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THE ROYAL SOCIETY OF NEW SOUTH WALES

The Society originated in the year 1821 as the Philosophical Society of Australasia. Its main function is the promotion of Science by: publishing results of scientific investigations in its *Journal and Proceedings*; conducting monthly meetings; awarding prizes and medals; and by liason with other scientific societies.

Membership is open to any person whose application is acceptable to the Society. Subscriptions for the Journal are also accepted. The Society welcomes, from members and non-members, manuscripts of research and review articles in all branches of science, art, literature and philosophy for publication in the *Journal and Proceedings*.

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Editorial

DONALD HECTOR
HON. SECRETARY (EDITORIAL)

In this, my first editorial of the Journal, I must first acknowledge the contribution made by Professor Jak Kelly the previous editor. Unfortunately, Jak became seriously ill recently and was unable to continue as editor. Jak made a strong contribution to the Journal since he became editor in 2009 and is one of the inaugural Fellows of the Society. We wish you well in your recovery.

One of the challenges facing peer-reviewed publishing that has developed over the last couple of decades is a degree of specialisation among journals with ever-more focused readerships. Performance of academics is tied to their 'citation impact' which further reinforces specialisation of publications. This severely disadvantages multidisciplinary publications such as the *Journal and Proceedings of the Royal Society of NSW*. The Journal has a proud history of publishing important work, particularly in the field of science and technology and it is important that it recovers its prestige in academic publishing. The Council of the Society is committed to re-establishing the Journal's position in learned publishing in Australia and is taking these steps to encourage large numbers of high quality submissions from respected authors. The publications committee has been working on a programme to achieve this and over the next few months you will see a number of initiatives aimed at improving the Journal's formal and informal ranking. Some of those that we are currently working on are:

Scholarship Programme – implementation of a scholarship prize in science and technology that will be based on papers submitted for publication to the Journal. This will be focused particularly on researchers in the first decade of professional practice. This would be expected to be attractive to researchers in universities, government research establishments (CSIRO, ANSTO), engineering firms and industrial companies with substantial research and development capabilities. Funding for first two years of this programme has already been secured. The Society will be making a formal announcement regarding the awards shortly.

Invited papers – inviting knowledgeable experts on topics of current interest to submit papers reviewing their work or the state of the science in the area. Depending on interest, this could lead to special editions of the Journal.

Opinion pieces – encouraging members to submit well researched, well considered opinion pieces on subjects of interest to the Society. The expectation is that these would be to high standards and properly referenced but may not undergo peer-reviewed.

Schools publication – we have begun a project to explore interest in a schools publication that would have papers from top students in their final year at school. If this is feasible, a new publication separate to the Journal and Proceedings will be established.

Broadening the content – the Society's Act of Incorporation states that it is 'for the encouragement of studies and investigations in Science Art Literature and Philosophy'. Historically, the Society has focused heavily on science. A major point of differentiation for the Journal would be to have it as a publication that welcomes papers where science, art, literature and philosophy intersect. We hope to attract and include papers that cover the full range of the society's interests.

Advertising – the Society is making a media kit available to organisations that might wish to advertise in the Journal. Advertising will be low-key, typical of advertising found in high quality academic journals.

These are just a few of the things we are intending to launch over the next few months with the aim of improving appeal and circulation of the Journal.

On a sad note, I have to report that Patricia Callaghan, a long-serving member of Council and Hon. Librarian of the Society died on 1 November aged 88. Her love of science was strong from the start and through her various roles, especially as a tutor and researcher at Macquarie University, Patricia kindled a thirst for learning in many young people. She joined the Society in 1984.

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The Clarke Memorial Lecture, 5th December 2007

The Architect and The Statesman: Archibald Liversidge, Edgeworth David and the Spirit of Science in Sydney, 1874 – 1934

ROY MACLEOD AND DAVID BRANAGAN

This is the first Clarke Memorial Lecture to be presented by two authors, following the recent publication of their biographies of Edgeworth David (Branagan, 2005) and Archibald Liversidge (MacLeod, 2009). Both colonial scientists followed in the pioneering footsteps of the Reverend W.B. Clarke as leaders of the Royal Society of New South Wales.

Abstract: Archibald Liversidge, FRS and T.W. Edgeworth David FRS, professors in the sciences at the University of Sydney between 1872 and 1923, had a profound influence on the university, the Royal Society of New South Wales, and on the history of Australian science. They were very different: Liversidge, a shy bachelor, little known to the general public; David, a charismatic figure whose activities made him a household name. However, they worked together effectively within the university, in science and technical education, and in the application of science to economic development. Their pioneering work is still bearing fruit today.

Keywords: Liversidge, Edgeworth David, University of Sydney (Science Faculty, School of Mines), Science House, Australasian Association for the Advancement of Science

INTRODUCTION

It is customary at the Clarke Memorial Lecture to pay homage to the Reverend William Branwhite Clarke (1798–1876), a pioneer of Australian geology.[1] It is particularly fitting that the subjects chosen for this lecture were deeply indebted to him and his work. Archibald Liversidge FRS MA LLD (1846–1927), and Sir TW Edgeworth David KBE CMG DSO FRS MA DSc LLD (1858–1934), were among the most distinguished scientists in colonial New South Wales. Arriving in Sydney in 1872 and 1882 respectively, they gave shape to colonial science under the Southern Cross. In many ways their interests were complementary. Both were educated in England, both were strong Empire men, and both saw the pursuit of natural knowledge as a way of making sense of nature's contrarieties, while bringing economic benefit to mankind. In ends and means, they were united. Yet in personal terms, they differed greatly. Liversidge, a younger son of an artisan cartwright, was born in the East End of London and was bred in the rapidly expanding world of technical education and applied chemistry. David, a Welsh-born son of the manse, was a product of Oxford and heir to a tradition of gentlemanly geology. Thus came to Sydney an Englishman and a Welshman, sons of the working class and the middle class – a short chubby man with glasses and a stammer and a thin man of medium height with an aristocratic mien. Their many personal differences never threatened their friendship, nor tarnished their professional relationship. Even so, the differences that surfaced in their approaches to colonial science, university administration and public affairs remain to fascinate scholars today. Their special 'combination of talents' lent a particular character to science in Sydney and at the Royal Society of New South Wales.

[1] On this occasion, the introduction was given by Professor R.H. Vernon, Chairman of the NSW Division of the Geological Society of Australia, co-sponsor of the lecture. Brief mention of the recent discovery of previously unknown letters of the Rev. W.B. Clarke, was made by the speakers. See Branagan and Vallance (2009).

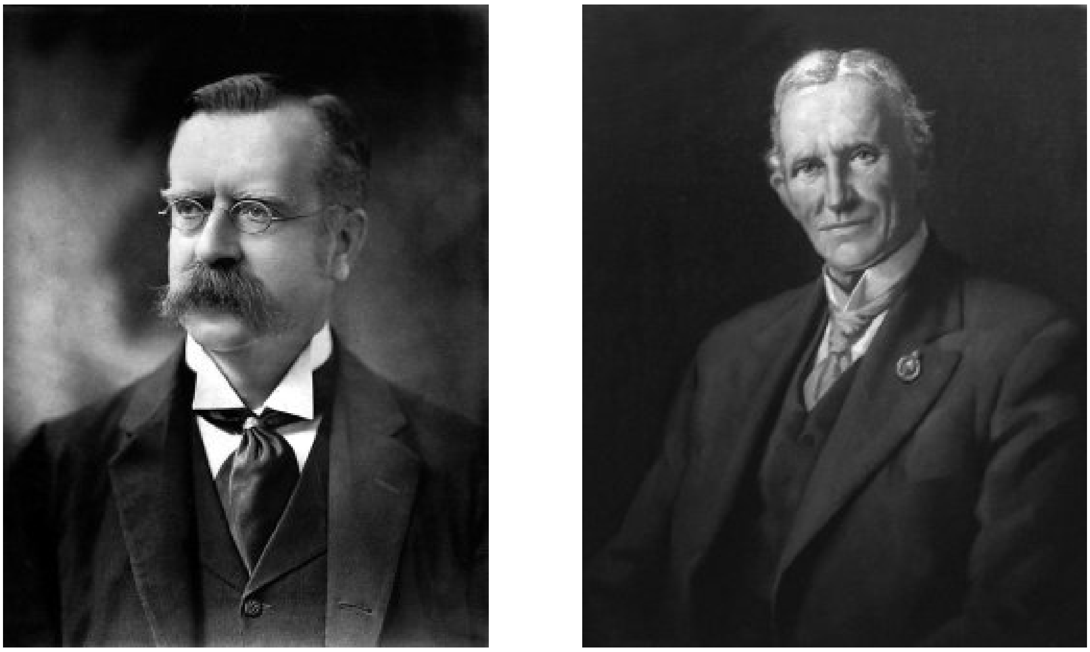

Figure 1. Archibald Liversidge and Edgeworth David.

Looking back, Liversidge and David can be cast as 'public scientists' – they were advocates and achievers, prophets and proselytisers. But the former remains best known as an architect and builder, a promoter and organiser; whilst the latter is remembered more as a statesman and inspiration – Liversidge, a careful analyst and tireless believer in inter-colonial cooperation; David, an adventurer, explorer and speaker for the nation. Together, their work helped create something uniquely 'Australian' in an otherwise distinctively British world of science. In the histories of Sydney University and the Royal Society of New south Wales their legacies were to prove both lasting and incomplete. Together, they made it possible for all the sciences in Sydney to come together and flourish; yet both were destined to leave for later generations the larger task of creating a scientific spirit among the Australian people, in a foreign land they found strange but came to know well.

Their influence spanned a generation[2]. They followed each other as Deans of Science – Liversidge from the foundation of the Faculty in 1882 to 1903 (excepting 1896), and David from 1904 to 1908, with a second period (1919–1923) after Liversidge had retired. To the Royal Society of New South Wales both contributed greatly – Liversidge as Secretary from 1874 to 1884 and 1886 to 1888, and President in 1885, 1889 and 1900 (MacLeod 2009); and David as President in 1895 and 1910, and as an almost permanent Council Member (Branagan 2005).

Liversidge and David led what historians often regard as the third generation of science in Australia – following, first, the early European explorers, culminating in the early years of settlement; and second, the gentlemen collectors and botanising parsons, epitomized by W.B. Clarke, whose traditions dominated colonial science throughout the Empire from the 1820s to the 1870s. Liversidge and David led the first generation of Australian analytical geologists and chemists for whom the field and the laboratory were professional preserves. Given the tiny community of well educated people in New South Wales - perhaps one hundred in a population that, in 1872 (when

[2] Surprisingly, no correspondence between them has survived. The reason may lie in the fact that for the many years (1891–1909) they were university colleagues, they worked in close proximity; but this explanation does not completely dispel the mystery.

Liversidge arrived), counted 138,000 in Sydney, and 550,000 in all NSW – they enjoyed a special, almost privileged status. They were prophets, like Clarke, but they were also commentators and consultants, contributing to what later generations would call 'evidence-based' policy for exploration, mining and manufacture. They came to Sydney as young men in a young man's country – thanks to the gold rushes, a male-dominated world, in which less than 10% of Sydney's population was older than fifty. In their working lives, they remained young, even as the rest grew old – and even their later photographs and portraits keep alive a sense of youth and zest we wish our generation shared. Of course Liversidge and David were also blessed in many ways – with good health, certainly, but also by a university that gave them scope to innovate and develop. In academic dress they could do pretty much as they wished – and what they did was remarkable.

LIVERSIDGE, ARCHITECT OF SCIENCE

'Not only the University of Sydney and the State of New South Wales, but the whole of the Commonwealth will be the poorer by the departure for England of Professor Archibald Liversidge, MA, FRS'. So the *Sydney Evening News* on Boxing Day, 1907 mourned the close of thirty-five years since the arrival in Australia of a man, who perhaps more than any other, embodied Britain's legacy of colonial science. In its announcement, the press was premature – the shy chemist went on to complete another two decades of research in England – but in its celebration of a man who had fought the 'battle of science and engineering' in Sydney, it paid him timely tribute.

Today, Liversidge is remembered as the first Dean of Science at Sydney University, and for inspiring the foundation of the Australasian Association for the Advancement of Science (AAAS), later named the Australian and New Zealand Association for the Advancement of Science (ANZAAS), and for ensuring its continuance during its first twenty years. But the current of his influence ran far wider and deeper. Espousing a colonial nationalism that drew from imperial obligation, Liversidge guided colonial science into the twentieth century. From him came a catalytic spark that gave life to proposals for technical education, for system in the use of the colony's mineral resources, and for rigour in the installation of metallurgy and applied chemistry as university subjects. Viewed from London, Liversidge was the classic 'servant of Empire', and a reflection of the Royal School of Mines in its imperial aspect. Within his field, his influence was typically careful, conservative, and custodial. Working at the same time as David Orme Masson (1858–1937) at Melbourne and Ralph Tate (1840–1901) at Adelaide, he dominated the colonial stage in the mineralogical sciences, and epitomized the virtues of 'practical idealism' *sans doctrine* that Australians deemed appropriate for its men of science (MacLeod, 2009).

Liversidge was born in suburban London in 1846, the eighth of nine children, and youngest of four surviving sons, of a well-known City carriage builder. Educated privately to the age of nineteen, in 1866 he entered the Royal College of Chemistry and the Royal College of Mines in London, where he studied with such Victorian 'giants' as Edward Frankland (1825–1899) in chemistry, Andrew Ramsay (1814–1891) in geology, Warington Smyth (1817–1890) in mineralogy and John Tyndall (1820–1893) in physics. The course at the RSM, still under the influence of Prince Albert (1819–1861) and Augustus von Hofmann (1818 - 1892), cultivated a broad spectrum of technical skills useful to trade and industry. In 1869, Liversidge took these skills, along with the Associateship of the RSM, to Cambridge, where in 1870 he matriculated as an Exhibitioner at Christ's College. Admitted to read for the Tripos in Natural Sciences, within just nine months he was demonstrating laboratory chemistry to fellow undergraduates and organising a Natural Sciences Club – a premonition and foretaste of things to come.

Liversidge's early successes in the laboratory, in a university not yet generously endowed with scientists, caught the attention of Michael (later Sir Michael) Foster (1836–1907), the brilliant physiologist of Trinity, who recruited him to a small band of undergraduates. These included H. Newell Martin (1848–1893), Frank Balfour (1851–1882) and Sydney Vines (1849–1934) who would go on to transform experimental biology. A bright future awaited him. But scientific jobs were not plentiful. His teachers, Huxley (1825–1895) and Tyndall, had once looked overseas, and by some accounts, had considered the new university in Sydney. Liversidge had no special association with Australia, and whilst he had learned much about mining, had no colonial experience. Nevertheless, fate declared an interest. In 1871, Sir Roderick Murchison (1792 - 1871), doyen of British geologists and retiring Director of the RSM was approached by Richard Daintree (1832–1878), Agent-General for Queensland in London, who had been asked to find a successor to Alexander Morrison Thomson (1841- 1871), Sydney's popular professor of geology, who had arrived in 1866, but who had just died, at the age of only twenty-nine, following a field trip to the Wellington Caves. Professors were young when appointed in those days, and Murchison recommended Liversidge, by his experience groomed for a career at a young university that set store by looking like a London college. So it was in 1872, even before he could sit his Cambridge Tripos, that Liversidge accepted the University's appointment as Reader in Geology and Assistant in the chemical laboratory. He arrived in Sydney the same year.

If Liversidge's academic job was secure, his scientific future was not. He had few colleagues in Sydney, and twenty years after the University's founding, fewer than thirty students graced its fine neo-gothic sandstone building. But he rose to the occasion and launched a proposal for a new School of Science. In 1874, just two years after he arrived and at the age of twenty-eight, he was promoted to Professor of Geology and Mineralogy. Contenting with the university's dominant classical ethos, he turned to the wider colonial community, serving as a consultant to the newly established Department of Mines, joining in Transit of Venus observations and becoming a Trustee of the Australian Museum. He also looked to the Royal Society of New South Wales, finding in it both intellectual stimulus and personal friendship. Serving as its Hon. Secretary and editor from 1874 to 1884, he rationalised and rejuvenated its scientific sections, and helped find it a new home in Elizabeth Street.

During the 1880s, science 'came of age' in New South Wales, and colonial science established a firm claim upon public support. Liversidge brought a synthesis of London and Cambridge. His analytical approach to the natural world combined the analytical naturalism of Jermyn Street (the RSM and South Kensington Museum of Natural History) and the intellectual passion of Cambridge. For Sydney, he became both a Huxley and a Tyndall, mediating the agnostic naturalism of the one and the materialism of the other, in a culture that tolerated authority but resisted dogma. His text was the 'Book of Nature'. Working tirelessly, by the time he retired he had produced a major survey of minerals in New South Wales (Liversidge 1888a), invented new analytical apparatus, and published over 100 papers in chemistry, mineralogy and geology. Together, his output supplied a global demand for information about the composition of Australian and Pacific minerals. He was Australia's first geochemist, and possibly one of the first in the English-speaking world.

At the University, his presence was felt everywhere – notably on committees dealing with a broad spectrum of policies, ranging from buildings and grounds to student discipline. 'After Homeric battles with the forces of Arts', as Edgeworth David later put it (David 1930), he won approval for the establishment of a Faculty of Science, of which he was to remain Dean for the next twenty years (1883–1903). Until the early 20th century, all Sydney students were obliged to take elementary chemistry in their first year, so nearly every student had contact with the shy professor and his meticulously organised – some would say, ambitious – lecture demonstrations.

Figure 2. Lecture room set up for a Liversidge lecture-demonstration.

Outside the laboratory and classroom, Liversidge's early fascination with collecting natural and man-made objects gave him a commanding position in the 'exhibition movement' of his day. His efforts helped 'sell' New South Wales to the world at large – beginning with the Paris Exhibition of 1878, and continuing with the Sydney International Exhibition (the 'Garden Palace') in 1879 – from which grew the Industrial, Technological and Sanitary Museum, later the Museum of Applied Arts and Sciences, which we know today as the Powerhouse in Ultimo. His influence on the making of key scientific appointments - notably, at the Technical College and at the Botanic Gardens, became the stuff of legend (MacLeod, 2005b). Building an extensive correspondence, he encouraged intercolonial ties, especially with Victoria and South Australia, and encouraged scientific exchanges across the Tasman.

Many of these achievements were recognised by his peers. In 1882, he was elected a Fellow of the Royal Society of London (one of only three then living in Australia). In 1887, Cambridge awarded him an M.A. *honoris causa*, in lieu of the undergraduate degree he never took. It was entirely appropriate that, in 1888, the first great meeting of inter-colonial science, the inaugural meeting of the Australasian Association for the Advancement of Science (AAAS) – a harbinger of political federation – took place in the Great Hall of Sydney University.

In the 1890s, Liversidge continued to be a 'scientific ambassador' for NSW and by extension, for Australia in general, at major exhibitions in Europe. He also continued membership in leading British scientific societies, including the Mineralogical Society, the Chemical Society and the Geological Society of London. His studies on the origins of nuggets and gold in seawater attracted attention in Europe and the United States. In recognition of his contributions to colonial science, Glasgow University awarded him an honorary LL.D in 1896.

In 1882, following the establishment of the Faculty of Science, there was a redistribution of duties, and Liversidge translated to the Professorship of Chemistry and Mineralogy, leaving the teaching of the non-mineralogical aspects of geology to the newly-appointed Professor of Natural History and William Hilton Hovell Lecturer in Geology and Physical Geography, William John Stephens (1829–1890), a former school headmaster and a classics scholar, doubling for a time as Professor of Classics. In 1891, following the death of Stephens, duties were again rearranged and Liversidge became Professor of Chemistry, and the newly-appointed Edgeworth David, Professor of Geology, joining Richard Threlfall (1862–1932) in Physics and William Haswell (1854–1925) in Biology, in a four-fold division of scientific interests. All Liversidge's colleagues spent years fighting for accommodation for their respective departments. In 1888 a successful end to Threlfall's struggle to get funds for a fine physics building (ironically, now named the Badham Building) was not enough to keep him in Sydney. Liversidge's turn finally came in 1890, with the building of a fine structure that was at the time one of the most highly praised chemical laboratories in the British Empire, a memorable testament to his tenacity and foresight (Fig. 3).

Figure 3. School of Mines/Geology building (right), former Engineering Building (left).

In 1907, just over a century ago, Liversidge retired and departed Sydney for the last time. He said he would return, but he never did. In England he held office in the Chemical Society and the Society for Chemical Industry. He represented New South Wales on the commission that launched the International Catalogue of Scientific Periodicals, and he nominated Australians for the 'blue ribbon' of the Fellowship of the Royal Society of London. During the Great War he advised the Royal Society and the Chemical Society and contributed to war work on minerals and light alloys, such as those used in German airships. He also helped to launch the first strategic minerals survey of the Empire, a typically far-sighted work, involving co-operation with Britain, Canada, and South Africa. For many years he held a visiting appointment at the Davy-Faraday Laboratory at the Royal Institution in London, where he continued to work on the origins and appearance of trace elements.

In 1902, the year in which Sydney University celebrated its Jubilee, Liversidge's hand was everywhere to be seen – a fact that David, whom he had helped appoint, clearly recognised. In many ways, his life in Sydney must be counted a success. Yet, despite his work for the colony, memory of his achievements seemed to evaporate as soon as he sailed through Sydney Heads. Unlike David he received no public honour and even today his achievements remain unrecognised. Whilst several monuments survive him, such as the library of the Royal Society of New South Wales and the Chemistry (now Pharmacy) building at Sydney University (Fig. 4), his name is missing. There is no structure named for him in Sydney, although the planners of Australia's capital, with greater sympathy, named a street after him, appropriately next to the Australian National University and the Australian Academy of Science.

Figure 4. Chemistry Building (now Pharmacy School).

In this sense, Liversidge's life is a story of high promise, tinged by sadness, perhaps regret. He may have left London, but he remained an Englishman. A bachelor, he left no family in Australia, and willed his books and papers to Cambridge rather than to Sydney. And whilst he embraced the results of the latest research, he had little opportunity – until he retired to London – to work at the research fronts then opening for European scientists in radioactivity, X-ray crystallography and organic and physical chemistry. His empirical studies in geochemistry were not popular and did not find theoretical closure in his lifetime. Indeed, only recently have some of his early conjectures about ore genesis been widely confirmed (Butt and Hough, 2007). Other far-sighted proposals of his; the introduction of the metric system, the establishment of a federal Academy of Science, and the founding of an Australian equivalent of *Nature*, were to be many years in coming.

Still, Liversidge's record speaks for itself. When he arrived, there were over a dozen seldom-communicating scientific societies scattered throughout Australia and New Zealand, and colonial governments lacking in commitment to research and technical education. By the time he departed, there was a collective commitment to scientific cooperation on a national basis, and a commitment to science and engineering in higher and further education (MacLeod 2009). At Sydney University his struggles produced a curriculum and laboratory equal to any in the Empire. When Liversidge arrived there were perhaps twenty-five students each year studying chemistry in an over-crowded, ill-ventilated room. When he left there were nearly 400 students whose education included chemistry, with seven lecturers, a set of laboratories and lecture rooms and a thriving community of scholars across the city. His London training found its reward in the establishment of the University's School of Mining and Metallurgy, conceived in 1892 along lines that were to rival the RSM. For years the School was to be the 'backbone' of the Faculty of Science; in 1901, 106 of the Faculty's 118 students were in engineering and most of these studied mining engineering (Fig. 5). Regrettably, with the passage of years, this – among Liversidge's greatest achievements – has been largely forgotten (MacLeod, 1995a).

We hope that Sydney University, in rewriting its history, will remember Liversidge's service to the community and to the community of science. In this lay perhaps his greatest gift to Australia – an abiding sense of *fraternity. Frater ave atque vale* (David 1930, xiv).

DAVID, THE STATESMAN

David's life in science played out in two parallel dimensions: (a) as a university figure, where he cut a leading figure in geology, in the Faculty of Science and in other academic activities; (b) and as a statesman of science, influencing both government and industry in the support of scientific endeavours (including the Funafuti expeditions, the Antarctic expeditions of Shackleton, Scott, Mawson, the Japanese and Amundsen. During the First World War, David patriotically served with former mining and civil engineering students in the Australian Tunnellers Corps on the Western Front (Branagan 1987, 2005) (Fig. 6). Near the end of his life, he helped score a signal success for science in the opening of Science House, a place that was to be a home for the Royal Society and kindred bodies, which today remains a vision still waiting to be fulfilled.

Figure 6. Edgeworth David (on left) and Professor James Pollock en route to Europe with the Australian Tunnellers.

David's background was comfortably middle class. His undergraduate days at Oxford were devoted mainly to classics and history, and geological studies were peripheral to his curriculum. However, he was greatly influenced by the eccentric John Ruskin (1819–1900), who included material on landscape and geology in his lectures, and by Joseph Prestwich (1812–1896), a successful businessman who was appointed Professor of Geology at the age of 62, and who gave an optional course. Prestwich recognised David's interest and potential, and encouraged him to do field work around his home in Wales. Others who influenced David's future in science were his relative William Ussher (1849–1920), who worked for the British Geological Survey, and Dr Charles Vachell (1848–1914) of Cardiff. All three probably recommended that he attend courses at the Royal School of Mines in London, at which he enrolled in 1882.

As it happened, David was to be at the RSM for only six months. The Geological Survey of New South Wales had literally lost a member, Henry G. Lamont Young (1851–1880), who had mysteriously vanished while examining a new goldfield near Bermagui on the south coast of the colony (Branagan & Packham 2000, p. 319; Anon 1980). When the British geological establishment was asked to recommend a replacement, Professor J.W. Judd (1814–1916) and others had no hesitation in recommending the relatively untried twenty-four year-old David for the job. Although lacking experience, David had published one paper on the glacial features around Cardiff, and had two more papers in the pipeline. What's more, the young man had led a field trip for the local Naturalists' Society. David had little hesitation in accepting the offer, and knowing he had no practical knowledge of mining, raced off for a couple of weeks to examine the geology and tin mines of Cornwall. In late 1882, David was farewelled by his close family, wondering if they would ever see him return from 'the other side of creation'. He arrived in Sydney in November 1882, having met on board ship a fellow passenger, Caroline Mallett, who would later become his wife.

Although David's nine years in the Geological Survey of NSW are often underplayed, they were vitally important in many ways. His appointment to the Survey was the first of a university graduate, and his qualifications, or lack of them, did not go un-noticed. One colonial parliamentarian sniffed that the Survey did not need 'university toffs', and some officials wondered whether he had the physique to withstand the rigours of the Australian bush. Perhaps David had a hint of these feelings, but was determined to prove his mettle.

The remarkable story of his successes in the Survey can be briefly summarised. His short first job, collecting fossils around Yass and recording their stratigraphic position for display at an exhibition in Amsterdam, showed how rapidly he adapted to the new field of palaeontology, which remained an interest for the remainder of his life. Then it was off to the New England highlands of NSW, where he studied the distribution and mining of tin. Here, he proved himself not only an able geologist, but also a successful bushman, able to live with working miners and 'aristocratic' squatters. The results of his work, published in the Survey's first Monograph, enhanced the reputations of both David and the Survey (David 1887).

David's studies of coal in the Hunter Valley (David 1907), which led to a new and important coalfield, were interrupted by rushed visits to Sydney to woo and marry Miss Mallett. Soon, his work became known among both politicians and commercial men. In 1885, David's interest in glacial events was revived by R.D. Oldham (1858–1936), another RSM man from India, who visited the Hunter region with David, and who recognised evidence of glacial action that was many millions of years old, well before the great coal-forming events that David had recorded. This late Palaeozoic glacial event was to feed David's imagination, and his studies of it were to make his name in international circles (David 1896, 1906).

By 1890, David's reputation was firmly established. In addition to his Survey work he was involved in the examination of students at Sydney University and at the Sydney Technical College, which Liversidge had helped establish. A turning point in his life came in November 1890, with the sudden death of William John Stephens, the sixty-one year old Professor of Natural History (including Geology). As in the appointment of Liversidge and all other Sydney professors, the University's Senate turned naturally to 'Home' for a replacement. By this time, however, the world had changed, and there was apparently enough choice, so the position was advertised internationally. David's boss, the Government Geologist, Charles Wilkinson was ailing, and although only thirty-three, David was clearly in line for this prestigious and well-paid post. However, David wanted to work on research problems that could not be solved amidst the many calls made on his time by the Survey. Accordingly, he threw his hat into the ring for the chair, which had been redesignated as Geology and Physical Geography.

The story of his appointment is well-known. From a field of twenty or more, the 'Home Committee' selected William J. Sollas (1849–1936), then at Trinity College, Dublin, and very well qualified for the position. In Sydney, however, the University's Senate demurred. David had been an examiner for the University in 1890, and had given the geology lectures in the first term of 1891. These were well received by students, and many members of Senate seemed to feel that someone well-acquainted with the local geology and colonial community might be a better bet than someone coming fresh from Britain. Consequently, the Senate 'thumbed its nose' at the 'Home' committee, and appointed David. His early success as a lecturer soon justified their decision. His name became a byword among Sydney students. His course was required for all first year students in Arts, and in later years, it became a badge of honour to have been a 'student of Professor David'.

The beauty of David's lectures was that, although linked to a printed syllabus, they embraced subjects likely to attract the interest of the young. David had the 'gift of the gab', which he combined with an ability to maintain discipline, a skill sadly lacking in Liversidge. One of David's first innovations was the introduction of field trips, which he believed were essential to an understanding of geology. This radical move quickly became an accepted part of departmental activities. Only four weeks after his first lecture, David took a group of beginning students to examine the coastal cliffs at Coal Cliff, fifty km south of Sydney. In an operation that today would draw the condemnation of Health and Safety bureaucrats, David had his students negotiate a steep, slippery path from the railway, nearly to sea-level, and, equipped with lighted candles, explore an operating coal mine. His longer field trips with senior students to the Hunter Valley sought to uncover new facts, and on more than one occasion there was opportunity to dig and determine whether the 'Prof' had got it right when he predicted a coal seam not far below the surface. Geology was not a dry science for David, or for those who studied with him.

This romantic view of science was reinforced for the general Australian public when David and several students (W.G. Woolnough (1876–1958) and W. Poole (1868–1928) sailed to Funafuti to test Darwin's theory of coral atoll formation. (MacLeod, 1998a; Branagan, 2005). From this work came election as an FRS in 1900. His profile was further enhanced when, without University permission, he remained with Shackleton's expedition (1907–1909) after reaching Antarctica, and led several expeditions, one life-threatening, which became an Antarctic legend. David topped this by becoming the innovator of the Australian Tunnellers Corps in 1915, and taking a leading role in British geology on the Western Front. Not even his former student, Douglas Mawson, famous for his pre-war Antarctic exploits, managed to have his scientific skills harnessed so successfully for war service (MacLeod, 1988c.).

Although David spent much time away from the University in these years, he still managed to exert significant influence on academic affairs. He was a strong supporter of Liversidge's educational ambitions, and offered his continuing support for intercolonial science through his very long association with the Australasian Association for the Advancement of Science (AAAS). While still merely a Geologist for the New South Wales Geological Survey, as yet relatively little known, his name appears in the records of the Association's first meeting, which took place in 1888 in Sydney, where he presented three papers and helped lead a four-day excursion to the Jenolan Caves. Liversidge presented only one paper – concerning the 'Proposed Chemical Laboratory at Sydney

University' – which he accompanied with twelve detailed plates (Liversidge 1888b).

In 1904, David delivered his first Presidential Address to the AAAS ('The Aims and Ideals of Australasian Science'), and was a member of many Research Committees (David 1904). His address was a successor to a lecture on 'University Science Teaching' that he had delivered at Sydney University on 3 October 1902 (David, 1902), and moved from the experience of one university to a broader vision of science in the new nation as a whole (David 1904, p.4).

A 'FINAL' HOME FOR SCIENCE

David had a way with politicians and administrators, learnt early during his time in the NSW Department of Mines. However, it was Liversidge – the arch-organiser and administrator – who scored greater goals with the political leadership of New South Wales (MacLeod, 2001, 2009). For our purposes, it will suffice to remind the reader that Liversidge played a large part in re-establishing the Royal Society of New South Wales, and in finding a suitable building for its library and meetings in Elizabeth Street, Sydney. But Liversidge had greater ambitions, and sought to bring about a single home for all the sciences, and for the members of all the colony's scientific societies.

In his 1890 Presidential Address to the Royal Society of NSW, Liversidge expressed his hope of seeing in Sydney a 'modest edition of Burlington House, Piccadilly, which had been built by the Imperial government to lodge learned societies' (Liversidge 1890). In 1895, Liversidge and David acquired land adjacent to the Society's building in Elizabeth St, and made further acquisitions in 1905. The Engineering Association of New South Wales and the Institute of Architects rented rooms, as did the Institution of Surveyors and the Dental Association of New South Wales. Liversidge's return to England in 1908, and the coming of the First World War interrupted plans for a new site. However, in 1922, when the Society's premises were again enlarged and other scientific societies became tenants, the Governor of NSW, Sir Walter Davidson (1859–1923), a former school classmate of David, pushed for the construction of a 'Science House' – perhaps as close as Sydney could come to a version of 'Solomon's House' in Francis Bacon's utopian *New Atlantis*.

David played almost no part in the practicalities of the project, as he was overseas during the mid-1920s when negotiations took place between the three societies (the Royal, the Linnean, and the Institution of Engineers) and the NSW State government. On his return to Australia, his attention was interrupted by a search for Precambrian fossils in South Australia, and poor health diminished his interest. However, as a Council member of the Royal Society of NSW, he was always supportive, and spoke at several early Science House meetings. In his obituary of Liversidge for the Royal Society of London, David (1930) recalled his colleague's foresight in acquiring the Elizabeth St. site:

> '*This building has quite recently been sold and the Royal Society of New South Wales, the Linnean Society of New South Wales and the Institute [sic] of Engineers, Australia, are sharing equally between them the cost of the erection of a building to be called Science House. The housing under one roof of the libraries of the Royal and Linnean Societies of New South Wales [the Engineers' library was forgotten!] will be a great boon to scientific workers in that State [and so it proved for some fifty years]. This creation of a sort of Burlington House, on a small scale, for Sydney was one of Liversidge's ideals, to the realisation of which his foresight contributed not a little.*'

In 1925, when David was preparing to travel to England to 'complete and publish' his *Geology of the Commonwealth*, the project at last took off. The Royal Society of NSW invited the Linnean Society and the Institution of Engineers Australia to join an Executive Committee, which made a formal approach to the State Government for assistance 'in the shape of a site for the erection of Science House' (Vonwiller 1931, p. 3). On 28 July 1927, the Premier, J.T. Lang, authorised a grant of land on the corner of Essex and Gloucester Streets. The next State Government endorsed his action, and the 'Science House (Grant) Act' was passed on 16 June 1928. In the expectation of quick construction the Royal Society's house at 5 Elizabeth Street was sold in October 1927. A design competition was won by the firm of Peddle, Thorp & Walker in 1928; tenders were received in December 1929; and construction began on 7 March 1930. The foundation stone was laid on 24 June 1930. Once building began, the Institution of Engineers plotted its progress (Anon. 1930a,b; 1931 a, b, c). In 1932. the new building won a well-deserved Sulman Award for Architecture (Fig. 7).

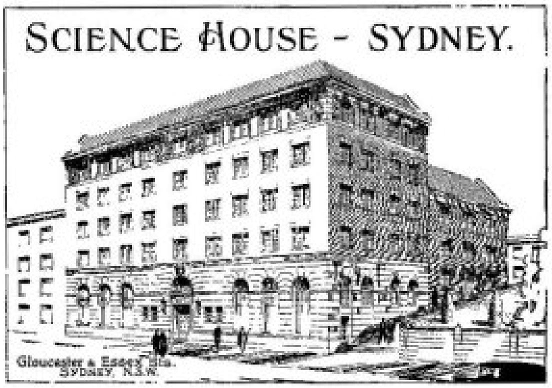

Figure 7. Sketch of Science House, Sydney.

The Royal Society's Annual General Meeting of 6 May 1931 – the day preceding the official opening of Science House – was the first held there by the Society. Co-incidentally, it was also the Society's 500th General Meeting, and marked the beginning of the Society's 75th year. In his Presidential Address, O.U. Vonwiller picked up on what David had written about Liversidge, and recounted the history of the long move to Science House, so that both the 'Architect' and the 'Statesman' were suitably remembered. They were soon to be remembered anew by the establishment of lectures (and medals) in their names. The bachelor Liversidge had not forgotten Australia at his death, and left a number of legacies: to the Royal Society, to the University of Sydney and to the AAAS, (which became ANZAAS). The first Royal Society 'Liversidge Lecture' was given in Science House on 24 September 1931 by Harry Hey, of the Electrolytic Zinc Co, Tasmania (Hey, 1931). The first ANZAAS Liversidge lecture was given on June 1930 by the West Australian chemist, Professor N.T. Wilsmore, the topic being 'Chemistry in its Relation to the State'. The first of the University of Sydney Liversidge Research Lectures – entitled 'Research in its relation to the University', and 'Some Problems in Carbohydrate Research' – were delivered in 1931 by Prof A. Killen Macbeth, an organic chemist from Adelaide University. The same year also saw the appointment of the first two Liversidge Research Scholars. The first David Lecture, sponsored by the Australian National Research Council (ANRC), and continued by ANZAAS, was given in Science House in November 1933 by E.W. Skeats (Skeats 1934), David being present.

But it is time to leave the story. By 1933, the 'Architect' had long departed, and the 'Statesman' would be nationally mourned less than a year later. In the midst of the Great Depression, the Royal Society of NSW faced many challenges – as Vonwiller put it: '*in common with the rest of the country, . . . difficulties of an abnormal kind.*' In August 1930, the State Government's subsidy, essentially for the *Journal*, was cut from £č400 to č200, [it was never restored to its former level].

With great foresight, Vonwiller saw:
'*. . . the time has come when we must review our position in view of altered conditions, and, if necessary, make changes, perhaps radical changes, in our methods, if we are to maintain our position and extend our influences and usefulness.*' (Vonwiller, 1931).

Vonwiller's message would reverberate through the Royal Society's meetings for the next eighty years. But in 1932, there were signs of hope. The opening of Science House coincided with the completion of the Sydney Harbour Bridge, designed by one of David's great friends, John Job Crew Bradfield (1867–1943), engineer and long-time member of the Royal Society of New South Wales. Today, the Bridge stands as an icon of Sydney, and of Australia, and as an emblem of the power of science and engineering. And today there are fresh signs that Science House – after thirty years of alternative use – may soon be restored to science. This is certainly a consummation devoutly to be wished. Should current discussions now succeed, a revived Science House will become for future generations a fitting, and, we hope, lasting tribute to Archibald Liversidge and Edgeworth David –

architect and statesman – and to their vision for the future of science and the scientific community in New South Wales.

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Correlation of the Devonian Formations in the Blantyre Sub-basin, New South Wales with the Adavale Basin, Queensland

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Abstract: The Devonian stratigraphic sequences of the Blantyre Sub-basin in the central part of the Darling Basin, New South Wales and in the Adavale Basin in south central Queensland have been reviewed and correlated, and are broadly comparable, but the former is in a more intracratonic or proximal situation than is the latter. The three major units of the Blantyre Sub-basin can be correlated with the eleven lithostratigraphic units of the Adavale Basin. The information obtained is particularly relevant to an understanding of the petroleum prospectively of the Blantyre Sub-basin.

Keywords: Blantyre Sub-basin, Darling Basin, Adavale Basin, Devonian sequence, lithostratigraphic units, stratigraphic correlation, seismic lines, wireline logs, lithofacies.

INTRODUCTION

This paper presents the results and major conclusions of a regional seismic stratigraphic and well log analysis of the Devonian sequences in the Blantyre Sub-basin of the Darling Basin in New South Wales and the Adavale Basin in Queensland. This paper is one of the first detailed, comprehensive published accounts of a comparison of the stratigraphy and sedimentology of the Blantyre Sub-basin and the Adavale Basin. Of the studies of the Blantyre Sub-basin which have already been published, that by Khalifa (2009) and Khalifa & Ward (2009, 2010) have been the most important in defining subsurface stratigraphic and sedimentological framework in the central part of the Darling Basin.

The Blantyre Sub-basin is proving to be an important region for petroleum exploration, and is typical of sedimentary sub-basins in the Darling Basin, western New South Wales. Figure 1 shows the geographical location of the Blantyre Sub-basin in the central part of the Darling Basin in NSW and Adavale Basin in Queensland. The Adavale Basin is of approximately the same age and size as the Darling Basin (Bembrick 1997a; Alder et al. 1998; Passmore and Sexton 1984; Geological Survey of Queensland 2005, 2006; McKillop et al. 2007; Campbell & King 2009).

Many previous authors have documented and debated the age range of the Devonian sequence in the Darling Basin (Packham 1969; Ward et al. 1969; Brown et al. 1982; Glen 1979, 1982a, b; Glen et al. 1996; Byrnes 1985; Neef et al. 1989, 1995, 1996a, b; Neef 2003, 2004, 2009; Mullard 1995; Bembrick 1997a, b; Alder et al. 1998; Cooney & Mantaring 2007; Blevin et al. 2007; Khalifa 2005, 2006a, 2009; Khalifa & Ward 2009).

Several authors (e.g. Bembrick 1997a, b; Alder et al. 1998) have used four seismic marker unconformities (A, B, C & D), originally described by Evans (1977), to divide the stratigraphic sequence of the Darling Basin into three informal units.

Aspects of the lithostratigraphic units in the Blantyre Sub-basin and Adavale Basin have been described in the literature by authors such as Auchincloss (1976), Paten (1977), Catuhe & Laws (1979), Glen (1979, 1982a), Price (1980), Pinchin & Senior (1982), Sexton (1983), Moss & Wake-Dyster (1983), Passmore & Sexton (1984), Evans et al. (1990), De Boer (1996), Bembrick (1997a, b), Alder et al. (1998), Scheibner & Basden, (1998), McKillop et al. (2007) and Campbell & King (2009). A more recent appraisal of the subsurface stratigraphy and sedimentary facies of the Blantyre Sub- basin, relevant to the present discussion, is given by Khalifa (2005, 2006a, b, 2009) and Khalifa & Ward (2009, 2010).

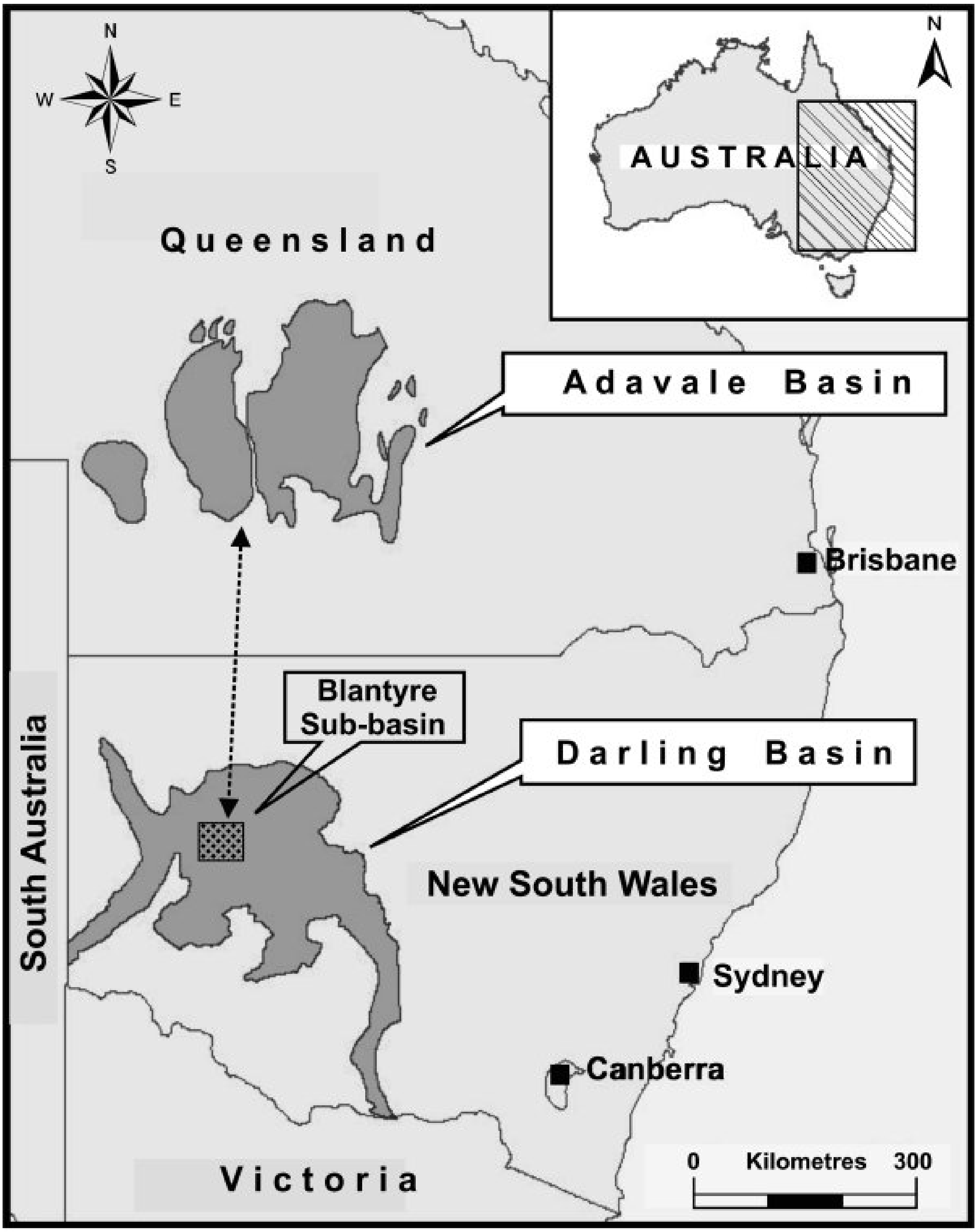

Figure 1. Geographical location of the Blantyre Sub-basin in the central part of the Darling Basin, NSW, in relation to the Adavale Basin, in south-central Queensland with boxes indicating the study areas used in the text (modified after Cooney & Mantaring 2007).

The scope of the current investigation was to review the Blantyre Sub-basin Devonian sequence and compile a framework of the stratigraphic sequence and lithostratigraphy into which information from further studies could be integrated. The purpose of this paper is to compare the lithostratigraphic units of the whole of the Blantyre Sub-basin, and relate them to several different the stratigraphic units within the Adavale Basin using the subsurface stratigraphy for correlation. A series of seismic lines, wireline logs and lithological logs has been used in this research.

STRATIGRAPHIC SETTING

The Devonian Stratigraphy of the Blantyre Sub-basin

The Devonian stratigraphy of the Blantyre Sub-basin has been summarised by Khalifa (2005, 2009) and Khalifa & Ward (2009) and consists of three main lithostratigraphic sequences - the Winduck, Snake Cave and Ravendale Intervals - separated by regional seismic sequence boundaries mapped as horizons 1, 2, 3 and 4/5 shown in Figure 2. The distribution of the seismic markers defining the lithostratigraphic sequences is illustrated in a series of regional seismic sections, using the Blantyre-1 and Mount Emu-1 wells for control, as interpreted by Khalifa (2005, 2006a, 2009) and Khalifa & Ward (2009) in Figures 3a, b and c. In the current paper key horizons are designated utilizing a similar nomenclature to that applied by previous authors to the Darling Basin (Bembrick 1997a, b; Alder et al. 1998; Cooney & Mantaring 2007; Blevin et al. 2007). These key divisions correspond to the four seismic horizons A, B, C and D identified in the lithostratigraphic sequences of latest Silurian to late Devonian age by Evans (1977).

Khalifa (2005, 2006a, 2009), Khalifa & Ward (2009), Khalifa & Mills (2010) suggested that Horizon 1 is the base of the Winduck Interval/top of undifferentiated Proterozoic complex and/or Cambro-Ordovician sediments, Horizon 2 is the base of Snake Cave Interval/top of Winduck Interval, Horizon 3 is the base of Ravendale Interval/top of Snake Cave Interval and Horizon 4/5 is the base of undifferentiated Upper Carboniferous-Permian sediments. Horizon 4/5 may be the top of either the Snake Cave, or Ravendale Intervals, or even locally the top of Winduck Interval within the sub-basin (Figure 2).

In general the stratigraphic framework of the Blantyre Sub-basin comprises three lithostratigraphic sequences of latest Silurian to Devonian age, the succession in the sub-basin is subdivided on the basis of regional seismic horizons into three major intervals as follows: (1) Latest Silurian to Early Devonian (Pragian) Winduck Interval and equivalents, (2) Early Devonian (Emsian) to Middle Devonian (Eifelian) Snake Cave Interval and equivalents, and (3) Middle Devonian (Givetian) to Late Devonian (Famenian) Ravendale Interval and equivalents (cf. Bembrick 1997a, b; Alder et al. 1998; Cooney & Mantaring 2007). The generalised stratigraphy is summarised in Figure 2, which shows major sedimentological changes across the Blantyre Sub-basin based on earlier work such as Khalifa (2005, 2006a, 2009), Khalifa & Ward (2009, 2010) and Khalifa & Mills (in prep) provide updated summaries of the scheme, as discussed below.

The Devonian Stratigraphy of the Adavale Basin

The Adavale Basin is an onshore entirely concealed subsurface basin, approximately 850 kilometres west-northwest of Brisbane in south central Queensland. The preserved areal extent of the basin is 66,000 square kilometres, including the Warrabin and Barcoo Troughs. The basin overlies a basement of early Palaeozoic metamorphic and igneous rocks of the Lachlan or Thompson Fold Belts (Heikkila 1966; Slanis & Netzel 1967; Auchincloss 1976). During the Early and Middle Devonian, the basement rocks were overlain by volcanics and continental clastics, and by marine clastics deposited in a westerly-transgressive sea (Galloway 1970; Paten 1977; Price 1980).

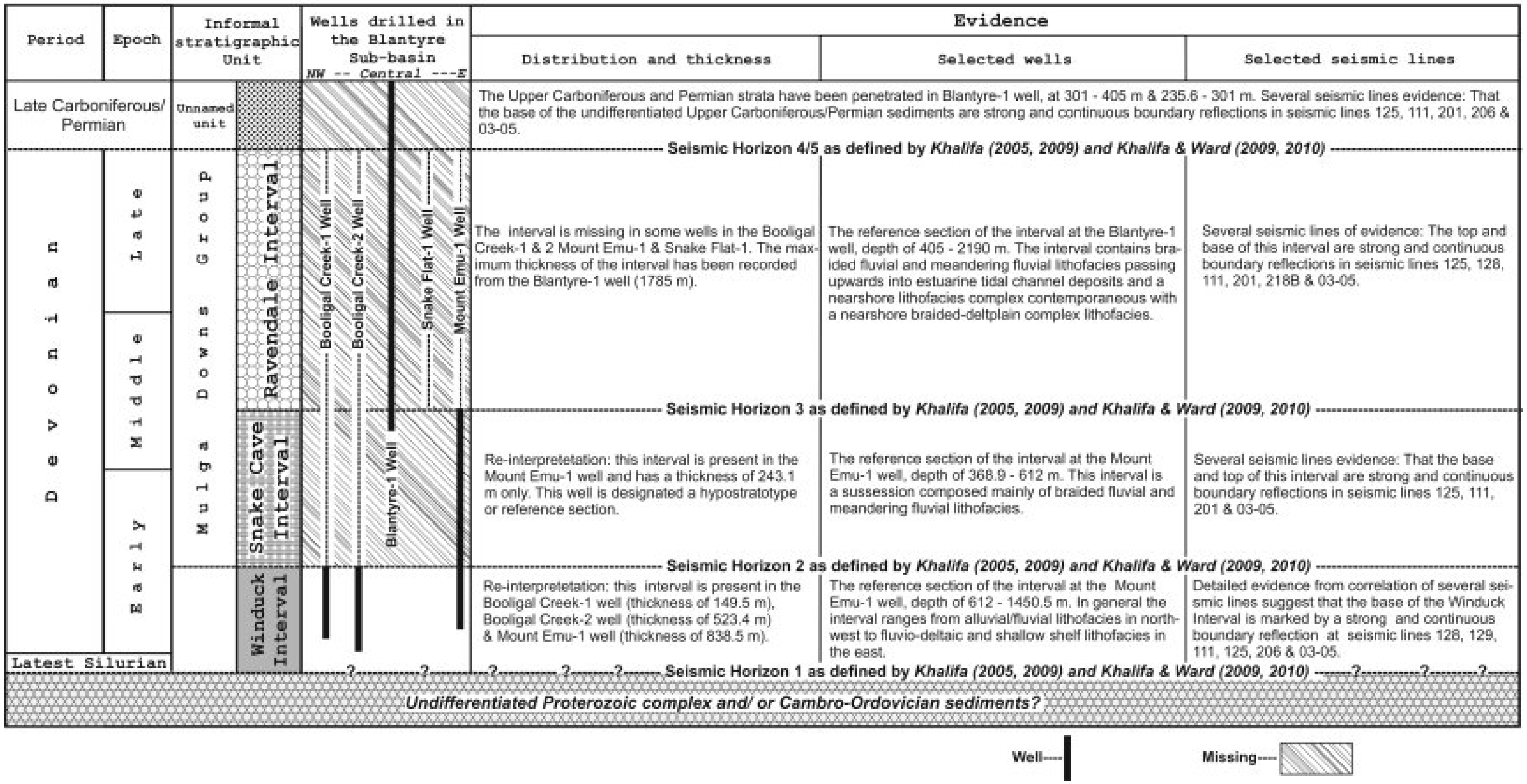

Figure 2. Generalised lithostratigraphic subdivision of the Devonian sequence (Winduck, Snake Cave and Ravendale Intervals), and correlation in the Blantyre Sub-basin. Regional seismic markers from Khalifa (2005, 2009) and Khalifa & Ward (2009, 2010) are correlated with the three informally named 'Intervals' described by Bembrick (1997a, b).

This early marine deposition was succeeded by more restricted marine and evaporite deposition in a regressive sea, and by continental clastics, during the Middle and Late Devonian and possibly into the Early Carboniferous. Seismic data suggest that the total thickness of strata in the basin may be as much as 8500 m (Passmore & Sexton 1984).

The Adavale Basin and associated troughs were discussed in detail by Paten (1977), Moss & Wake-Dyster (1983), Passmore & Sexton (1984); Evans et al. (1990); De Boer (1996), Geological Survey of Queensland (2005, 2006) and Campbell & King 2009. Paten (1977) provided detailed information on the Devonian stratigraphy and suggested revisions to lithostratigraphic relationships and nomenclatures used by previous workers. The Devonian lithostratigraphy has been divided in into several units of the Gumbardo Formation consisting mainly of continental volcanic sediments with red bed unit. The Eastwood Beds and the Log Creek Formation are divisions of a sequence of sandstones and carbonates. The Bury Limestone and Cooladdi Dolomite are divisions of a sequence of carbonates. The Lissoy Sandstone is generally siliciclastic sediments overlain by the Cooladdi Dolomite. The Etonvale Formation contains a sandstone member, a Boree salt member, an evaporitic carbonate and a shale/siltstone member and the Buckabie Formation consists of continental redbeds of sandstone, shale and siltstone (Figure 4).

The Devonian sequences have been affected by two major tectonic and depositional events (Moss & Wake-Dyster 1983; Passmore & Sexton 1984). In the mid- Devonian the sequence was uplifted during the Tabberaberran Orogeny. Minor erosion took place prior to a marine transgression in which the Cooladdi Dolomite was deposited widely through the Adavale Basin. In the mid-Carboniferous the entire Devonian sequence was folded and faulted during the Kanimblan Orogeny. The Devonian sequences were stripped from basement highs during a major period of erosion which peneplaned the region separating the Adavale Basin from surrounding depressed areas also containing substantial thicknesses of Devonian sediments. Devonian sequences have been penetrated in exploration wells in the Cooladdi, Warrabin and Barcoo Troughs; the existence of Devonian sequences in the Quilpie and Westgate Troughs is inferred from geophysical information.

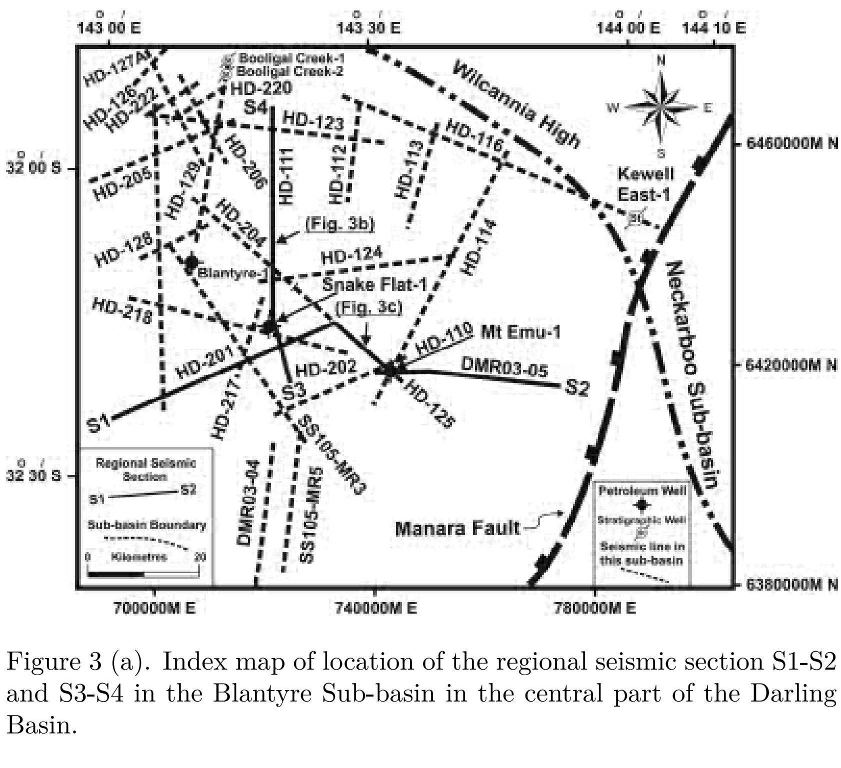

Figure 3 (a). Index map of location of the regional seismic section S1-S2 and S3-S4 in the Blantyre Sub-basin in the central part of the Darling Basin.

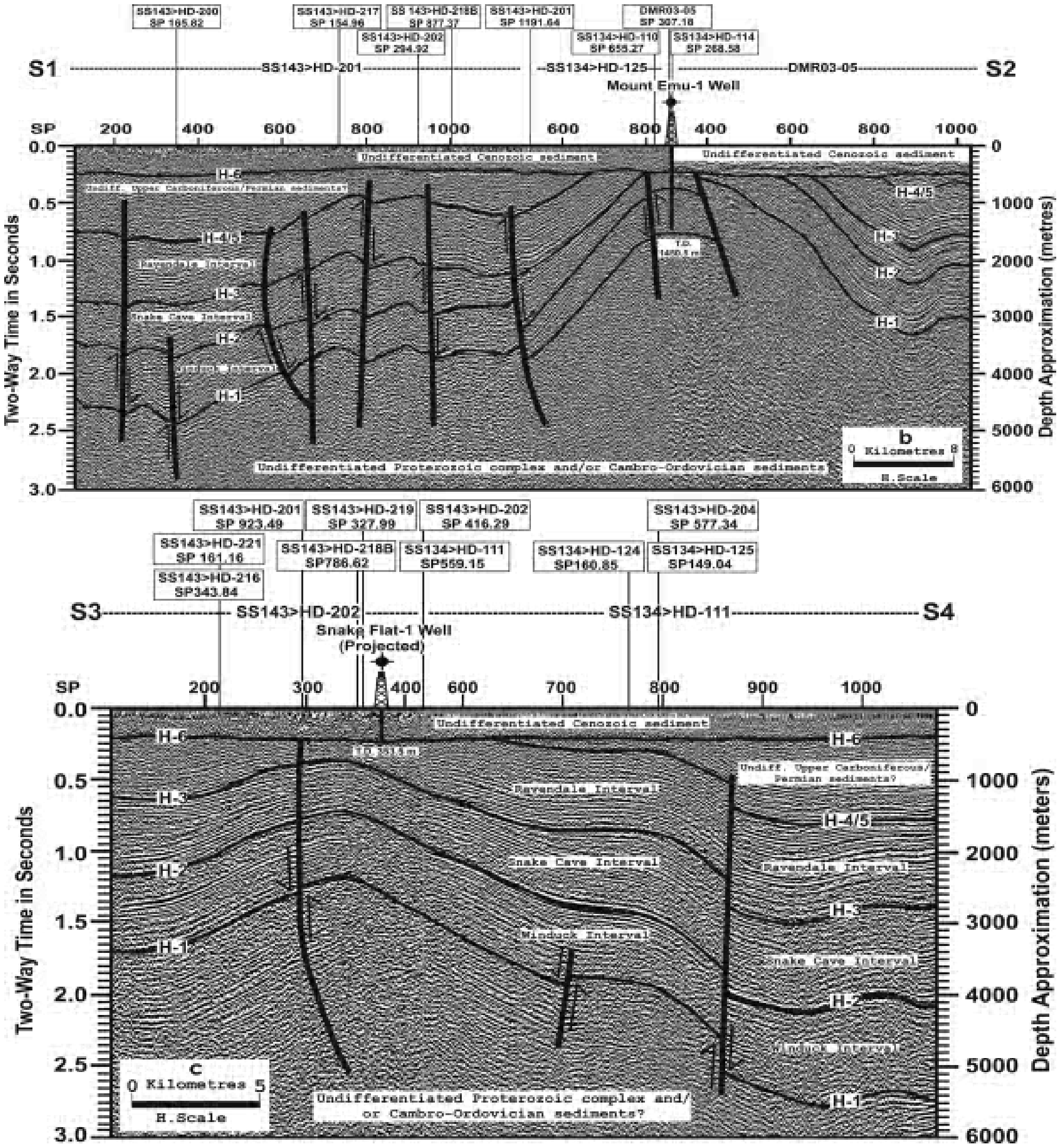

Figure 3 (b). Interpreted regional seismic section S1-S2, showing the geometry of the lithostratigraphic sequences within the Blantyre Sub-basin. The section is based on well data and seismic lines SS143>HD-201, SS134>HD-125 and DMR03-05. (c) Interpreted regional seismic section S3-S4, showing the geometry of the lithostratigraphic sequences within the Blantyre Sub-basin. The section is based on well data and seismic lines SS143>HD-202 and SS134>HD-111. See location of regional seismic section S1-S2 and S3-S4 is shown in Figure 3a.

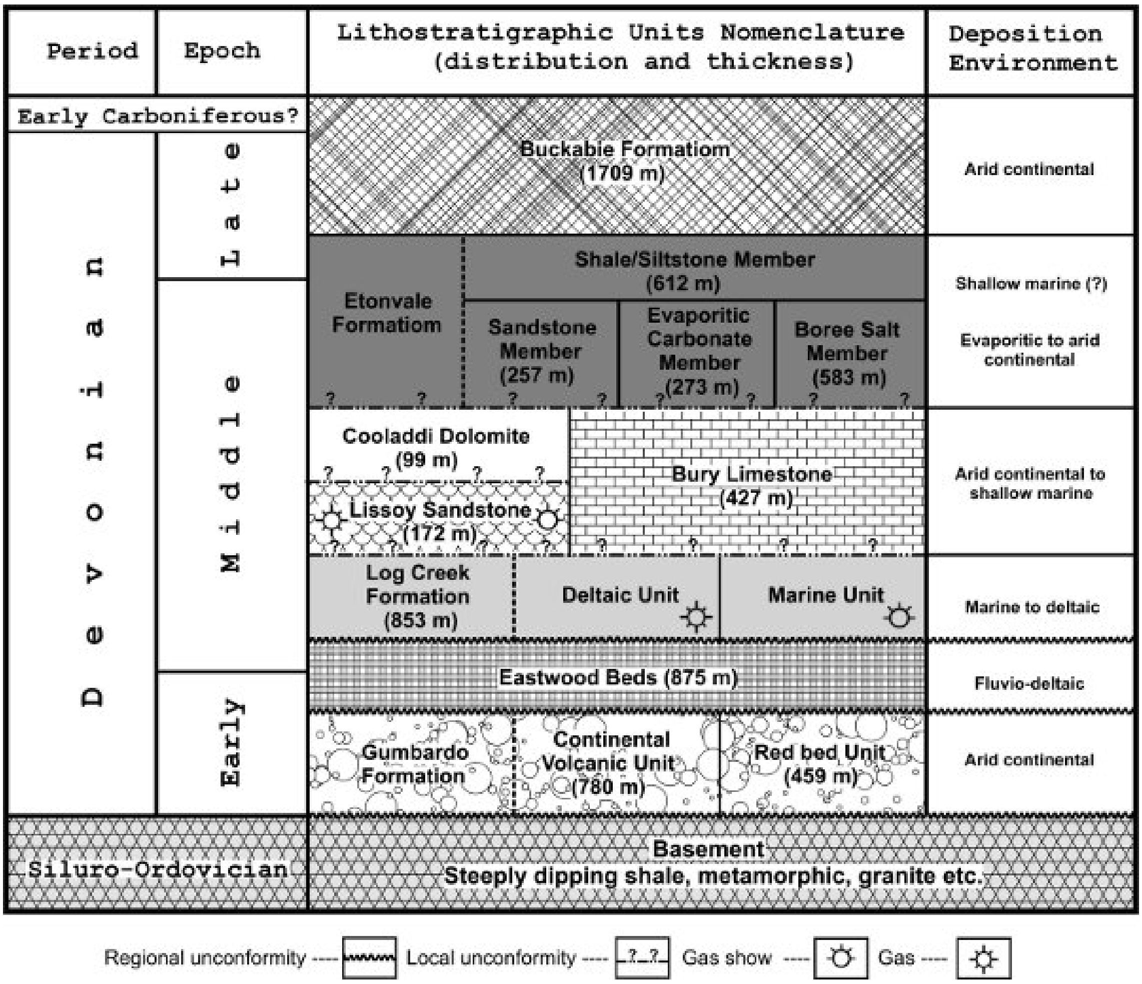

Figure 4. Major lithostratigraphic units of the Devonian sequence in the Adavale Basin and thicknesses of the units drilled (modified from Paten 1977; Wake-Dyster 1983 Passmore & Sexton 1984; De Boer 1996; Campbell & King 2009).

OBSERVATIONS AND DISCUSSION

Lithostratigraphy and Correlations

The Blantyre Sub-basin lithostratigraphy was comprehensively reviewed by Khalifa (2005, 2006a, 2009) and Khalifa & Ward (2009) so this section is simply a summary of the data significant to the Blantyre Sub-basin. The results resulted in a new lithostratigraphic correlation of the Winduck, Snake Cave and Ravendale Intervals for the Blantyre Sub-basin (Khalifa & Ward, 2009) (Figure 5). The Adavale Basin stratigraphic succession has recently been summarised by Paten (1977), Moss & Wake- Dyster (1983), Passmore & Sexton (1984) and De Boer (1996), shown in Figure 4.

As part of the preparation for this paper, a palaeogeographic study compared the Devonian sequence of the Blantyre Sub-basin with that of the better-understood Adavale Basin, in Queensland to the north (Figure 1). After a review of the available published and unpublished literature, a comparison was drawn up from the work of Bembrick, 1997a, b; Alder et al. 1998; Cooney & Mantaring 2007; Khalifa 2005, 2009; Khalifa & Ward 2009, 2010 and extended to show the relation of the Adavale stratigraphy to the results of the present study (Figure 5). The Adavale Basin has up to 8000 metres of Devonian sediments (Moss & Wake-Dyster 1983; Passmore & Sexton 1984; Evans et al. 1990; Geological Survey of Queensland 2005, 2006; Campbell & King 2009) and a short summary of the comparative stratigraphic sequence and lithostratigraphy, from bottom to top, is given below:

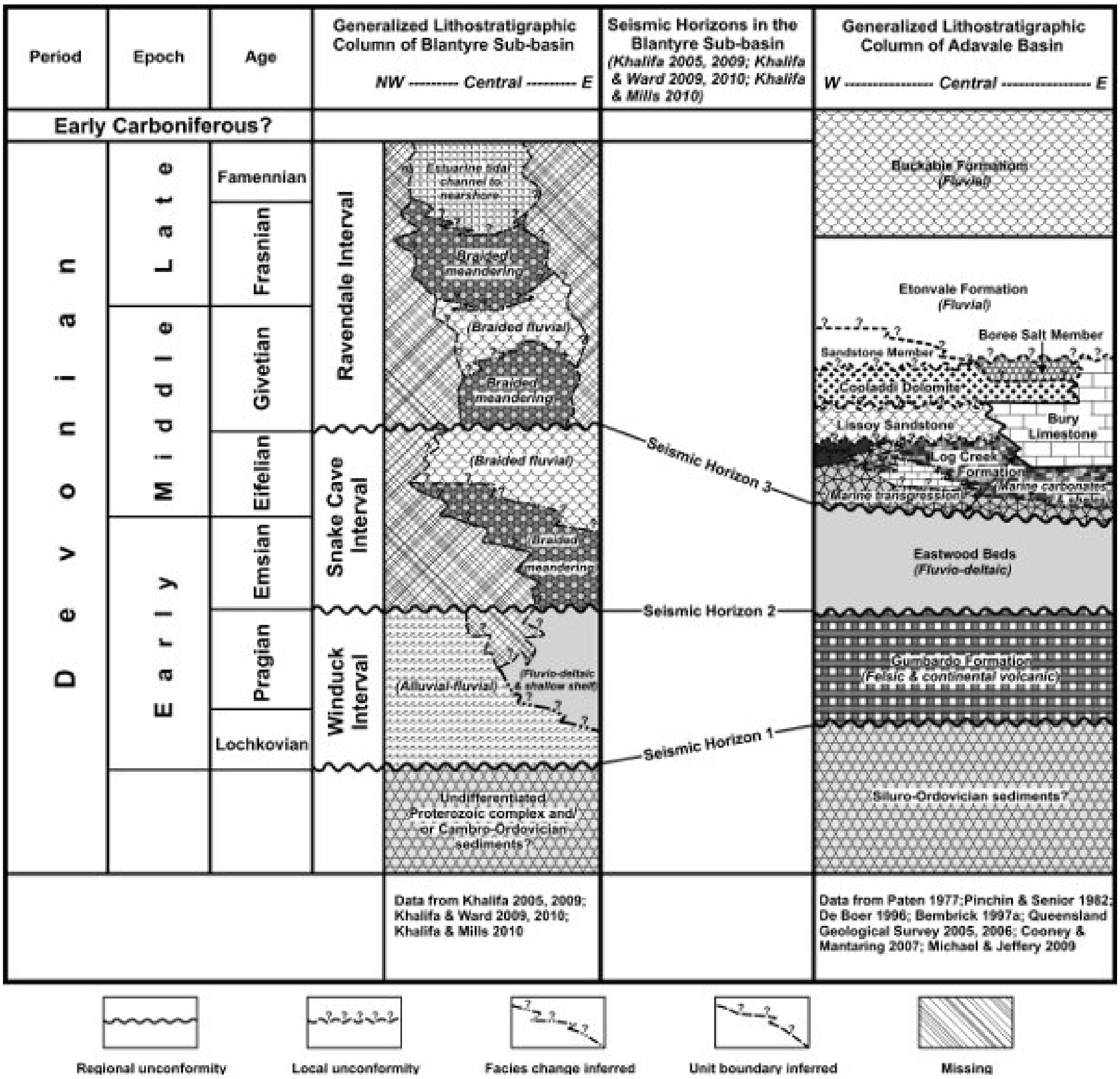

Figure 5. Lithostratigraphic correlation of the Devonian sequence and its equivalents in the Blantyre Sub-basin with that of the Adavale Basin as delineated in the present-day.

Winduck Interval Equivalent – Gumbardo Formation Description and Stratigraphic Correlation

Horizon 1 marks the base of the Winduck Interval identified within the main Blantyre Sub-basin, on the results of regional mapping by Khalifa (2005, 2009: Figures 8-9). The base of this interval is a laterally continuous high-amplitude reflection throughout the Blantyre Sub-basin (Figures 3a, b). It is probably equivalent to the horizon used by Bembrick (1997a, b), Alder et al. (1998) and Cooney & Mantaring (2007), and also to the 'Horizon A' seismic marker as defined by Evans (1977). Horizon 1 is widespread throughout the Blantyre Sub-basin. Its depth ranges between 0.2 to 2.7 s TWT (two-way travel time), being shallowest near the northern margin and deepest in the faulted central part of the Blantyre Sub-basin (Khalifa 2005, 2009; Khalifa & Ward 2009).

A boundary between the Winduck and the Snake Cave Intervals (Horizon 2) can be seen in data from the Mount Emu-1 well. The synthetic seismogram (Khalifa & Ward 2009: see data in table 2 at Geological Society of Australia or National Library of Australia) shows only a relatively weak event at the depth taken as the boundary from the well log. Khalifa & Ward (2009) interpreted the seismic line SS134>HD-125 as showing a stronger reflector 0.36 seconds TWT (612 m) shallower than this horizon, and this was taken as the boundary for the current seismic interpretation.

The Winduck Interval occurs in the Booligal Creek-1 (260–409.5 m) and Booligal Creek-2 (238?-761.4 m) wells, on the northwestern flank of the Blantyre Sub- basin (Khalifa and Ward 2009: Figure 8 and data table 1). This interval is represented in these wells by core samples that are quite similar lithologically, composed mainly of brown to light brown, reddish brown and white sandstones that are medium- to coarse- grained. The grains are commonly micaceous, with intercalations of siltstone and some shale that are variable in thickness. The sandstones and siltstones display small-scale cross bedding and horizontal-laminations (Jessop & Cowan-Lunn 1996; Khalifa 2005; Khalifa & Ward 2009; Khalifa & Mills, in prep).

The Winduck Interval of Early Devonian (Lochkovian and Pragian) sedimentation in the Blantyre Sub-basin has complete equivalent in the Adavale Basin where the initiation of deposition began in the Early Emsian with the Gumbardo Formation (cf. Bembrick 1997a; Alder et al. 1998; Cooney & Mantaring 2007). This formation consists of felsic and continental volcanic and rests unconformably upon basement (Paten 1977; Moss & Wake-Dyster 1983; Passmore & Sexton 1984; Evans et al. 1990). The Gumbardo Formation may represent a correlative of the upper part of the Winduck Interval (Figure 5). The Gumbardo Formation is below drilled depths in the east of the Adavale Basin (Auchincloss, 1976; cited in Evans et al. 1990: Figure 6).

Khalifa (2009) has described the strata of the Winduck Interval, as defined from seismic line DMR03-05, as having an estimated thickness in the Blantyre Sub-basin of approximately 1,400 m (Khalifa 2009: Figure 8). At the central part of the Blantyre Sub-basin in the Mount Emu-1 well, the interval is 838.5 m thick and consists of interbedded sandstone and shale, overlying relatively pure sandstone (Khalifa 2005; Khalifa & Ward 2009: Figure 5).

Snake Cave Interval Equivalent – Eastwood Beds Description and Stratigraphic Correlation

Horizon 2 is taken for this paper as the base of the Snake Cave Interval as defined by Khalifa & Ward (2010: Figures 7, 11 & 14). This horizon shows a strong and continuous reflection across the Blantyre Sub-basin (Figures 3a, b), and is taken as the Winduck/Snake Cave boundary. The interpretation of synthetic seismograms suggests that the contact between the base of the Snake Cave Interval and the top of the Winduck Interval is marked by a sharp increase in the Mount Emu-1 well (Khalifa & Ward 2009: data in table 2 at Geological Society of Australia or National Library of Australia). It is probably equivalent to the horizon used as a similar marker by Bembrick (1997a, b), Alder et al. (1998) and Cooney & Mantaring (2007), equivalent to the 'Horizon B' seismic marker as defined by Evans (1977).

Horizon 2, recognised in all of the regional seismic sections within the Blantyre Sub-basin, ranges in depth between 0.02 and 2.2 s TWT (two-way time), being shallowest near the northern margin of the sub-basin and deepest in the faulted region in the central part of the sub-basin (Khalifa & Ward 2009: Figures 10–12).

A representative of seismic Horizon 2, as the base of the Snake Cave Interval in the Blantyre Sub-basin, appears also to be present at approximately the same stratigraphic level in the Adavale Basin. Khalifa & Ward (2009) suggested equivalence for this horizon and it is clear that the presence of a local angular unconformity between the Snake Cave and the Ravendale Intervals, as indicated by Horizon 2 in regional seismic section A2-B2 in the Blantyre Sub-basin (Khalifa & Ward 2009, Figure 11), is repeated in the Adavale sequence.

Of the studies of the strata of the Snake Cave Interval in the Blantyre Sub-basin, which have already been published, that by Khalifa (2009) and Khalifa & Ward (2009) has been devised by combining information from seismic lines and well logs. In the wells, the maximum thickness of the Snake Cave Interval (243.1 m) has been recorded in the Mount Emu-1 well, and the minimum thickness around 100 m in the Blantyre-1 well. However, the observed thickness in seismic sections reaches an estimated 1,600 m in the western Blantyre Sub-basin (see Khalifa 2009, seismic line SS143>HD-218B Figure 9).

The Snake Cave Interval appears to be a time-equivalent to the complete Eastwood Beds in the Adavale Basin. Figures 4 & 5 shows the Log Creek Formation, overlying the Eastwood Beds. The Eastwood Beds has been encountered only at the northern end of the basin (see Evans et al. 1990, cross-section Figure 9, pp. 93). The Eastwood Beds were probably deposited in a fluvio-deltaic environment (Paten 1977; Passmore & Sexton 1984 cited in Evans et al. 1990). However, the Snake Cave Interval in the Blantyre Sub-basin is a succession mainly composed of braided and meandering fluvial lithofacies as documented by Khalifa (2005, 2006b) and Khalifa & Ward (2010, Figures 4, 8, 12a, 15 & 16).

However, at the close of Eastwood Beds deposition, uplift and erosion in the Adavale Basin occurred, followed by a marine transgression above a mid-Eifelian hiatus. This Eifelian transgression in the Adavale Basin was interrupted in its westward progress by a brief regressive pulse, and transgression was not completed until the rocks of Early Givetian age were deposited (Figure 5).

Ravendale Interval Equivalent – Several Lithostratigraphic Units Description and stratigraphic correlation

Seismic Horizon 3, corresponding to the Snake Cave/Ravendale boundary, has been traced by Khalifa (2005) and Khalifa & Ward (2010, Figures 7, 11 & 14) throughout the Blantyre Sub-basin. It is probably equivalent to the horizon used as a similar marker by Bembrick (1997a, b), Alder et al. (1998) and Cooney & Mantaring (2007), equivalent to the 'Horizon C' seismic marker as defined by Evans (1977). As shown in Figure 3a, b; Horizon 3 is defined throughout the Blantyre Sub-basin.

Khalifa (2005) and Khalifa & Ward (2009) mapped Horizon 3 as widespread throughout the Blantyre Sub-basin, at a depth ranging from 0.25 to 1.5 s TWT (two-way time). Horizon 3 marks the base of the Ravendale Interval and is shallowest in the southeastern and northern parts of the sub-basin and deepest in the faulted region in the central part of the sub-basin (Khalifa & Ward 2009, Figure 10).

The Ravendale Interval is widespread in the Blantyre Sub-basin, but locally is hard to distinguish from the overlying undifferentiated Upper Carboniferous-Permian sediments. Khalifa (2005, 2006a, 2009) recorded that the strata of the Ravendale Interval reach a maximum thickness of approximately 1200 m (0.3 s TWT) in the western Blantyre Sub-basin (Khalifa 2009, Figure 9). However, the base of the Ravendale Interval is missing in part of the Blantyre Sub-basin, especially in the northeast, due to erosion after deposition and uplift (see Khalifa 2009, regional seismic section F3-F4 on Figure 8).

The sediments of the Ravendale Interval were deposited under a braided fluvial and meandering fluvial lithofacies passing upwards into estuarine tidal channel deposits and a nearshore lithofacies described by Khalifa & Ward (2010, Figures 10, 12b & 17).

Rocks of Late Devonian age are widespread throughout the Adavale Basin. These are mapped as several different lithostratigraphic units, including the Log Creek Formation sequence (including the deltaic unit and marine unit), Lissoy Sandstone, Bury Limestone, Cooladdi Dolomite, Etonvale Formation (divided into four members: Boree salt, sandstone, shale/siltstone and evaporitic carbonate members) and Buckabie Formation (Figures 4-5). The whole sequence is probably equivalent to the Ravendale Interval in the Blantyre Sub-basin. The Tabberabberan event within the Middle-Late Devonian, represented by Seismic Horizon 3 in the Blantyre Sub-basin, appears to be present at approximately the same stratigraphic level in the Adavale Basin.

The Ravendale-equivalent sequence in the Adavale Basin includes an extensive carbonate succession with limestones and dolomites. Paten (1977 cited in Evans et al. 1990, Figure 11) suggested that the limestone/shale facies of the Bury Limestone in the south and southeastern parts of Adavale Basin was deposited within an open sea. In the western part of the basin, however, this sequence is represented by the Cooladdi Dolomite, which was formed in a more landward zone with evaporitic lagoons and restricted water circulation. The nature of these facies of the Log Creek Formation indicates open sea towards the east and southeast during the period of maximum marine transgression in the Adavale Basin (Figure 5).

This marine section, however, appears to be younger than the possible shallow marine deposits interpreted in the present study within the Ravendale Interval. Clastic sequences, such as the Lissoy Sandstone (Figure 5), were also deposited in delta complexes within the Adavale Basin, with distribution varying according to the interplay of eustatic changes in sea level (Shaw 1995). No equivalents to the Bury Limestone, Cooladdi Dolomite and Lissoy Sandstone appear to be present in the lower part of the Ravendale Interval in the Blantyre Sub-basin (see also Bembrick 1997a).

The Etonvale Formation, overlying the Bury Limestone and Cooladdi Dolomite, contains three different lithofacies: dominantly sandstone, shale, and salt (Galloway 1970). The Boree Salt Member is confined to the east of the Adavale Basin (Moss & Wake-Dyster 1983, Table 1), resting upon the Bury Limestone. The remainder is regarded as representing fluvial deposits.

The Buckabie Formation may represent a correlative to the upper part of the Ravendale Interval (Figure 5). The Buckabie Formation has been variously regarded as Late Devonian and possibly Early Carboniferous (Paten 1977; Wake-Dyster 1983; Passmore & Sexton 1984; Evans et al. 1990). The Buckabie Formation consists of interbedded red sandstone and shale, and was probably deposited in a non-marine, fluvio-lacustrine environment (Paten 1977; Wake-Dyster 1983). The Ravendale Interval in the Blantyre Sub-basin, however, has been divided in the present study into three different lithofacies, represented, from oldest to youngest, by meandering fluvial, braided fluvial, and estuarine tidal channel/nearshore transgressive marine deposits (see Khalifa & Ward 2010, Figure 17). Marine sediments are possibly represented near the top of the Etonvale Formation in the Adavale Basin (Paten 1977; Wake-Dyster 1983; Passmore & Sexton 1984; Evans et al. 1990), marking a marine transgression before the regression that formed the Buckabie Formation. It is possible that this marine transgression is also represented in the shallow marine lithofacies of the Ravendale Interval in the Blantyre well (Khalifa 2005, 2006b; Khalifa & Ward 2010, Figure 12b).

CONCLUSIONS AND SUMMARY

1) The stratigraphy and correlation of lithostratigraphic sequences including the Winduck, Snake Cave and Ravendale Intervals are consid-

ered as separated by regional seismic sequence boundaries mapped as horizons 1, 2 and 3 in the Blantyre Sub-basin based on a combination of geophysical and geological data, originally described by Khalifa (2005, 2006a, 2009) and Khalifa & Ward (2009). The work reviews the subsurface distribution of the latest Silurian to Devonian sequence throughout the Blantyre Sub-basin.

2) Figure 5 provides a lithostratigraphic diagram of the Devonian sequence, showing the distribution of the different units. The Winduck Interval is latest Silurian (Lochkovian) to Early Devonian (Pragian) in the Blantyre Sub-basin and has no equivalent in the Adavale Basin, deposition being initiated there in the Early Emsian with the Gumbardo Formation. The Snake Cave Interval is of Early Devonian (Emsian) to Middle Devonian (Eifelian) and appears to be a time-equivalent to the sequence encompassing Eastwood Beds in the Adavale Basin. However, rocks of Late Devonian age are widespread throughout the Adavale Basin and are mapped as several different lithostratigraphic units, including the Log Creek Formation, Lissoy Sandstone, Bury Limestone, Cooladdi Dolomite, Etonvale Formation and Buckabie Formation. The whole sequence is probably equivalent to the Ravendale Interval in the Blantyre Sub- basin.

3) Future work could undertake a more detailed regional seismic stratigraphic and well log analysis of the relationship of the Blantyre Sub-basin to the Adavale Basin and other eastern Australian basins or sub-basins of Devonian age and examine the relation of these areas to the tectonostratigraphic sequence development of eastern Australia.

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Possible Cosmological Spatial Variation in the Fine-structure Constant

JULIAN A. KING, JOHN K. WEBB, MICHAEL T. MURPHY, VICTOR V. FLAMBAUM, ROBERT F. CARSWELL, MATTHEW B. BAINBRIDGE AND F. ELLIOT KOCH

Abstract: Quasar absorption lines can be used to search for variations in the fine-structure constant, $\alpha \equiv e^2/(4\pi\epsilon_0\hbar c)$, over cosmological times and distances. Previous results from the Keck telescope, in Hawaii, have yielded evidence that α was smaller in the past at the 5σ level. We have analysed 154 quasar absorbers using publicly availble spectra from the VLT (Very Large Telescope), in Chile. The VLT results individually suggest that α may have been larger in the past. A joint analysis of the VLT and Keck data sets finds $> 4\sigma$ evidence for spatial variation in α that is well-represented by a dipole across the sky. The VLT and Keck data sets demonstrate a number of consistencies which supports the idea that the detected dipole effect is real. We are unaware of any systematic effect which can explain the observed dipole effect.

Keywords: fine-structure constant, quasar absorption lines, variation of fundamental constants, cosmology

INTRODUCTION

Quasar absorption lines (QALs), generated by the absorption of light by gas clouds located along the line of sight to quasars, can be observed at extremely high redshifts (z) corresponding to light-travel times approaching the age of the the universe. QALs can be used to constrain evolution in certain fundamental constants throughout time and space (Bahcall et al. 1967). The relative wavelengths of certain transitions observed in QALs can be used to constrain the fine-structure constant, $\alpha \equiv e^2/(4\pi\epsilon_0\hbar c)$. In particular, by comparing the relative spacings of the transitions with precise laboratory measurements one can constrain the relative deviation in α from laboratory values, $\Delta\alpha/\alpha \equiv (\alpha_z - \alpha_0)/\alpha_0$ (where α_z is the value of α at redshift z).

The many-multiplet method

For a particular atomic or ionic transition, the observed rest-frame wavenumber at redshift z, ω_z, depends on α as

$$\omega_z = \omega_0 + qx \tag{1}$$

where

$$x = (\alpha_z/\alpha_0)^2 - 1 \tag{2}$$

provided that $|\Delta\alpha/\alpha| \ll 1$. q is the "sensitivity coefficient" which determines how sensitive a particular transition is to a change in α (Dzuba et al. 1999, Murphy et al. 2003). The sign and magnitude of q is different for different transitions; $|q|$ increases with the square of the nuclear charge (Z^2), and the sign of q is opposite for *s*-*p* and for *d*-*p* transitions. In the many-multiplet method, one compares the relative spacing of transitions from different atomic and ionic species to measure $\Delta\alpha/\alpha$. The use of transitions from different species yields an order-of-magnitude sensitivity improvement from just examining transitions from one species. The use of a number of transitions that have q values of differing sign and magnitude helps control systematic effects (which do not "know" about the signs and magnitudes of the values of q).

Previous results and objective

Significant evidence has emerged from HIRES (High Resolution Echelle Spectrometer) on the Keck Telescope, in Hawaii, that α may have been smaller in the past. In particular, Murphy et al. (2004) analysed 143 absorption systems with spectra from the Keck telescope (see also Webb et al. 1999, 2001, Murphy et al. 2001, 2003), giving a weighted mean over all the systems of $\Delta\alpha/\alpha = (-0.57 \pm 0.11) \times 10^{-5}$ — evidence that α may have been smaller at high redshift at the 5σ level. Due to the location of the Keck telescope (latitude $\sim 20°$N) the observations are obtained preferentially in one celestial hemisphere. Additionally, the use of only a single telescope to observe the quasar absorbers is undesirable.

Chand et al. (2004) analysed 23 absorption systems using spectra from UVES (the Ultraviolet and Visual Echelle Spectrograph) on the VLT (Very Large Telescope), in Chile (at $\sim 25°$S), however their analysis was shown to be unreliable (Murphy et al. 2007, 2008).

We have attempted to verify or dispute the results of Murphy et al. (2004) by analysing a large number of quasar absorbers from spectra in the publicly available VLT/UVES archive.

ANALYSIS METHODS & METHODOLOGY

To measure $\Delta\alpha/\alpha$ in each quasar absorber, we use the non-linear least squares program VPFIT to fit Voigt profile models to the observed absorption profiles. If the absorption occurred in a single cloud of gas, with no internal velocity structure, the absorption lines would comprise just a single, symmetric component, making the measurement of $\Delta\alpha/\alpha$ straightforward. However, in practice the vast majority of absorption systems display complicated "velocity structure". In order to measure $\Delta\alpha/\alpha$ reliably from such complicated profiles, a model of the velocity structure, with a minimum number of parameters, is constructed and fitted to all available transitions simultaneously. To determine the minimum number of parameters required for the model, we compare models with different numbers of parameters using the Akaike Information Criterion (AIC) (Akaike 1974). We attempt to find the model which minimises the AIC (and therefore best explains the data). VPFIT includes $\Delta\alpha/\alpha$ as a free parameter in the least-squares fit. By simultaneously minimising χ^2 with all other free parameters, we estimate $\Delta\alpha/\alpha$ and its associated error in each quasar absorber.

When we combine the $\Delta\alpha/\alpha$ values obtained from different absorbers under particular models, χ^2_ν ($\equiv \chi^2/\nu$, the χ^2 per degree of freedom) is somewhat greater than the expected value of unity, reflecting unmodelled uncertainties. The most likely sources of these uncertainties are such that the error introduced will be random from absorber to absorber, and therefore will average out over large numbers of absorbers (King et al. 2011). To account for the excess dispersion in the data, we grow our statistical errors ($\sigma_{\rm stat}$) in quadrature with an additional term $\sigma_{\rm rand}$ (i.e. $\sigma_i^2 = \sigma_{i,\rm stat}^2 + \sigma_{\rm rand}^2$) until χ^2_ν about the particular model is ~ 1.

Our methods and methodology are described in detail in Webb et al. (2010) and King et al. (2011).

VLT RESULTS

We have analysed 154 absorbers from 60 quasar sightlines, yielding 154 values of $\Delta\alpha/\alpha$. We consider different models for $\Delta\alpha/\alpha$ below, and compare our values of $\Delta\alpha/\alpha$ to those from Keck. One of the values of $\Delta\alpha/\alpha$ is clearly distinguished as an outlier using the Least Trimmed Squares method (Rousseeuw 1984), and therefore we exclude this $\Delta\alpha/\alpha$ value from all of our statistical analyses. For each absorber, the quasar name, redshift and $\Delta\alpha/\alpha$ value are available in King et al. (2011).

Weighted mean model

After adding $\sigma_{\rm rand} = 0.91 \times 10^{-5}$ in quadrature with our statistical errors, the weighted mean of the 153 VLT $\Delta\alpha/\alpha$ values is $\Delta\alpha/\alpha = (0.21 \pm 0.12) \times 10^{-5}$, with $\chi^2_\nu = 0.99$. This result differs from that of Murphy et al. (2004) at the $\sim 4.7\sigma$ level.

DIPOLE FIT

The Keck sample is dominated by quasars located in the northern celestial hemisphere, whilst the VLT sample is dominated by quasars located in the southern celestial hemisphere. The average Keck results of Murphy et al. (2004) suggest that $\Delta\alpha/\alpha < 0$, whilst the average VLT results suggest that $\Delta\alpha/\alpha > 0$. This north/south difference motivates us to consider potential spatial variation in α. We model the potential spatial variation by a simple dipole+monopole model as a first approximation, namely

$$\Delta\alpha/\alpha = A\cos(\Theta) + m, \tag{3}$$

where A is the dipole amplitude, Θ is the angle between the direction of maximal increase in $\Delta\alpha/\alpha$ (the dipole direction) and the quasar sightline under consideration and m is a constant which allows for a potential universal offset (a monopole) from the laboratory value of $\Delta\alpha/\alpha \equiv 0$. The dipole direction is given in J2000 equatorial coordinates (right ascension, RA, and declination, dec.) and is found when the dipole+monopole model is fitted to the $\Delta\alpha/\alpha$ values.

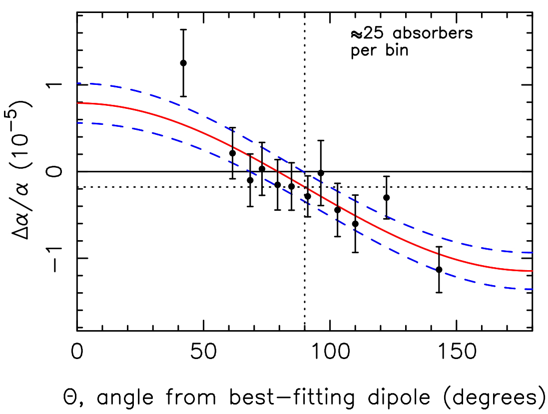

Figure 1. Plot showing binned values of $\Delta\alpha/\alpha$ (and associated 1σ uncertainties) for the combined Keck+VLT sample against the angle from the dipole direction. The red (solid) line shows the model, $\Delta\alpha/\alpha = A\cos(\Theta) + m$. The blue, dashed lines show the 1σ uncertainty on the model fit. The horizontal dotted line shows the value of the monopole, m. The $\Delta\alpha/\alpha$ values are well-represented by the dipole+monopole model, which is preferred over the monopole-only model at the 4.06σ level.

For a dipole+monopole fit to the combined Keck+VLT data, we find that $m = (-0.178 \pm 0.084) \times 10^{-5}$, $A = 0.97 \times 10^{-5}$ (1σ confidence limits $[0.77, 1.19] \times 10^{-5}$), RA $= (17.3 \pm 1.0)$ hr, dec. $= (-61 \pm 10)^\circ$. The dipole+monopole model is preferred over the monopole-only model at the 4.06σ confidence level, yielding signficant evidence for angular and therefore spatial variations in α. We show the dipole fit to the combined Keck+VLT sample in Figure 1.

The combined Keck and VLT $\Delta\alpha/\alpha$ sample displays several consistencies which suggest that the observed spatial variation in α is real:

i) Good alignment between Keck and VLT dipoles. The dipole directions in dipole+monopole models fitted independently to the Keck and VLT samples point in a similar direction, with the dipole vectors being separated by only 24 degrees. A bootstrap analysis shows that the chance of obtaining alignment this good or better by chance is ≈ 6 percent. For a dipole-only model, the dipole vectors are separated by 16 degrees, with a chance probability of 14 percent. The good alignment for a dipole-only model is illustrated in Figure 2.

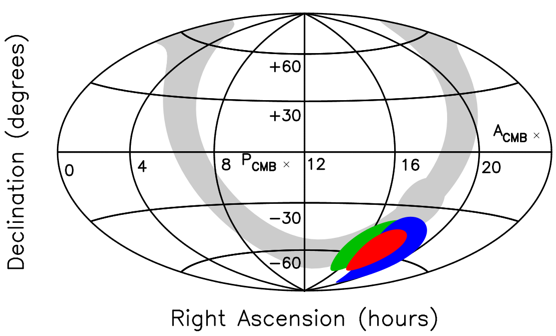

Figure 2. Plot in J2000 equatorial coodinates showing the 68.3 percent confidence limits on the location of the dipole direction in a dipole model fitted to $\Delta\alpha/\alpha$ values from Keck (green region), VLT (blue region) and the combined VLT+Keck sample (red region). The location of pole and antipole of the CMB dipole are marked for comparison (Lineweaver 1997). The grey band schematically indicates the galactic plane.

ii) Good alignment between dipole directions in dipole+monopole models fitted to $z < 1.6$ and $z > 1.6$ sample cuts. The dipole vectors in dipole+monopole models fitted to $z < 1.6$ and $z > 1.6$ cuts of the combined Keck + VLT sample are separated by 13 degrees. A bootstrap analysis shows that the chance of obtaining alignment this good or better by chance is ≈ 2 percent. This close alignment is particularly interesting because the transitions fitted in low- and high-redshift absorbers are quite different, and the expected pattern of line shifts for the high-redshift transitions is qualitatively very different to the low-redshift transitions. The fact that good agreement is found between the dipole directions in low- and high-redshift samples implies that it is unlikely that the observed dipole effect is due to unknown systematics.

iii) Good consistency in the overlap region. In the region of the sky which contains absorbers from both the Keck and VLT samples there is no significant evidence for inconsistency of the $\Delta\alpha/\alpha$ values between the two telescopes.

iv) No outliers. No values of $\Delta\alpha/\alpha$ deviate by more than 3σ from the dipole+monopole model after the inclusion of $\sigma_{\rm rand}$, which suggests that the result is not being caused by statistical outliers. Further investigations (see Webb et al. 2010, King et al. 2011) show that the observed dipole effect is not being caused by a deviant subsample of the $\Delta\alpha/\alpha$ values.

SYSTEMATIC ERRORS

We have considered a range of potential systematic effects which could spuriously give rise to the observed dipole effect, including: the effect of differences in the isotopic abundances of Mg in the absorption clouds relative to terrestrial values; the dual-armed nature of the UVES spectrograph; systematic differences in the wavelength calibration scale of the Keck/HIRES and VLT/UVES spectral data, and; wavelength scale distortions that occur within each echelle order in the spectrograph, observed in both Keck/HIRES and VLT/UVES spectral data. None of these effects are of sufficient magnitude or character to be able to explain the observed dipole effect (King et al. 2011).

DISCUSSION

The confirmed detection of cosmological variation in α would demonstrate new physics at the most fundamental level. It would show the existence of a preferred cosmological frame, which would demonstrate the incompleteness of the Einstein Equivalence Principle.

Berengut & Flambaum (2010) explicitly demonstrate that the results presented here are consistent with measurements of β-decay in meteorites, atomic clock measurements and the natural nuclear reactor at Oklo. We are unaware of any experimental result which is in conflict with the results described here.

CONCLUSION

We have outlined here statistically significant evidence that the fine-structure constant may be different in different places in the universe. From an analysis of 293 absorbers from spectra from Keck/HIRES and VLT/UVES, we find $> 4\sigma$ evidence that the cosmological variation is well-described by a dipole+monopole model, implying the existence of a preferred axis in the universe. Our results demonstrate significant internal consistencies which suggests that the observed effect may be real. We are unable to find a systematic effect which explains the observed variation in α.

Clearly, the observed effect must be verified independently. Many of the absorbers in our sample lie near the equatorial region of the dipole, yielding reduced sensitivity to detect variation in α. This means that future, targeted observations along the dipole axis will have signficantly increased sensitivity to confirm or refute the effect described here.

ACKNOWLEDGMENTS

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Author Biographies

These are biographies of authors that have contributed to our Journal.

Professor Roy MacLeod

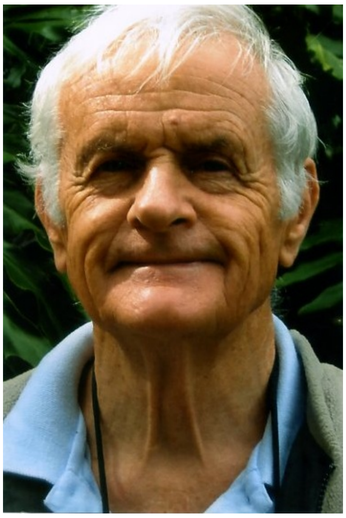
ROY MACLEOD is Professor Emeritus of (Modern) History at the University of Sydney, and an Honorary Associate in the History and Philosophy of Science. He was educated in history, the biochemical sciences, and the history of science at Harvard University (summa cum laude), in sociology at the London School of Economics, and in history and the history of science at Cambridge, where he took the PhD degree in 1967.

He is the author or editor of 22 books and about 120 articles in the social history of science, medicine and technology; military history, museum history, Australian and American history, European history; research policy, and the history of higher education. Roy MacLeod's most recent book, *Archibald Liversidge: Imperial Science under the Southern Cross* has just been published by the Royal Society of NSW and Sydney University Press.

Professor Roy MacLeod

Dr David Branagan

David Branagan is an Honorary Associate in the School of Geosciences, University of Sydney, where he taught for thirty years. He has been a member of the Society since the 1960s, served on Council for some years and was President, 1995–96. His career included work in government and industry prior to his university appointments. He has published widely on aspects of the geology of the Sydney region, and more recently on the history of geology, and was President of the International Commission for the History of Geological Sciences (1992–1996). He is an Honorary Life Member of the Geological Society of Australia, and has been recipient of awards from the State Library of NSW (C.H. Currey Fellow), National Library of Australia (Harold White Fellow), Turnbull Library,Wellington (NZ) (James Cook Fellow), University of Oklahoma (Mellon Fellow).



Dr David Branagan

Dr Mohamed Khalifa

Dr Mohamed Khalifa description samples in the core library at the Geological Survey of NSW.

Mohamed KA. Khalifa received his BSc degree in geology from University of Al-Fateh, Tripoli, Libya in 1990, PG.DipSci degree (1992) and MSc (1995) in geology from University of Jordan, Amman, Jordan and his PhD degree (2005) in geology from University of New South Wales, Sydney, Australia.

He currently works as a senior lecturer of Petroleum Geoscience at the Geoscience and Petroleum Engineering Department in the Universiti Teknologi Petronas, Malaysia. He has industry and research experience as a project geologist/petroleum researcher at the Petroleum Research Centre in Libya; a petroleum geoscientist at 3D-GEO Pty Ltd in Melbourne, Australia; and an exploration geologist with Triassic Geological Services Pty Ltd in Brisbane, Australia. Also, he gained teaching experience as a lecturer at the Department of Geology, 7th April University in Libya; and as a teaching assistant at the Department of Geology, University of Jordan. Also, he worked as a geoscientist/petroleum researcher in academia while successfully carrying out a Ph.D project (Darling Basin, NSW) at the University of New South Wales, Sydney – which was conducted in collaboration with the New South Wales Department of Primary Industries Mineral Resources Division (Coal and Petroleum Development) in Sydney, Australia.

His main teaching and research interests are seismic/sequence stratigraphy, stratigraphic and structural interpretation of seismic data, sedimentary facies analysis, reservoir stratigraphy and basin analysis. Recent seismic/sequence stratigraphic and lithostratigraphic studies include the following areas: Darling Basin (New South Wales) and, Eromanga, Adavale and Galilee Basins (Queensland), Wadi Sirhan Basin (Jordan) and Sirt Basin (Libya).

Editors Note: Dr Khalifa's previous publication in our Journal is:
Khalifa, M.K., 2009. Tectonostratigraphic Evolution of the Blantyre Sub-basin and Adjacent Regions, New South Wales, Based on Integration of Seismic, Gravity and Well Data. *Journal and Proceedings of the Royal Society of New South Wales* **142**, Parts 1 & 2, pp. 29–56.

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Thesis Abstract: Playing with Fire? Bushfire and Everyday Life in Changing Rural Landscapes

CHRISTINE ERIKSEN

Abstract of a Thesis submitted for a Doctor of Philosophy
University of Wollongong, 2010

The severity of the January 2003 Canberra bushfires initiated a national enquiry on bushfire mitigation and management by the Council of Australian Governments. One of the core messages conveyed by the enquiry was a concern about community complacency, particularly in the rural-urban interface, that previous and subsequent enquiries and research have also expressed. The enquiry also highlighted the importance of retaining local environmental knowledge on bushfire considering the demographic changes associated with amenity migration. These issues form the core of this thesis.

This thesis examines how experiences of place, culture, events and context mediate how diverse types of landholders in changing rural landscapes in southeast Australia relate to bushfire risk. It builds on a growing international concern about the increasing number of people living in rural-urban interface areas in light of the increased frequency of tragic bushfires, and the predicted increase in high fire danger weather with climate change. It focuses on the dynamics of local environmental knowledge and bushfire management in changing rural landscapes by investigating: i) how amenity migration is influencing awareness, preparedness and attitudes to bushfire; and ii) how amenity migration is influencing and challenging the interpretation and uptake of bushfire risk communication.

A mixed-methods research approach, involving postal surveys and in-depth interactive interviews, was used to explore the significant factors that influence if, how and to what extent landholders' prepare for bushfires. The qualitative data particularly provided insights into how landholders gain knowledge on bushfire issues, and the actual characteristics of local environmental knowledge present within changing rural landscapes.

The thesis develops a nuanced, complex and critical understanding of landholders' engagement with bushfire risk in changing rural landscapes. It demonstrates how attitudes, awareness, and actions towards bushfire management are tied to a range of emotions and experiences that are deeply embedded in traditions as well as dilemmas in everyday life. While acknowledging the importance of the scientific discourses that underpin official bushfire management policy and practice, the thesis reveals that official rationality often does not translate well into landholders' everyday life. Instead local knowledge, lifestyles, gender roles, learning styles, and conflicting priorities, all mediate how landholders' relate to living with fire on the land. It is these complex frames of reference in everyday life that determine if, how, and to what extent landholders prepare for bushfire, rather than landholders' risk awareness.

The thesis concludes with one core recommendation: the need to include meaningful engagement in future bushfire risk communication, education, and management programmes in the form of local, context specific, and interactive initiatives. This recommendation is all the more pertinent given the findings of the 2009 Victorian Bushfires Royal Commission into the 'Black Saturday' bushfires. It is a tragic irony that Australia is licking its' burn wounds once again as this PhD project comes to a close.

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Studentships

The Council of the Royal Society of NSW funds the Royal Society of New South Wales Studentships in order to acknowledge outstanding achievements by young researchers. Applications are considered from PhD candidates, enrolled in a university within New South Wales, who have completed at least two years of candidature by 30 April. There is no restriction with respect to field of study within the sciences and up to three Studentships will be awarded each year. Applicants must be Australian citizens or permanent residents of Australia.

The Studentship Awards for 2010 were presented on Wednesday, 1st December 2009 at St. Paul's College, University of Sydney.

Targeted Delivery of Chemotherapeutic Agents Using Novel Isatin-based Compounds

Lidia Matesic
School of Chemistry, University of Wollongong.

Targeted drug delivery increases the availability of a drug at the target site while reducing its availability at other sites. A novel strategy which shows promise for the targeted delivery of cytotoxins into tumour cells exploits the urokinase plasminogen activation (uPA) system. Once the uPA system has been used to deliver the cytotoxin into the cell, the cytotoxin must be released in an acidic intracellular environment. Lidia is working on isatin, a natural substance isolated from the *Isatis* genus of plants, which has anti-cancer activity. The chemical structure of isatin has been modified to improve potency against human cancer cell lines. Lidia is investigating the properties of a range of imine-based acid-labile linkers, to join isatin to the PAI2 component of the uPA system. These linkers are designed to allow effective release of isatin within the target cell.

Factors Affecting the Drainage of Gas from Coal and Methods to Improve Drainage Effectiveness

Dennis Black
Faculty of Engineering, University of Wollongong

The objectives of Dennis's research are to investigate and isolate specific geological properties and operationally controlled factors that impact on coal seam gas production. The research will lead to recommendations to improve the efficiency and effectiveness of gas drainage, particularly in known difficult drainage zones. The success of this project will have significant impact on the health and safety of mine personnel, economics and environmental performance of underground coal mining in Australia and beyond, through increasing the effectiveness of coal seam gas extraction. This will contribute to improving the utilization of coal resources. Increased gas extraction from in situ coal seams also serve to reduce the gas content ahead of mining. This will inevitably reduce the risk to mine and personnel safety, as well as reducing the mine's fugitive emissions.

Evolutionary Dynamics of the Human Pathogens P. *aeruginosa* and Hepatitis C Virus

Kerensa McElroy
School of Biotechnology and Biomolecular Sciences, University of New South Wales

Kerensa's research focuses on using mathematical and bioinformatics tools to understand the evolution of human pathogens. She has developed mathematical models to explain the structure of pathogen populations by analyzing the vast quantities of DNA sequences obtained by pyrosequencing technology. Her bioinformatic research is complemented by wet-lab approaches. She is studying two important human pathogens, the bacterium *Pseudomonas aeruginosa* and the Hepatitis C Virus (HCV). She has shown that four out of 10 HCV patients are likely to have been initially infected with only a few (1–3) as opposed to many (>3) founding viruses. She has discovered that a pathogenic P. *aeruginosa* strain has an elevated death rate compared to a harmless, environmental strain. She aims to develop techniques in her PhD that are applicable to as broad a range of pathogens as possible.

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Biographical Memoir

Joyce Marie Cole (née cooper)
1916 – 2010

Joyce Cole, one of the longest standing members of the Society, died in March this year aged 94. She was brought up in Sydney, educated at North Sydney Girls High School and graduated from the University of Sydney with a Science Honours degree in 1936. She worked in the Department of Pharmacy at Sydney University, where she met Ted Cole, who became her husband. Ted completed a Masters and a PhD, and went on to be an Associate Professor in the School of Chemistry at the University of NSW. Joyce's career in science was interrupted by marriage and children. Subsequently she took up secondary school science teaching, for many years at Abbotsleigh and then at SCEGGS Redlands where she was Senior Science Mistress in the 1970s. Joyce was also a very longstanding member of the Australian Federation of University Women and the Australian College of Educators. She is survived by her son Ted Jr and by grandchildren Edward and Stephanie. Her daughter Alison predeceased her.

Joyce was interested in young people and was very skilled at engaging their interest. She was a highly capable teacher, and was well regarded for innovatory application of audio-visual technology as an integral teaching aid. She maintained enthusiasm and curiosity about science throughout her long life. She joined the Royal Society of NSW in 1940, before the proliferation of specialized scientific societies. At the time she became a member of the Society, she considered it a good organization for young scientists to join early in their career. In more recent years, although she was not able to participate in the Society's activities, she was keen to maintain her membership, to support the Society's role in fostering science.

Ted Cole Jr and William Sewell

Biographical Memoir

Dr Robert Robertson-Cuninghame

1924 – 2010

The Society would like to record the death of a long-standing member, Dr Robert Robertson-Cuninghame, who passed away on 9 September aged 86.

Robert Clarence Robertson-Cuninghame was a First Class Honours graduate of the University of Sydney, a Rhodes Scholar, an Oxford DPhil, Chancellor of the University of New England from 1981–93, and a great supporter of the New England Branch of the Society. He had been a member of the Society since 1982.

His ancestors had selected land in the New England district in 1838. His mother Nancy was a granddaughter of Frederick White, who built Booloominbah, a rural homestead outside Armidale at that time. He was therefore a cousin of the Australian Nobel laureate Patrick White.

In 1936 a family member bought and gave the property to the University of Sydney on the condition the university establish a college at Armidale, to be called the New England University College. The college was established in 1938, with Booloominbah remaining as the foundation building. In 1954 the college gained autonomy, later becoming the University of New England.

In 1949, following war service and the completion of his undergraduate studies, Robertson-Cuninghame won a Rhodes Scholarship to Oxford, where he was a member of Trinity College. He was invited to join the Department of Agricultural Science at the University of Sydney but had to choose between becoming an academic and returning to the land. He chose the latter.

Some years later he was invited to join the Council of the University of New England, where he served as Deputy Chancellor from 1971 to 1981, when he became the university's fourth Chancellor. In 1988 he became an Officer of the Order of Australia for services to learning and in 2001 he was awarded the Centenary Medal by the federal government for services to education.

He is survived by his wife, Patricia (née Cotton), only daughter of C.M. Cotton, who was the brother of Professor L.A. Cotton, Professor of Geology at Sydney University from 1925–48, and of Professor F.S. Cotton, Professor of Physiology at the same university, three daughters, two sons-in-law and four grandchildren.

John Hardie

Archibald Liversidge
Imperial Science under the Southern Cross

Roy MacLeod
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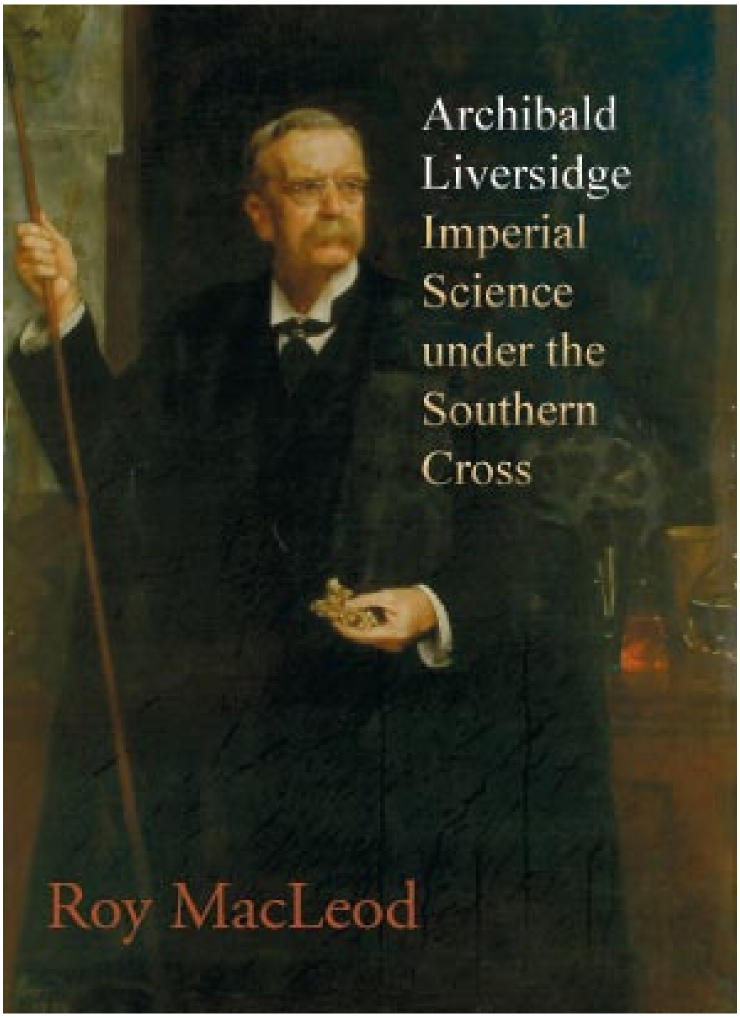
When Archibald Liversidge first arrived at Sydney University in 1872 as reader in Geology and Assistant in the Laboratory he had about ten students and two rooms in the main building. In 1874 he became professor of geology and mineralogy and by 1879 he had persuaded the senate to open a faculty of science. He became its first dean in 1882.



In 1880 he visited Europe as a trustee of the Australian Museum and his report helped to establish the Industrial, Technological and Sanitary Museum which formed the basis of the present Powerhouse Museum's collection. Liversidge also played a major role in the setting up of the Australasian Association for the Advancement of Science which held its first congress in 1888.

For anyone interested in Archibald Liversidge, his contribution to crystallography, mineral chemistry, chemical geology, strategic minerals policy and a wider field of colonial science.

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