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Dr Gavin Young with the life-sized model of the giant Devonian lobe-finned fish *Edenopteron* built by Baz Waterhouse. Photo: Belinda Pratten, courtesy ANU Media Office. Hear Dr Gavin Young deliver the Mawson Lecture, Tuesday, 8 July 2014.

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artefacts of the HyPy method or related to mineralisation of the sample. The $\delta^{13}C$ values of the *n*-alkanes suggest biological (i.e. algal/bacterial) origins and the relatively heavier isotopes for the PAHs are likely related to the thermal maturity of the samples. These HCs are structurally distinct from the carbonaceous “graphite” like material in the matrix and infill to mineral grains detected in SEM-EDS. HyPy products of samples 50 m from the ore zone *vs* those proximal to the ore zone show an increase in the PAHs over *n*-alkanes, however an increase in *n*-alkanes over PAHs at the ore zone is still being investigated.

Further analyses of samples with spatial variation in proximity to the ore using other techniques (e.g. Raman spectroscopy and X-ray microspectroscopy) will be conducted to further establish any trends or hydrothermal footprint in the petrogenic markers and its possible relationship to Au mineralisation.

39TH SYMPOSIUM ON THE ADVANCES IN THE STUDY OF THE SYDNEY BASIN

01SBA - 39TH SYMPOSIUM ON THE ADVANCES IN THE STUDY OF THE SYDNEY BASIN

01SBA-01. THE EMPLOYMENT CYCLE FOR GEOSCIENTISTS: WHERE TO NEXT?

Geoff Sharrock

President, The Australasian Institute of Mining and Metallurgy

Coal is the principal mineral commodity produced in the Sydney-Gunnedah Basin, and during the last forty years coal exports from have increased dramatically due to the demand from Asia. Initially, this demand was from Japan and Korea and most recently from China. NSW coal production increased from 48 million tonnes in 1980 to 250 million tonnes in 2013. Export capacity at the port of Newcastle has increased from 16 million tonnes in 1976 to 180 million tonnes in 2013.

In 2004 demand outstripped supply, coal prices rose rapidly, and the need to identify and prove coal resources and reserves to sustain additional capacity resulted in a significant increase in exploration activity and consequently jobs for geoscientists.

By mid-2012 coal export prices began falling. Operators moved quickly to reduce costs, with exploration activity reducing dramatically. Contractors were the first to bear the brunt of staff reductions followed by employees. Capital flows to junior explorers dried up. Projects were put “on hold” or abandoned.

The coal industry has been particularly hard-hit compared to other sectors of the mining industry that also boomed in the last decade. Mines in the Sydney-Gunnedah Basin more so than those in the Bowen Basin, due to the predominance of thermal coal in this basin. Many mines would now be operating below cash cost, with export tonnages remaining high due in part to “take or pay” contracts with rail and port operators.

Members of the Australasian Institute of Mining and Metallurgy, just as those in kindred professional societies, have suffered from the downturn in commodity prices, and, in some cases, the complete cessation of exploration activities.

Last year, the AusIMM conducted a survey of members and found that unemployment and underemployment had risen from 2% to 10%. AIG surveys show that 19% of members are unemployed and 15% are underemployed. Recent data indicates that this unemployment is continuing to rise.

Professionals who have been in the industry a long time have seen downturns in the coal sector before, including reductions in revenue. Coal prices reduced year on year in the late 1980’s, and factors such as concentration of ownership resulted in mining professionals losing their employment.

The current downturn has factors that were not in evidence during previous contractions. We now have the mining industry under community pressure as never before. We have other industries running campaigns against coal mining and investment fund managers expressing a view that they do not want to invest in coal.

The Institute has responded to the situation in a number of ways. We have put in place a Member Assistance Program (MAP) to help our members through this difficult time. We have raised the matter of the large number of unemployed geologists with the Federal Minister for Resources. We have made suggestions for alleviating unemployment. Geologists are trained scientists who are able to carry out other duties but this resource does not seem to be recognised by many companies.

Even with these issues, Australian coal will be needed in Asia for many years to come and professionals will be needed to operate the industry, albeit perhaps not at the levels of employment seen during the boom. Employment prospects and potential career paths for geoscientists, both within and outside the industry, are discussed.

01SBB - 39TH SYMPOSIUM ON THE ADVANCES IN THE STUDY OF THE SYDNEY BASIN

01SBB-01. A CHARACTER SET IN STONE: LANDSCAPE, GEOLOGY AND THE 1788 SETTLEMENT AT SYDNEY COVE

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The newly occupied landscape of Sydney Cove is only briefly described in accounts of the first British settlement. Authors focus on the human dramas that unfolded between settlers and Aboriginals, and within the European community (e.g. Tench 1789, 1793). References to landscape tend to be observations about potential exploitation: anchorages, reliable water sources, soil quality and building materials (e.g. Collins 1798, 1802). Yet despite the constraints of the new settlement, trained personnel recorded many landscape features on maps and charts, including shorelines: rocky bluffs, cliffs and wave-cut platforms; sandstone ledges; alluvial flats, beaches, mud flats and mangroves; water courses and wetlands; vegetation density; and topography. Paintings, drawings and written accounts provide additional detailed information. Modern development has obscured most of these details and it is now difficult to envision the landscape that settlers first saw in 1788. It was the aim of this study to draw together the various observations and to combine them in a single landscape map compilation. No such reconstruction exists in the literature. A particular goal was to determine how geology influenced the earliest phase of Sydney's development.

The mapping-based approach produced detailed landscape feature maps of Sydney Cove, which then formed the basis for a 3D digital terrain model (Figure 1), calibrated by modern topographic data. Geological mapping (e.g. Herbert 1983; Osch 2007) was referenced against the landscape maps and model to determine the influences of geology on the 1788 landscape. The results reveal that geology had a profound influence on early Sydney, from the choice of the site (reliable freshwater, secure anchorage), to the pattern of its subsequent development.

The landscape of inlets and headlands was produced by the interactions of northeast-trending structures and the shallowly dipping strata. The ridgelines bordering both shores of Sydney Cove (Bennelong Point to the east and Dawes Point to the west) slope more gently on their eastern sides, and are steeper and more prominently bluffed on their western sides. This asymmetry is probably the result of the undulating dip of strata in the underlying Hawkesbury Sandstone (particularly the "facies bedding" and "clay seams" described by Pells 2002). The more gently sloping but rocky eastern shore of Dawes Point became the site of most of the original 1788 encampment and eventually evolved into 'The Rocks' area (Sydney's oldest residential suburb).

The reliable freshwater source was a rivulet rising from springs at the contact between the Wianamatta Group and the underlying Hawkesbury Sandstone at the head of the 'Tank Stream Valley' (e.g. Collins 1798; Karskens 2009). It flowed northward through the valley, roughly following the trace of the 'GPO Fault Zone' (Osch, Pells & Braybrooke 2004) and divided the military (western) from the administrative (eastern) sector of the first camp (Phillip 1789). Government institutions still dominate the east of the CBD. Temporary shelters were first placed in the more level areas with fewer trees on the western shore of the cove. Sandstone outcrops still formed obstacles that the settlers had to work around, particularly on the western side. Huts were located on flat spots while a network of interconnecting paths developed around the sandstone ledges and approximately parallel to the strike of bedding (e.g. Karskens 1999). Tracks eventually became roads such as George Street. Early farming was mostly unsuccessful because the sandstone soils were poor and alluvial flats provided the first arable land (Farm Cove). Shale-derived soils were of better quality but occurred mainly to the west, where a second settlement was founded at Parramatta (e.g. Karskens 2009). This shifted the centre of agriculture westward.

The study shows that the geology and landscape of Sydney Cove set development patterns in place that have persisted throughout its subsequent history.

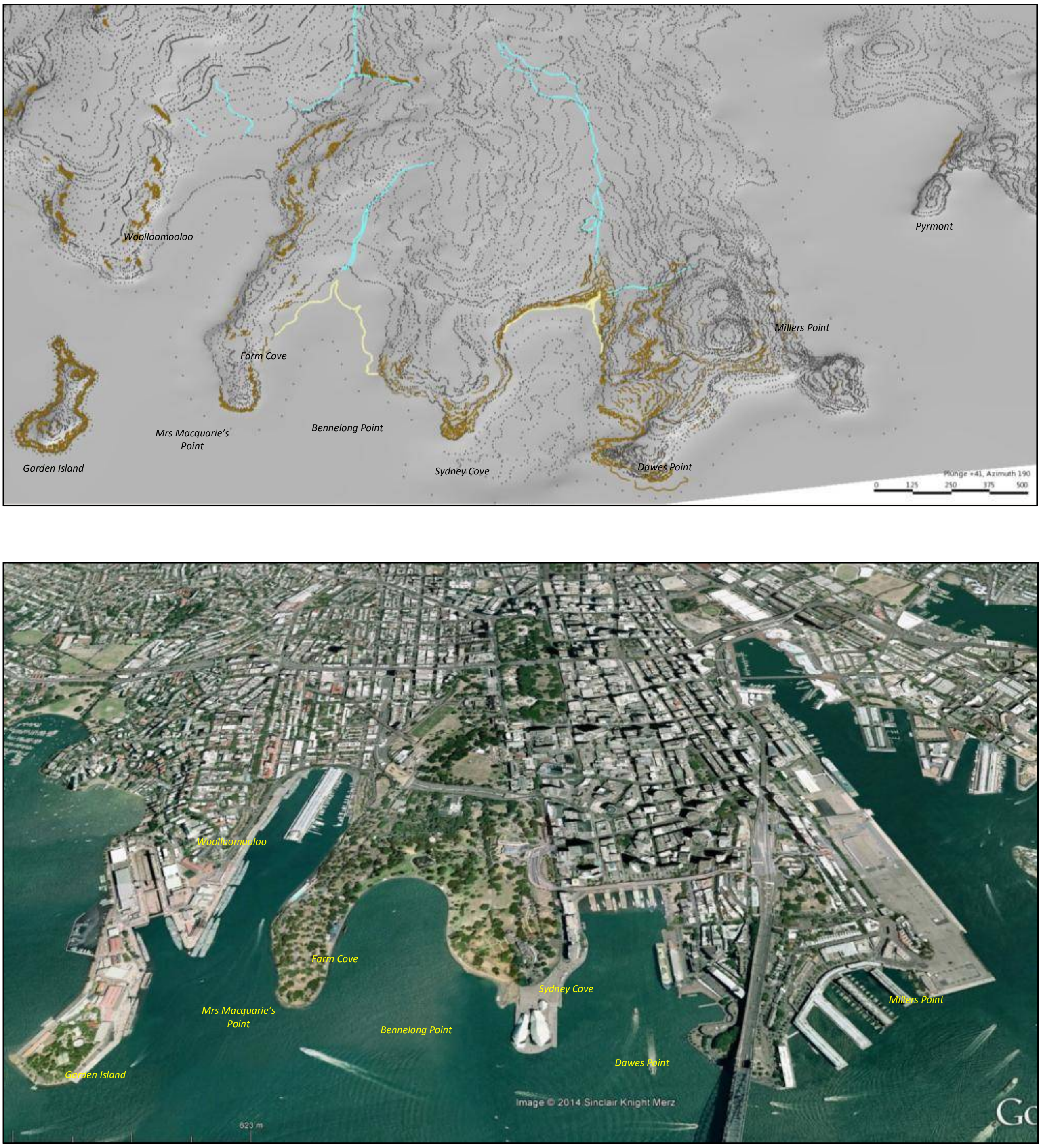

Figure 1. Two views of Sydney Cove (Circular Quay) comparing the reconstruction of the 1788 landscape (upper) to the modern Sydney CBD (Google image, lower). Both views are taken from approximately the same viewpoint and are looking to the south, along the course of the 'Tank Stream' Valley. The upper image presents a screen shot of part of the 3D digital terrain model developed from the historic map compilation. Features shown include rocky bluffs and platforms (brown lines), historic drainage lines (light blue lines), wetlands (light blue polygons), and beaches (yellow lines). Spot height information is shown as dark grey point data overlain on the shaded DTM triangulation (pale grey), to illustrate the subtle variations in the original landscape of the city. The floor of Sydney Cove is modelled as a part of the DTM surface and is based on 1788 depth soundings. The DTM model was created using Leapfrog and Vulcan.

01SBB-02. COAL EXPLORATION – 1830 STYLE

Russell Rigby

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The Australian Agricultural Company (AACo) shipped the first coal from its new mine (A Pit) in Newcastle in December 1831. Although most of the miners were convicts, the coal was raised in the shaft by a steam winding engine, sent to the wharf along the first railway in Australia, and loaded into the first steam ship in Australia, using a high level chute. For the previous 30 years mining had been been a Government operation, with the convict work force winding the coal using a hand windlass or horse whin, wheel barrows and bullock wagon to transport the coal to the wharf, and loading using baskets. Convicts were sent to work in the mines in Newcastle as punishment for secondary offences, as much as to provide productive labour.

The changes in technology were not restricted to the mining operations. Before the AACo decided to establish the new mine, John Henderson, the Company's Colliery Superintendent, had inspected the Government mines in 1827, and commented that the condition of the mines was so bad, and the layout so unplanned, that the Company should not consider taking over the operation, but start a completely new mine in the Yard Seam. Because there was still a dispute about the terms of the Company's coal grant Henderson did not get this opportunity until 1830. In the meantime he drilled several bores on Macarthur's and Blaxland's properties on the Parramatta River looking for coal, without any success.

By the time Henderson returned from England in 1830 the issues with the coal grant had been resolved, and he conducted a boring program in the area immediately west of Newcastle town to plan for the new pit. The prospecting included field mapping and drilling seven holes to test the extent, thickness and quality of the seams. This was the first systematic mineral exploration program in Australia.

Copies of Henderson's original reports still survive in the Butlin Archives of the Australian National University. The large scale plan and sections of the 1830 exploration and mine planning were drawn up by Henderson and the AACo surveyor John Armstrong, and are now held by the Turnbull Library in New Zealand. The level of detail of the plan and sections enables detailed logs of the bores to be made, and the accuracy of the surveying means that the collar position and level of the bores can be located to within one or two metres. The geological data contained in the reports and plans is directly relevant to present and future planning of the inner city area of Newcastle.

Henderson recognised that there was potential for more coal seams beneath the Yard Seam. The bores intersected another thin seam, but it was not until 1848 that the 3 m thick Borehole Seam was discovered (in a borehole!) about 3.5 km west of the A Pit. Subsequently this seam was intersected 55 m under the AACo's early operations, beyond the reach of Henderson's equipment (approx 37 m). The seam was 6 m thick – what might have been?

01SBB-03. LITHOLOGY AND ENGINEERING BEHAVIOUR, NEWCASTLE COAL MEASURES

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This presentation relates the lithology and fabric of the four main groups of the Newcastle Coal Measures' rock types to their geotechnical properties and engineering behaviour. The four groups are: massive sandstone and conglomerate; claystones and tuffs; mudstone, shale and siltstone; and the coal itself. Although their geological relevance is primarily concerned with underground coal mining, these rocks are exposed at the surface across most of Newcastle and its suburbs, and are thus significant in terms of urban environmental geology.

The key mining issues include longwall support design and panel layouts, caving and subsidence mechanisms, soft floors and stiff roofs, water inflows and pillar design.

The urban geotechnical issues include landslides and rock falls, shallow abandoned mine workings, reactive and erodible soils, waste disposal and potential sources for geomaterials.

KEYWORDS: geotechnical, coal, conglomerate, tuff, subsidence, Newcastle

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01SBB-04. A GOLD-BEARING ALKALINE INTRUSION IN THE SOUTHERN SYDNEY BASIN

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Of the many Jurassic intrusions emplaced in the southern Sydney Basin only that at Mount Broughton 4.5 km south of Moss Vale is known to contain mineralisation, albeit of minor significance. The *Conlons Find* gold–silver occurrence was described by J.E. Carne in 1908 as "disseminated coarse visible gold in chalcedonic quartz stringers cutting weathered 'diorite' host rock which also assayed a trace of gold". A composite chip sample of discontinuous veinlets assayed 1.65 gm/t gold and 3.3 gm/t silver. The probable site with old shallow workings has been relocated, but chalcedony veinlets so far collected in the vicinity lack visible gold.

On different generations of geological maps Mount Broughton is shown variously as Tertiary basalt–basanite or as a syenite–microsyenite body resembling major intrusions to the north at Mount Gibraltar (The Gib) and Mount Misery in the Southern Highlands of New South Wales. Recent construction of a large stone wall at Mount Broughton from local outcrops has provided uncommonly fresh intrusive material dominated by plagioclase phenocrysts, differing mineralogically and texturally from the other Southern Highlands intrusions. Remnants of Tertiary basanite occur near the crest of the 90 m high Mount Broughton. Alkali basalts overlying laterite and Wianamatta Group shales surround its base. The intrusion is extensively weathered.

The fresh intrusive rock is compact and pale grey in colour. Relatively close-packed plagioclase phenocrysts are stout, euhedral to subhedral laths of uniform size in particular specimens but varying from 5 mm to 1 cm in length at different outcrops. In places they are distinctly aligned. They range from An30 to An20 in composition with thin albite rims and occasional overgrowths of alkali feldspar, and are set in a finer mesostasis dominated by thin laths (0.2–1 mm long) of alkali feldspar (Or60–Or90), themselves enclosed by a groundmass of carbonate aggregates (calcite, ankerite and siderite) with deep green Fe-chlorite, or by interstitial chalcedony or rare coarser quartz. Plagioclase phenocrysts contain common apatite needles and are accompanied by minor magnetite. Primary mafic silicates are lacking, but scarce pseudomorphs after former amphibole and pyroxene now consist of Fe-chlorite plus carbonate and chalcedony and a clay mineral (kaolin?), respectively. Infrequent miarolitic cavities are typically lined by tiny quartz crystals followed by complex layers of carbonate, Fe-chlorite, and hematite, with a final chalcedony infill. Amoeboid patches of chalcedony within the mesostasis are less clearly filling cavities. Sulfides are absent.

Darker grey patches of segregated, alkali feldspar-dominated mesostasis within the more abundant plagioclase-rich assemblage range from microscopic bodies to pods several centimetres across. Plagioclase-free mesostasis-like material also forms 'dykes' up to 10 cm wide with irregular, non-matching borders. These all appear the product of a dilation and 'filter pressing' stage during magma crystallisation. Since late stage alteration products including carbonates are pervasive throughout the intrusion without indications of an external fluid source, igneous crystallisation evidently merged into a hydrothermal-deuteric phase involving replacement of mafic minerals and deposition of the same assemblages in miarolitic cavities. Fracture-filling chalcedony veinlets (presumably equivalent to those in which Carne identified visible gold) constitute the final stage.

The bulk CO_2 content (7.4 wt%) of a typical Mount Broughton intrusive sample implies about 15 wt% carbonate, which would account for a substantial proportion of the bulk Fe and Ca. Adjusting for carbonate, bulk SiO_2 content (53.0 wt%) becomes about 64 wt% for the feldspar-dominated silicate component. The bulk K_2O/Na_2O weight ratio of 0.79, allowing for average mineral compositions, corresponds to a ratio of about 40% alkali feldspar and 60% plagioclase, classifying the rock as (leuco)monzonite. It contains elevated P and rare earth elements, with pronounced LREE enrichment but negligible Eu anomaly in chondrite-normalised plots. Relative to 'calc-alkaline' monzonites Mount Broughton is also highly enriched in K, Rb, Zr, Ba, and Th, and is depleted in Sc and V, reflecting its alkaline affinity and leucocratic character. 'Ore element' abundances are unexceptional (Cu 33, Zn 165, Ag 0.6, Au 0.01, all ppm), as is bulk sulfur (100 ppm).

The mesostasis-like pods and dykes at Mount Broughton probably resemble K-rich Mount Gibraltar microsyenite in geochemistry, whereas the bulk monzonite represents a prior stage of fractionation from which early-formed plagioclase has not been removed. No evidence exists in the region of a likely mafic parental magma – nearby Jurassic dolerite at Mount Gingenbullen is tholeiitic rather than alkaline. Nor, indeed is it clear what structural or tectonic features govern the presence of the Jurassic alkaline intrusive provenance at the southern end of the Sydney Basin.

The gold described by Carne at Mount Broughton has evidently concentrated in the final silica precipitate within dilational fractures following extensive magma fractionation and hydrothermal deposition, especially of carbonates. Since sulfides are absent, gold may have been leached and transported as a hydroxide complex in an ultimately oxidised CO_2-rich aqueous fluid, and deposited as a consequence of cooling. Alkaline microsyenites at Mount Gibraltar and Mount Misery near Bowral and Berrima, respectively, also contain carbonates, chlorite and chalcedonic quartz as alteration products of scarce mafic minerals (including riebeckite and aegirine), as a groundmass to dominant potassium feldspar, and as fillings of miarolitic cavities. Their secondary minerals are distinctly less abundant than at Mount Broughton, but the same post-magmatic hydrothermal processes were operative. The restricted occurrence of mineralisation at Mount Broughton and the lack of discoveries at other alkaline intrusions, however, discount the Southern Highlands of New South Wales as a significant gold province deserving comprehensive exploration.

01SBC - 39TH SYMPOSIUM ON THE ADVANCES IN THE STUDY OF THE SYDNEY BASIN

01SBC-01. CA-IDTIMS DATING IN AUSTRALIA: THE PAST, PRESENT AND FUTURE

Bob Nicoll, John Laurie, Simon Bodorkos & Tegan Smith

Geoscience Australia, Canberra ACT Australia

Chemical Abrasion-Isotope Dilution Thermal Ionisation Mass Spectrometry (CA-IDTIMS) is a refinement of the classical IDTIMS technique. In this relatively new technique, target zircons are selected using a traditional combination of optical evidence for good crystallinity and cathodoluminescence evidence indicating a single crystal growth phase. The zircons are then annealed at high temperatures, followed by 'chemical abrasion' using hot concentrated, pressurised hydrofluoric acid. The annealing repairs minor crystal lattice defects, while the chemical abrasion removes domains that are damaged beyond repair. Surviving crystalline zircon tends to have an undisturbed isotopic composition, the measurement of which is limited only by the rapidly improving sensitivity of modern mass spectrometers.

CA-IDTIMS analyses provide unprecedented analytical precision, with 95% confidence intervals routinely less than 100 000 years. This yields unique opportunities to resolve very closely spaced magmatic events, even if they occurred hundreds of millions of years ago. This allows us to improve the accuracy of correlation of eruptive events, infer rates of sedimentation, and constrain the timing of geological and biological events. The precision is such that the variations in residence times of zircon crystals in the magma chamber need to be taken into consideration when interpreting results.

Studies in Australia which eventually led to the current CA-IDTIMS work started in 2005 with a pilot study on upper Permian tuffs in the Bowen Basin by Ian Metcalfe (UNE), Bob Nicoll (ANU) and Roland Mundil (Berkeley Geochronology Center, USA). This was followed by an ARC Discovery grant to Metcalfe, Nicoll and Yuri Amelin (RSES, ANU), which initially focused on middle Permian to Lower Triassic tuffs in the Bowen, Gunnedah and Sydney basins. With Geoscience Australia's involvement, and the support of industry, state geological surveys and universities, the scope of the program has widened to include the Permian in the Canning, Tasmania, Southern Carnarvon and Perth basins and the Mesozoic in the Eromanga and Surat basins, as well as the Paleozoic in the Lachlan Fold Belt.

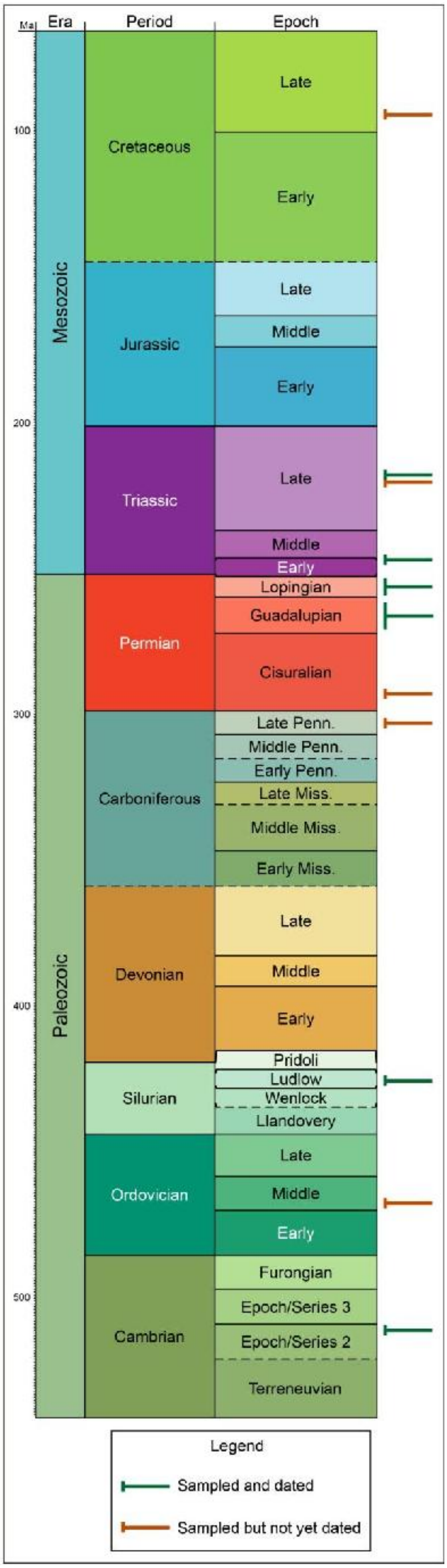
The overarching aim of these studies is threefold: To refine lithostratigraphic correlations across the continent; to improve the calibration of Australian biostratigraphic zonation to the International Geological Time Scale; and to improve the calibration of the timescale itself. To date the program and its collaborators have collected more than 450 samples, of which about 140 samples have been analysed, with approximately 100 of these providing usable dates (Figure 1) ranging in age from the early Cambrian to the Late Cretaceous (Figure 2). Dating of the samples is being undertaken by laboratories at Boise State University (Boise, Idaho) and the Research School of Earth Sciences, Australian National University (Canberra, ACT).

The bulk of the samples have been collected from Permian rocks in the Sydney, Gunnedah and Bowen basins. Additionally, Late Triassic samples have been acquired from sediments in Queensland and Tasmania and initial test samples of early Cambrian (SA), Ordovician (WA), Silurian (ACT), Carboniferous (NSW) and Cretaceous (Queensland) rocks have also been obtained. Jurassic samples from Queensland and New South Wales have been discussed with interested collaborators but not yet collected. Sampling selection is constrained by the presence of felsic igneous rocks, such as rhyolites or rhyolitic ash deposits, as zircons are normally restricted to rocks of this composition. Zircon abundance can be highly variable, with samples as small as 200 g producing results, but where possible samples of 3 to 5 kg are collected. Natural and man-made exposures, mine sections and drill core have been collected; drill cuttings are avoided due to potential downhole contamination. Supporting biostratigraphic analyses are required to allow calibration of biostratigraphic schemes to the International Geological Time Scale. In the case of palynomorphs, fresh rock samples are required as weathered rock usually contains no usable palynomorphs. On the other hand, macro-fossils tend to survive weathering better and natural outcrops are preferred because of the ability to take larger samples.

The middle and late Permian study in the Sydney, Gunnedah, Bowen and Canning basins (Figure 3) has demonstrated very significant changes to the ages generally ascribed to the palynostratigraphic zones (further described in Laurie *et al.* this volume). This can also lead to significant changes in the correlations of lithostratigraphic units and the understanding of depositional rates, as well as the precise timing of geological and biological events. In addition it has also been possible to correlate some of the ashfall tuffs to individual eruptive events. Results so far demonstrate that the Awaba Tuff across the Newcastle Coalfield is approximately 253.2 Ma in age, and that it is the same unit as the Nalleen Tuff in the Hunter Coalfield, confirming a correlation based on geochemical analysis; that the Nobbys Tuff across the Newcastle and Hunter coalfields is approximately 255.0 Ma in age; and that enough datable zircons can be obtained from thin tuffs in core material to provide useful dates.

This project is possible thanks to collaborators from universities, state geological surveys and private companies: Yuri Amelin (Australian National University); Ian Metcalfe (University of New England); Joan Esterle and Syeeda Areeba (University of Queensland); Scott Bryant (Queensland University of Technology); Peter McCabe (University of Adelaide); Jim Crowley (Boise State University); Kevin Ruming, Erin Holmes and Phil Blevin (New South Wales Trade and Investment, Resources and Energy); Arthur Mory (Geological Survey of Western Australia, John McKellar (Geological Survey Queensland); Liz Jagodzinski (South Australia Department for Manufacturing, Innovation, Trade, Resources and Energy); Mel Wilkinson and Geoff Wood (SANTOS); Malcolm Ives (Centennial Coal); Chris Knight (Muswellbrook Coal), and Malcolm Bocking (baCBM).

The future of CA-IDTIMS studies is only limited by the availability of new material to date. We are only scratching the surface of the potential of middle and upper Permian sediments. The early Permian record is virtually untouched. The Jurassic has only been discussed and only preliminary analyses have been conducted in the Triassic sequences. Felsic volcanics are common in the Lachlan Fold Belt of Eastern Australia and Liz Jagodzinski's early sampling is opening the window on the Cambrian in South Australia. This work will greatly improve local and regional correlation, within and between basins. Additionally, the well-constrained revisions to biozones in dated basins have implications for the revision of stratigraphic time sequences in basins without tuff beds.



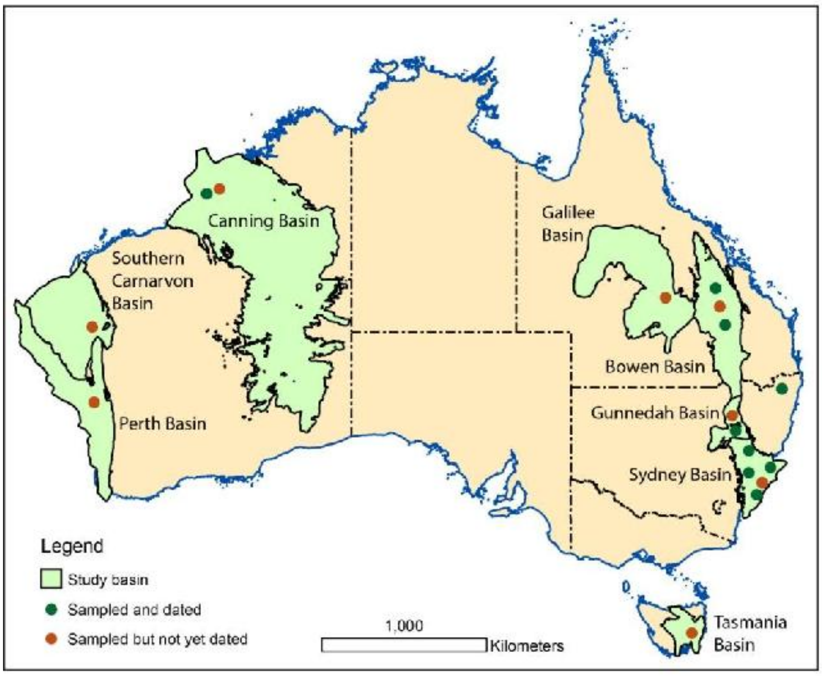


Figure 1: Map showing study sample locations

Figure 2: Chronostratigraphic levels of sampled study material

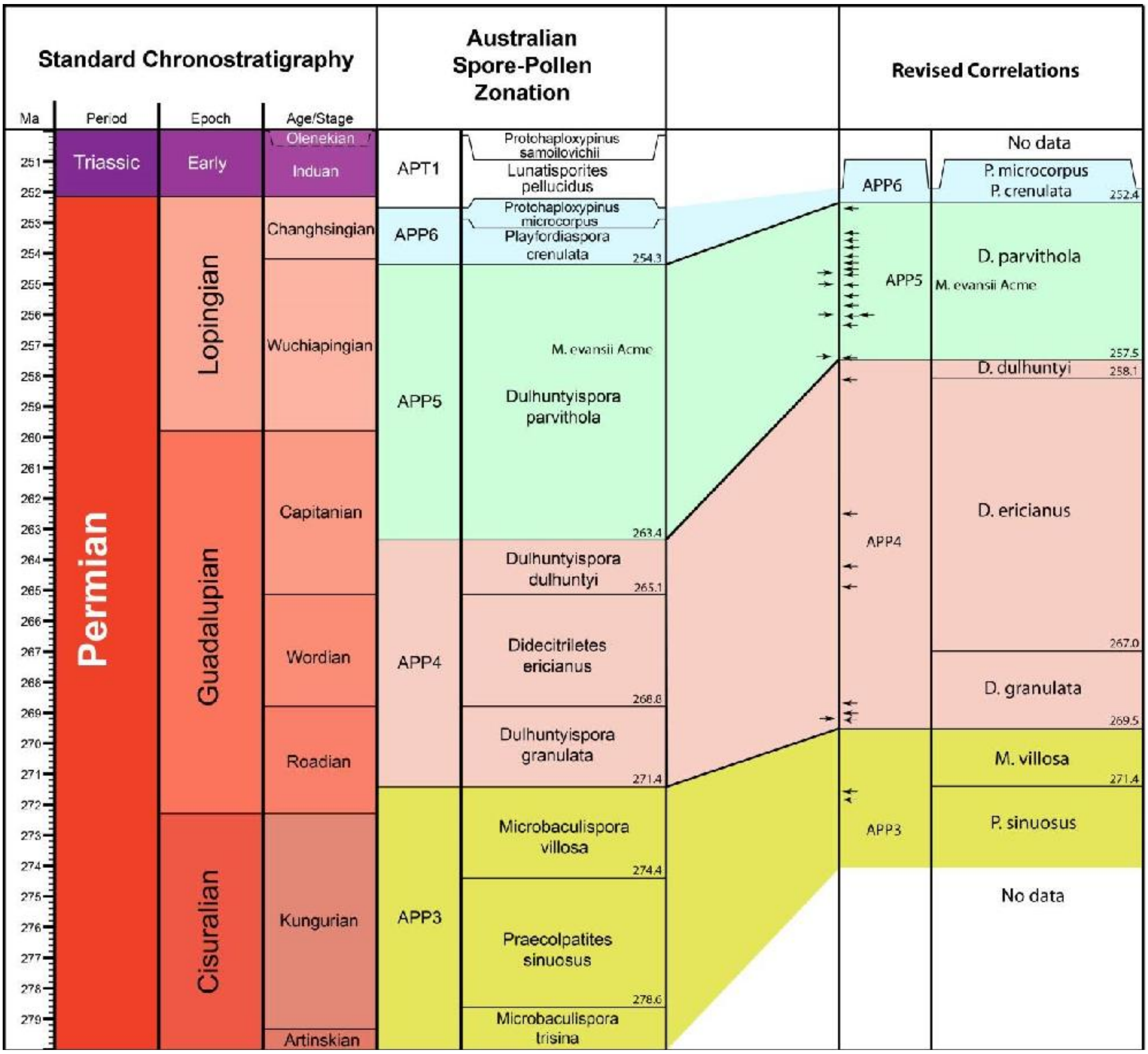


Figure 3. Revisions to calibration of part of the Permian palynostratigraphic scheme of Price (1997). To the left is the Permian timescale of Henderson *et al.* (2012); in the middle is the calibration of the palynostratigraphy by Mantle *et al.* (2010) and to the right is the new calibration based on CA-IDTIMS dates obtained in this study. Arrows along the left margin of this column represent individual CA-IDTIMS dates.

01SBC-02. REVISING STRATIGRAPHIC CORRELATIONS IN THE SYDNEY-GUNNEDAH BASIN – DOES RECENT TUFF BED GEOCHRONOLOGICAL DATA JUSTIFY IT?

Kevin Ruming[1], Erin Holmes[1], Malcolm Bocking[2], Jim Crowley[3], Robert Nicoll[4], Roger Cameron[5], Malcolm Ives[6], Mel Wilkinson[7] & Sonja Zink[8]

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Approximately 373 samples have been collected for high precision U–Pb Chemical Abrasion Isotope Dilution Thermal Ionisation Mass Spectrometry (CA-IDTIMS) age analysis throughout the Sydney-Gunnedah Basin. The age dates are obtained by analysing Pb–U ratios of zircon grains extracted from tuff samples collected from core and outcrop.

Samples have been collected from throughout the basins and in all the major stratigraphic units from the Triassic to early Permian. Over 80 samples have been analysed and approximately another 100 are in progress.

Stratigraphic correlations and terminology have been long established and debated for the basin. The latest revisions were ratified by the Coalfield Geology Council in 1999. These new data provide the opportunity to review existing correlations within and between the different coalfields.

Relationships between the stratigraphic units throughout the basin and across the coalfields are best illustrated using a 3D 'fence' diagram. A revised fence diagram, incorporating these new age determinations, shows that the majority of the previous correlations are supported by the new data. The new data also show that some previous correlations are incorrect. The new dates also allow us to apply a rigorous time framework to depositional rates in coal beds and associated clastic sediments.

Analysis of these new data will require making clear distinctions between chronostratigraphic and lithostratigraphic units. The tuff layers can be considered geologically instantaneous, whereas the basin-wide regressive–transgressive episodes may have spanned timeframes of sufficient magnitude that some of the tuff layers (chronostratigraphic units) cut across some of the lithostratigraphic units. These new data warrant additional discussion and possible revision of the currently accepted stratigraphic correlations and terminology of the Sydney-Gunnedah Basin.

01SBC-03. PERMIAN STRATIGRAPHY AND TUFF BED GEOCHRONOLOGY OF THE SOUTHERN SYDNEY BASIN

Erin Holmes[1], Magda Husykens[2], Sonja Zink[2], Robert Nicoll[3], John Laurie[3] & Jim Crowley[4]

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Approximately 15 high precision U–Pb CA-IDTIMS dates have been obtained from various stratigraphic units of the Southern Coalfield of the Sydney Basin. Dated samples have been collected from various geographic locations, covering a range of stratigraphic units from Triassic Narrabeen Group units through to Permian Shoalhaven Group units. The dates range between approximately 247 and 264 Ma.

The stratigraphy and terminology of the Southern Coalfield has long been established, with the last revision ratified by the Coalfield Geology Council in 1999. The new CA-IDTIMS dates allow a chronologic revision of the Southern Coalfield stratigraphy, and also provide preliminary definitions of depositional rates for the sedimentary sequences. The dates furthermore have allowed preliminary correlations between particular Southern Coalfield units and similar aged units of the Western, Hunter and Newcastle Coalfields.

Some of the most significant findings are reflected in the dates of the upper units of the Sydney Subgroup and the lower Narrabeen Group. It is proposed that the top of the Permian is in fact stratigraphically higher than previously thought, and as a result it is proposed that the stratigraphy of the Sydney Subgroup and the Narrabeen Group need to be redefined.

01SBC-04. FROM WHENCE COMETH THE RAIN: SOURCE OF THE MIDDLE TO LATE PERMIAN ASHFALL TUFFS OF THE SYDNEY AND GUNNEDAH BASINS

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The late Permian Wandsworth Volcanic Group (WVG) in the southern New England Orogen (SNEO) is dominated by a monotonous series of amalgamated rhyodacitic to felsic eruptive facies, with minor interbedded flows, intrusions and sedimentary rocks. The area enclosing known exposures of the WVG covers more than 30 000 km^2, with a minimum thickness of 2 km. The top of the succession, as well as the vast majority of the pile representing non-welded material, has not been preserved. Field relationships indicate a broadly contemporaneous (though not necessarily genetic) relationship with late Permian granite magmatism, while Triassic plutons (typically in the range 246–243 Ma) intrude the WVG. SHRIMP U–Pb zircon dating indicates ages around 256.4 ± 1.6 Ma for basal units of the WVG, and 254.1 ± 2.2 Ma for the youngest preserved member of the WVG (Dundee Rhyodacite), defining a short period of substantial intermediate to acid eruptive volcanism. The compositionally primitive Drake Volcanics to the northeast is older (264.4 ± 2.5 Ma) and at Halls Peak is older still (early Permian). Granites of the I-type Moonbi Supersuite and Uralla Supersuite are dominantly 256–251 Ma, and thus overlap in timing (and space) with the WVG event. Interestingly, many mineralised leucogranites (e.g. Parlour Mountain, Oban River, Gilgai), which were formerly regarded as Triassic, are now established as synchronous with the Moonbi and Uralla supersuites and the WVG. The age range of eruption of the WVG permitted by the SHRIMP results (*ca* 6 Ma) has been further constrained by CA-ID-TIMS U–Pb zircon analysis, which yielded oldest and youngest ages of 255.54 ± 0.16 Ma and 253.26 ± 0.15 Ma respectively, indicating a maximum eruptive time range of *ca* 2 Ma for the preserved pile. Our new results coincide with those determined from CA-ID-TIMS dating of tuffs in the Sydney Basin and Gunnedah Basin. WVG exposures at Attunga are exactly (within *ca* 0.1 Ma) coincident with the age of tuffs within the Trinkey Formation located in the Gunnedah Basin to the west. The Dundee Rhyodacite is similarly closely matched to the thick Awaba Tuff in the Sydney Basin. Notably, much of the late Permian volcanic and plutonic magmatism in the

SNEO is restricted to a remarkably small time range, which coincides exactly with the range of ash fall events in the Sydney and Gunnedah basins, and possibly further afield. This suggests that the SNEO, and the WVG in particular, was the dominant source of volcanic material erupted into these adjacent basins. Furthermore, the adjacent basins may provide a more complete record of Permo-Triassic magmatism in the SNEO than currently preserved within the orogen itself.

01SBD - 39TH SYMPOSIUM ON THE ADVANCES IN THE STUDY OF THE SYDNEY BASIN

01SBD-01. PHYSICAL VOLCANOLOGY AND XENOLITH PETROLOGY OF A DYKE INTRUDING THE GERRINGONG VOLCANICS, SOUTHERN SYDNEY BASIN: ASSOCIATED WITH PROXIMAL MID PERMIAN VOLCANOES

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The mid Permian Gerringong Volcanics (GV), southern Sydney Basin, outcrop along the coast between the Shoalhaven River in the south and Wollongong in the north. A series of mafic extrusions are interbedded with fossiliferous volcaniclastic shallow marine sediments. Numerous mafic dykes along the coast, which intrude both the sedimentary and igneous rocks, have been reported as being generally Jurassic to Cenozoic in age.

This research describes the physical volcanology of a mafic dyke and petrology of xenoliths found within, intruding the Westley Park Sandstone Member of the GV, on a coastal rock platform near Gerringong. Cylindrical flow structures, or lobes, within the dyke have incorporated the surrounding wet, soft, unconsolidated sediments during intrusion. Other syndepositional features include contact metamorphism and pepperite formation at the contact.

The dyke contains abundant (in places, up to 50 volume% of the dyke) metasedimentary xenoliths, largely confined to the centre of a few lobes at one end, and rare K-feldspar megacrysts. Quartz-rich metasedimentary xenoliths (rarely >95% quartz) predominate (GB1), followed by quartzo-feldspathic metasedimentary xenoliths (GB2). These xenoliths have a pronounced equigranular-texture, are largely massive and vary from fine to medium grained. Rare fine-grained metasedimentary xenoliths have pronounced relict fine laminations.

Quantitative X-ray diffraction analysis revealed that GB1 contains quartz (35%), albite (40%) and K-feldspar (25%) while GB2 contains quartz (27%), albite (30%), K-feldspar (33%), chlorite (8%) and diopside (2%). This is also shown by the major element chemistry through semi-quantitative XRF with GB2 containing more iron, potassium, and calcium compared to GB1. Some of the xenoliths also contain rare disseminated pyrite. In terms of trace element chemistry, both metasedimentary types are similar in Rb (104, 118), Sr (529, 521), and Ba (971, 1174) but differ in Zr (110, 374), Nb (4, 21), Cr (bdl, 19) and Ni (bdl, 46). These differences most likely reflect differing abundances of detrital grains of zircon, spinels and ferromagnesium phases.

The host basaltic dyke largely comprises chamosite, Ca-plagioclase, K-feldspar and clinopyroxene. This would reflect an initial primary mineralogy of olivine, anorthite, sanidine, and clinopyroxene, akin to the primary shoshonitic assemblage ascribed to the upper Permian volcanics of the southern Sydney Basin.

There is a complete lack of any reaction rims between the quartz-rich metasedimentary xenoliths and host shoshonitic basalt, suggesting derivation of the xenoliths from shallow depths. At this stage, the metasedimentary xenoliths may represent contact metamorphosed pebbly sandstones and siltstones of the immediately underlying units, possibly the quartz rich Snapper Point or Nowra sandstones.

At least four intrusions along the coast have been located that exhibit classic features associated with syndepositional sediment intrusion. This includes magma/sediment mixing at the contact, with pepperite, metamorphosed sediments at the contact, pillows, or small flow tubes and sediment liquefaction and slumping. Numerous others have also caused sediment slumping adjacent to the intrusions.

Evidence suggests that the sources for these intrusions were Permian volcanoes situated off the present-day coastline, associated with subduction and stress related foreland loading from the Currarong Orogen to the east, the southeasterly extension of the New England Orogen.

01SBD-02. RECALIBRATING THE PERMIAN PALYNOSTRATIGRAPHIC SCHEME VIA U–PB ZIRCON CA-IDTIMS DATING OF TUFFS IN EASTERN AUSTRALIAN BASINS

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Accurately recording a sequence of geological events requires precise determination of their relative ages, but understanding their duration or temporal separation of these events, requires accurate determination of their numerical ages. Accurately determining the numerical age of every lithological unit is still only a dream, but it is much closer than it was when the reality of radioisotopic dating dawned on the broader geological community just over a century ago with the publication of the overview by Holmes (1913). Here we report on the application of one of the more recently developed techniques: Chemical Abrasion-Isotope Dilution Thermal Ionisation Mass Spectrometry (CA-IDTIMS). This technique (Mattinson 2005) utilises the U–Pb system in zircon, and features sample preparation procedures that dissolve and leach zircon domains affected by isotopic leakage ('chemical abrasion'). Zircon that survives this process tends to preserve U–Pb systems unaffected by post-crystallisation disturbance, which results in a high degree of isotopic uniformity in rocks characterised by a simple magmatic crystallisation history. The technique is capable of delivering considerably more precise dates than has hitherto been possible, with 95% confidence intervals of the order of 0.1–0.2% routinely achieved on cogenetic populations of magmatic zircons.

Basins studied

Because this project derived from an investigation into the Permian–Triassic boundary in tuff-rich sequences in China, the natural progression was to examine a similar interval on this continent, where tuffs were known to exist in large numbers. The three eastern Australian coal basins (Sydney, Gunnedah and Bowen) were therefore the main focus. However, an opportunity to analyse samples from the Canning Basin was also taken. The Newcastle Coal Measures in the Lopingian of the Sydney Basin can be used as an example to illustrate the large number of tuff beds in these eastern Australian basin successions. It is a Lopingian group-level unit about 450 m thick, is divided into eight formations and contains over 140 recorded tuff beds. Of these, three are relatively thick (up to 30 m) and are formations in their own right. These are the Awaba, Warners Bay and Nobbys tuffs.

Previous dating

Previous U–Pb zircon dating of the Permian sequences of Australia has utilised the Sensitive High Resolution Ion Micro Probe (SHRIMP) (Roberts *et al.* 1995, 1996, 2006) or Thermal Ionisation Mass Spectrometry (TIMS) (Gulson *et al.* 1990). The early SHRIMP dates indicated some problems with the precision of the technique when ages obtained were compared with established dates from other methods. For example, a SHRIMP date of 250.1 ± 2.8 Ma (all dates quoted are ^{206}Pb/^{238}U, with uncertainties at the 95% confidence level) for a tuff in the Black Alley Shale in the Bowen Basin indicated an earliest Triassic age for this unit and overlying *Glossopteris*-bearing coal measures (Roberts *et al.* 1996). This date is anomalous, however, considering that Early Triassic palynofloras first appear stratigraphically hundreds of metres above (Foster *et al.* 1997, 1998) and *Glossopteris* is known elsewhere only from rocks of Permian age. CA-IDTIMS data on single zircons from a volcanic ash layer underlying the Rewan Formation (Bowen Basin) yield a robust age of 252.2 ± 0.4 Ma (Mundil *et al.* 2006), indicating that the base of the Rewan Formation correlates with the P–T boundary interval in southern China (Shen *et al.* 2012; Burgess *et al.* 2014). This correlation is consistent with palynostratigraphic data (Foster 1982). However, it should be noted that this CA-IDTIMS date and its 95% confidence interval lie entirely within the 95% confidence interval of the SHRIMP date; a factor which should be taken into account when interpreting these dates.

The SHRIMP dates presented by Roberts *et al.* (1995, 1996) were calibrated using the reference zircon SL13, which is now known to be affected by heterogeneity in ^{206}Pb/^{238}U (Compston 1999). This, in combination with possible problems related to minor but undiagnosed loss of radiogenic Pb from both reference and sample zircons, and even potential matrix effects on the measured Pb/U, raised fears that the accuracy of Phanerozoic SHRIMP dates might be limited to about ± 2% (Black & Jagodzinski 2003). Subsequent use of carefully characterised reference zircons that are homogeneous in ^{206}Pb/^{238}U (such as TEMORA: Black *et al.* 2003, 2004) has since demonstrated that Paleozoic SHRIMP ^{206}Pb/^{238}U dates with uncertainties of ± 1% at the 95% confidence interval are usually within experimental error of CA-IDTIMS dates from the same rock (e.g. Bodorkos *et al.* 2012). Age resolution of 1% is not sufficient to distinguish between the numerous ashfall tuffs in the eastern Australian Permo-Triassic; however, some of the zircon populations selected for CA-IDTIMS analysis were first mounted, imaged using cathodoluminescence, and then analysed by SHRIMP. The images and isotopic data assisted in identifying any SHRIMP-resolvable inherited components (Bodorkos *et al.* 2012), thereby refining targeting of the CA-IDTIMS analyses.

Correlation to the timescale

The Permian portion of the International Geological Time Scale (Henderson *et al.* 2012; see Figure 1) has marine fossil zonations as its prime correlative tools. These comprise conodont, fusulinid and benthic foraminiferal, and ammonoid zonations. Each of the nine stages of the Permian time scale has, or will have, its base defined by a Global Stratotype Section and Point (GSSP). All of these are located in the northern hemisphere (USA, China, Russia or Kazakhstan), and were at low latitudes at the time of deposition. Because all of these Permian stage subdivisions were defined in marine successions and the Australian Permian was in high latitudes and largely non-marine, Permian successions in this continent are difficult to correlate globally. The most effective technique for correlating the mostly non-marine Permian–Triassic successions in eastern Australia is the spore-pollen zonation erected by Price (1997), which has been time-calibrated by Mantle *et al.* (2010; see Figure 1). However, this palynostratigraphic zonation is fairly broad — only 13 zones span the entire Permian — and correlating this zonation to the global geological timescale has proven difficult at best. The reasons for this are twofold. Firstly, conodonts and fusulinids have never been found in the eastern Australian successions, and ammonoids are very rare. Conodont faunas recovered from the Tethyan margin of Western Australia are scarce and mostly endemic (Nicoll & Metcalfe 1998). Secondly, the high latitude flora of the Permian and Triassic was largely endemic to the circumpolar Gondwanan continents, so precise correlation to the northern hemisphere is almost impossible.

Leonova (1998) attempted a broad, stage-based correlation of the Sakmarian to Roadian interval between Australia and Russia, based on the presence of ammonoid genera recorded from the Permian of Australia, most of which are from Western Australia. In their overview of the 'anchor points' for the Permian in Australia, Foster & Archbold (2001) reviewed and summarised the evidence for international correlation. They noted that palynomorphs are "the most widely used groups for local correlation within and between…basins" (Foster & Archbold 2001, p. 179), but that the macrofauna which have traditionally provided ties to the international scale are scarce or absent. Even correlation of the macrofauna between western and eastern Australia is hampered by substantial provincialism, because the western Australian margin opened onto the relatively warm Meso-Tethys Ocean and the eastern margin onto the high latitude cold water southern Panthalassic Ocean. Thus, correlation of palynozones defined in eastern Australia to the global timescale is based on extremely limited evidence. Below, we summarise new U–Pb zircon CA-IDTIMS data obtained from tuff layers with palynological control, and evaluate our results in terms of the numerical age constraints placed on the Australian palynostratigraphic zonation of the second half of the Permian. The preliminary CA-IDTIMS dates quoted below have been rounded, pending assessment of the systematic uncertainties prior to formal publication, but the 95% confidence intervals are generally less than 0.4 Ma.

Praecolpatites sinuosus **Zone (APP3.2):** One tuff sample from Muswellbrook Coal Sandy Creek DDH 32 from within the *P. sinuosus* Zone produced a CA-IDTIMS date of 271.6 Ma. Roberts *et al.* (1996) obtained a SHRIMP date of 268.9 ± 2.0 from a nearby outcrop sample (Z1842), and re-analysis of selected SHRIMPed grains using CA-IDTIMS yielded a date of at 271.9 Ma. Chris Knight (Muswellbrook Coal, pers. comm. 27 March 2014) maintains there is only one tuff bed in this part of the section, and thus that sample Z1842 and our sample from Sandy Creek DDH 32 are from the same stratigraphic level. The age of the base of the *P. sinuosus* Zone remains to be determined.

Microbaculispora villosa **Zone (APP3.3):** The *M. villosa* Zone has not been dated directly by CA-IDTIMS, but the zones above and below have been. Roberts *et al.* (1996, p. 412) obtained a SHRIMP date of 272.2 ± 3.2 Ma from a sample (Z2015) obtained probably from the *M. villosa* Zone. There is no associated palynology, so this zonal assessment is based on a probable correlation. The sample is awaiting analysis by CA-IDTIMS. In our interpretation, the base of the *M. villosa* Zone is probably slightly younger than the dates obtained from the *P. sinuosus* Zone and is placed at about 271.4 Ma (see Figure 1), which is considerably younger than the previous calibration of 274.4 Ma (Mantle *et al.* 2010).

Dulhuntyispora granulata **Zone (APP4.1):** No CA-IDTIMS dates have been obtained from the *D. granulata* Zone in eastern Australia, but four dates ranging from 268.8 Ma to 269.3 Ma have been obtained from tuffs in core from the Lightjack Formation in the Canning Basin of Western Australia. Palynological samples were assessed from the same core and all samples lie within the *D. granulata* Zone. We therefore tentatively place the base of the *D. granulata* Zone at about 269.5 Ma (see Figure 1), a little over two million years younger than the calibration of Mantle *et al.* (2010).

Didecitriletes ericianus **Zone (APP4.2):** A sample obtained from a well near the boundary between the Sydney and Gunnedah basins (Brawboy 1) and lying within the *D. ericianus* Zone (Wood & Gallagher 2012) gave a CA-IDTIMS date of 262.5 Ma. Another three samples from other wells in the Gunnedah and northern Sydney basins, and all within the *D. ericianus* Zone, gave CA-IDTIMS dates of 258.1 Ma, 264.1 Ma and 264.9 Ma. These results indicate that the *D. ericianus* Zone is quite long, with its base tentatively placed at 267.0 Ma, about half way between the lowermost *D. ericianus* Zone date and the uppermost *D. granulata* Zone date (see Figure 1).

Dulhuntyispora dulhuntyi **Zone (APP4.3):** No tuff beds from within this zone have been dated. However, based on the youngest dates associated with the underlying *D. ericianus* Zone (258.1 Ma) and the oldest dates of the overlying

D. parvithola Zone (257.4 Ma), the *D. dulhuntyi* Zone comprises only a short interval, with its base probably at about 258.0 Ma (see Figure 1).

Dulhuntyispora parvithola **Zone (APP5):** About 20 samples belonging to the *D. parvithola* Zone have been obtained from the Bowen, Gunnedah and Sydney basins and the CA-IDTIMS dates range from 257.4 Ma up to 252.5 Ma. Based on these dates, the base of the *D. parvithola* Zone is assigned an age of about 257.5 Ma (see Figure 1). This is almost six million years younger than the calibration of Mantle *et al.* (2010). Wood & Gallagher (2012) have also determined the position of the *Micrhystridium evansii* Acme in the well Brawboy 1. The nearest CA-IDTIMS date (255.7 Ma) obtained from this well is from about 19 m below *M. evansii*. The *M. evansii* Acme is therefore suggested to lie at about 255 Ma (see Figure 1). This confirms the conclusions independently drawn by Smith & Mantle (2013) on the age of the *M. evansii* Acme based on bracketing CA-IDTIMS and palynological data obtained from the well Meeleebee 5 in the Bowen Basin.

Playfordiaspora crenulata **Zone (lower APP6):** No tuffs within this zone have been dated but dates obtained from the underlying *D. parvithola* Zone clearly indicate that the previous calibration of this zone (Mantle *et al.* 2010) requires revision. Mantle *et al.* (2010) specified a date of about 254.3 Ma for the base of this zone, whereas the youngest sample from the underlying *D. parvithola* Zone has a date of 252.5 Ma. As a consequence, a date of about 252.4 Ma seems more likely for the base of this zone (see Figure 1).

Conclusion

This study demonstrates the utility of high precision CA-IDTIMS in refining the correlation of endemic biostratigraphic schemes to the international timescale. In turn, this will have a major impact on the correlation within and between basins. This technique of calibrating palynozones to the timescale using CA-IDTIMS can be extended throughout the non-marine successions from the Devonian to the Cenozoic in the eastern half of Australia, as these successions are mostly correlated using palynostratigraphy and they are replete with tuff beds. To recalibrate this entire palynostratigraphic scheme will be the most significant advance in Phanerozoic palynostratigraphy since this scheme was erected.

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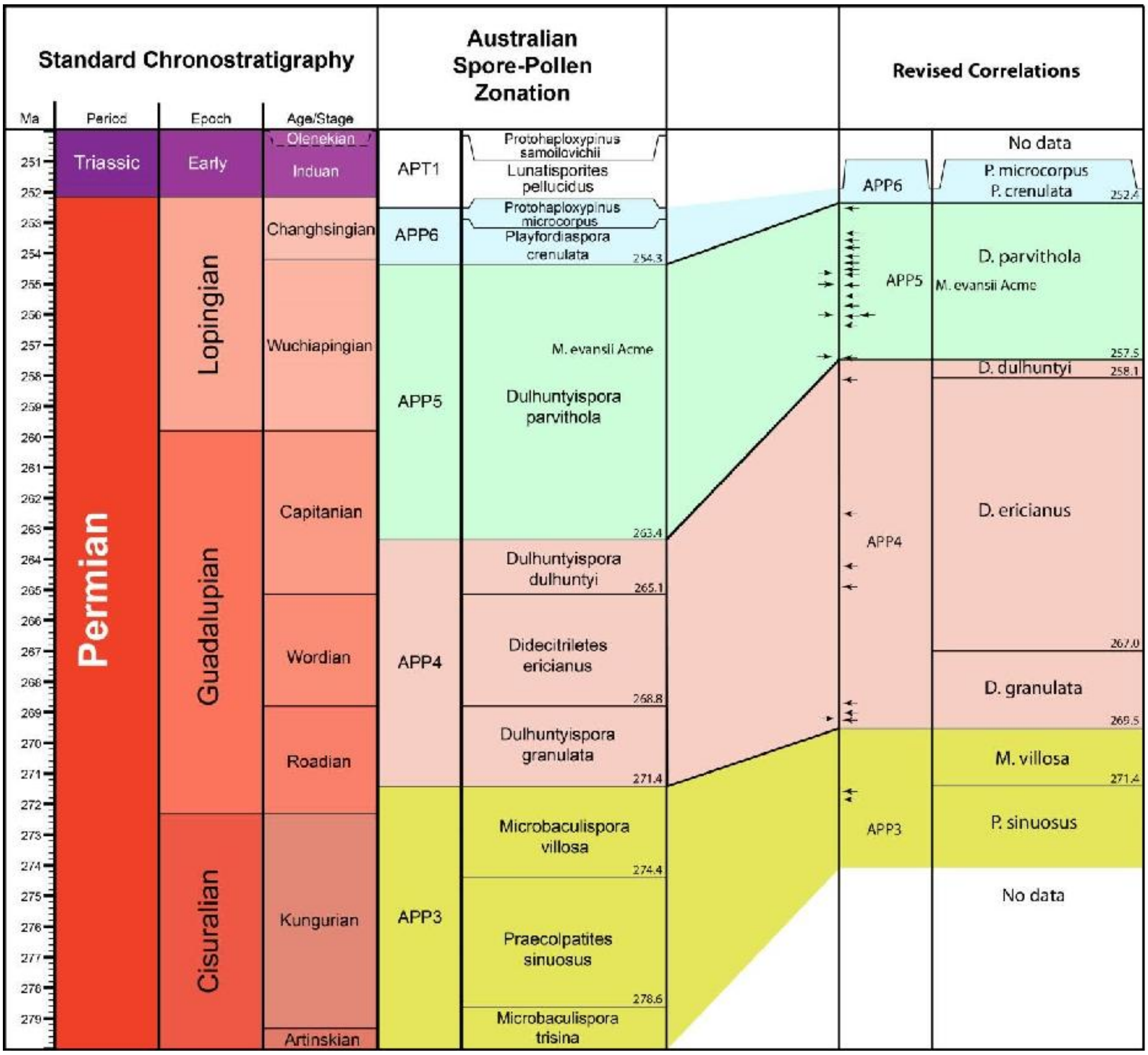

Figure 1. Figure showing revisions to calibration of part of the Permian palynostratigraphic scheme of Price (1997). To the left is the Permian timescale of Henderson *et al.* (2012); in the middle is the calibration of the palynostratigraphy by Mantle *et al.* (2010) and to the right is the new calibration based on CA IDTIMS dates obtained in this study. Arrows along the left margin of this column represent individual CA-IDTIMS dates.

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01SBD-03. AGE OF THE YARRABEE TUFF MEMBER AND ITS SIGNIFICANCE TOWARDS REGIONAL STRATIGRAPHY OF THE FORT COOPER COAL MEASURES

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The late Permian Fort Cooper and equivalent Coal Measures in the Bowen Basin host abundant tuffaceous horizons, one of which is the “Yarrabee Tuff Member”, which represents a series of discrete but closely spaced eruptive events. Commonly only one of these tuffs is tracked as a regional time marker, but this laterally consistent series of tuffaceous beds is used throughout the basin to distinguish the overlying Rangal (and equivalent) Coal Measures from the underlying Fort Cooper Coal Measures.

Seven hundred open file and proprietary wells were used to develop a regionally consistent stratigraphy across the basin. Samples of the Yarrabee tuffs from four different locations were collected and dated to verify the stratigraphic correlations and test the variability in age for this marker horizon. The U–Pb CA-IDTIMS zircon technique was used and has a precision of ± 0.05%. Early preliminary dates cover a range from 252.68 ± 0.20 to 253.22 ± 0.13 Ma. Variation has also been observed in previous dates of the Yarrabee Tuff, e.g. 252.49 ± 0.06 Ma from Yebna 1 well[1] and 252.54 ± 0.04 Ma from Meeleebee 5 well[2].

Variability in age dates of previous and current studies range from 0.05 my to 0.5 my, which is greater than the precision level of the dating technique. Such a wide variation within different parts of the Bowen Basin suggests either multiple eruptions of varying size from a volcanic arc or group of volcanoes, frequently erupting for a span of hundreds and thousands of years forming an incremental suite of sequential tuff layers constrained by a set of isochronous surfaces rather than a isochron. This may correlate with the massive volcanic eruptions interpreted to have occurred during the end of Permian time lasting for about less than 0.5 my. Volcaniclastics of such kind may assist in providing a high-resolution geochronology of the sequence and also help in unravelling the tectonic processes and impacts on sedimentation rates for peat and siliciclastics during Fort Cooper time.

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01SBD-04. DATING OF SHALLOW BRITTLE FAULTS WITHIN THE SYDNEY BASIN – NEW CONSTRAINTS ON THE BREAK UP OF GONDWANA

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Neotectonic brittle faults are associated with near-surface deformation. Displacement on the fault planes produces fault gouge composed of rock fragments and authigenic illite. Numerous studies have demonstrated that the absolute timing of brittle fault history can be determined using isotopic dating techniques of illite clay minerals. The understanding of the timing of clay-rich fault gouge formation is important for: (1) hydrocarbon exploration because faults may act as either a conduit or a seal for fluids and/or hydrocarbons; (2) civil engineering in the evaluation of earthquake hazards; and (3) ascertaining the suitability for waste storage. Several construction sites within the Sydney area and a cliff face and open cut in the Newcastle area, have enabled fresh exposures of brittle fault zones thus avoiding problems associated with surface weathering and contamination.

K–Ar data of authigenic illite from N–S, NNE and E–W trending faults within the Sydney Basin containing well-developed gouge will be presented. Results obtained from gouges are commonly difficult to interpret as clay minerals of detrital and/or authigenic origin, and detrital micas, can be present within the host rocks. Most of the investigated clay gouges comprise illite/smectite and kaolinite with distinct morphologies suggesting an *in-situ* authigenic origin. Four main groups of illite ages were obtained, namely: (1) ages from 272 to 281 Ma, that are older than most of the host sediments and interpreted to be of detrital origin; (2) ages from 235 to 245 Ma, which are believed to represent an early diagenetic overprint related to burial; (3) ages from 120 to 150 Ma that date brittle faulting, related to the break up of Gondwana and that occurred prior to the opening of the Tasman Sea; and (4) ages of *ca* 110 Ma in gouge and associated host rock in the Sydney area and West side open cut, south of Newcastle that record a distinct thermal overprinting event. The thermal event is interpreted to be related to the break-up of Gondwana and associated volcanism during the early Cretaceous.

The illite age data provide new insights into the timing of low temperature brittle deformation events in the Sydney Basin and thermal events associated with the rifting of eastern Gondwana in the Cretaceous. They provide absolute time constraints on the younger, neotectonic movements in eastern Australia.

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02SBA-01. SMALL FAULT IDENTIFICATION THROUGH SEISMIC DIFFRACTION IMAGING

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Faults are one of the most important geological structures that need to be delineated before any underground coal mining operation can commence. Even an unexpected small fault with a throw of a few metres can create safety issues and lead to costly delays in production. While seismic surveys are quite successful at locating faults with throws greater than 5–10 m, reliable techniques for resolving more subtle faults, shears and other minor features are yet to be developed.

There are two types of seismic energies that can be used for subsurface imaging: specular reflections and diffractions. Specular reflections are created by smooth surfaces between layers of differing impedance contrast such as at coal-rock interfaces. Specular reflections are used in conventional seismic reflection surveys. Diffractions can occur at local discontinuities between layers caused by faults, pinch-outs and fractures. Diffractions can therefore be used for fault identification but they are often ignored or suppressed by modern high fold reflection surveying and by data processing procedures such as stacking and migration. In the past, diffraction patterns on low fold reflection sections were sought by seismic interpreters as an indication of small faults where the discontinuities of the seismic reflections are less evident. In recent years, the interest in diffraction imaging has rekindled and imaging techniques have been developed for petroleum seismic data processing, which makes small fault detection possible through diffraction imaging as well as by conventional seismic reflection mapping.

In this paper, we demonstrate that diffractions can be separated from reflection seismic data through f–k or moving average filtering of the NMO-corrected common-offset and shot gathers. The extracted diffractions can be used to identify small faults that are difficult to detect using conventional seismic reflection processing. Numerical examples illustrate that the extracted diffractions can be used to identify faults with a throw of 1m, even in a moderately noisy environment, and when the migration velocities are not accurate. In addition, there is an opportunity to extract the diffraction signals from existing final stacked seismic sections without the need for extensive reprocessing. The feasibility to extract diffractions from post-stacked seismic sections is tested by both numerical and real data examples.

02SBA-02. INTEGRATED ANALYSIS AND MODELLING OF GEOPHYSICAL LOGS FROM COAL MEASURE STRATA

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Introduction

In coal mining, there are well established qualitative applications of geophysical logs such as picking tops and bottoms of coal seams from density logs, estimating UCS from sonic logs and identifying marker bands from natural gamma logs. However, there is less use of quantitative methods aimed at estimating rock properties, be it for geological purposes such as mapping sandstone and siltstone interburdens or for geotechnical applications aimed at determining rock quality via the Geophysical Strata Rating (GSR).

Successful quantitative analysis requires an understanding of the physical basis of the log measurements, their precision and the sources of noise that might be present. If measurements from different logs are to be combined, the resolution provided by each of the logs should be matched using appropriate filtering, resampling and choice of end points. Different processing parameters may be required when logs are being assessed for holes from separate drilling programs and where different logging tools with different calibration factors have been employed.

One of the great attractions for quantitative geophysical log analysis is that it allows interpolation of results between holes and the creation of 3D models of the subsurface. Done properly, powerful insights into the subsurface geology are provided. Core and chip logging are unlikely to deliver equivalent results.

Sample rate issues

While it is now common practice to acquire geophysical logs at 1 cm depth intervals, this does not provide measurements, which are uniquely representative of each point in the borehole and free from the influence from points nearby. In the case of sonic logging, the velocities are measured between receivers typically separated either by 20 cm or 1 foot, depending on the tool. The velocity that is obtained represents the velocity of the sonic wave (a seismic P-wave) over the interval between these receivers.

In the case of the radiometric logs (density, neutron and natural gamma), the measurements are reliant upon radiation caused by rock mass interactions with radiation from an artificial source, or from the decay of naturally occurring radioactive materials. In both cases, the nuclear processes that are occurring do not provide constant radiometric flux and there is a certain amount of randomness in the measurements. In the case of the density and neutron measurement, the distance between the source and the detectors might limit the vertical resolution to about 20 cm. For natural gamma measurements, natural gamma radiation might be received at the detector from a volume of material within a radius of about 30 cm. Because the total amount of radiation that is received also tends to be much lower than for the density and neutron measurements, natural gamma readings show more variability (are inherently more noisy).

So while the use of 1 cm spaced logging data may be useful for detecting coal seam margins, quantitative log analysis which is mainly directed towards determining properties of the clastic rocks beyond the coal does not require such densely sampled data. Pre-processing of logs by resampling them to 5 cm intervals will provide 4 measurements over a typical minimum detectable geological unit. Resampling also provides the opportunity for smoothing or filtering to be applied to improve data quality. The size of the geophysical data files that need to be manipulated is also reduced.

Porosity and clay content

Logging contractors often provide with the final borehole logging files, an interpretation of the porosity of the borehole strata. This involves a calculation, which is based on a simple rock model whereby the rock grains are assumed to be quartz with a density of 2.65 t/m^3, and any departures from the measured density are assumed to be due to fluid-filled pore spaces. A problem with this is that rocks containing grains that are lithic or are dominantly comprised of clay minerals, might have rock 'matrix' densities that are slightly greater than quartz (about 2.7 t/m^3). A better approach for porosity determination is to determine the matrix density from inspection of the density logs and to ensure that the calculated porosities are geologically plausible. This approach also allows variations in the calibration of different density tools to be accommodated.

For determination of the clay content, the usual calculation involves scaling natural gamma logs so that the maximum readings correspond to clay-rich materials and the minimum readings correspond to materials, which are deficient in clay (i.e. quartz rich). The main issue with this approach is that not all clay rich materials are emitters of natural gamma radiation. The main sources of natural gamma radiation are an isotope of potassium (^{40}K) and any uranium and thorium that might be present. Potassium is present in many clay minerals but kaolinite is a clay mineral that contains no potassium and is not detected by a natural gamma log. Similarly, sandstones that contain heavy minerals (rutile etc.) may include thorium and may be associated with anomalously high natural gamma readings.

Neutron logs provide an alternative approach to determining clay content. This is because neutron logs respond to the hydrogen that is present in the rocks. In clastic rocks, hydrogen is present in pore waters and in water bound within the clay minerals. If allowance is made for the water present in the pores via the porosity determinations from density logs, the amount of clay that is present can be inferred from neutron logs. It is often helpful to be able to calculate the clay content from both natural gamma and neutron logs.

Knowledge of the porosity and the clay content allows objective geological characterisation. For example, porous sandstone units can be identified as units with low clay contents and high porosities. In the case of claystones and siltstone, these both have high clay contents but the claystones have lower porosities. Gradational rock units can also be characterised. Correlation of units between holes is made easier.

Geophysical Strata Rating

Estimation of Uniaxial Compressive Strength (UCS) from sonic logs is practiced throughout Australia's coalfields. More recently, the GSR has been introduced as an empirical measure, which takes the sonic velocity, porosity and clay contents determined from the geophysical logs and provides a measure of rock quality on a scale of 10 to 100. The advantage of the GSR over sonic-based UCS estimations is that with the GSR, consideration is made of the geotechnical effects of variations in porosity and clay content, and the velocity measurements are corrected for the increase in velocity that occurs with depth.

The GSR, porosity and clay content are all objective measures of rock properties. Because they are obtained along the full length of a borehole, it is possible to interpolate them between boreholes to construct 2D and 3D models of the subsurface.

Modelling

Figure 1 shows an example of a section from a model of clay content based on the interpretation of natural gamma logs. This section is cut from a 3D model which has been flattened so that the top of the working coal seam is at 0 m elevation. To construct this model, the elevations of major coal seams and other key horizons were determined and then interpolated between boreholes. These interpolated horizons were then used to constrain the interpolation of the geophysical parameters between horizons. Through this process, variations in layer thickness could be accommodated. Figure 1 clearly shows how the data obtained from quantitative analyses of geophysical logs allows detailed stratigraphic information on the geological conditions at mine sites to be obtained.

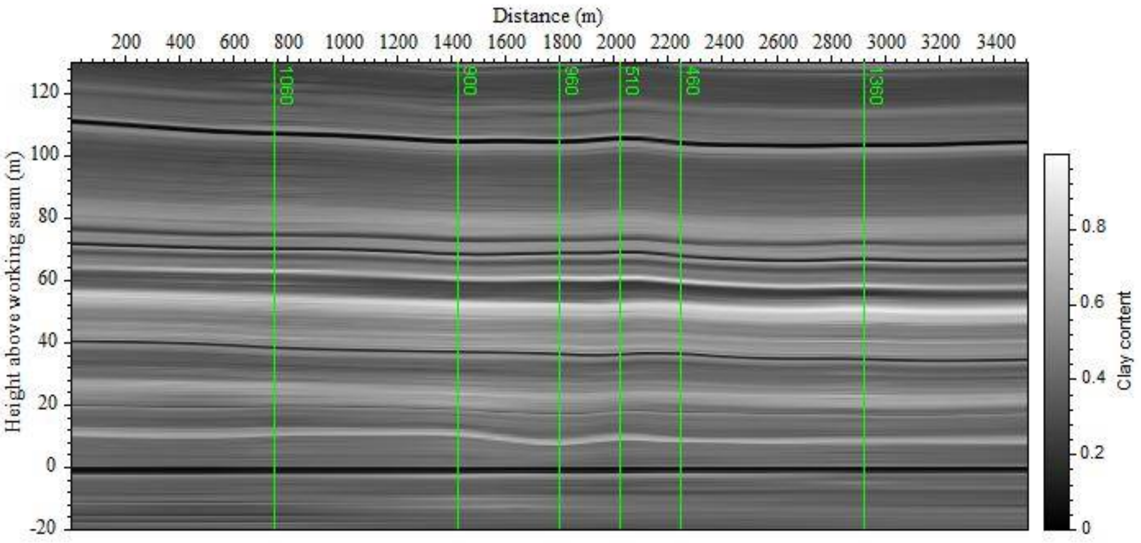

Figure 1. Vertical cross section through a 3D model based on the interpolation of clay content determined from natural gamma logs. Clay-rich bands have lighter colours and sandstones are grey. Coal seams are black.

Conclusion

This extended abstract briefly touches on how quantitative interpretation of geophysical logs can provide powerful understanding of geological conditions. Logs are routinely obtained in exploration boreholes but the geological and geotechnical benefits that the logs can provide are lost if their use is restricted solely to the determination of depths to coal seam margins. In undertaking quantitative log analysis, the physical basis of the logging measurements needs to be recognised. The logs should be resampled and filtered so that any noise in the data is reduced and the logs provide data at depth increments that match the reality of the measurements.

02SBA-03. MOVING WINDOW POWER SPECTRUM ANALYSIS OF POTENTIAL FIELD DATA : NEW TOOLS FOR IMAGING BASEMENT TOPOLOGY AND STRATIGRAPHY IN THE SYDNEY BASIN

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Spector & Grant (1974) published a novel, if not revolutionary, methodology to extract geological contacts (surfaces) from potential field (magnetics and gravity) images, utilising the radial power spectrum.

It has long been recognised that longer wavelength anomalies arise from deeper targets. By reducing the focus to tops of a continuum of equisized vertical prisms with unlimited depth extent, the method minimises many of the ambiguities inherent in potential field interpretation including target magnetisation/density contrast, location, strike and size. The target becomes an interface that is well suited to subhorizontal stratigraphic mapping in sedimentary basins.

Original applications in minerals exploration suffered sampling noise and computational shortcomings. The method has since been refined by others (Kivior & Boyd) to overcome noise limitations through window subsets, window size optimisation, and a moving window concept resulting in the more refined Moving Window Power Spectrum Analysis (MWPSA). Modern computing power readily available to geophysicists is also now up to the task.

The MWPSA method has been patented overseas by a major oil company. The company has embraced the method for mapping basin basement and suitable stratigraphy.

The concept is being developed by others including Geoscience Australia.

Preliminary work indicates up to 6 surfaces can be mapped in the Bowen Basin with the deepest surface at 1200 m depth.

This method could be applied throughout the Sydney Basin to existing magnetic and gravity datasets (airborne and ground) for both academic and commercial purposes. For example:

1) Using aeromagnetic data to map magnetic basement and strata with marked magnetic contrast (e.g. sills, tuffs).
2) Mapping the base of basalt flows
3) Using gravity data to map basement, faults and image coal seams.

Note that MWPSA processing is both computationally and labour intensive, and currently may cost more than the initial survey. That said, the results are still significantly lower cost compared to seismic and drilling.

There is potentially a niche application for gravity interpreted with MWPSA in environmentally sensitive and/or noisy areas such as exploring beneath urban areas where seismic, electrical and magnetic data cannot be readily acquired.

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02SBB-01. A GEOLOGICAL REVIEW OF THE COBBORA AREA, NSW

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The Cobbora exploration area is located on the western fringe of the Sydney-Gunnedah Basin in central NSW. Smaller reconnaissance style coal exploration programs were carried out in the 1970 to 1990's, but in the past 10 years two substantial exploration programs have defined the local geology and have resulted in some areas undergoing mine design.

The Cobbora area is defined as the southernmost part of the Gunnedah Basin. However, the local geology has been described using a mix of local and well-established descriptors from the nearby Western Coalfield, which is considered to be the northernmost area of the Sydney Basin.

A review has been carried out of the newly available exploration data to either reconfirm that the Cobbora area is part of the Gunnedah Basin or explore the possibility that it may instead be part of the Sydney Basin, or even a new sub-basin. The review aims to identify correlations and common naming conventions used within the Cobbora area against exploration areas in the southern Gunnedah Basin and the northern Sydney Basin. Key stratigraphic sequences have been identified and geophysical data are used to establish correlations.

02SBB-02. SEDIMENTARY AND COAL SEAM STRATIGRAPHY IN THE MAULES CREEK SUB-BASIN – AN UPDATE

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Early Permian geology of the Maules Creek Sub-basin comprises an early mafic (Werrie Basalt) and felsic (Boggabri Volcanics) volcanic episode with dominantly marine clastic sediments (Goonbri Formation). The early formations are overlain with a westerly grading para-dis-non conformable contact by late early Permian terrestrial sediments and coal seams (Maules Creek Formation).

The Goonbri Formation is now recognised to be a marine formation equivalent to the upper Dalwood Group in the Hunter Coalfield with thickness up to 50 metres in the east of the sub-basin. A 1 m thick pelletoidal claystone marks the boundary between the Goonbri Formation and the Greta Coal Measures in the Vickery area in the type bore VKY001C. The Goonbri Formation becomes coaly towards the northeast of the sub-basin.

The pelletoidal claystone of the Leard Formation is diachronous and is sourced from deeply weathered Boggabri Volcanics shed from paleotopographic highs to the west during periods of basin erosion (lowstands).

Recent exploration and mining in the Maules Creek Sub-Basin has allowed the five previous formal and informal coal seam naming conventions to be consolidated into the one stratigraphy. The new coal stratigraphy of the Maules Creek Sub-basin in decending order is: Herndale (2 splits), Onavale (3 splits), Teston (3 splits), Thornfield, Braymont (5 splits), Bollol Creek (New), Jeralong (3 splits), Merriown (3 splits), Velyama, Nagero, Northam (3 splits), Therebri (2 splits), Flixton, Tarrawonga (3 splits), Templemore (4 Splits), and Cranliegh (5 splits).

The Maules Creek and Leard formation names remain, as the predominant westerly source of sediment for these formations is not consistent with the northeasterly source for the Rowan and Skeletar formations of the Hunter Coalfield.

Reference

Thomson S. 1993. Leard–Maules Creek Alluvial/Lacustrine System. *In:* Tadros N.Z. ed The Gunnedah Basin, New South Wales, p. 169–195. Geological Survey of New South Wales, Memoir Geology 12.

02SBB-03. OVERVIEW OF GROUNDWATER RESPONSES TO LONGWALL COAL MINING IN THE SYDNEY BASIN, AUSTRALIA

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Longwall coal mining operations often depend on the hydraulic and geomechanical properties of the strata above the mined seam to limit environmental effects. The overburden strata in the constrained zone above longwalls plays an important role in controlling fracturing, depressurisation, change in hydraulic properties and therefore groundwater flow. A review of the current state of knowledge of these processes above longwall mines will be presented in this paper.

A number of detailed geotechnical studies have been undertaken to understand subsidence induced fracturing and its propagation above the seam. However, very few studies have addressed the change in hydraulic parameters that influence groundwater flow through the disturbed and undisturbed zone. Some studies have attempted to define the extent of the zone of fracturing, based on the responses at a number of operations worldwide and linking it to maximum surface tensile strains. These are mainly based on geotechnical understanding and changes in bulk hydraulic conductivity as this drives the increase in groundwater inflow into the underground workings. These studies mostly assume that the changes that occur are finite, however it has been shown that this is not the case, as the preferential pathways may change, the reduction in groundwater saturation can result in decrease in permeability and clays with swelling properties may result in reduction in fracture size or may completely close fractures. The observed pressure head reduction in the strata above the fractured zone may not necessarily be associated with water movement but rather with redistribution of stresses following the passage of the longwall.

Current groundwater modelling studies within the Sydney Basin generally assume at least one aquitard layer, which generally coincides with the geotechnical estimate of the height of the zone of fracturing. This layer serves to provide the limit to the vertical extent of longwall mining impact on groundwater. However, this layer may not hydraulically represent an aquitard, as its properties may be similar to the underlying and overlying strata. There are limited studies that characterise mineralogy and behaviour of these aquitard units and tracer techniques are rarely applied to study the degree of hydraulic disconnection or connection.

The groundwater response to longwall mining therefore requires a multidisciplinary approach including: geomechanics, hydrogeology and geochemistry. Although, generalisations can be made based on theory, or worldwide experience, this may not always be applicable to a specific site. This paper aims to present the current understanding of the depressurisation and the impact from underground mining on groundwater within the Sydney Basin by using examples from several underground operations and a wide monitoring network of multilevel piezometers. The paper also identifies the areas where knowledge gaps exist to better focus research directions.

02SBB-04. AN EVENT HORIZON IN THE SYDNEY BASIN: PASSAGE OF A FOREBULGE?

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The Sydney Basin is well exposed along the coastline of Sydney's eastern suburbs, where the Hawkesbury Sandstone comprises predominantly medium- to coarse-grained fluvial sandstones deposited as a set of stacked channels. However, a number of localities along the coast, from La Perouse to Manly (25 km), display an unusual succession of rocks over a 2–3 m interval, indicative of a change from the normal depositional regime of the Hawkesbury Sandstone. This succession includes: polymict pebble to boulder conglomerate with weathered, ferruginous shale clasts; beds with overturned cross bedding; metre-thick shale horizons that are commonly deformed into slump deposits with isoclinal folds and fluidised textures of sandy matrix; and thick overlying channel fill deposits of cross laminated medium- to coarse-grained sandstone with basal, rounded quartz pebble lags. The orientation of cross bedding commonly dramatically changes direction across this interval.

These features denote a change from a higher energy regime below (sandstone deposition in a developing basin), to a lower energy and even non-depositional regime (shale deposition, exhumation and peneplanation), and back to a higher energy regime (thick bedded, coarse-grained sandstone deposition) marked by a change in paleocurrent direction.

The changes across this compressed interval suggest a period when the basin was temporarily inverted and exposed to weathering and erosion (polymict pebble to boulder conglomerate on a peneplained surface), followed by renewed, rapid basin deepening (slump deposits, overturned cross bedding, thick overlying sandstone beds), with a change in the direction of paleocurrent flow. We interpret this succession to reflect the passage of a forebulge on the outer edge of the developing foreland basin (Sydney Basin) that developed in response to collision between the New England Orogen (NEO) and the Lachlan Orogen. Slumps and beds with overturned cross bedding are attributed to seismogenesis accompanying the passage of the forebulge, stemming, ultimately, from a period of increased orogenesis in the NEO.

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02SBC-01. CHANGES TO THE AUSTRALIAN COAL REPORTING GUIDELINES

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The 2003 edition of the Australian Guidelines for Reporting of Inventory Coal, Coal Resources and Coal Reserves (the Guidelines) originated in 1971 as the "Code for Calculating and Reporting Coal Reserves". Successive editions saw it advance to the point where in 1989 the JORC Committee recommended the adoption of the 1986 edition, called the "Code for Reporting of Identified Coal Resources and Reserves", as an appendix to the 1989 edition of the "Australasian Code for Reporting of Identified Mineral Resources and Ore Reserves".

Over time, revisions to each document have been published, with the 2012 edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC Code), suggesting that "for guidance on the estimation of Resources and Reserves in relation to coal deposits and for statutory reporting not primarily intended for the purposes of the investing public reference be made to the Guidelines or its successor documents".

The 2003 edition of the Guidelines continued to use suggested maximum distances around Points of Observation, within which Coal Resources could be classified as Measured, Indicated or Inferred. In recent years a groundswell of professional geologists began to question the application of these arbitrary limits, with no regard for other criteria.

Failing to recognise the geological complexity in a coal deposit results in inadequate representation of the risks in the Resource classification. This could potentially harm the operational viability of a mine and lead to poor investment decisions. During the last minerals boom investor risk was in some cases not properly addressed by Coal Resource reports issued under the direction of the Guidelines, with consequential damage to the reputation of the mining industry as an investment choice.

A reassessment of the application of the Guidelines was seen by many as needed when estimating and classifying Coal Resources. Only through greater confidence in the preparation of higher quality technical estimates and reports could confidence in the minerals industry at large be restored.

In 2012, the Coalfields Geology Council of NSW and the Queensland Resource Council, combined with a group of dedicated industry professionals, commenced a review of the 2003 edition of the Guidelines with the mandate to provide a better supporting document to the JORC Code. The review culminated in the publication of an exposure draft of the "Australian Guidelines for the Estimation and Classification of Coal Resources" in March of 2014.

Consideration of developing a best practice manual was assessed against a more generalist guideline when undertaking the review. Confidence in an estimation to then assist in the classification of Resources is now prescribed through assessment by a number of methods such as evaluation of the local geological conditions, data analysis through verification, statistical and geostatistical methods, geological modelling and identifying critical data.

This paper details the changes to the Guidelines and the challenges faced by the review committee in undertaking the review. The new guidelines provide an opportunity for technical professionals working with coal deposits to provide more assurance and confidence to the investing public through undertaking more appropriate studies that provide a more rigorous assessment and classification of Coal Resource risk.

02SBC-02. RESOURCE CLASSIFICATION IN COAL: IT'S TIME TO STOP GOING AROUND IN CIRCLES

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Since 1961 the Australian Coal Guidelines (under a variety of titles) has recommended the use of distances between boreholes for resource classification in coal. In each edition of the Guidelines, the maximum recommended distance between boreholes has been specified for each level of confidence in resource classification.

In this presentation, four geostatistics based methods of resource classification were applied to a dataset in the Sydney Basin, and the results compared to the recommendations of the Guidelines. When significant differences between the methods were discovered, the question of 'what were the recommendations of the Guidelines based upon?' was raised.

The source of the wisdom of resource classification in the coal Industry is unravelled, using interviews with present and past members of the committee across the past six decades, records of the Standing Committee for Coalfield Geology (now the Coalfield Geology Council of NSW (ed)), and letters between the SCCG and the Joint Ore Reserves Committee (JORC). The growing divide between the Australian Coal Guidelines and the JORC code through the late 1970's is illuminated, and begins to explain how the two reference documents became so disparate.

As the audience and purpose of resource reporting and evaluating project risk has changed over the past six decades, the technology that we use to assess confidence in coal estimation has not. This paper not only challenges the distances between boreholes that the Guidelines have recommended to date, it also challenges the concept of using distances in resource classification at all.

02SBC-03. CAN NEW STANDARDS IMPROVE COAL RESOURCE ESTIMATION AND REPORTING PRACTICE?

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Recent implementation of JORC 2012 has tightened some definitions and added new checks for resource estimators to consider. CoalLog standards were designed to improve and upgrade the collection and coding of geological and geotechnical data, which ultimately can lead to improving efficiency and accuracy in resource estimation. The draft revision of the Australian guidelines for coal estimation and reporting also aims to improve standards.

Are the changes needed and will they work? We consider some examples of past poor practice and inconsistent resource classifications, both from the Sydney Basin and elsewhere.

Although compliance with JORC 2012 would eliminate some of the most extreme differences between resources defined by different competent persons, as resource classification relies on the judgement of a single competent person, some inconsistency in classification is likely to remain. It will not remove the option for some promoters to seek the competent person who will give the most generous figures.

Adherence to the maximum distances between points of observation in the old Australian coal resource guidelines may have improved consistency in classifications, but sometimes this was at the expense of geological common sense. Use of the maximum distances in unfavourable geological environments or with an insufficient distribution of core quality data, has led to some exaggeration of resources. We therefore applaud the removal of the standard distance buffers from the current draft coal resource guidelines. However the draft guidelines will leave a lot more discretion in classification to the competent person, therefore perhaps decreasing consistency in classification.

We conclude with some suggestions for consideration to improve efficiency and consistency in resource estimation and classification. We also recommend a system of peer review of resources, either to be recognised as best practice or as mandatory in future updates of standards.

02SBC-04. COAL EXPLORATION DATA INTEGRITY AND MANAGEMENT

Brett Larkin

GeoCheck Pty Ltd

The principal asset of nearly every coal mining company is the coal it has in the ground. However, the true size of this asset will only be known once it has been mined and maybe not even then. In the meantime investment decisions are based on a resource estimate derived from the company's exploration database. From one point of view then, the real asset that the company has is its data. Considering this, it is astounding how often the data's collection and management is left to the most inexperienced members or even non-members of the company.

Data integrity starts at the drill site. Issues here include:

- Coring the appropriate intervals
- Achieving the required core recoveries
- Good reconciliation of geologist and driller's depths
- Appropriate sampling
- Consistent geological logging using a thoroughly reviewed system such as CoalLog
- Recording only source data such as defect position rather than summary data such as RQD
- Quality core photography
- Timely geophysical logging
- Consistent geological and geophysical zero depths
- Well-calibrated geophysical tools

Data integrity continues during initial processing. Issues here include:

- Data entry that checks for invalid items, such as, incorrect codes or numerical values outside range.
- Double keying of numerical data such as analytical results.
- Checking that compulsory data such as unit depths, unit lithotypes, Rock Mass Units types, and sample numbers on analytical results, are entered.
- Checking for invalid combinations of items, such as depths out of order, percentages not adding up to 100%, appropriate qualifiers on lithologies, and seams out of stratigraphic order.
- Appropriate filtering and manipulation of the geophysical data.
- Appropriate adjustment of depths of non-geophysical data to the geophysical data.

Following data entry, integrity checks need to be made of the entire database by the project data manager. These include identification and rectification of:

- Data in inconsistent formats, for example, data that was collected using a slightly different dictionary to the one used in the database or data collected before the adoption of the CoalLog standard format.
- Missing data, for example, hole coordinates from the surveyors, lithological and sampling information from the data collection geologist, analytical results from the lab, geophysical data from the logging company, missing geophysically adjusted data, and seam interpretations from the analysing geologist.
- Incorrect data, for example, hole coordinates and seam naming. This is best performed using graphical output such as hole location plans and cross sections.

Finally, good data management is required on a continuing basis. Issues here include:

- Recognising that there is observational and interpretational data which can further be split into raw, working and finalised observational data and working and finalised interpretational data, each requiring different data management procedures.

- Preservation of raw data, including original hand-written coding sheets, data as initially collected on field tablets, unprocessed and unfiltered geophysical data.
- Regular backups.
- Ensuring that the data can be easily exported in a format for import into any system that requires it.

Poor data integrity checks and data management put at risk a company's most valuable asset, their exploration database.

02SBC-05. THE COAL QUALITY DATA EXCHANGE (CQDX) PROJECT – IMPLICATIONS FOR DATA UNDERPINNING RESOURCE REPORTING

Jared Armstrong

GSA member

A recent ACARP[1] project (C21014) examined the exchange of coal quality information between Geoscientific Information Management (GIM) Systems and Laboratory Information Management Systems (LIMS). This presentation examines the findings of the project, and its impact on data validation and data management that underpins resource reporting.

It was recognised that the process of exchanging coal quality data between laboratory and geological databases and modelling systems often required multiple data transformations and sometimes manual data transcription. Multiple data transformations and transcriptions increase the probability for the introduction of errors into the dataset. The ACARP project was commissioned to investigate ways the transformations and transcriptions could be minimised to increase efficiency and data quality.

The project achieved its primary objective by implementing a communication methodology (CQDX) through which both coal laboratory systems and mining companies could interact. The methodology produces more reliable data sets and clearer instructions between all parties involved which in turn reduces laboratory turnaround time. This was achieved by:

- Innovating and enhancing an existing technology to work with coal quality data
- Building a secure and sustainable methodology
- Proving its viability by demonstrating the technology works in a production environment
- Engaging the coal industry via a series of meetings, presentations and an information session during the project
- Researching and proposing a governance framework for effective management of this technology as a standard going into the future

The JORC Code has undergone a number of revisions since 1971, with emphasis on Materiality, Transparency and Competence at the core of each of revision. It is assumed future revisions will continue this focus. The theme of increased transparency is complemented by the CQDX ACARP project whereby a key deliverable was increased transparency of data delivery into geological databases and modelling systems.

To understand the relevance of CQDX to reporting a resource statement in accordance with the JORC Code, it is important to understand the various components that underpin a public statement. Like the tip of an iceberg, the public statement represents the results of the entire estimation and reporting process. The public statement is underpinned by geological models that are in turn supported by a range of detailed interpretations and evaluations based on available data as described in the recently circulated exposure draft of the Australian Guidelines for the Estimation and Classification of Coal Resources (March 2014). Thus, the quality of these data significantly influences the quality of the public statement.

Preparation of a public statement compliant with the JORC Code is no trivial task. Preparation of the model, interpretation of evaluations and preparation of original data sets takes significant time. The preparation of data sets using CQDX can significantly contribute to a reduction in this time and increase data reliability and validity. CQDX provides a degree of transparency, efficiency and compliance between laboratories and geological databases and modelling systems never before realised.

Reference

[1] Australian Coal Industry Research Program (ed)

02SBD - 39TH SYMPOSIUM ON THE ADVANCES IN THE STUDY OF THE SYDNEY BASIN

02SBD-01. COAL SEAM GAS IN NSW – 35 YEARS OF DISCOVERY IN A NUTSHELL

Malcolm Bocking

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The first dedicated coal seam gas (CSG) boreholes in NSW and Queensland, at Appin and Blackwater, were drilled and hydraulically fractured by BHP's Hematite Petroleum, in 1980. Nine years earlier, similar trials had been undertaken in Alabama, USA, long considered the birthplace of the modern CSG industry. Those trials foresaw hydraulic fracturing of vertical boreholes as a way to remove gas ahead of mining. Simultaneously, based on experience at the Island Creek Mine in Virginia, USA, AGL stepped forward with Occidental to prospect in the Sydney Basin. They planned for the commercial production of methane utilising horizontal drilling in virgin coal long before its subsequent mining. The resulting 26 deep Moonshine and Bootleg holes were the first of more than 300 deep boreholes drilled by 30 Operators, to investigate CSG in NSW. To date, one commercial CSG field utilising both hydraulically fractured vertical boreholes and horizontally drilled boreholes, is producing at Camden, and a second is approved at Gloucester, both under the stewardship of AGL. Pilot production has also been undertaken by others elsewhere.

The CSG investigation holes that are drilled to evaluate the gas present, its distribution, producibility and origins, also reveal information on the enclosing stratigraphic sequence, the coal itself, its permeability, age, chemistry, origin, the enveloping stress field and any aquifers, as well as the presence of conventional gas and oil. They now illuminate these aspects, with a clarity not available from earlier drilling, across the Permo-Triassic Sydney Basin, its northward extension the Gunnedah Basin, the ancillary Gloucester Basin and their Triassic–Jurassic–Cretaceous counterparts the Clarence-Moreton and Surat Basins.

To date the information from 257 CSG exploration boreholes is available in the public domain. These, together with available information from three very deep-cored stratigraphic holes drilled for geothermal and sequestration studies, form the basis for this review. Largely cored and although generally less than 1200 m deep, the boreholes do provide continuously cored intervals of up to 1700 m, in holes up to 2220 m deep. Such material housed in the NSW Trade and Investment drill-core library, continues to support further studies such as the current IDTIMS chrono-stratigraphic program. (Some 55 000 coal exploration boreholes also exist in NSW, but, with some exceptions, are proprietary, shallower and clustered within the coal mining areas that cover only 10% of the coal basins of NSW.)

This data synthesis presents some lesser-known elements to the geology of the Sydney-Gunnedah basin as well as the state-wide patterns of CSG distribution, composition and origin and the extent of coal development. The results provide for a variable energy resource density of up to 25 PJ/km^2 for 'gas in place'.

Energy resource recovery and utilisation throughout the world follows various models and is provided with growth by emerging technologies. However, historic and recent environmental protection led changes to energy resources regulation, now limiting access to both coal and CSG in the energy rich basins of NSW. When these limitations are overlaid on the pattern of gas resource distribution, the available opportunities for development become apparent.

02SBD-02. OBSERVATIONS ON THE DISTRIBUTION OF COAL SEAM GAS IN THE SYDNEY BASIN AND THE DEVELOPMENT OF A PREDICTIVE MODEL

Scott Thomson[1]**,** Duncan Thomson[1] & Peter Flood[2]

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Gas content and gas composition trends with depth have been investigated for the Sydney Basin.

Four distinct zones have been identified, which can be classified according to depth below ground surface. An upper low gas zone (Zone 1, 0–100 m), dominated by CO_2 and with very low gas contents (<0.7m^3/t), is underlain by a biogenic methane-rich zone (Zone 2, 100–~250 m), with a rapid rate of increase in gas content with depth, followed by a mixed gas zone (Zone 3, ~250–~600 m), comprising biogenic and thermogenic methane and magmatic CO_2, and having a lower rate of gas content increase with depth relative to Zone 2. Zone 4 (~600 m+) contains thermogenic methane and other 'wet gases'.

A model is proposed that provides a rationale for the origin and timing of emplacement of the various coal seam gases in the Sydney Basin.

02SBD-03. SYDNEY BASIN GAS LAYERING – THE HYDROCHEMICAL LINK

Agi Burra, Joan Esterle & Sue Golding

University of Queensland

The delineation of the extent of CO_2-rich gases and higher hydrocarbons in coal seam gas reservoirs in the Sydney Basin is important for reservoir production optimisation and also safety in under-ground coal mines.

Gas distribution in the Sydney Basin is complex and varied; however, some underlying patterns are discernable. Hydrocarbons of thermogenic origin at depth are overlain by shallower zones of biogenic methane. The depth of the interface between these two layers varies, but a zone of mixed gases is consistently present. Some areas also contain significant volumes of CO_2 gas in the mixed gas zone and it is commonly attributed to magmatic origins. CO_2 is not always present in intruded or heat-affected areas and it can occur in areas that were not subjected to igneous activity. An alternative hypothesis for the origin of the deep-seated CO_2 is from mineral dissolution and/or a by-product of methanogenesis through the acetate fermentation pathway. It is hypothesised that hydrodynamics and hydrochemistry of formation waters in the subsurface play an important role in defining the extent of coal seam gas layering: both by limiting meteoric influx (and thereby biogenic methane accumulations), as well as regulating the level of bicarbonate saturation and salinity in the groundwater (and thereby the presence of various gas types).

Meteoric influx penetrates along bedding and via vertical fractures. The shallow, hydrostatic (gravity-driven) flow is countered at depth by geopressured formation waters migrating towards lower pore pressures. A transitional zone where these two flow regimes meet is postulated to provide the conditions for the mixed gas zone region to develop. Overprinting the hydrodynamic framework is the hydrochemical facies development of groundwaters from fresh, bicarbonate-rich composition in highland (or inland) recharge areas towards more saline and sodium-rich makeup in coastal or low-lying discharge areas. Formation waters associated with methanogenesis exhibit sodium-rich and brackish characteristics. On the other hand, excess CO_2 from bicarbonate-rich waters are normally precipitated as carbonates along flow paths, and may also be liberated under marked chemical changes, for example, in salinity or alkalinity. In these instances, CO_2 may be liberated and trapped as a gas in the coal matrix.

In this manner, hydrodynamic and hydrochemical changes along the groundwater flow path result in the development of gas layering in the subsurface. A dataset consisting of over 2000 coal seam gas samples from ~100 boreholes was collated from publically available data (supplemented by a private dataset from the Hunter Coalfield), including approximately 88 gas carbon isotope results to assist with gas origin interpretation. Hydrochemical, porosity and permeability data were sourced from literature and used to identify the extent of groundwater flow under hydrostatic pressure, as well as assisting in the delineation of various hydrochemical regions in the basin.

Results show that gas contents increase with depth in the hydrostatic flow section of the strata, culminating in 'peak gas contents' at the top of the transitional flow zone. Below this horizon, the influence of biogenic and hydrostatic sources decrease, and the appearance of thermogenic ethane signals the upper extent of the geopressured waters. A mixed gas zone exists between these two flow layers that contains significant volumes of CO_2 gas in some (mainly, up-gradient and fresh water hosting) regions. The origin of this deep CO_2 gas is thought to be magmatic; however, due to the hydrochemical development of groundwater along flow path (including with depth) from bicarbonate-rich fresh water to more Na and Cl-rich brackish waters, the deep CO_2 gas in the mixed gas zone may alternately have originated from the excess bicarbonate contents in the groundwater where abrupt chemical changes in parameters such as salinity, temperature or pressure have occurred. As a result of the extent of groundwater facies in the basin, up-gradient fresh-water regions, particularly in the vicinity of geological features assisting the rapid and deep penetration of freshwaters into sediments (e.g. extensive fracture sets associated with large regional monoclines around the edges of the basin), appear to host large volumes of deep CO_2 whereas more saline and Na and Cl-rich waters down-gradient are almost completely devoid of deep CO_2 gas. The base of the hydrostatic flow regime marks the disappearance of biogenic methane and high concentrations of CO_2 from reservoirs, leaving thermogenic gases (including higher hydrocarbons) dominant in deep gas accumulations.

The significance of these findings is that gas zonation can be traced across the coal seam deposits of the Sydney Basin, and the various gas markers identified such as the 'peak gas' (or ethane) horizons can be mapped with more confidence across the region. Additionally, groundwater chemistry can provide further assistance in the tracking of likely coal seam gas accumulations in the subsurface, particularly in the context of delineating the undesirable, deep (and high volume) CO_2-accumulations, which are associated with outbursts in underground coal mines and considered an impurity in coal seam gas (CSG) produced for energy utilisation. This study introduces key gas zone horizons that can be identified and utilised for the optimisation of CSG exploration and production, and gas drainage activities.

A more detailed discussion of the data, phenomena and conclusions presented here is provided in Burra *et al.* (2014).

Burra A, Esterle J & Golding S 2014. Coal seam gas distribution and hydrodynamics of the Sydney Basin, NSW, Australia. *Australian Journal of Earth Sciences* **61**, 427–453.

02SBD-04. GAS PENETRATION INTO FINE PORES OF COALS: COMPARING SYDNEY BASIN AND NORTH AMERICAN COALS

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The porous nature of coals allows them to store and release a large amount of gas, a property important in determining the rate and amount of fugitive emissions from coal seams. However, the nature of the pores and how gas is stored and released is still poorly understood.

Small-angle neutron scattering (SANS) and ultra small-angle neutron scattering (USANS) are increasingly used to characterise, non-destructively, the pore size distribution of materials over the size range 1 nm to 10 µm. SANS and USANS record the scattering from all pores, including pores that are inaccessible to fluids and therefore cannot be measured with techniques that involve gas sorption or fluid intrusion, such as mercury porosimetry. Recent developments have allowed SANS and USANS to be able to discriminate between pores accessible to gases and those inaccessible to these gases.

We determined the fraction of inaccessible pores as a function of pore size in eighteen bituminous Sydney Basin coals and six coals of similar rank from the US and Poland. For pores of greater than 50 nm radius, all pores in all coals were largely accessible to methane. In the case of pores of around 8 nm size, regional differences were apparent. In the Sydney Basin coals the fraction of 8 nm pores that were accessible to methane increased with increasing amounts of inertinite and the relationship was linear, suggesting that all of these pores in inertinite are accessible by methane. In contrast, pores of this size in inertinites from the eastern U.S. and Poland were not accessible to methane. Regional differences in inertinite behaviour have been suggested before but this was the first time that such differences have been observed (Sakurovs *et al.* 2012) .

The work reported here reports an extension of this study using SANS. Further vitrinite-rich and inertinite-rich US coals were examined, and they followed the trend established previously for US coals. Seven western Canadian coals were also examined. Although the western Canadian coals were found to be more similar to Australian coals in their relationship between maceral composition and closed porosity than they were to US coals, there were also systematic differences from Australian coals. These differences may explain previously suspected regional variations that are not observed by standard tests of coal properties but nevertheless affect their industrial utility. These results also suggest that relationships between coal permeability and other coal properties found for some coals may not be universally applicable.

Sakurovs R., He L., Melnichenko Y. B., Radlinski A. P., Blach T., Lemmel H. & Mildner D. F. R. 2012. Pore size distribution and accessible pore size distribution in bituminous coals. *International Journal of Coal Geology* **100**, 51–64.

MAWSON LECTURE

Early vertebrate evolution – some contributions from the rocks of East Gondwana (Australia–Antarctica)

Dr Gavin Young

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'Deep Time' (the great age of the Earth) was only widely accepted in western science less than 200 years ago. This gave time for species to evolve, and enabled Charles Darwin to formulate his evolutionary theory. As tangible evidence of past evolutionary change, fossils (biological inclusions in sedimentary rocks) received detailed discussion in Darwin's revolutionary book (1859).

At that time fossil vertebrates from Australian rocks were hardly known, although the giant extinct marsupial *Diprotodon* from Wellington caves was noted by Darwin (1859). However much older fossils had already been discovered. Reverend W. B. Clarke (before 1844) had identified Devonian fossil bones in coastal red mudstones near