/depth migration, Stolt migration and Explicit FD migration. These various implantations yield to a least to precise imaging accuracy in complicated structure(s) in the models. Stolt was fastest migration implementations and was able to image the constant velocities areas to mild laterally and vertically variant velocities accurately, but it fails in areas where there is a very large contrast in velocity. On the other hand, the main advantages of Kirchhoff depth migration over Stolt migration and Kirchhoff time migration are its ability to handle lateral velocity variations with comparable efficiency. It has seen that Kirchhoff depth migration can be no more accurate, at least for moderate dips, than the finite difference methods which also has higher quality migrated images. The computational time amount of theses migration algorithms is directly proportional to the seismic migration algorithm used, amount of processed data, and frequency content of the seismic data involved, as well as adequate buffer size, allocation of memory in seismic migration algorithms, and particular migration operator performance (i.e. Stolt factor, maximum dip calculation, travel time solver, etc.).

Given its content, this thesis can be a handy manual for new seismic imaging users, as it can give them knowledge of what can be expected from the modelling and various migration algorithms, applied on different geological environments. The results of created six models are the following: 144 post-stack data sets with different CDP spacing and frequency content, 18 pre-stack data with different frequency content, and more than 642 migrated images and special migration tests.

Abdulrahman Al Jaafari, Curtin University: 'Geophysical characterization of landslides in Serbia and Bosnia and Hercevgovina – a GWB project'.



Landslides are considered one of the main problems in Serbia and Bosnia & Herzegovina (BiH). The locality investigated in this research is near the city of Lopare. Landslides in this area are particularly devastating as they appear to be the result of liquefaction of sand caused by heavy rainfall. Landslides here were investigated by a combination of seismic and resistivity data. Seismic investigations utilized reflection, refraction and surface waves. The methodology known as Multi-Channels Analysis of surface waves (MASW) was used to invert for shear wave velocity along reflection profiles. The output of each individual method is initially analysed. Final analysis utilized joint interpretation of these diverse data sets. The main body of the landslide is well defined by the reflection method. Its internal composition is characterized by low shear wave velocity and resistivity values.

Nicolas Galindez Carrasquero, Curtin University: 'Comparative advantages and disadvantages of using two different source geometries in the North-West Shelf'

Honours

Petr Lebedev, Curtin University: 'Cloud based cooperative magnetotelluric and seismic inversion'

Christian Proud, Curtin University: 'Modelling-driven workflow for 3D seismic inversion for Stage 2C of the Otway Project'.

Seismic inversion refers to a group of methods which aim to convert recorded seismic amplitudes into properties of the subsurface. Seismic inversion has many input parameters, many of which have uncertainty that affects the resulting subsurface models. Uncertainty analysis can therefore be a time-consuming task. Many studies fail to quantify sensitivity and accuracy of seismic inversion in realistic scenarios. They utilise oversimplified subsurface and noise models. To quantify the sensitivity and accuracy of post-stack and pre-stack seismic inversion we use full-Earth static models and synthetic seismic data derived from these. Parameters were varied one at a time and various statistical measures were used in quantifying the accuracy and sensitivity. We found that pre-stack simultaneous inversion when inverting for P-impedance was less sensitive than post-stack inversion. The accuracy of pre-stack simultaneous inversion was superior to that of post-stack inversion producing on average 30% lower root-mean-square error. This increased accuracy is thought to be due to the increased bandwidth of the extracted angle-dependent wavelets compared to wavelets extracted from post-stack data. Whilst angle-dependent wavelets are most sensitive to changing parameters the pre-stack algorithm appears to be more robust in the presence of noise. Understanding and quantifying inversion sensitivity and accuracy allows us to focus research into accurate determination of only the most influential parameters into inversion.

Kristopher James Wright, Curtin University: 'Palynological and geophysical analysis of the stratigraphy and palaeoenvironmental context of a palaeovalley near Mulga Rock, Western Australia'.

The stratigraphy and palaeoenvironmental context of Vimy Resources Ambassador lignite-hosted uranium deposit in the Narnoo palaeovalley at Mulga Rock has been evaluated to determine if there is a correlation between changes in palynoassemblages and seismic characteristics. The Narnoo palaeovalley is a Cenozoic inset-valley within the southern Proterozoic Officer Basin and is located 240 km ENE of Kalgoorlie.

Prior to this study the lignites and carbonaceous clays were dated as late Eocene, and a trial seismic survey was conducted over the East and West Ambassador prospect areas, now excavated as geotechnical trenches. In total, 31 samples were collected and palynologically processed from six boreholes along the seismic lines. Sixteen lignite and carbonaceous clay samples from three East trench boreholes were palynologically analysed and dated as late Eocene on the presence of restricted index species *Proteacidites nasus*, *Tricolpites incisus*, *Anacolosidites acutullus*, *Proteacidites reticulatus* and *Proteacidites rynthius*. The two lithological units were palynologically distinguished by changes in abundance of major palynomorph groups, with *Haloragacidites harrisii* prominent in the lignitic unit and *Proteacidites* and *Myrtaceaidite*s species prominent in the carbonaceous clays. These palynological trends are interpreted as shifts in depositional environment from a meandering river to a swampier/lacustrine setting across the carbonaceous clays – lignite boundary.

Seismic attribute analysis of the three trial seismic lines showed that continuity of cosine of instantaneous phase, rate of change of instantaneous frequency and amplitude of reflection strength, could be used to successfully segregate major lithological sequences of the East and West trenches through examining 2D attribute profiles and their intra-sequence lateral changes. Finer discrimination of attribute sequences using vertical attribute 'logs' at borehole locations on the East and West seismic sections proved a direct correlation between changes in attributes and the boundary between lignites and carbonaceous clay.

Comparison of palynology results and the geological and geophysical data of the East and West trenches revealed them to be environmentally distinct from one another. The West trench area is interpreted as belonging to the main palaeovalley system, and the East trench area as a tributary or bisection of the main palaeovalley.

The correlation of results obtained in this project have shown that within the late Eocene sediments of the Narnoo palaeovalley, changes in seismic attributes can be used to infer stratigraphic and palynological changes.

Minzhan Li, Curtin University: 'Using S-P time methods to accurately locate some southwest Australian earthquakes'.

The uncertainty of earthquakes' location within Western Australia is high. The uncertainty of location is originating from the poor seismic networks, quality of recorded data reading, and velocity model. There are many methods that have been tried to improve the precision of earthquake location, but the uncertainty of locations of events is still high in south west Australia. Yilgarn Craton is considered seismically active area. It is believed that the majority of events happened in this area have cluster nature with shallow depth (<5 km).

In this study, the manually s-p time method was used on clustered events in South West Australia zone, including Kellerberrin, Kalannie and Koorda area. Because the data recorded at more closed temporary stations are used, the corresponding results should have better quality. The cluster centers are improved in each swarm. One of them is same as the cluster center suggested by Dent (Koorda, 2011).

The s-p time at close stations and similar seismograms of events within same cluster indicate these events are much more closely located than Geoscience Australia suggested. The locations of events have been improved in this study. Compared to IASPEI model, WA2 model is more suitable in SWA zone. It is necessary to work more on velocity model to improve the accuracy of location of events.

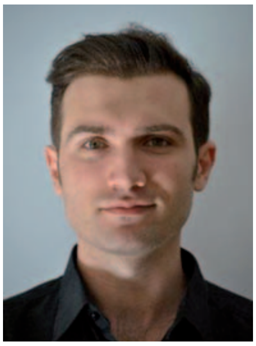
Shihao Chen, Curtin University: 'Seismic Processing of high resolution long offset 2D data over a large displacement fault: Perth Basin WA'.

Curtin Department of Exploration Geophysics in partnership with the Western Australia Department of Water have acquired and processed new geophysical data spanning 2000 km^2 of the Perth Basin for better understanding the geological structures that have significant impact in process of design hydrological model and optimal water exploitation regime. The main goal of the reprocessing the seismic line, acquired along the Bindiar road, was to explore and carefully parametrize each processing step in order to improve quality at each stage for the purpose of better imaging of the Badamina fault. Even smallest improvement, i.e. in pre-processing phase, will have a significant impact on the next coming processing phase. Also, different strategies were used for the defining the near surface velocity model, such as including the variable weathering velocity along the line (usually, processors are using only one the most representative value). In order to improve static corrections, various offset ranges were tested. Significant period of time was devoted to pre-processing phase, where several methods were used for coherent noise removal (surface waves, direct and refracted waves and their repetitive pattern due to bouncing energy between fresh rock and surface, which significantly masks near surface events of interest). Thanks to detailed tests and pre-processing modules parametrization, we managed to remove the all types of coherent noise form the data. Thanks to previous steps, velocity analysis was more reliable, as well as quality of residual static correction calculation. Additional improvements of the velocity model were done through DMO processing. Obtained DMO velocity model used for CRS processing gave satisfactory result that was adopted as a final product. Migrated CRS stack, after depth conversion, revealed area of interest in much better details with improved spatial and temporal resolution, confirming the results of other geophysical methods used, such as TEM, ERI, as well as the results from boreholes in the vicinity of the seismic line.

Sheng Han, Curtin University: 'Kinematic redatuming using emergent rays'.

Redatuming aims to recover the seismic events distorted by irregular topography and complex weathering layers. This correction normally is conducted by placing source and receiver to a new imaginary surface below the complex overburden, and it is conventionally conducted by static correction or wave-equation based redatuming methods. However, while the former method has fast computing time, it assumes seismic waves only travel vertically in the overburden; the latter method produces more accurate results, but costs a huge computing time. This project presents a method that is slotted in between these two extrema. The presented method involves using horizontal slowness for the same emergent ray to assign the given sample the new source and receiver position on the new datum, and then subtract the one way travel time from acquisition surface to new datum. The method can be used for anisotropic or heterogeneous media. It can give comparatively good results as compared to the finite difference redatuming method on the synthetic models that are tested in this project, and it can be further developed using velocity independent scheme to become a method that does not require a known velocity model.

Ryan M. Vitas, Curtin University: 'Pre-stack depth migration of the Balaka 2d seismic line'.



This paper presents an insight into pre-stack depth migration of seismic data acquired near Broken Hill in NSW, Australia. The survey in question, known as the Balaka seismic line, was designed and implemented as part of a large scale hydrogeological investigation into drought security for the region. The seismic line was carried out as a means of delineating structural features that were imaged using airborne electromagnetics.

With today's availability of cheap processing power, modern practice strives to conduct seismic imaging as accurately as possible. It has already been well established that the pre-stack depth migration algorithm is the most robust and effective migration technique for imaging the subsurface. Where this imaging technique has been rapidly growing in popularity since the influx of these fast, modern processing systems.

The focus of this project is to analyse a number of necessary techniques required to go from raw seismic data to a full depth migrated image, while simultaneously looking at different migration methods. The primary migration algorithm involved will be the Kirchhoff integral method, and the dissertation itself is sub-divided into four main chapters: 1) introduction; 2) time processing; 3) time imaging; 4) depth imaging; 5) concluding remarks.

Pre-stack depth migration is already accepted as the most complete and accurate migration method, and the findings of this project support this conclusion. The final pre-stack depth migrated image was able to not only increase the lateral continuity and resolution far better than the other techniques, it was also able to illuminate a secondary potential lithological boundary at depth which may be of interest in regards to interpretation.

The results of this final depth image will be able to be used in assisting further interpretations made for the Broken Hill Managed Aquifer Recharge project. These include gaining a greater insight into the geological structure of the subsurface, and even assisting in constraining any necessary future geophysical surveys.

Layne van Zaanen, Curtin University: ‘Comparison of borehole seismic receivers’.

Jefferson Bustamante, University of Western Australia: ‘Modeling Stress-Induced Azimuthal Anisotropy’.

New discoveries of hydrocarbon reservoirs are getting deeper and in increasingly complex geology, as a consequence one commonly needs to re-evaluate the isotropic acoustic assumption when trying to improve the precision of the analysis. One way to lessen this assumption is to evaluate elastic materials under anisotropic conditions. The aim of this thesis is to evaluate which rock physics model, the one presented by Mavko in 1995 or the model proposed by Sayers in 2001, generates the best theoretical predictions. A comparative analysis between the two models is presented. Theoretical descriptions of the approaches and applications are evaluated. The models are then compared for three different kinds of rocks: Massillon sandstone, Barre Granite, and Ottawa sand. Finally, a 3D finite-difference model is used to evaluate how the models could be used in further analysis. It is found that in general, Mavko’s model generates better approximations with a maximum calculated error of 4% on the Massillon sandstone. It is also found that neither of the models is a good approach when comparing with unconsolidated rocks.