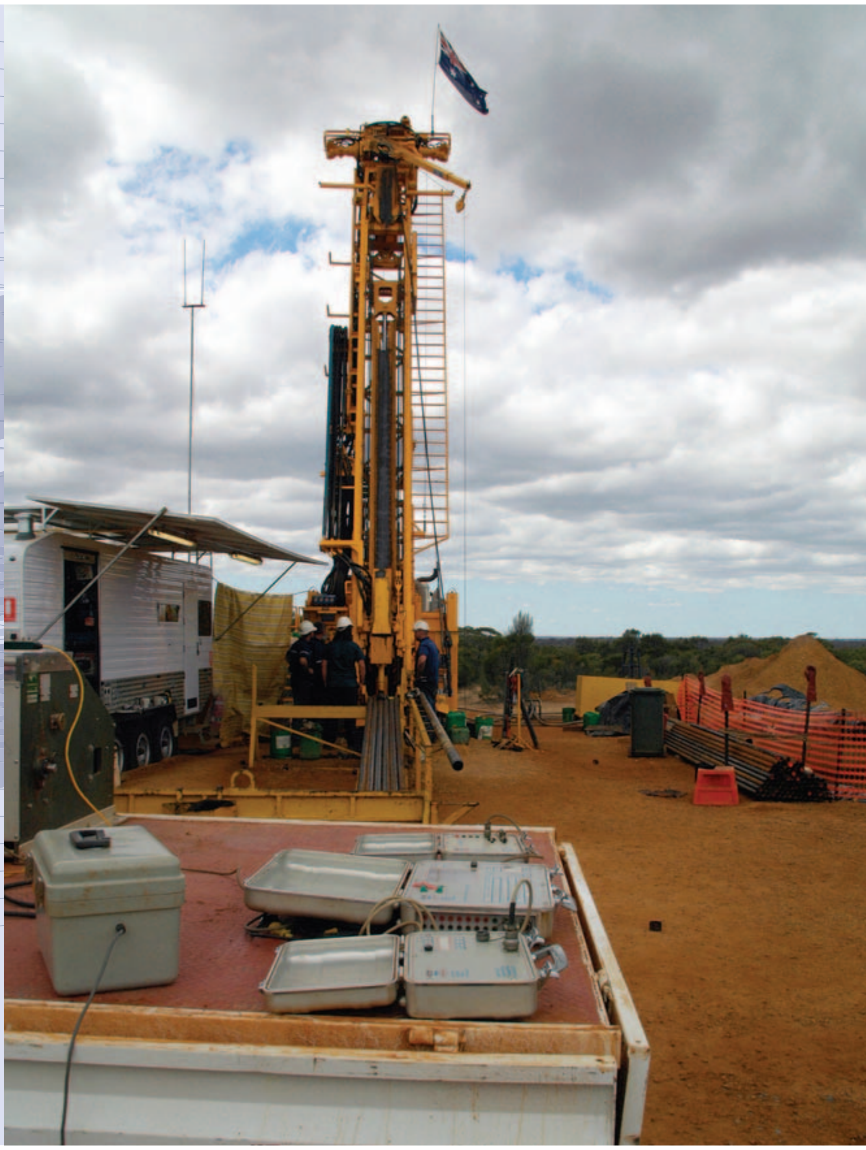
AUGUST 2008 • ISSUE 135
ABN 71 000 876 040 ISSN 1443-2471

PREVIEW

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS



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FRONT COVER

Gold pour from smelting furnace at a metal recycling laboratory at Mascot south of Sydney. Image courtesy of NSW Department of Primary Industries.

Preview is available online at
www.publish.csiro.au/journals/pv
ISSN: 1443-2471 eISSN: 1836-084X

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David Denham

Australia's gold endowment

Gold has played a crucial role in Australia's history and it continues to make a major contribution to the prosperity of the nation. From the gold rushes throughout the continent during the 19th century, to the recent development of giant low grade deposits like the Super Pit at Kalgoorlie and Olympic Dam in South Australia, gold has been a cornerstone of our minerals industry. Although production has declined gradually over the last few years, we still produce over 10% of the world's gold and with Economic Demonstrated Resources of about 5500 tonnes and a current annual production of about 240 tonnes we should be in good shape for the future. However, the giant deposits are harder to find and more expensive to develop so we have to be smart to maintain our share of the market.

In this issue of *Preview* we are focussing on gold. We ask three questions: Why do we hunt for gold? Where do we hunt for gold? and How do we hunt for gold? We consider the national scene and also the situation in each of the States and the Northern Territory. In the October *Preview* we will complete this review of gold.

Where are the Exploration CRCs?

In the Research News section it is disappointing to learn that both the pmd*CRC and LEME2 are no more. That would not normally be so bad but unfortunately there are no CRCs in the pipeline to fill the minerals exploration research gap. The nearest we have is CSIRO's Minerals Down Under Flagship but this does not have the same imperative to include interactions with industry, academia and government agencies as a fully fledged CRC. I hope that in the ASEG we have members working to fill this gap.

Climate Change

Climate Change has dominated the political landscape in Canberra this month – only the Pope with his fleeting visit to Sydney was able to push this issue from the front pages for a few days.

As Ross Garnaut said in his speech at the National Press Club: 'Climate change is a diabolical policy problem. It is harder than any other issue of high importance that has come before our polity in living memory'. And I haven't heard anybody argue with that.

So what did he report? Well, he produced a well reasoned 537 page report covering the whole spectrum of Climate Change and the economic consequences. He argued persuasively for a cap and broadly based trade scheme. He included transport but not agriculture at this stage. His argument for Australia acting now rather than later to address carbon emissions was straightforward. (1) Controlling climate change and life on Earth is a global problem. (2) The main emitters/polluters are China and the US and Australia's emissions are trivial compared with those. (3) However, Australia's per capita emissions are the highest in the OECD and it is therefore unreasonable to continue generating CO_2 limitlessly while expecting China and the US not to reduce their emissions.

He made a big plug for a huge increase in basic research and development of low-emissions technologies, and argued that this is an international public good, requiring high levels of expenditure by developed countries.

Australia should make a proportionate contribution alongside other developed countries, in its areas of national interest and comparative research advantage. This would require a large increase in Australian commitments to research, development and commercialisation of low-emissions technologies, to over $3 billion per annum.

He also recommended a 2010 start for the scheme.

The week after Garnaut, Senator Penny Wong launched the *Carbon Pollution Reduction Scheme* Green Paper. This 618 page document outlines the Australian Government's approach to the design of a national emissions trading scheme. Fortunately there is a 70 page summary!

The three 'pillars' of the scheme are: reducing Australia's greenhouse gas emissions, adapting to unavoidable climate change, and helping to shape a global solution that both protects the planet and advances Australia's long term interests.

In essence, it endorses Garnaut's cap and trade scheme and commits to reduce emissions by 60% from the 2000 levels by 2050. This means a cut from 491 Mt CO_2-e to 196 Mt CO_2-e in 50 years. As 2007 levels were estimated to be 585 Mt CO_2-e, an increase of 9 Mt CO_2-e, or 1.6% from the 2006 level and still rising, this is going to be very difficult.

The government's scheme will not be as broadly based as that proposed by Garnaut. It will only apply to entities and facilities producing direct emissions of at least 25 000 tonnes of CO_2-e (roughly about 1000 firms); fuel (for transport) taxes will be cut on a cent for cent basis, so effectively petrol will not be included; agriculture will be excluded from the scheme at this time, even though it is the second largest polluter (90 Mt CO_2-e) after 'stationary energy' (280 Mt CO_2-e).

The mechanics of setting the cap are of interest: (1) Significant emitters of greenhouse gases need to acquire a 'carbon pollution permit' for every tonne of greenhouse gas that they emit. (2) The quantity of emissions produced by firms will be monitored and audited. (3) At the end of each year, each liable firm would need to surrender a 'carbon pollution permit' for every tonne of emissions that they produced in that year. The number of 'carbon pollution permits' issued by the Government in each year will be limited to the total carbon cap for the Australian economy. (4) Firms compete to purchase the number of 'carbon pollution permits' that they require. Firms that value carbon permits most highly will be prepared to pay most for them, either at auction, or on a secondary trading market. For other firms it will be cheaper to reduce emissions than to buy 'permits'.

Certain categories of firms might receive some 'permits' for free, as a transitional assistance measure. These firms could use these or sell them.

In addition the Government will provide assistance to the most heavily emissions-intensive trade-exposed activities and also to existing coal-fired electricity generators. Why the government should be supporting coal fired generators is difficult to argue. One would expect, given the large gas reserves that we have that it should be encouraging changing over to gas until renewable systems of power generation are in place.

Anyway, the Green Paper is a start. It is only a discussion paper and feedback is invited before the White paper is released later this year. So go to http://www.greenhouse.gov.au/greenpaper/index.html and have your say.

ASEG's financial position for 2007

The financial statements for the year ending 31 December 2007 for the Australian Society of Exploration Geophysicists have been audited and were presented at the AGM of the Society on 5 May 2008. This report is largely based on these statements and the report prepared for the AGM by the Treasurer at that time, John Watt. These show that the Society is in a sound financial position going into 2008.

The statements refer to the consolidated funds held by the society as a whole, including the State Branches. The audited version of the profit and loss statement and end of year balance sheet can be found on the ASEG website.

The Society's revenue source continues to be derived from membership subscriptions, corporate sponsorship, publication sales, publications advertising, surpluses from conventions and meetings and income from accumulated investments.

The Society's funds are used to promote, throughout Australia, the science and profession of geophysics. In 2007 this was achieved by funding the publications: *Exploration Geophysics*, *Preview*, and the *Membership Directory*; by the payment of capitation fees for the administration of State Branch organisations; by funding the national administration of the Society; by funding continuing education programs; by the provision of loans and grants for conventions; by the provision of subsidies for student members; for branch and Federal meetings; and for the ASEG Research Foundation.

The profit and loss account for the year shows a profit of $81 680. The end of year balance shows a surplus of $801 315 as of 31 December 2007. The positive result for the year can largely be attributed to the success of the ASEG/PESA 2007 conference. A change of publisher resulted in a small decrease in advertising revenue that will be corrected during 2008.

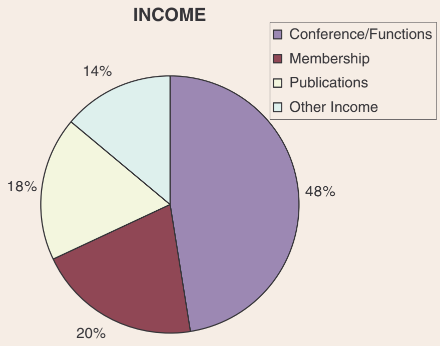
The major expenses for the Society include:

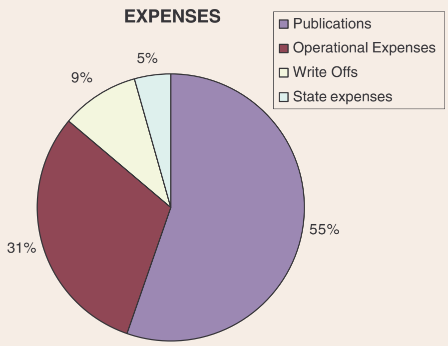
- publications resulted in a net loss of $113 528 (after advertising and sales income);
- operational expenses of $120 322; and
- Write offs of $35 759 resulting from the deletion of incorrectly accrued invoices over 3 years and the removal of non-existent bank account balances. A full explanation has been made by the bookkeeper and is available for inspection.

The major sources of income for the society were from publications, membership fees and the ASEG/PESA 2007 conference. Publications and advertising income was $101 394; total membership fees collected were $113 560, up 7.5%, and conference income was $200 000 (within the 2007 calendar year).

The costs of running the Society are under continual review. The budget for 2008 is similar to that for 2007, with allowance for not having a conference within the 2008 calendar year. There will be some additional income still to come from the 2007 conference once the books for that event are finalised. One major new initiative budgeted for in 2008 is the undertaking of a review of the Society and its operations by an independent consultant. A tender process for this will determine the cost of such a project. It is expected that such a review will provide a clear basis for strategic improvements to the Society and the benefits it provides it members.

Dave Cockshell
Treasurer





ASEG STUDENT SPONSORSHIP PROGRAM FOR 2008

The ASEG understands that the future of geophysics is in the hands of those that are yet to step foot in an exploration office, on the drill floor of an oil rig, or down the shaft of a mine. With the workforce becoming older every year new blood is desperately needed to keep our profession alive and well.

The ASEG is proud to announce that Rio Tinto and Origin Energy are the 2008 participants of the Student Sponsorship Program.

By participating in the Student Sponsorship Program students get exposed to the industry much earlier in their career. Not only do students get free ASEG membership but they receive the ASEG publications *Exploration Geophysics* and *Preview*. Most importantly however, students can get their foot in the door for graduate and vacation positions as their details are forwarded to their sponsorship company.

If you are a student studying geophysics or a related field and are interested in joining the Student Sponsorship Program go to www.aseg.org.au and follow the links. For more information about the program or any membership inquires please contact Emma Brand (emma.brand@originenergy.com.au).

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ASEG News

New faces on the FedEx

At the ASEG's AGM in May this year Michael Asten and David Cockshell joined the Federal Executive Committee. Here are a few words supplied by the new officers to provide some background for those who do not know them already.

Michael Asten, President Elect

I am currently in joint roles as a Consultant Geophysicist in Flagstaff GeoConsultants and as a Professorial Fellow at Monash University. I have been a member of the ASEG since 1971 and have been active in organising ASEG Conferences (Technical Chairman, Special Editor of *Exploration Geophysics*, General Chairman, Sponsorship Chairman), workshops, presenting at conferences, and authoring and reviewing papers for *Exploration Geophysics*. I have also had the pleasant opportunity of working with our International Affairs Committee to represent the ASEG at conferences of the SEG and Engineering and Environmental Geophysical Society and contributing to the international collaboration in publication and online accessibility of geophysical literature.

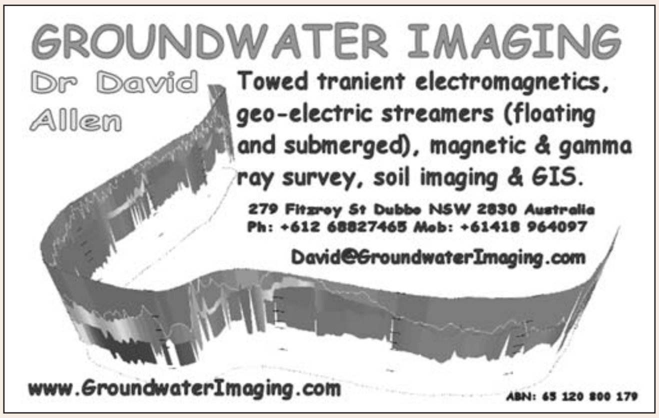
In 35 years as a geophysicist I have been a Company geophysicist for 18 years, university academic, visiting fellow, and consultant geophysicist. Over this time I have taught graduate level courses in geophysics for four Australian universities and six international mining companies on four continents. I am currently assisting the Minerals Council of Australia in a joint ASEG–MCA initiative to perform an assessment of tertiary-level geophysics course offerings, staff resources and graduate output in Australia.

Our profession faces challenges over the next decade in the supply of graduates, the ongoing up-skilling of our professionals, and the supply of university staff and equipment resources. I plan to use my time on the Federal Executive to find ways we as a professional society can best address these challenges.

David Cockshell, Treasurer

Dave completed his BSc (Hons) degree at University of Adelaide in 1975 majoring in geophysics. He was employed as a Grade Control Officer/Mine Geologist in Western Australia by Windarra Nickel Mines/Western Mining during 1975–76. He joined the South Australian Department of Mines and Energy in 1977 as a geophysicist. He has remained with this agency since then and is currently the Chief Geophysicist for the SA's Department of Primary Industries and Resources' Petroleum & Geothermal Group. Dave has had experience with a wide range of geophysical techniques in the engineering, environmental, hydrological and petroleum fields. His expertise covers data acquisition and interpretation as well as environmental management and petroleum regulation. He has also promoted South Australia as a petroleum investment destination nationally and internationally.

He has been a member of Australian Society of Exploration Geophysicists since 1977, serving on the SA Branch Committee from 2001 until 2007, primarily in the role of Treasurer. He was also the Treasurer for the 2003 ASEG Conference in Adelaide. Dave is also a member of the Society of Exploration Geophysicists, Petroleum Exploration Society of Australia and the Environment Institute of Australia and New Zealand. In his spare time he is a very active Rotarian.



John Bewers Boniwell
11 March 1927–3 May 2008

John Bewers Boniwell died on 3 May 2008 in his 82nd year, in Mississauga (Toronto), Canada. John was well known in the mining exploration community as a geophysicist of considerable experience and ability. Born in Tasmania in 1927, he received his degree in physics, mathematics and geology from the University of Tasmania in 1949. His first job was with the Commonwealth Bureau of Mineral Resources (BMR), based in Melbourne, Australia.

John immigrated to Canada in 1954, where he joined Rio Canadian Exploration Ltd as an exploration geophysicist. There, as well as back in Australia, he worked with some of the early mobile electromagnetic systems. He participated with Harry Seigel on the application of the Mobrun truck-borne EM system, helping to discover the VMS base metal mine (Mobrun) in northwestern Quebec. He was one of those who pioneered the use of the Rio-Mullard airborne EM system, which led to the discovery of the Poirier base metal mine in northwestern Quebec in 1959.

In 1964, he became Chief Geophysicist for Barringer Research Ltd and assisted in Barringer's launching of the first commercially available airborne INPUT EM system. He set up Barringer's exploration services division, which worked in Canada, United States, Europe, Australia and Fiji. In 1969, John became an independent consultant, then in 1972, formed Excalibur International Consultants Ltd. Concurrent with his consulting practice, he was at various times a part of the management of Tesla-10 Holdings Ltd and Questor Surveys Ltd, both in Mississauga, Canada; TerraMin Research Laboratories Ltd in Calgary, Canada; and Tesla-10 Pty in Perth, Australia. He continued to consult to the mining industry until a few months before his death. John was a member of the CIMM, GAC, SEG, ASEG and KEGS.

John had clear ideas on the nature and role of geophysics in mining exploration. He saw that there was an identity between geology and geophysics, that they were most successful when applied together. He was an editor with Melvyn Best of a CIM volume, *A Geophysical Handbook for Geologists*, published in 1989. The paper on Mobrun, written in 1957, with H.O. Seigel and H.A. Winkler describes the Mobrun discovery, unique in the annals of exploration geophysics.

Family, friends, hard work and spirituality (preferably with Scotch or later a robust red) these were things John stood for. Also fun. John took his recreation seriously and had a gift for simultaneously extracting both pleasure and maximum frustration from his pastimes; be it hiking on the Bruce Trail, bridge, tennis, rowing (begun at the University of Tasmania) or sailing. He has been described by various associates as "me mate", "a great mentor", "a great and constant friend". John was a man of great personal convictions which sometimes meant that he could be difficult, especially when he met with ideas or representations that did not fulfill his expectations. Regardless, he always wrote interpretations with high standards that he placed on himself as well as others. His geophysical reports were as well known for their scientific content as their captivating, often humorous, writing style.

John was a long time supporter of his Church, where he regularly contributed his time and writing ability. He never forgot his Australian origins. The singing of Waltzing Matilda at his memorial service was a reminder of that. He leaves his wife Diana, children, Andrew, Kirsty and Simon, a grandson and two brothers, Robert and Dudley, and sister Cleone.

Contributed by Laurie Reed (lereed@aztec-net.com), Frank Jagodits, Andrew Boniwell, Noel Mattocks, Harry Seigel, Roger Caven and Rod Marcroft.

New members

The ASEG welcomes the following 14 members to the Society. Their membership was approved at the Federal Executive meetings held on 28 May and 24 June 2008.

Name	Organisation	State
Caleb Craig Ames	Uranium Exploration Australia	SA
Caroline Byrne	Contractor	NSW
Joel Chin	University of Adelaide	SA
Ross Costelloe	Geoscience Australia	ACT
Osni Bastos De Paula	Curtin University	WA
Michael Jon Enright	Rio Tinto Exploration	WA
Adam Patrick Kroll	UTS Geophysics	WA
Darren Kyi	Macquarie University	NSW
Richard Langford	Geological Survey of WA	WA
Michael Lees	UTS Geophysics Pty Ltd	WA
Richard David MacRae	Lorotech Pty Ltd	Vic
Holly Emma McNabb	Macquarie University	NSW
Trent Lesly Retallick	Quantec Geoscience	Qld
Ming Wen	Sinogold Ltd	China

ASEG News

Australian Society of Exploration Geophysicists, Honours and Awards 2009

ASEG members are invited to submit nominations for the next round of ASEG Honours and Awards. Nominations that are judged to be appropriate and are then subsequently selected will be presented at the 20th ASEG Conference, in Adelaide, 22–26 February 2009. Details of the available awards follow:

ASEG Gold Medal

For exceptional and highly significant distinguished contributions to the science and practice of geophysics by a member, resulting in wide recognition within the geoscientific community. The nominee must be a member of the ASEG.

Honorary Membership

For distinguished contributions by a member to the profession of exploration geophysics and to the ASEG over many years. Requires at least 20 years as a member of the ASEG.

Grahame Sands Award

For innovation in applied geophysics through a significant practical development of benefit to Australian exploration geophysics in the field of instrumentation, data acquisition, interpretation or theory. The nominee does not need to be a member of the ASEG.

Lindsay Ingall Memorial Award

For the promotion of geophysics to the wider community. This award is intended for an Australian resident or former resident for the promotion of geophysics (including but not necessarily limited to applications, technologies or education), within the non-geophysical community, including geologists, geochemists, engineers, managers, politicians, the media or the general public. The nominee does not need to be a geophysicist or a member of the ASEG.

Early Achievement Award

For significant contributions to the profession by way of publications in Exploration Geophysics or similar reputable journals by a member under 36 years of age. The nominee must be a member of the ASEG and have graduated for at least 3 years.

ASEG Service Medal

For outstanding and distinguished service by a member in making major contributions to the shaping and the sustaining of the Society and the conduct of its affairs over many years. The nominee will have been a member of the ASEG for a significant and sustained period of time and will have at some stage been one of the following: Federal President, Treasurer or Secretary, State President, Conference Chairperson or Standing Committee Chairperson, Editor of Exploration Geophysics or Preview. Honorary Members are not eligible.

ASEG Service Certificate

For distinguished service by a member to the ASEG, through involvement in and contribution to State Branch committees, Federal Committees, Publications, or Conferences. Honorary Members or holders of the ASEG Service Medal are not eligible.

Nomination Procedure

For the first five award categories, any member of the Society may nominate applicants. These nominations are to be supported by a seconder, and in the case of the Lindsay Ingall Memorial Award by at least four geoscientists who are members of an Australian geoscience body (e.g. GSA, AusIMM, AIG, IAH, ASEG or similar). Nominations for the ASEG Service Medal and the ASEG Service Certificates are to be proposed through the State and Federal Executives with their backing.

All aspects of the criteria should be addressed, and a nomination must be specific to a particular award. To gain some idea of the standard of nomination expected, nominees are advised to read past citations for awards as published in *Preview*.

Nominations including digital copies of all relevant supporting documentation are to be sent electronically to:

Roger Henderson
Chairman, ASEG Honours and Awards Committee
Email: rogah@tpg.com.au

The absolute deadline for applications is 19 December 2008.

New South Wales

In May, Edward (Ted) Bowen from the Petroleum Prospectivity and Promotions Group of Geoscience Australia gave an interesting talk on the results of recent data acquisition in onshore and offshore frontier basins by Geoscience Australia. Ted discussed how GA had recently embarked on a wide-ranging data acquisition program, funded by the Australian Government's Energy Security Program. The onshore component involves the assessment of the petroleum, uranium, thorium and geothermal potential of the continent, while the offshore program is designed to provide precompetitive data and interpretive material to stimulate petroleum exploration in underexplored regions of the continental margin. Many questions and much discussion followed the talk.

In June, we held a 'student' evening to encourage as many students as possible to come along and meet with industry geophysicists. Wayne (Staz) Stasinowsky of Encom Technology Pty Limited gave an informal talk on his Antarctica adventures earlier this year. Staz kept the audience entertained with his exploits down south, even showing us some old geophysics equipment that had been used on the southern continent many years ago. The evening was well attended, with 15 students and even more industry geophysicists attending. After the talk the students and the geophysicists mingled and discussed the merits of being an ASEG member. It was a good meeting and enjoyed by all.

An invitation to attend NSW Branch meetings is extended to interstate and international visitors who happen to be in town at that time. Meetings are held on the third Wednesday of each month from 5:30 pm at the Rugby Club in the Sydney CBD. Meeting notices, addresses and relevant contact details can be found at the NSW Branch website.

Mark Lackie

South Australia

Things have been moving along smoothly for the SA Branch since we last corresponded. We've put together an interesting set of monthly meetings that have been well attended.

In mid-April we co-hosted a student barbeque/tour of the Visionarium at the Australian School of Petroleum at the University of Adelaide with the local PESA Branch. The presentation was very interesting and may be the subject of another visit sometime in the future. On top of that we signed up more than 10 new student members that night.

In May, Dennis Cooke from SANTOS gave an interesting talk on 'What the geological record says about global warming', hardly a sensitive subject at all in this day and age! As expected, this talk was well attended, with Dennis providing a balanced perspective on some very interesting climate variations that have occurred during the Earth's long history.

Right at the end of May, the SA Branch along with the local PESA group and the SPE group held a quiz night to benefit the Royal Flying Doctor Service. Over 100 attendees enjoyed a fabulous evening of competitive frivolity and raised over $3000 for the RFDS. Thanks go out to our sponsors for the night, Beach Petroleum, JRS and PIRSA.

In mid-June, Graham Baines from the University of Adelaide gave a talk titled 'Mysteries of the deep: the evolution of a submerged plate-boundary at the southwest Indian Ridge', during which Graham took us on his extended PhD cruise in the Indian Ocean looking at the development of plate boundaries (and he did actually take a look from a small submarine, but 'the biology kept getting in the way of perfectly good geology').

Looking to the future, the Melbourne Cup Luncheon will be held at the Wine Centre again, on the 2 November, and the ASEG 2009 Conference will be held at the Adelaide Convention Centre from 22–25 February. It also won't be too long before we choose this year's ASEG wine for your purchasing pleasure.

The SA Branch holds technical meetings monthly, usually on a Thursday night at the Historian Hotel, from 5:50 pm. New members and interested persons are always welcome. Please contact Luke Gardiner (luke.gardiner@beachpetroleum.com.au) for further details.

Mike Hatch

New WA Centres of Excellence announced

The Western Australian Premier, as Minister for Science and Innovation, recently announced funding for two new minerals and energy related Centres of Excellence.

The WA Geothermal Centre of Excellence

The WA Geothermal Centre of Excellence, a joint venture between CSIRO, University of Western Australia and Curtin University, was awarded $2.3 million over 3 years to build capacity and knowledge within WA to undertake exploration and development of both shallow and deep dry geothermal resources. Klaus Regenauer-Lieb who has been recently appointed as the Premier's Science Fellow at CSIRO will lead the Centre and Arcady Dyskin will lead the program focussing on development of deep geothermal resources because of his expertise in fracture mechanics and micromechanical modelling. GSWA will provide pre-competitive geoscience information to help in research by the Centre and may undertake collaborative work with the Centre on deep geothermal resources.

The new research facility complements the late 2007 policy initiative in which the Western Australian Parliament passed amendments to the Petroleum Act – now renamed the Petroleum and Geothermal Energy Resources Act – to facilitate exploration and development of commercial geothermal resources in the State. Early in 2008, the first acreage release, covering the Perth Basin and nearby areas, was offered and 64 submissions covering 12 160 km^2 were received. The most popular areas were Dongara, Eneabba, Kwinana and Pinjarra.

The Centre for 3D Mineral Mapping

The Centre for 3D Mineral Mapping (C3DMM) has been granted $1.5 million over 4 years to develop new tools to generate low-cost, 3-D maps of mineral resources. Tom Cudahy will direct the Centre, which is a joint venture between CSIRO and the WA Centre for Exploration Targeting. The new Centre aims to better develop hyperspectral sensing in order to increase the efficiency of mineral exploration. Hyperspectral sensing is a tool to generate low-cost, highly specific maps of mineral systems for the next generation of mineral exploration.

A relatively new method of mineral exploration, hyperspectral sensing detects and measures around a hundred frequencies from the infrared and near infrared parts of the electromagnetic spectrum. As different minerals reflect light of different IR wavelengths – and as the amount of reflected radiation is proportional to the quantity of the minerals within the targeted material – hyperspectral sensing provides data on the surface mineralogy with a high level of specificity and quantification.

The Centre will capitalise on the Australian National Virtual Core Library (ANVCL – CSIRO and State/NT geological surveys) and Next Generation Mineral Mapping (NGMM – CSIRO and Geological Survey of Queensland) initiatives. GSWA is a collaborating institution of the new Centre.

End of an era for CRCs

The 30 June 2008 saw the end of an era in Australian mineral exploration research. On that date both the Predictive Mineral Discovery*Cooperative Research Centre (pmd*CRC) and the Landscape Environments and Mineral Exploration Cooperative Research Centre (CRC LEME) closed.

Each has been operating for 7 years and each was preceded by a 7-year period of similar CRCs. pmd*CRC was preceded by the Australian Geodynamics CRC, which operated from 1993 to 2000, and CRC LEME was preceded by what is commonly called LEME 1, the CRC for Landscape Evolution and Mineral Exploration, which operated from 1995 to 2001.

To mark their research work, we are providing a brief outline of some of their key achievements.

pmd*CRC

Seven years ago pmd*CRC was established to apply the collective knowledge and expertise from government agencies (CSIRO and Geoscience Australia), universities (James Cook University, The University of Melbourne, Monash University and The University of Western Australia) and industry (through AMIRA International) to the ever-growing challenges surrounding successful mineral exploration in Australia.

The 7 years of research have marked some significant breakthroughs in the science underpinning mineral exploration. The CRC set out in 2001 with a very clear set of objectives to contribute to a change in exploration practices to help revitalise an industry struggling to make new discoveries in traditional mineralised regions in Australia.

The highlights of the CRC have included the development of a range of new technologies and unique work practices that were developed through the CRC's Integrated Research Programs: Terrains and Architecture, System History, Fluid Sources, and Process Simulation and Modelling. Through a major effort to strengthen the mineral systems approach to exploration science and mineral exploration, a very much clearer understanding of the relationships between fundamental physical and chemical processes, observable features and exploration applications was developed to provide a range of new methodologies for targeting and spatial prediction of mineral systems.

The CRC has also effectively demonstrated, through case studies, the methods used to enmesh the technologies, techniques and practices with system-based concepts by integrating across disciplines and scales to produce a multilayered understanding of some key Australian mineralised terrains including the Mt Isa Inlier in Queensland, the Eastern Yilgarn Craton of WA, the Tasmanides of Victoria and NSW, together with parts of the Broken Hill region of NSW.

An important legacy of the CRC is the new knowledge and data accessible to industry through the CRC website, to be housed in future at Geoscience Australia, and access to new simulation and modelling technologies for ongoing research through CSIRO and the four university partners. Commercial access to modelling and simulation technology to help industry with targeting solutions is being established through the CRC spin-off company Ausmodel Pty Ltd.

The CRC has presented a new way of looking at and of thinking about the issues surrounding exploration. It also represents a significant change to the work practices and the relationship between science and the exploration industry in Australia to ensure future success and economic development.

CRC LEME

For the past 14 years, CRC Landscape environments and mineral exploration LEME, in partnership with our industry end users, has delivered significant benefits to exploration practitioners faced with the vexing task of mineral exploration through cover. In the last 7 years (LEME 2) we have brought together scientists and partners from the traditionally disparate scientific disciplines of geology, geophysics, geochemistry, soil science, microbiology, molecular biology, biochemistry, hydro-geochemistry, hydrology, plant biology and ecology to develop a unique approach to the identification of potential zones of mineralisation and determination of mineral transport and transformation processes in landscapes dominated by cover. The knowledge generated has, in turn, provided new tools and 'pre-competitive' geoscience information to explorers. This multi-disciplinary, multi-agency approach would not have been achieved if it was not for the existence of the Federal Governments CRC Program and the funding provided.

Hydrogeochemical techniques to vector in on buried mineralisation have been successfully trialled in the Tanami and Yilgarn, and the application of high energy X-ray techniques has led to significant advances in gold mineral host understanding.

Hyperspectral analysis of surface illite has been identified as a mineralisation vector and application of hyperspectral surveys to diamond exploration has aided the discovery of two new kimberlites at Pine Creek, South Australia, employing spectral analysis of HyMap data.

The CRC's strategy to focus on biological mechanisms of regolith trace element and mineral transport has delivered significant advances. A highlight has been the isolation of bacteria that precipitates gold in the regolith. The development of phyto-exploration as an effective exploration-through-cover tool has delivered encouraging results. Other highlights include the discovery of an extension to the Pinnacles Pb/Zn lode near Broken Hill, partially the result of a River Red Gum leaf geochemical survey, and the detection of anomalous gold concentrations in leaves of the common native grass Spinifex, with the observation that its roots penetrate as far as 30 metres down into the regolith. The uptake of uranium and thorium by a variety of native Australian plant species has also been demonstrated by LEME researchers in collaboration with Heathgate Resources, demonstrating that phyto-exploration is a viable method for uranium exploration through cover.

Phyto-exploration has significant potential to increase exploration search space, allowing explorers to access culturally sensitive land where techniques such as drilling, involving heavy equipment access, can be unacceptable to traditional owners.

With our State Geological Survey and Industry partners LEME has delivered a number of key 'pre-competitive' geoscience products including the *Northern Territory Regolith Landform Map and Atlas of Regolith Materials, Laterite Geochemical Atlas and Database for the Western Yilgarn Craton, Map of Palaeodrainage and Tertiary Coastal Barriers of South Australia* and recently released *Queensland Regolith Landform Map and Atlas*. The laterite atlases and palaeodrainage maps have had significant, quantifiable impacts on exploration activity.

In addition to the 300 Open File Technical reports, symposium proceedings and general data, released by LEME, we will also release in 2008 a series of six regional Exploration Under Cover *Explorers Guides* covering the Tanami, Gawler, Curnamona, Yilgarn, Thomson Orogen and Cobar provinces.

Field guides to phyto-exploration and hydrogeochemical exploration, a Digital atlas of regolith maps and a regolith geoscience reference book (published by CSIRO) will also be released by the third quarter 2008. The CRC has also entered into a collaborative agreement with AMIRA to transfer all relevant LEME technical reports and mineral prospect data into the AMIRA online database, *Data Metallogenica*, an international geoscience and prospect information repository.

All LEME publications are digitally available as .pdf files free of charge from our website: http://www.crcleme.org.au. CSIRO will maintain the LEME website for 5 years after cessation of operations in 2008.

Whilst LEME will officially cease on 30 June 2008, regolith research will continue in the core parties through initiatives such as: the CSIRO Minerals Down Under Flagship, the AMIRA P778 Predictive Geochemistry in Areas of Transported Overburden Project, the PIRSA/University of Adelaide Centre for Exploration Under Cover, and the GA Onshore Energy Initiative. In addition, a bid for a new CRC in Deep Exploration is currently being scoped by AMIRA International, focussing on buried mineralisation, innovative drilling and real-time downhole data acquisition technologies.

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Australia's offshore seafloor exploration and mining industry – opportunities and challenges

Australia's seafloor is emerging as the new frontier for minerals exploration and mining, as the global resources boom continues and onshore deposits become increasingly difficult and expensive to access. Despite these drivers, it is unclear whether the mining industry has the social licence to operate offshore.

Geoscience Australia and CSIRO's Wealth from Oceans National Research Flagship released the Australian Offshore, Minerals Location Map in 2006 (Fig. 1), which depicts known mineral occurrences and deposits within Australia's 200 nautical mile exclusive economic zone and extended continental shelf. Regionally, companies are being formed to take advantage of this prospectivity. One such company is Nautilus Minerals, which, with the backing of major international companies such as Anglo American, Teck Cominco and Epion Holdings, now has well-advanced plans to mine Solwara1, a deep sea sulfide deposit in PNG waters, in 2009 (Nautilus, 2008) Other relatively young companies exploring in the southwest Pacific and expecting to delineate commercially viable prospects include Neptune and Bluewater Metals.

Australia also has particular interest in bulk commodities like building sand, which need to be close to market, and other commodities, such as heavy mineral sands, diamonds and other placer deposits. In Australian waters, there are currently only two offshore mining operations: sand dredging in Moreton Bay, Queensland and carbonate sand mining in Cockburn Sound, Fremantle, Western Australia. However, about 15 exploration licences have been granted nationally and about 30 are listed as 'pending' for offshore exploration, mining, and retention in both State/Territory and Commonwealth waters. Clearly the interest is there.

The Wealth from Oceans Flagship set out to determine the opportunities and challenges for the development of a successful seafloor mining and exploration (SEM) industry in Australia; to identify the key stakeholders and capture any of their issues and concerns; and finally to understand the public and political context surrounding the industry.

In a report recently released by the Flagship (Littleboy and Boughen, 2007; http://csiro.au/resources/SEMReport.html), the question is asked – does this nascent industry have support amongst the wider community? If not, why not? In particular it discusses the regulatory and social issues raised as a result of the mining industry's increasing interest in exploring and mining Australia's seafloor. Complemented by two desktop studies detailing the international and national status of the SEM industry (Johns, 2007; Tsamenyi et al., 2007), the study was guided by an advisory committee, comprising a mix of representatives from industry, government, research and environmental NGOs.

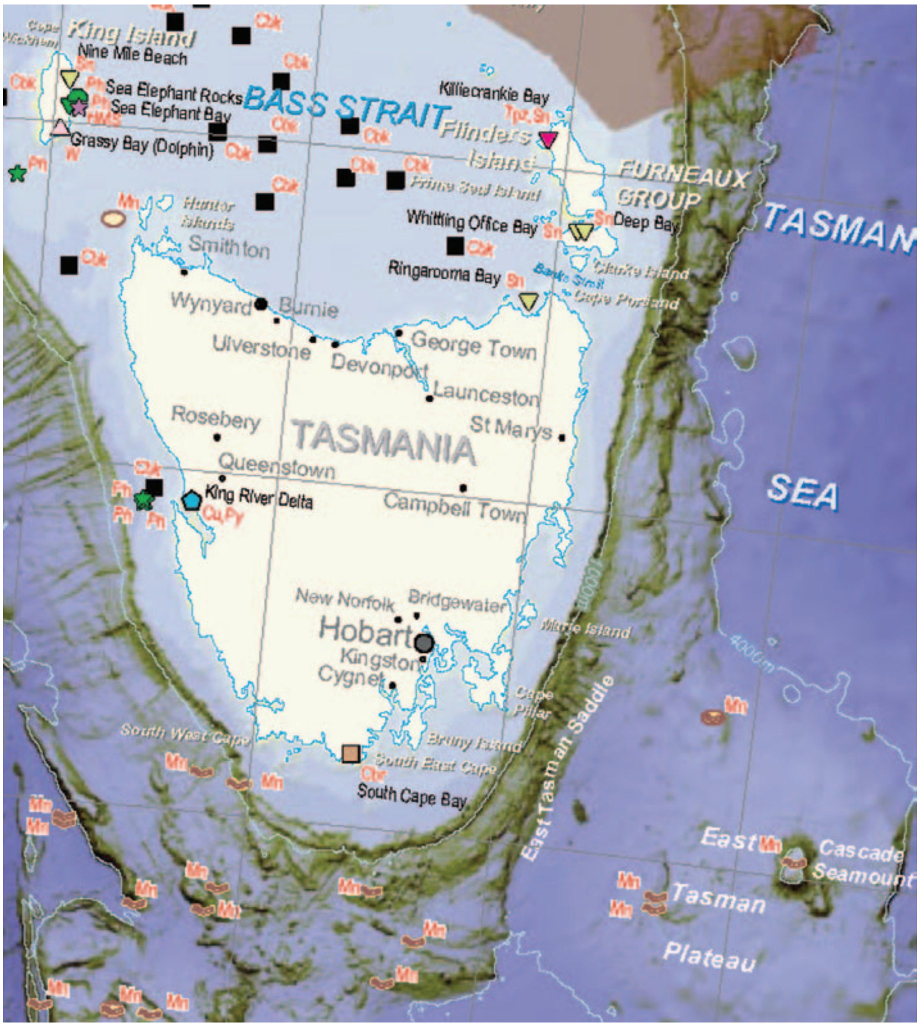

Fig. 1. *Extract from the Australian Offshore, Minerals Location Map (2006, produced by Geoscience Australia, in partnership with CSIRO's Wealth from Oceans Flagship, all the State and Northern Territory Geological Surveys).*

The study involved a series of small group workshops with key stakeholders from government agencies, industry and other interested parties – mainly fisheries and environmental NGOs. The workshops explored perceived benefits and opportunities and identified participants' main issues and concerns.

The potential environmental impact of seafloor activities is naturally a common concern. All groups perceived a lack of scientific data to inform decision making and the need for detailed information on specific projects. A key recommendation of the report is that an improved information base is essential to help understand environmental, social and economic impacts of seafloor activity across a range of techniques and technologies, terrains and ecosystems. Scientifically tested baseline data are needed to better understand the conflicting requirements of users of the ocean and to underpin policy and regulation. From this Australia will be able to develop best practice in licence applications and environmental impact assessments.

Although Australia is one of only a few countries in the world that has legislation specific to SEM, there are concerns about the level of understanding of the current regulations. Communication is critical to ensure the decision process can be effective and not vulnerable to political issues and subjective judgements. If the industry is to grow, then it will need to work closely with government to improve awareness of the regulatory systems and with the general public to identify and analyse potential issues.

The SEM industry is at a major turning point, similar to the oil and gas industry in the 1970s. Increasingly people are talking about the ocean floor in terms of its mineral resource potential and new discoveries and improved knowledge and access are adding to this interest. The long-term aim of this research is to develop a blueprint for best practice in seafloor activities – particularly in the design and monitoring of environmental impact assessments. The Flagship aims to provide factual, unbiased scientific tools, including tested protocols for SEM management strategies, to help determine the social and environmental impact of SEM projects. Future work will focus on conducting baseline studies to measure the impact of seafloor activity. The data will be used to model the geological and environmental changes and make risk-based assessments of impact. In parallel, the Flagship will facilitate debate to explore in more depth the general concept of SEM, and the issues and concerns of the general public. Outcomes will help guide and inform the metrics used for environmental assessments.

These tools will be critical to any development of Australia's seafloor minerals sector to ensure social and economic wealth while maintaining environmental integrity.

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Japan Energy Corporation wins offshore permit

Japan Energy Corporation has been awarded a new offshore petroleum permit to explore in WA-412-P (released as W07-17) in the Carnarvon Basin off Western Australia.[1] The work program commitments for the awarded permit are valued at $78.6 million over the next 6 years. The company has proposed a guaranteed work program consisting of 500 km^2 of new 3D seismic surveying, 700 km of 2D seismic reprocessing, one exploration well and geotechnical studies, with an estimated value of $44.6 million. The secondary work program consists of 200 km^2 of new 3D seismic surveying, one exploration well and geotechnical studies, with an estimated value of $34.0 million. There were no other bids for this area.

Summary of areas currently available for bidding

There are still 23 areas available for bidding and a summary of these is shown in the table below.

Release/round	Areas	Bid closing date
2008 acreage release, first closing round [17 areas]	AC08-1 to 8; W08-7 to 10 and 16 to 20	Thursday, 9 October 2008
Re-release of 2007 areas (from second closing round) [6 areas]	V07-2 NT07-3 W07-19, 20 and 21 AC07-3 (*from first closing round*)	Thursday, 9 October 2008

Further information on these areas and application requirements can be found by visiting this website: www.ret.gov.au/petexp or by requesting a free CD-ROM by e-mail: petroleum.exploration@ret.gov.au

Amendment to Offshore Petroleum Act to allow CO_2 injection and storage in offshore areas

Legislation to amend the OPA in relation to carbon dioxide injection and storage in Commonwealth waters was publicly released on 17 May 2008. The legislation provides for access and tenure and a system for managing potential interactions with the petroleum industry as well as ensuring that storage is safe and secure.

The draft legislation has been referred to the House of Representatives Standing Committee on Primary Industries and Resources which invited submissions and will make recommendations to the Government on the legislation. The legislation has also been referred by the Senate Selection of Bills Committee to the Standing Committee on Economics. The Senate Committee will report its findings to the Senate on 16 October. The Government introduced the legislation into the House of Representatives on 18 June 2008.

More information is available from the Department of Resources, Energy and Tourism's website at www.ret.gov.au.

Welcome to Hythane

You may not have heard much about Hythane. It is a gas comprising up to 20% hydrogen mixed with compressed natural gas, and India will become the first country in the world to approve the use of Hythane to power automobiles from publicly available bowsers. Hythane-powered cars produce significantly lower emissions than those operating on diesel or natural gas.

This is of particular interest because the Australian company Eden Energy Ltd has been working with the Indian authorities for the past 15 months to achieve this approval and has been promoting the use of Hythane in India for the past 4 years.

It just shows the opportunities that are available when new technologies are developed to reduce greenhouse gas emissions. We should not be frightened of adapting to climate change.

[1]See Preview 132, February 2008 for map of area.

Update on Geophysical Survey Progress from the geological surveys of Queensland, Western Australia, Northern Territory and Tasmania and Geoscience Australia (Information current at 10 July 2008)

Tables 1–3 show the continuing acquisition by the States, the Northern Territory and Geoscience Australia of new gravity, magnetic, airborne EM and radiometric data over the Australian continent. All surveys are being managed by Geoscience Australia and there is one new gravity survey in this issue. This is the Windimurra survey and the locality diagram is shown below.

Table 1. Airborne magnetic and radiometric surveys

Survey Name	Client	Contractor	Start Flying	Line-km	Spacing AGL Dir	Area (km²)	End Flying	Final Data to GA	Locality Diagram (Preview)	GADDS release
AWAGS2	GA	UTS	29 Mar 07	145 350	75 Km, 80 m N–S	7 659 861	100% complete @ 14 Dec 07	TBA	124 – Oct 06, p. 15	TBA
South Kimberley	GSWA	GPX	24 Jan 08	163 000	400 m, 60 m N–S	57 920	76.5% complete @ 6 Jul 08	TBA	128 – Jun 07, p. 26	TBA
Cooper Basin East	GSQ	UTS	8 Jan 08	214 352	400 m, 60 m N–S	76 980	76.1% complete @ 6 Jul 08	TBA	130 – Oct 07, p. 29	TBA
Cooper Basin West	GSQ	Fugro	8 Nov 07	N–S lines 161 088 E–W lines 47 993	400 m, 60 m N–S & E/W	N–S lines 57 700 E–W lines 16 710	68.9% complete @ 6 Jul 08	TBA	130 – Oct 07, p. 29	TBA
Normanton	GSQ	Thomson	25 Apr 08	114 487	400 m, 80 m E/W	74 410	22.1% complete @ 6 Jul 08	TBA	132 – Feb 08, p. 23	TBA
Cooper Basin North	GSQ	TBA	TBA	166 373	400 m, 80 m E/W	59 480	TBA	TBA	134 – Jun 08, p. 22	TBA
Offshore NW Tas	GA	Fugro	21 Jan 08	43 824	800 m, 90 m E/W	27 512	100% complete @ 6 Apr 08	28 May 08	132 – Feb 08, p. 24	TBA
Offshore SW Tas	MRT	Fugro	15 Jan 08	26 554	800 m, 90 m E/W	16 745	100% complete @ 3 Mar 08	28 May 08	132 – Feb 08, p. 24	TBA
South-West Catchment Council – Dumbleyung	GSWA, DAFWA and SWCC	Fugro	7 Mar 08	74 360 total (67 583 @ 100 m spacing and 6777 @ 400 m spacing)	100 m, 30 m NS and 400 m, 60 m NS	7783 total (100 m lines: 5948; 400 m lines: 1835)	69% complete @ 6 Jul 08	TBA	132 – Feb 08, p. 24	TBA
Byro	GSWA	GPX	3 Apr 08	83 855	400 m, 60 m E/W	29 750	84.9% complete @ 6 Jul 08	TBA	133 – Apr 08, p. 20	TBA
Balladonia	GSWA	TBA	TBA	43 449	400 m, 60 m E/W	14 960	TBA	TBA	134 – Jun 08, p. 22	TBA
Esperance	GSWA	TBA	TBA	82 674	400 m, 60 m E/W	29 200	TBA	TBA	134 – Jun 08, p. 21	TBA

Table 2. Airborne electromagnetic surveys

Survey Name	Client	Contractor	Start Flying	Line (km)	Spacing AGL Dir	Area (km²)	End Flying	Final Data to GA	Locality Diagram (Preview)	GADDS release
Paterson	GA	Fugro	8 Sep 07	28 367	1000 & 2000 m for GA; 200 m – 666 m company infill; 120 m; E/W & SW/NE North & South, respectively of the Rudall River NP	33 950	49% complete @ 6 Jul 08 Recommence 27 May 08 after demobilising on 30 Nov 07	TBA	130 – Oct 07, p. 30	TBA
South-West Catchment Council: Darkan – Wagin	GSWA, DAFWA and SWCC	Geoforce	10 Jun 08	1127	300 m N–S	288.6	21 Jun 08	TBA	133 – Apr 08, p. 20	TBA
Pine Creek	GA	TBA	TBA	29 058	1666 & 5000 m for GA; 200 m – 1000 m company infill; E/W flight lines; Flying height to be confirmed	72 412	TBA	TBA	133 – Apr 08, p. 21	TBA

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Table 3. Gravity surveys

Survey Name	Client	Contractor	Start Survey	No. of stations	Station Spacing (km)	Area (km²)	End Survey	Final Data to GA	Locality Diagram (Preview)	GADDS release
Westmoreland – Normanton	GSQ	Integrated Mapping Technologies	TBA	5977	4 regular	95 620	41% complete @ 6 Jul 08	TBA	133 – Apr 08, p. 21	TBA
Central Arunta	NT	Atlas Geophysics	6 May 08	9958 in Area A and a possible 1128 in Area B	4 regular with selected areas for infill at 500 m to 2 km	97 600	68.3% complete @ 7 Jul 08	TBA	133 – Apr 08, p. 21	TBA
West Musgrave	GSWA	Daishsat	1 May 08	1674 in Area A and a possible 2277 in Area B	2.5 km regular	24 340	100% complete @ 6 June 08	TBA	133 – Apr 08, p. 21	TBA
Windimurra	GSWA	Quotation Request closed 18 Jun 08	TBA	5210	2.5 km regular	~30 000	TBA	TBA	This issue	TBA

TBA: To be advised

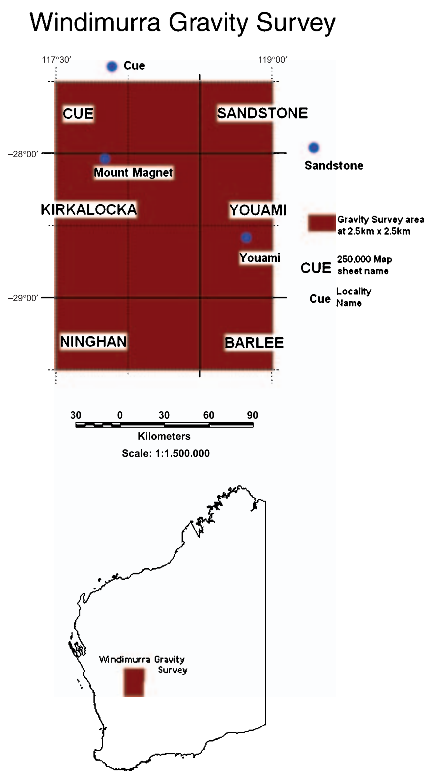

Fig. 1. *Location of the Windimurra gravity survey in Western Australia (see Table 3).*

Seismic surveys

As part of the Onshore Energy Security Program (OESP) and with the cooperation of Primary Industries and Resources South Australia (PIRSA), Geoscience Australia is conducting a deep crustal seismic reflection survey in South Australia. This survey consists of three traverse lines (Figure 2), one across the Gawler Province, one across the Curnamona province and one in the Arrowie Basin. The traverses will help in the assessment of uranium, geothermal energy and hydrocarbon resource potential in these regions of South Australia. At time of writing, 254 km had been acquired across the Eyre Peninsula (Gawler Line), 60.8 km in the Arrowie Basin and 71 km of the proposed 258 km had been acquired along Curnamona line. This survey is planned to be completed in mid-July.

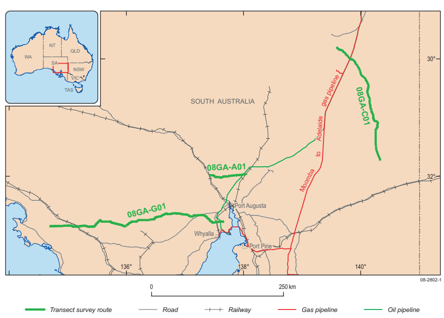

Fig. 2. *Gawler–Curnamona–Arrowie seismic survey proposed traverse line location map.*

The next survey to be conducted by Geoscience Australia is planned for later this year and will consist of one continuous traverse crossing from the Gawler Province, over the Officer Basin to the Musgrave Block and then into the Amadeus Basin in the Northern Territory. This traverse is planned to be approximately 585 km long and will be jointly funded by GA, AuScope and PIRSA (see Figure 3).

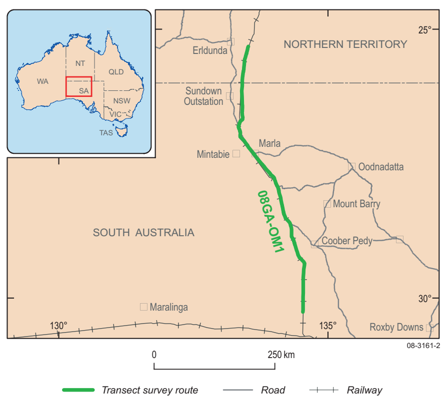

Fig. 3. *Location of the traverse for the Gawler–Musgrave–Officer–Amadeus seismic survey.*

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Seismic shift in understanding the structure of central Victoria

An exciting new interpretation of the structural development of central Victoria in Palaeozoic times has emerged from data collected from the central Victorian seismic transect in June 2006.

The deep-seismic transect, carried out across several basement structural zones in central Victoria, sheds new light on the distribution and development of the source rocks and fluid pathways responsible for gold deposits in the central Victorian goldfields. The seismic transect consists of four overlapping lines that cover 395 km. The lines extend east from Glenorchy near Stawell in the state's west, pass north of Bendigo en-route to Violet Town in central Victoria, before turning north towards Cobram on the Murray River. The project was collaboration between the predictive mineral discovery Cooperative Research Centre (pmd*CRC), Geoscience Australia, GeoScience Victoria, DIIRD and industry partners. It is the first major seismic survey to be conducted across the world-class Victorian orogenic gold province.

Previous deep-seismic reflection surveys in the region consisted of short, isolated lines which did, however, give the first real direct evidence of the sub-surface geometry of some major structures such as the west-dipping Heathcote, and east-dipping Moyston faults (Gray et al., 1991; Korsch et al., 2002).

The current deep-seismic transect is much larger in scope, links the earlier surveys together and traverses the entire width of the Western Lachlan Fold Belt in Victoria (comprising the Stawell, Bendigo and Melbourne zones), and a small part of the Central Lachlan Fold Belt (part of the Tabberabbera Zone).

Processed data from the four seismic traverses were geologically interpreted at a number of project workshops held at GeoScience Victoria last year. Workshop participants included Geoscience Australia, GeoScience Victoria, the University of Melbourne and member companies of the pmd*CRC project.

The final results – detailed geological interpretations called 'cross-sections' that represent a vertical slice cut through the full thickness of the earth's crust (nearly 40 kilometres) across central Victoria – represent the consensus view among workshop participants. These final results were delivered at a public workshop on 21 February 2008. The cross-sections are reconciled against surface geological data – including geological maps and shallow cross-sections based on directly measured surface structures – wherever possible, further refined by computer modelling. Such steps ensure subsurface interpretations are consistent with observed gravity and magnetic data.

The computer modelling, called forward modelling, uses real-world rock density and magnetic susceptibility measurements from GeoScience Victoria databases, and compares them with theoretical properties assigned to the interpreted cross sections. Early in the interpretation process it was apparent that many structures visible in the seismic data near surface did correlate strongly with the known positions of faults and other boundaries between different surface rock types. As these are based on many years of detailed geological mapping, drilling and interpretation of aeromagnetic data, the good correlation gave confidence the seismic data were imaging real structures. It allowed the position and character of these structures to be interpreted to great depths in the earth's crust.

Previously, geologists were forced to speculate about the types of structures that may occur at depth. Speculation was based on surface structures and theories based on scale-modelling other world examples. Now, for the first time, structures at deep levels in the crust beneath central Victoria have been directly imaged and, unsurprisingly, the reality is a little different from previous educated guesswork (see Figure 4). The new data allow previous tectonic models proposed for the region to be tested and refined.

The most obvious results from the seismic data are the big differences visible in the seismic character between the mid and lower crust of the Stawell and Bendigo zones to the west and of the adjacent Melbourne Zone. The differences suggest a lower crustal substrate beneath the Melbourne Zone that is of different composition and structural evolution to adjacent regions. Large lateral changes in lower crustal seismic character tend to support geological models for Victoria that advocate diversity in lower crustal composition as a way to explain structural

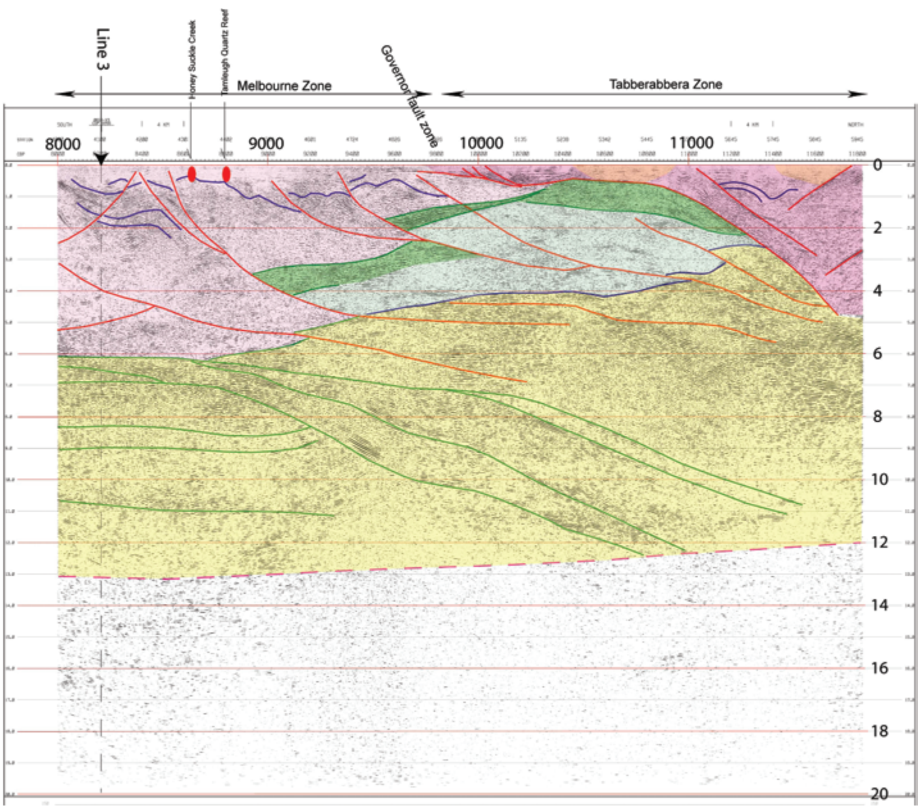

Fig. 4. *Interpretation of Line 4 of the central Victorian seismic transect (Violet Town to Cobram). This line shows seismically quiet sedimentary rocks of the Tabberabbera and Melbourne zones (purples) overlying strong seismic reflectors – cut by several faults – interpreted to represent igneous and metamorphic rocks in an older substrate (green, blue and yellow units).*

and temporal variations in the upper crust. The 'Selwyn Block' model (Cayley et al., 2002) is one such example.

Most structures visible within the lower crust of the Melbourne Zone cannot be traced to surface. Instead, they appear disconnected from the open folds known to occur in the upper crust here. This is known as a 'thin-skinned' style of deformation where structures at depth appear to have developed independently from structures in overlying rocks.

Importantly, this predominantly 'thin-skinned' style of deformation does not seem to extend west into the older Bendigo and Stawell zones as previously speculated. Instead, many of the structures mapped at surface in the Stawell Zone and especially in the Bendigo Zone, can be traced in the seismic data, unbroken, to the deepest levels of the crust imaged – depths of nearly 40 kilometres. The well-known west-dipping Whitelaw Fault near Bendigo is an example.

Direct structural linkage between the upper and lower crust in the Bendigo Zone suggests a predominantly 'thick-skinned' style of deformation – where the whole crust was deformed together – when this area was deformed in the Late Ordovician–Early Silurian. This is an important advance on previous interpretations. It allows geological understanding of the rocks and structures visible and directly measurable at surface to be projected down through the entire crust. It also constrains geologists' attempts to 'undeform' the whole crust, restoring cross-sections of the central Victorian region to possible undeformed configurations that existed before strong deformation events over 440 million years ago. This is a critical analytical step because it allows geologists to model the geometry of the crust during deformation, which was a time when deep crustal gold sources, fluid pathways and world-class gold deposits of the region were most-likely evolving.

Results of the seismic interpretation are to be published in a forthcoming series of research papers. They are being used to update a regional scale 3D geological model of Victoria being built within another pmd*CRC project and are also being fed into new predictive mineralisation models for the region.

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Continued on p. 38

Why do we search for gold?

Summary

Gold has played a role in most human civilisations. Its role used to be limited to jewellery, ornamentation, currency and banking, but in addition it is now in demand for a wide range of industrial, medical and research activities. And at US$30 000 a kilogram it is certainly worth hunting for.

Ancient gold

Ian Fleming's Goldfinger loved only gold, and while his obsession was somewhat extreme, I suspect that there is a little bit of Goldfinger in most of us. Gold is embedded in our culture. It has been known and highly valued for thousands of years and was probably the first metal used by humans. The Egyptians, as far back as 2600 BC used gold from Nubia (now northern Sudan and Southern Egypt) for decoration and rituals. The famous funerary mask of Tutankhamen (Figure 1) dates from 1324 BC and the Turin Papyrus of about 1160 BC shows one of the gold mines on the earliest known geological map.

In ancient Greece the legend of the Golden Fleece, of Argonaut fame, may refer to the use of fleeces to trap gold dust from placer deposits. Whatever it was used for, there was clearly a very high value placed on gold in those times.

Fig. 1. *Mask of Tutankhamen's mummy, as displayed at the Egyptian Museum at Cairo, image taken from Wikipedia.*

Fig. 2. *Jason bringing Elias the Golden Fleece. Side A from an Apulian red-figure calyx crater, 340 BC–330 BC. Purchased by the Louvre in 1818 from the collection of Joseph-François Tochon d'Annecy. Accessed from http://www.mlahanas.de/Greeks/Mythology/JasonPeliasLouvreK127.html.*

Gold is mentioned frequently in the Bible. In Genesis 2:11 at Havilah, where the Pison River flowed, it is stated that 'the gold of that land is good' and of course the Magi (Matthew 2:11) brought gifts of gold to the baby Jesus and the Book of Revelation (21:21) describes the city of the New Jerusalem as having streets paved with pure gold.

In China, the Chu Kingdom produced gold coins named Ying Yuan in the 5th or 6th century BC and the Romans developed new methods of extracting gold throughout Europe. They operated mines in Spain, Romania, Transylvania and even Wales. The Las Médulas gold mine in Galicia (in the Leon Province Spain) was one of the largest and seven long aqueducts were built to sluice the large alluvial deposit. This mine site is now a UNESCO World Heritage site.

In Africa, the Mali Empire, which extended from Timbuktu to the Atlantic Ocean, became renowned for the wealth of its rulers. It was famous for its gold and Figure 3 shows the most powerful ruler – Mansa Musa who reigned from 1312–1337. This part of Africa is still a hot gold prospect.

The European exploration of the Americas was encouraged by reports of the gold ornaments displayed in great profusion by Native American peoples especially in Central and South America. When the Spanish conquered the Inca Empire in the 16th Century

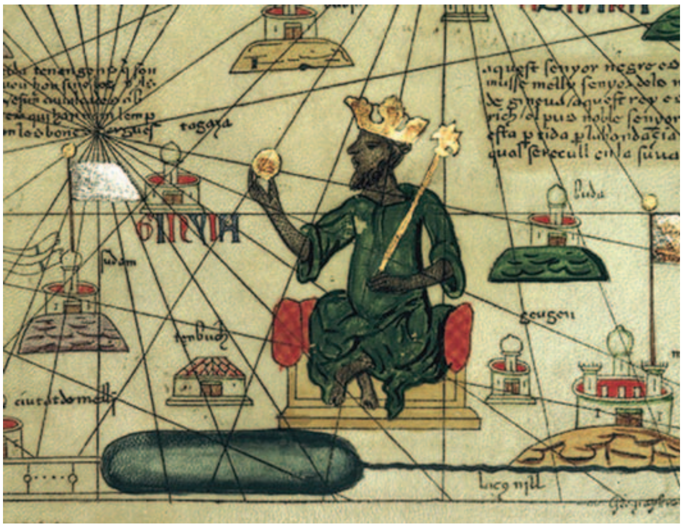

Fig. 3. *Mansa Musa, ruler of the Mali Empire, holding a gold nugget, from a 1375 Catalan Atlas of the known world (mapamundi), drawn by Abraham Cresques of Mallorca (see http://en.wikipedia.org/wiki/Mali_Empire#Gold).*

Fig. 4. *Gold statuette of a seated Quimbayan chief (200 and 1000 CE) from Colombia. Held by the Museo de América, Madrid, Spain. Photograph by Luis García 06 April 2008 (see http://commons.wikimedia.org/wiki/Category:Quimbaya_culture).*

they discovered a culture where gold reflected the glory of their Sun God (the sweat of the sun). The Incas believed it was entrusted to them for safekeeping. It took on value only when crafted into ceremonial articles – vessels, jewellery, figurines – or adornments for tombs and temples. By law, all gold and silver of the realm belonged to the Inca Emperor, who used it to bedeck his palace, beautify temples and reward loyalty. Unfortunately, the Spaniards had no time for works of art and melted them all down to ingots for transporting back to Spain. Figure 4 came from what is now Colombia and escaped the Spaniards' furnaces.

Nineteenth century exploration

During the 19th century, when Europeans were at their most expansive, large gold deposits were discovered all over the world. The first discovery of gold in Australia was in 1823 by a government surveyor named McBrien at Fish River in New South Wales. In the United States, the first major gold strike occurred in a small north Georgia town called Dahlonega in 1828. In South Africa, in March 1886 an Australian gold miner, George Harrison, stumbled across a rocky outcrop of the main gold-bearing reef. The Witwatersrand Gold Rush started, Johannesburg was established, and as they say, the rest is history. In New Zealand, although the Maori had long known of the existence of gold in Central Otago, they had no use for the metal and it was not until the 1860s when the Otago Gold Rush got underway that gold mining took off. Further significant gold rushes outside of

Fig. 5. *Twelve gold ingots from Sveriges Riksbank (the central bank of Sweden). The ingots shown are together worth approximately US$5.0 million as of July 2008; their value changes as the price of gold fluctuates.*

Fig. 6. *'Typical' Indian bride from a passtehroti advertisement (see www.passtheroti.com; http://images.google.com.au/images?hl=en&q=indian+gold&um=1&ie=UTF-8&sa=X&oi=image_result_group&resnum=1&ct=title).*

Australia occurred in California in 1848 and at Klondike on the Yukon River in Canada in 1896.

At present gold is being mined throughout the world and the main producing countries are China, Australia, South Africa and the United States – but more on this later.

Uses of gold now

Before the 19th century, gold was used mainly for jewellery, ornamentation and for currency and banking. Nowadays the use of gold has spread throughout society. Some of the main uses are listed below.

Coins and banking

Since the first gold coins were struck by King Croesus of Lydia (present-day Turkey) during his reign between 560 and 547 BC, gold coins have continued as legal tender and banks have stored gold as ingots. In 2007, according to the World Gold Council, 473 tonnes of gold were used for bar hoarding and coins.

Jewellery

Most of the gold produced is consumed by the jewellery industry (~2399 t out of a total of ~3515 t in 2007) with India consuming the most. Private individuals in India own more than 14 000 t of plain necklaces, rings and bracelets – nearly 10% of the world's entire above-ground gold stocks, and a larger hoard than the US, German and French governments' put together. The jewellery industry in India contributes over 15% of the country's total exports and provides employment to 1.3 million people directly and indirectly. Gold jewellery forms around 80% of the Indian jewellery market, with the balance comprising fabricated studded jewellery (including diamonds) as well as gemstone studded jewellery. India consumes nearly 800 t of gold bullion annually, accounting for about 20% of world gold consumption and nearly 600 t of it goes into making jewellery.[1] China with a consumption of 326 t in 2007 is the second largest consumer.

Other uses

Other uses in 2007 included 311 t for electronics, 58 t for dentistry, 73 t for medals and imitation coins, 93 t for other industrial uses and 209 t for Electronic Fund Transfers (EFTs) and similar products. Some of these diverse uses are listed below:

Electronics

Gold's main role in electronics is in contacts, switches, relays and connectors. Contacts are electroplated with a very thin film of gold. Gold's other main role in electronics is in semiconductor devices, where fine gold wire or strip is used to connect parts such as transistors and integrated circuits, and in printed circuit boards to link components.

Space and aeronautics

Without gold, man wouldn't have visited the moon. Gold, in the form of sheets 0.15 mm thick, is used in space programs as a radiation shield. Because gold is such an effective reflector, it deflects the burning heat of the sun. More than 40.8 kg of gold was used in the construction of the famous US Columbia space shuttle.

Catalysis

Automotive pollution control catalysts for diesel engines contain gold, as well as the traditional platinum and palladium ingredients, to improve emission control.

Nanotechnology

Nanostructures are usually built using carbon, which actually attaches itself to other substances more or less indiscriminately. Gold can be more reliable and selects where it settles and can be used with precision to build new materials.

Dental

The advantages of gold and its alloys for dental applications are its bio-compatibility, malleability and resistance to corrosion. Gold has been used in dentistry for almost 3000 years. Current demand is about 60 t per year.

Environmental

Gold has a vital role to play in future technologies aimed at reducing automotive diesel emissions, purifying water and reducing energy consumption in chemical processing plants.

[1] http://goldnews.bullionvault.com/india_gold_jewelry_gems_diamonds_industry_120620073.

Engineering

Gold is used in a myriad of engineering applications including brazing alloys, as a lubricating coating and in electrical applications like potentiometers and spark plugs. It has also been used as a thin coating in building glazing to reflect heat radiation, keeping buildings cool in summer and warmer in winter.

Photography

Gold plays a role in photography as the ultimate means of stabilising and protecting the silver image, the universal commercial medium.

Food/Beauty

Gold is being used in luxury food goods as well as a range of toiletry and cosmetic products. In some Asian countries, gold is used in food and drink, from fruit jelly snacks to coffee. Japan's gold leaf production was based in Kanazawa, and visitors can still find gold leaf shops and workshops selling green tea, and even candy, with gold leaf. So gold will definitely be in demand for the foreseeable future, particularly when it is worth about US$30 000 per kilogram.

David Denham

Where to look for gold

Global scene

Gold is found wherever you look, but the trick is to find places where it is economic to mine. In the 19th century gold rushes, prospectors found easy pickings at or close to the surface and were able to profitably extract gold with comparative ease. Places like Bendigo, Ballarat and the Klondike were mostly worked out and abandoned, while some mines, like those at Witwatersrand or Kalgoorlie, are still active and profitable as a result of improved extraction and processing techniques. Remember, that when the demand goes up, the price rises and the incentive to keep producing goes up as well. In fact, it is estimated that 75% of all gold ever produced (~150 000 tonnes) has been extracted since 1910 (Wikipedia), driven by demand.

Values of 1 g/t or less, as found at Cadia in New South Wales and the Super Pit at Kalgoorlie, would have been abandoned by most 19th century miners. However, with better techniques these mines are still economic. Likewise the gold mines near Johannesburg are still profitable, but the annual output is declining rapidly because of the effort required to mine at greater depths. The Western Deep Level mine has shafts at depths of 3900 m, and although the values are close to 10 g/tonne, to produce one ounce (~31.1 g), requires 3.3 tonnes of ore, 5440 litres of water, 572 kilowatt hours electricity, 12 cubic metres of compressed air, lots of dynamite and tonnes of

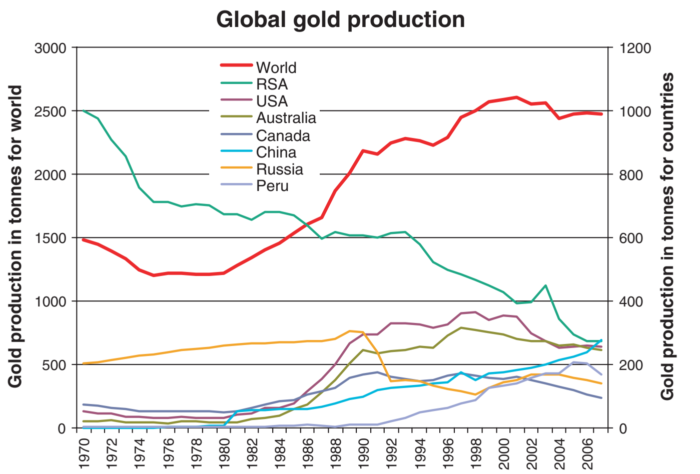

Fig. 7. *Global gold production from 1970–2007. The left hand axis indicates annual global production in tonnes and the right hand axis shows the annual production from the top six producing nations. Notice that production from South Africa, USA, Australia and Canada appears to have peaked. In 1970 South Africa dominated the global production. In 2007 production was shared more equally between several countries, as the search for gold became more global (data from GOLDSHEET Mining Directory, World Gold Council, USGS, ABARE and GFMS Ltd).*

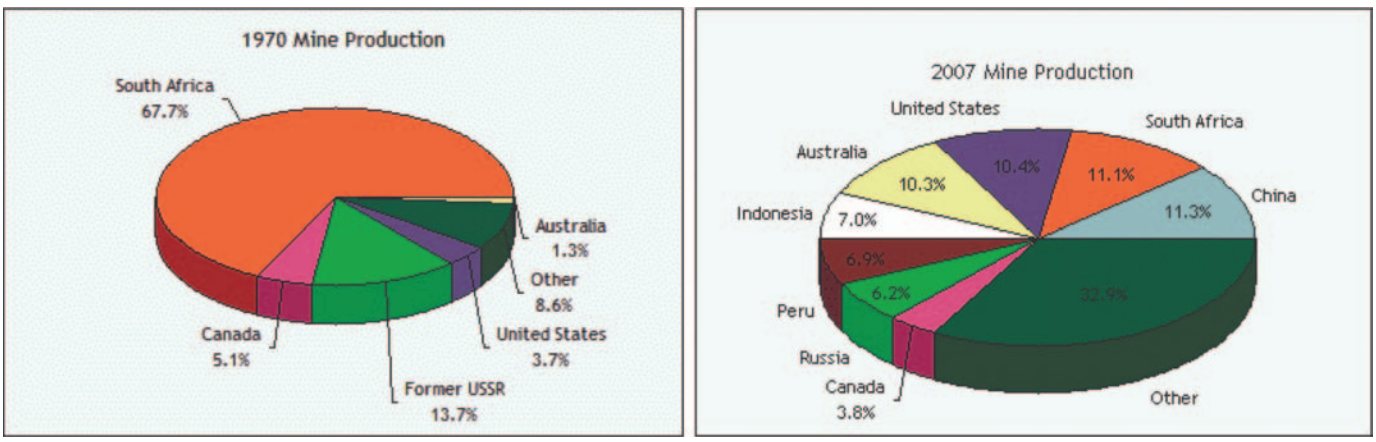

Fig. 8. *Global gold production in pie chart format for 1970 and 2007. Adapted from the GOLDSHEET Mining Directory. Notice how the South African output has declined and how many more countries are now making sizeable contributions to the total production numbers.*

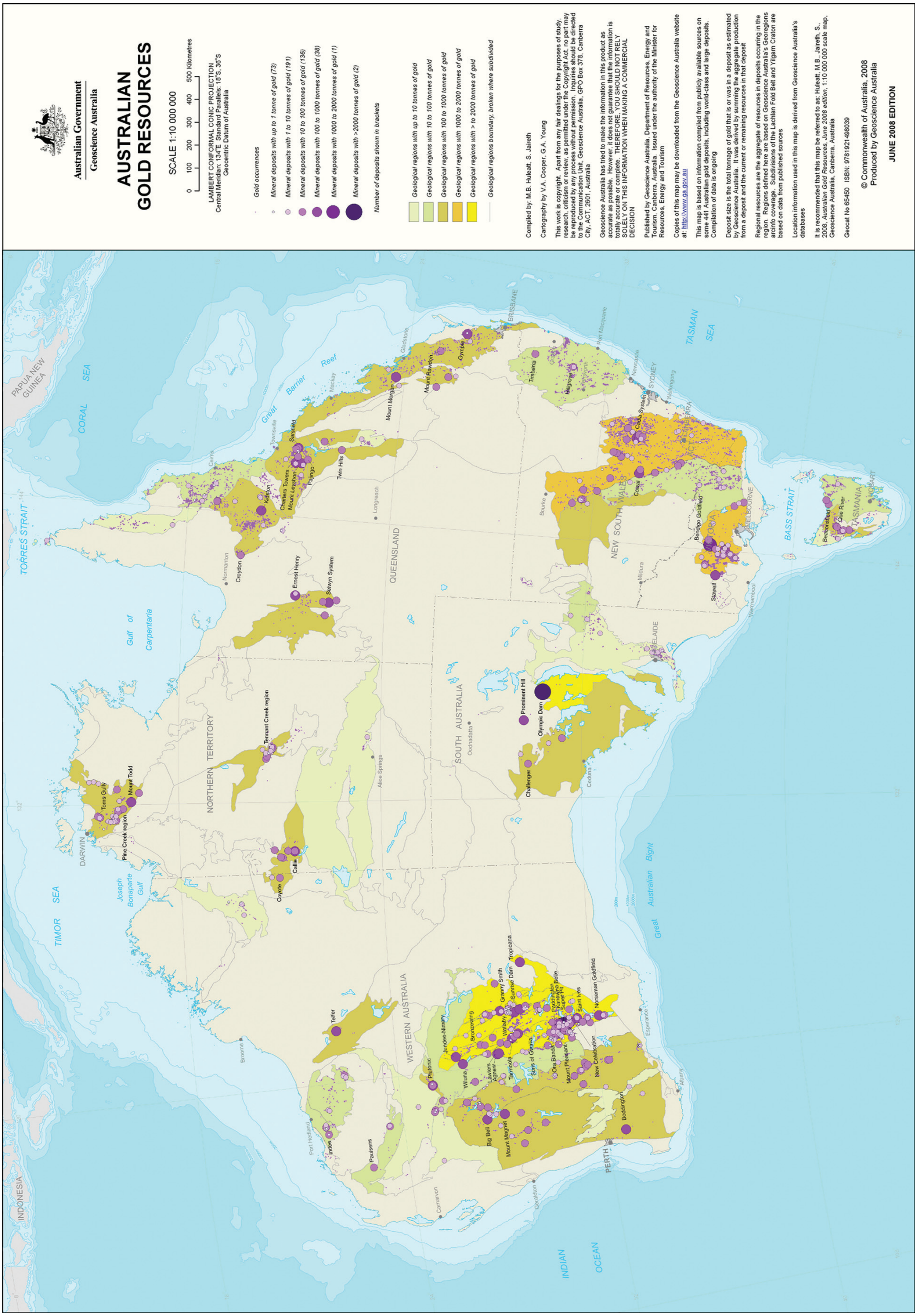

Fig. 9. *Australian gold resources produced by Geoscience Australia in June 2008 (see http://www.ga.gov.au/image_cache/GA11446.pdf).*

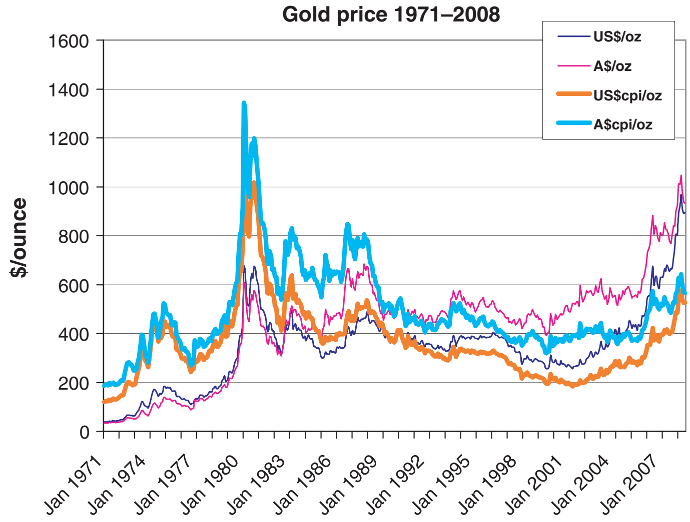

Fig. 10. *Monthly price of gold in $/ounce in US and Australian dollars at the time, and CPI adjusted to June 2008. Notice that the peak price in 1980 is still higher than the June 2008 price in real terms.*

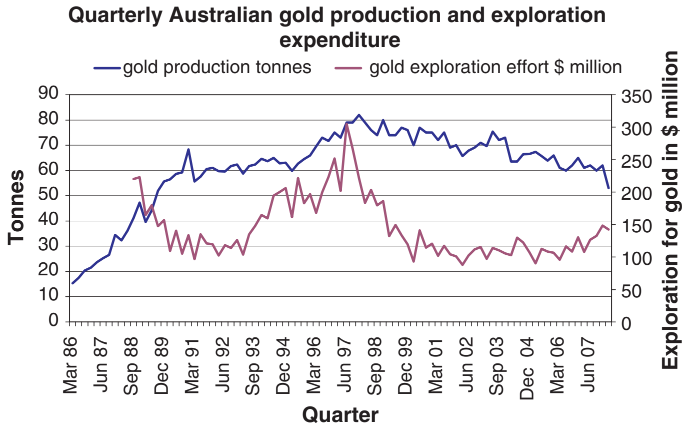

Fig. 11. *Quarterly Australian gold production (from ABARE) and quarterly investment in gold exploration from the Australian Bureau of Statistics (CPI adjusted). Notice that after peak exploration activity in 1997 there did not appear to be any flow-on effect in the gold production values – unless it still has to come.*

chemicals (http://www.southafrica-travel.net/north/a1johb04.htm). So it is not surprising that output from South Africa is declining.

Figure 7 shows the global production numbers since 1970. At the start of this period South Africa produced nearly 68% of the world's gold, but now it only contributes about 11%.

There is also evidence that Hubbert's Peak for oil also applies to gold, with South African, Australian, Canadian and the USA's gold production apparently past their peaks. Peak global production appears to have been in 2001, when a total of 2604 tonnes were mined. After that year the annual production has been declining gradually.

In 2007 South Africa (272 t) was no longer the world's leading gold producing country, having been overtaken by China (276 t), which is now the world's largest. According to GFMS, this is the first time that South Africa has not been the leading producer since 1905 (see Figure 8).

The world's largest producer in 2007 was Barrick Gold with 250.7 t, followed by AngloGold Ashanti with 170.4 t and Newmont Mining with 165.6 t.

Australian scene

Figure 9 shows the locations of Australia's gold resources. As one would expect, the majority of the deposits occur in areas of outcrop or under thin cover. Most of the easy-to-find deposits have been discovered and the challenge now is to explorer beneath – and within – the regolith. There are four prospects which either have produced or are expected to produce more than 1000 t of gold. These are Bendigo in Victoria, Olympic Dam in South Australia, the Super Pit at Kalgoorlie and Telfer in Western Australia. Even for world's fourth largest gold producer, giant deposits are as scarce as hens' teeth.

The development of gold resources depends mainly on three parameters:

1. The price of gold
2. The technologies available to the explorer
3. The investment in exploration

Figure 10 shows how the price of gold has changed since 1971. The charts are shown in contemporary US and Australian dollars which have also been CPI adjusted to June 2008 dollars. Although the June 2008 price of US$895/ounce might at first sight seem high it is nowhere near the CPI adjusted US$1099/ounce reached in January 1980. In Australian dollars the CPI adjusted comparison is $933/ounce in June 2008 compared to $1343/ounce in January 1980. Furthermore, exploration costs have increased significantly in real terms between 1980 and 2008, with the costs of labour, fuel, drilling and other operational factors being affected. So the profit margin is probably not as good now as it was in 1980.

Finally let us consider Australian gold production and the relationship between gold production and the investment in exploration for gold (see Figure 11). There are several matters of interest. The first is that, after the CPI adjustments have been applied, the peak exploration effort for gold in 1997 has not been surpassed during the current resources boom. The second is that the Hubbert Peak for Australian gold looks as though it was also reached in 1997 and that gold production will continue to decline from now on, just as happened in South Africa, the US and Canada.

Finally, there does not seem to be a strong correlation between exploration investment and gold production. If there was, then the exploration peak of 1997 should have been converted to a production peak some years later. However, too much should not be deduced from this observation because clearly if there was no exploration expenditure there would eventually be no production.

Perhaps the lead time is longer than 10 years and we can expect a jump in gold production in the next few years. Only time will tell.

David Denham

Gold in the States and Northern Territory

New South Wales

Gold has played a key role in the history of New South Wales and continues to make a major contribution to the State's economy. It was first discovered in New South Wales in 1823, 28 years before the initial gold-rush at Ophir, which triggered the 1850s Great Australian gold-rush. Since that time, over 150 deposits with more than 0.5 t of gold and many thousands of smaller occurrences have been discovered in the State (see Figure 12). Gold in New South Wales is associated with a wide variety of deposit types including porphyry Cu–Au, intrusion-related, orogenic Au and volcanic massive sulfide systems. The majority of known deposits occur in the Lachlan and New England Orogens.

History

The first recorded discovery of gold in Australia was by James McBrien at the Fish River near Bathurst in 1823. Other early finds include those by Count Paul Strzelecki near Wellington, the Reverend W.B Clarke in 1841, Hugh McGregor near Wellington in 1843, and William Tipple Smith in 1847. The first officially recognised discovery was made by John Lister and William Tom at Ophir, near Orange, in 1851 – although the initial credit for this discovery was given to Edward Hargraves, who had shown other members of the party how to pan for alluvial gold.

Exciting discoveries continued throughout the State with the majority of initial discoveries being made in the Lachlan Orogen during 1850–70 (see Figure 13). Major discoveries include those at Turon River (1851), Majors Creek (1851), Adelong (1852), Kiandra (1859), Lambing Flat (Young) and Forbes (1861), Parkes (1862) and Cobar (1871).

Gold discoveries were made throughout the New England Orogen in the 1850s and onwards but many were poorly recorded. Uralla was discovered in 1851, with Hillgrove being discovered in 1883 and Drake in 1886. The Holtermann Nugget was discovered by Beyers and Holtermann in 1872 (Figure 14). It weighed 318 kg,

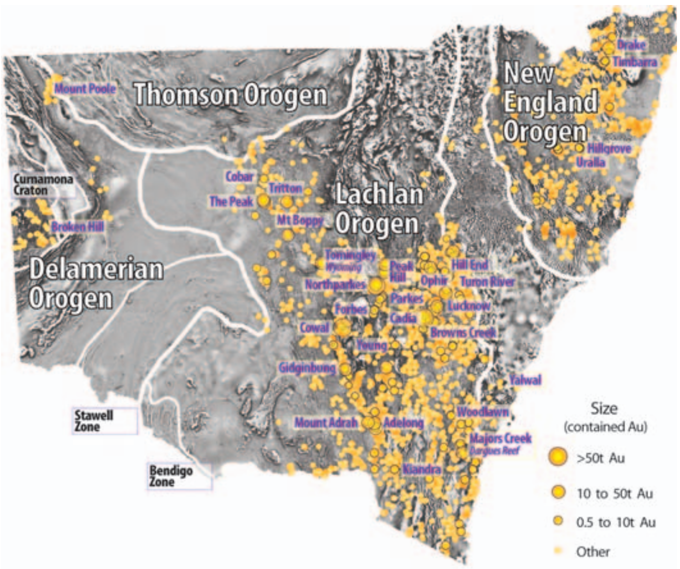

Fig. 12. *Distribution of small to very large gold deposits within New South Wales. The background image is the State-wide greyscale TMI 1st Vertical Derivative data.*

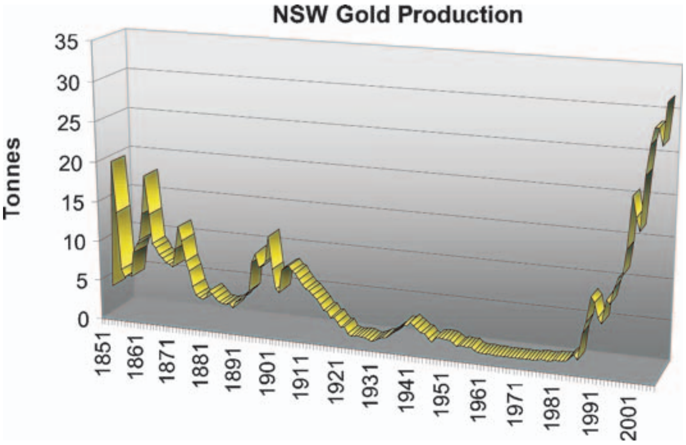

Fig. 13. *Gold production in New South Wales for the period 1851 to 2007.*

had an estimated gold content of 94.5 kg and was valued at £12,000 at the time.

Gold was first discovered in the far-western part of the State in 1880 at a location near Mount Poole, some 250 km north of Broken Hill. Following this, there was a gold-rush to the Mount Browne Goldfield (a few kilometres south of Mount Poole) in the following year.

Fig. 14. *The Holtermann Nugget, discovered by Beyers and Holtermann in 1872. The nugget in the photograph has been 'enhanced' for effect.*

Gold production in New South Wales initially peaked in 1852 (19.48 t), then in 1862 (18.07 t) and again in 1899 (11.9 t, Figure 13); however, between 1923 and 1933 the State's annual production fell to less than 1 t Au per annum. Production climbed above that level between 1934 and 1952; however, it didn't reach the levels seen during the later part of the previous century. More recently, a series of major discoveries at Goonumbla, Cadia, Blayney and at Lake Cowal, in the Lachlan Orogen, from the 1970s onwards have produced a resurgence in production. This has climbed steadily since 1984, exceeding the historic 1852 peak in 1999 with current production levels being greater than 32 t per year. New South Wales is now the second largest gold producing state in Australia!

Deposit types

New South Wales is host to a diverse range of gold deposit types with gold being produced as either a principal commodity (e.g. Cadia, Cowal) or as a by-product (e.g. Broken Hill, Tritton). These gold-bearing systems include:

- Porphyry Cu–Au (Cadia, Northparkes, Copper Hill, Cargo), Au-rich skarn (Browns Creek, Junction Reefs) and intrusion-related Au (IRG – Timbarra, Dargues Reef–Majors Creek) deposits.
- Orogenic Au (Cowal, Adelong, Hillgrove, Parkes, Wyoming) and orogenic base metal (Frogmore, Tritton) deposits including the Cobar-type Au–Cu systems (The Peak).
- High-, intermediate- and low-sulfidation epithermal Au systems (Gidginbung, Peak Hill, Drake, Yalwal); and
- Gold-rich volcanic massive sulfide (VMS) deposits (Woodlawn, Captains Flat and Lewis Ponds).

In addition, gold has been mined from a diverse range of modern and ancient placer, eluvial and beach deposits and a host of other deposit types where it is found as a minor commodity.

The majority of gold production is, at present, coming from deposits hosted by mafic to intermediate volcanic rocks and related intrusions of the Ordovician Macquarie Arc which is part of the Lachlan Orogen. The Macquarie Arc is evident as a series of linear magnetic highs on the Statewide TMI and TMI 1VD datasets and is host to the world-class Cadia porphyry Cu–Au system (Cadia Hill and Ridgeway mines, Cadia East deposit, etc.) which has a gold endowment in excess of 1000 t Au, the Goonumbla porphyry Cu–Au system (Northparkes mine) and the Cowal Au mine (see Figure 15). Other deposits associated with the Macquarie Arc include the Peak Hill and Gidginbung high-sulfidation epithermal systems, and the Browns Creek and Junction Reef Au-skarns.

The importance of IRG deposits in New South Wales has only been recently recognised. Over 40 t of gold was produced from hard-rock and alluvial deposits associated with the Braidwood Granodiorite which is host to the Dargues Reef deposit. Recent exploration at Dargues Reef has defined an initial resource containing 9.4 t Au. Dargues Reef and other IRG deposits associated with the Braidwood Granodiorite lie within narrow magnetite destructive alteration zones that are clearly evident on prospect scale TMI images of the area. Other important IRG deposits in New South Wales include the Timbarra deposit, in northeastern New South Wales, which contained a pre-mining resource of 12.3 t Au, and the Mount Adrah deposit near Adelong.

Historically many of the hard-rock deposits that were mined for gold in New South Wales were orogenic gold systems. Important past and present deposits include the Cowal mine, those in the Forbes–Parkes–Tomingley area including the Wyoming–Caloma system, Adelong, Hill End, Hillgrove and Mount Boppy. Many of these deposits are located adjacent to major northerly trending structural features that are defined as strong linear magnetic trends.

Fig. 15. *Cadia open cut near Orange in NSW. Notice how agriculture and farming co-exist in the area.*

Much of the State's gold production has come from sulfide-rich deposits. Deposits such as Broken Hill, Woodlawn, Captains Flat and some of the deposits in the Cobar area (e.g. Tritton) contain significant gold which is recovered as a credit during refining operations. These deposits have a diverse range of geophysical signatures with orogenic base metal deposits often being located adjacent to major structural features. By comparison, individual VMS and other sulfide-rich deposits contain minerals such as pyrrhotite and pyrite that are responsive to induced polarisation and electromagnetic methods.

Exploration potential

Aside from the better exposed portions of the Lachlan and New England Orogens, which remain under-explored by Australian standards, there is significant potential for new discoveries under cover. The Stawell and Bendigo zones, which host major gold systems in Victoria, are now interpreted, with new aeromagnetic data, to extend into south-western New South Wales. Similarly, new aeromagnetic data on the poorly exposed and poorly understood Thomson Orogen, which extends southwards from Queensland into north-western New South Wales, is providing new insights and attracting increased mineral exploration into this 'frontier' region of the State.

Conclusion

New South Wales has a rich history of gold discoveries and mining extending over the last two centuries. Recent discoveries have indicated that there remains significant potential for the discovery of additional large to world class deposits in many areas. High-resolution aeromagnetic and radiometric datasets acquired as part of New South Wales government funded exploration initiatives now cover over 80% of the State and assist explorers to 'lift-the-cover' and to identify new targets for further exploration.

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Northern Territory

Economically significant gold was first discovered in the NT in 1870. Exploration since then has outlined over 700 gold occurrences in the NT. These are concentrated in three geological regions namely the Pine Creek Orogen, Tennant and Tanami regions (Figure 16). Past production from these regions has been 90, 120 and 200 t respectively. Current resources are: Pine Creek Orogen 370, Tanami 180 and Tennant Creek 25 t. Minor gold is also present in the Arunta Region and some 3 t have been recovered from there. Almost all gold deposits of the NT are hosted within the 1800–1850 Ma stratigraphic interval except those in the Arunta Region which are within the Neoproterozoic strata. The gold-bearing uranium deposits of the Alligator Rivers area are yet another exception. Here the age of host rocks is about 2100 Ma.

History

Although gold was discovered in 1865 in the Finniss River area and in 1868 at Tumbling Waters in the Pine Creek Orogen, it was the discovery, in 1870, of coarse gold near Yam Creek which sparked a gold rush and resulted in several subsequent discoveries. Production from these deposits continued until 1915 when most mines ceased production. A total production of about 15 t is recorded for this period. A major boost in exploration during the early 1980s, resulting from an increase in gold prices and improvements in mining and metallurgical techniques, led in October 1985 to the opening of the first modern mining venture, the Enterprise mine.

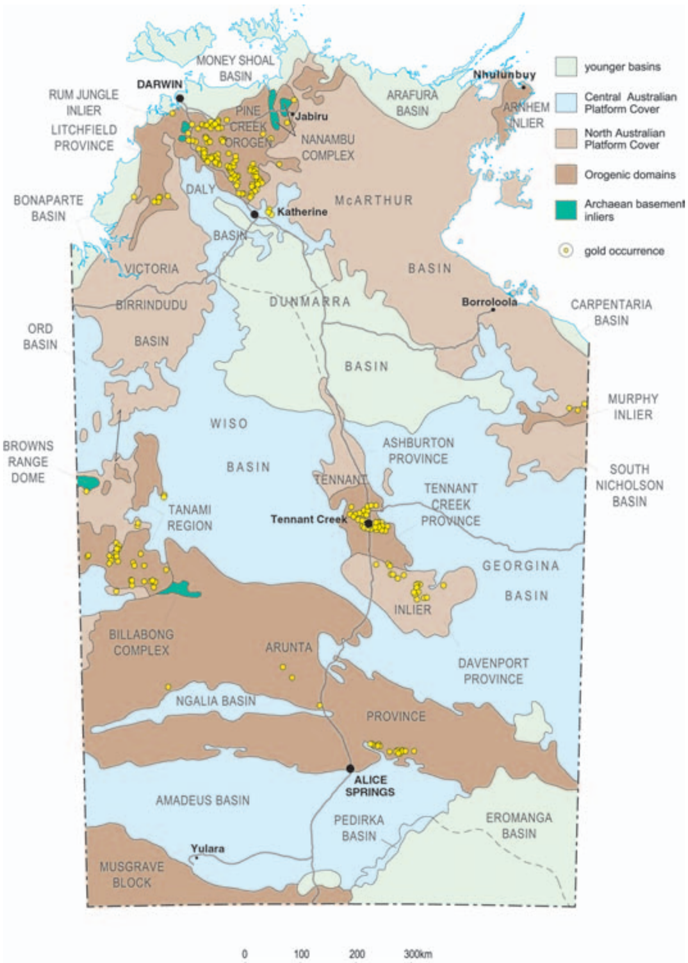

Fig. 16. *Location of the main gold deposits in the Northern Territory.*

Several other mining operations subsequently followed, resulting in gold production from 1985 to 2006 of about 70 t.

Gold in the Tanami Region was discovered around 1900, with small-scale mining continuing intermittently till 1955. A total production of 0.4 t is recorded for this period. In 1986, North Flinders Mines Ltd commenced production from the Bullakitchie and Shoe deposits. Production from several pits in the Tanami Field also commenced at about the same time. Callie is the only deposit currently being mined from the Tanami Region. Total production from the Tanami Region is estimated at about 220 t.

Although in the Tennant Region gold was discovered in 1874, significant mining and prospecting did not take place until 1932 when two small batteries were constructed near the Tennant Creek Township. Production dramatically increased during the 1960s and 1970s due to the discovery of several subsurface ironstone hosted deposits using ground and airborne magnetic surveys. From 1932 to 2006 the Tennant Creek Goldfield has produced about 130 t of gold.

In the Arunta Region, gold was discovered at Arltunga in 1887 and at White Range in 1897. Production from this region commenced in 1890 and practically ceased by about 1917, except for intermittent small scale mining which continued until 1934. Recorded production for this period amounts to 0.47 t of gold. During 1989–91 the reefs at White Range were mined by open cut producing 1.9 t of gold.

Deposit types

Gold deposits of Northern Territory are classified into seven types. These are, in order of abundance:

- Gold-quartz veins, lodes, sheeted veins, stockworks and saddle reefs, e.g. many deposits in the PCO, Tanami and Arunta regions, as well as in the Davenport Province of the Tennant Creek Region.
- Gold-ironstone bodies such as in the Warramunga Province of the Tennant Region.
- Gold in iron-rich sediments, e.g. many deposits in PCO and Tanami Region.
- Gold in association with platinum group elements, e.g. Coronation Hill and other occurrences in the Pine Creek Orogen.
- Gold in association with uranium, e.g. Jabiluka and Koongarra uranium deposits in the Pine Creek Orogen.
- Polymetallic gold deposits e.g. Iron Blow and Mount Bonnie mines in the Pine Creek Orogen.
- Placer deposits.

Gold-quartz veins, lodes, sheeted veins, stockworks and saddle reefs

This type includes approximately 60% of the NT gold deposits and has been a major source of gold. These deposits are usually contained within folded, faulted and regionally metamorphosed (usually lower greenschist facies) flysch sequences. A few are in intermediate to basic intrusives. Post to late orogenic granites have intruded the sediments causing superimposed contact metamorphism. Most deposits are within the contact metamorphic aureole. Vein quartz is the principal gangue and is locally accompanied by white mica, chlorite and minor K-feldspar. The width of the gold-bearing quartz veins ranges from a few millimetres to few metres. Pyrite and arsenopyrite are the main sulfides together with minor pyrrhotite, chalcopyrite, sphalerite and galena. Late-stage carbonate veining is noted in many deposits. Wall rock alteration effects are negligible and are confined to a few tens of millimetres along vein edges. Within this alteration zone, silicification and sericitisation are the main alteration processes. Gold is fine grained to microscopic in size and is rarely visible. In some deposits free gold is common but generally it is contained in arsenopyrite and to some extent in pyrite and pyrrhotite.

In the oxidised zone, which extends down to a depth of about 60 m, the majority of gold is free milling. The grade is generally low; usually less than 3 g/t gold and individual deposits may have less than 0.3 to more than 30 t of gold.

Gold in ironstone bodies

These deposits are only present in the Tennant Creek Region and are contained in linearly arranged, ellipsoidal to pipe-shaped discordant bodies of iron oxide-rich rocks (mostly magnetite). The host rocks are regionally metamorphosed flysch sequences which also contain felsic volcanics and porphyry intrusives and have been intruded by syn- to post-orogenic granites. The orebodies have complex mineralogy comprising native gold, chalcopyrite, pyrite, bismuth minerals and minor galena, sphalerite, cobaltite, uraninite and molybdenite. Apart from magnetite, other gangue minerals include hematite, chlorite, muscovite, talc, dolomite and sericite. The grade is generally high, about 20 g/t gold, but tonnages of individual deposits are low.

Gold in iron-rich sediments

These deposits are associated with iron-rich sediments (variously named as banded iron formations, ironstone, iron formations and silicate iron facies). These deposits are present in the Pine Creek Orogen and Tanami Region. The ore horizon is often bedding concordant and comprises a variety of gangue minerals, including quartz, siderite, ankerite, calcite, chlorite, cummingtonite, grunerite, ferroactinolite, almandine and tourmaline. Sulfides include pyrite, arsenopyrite, marcasite and traces of galena and sphalerite. Gold is submicroscopic in size and a large part of it generally occurs as native gold; however, a close association with arsenopyrite is also notable. In the oxidised zone the bulk of the gold is free milling and can be extracted by conventional metallurgical methods.

Gold in association with platinum group elements

Coronation Hill in the South Alligator River Valley area is the well known example of this type of deposit. Mineralisation is in microfractures, veinlets and disseminations in quartz–feldspar porphyry, volcaniclastic siltstone, debris flow conglomerate, sedimentary breccia and dolostone. Gold is microscopic in size and is associated with selenium ± replacive pyrite. The sulfide content of the ore is generally low, with minor pyrite and trace amounts of marcasite, pyrrhotite, sphalerite, chalcopyrite and galena. Platinum and palladium-bearing minerals are closely associated with gold and selenides.

Gold in association with uranium

Significant gold, often in economic concentrations, is associated with uranium deposits in the Pine Creek Orogen and Murphy Inlier. Mineralisation is hosted within a variety of rock types including carbonaceous shale, dolostone, arenite, dolerite and acid volcanics. It comprises fracture fill, breccia fill and also occurs within the matrix of arenites. Gold is microscopic to fine and is closely associated with uranium minerals. Other minerals include minor pyrite, tellurides and traces of galena and sphalerite. Vein quartz is rare and chloritisation is the main alteration process.

Polymetallic gold deposits

These deposits are contained as concordant lenses within interbedded pyritic shale, dolomitic siltstone and tuff. In addition to gold, they also contain lead, zinc, copper and silver. Quartz veining is almost non-existent. The common sulfide minerals in the primary ore are sphalerite, galena, arsenopyrite, pyrite, chalcopyrite, pyrrhotite and tetrahedrite. Zinc is the dominant element followed by silver and gold. The Mount Bonnie and Iron Blow mines in the PCO are the only representatives of this type of mineralisation in the Northern Territory.

Placer deposits

Many of the hard rock quartz vein-type gold deposits are associated eluvial/alluvial gold, which have been mined in most goldfields. The gold is usually fine grained, generally less than 1 mm in size, but some coarse nuggets has been reported from a few localities. There are few, if any, reported placer gold deposits associated with other deposit types.

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Queensland[2]

Queensland is the third largest gold producing State in Australia and has total gold resources and reserves of >950 t. Since the early gold rushes of the late 19th century, total documented gold production in Queensland has been >7000 t. The most significant current gold producers are Pajingo, Ernest Henry, Mount Rawdon, Cracow and Ravenswood.

Gold mineralisation occurs in a diverse range of deposit styles and geological provinces, ranging from the large, historically important, alluvial goldfields of north Queensland to the Proterozoic iron oxide–copper–gold deposits of the Mount Isa Orogen. The main gold mineralisation styles recognised in Queensland include: mesothermal Au–quartz veins, porphyry-related breccias, epithermal deposits, Proterozoic iron oxide–Cu–Au, alluvial deposits, volcanic-hosted massive sulfide, shear zone hosted hydrothermal and skarns (see Table 1 and Figure 17).

Mesothermal Au–quartz veins

Mesothermal deposits are generally high-grade, gold-bearing quartz veins that formed from hydrothermal solutions at high temperatures (200–300°C) and at substantial depths (1200–4500 m). The important historical goldfields in Queensland characterised by mesothermal quartz veins include the Gympie, Hodgkinson, Palmer, Charters Towers, Croydon and Etheridge Fields.

Porphyry-related breccias

Porphyry-related breccia style mineralisation is mainly associated with Carboniferous to Permian rhyolitic porphyries of the

[2]Information for Queensland has been extracted from Queensland Minerals 2008, produced by the Queensland Government's Department of Mines and Energy and available from www.dme.qld.gov.au.

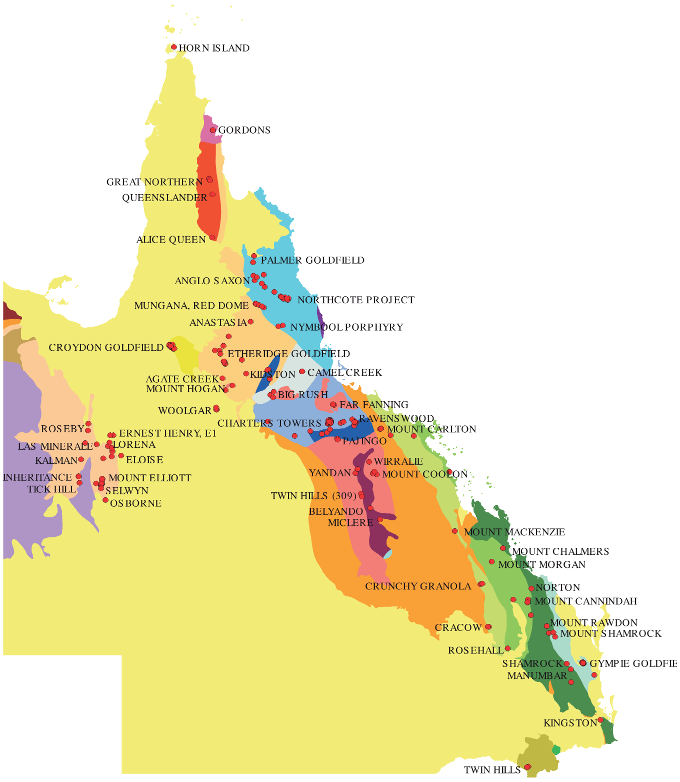

Fig. 17. *Locations of main gold deposits in Queensland (taken from Queensland Minerals 2008 – see footnote). See Fig.1 in Queensland Minerals 2008 for the Geological Framework map.*

Kennedy Province in north Queensland. The Mount Leyshon, Kidston and Mount Wright deposits are examples of porphyry-related mineralisation, which is commonly associated with subvolcanic intrusion, breccia development and multiphase hydrothermal activity. Mount Leyshon, south of Charters Towers, was the largest porphyry-related deposit in Queensland.

Epithermal deposits

Early Carboniferous epithermal gold (–silver) mineralisation of the low sulfidation (quartz–adularia) style occurs within Cycle 1 volcanics of the northern Drummond Basin in north Queensland. The Pajingo (Vera-Nancy and Scott Lode), Wirralie, Twin Hills (309 and Lone Sister), Yandan and Mount Coolon deposits are significant examples. Pajingo is the largest epithermal gold deposit in Queensland.

Proterozoic iron oxide–Cu–Au

Gold is produced as a by-product of processing copper ores from structurally controlled Proterozoic Cu–Au deposits of the Eastern Fold Belt Province in the Mount Isa Orogen. Deposits tend to be associated with magnetite-rich iron oxide bodies (e.g. Ernest Henry, Osborne, Selwyn, Mount Elliott, E1, Las Minerale) within spatially extensive sodic–calcic alteration zones and local K–silicate alteration. Gold is generally concentrated in the chalcopyrite lattice within the ore.

Ernest Henry differs from other deposits because it is developed within variably brecciated and altered felsic to intermediate volcanic rocks, with primary mineralisation forming within a

Table 1. Major (large and giant) gold deposits in Queensland

Name (Size)	Total historical production	Total in remaining resource	Principal mineralisation style
Charters Towers (G) (includes current CitiGold operations)	>250 000 kg bullion	>488 500 kg	Mesothermal Magmatic Related
Cracow Goldfield (L) (includes Golden Plateau and Klondyke)	32 314 kg (production for entire field)	26 896 kg	Epithermal
Croydon Goldfield (L)	>59 640 kg Au bullion	Unknown	Mesothermal Magmatic Related Au
Ernest Henry (L)	34 281 kg Au bullion	59 500 kg	Structurally controlled, breccia hosted
Gympie Goldfield (L) (includes current operation at Monkland and Lewis Decline)	>108 000 kg Au	3310 kg	Mesothermal, Magmatic related & alluvial
Hodgkinson and Palmer Goldfields (L)	>57 000 kg Au bullion	Unknown	Mesothermal, Metamorphic Related & associated alluvials
Kidston (L)	1309 kg Au bullion 112 495 kg Au	Mined out	Porphyry-related Breccia
Mount Leyshon (L)	107 670 kg Au	Mined out	Porphyry-related Breccia
Mount Morgan (G)	294 056 kg Au	16 234 kg	Volcanic-hosted massive sulfide?
Mount Rawdon (L)	17 599 kg Au	46 440 kg	Intrusive Related Au
Osborne (L)	17 857 kg Au	8638 kg	Structurally controlled
Pajingo (L) Vera-Nancy, (Cindy, Scott Lode)	28 930 kg Au bullion 53 044 kg Au	17 852 kg	Epithermal
Ravenswood (L) (Sarsfield, Nolans, Sunset)	42 812 kg Au	45 210 kg	Mesothermal Magmatic Related
Selwyn (L)	32 163 kg Au bullion	41 298 kg	Structurally controlled

magnetite–carbonate gangue. Magnetite makes up 20–25% of the primary ore.

Alluvial deposits

Significant alluvial gold production has accompanied hard rock gold mining, particularly in north Queensland goldfields. In many regions, it was the alluvial gold potential that led to the large 'gold rushes' that established the goldfields. The main alluvial gold mining area in Queensland is the Palmer River drainage system (Palmer River Goldfield).

Volcanic-hosted massive sulfide

Mount Morgan is one of the more significant historical mines in Australia in terms of total gold and copper production. It is hosted by a belt of Middle Devonian volcanic and sedimentary rocks of the Yarrol Province that forms a roof pendant in a Late Devonian tonalite intrusion. The genesis of the Mount Morgan mineralisation has long been controversial, but the deposit is now widely regarded as being a volcanic-hosted massive sulfide type.

South Australia[3]

The first recorded production of gold in South Australia was in 1846 from the Victoria Mine, 18 km northeast of Adelaide. The history of subsequent discoveries is characterised by short periods of high production before the mines became uneconomic. Gold mineralisation is widespread and found in most geological provinces of the State as primary and/or secondary deposits. However, South Australia is a minor contributor to Australia's gold output (1.2%), producing only about 3.5 t per year of which 99.9% comes from the Olympic Dam Cu–U–Au–Ag mine. The main gold producing geological provinces are as follows.

Gawler Craton

Gold in the Gawler Craton is dominated by Olympic Dam (Figure 18), which is Australia's largest underground mine. The Olympic Dam deposit is one of the world's largest known accumulations of metals and contains resources and reserves of approximately 2500 t of gold. In 2005–06 it produced 3.2 t of gold and in 2006–07 about 2.7 t.

The operator, BHP Billiton, is 2 years into a proposed 7-year expansion program, estimated to cost in excess of $7 billion. This will see operations converted to a huge open pit that will be one of the biggest of its type in the world. Establishing the open pit will require the removal of ~1 Mt of overburden every day for 4 years.

Western Mining Corporation discovered the deposit in 1975. Underground mining commenced in 1988 and a major expansion program from 1997 to 1999 has lifted the annual gold production to 2.5 t. The deposit is situated within the Mesoproterozoic Hiltaba Suite Roxby Downs Granite beneath ~300 m of undeformed Adelaidean and Cambrian platform sediments of the Stuart Shelf. The discovery was largely based on geophysical data that produced an 'anomaly of interest'.

Fig. 18. *View of the Olympic Dam operation (obtained from the website: www.abc.net.au/reslib/200705/r140801_484774.jpg).*

The Prominent Hill Prospect was discovered in November 2001 by Minotaur Resources Ltd, operator of the Mount Woods Joint Venture. It is 130 km north west of Olympic Dam and is currently owned by OZ minerals (Oxiana/Zinifex merger). Later in 2008 it is expected to produce gold from its estimated 115 t gold resource.

The Challenger Mine was discovered by Dominion Mining Ltd and Resolute Ltd (Gawler Joint Venture) as the result of a regional calcrete sampling program in 1995. Subsequent drilling has outlined a combined indicated and inferred resource of 15 t of gold. The first gold bar was produced in October 2002. The first year of operation was in 2003–04. In 2005–06, 0.6 t gold was produced. Currently production is derived from open cut and underground workings.

Most of the other deposits in the Gawler Craton were discovered in the late 19th century and are no longer producing significant amounts of gold. The Tarcoola Goldfield was discovered in 1893 when alluvial gold was found by a station hand. Mining of reef deposits began in 1900 and the goldfield grew to become the State's major reef gold producer. Between 1900 and 1955, gold bullion totalling 2400 kg was recovered. Since 1955 there has been a small intermittent production. The Glenloth Goldfield was found with the discovery of alluvial gold in 1893. Between 1901 and 1955, ~315 kg of gold were produced. Since 1955, gold production has been small and sporadic. The Earea Dam Goldfield was discovered in 1899 and produced 59.2 kg of gold during 1899–1903 and 1933–41. The Moonta and Wallaroo copper deposits have produced a combined total of ~3.6 t of gold, mainly from underground mining, between 1860 and 1923. From 1988 to 1993, the Poona and Wheal Hughes lodes of the Moonta system were mined by open-cut and underground decline to 423 kg of gold.

Peake and Denison Ranges

The ranges comprise Palaeoproterozoic inliers, which are a probable extensions to the Gawler Craton, surrounded by sediments of the Adelaide Geosyncline.

The Algebuckina Goldfield opened in ~1870 when gold was discovered in alluvial gravel of the Neales River, and activity continued to ~1898. Total production from the field was ~4.7 kg.

[3]http://www.pir.sa.gov.au/minerals/geology/commodities/gold; http://minerals.pir.sa.gov.au/mining_regulation/mineral_resource_development_in_south_australia/olympic_da

Curnamona Province

Gold occurrences are widespread, and generally associated with copper. The New Luxemburg Goldfield was the major producer with ~15.5 kg of gold between 1887 and 1916, predominantly from the Luxemburg and Queen Bee mines.

At Kalkaroo, Havilah Resources quote a Mineable Resource of 85 Mt grading 0.45% Cu, 0.51g/t Au and 101ppm Mo (an in-ground gold resource of around 1.4 Moz) and at White Dam (Exco Resources/Polymetals) report 9.1 Mt at 1.13g/t Au for 330,000 oz. Kalkaroo was discovered by the Placer/MIM JV in 1992 where chalcopyrite mineralisation with associated gold and molybdenum is present in veins and layer parallel disseminations within albitic metasediments, as well as along structurally controlled breccia zones. New drill results from these quartz breccia zones report high gold assays with 102 m @ 0.83% Cu and 1.6 g/t Au from KKRC136 being one example.

The White Dam was discovered by the MIM, Aberfoyle, Normandy JV in 1997. Fine (<5micron) gold is located within biotite and leucocratic melts associated with chalcopyrite, pyrite and molybdenum. Unusually this upper amphibolite grade deposit has no quartz veining associated with the gold mineralisation. The nearby similar Vertigo deposit contains around 50,000 oz Au.

Other Cu–Au deposits include Walter–Outalpa, Walparuta and Pimponda Mines.

On the Benagerie Ridge, significant gold and copper mineralisation was intersected by the Pasminco Australia Ltd – Werrie Gold Ltd joint venture, targetting a gravity trough, magnetic high signature. High-grade supergene gold zones are developed at the surface of deeply weathered upper Willyama Supergroup. Prospects include Portia, North Portia (20 Mt @ 1% Cu and 0.5 g/t Au), Shylock, South Nerissa, Lorenzo, Antonio, Arragon, Solanio and Jessica). Portia reports very coarse grained, nuggety gold and despite detailed drilling a resource figure is yet to be calculated. Havilah Resources is planning to trial mine the higher grade, nuggety gold found at the Portia Prospect.

If the gold resources of North Portia, Kalkaroo and White Dam are combined, the Olary Domain reports over 60 t of gold.

Adelaide Geosyncline

Gold deposits are spread throughout the Adelaide Geosyncline and historically, most of the State's largest reef and alluvial fields are within the geosyncline, but the last major gold discovery was the Mongolata Goldfield in 1930 and regular gold production ceased ~1950. The geosyncline accounted for ~70% of the State's total gold production prior to commencement of the Olympic Dam Mine in 1988. This Province contains the Teetulpa Goldfield, which was the State's most productive goldfield. It produced ~3132 kg of alluvial gold, mainly between 1886 and 1889.

Kanmantoo Trough

The Kanmantoo Mine operated between 1970 and 1976 producing ~260 kg of gold. The Kitticoola Mine opened in 1846, and closed in 1971 after five phases of mining. During this time 162.6 kg of gold was produced.

The future

Most of the easy to find gold resources have now been found in South Australia and all future discoveries will require innovative and determined geophysical techniques to 'penetrate the regolith'. It is not going to be cheap but it could be very rewarding, particularly if there is another Olympic Dam waiting to be found.

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Marc Davies
Geological Survey Branch, PIRSA
(Together with data from the websites: www.pir.sa.gov.au/mining_regulation/mineral_resource_development_in_south_australia/olympic_dam; www.pir.sa.gov.au/minerals/geology/commodities/gold)

Tasmania

Apart from alluvial deposits, the important gold deposits in Tasmania are hosted in the Cambrian Mount Read Volcanics, with three deposits (Mt Lyell, Rosebery and Henty with pre-mining endowments >30 t) and in Devonian deposits in clastic sedimentary rocks in NE Tasmania of Ordovician to Early Devonian age, where the sole deposit with more than 30 t is Beaconsfield (Figure 19).

Interest in the gold potential of the Arthur Lineament, a NE trending, probably exotic, belt of Proterozoic rocks in NW Tasmania is likely to increase following recognition by Mineral Resources Tasmania geologists that the Savage River magnetite mine has affinities with IOCG deposits. The zone consists of basaltic extrusives and intrusives, and carbonate and classic sedimentary rocks metamorphosed to peak high pressure amphibolite facies and multiply deformed in the Early Cambrian. The Alpine copper prospect currently being investigated by Stellar Resources Ltd is in the southern section of the Lineament.

The meridional Mount Read Volcanics in western Tasmania are metallogenicially divided by the NNE-trending Henty Fault, with a predominance of Cu–Au deposits to the SE and polymetallic Zn–Pb–Ag–Au–Cu deposits to the NW. Henty is the sole gold-only mine, but Mt Lyell contains the highest pre-mining gold endowment of any Tasmanian deposit (~3000 t). The Zn-rich massive sulfide deposits contain very significant gold credits ranging from 2.2 g/t at

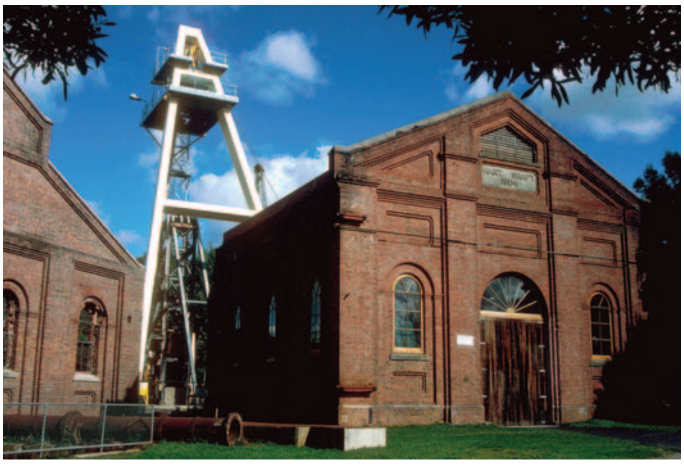

Fig. 19. *The old and the new at Beaconsfield, where the mine has been redeveloped, see http://www.beaconsfieldgold.com.au/BMJV.html.*

Rosebery to 3.3 g/t at Que River. The Henty gold mine consists of a series of small high-grade lenses of gold mineralisation in quartz ± sericite-altered volcaniclastic and volcanic rocks that occupy a large subvertical quartz–sericite alteration zone that transects the CVC–Tyndall Group contact at a low angle. The deposit is regarded as a submarine epithermal system formed from a magmatic fluid. Current opinion also favours a significant or dominant magmatic component in the fluids that formed the Mount Lyell deposits, with the fluids probably derived from Cambrian granite.

Siliciclastic sandstone, siltstone and conglomerate in the Beaconsfield area (Cabbage Tree Conglomerate) and the Mathinna Supergroup turbidites further east host economically important orogenic vein-style gold mineralisation, which is localised on structures associated with the last main Devonian deformation event. In the western part of the Eastern Tasmanian terrane, notably in the Beaconsfield and Lefroy districts, steeply dipping reefs have an east to ENE orientation and formed near-parallel to the axis of maximum principal stress, whereas to the east along the Mangana–Mathinna–Waterhouse gold lineament and elsewhere, the dominant orientation is NNW and orthogonal to this axis. The latter structures form as a response to failure on the steep eastern limbs of anticlines formed during the earlier fold event. In detail, gold-rich shoots within the reefs tend to pitch steeply, as a response to either favourable lithology for reef formation (Beaconsfield) or due to gold mineralisation during late transcurrent movement on the structures. There is also potential for intrusion-related gold in the region. Gold is also hosted within, and in the immediate country rocks of, Devonian granodiorite in the Lisle–Golconda area.

Gold occurs within the Permian country rock to Cretaceous alkaline porphyries near Cygnet in SE Tasmania. High temperature, highly saline fluids of probable magmatic origin accompanied early stages of gold mineralisation.

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Victoria

Victoria hosts one of the largest orogenic gold provinces in the world, with total historical production exceeding 2500 tonnes. Discovery and large scale mining of gold had a profound effect on the economic development of Victoria in the 19th century. It was also home to the Welcome Stranger the name given to a large gold nugget, measuring 61 cm by 31 cm, discovered by John Deason and Richard Oates at Moliagul, Victoria, on 5 February 1869 about 9 miles north-west of Dunolly. Found only 5 centimetres below the surface on a slope leading to what was then known as Bulldog Gully. It weighed 72.04 kg. It was assayed at 98.6 percent pure gold and is the largest alluvial gold nugget found in the world (Figure 20). The Welcome Stranger was broken up and sold for £9534. At today's value that would be over 2 million dollars just for the metal. As a collectors piece, it would be worth a fortune.

Most of the gold was produced in Victoria between 1852 and 1915. During that period, annual production varied between 90 t in 1856 and 10 t in 1915. After declining to less than 100 kg a year in late 1970s, annual gold production in Victoria increased to more than 3 t in 1990 and has exceeded 6 t in the last 3 years.

There are currently two major producing gold mines in Victoria, at Stawell and Fosterville. Major mine development is also underway at Bendigo and Ballarat, where large scale gold production is scheduled to start in 2008.

Fig. 20. *Welcome Stranger replica displayed in Dunolly's Rural Transaction Centre.*

Research conducted in the last 5–10 years has considerably improved the understanding of the economic geology of gold in Victoria. Major advances have been made in establishing the timings of mineralisation. Studies into the characteristics of alteration associated with mineralisation have established the existence of subtle alteration halos extending tens to hundreds of metres away from orebodies. Recent deep seismic surveys have provided new information on the probable crustal scale regional controls of gold mineralisation.

Deposit types

Moore (2007) classified the gold deposits of Victoria into four dominant types. These are:

- Alluvial.
- Orogenic.
- Volcanic-hosted massive sulfides (VMS).
- Intrusion-related.

A few minor occurrences with anomalous gold grades have been also related to epithermal and porphyry copper mineral systems.

Orogenic gold

Orogenic gold deposits represent by far the most important type of primary gold mineralisation in Victoria. They account for almost all primary gold production (in excess of 1100 t) and include most of known and potential resources. These deposits are usually hosted by folded, faulted and regionally metamorphosed (usually greenschist facies) Cambrian to Devonian turbidites and, less commonly, by Cambrian metavolcanic and sedimentary rocks and Devonian dykes. Mineralisation is associated with the late stages of regional deformation or periods of reactivation of older structures. The timings, character and intensity of orogenic gold mineralisation vary considerably across Victoria and display a close relationship with the geological history of host terranes (structural zones). Moore (2006) subdivided orogenic gold deposits into two subtypes based on the interpreted depth and temperature of deposition and which is reflected in the ore geochemistry: mesozonal and epizonal.

Mesozonal orogenic gold

These deposits have been the main source of historical primary gold production and also the predominant original source of gold in alluvial deposits. They are most abundant in the Bendigo and Stawell structural zones and in the Walhalla–Woods Point belt in the eastern Melbourne Zone. The goldfields of this type in Victoria that produced over 1 Moz (31 t) of gold from quartz veins include Bendigo (560 t), Stawell (125 t), Ballarat (88 t), Walhalla (68 t), Maldon (56 t), Woods Point (40 t) and Clunes (37 t).

The gold is associated with quartz veins that occupy dilational sites connected with faults and fold axes ('saddle reefs' and 'trough reefs'). The mineralised faults are usually reverse faults, which are often associated with folding and characterised by displacements of less than 100 m. Individual quartz veins are occasionally more than 20 m and can be traced for many hundreds of metres both along the strike and vertically. Auriferous quartz veins are often grouped into vein systems which can form mineralised areas covering up to 150 km^2. Such discrete mineralised areas may contain over 100 t of gold, with typical grades for current large-scale underground mining between 5 g/t and 30 g/t.

The host quartz veins usually contain minor amounts of sulfides and ferro-magnesian carbonates and a few percent of sulfides, although in eastern Victoria sulfides may be the dominant mineral type. These are mostly dominated by pyrite (occasionally pyrrhotite) and arsenopyrite, with subordinate chalcopyrite, sphalerite and galena. Native gold occurs both as free grains and as submicroscopic inclusions in sulfides. Mineralogical and geochemical characteristics of gold mineralisation display some broad regional variations. Gold is usually of a fineness greater than 920 (1000 × Au/(Au +Ag)), but in the Stawell Zone it often drops below 750 and occasionally below 300.

Mineralisation is associated with low-salinity fluids that precipitated gold at depths of 6 km to 12 km and at temperatures between 300 and 475°C. The main phase of the mesozonal orogenic mineralisation in the Bendigo and Stawell zones took place around 440 Ma and in the Melbourne Zone at around 380 Ma.

Epizonal orogenic gold

These deposits are most common in the western part of the Melbourne Zone and the eastern Bendigo Zone. Most individual deposits are small; the only major known ore field of this type in Victoria is the Fosterville goldfield in the Bendigo Zone with at least 130 t of gold production and resources. Other Victorian examples contained less than 10 t of gold and include Costerfield, Nagambie, Heathcote and Bailieston. Typical grades for underground mining vary between 5 g/t and 15 g/t.

Epizonal orogenic gold deposits are characterised by the gold typically as submicroscopic inclusions in sulfides in quartz–sulfide veins and stockworks associated with discordant faults. Free gold is rare in unoxidised ores and gold may also be present as aurostibite ($AuSb_2$) and other minerals.

The dominant sulfides are usually arsenopyrite, pyrite and stibnite. The mineralogical characteristics of ores generally change with the temperature of gold deposition from assemblages dominated by arsenopyrite and pyrite at higher temperatures (Fosterville) to ores with stibnite as a dominant sulfide at lower temperatures (Costerfield).

The mineralisation is associated with low-salinity fluids precipitating gold at the depth of 2 km to 6 km at the temperatures between 170 and 300°C. As far as is known, epizonal orogenic deposits in Victoria formed around 380 Ma, but because of the low temperatures of formation, the deposits in the Bendigo Zone are not well constrained. Those in the Melbourne Zone just postdate the only major deformation there, the Tabberabberan deformation, of 380 Ma.

Gold in VMS deposits

There are only a few known volcanic-hosted massive sulfide (VMS) deposits and occurrences in Victoria which have anomalous gold grades. The best known examples include Currawong copper–zinc deposit (9.5 Mt ore) in the Omeo Zone and Mount Ararat copper deposit (1 Mt ore) in the Stawell Zone. Gold is associated with pyrite, chalcopyrite and sphalerite. Gold grades vary between 0.5 g/t and 2 g/t.

Intrusion-related gold

Several small deposits have been classified as intrusion-related based on their spatial and temporal relationships with felsic intrusions, unusual geochemical characteristics and their relatively late timing. Unlike the orogenic gold deposits, they significantly post-date the main orogenic phase in the host terrane. Wonga at Stawell (~10 t gold) is the largest Victorian deposit classified as intrusion-related, but most others recorded are yet to be mined.

Gold occurs in quartz veins with minor sulfides. These deposits also usually have anomalous concentrations of Mo, W, Bi, Sb, Cu, Te and sometimes Sn, B and F.

Considerable uncertainties remain in relating many of these deposits to a magmatic source. In particular, deposits hosted by meta-turbidites and characterised by gold grades exceeding 5–10 g/t (up to 30 g/t) share many attributes with some orogenic gold deposits.

Most deposits classified as intrusion-related formed around 370 to 380 Ma in the Melbourne Zone and eastern Bendigo Zone and 400 to 420 Ma elsewhere.

Alluvial deposits

Alluvial deposits were mostly formed from products of weathering and erosion of primary gold mineralisation. The largest alluvial deposits are typically strongly associated with major orogenic gold deposits (e.g. Ballarat, Bendigo, Castlemaine). However, several major alluvial goldfields occur in areas where only trivial primary deposits are known (Creswick, Chiltern, Ararat, Beaufort).

The largest alluvial goldfields extended over 10 km and produced more than 100 t of gold, but production records are often very poor or nonexistent so there is considerable uncertainty with most figures. Total Victorian alluvial gold production is close to 1500 t.

Alluvial deposits were typically traced to their primary sources and were the vector to primary gold mineralisation used by early prospectors. As yet no significant primary deposit mined has been found by any other means.

Gold is usually hosted by Eocene to Recent gravels, including ridge-forming cemented gravels. The gold grain size greatly varies both within and between deposits and is likely to be related to properties of the primary mineralisation of the source. Some areas in central and western Victoria are well known for the abundance of gold nuggets.

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Western Australia[4]

Western Australia dominates Australia's gold industry. It produces annually approximately 170 t or about 70% of our total output and 60% of the exploration investment for gold is spent in WA. Kalgoorlie Consolidated Gold Mines, with its Super Pit in Kalgoorlie and operations at Mt Charlotte produces more than 25 t per year.

The Super Pit is the biggest gold mine in Australia and is one of the world's largest open cuts. It is 290 m deep, 3 km long and 1.5 km wide (Figure 21) and in the next decade it is expected that mining will be conducted at a depth of 600 m. The Super Pit was opened in 1989 and has produced more than 1600 t of gold. The massive ore-carrying trucks carry 220 tonnes of ore in one load and it takes seven truckloads to produce 63 g of gold (Figure 22). In fact the only record WA cannot claim seems to be that of the largest nugget. The Golden Eagle nugget, which was found in January 1931 at Widgiemooltha, about 100 km south of Kalgoorlie, contained only about 40 kg of gold – much smaller than the 318 kg Holtermann Nugget discovered in 1872 in New South Wales and containing an estimated 94.5 kg of gold.

WA's most significant goldfields are located in the Goldfields–Esperance and Mid West regions, with new production commenced or planned for the Pilbara and Great Southern regions (Figure 23).

Fig. 21. *The Super Pit, at Kalgoorlie operated by KCGM, showing the extent of the pit in early 2008 (image provided courtesy of KCGM).*

Fig. 22. *One of the trucks used to transport the ore (image provided courtesy of KCGM).*

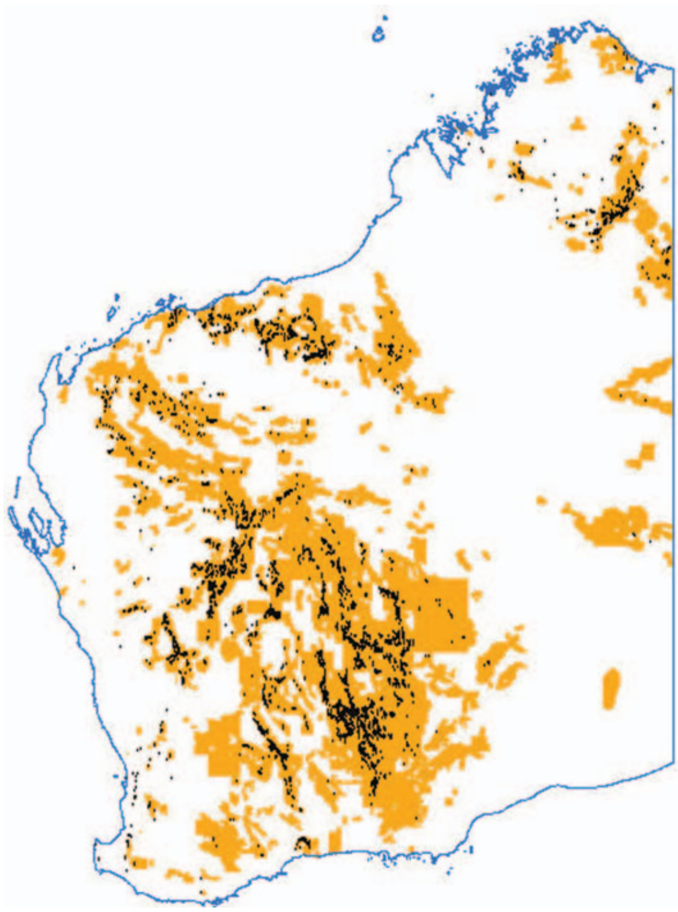

Fig. 23. *Gold exploration and mining leases in WA, outlined in yellow, and known deposits, shown in black (image provided by DOIR WA Government).*

The majority of gold mined in WA is obtained from the Yilgarn Block. This area comprises narrow zones of folded and metamorphosed sediments and volcanic rocks surrounded by granite and granite–gneiss.

WA's 10 largest projects produce ~122 t of gold annually and accounted for 72% of the State's total gold production in 2005. These projects comprise (from 1 to 10): Super Pit (Kalgoorlie Consolidated Gold Mines Ltd, Newmont and Barrick Gold),

[4]Information taken from Overview of Mineral Exploration in Western Australia for 2006–07 by P.B. Abeysinghe and D.J. Flint as well as other sources.

St Ives (Gold Fields Ltd), Sunrise Dam (AngloGold Ashanti Ltd), Telfer (Newcrest Mining Ltd), Granny Smith (Barrick Gold), Jundee-Nimary (Newmont), Kanowna Belle (Barrick Gold), Plutonic (Barrick Gold), Agnew (Gold Fields Ltd) and Marvel Loch (St Barbara Mines Ltd).

Although the gold price increased during 2006–07 to a 24-year high of US$679/ounce, gold production fell in WA by 5.7% to 157 t. Fortunately, because of the price rise, the value increased by 10% to $4.1 billion.

Gold exploration expenditure increased in 2006-07 by 12%, reversing the declining trend of the last three years. However, expenditure is still well below the historic peaks of 1987–88 and 1996–97.

Although gold exploration has been the backbone of the mineral exploration industry in Western Australia since the early 1980s (reaching levels of around 75% of total mineral exploration expenditure in the mid-1990s), its proportion of total exploration expenditure during 2006–07 declined to 33% (Figures 24 and 25). However, gold retains its number one position in terms of exploration dollars spent which, in 2006–07, increased by 12% to $267.9 million.

This increasing exploration expenditure will hopefully lead to further discoveries and halt falling gold production in the State, which has shown a continuous decline over the last 9 years (Figure 26). An inadequate level of greenfields mineral exploration remains an ongoing concern for the future of gold mining in the State.

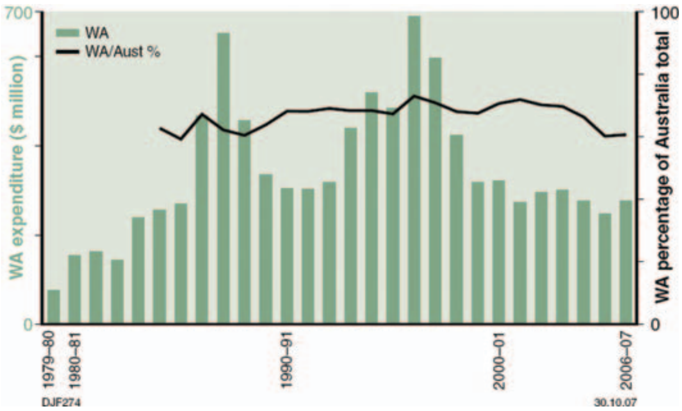

Fig. 25. *Gold exploration expenditure in Western Australia (2006–07 dollars).*

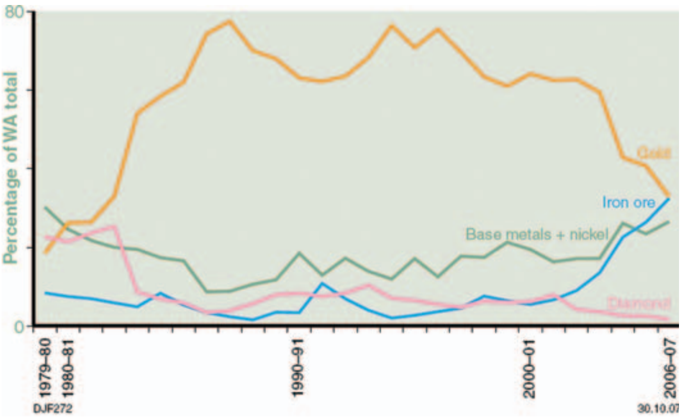

Fig. 24. *Investment in gold exploration in Western Australia. Notice how the percentage invested in gold exploration has declined in recent years.*

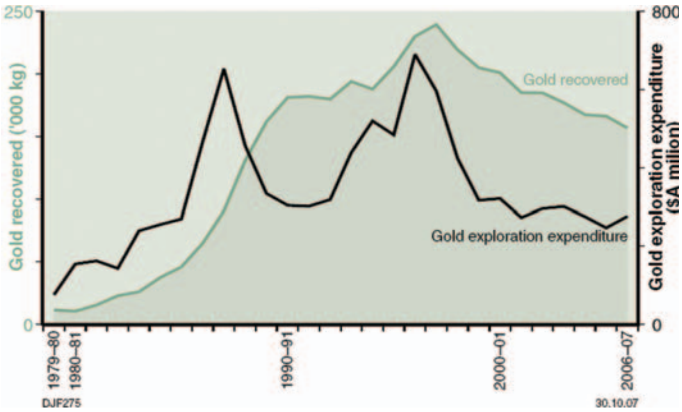

Fig. 26. *Gold exploration expenditure and gold production in Western Australia (2006–07 dollars).*

Modern day tool chest for a treasure hunt

How we hunt for gold

The primary tool chest used in gold treasure hunting has evolved through time with new advances in our understanding of mineral systems, and with new technologies becoming available. In some ways we have become more sophisticated, such as in our use of computers, but in many other ways the same principles apply as were used by the likes of Paddy Hannan a century ago in his hunt for gold which found the Golden Mile.

While different tools can be used at different scales, we should view the world as fractal. Many of the principles behind the application of the techniques we use are independent of scale. For example: whether we are targeting at a craton scale or local mine scale there is a fundamental belief that fluid conduits are important for gold occurrences.

What are our modern tools?

Tools can be viewed as new technology, like the emerging spectroscopy used to define alteration and mineralogy at all scales; or geophysical potential field data of gravity, magnetics and SAM. Tools can also be viewed as concepts or models used to target in exploration. An example of this is the targeting of breaks in dolerites, interpreted from magnetic imagery as being areas of structural demagnetisation resulting from gold-bearing hydrothermal fluids flowing through favourable granophyric zones. This is but one model and has yielded many new deposits. Through CRCs and other forums we have been exposed to new models to use in the targeting stage of exploration.

There are two ways to approach exploring for gold:

1. Follow-up of existing gold occurrences in stream sediments or soils, testing around areas exploited by the old timer or defining geochemical proxies or pathfinder elements to buried gold deposits.
2. Through the application of new developments in our understanding of the science of gold systems. As explorers, applying recent findings and learning to exploration has provided us with a whole range of new tools to add to our tool chest, and enabled us to be more predictive in our endeavours. This was one of the many goals set out by the pmd*CRC.

The CRC and others set out to answer the five questions thought to be important in the formation of large-scale gold deposits:

1. What is the role of geodynamics (stratigraphy, structural, metallogenic, and metamorphic history)?
2. What structural architecture is required?
3. How is metal transported and deposited?
4. What and where are the fluid sources and reservoirs?
5. What are the fluid flow drivers and pathways?

Many new discoveries in science were revealed while researching these five questions, which now help to guide us gold hunters towards our ultimate treasure. Much like an old fashioned treasure map, the key questions are important to discoveries, but it is when we look at the entire map not as individual components but as a whole that we can realise the true value. The work of Andy Barnicoat and Richard Blewett from Geoscience Australia through the pmd*CRC exposed us to the concept of focusing on mineral systems. To form gold deposits all the factors studied in the pmd*CRC playing a role, and are interdependent and interrelated. Previously we may have only considered one or two of these processes in defining our exploration targets. We now know that the relationship and interdependency between structural architecture and fluid source is just as important as what is driving metal deposition.

In the exploration process we now ensure that we apply a holistic approach to our targeting and consider all of the five questions where possible. Additionally we are expanding our tool kit by collecting new data based on the five questions to help us target more effectively.

How we target: a holistic approach to targeting at Neptune

The Neptune area is situated north of the Victory–Leviathan complex and south of the Revenge Complex where we have mined

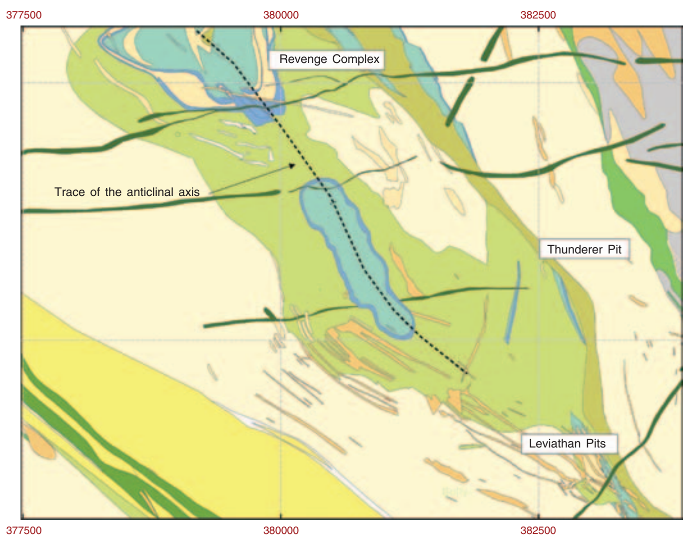

Fig. 27. *Interpreted surface geology map, Neptune area.*

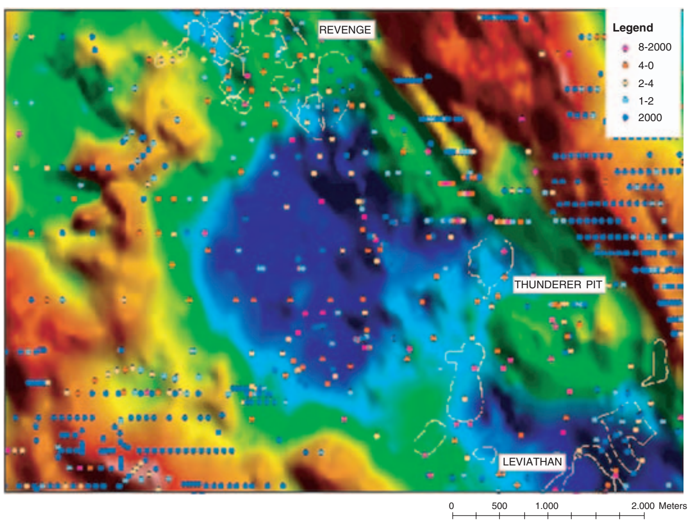

Fig. 28. *Bouger Gravity and distribution of molybdenum.*

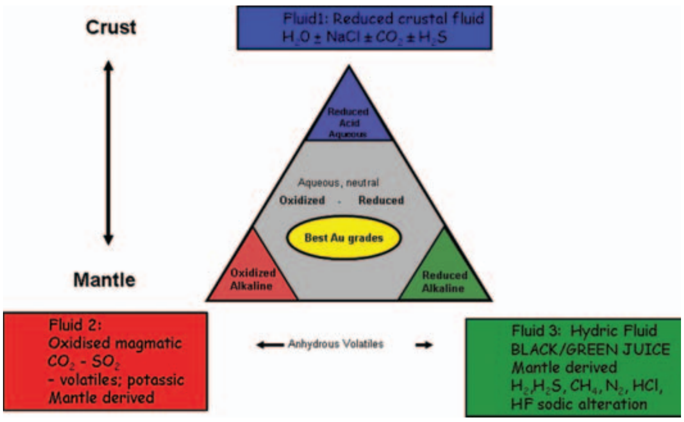

Fig. 29. *Three-fluid diagram of crust mantle interactions: based on isotopes, geochemistry and mineralogy and fluid inclusion end members.*

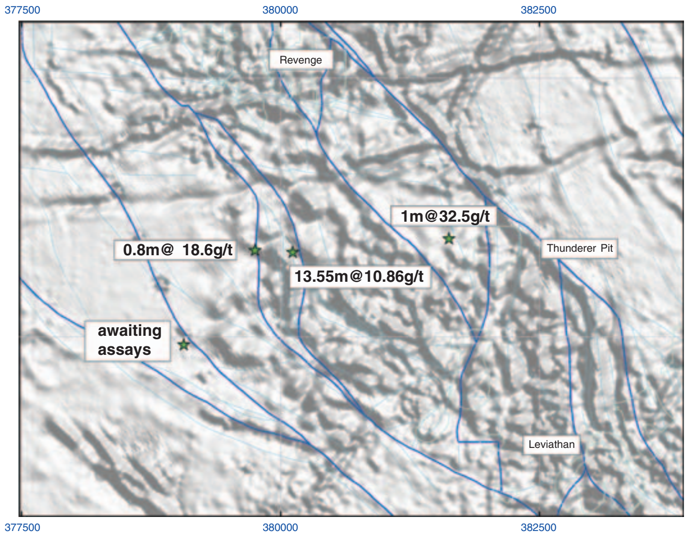

Fig. 31. *Magnetic image of the Neptune target area with recent drill results and structural interpretation.*

in excess of 3 Moz and 2 Moz, respectively. The geology of this area is dominated by a gently plunging open anticline, with lower Devon Consols Basalt in the core of the anticline, and Kapai Slate, differentiated Defiance Dolerite and Paringa Basalt on the flanks of the anticline (Figure 27). This area has undergone many phases of exploration activities and failed to generate a minable reserve, despite all the favourable ingredients for mineralisation being present, and being immediately adjacent to two world class mining centres. The 'Hunt for Gold' approach utilised for targeting in this area incorporated analysis of the whole system rather than individual components.

Fluid source and reservoirs

The research of Dave Champion (GA) in the CRC and Scott Halley demonstrates that there is a clear spatial and temporal association between intrusions and gold occurrences. Whether we are looking at heat generated by the intrusions, the circulation of fluids or whether the intrusions are themselves the direct source of the gold, they are important. Through their work we are also aware of the types of granites that are important at the time of gold mineralisation and the distinct geochemical characteristics. As explorers we can vector towards the enriched intrusions. Gravity lows or geochemical hydrothermal distribution of tungsten and molybdenum are indicators of intrusions in the Neptune area (Figure 28).

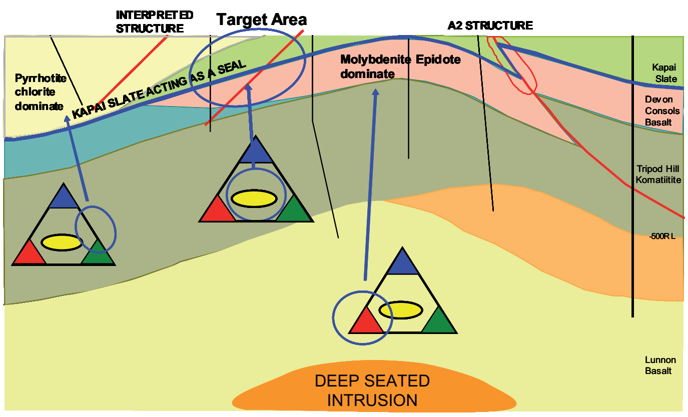

Fig. 30. *Cross section of stratigraphy and alteration zones in the Neptune area.*

Metal transport and deposition

Great strides have been made in our understanding of the depositional mechanism for gold at St Ives through the works of John Walshe (CSIRO), Peter Neumayr (formerly CET) and Scott Halley. Previous methods simply targeted the intersection of structures with iron-rich zones of differentiated dolerites with great success. However, this is not the only mechanism for depositing gold and the role of fluid mixing as a depositional mechanism is becoming clearer in many of the deposits that have been studied at St Ives. Figure 29 illustrates the importance of the interplay of three end member fluids in the process of gold mineralisation.

A variety of methods can be used to define possible gradients and proxies for the three end member fluids in our continual search for gold. The cross section illustrated in Figure 30 highlights different fluid interaction events defined through detailed relogging of historic diamond holes and multi-element analyses to determine mineralogy and alteration assemblages. Discrete target positions were defined as a direct result of this work. The anticline axis appears to be dominated by oxidised fluids as defined by the presence of epidote and molybdenum. On the flanks of the anticline the rocks are dominantly acidic in nature with pyrrhotite visible in core. The main target location is at the gradient position between the two fluid types. In this example the Kapai Slate appears to be acting as an aquitard.

Structural architecture

Interpretation of magnetic and gravity imagery, with added cross sectional interpretation by John Miller (CET) and St Ives geologists, highlighted the structural complexity of the Neptune area. Importantly, the area delineated as having a discrete geochemical gradient also coincided with an apparent dilation jog position, as illustrated in Figure 31. Finally our hunt for gold yielded success with recent drill holes confirming the presence of significant mineralisation.

In summary the Neptune area was a test case of applying the five questions holistic approach to exploration rather than simply searching for the answers to a single parameter. What became evident in the process is that answers to all the five questions are important to defining a mineral deposit.

Exploration at the St Ives Gold Mine has been successful in defining more than 10 Moz of mineralisation since 1980. Recent advances made by St Ives Gold geologists working with the geoscientists in the CRC, and Scott Halley have added many new tools and model concepts to the St Ives exploration project. New and exciting discoveries are merely waiting to be made.

Treasure hunting has evolved through time for exploration geologists, with great advances in new data availability to add to our targeting tool kit and to ensure our never-ending search for new gold-filled treasure chests remains successful. What is important as treasure hunters is that we are open to new concepts, embrace new technologies and continue to support research.

Acknowledgments

St Ives Gold Fields would like to acknowledge the efforts and contributions of Scott Halley of Mineral Mapping Pty Ltd, John Walshe of CSIRO, Richard Blewett, Dave Champion and Andy Barnicoat of Geoscience Australia, John Miller of the CET and Peter Neumayr formerly of the CET.

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Continued from p. 18

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Social networking and your status on the internet

Like it or not, your presence on the internet is growing fast. Indeed, recruitment companies and potential employers are increasingly likely to scan the internet for any footprint you have left behind or, conversely, have promoted. As suggested later on, your perception of the world may soon be customised according to how you have allowed your persona to be stored on the internet. Social networking sites are a booming business and represent popular fora that others might use to search for information about you.

A representative cross-section of sites includes:

- MySpace (http://www.myspace.com)
- Facebook (http://www.facebook.com)
- Bebo (http://www.bebo.com)
- LinkedIn (http://www.linkedin.com)

MySpace lists itself as 'A place for friends', and it is the historically most popular social forum. To me, MySpace is a vehicle for bored people to post personal minutia, exchanging far more personal information and imagery than is often healthy. Disconcertingly, since signing up to investigate I seem to receive quite frequent unsolicited requests to become someone's friend. Such is the nature of these networks; you build communities of contacts and friends by invitation. You can select how little or how much of your personal details are made public, thus implicitly deciding how easy it is for search engines to find you and your personal data. The worldwide web is full of scammers and creeps, so beware.

Bebo is the fastest-growing network, again being 'A social media network where friends share their lives and explore great entertainment'. As such, the content is somewhat more 'mature' than MySpace, with an explicit focus on expression through audio and video media.

Facebook is 'A social utility that connects you with the people around you', and my preference. Common to most such services, you can build quite elaborate homepages, comprised of potentially hundreds of links to business, gaming and trivia applications and so on, each of which will regularly invite your personal network to indulge in various forms of banter, fun and interaction.

As the popularity of online social networking grows; however, pressure is building within many companies to regulate employee access during company hours. As of April 2008, Telstra, Suncorp, Citigroup and ACP Magazines had all banned internal internet access to Facebook during business hours. In contrast, Seek, REA Group and Siemens all encourage Facebook use during business hours to create new business opportunities (Source: BRW magazine). Although a subject of philosophical debate, online social networking is inevitably going to play a larger role in our lives, maturing from the recreational distraction of concern to many employers to a vehicle that enables more efficient marketing and business growth.

If you only look at one of sites from this article, please try the following link: http://mccd.udc.es/orihuela/epic/ and consider the scenario proposed, where Google has merged with Amazon.com by 2014 to produce a truly personalised but grossly superficial direct feed of 'News', social networking and advertising content to virtually everyone on earth. Note that the term 'Fourth Estate' refers to the press, both in its explicit capacity of advocacy and in its implicit ability to frame political issues (attributed to Thomas Carlyle, early 19th century). In many ways, the scenario is uncomfortably prophetic.

The inescapable message is that your profile and every piece of information you have ever registered online (whether 'private' or not) is going to be used to affect how you are treated as a potential customer and as a potential employee, and what your status will be in the global 'mediascape' that will be an intrinsic part of our lives.

In the meantime, let us return to our initial topic on career growth and how the internet can affect you today. Like most advertising, the most popular media has shifted away from the printed press to online. In Australia, when searching for jobs in mining or oil and gas consider: MyCareer (Fairfax: http://mycareer.com.au/, on 'Mining, Oil and Gas'), CareerOne (News Corporation: http://www.careerone.com.au/, on 'Mining and Resources'), LinkMe (Sensis: http://www.linkme.com.

au/, jobs found by using a keyword search facility), and Seek (http://www.seek.com.au/, 'Mining, Oil and Gas jobs' link), which is by far Australia's largest online recruiting resource. But if we return to the more sophisticated media of online social networking, LinkedIn is designed to 'Share knowledge and tap into relationships'. Whereas the other sites are focused upon recreation, LinkedIn is specifically designed for business networking.

You either recruit contacts by qualifying for a direct invitation (past colleagues, business associates etc.) or by referral from an established contact. The network rapidly grows as you add contacts. For example, after building only 12 contacts I effectively had either direct or indirect access to over 46 000 other people in the LinkedIn network!

You can track who looks at your profile and publish quite comprehensive information about your résumé and interests. Furthermore, there are also specific networks for many industries you can apply to become a member of, thus instantly creating a plethora of new opportunities and ideas for your career. For an Australian, however, the main challenge is that sites such as Facebook and LinkedIn are mainly patronized by US citizens. But the rest of the world is catching up. LinkedIn is an example of what is rapidly coming – a forum to customise how you can tap into the vast resources of the industry many of us work in, and all of its associated industries. And remember, once posted onto the web, your information may stay there forever.

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The Australian miracle; an innovative nation revisited

by Thomas Barlow

Publisher: Picador Pan-Macmillan Australia Pty Limited, 2006, 288 pp.
RRP: $24.95, ISBN: 9780330422321

This paperback is not particularly about geophysics, or even science at all in a technical sense. However, it makes provocative reading regarding the manner and strategies under which science and innovation are promulgated. It is relevant to geophysics research and development in Australia, and readers of *Preview* should find it stimulating indeed. Its relevance is not least because the ASEG brings together a healthy mix of private enterprise and government research and development, a situation implicitly applauded by author Thomas Barlow in this book.

Barlow, we are told, is the CEO of a materials company. He has been a Research Fellow at Oxford and MIT, a columnist with the Financial Times and Scientific Adviser to the Minister for Education, Science and Training in the Australian Government. From the context I guessed his subject was chemistry (confirmed by a web search).

The style of the book is that of an after-dinner speech. Statements are asserted, and interwoven with opinions, predictions and ideas generally. Historic facts are not backed up with references cited: it is not that sort of book. As with an after-dinner speech, it is best just to go with it, and see to what extent you find it convincing.

The premise of the book is that a mantra has developed of pessimistic opinions about Australian innovation. These opinions are expressed widely, with force and consistency of rhetoric, and the book has been written as a response to such overwhelming negativity. The reader must from the start accept such an assertion, otherwise the whole exercise is based on knocking down a straw man.

Chapter 1 presents 'Ten myths' about Australian science, which (if accepted) demonstrate the negativity mentioned. These range from 'Australians are hopeless at profiting from their inventions because Australian researchers aren't commercial enough' (No. 2) to 'All of Australia's best scientists go overseas, leaving Australia the victim of a *brain drain*' (No. 8). It is asserted that these 10 points are entrenched in the general imagination of the Australian populace.

Chapter 2 then presents 'The Australian miracle', which is the progress made in Australia in the first century of European settlement. The Australian colonies progressed from one of the poorest to one of the richest countries in the world: an economic miracle, illustrated in the book by individual case histories and anecdotes. As the author is at pains to point out, this progress was not only due to gold. A resilient and enterprising culture was bred of necessity, which led to an innovative use of technology and transformed the country with railways, telegraph and water engineering.

Given what was demonstrated in the nineteenth century, Chapter 3 then asks 'Are we our own worst enemy?' today? This chapter again quotes examples and anecdotes to make the point that there is excessive pessimism about Australian science, and a false(!) linkage to insufficient government funding. The author asserts that at almost every gathering of innovation specialists in the country, the purported lack of government interest in science is the favourite topic. He laments that Australians should be incapable of having ideas without first asking government bureaucrats to hold their hands. There are some pointed comments on scale being king in research projects, rather than quality or merit; and secondly when scale becomes an end in itself, the pursuit of size may provide a broader justification for mediocrity. Cooperative Research Centres (and the philosophy which has spawned them) come in for a serve here.

Chapter 4, on 'Priority setting', prescribes ways to put things right. Barlow turns to economics, and strongly favours decentralised free-market economies. He is strong for small government, efforts by individuals, and market forces, which he says can operate in science as well as anywhere else. He believes firmly in the benefits of competition between small groups, and advocates leaving decisions in the hands of the researchers. He also advocates legitimising the pursuit of the unknown, because the future value of scientific results is unpredictable.

Chapter 5, 'Understanding ourselves' is a calmer view of Australia, and what might be. In some respects it revisits the material of earlier chapters, with further anecdotes about Australian innovative success in the past, and the damage which the unjustified pessimism of the present is doing to the national self confidence. Amongst the examples quoted to cheer the reader up and demonstrate that Australia can (and does) lead the world still in innovation is the airborne gravimeter. Australian exploration geophysics is given plaudits here. The author closes with the opinion that Australian technological and scientific enterprise will rise strongly, even miraculously, in the 21st century, if Australians will only understand themselves and seize the opportunities which abound.

In summary, the author has a good knowledge of Australian scientific, social and economic history, and his 'Australian miracle' is basically how well Australia did in innovation in the 19th century. He says that we should be able to do as well today in international competition, but we need to return to more of the self-reliant and individual enterprise of the 19th century, and less of the government-funded and directed monopolistic entities of today.

I first read the book in 2006, about the time of the death of Milton Friedman. Newspapers were then reviewing Friedman's neo-liberal contributions, contrasting them with those of the more socialistic Keynes who had earlier held sway. Barlow I think would get on very well with Friedman. Actually, I also think Barlow would get on very well with *Preview*'s Eristicus; for they have the same gift for the perceptive analysis of the politics of science.

Copies can be ordered from Macmillan Customer Service Tel. 1300 135 113, Fax. 1300 135 103 or email: customer.service@macmillan.com.au.

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3D Structural Geology: A practical guide to quantitative surface and subsurface map interpretation, 2nd Edition

by Richard H. Groshong, Jr

Publisher: Springer, 2006, 392 pp. + CD
RRP: $186.16, ISBN: 978-3-540-31054-9

Richard Groshing has revised his *3D Structural Geology* in a 2nd edition. His key approach to structural interpretation is to keep all three spatial dimensions in mind. While, until the advent of modern imaging techniques, most structural mapping and interpretation was performed in 2D, Richard's philosophy stresses that whether the analysis is being done in 2 or 3 dimensions, representations of geological structures must involve consideration of their 3D interpretations.

Worked examples are provided throughout the book, and at the end of each chapter there are exercises to put into practice the newly learned structural techniques. In many cases techniques are presented both as traditional pen and paper techniques, and quantitatively as might be found in software packages. The text is aimed at the professional or advanced student, with a strong practical focus. The text is supplemented by a CD, which allows for better visualisation of many of the 3D diagrams in the text.

Chapter 1 provides a concise overview of the basics of structural geology, briefly defining structural elements with reference to the mechanical origin of the structures. This overview is intended to refresh the reader's memory of the basics of structural geology, which it does very well. While the capable reader without a structural background could use this chapter as an entrance into the book, the fast pace of the chapter makes it more suited as a refresher than a first introduction.

Chapter 2 describes basic 3D methods for creating structural maps. It discusses location of points in 3D, plane and line orientations, including the use of stereograms and tangent diagrams and 3-point problems, and introduces the concepts and methods of apparent dip and structure contours.

In Chapter 3, techniques for interpolating structural data to structural contours are described. Various interpolation methods, using both TINs and grids, are described, with numerous figures showing the different results obtained by applying the different methods to the same data. The use of additional information such as bedding thickness, relationships with other surfaces and fluid flow is described.

Chapter 4 details various ways in which the thickness of a geological unit can be defined and measured. Different methods, using field or core data, geological and topographical maps, and structural contour maps, for calculating thickness are described, including for tricky situations such as when beds are folded. Interpretation of thickness measurements is also briefly covered.

Chapter 5 describes the geometry of folds (trend, plunge etc.) and their structural interpretation. Representation on structure contour maps, tangent diagrams and stereograms are shown.

The construction and interpretation of cross-sections is shown in Chapter 6. The incorporation of dip information using dip-domains is described. The projection of data not on the plane of the cross-section is described as a method of utilising all available information.

In Chapter 7 we come to faults, and we learn how to recognise them on seismic reflection profiles, structural contour maps and by rock type. Unconformities are discussed due to their geometrical similarities to faults, which can lead to ambiguity in distinguishing whether a feature is a fault or an unconformity. Fault displacement and geometry are then described, before a discussion of criteria for establishing correlation of separate fault observations. Chapter 8 follows on from the previous chapter, where our new knowledge of fault geometry is translated onto maps. Construction of fault maps and the interpretation of faults on maps are described.

Chapter 9 provides a detailed explanation of dip-sequence analysis. Dips collected down a well or along a traverse are used to constrain a structural interpretation, and noise is reduced by examining the dip components in both the strike and dip directions.

The techniques described in the previous chapters will prove valuable to the practitioner who needs to interpret geological data into a 3D structural map. Chapter 10 describes the perhaps less exciting, but very important, issue of quality control. Sources of error are described, along with tips on recognition (e.g. the interpretation is geometrically impossible) and correction of such errors. The aim is to produce a geologically reasonable structural interpretation.

Chapter 11 deals with validation, restoration and prediction from structural interpretations. In a chapter that I found very interesting, techniques were described for returning a deformed structure to its original shape. Doing so provides a check on the interpretation, as the restoration must be geometrically possible and not add or lose material. In teaching these techniques, this chapter also provided something of a synthesis of the material covered in the previous chapters.

Chapter 12 is essentially an appendix covering the mathematical details of direction cosines and vector geometry. It provides a good background/refresher for those who are not familiar with these mathematical methods.

3D Structural Geology is an excellent advanced text on structural methods and interpretations. The text is clear and concise, technical terms are well defined and repeated use within the text builds familiarity. Most equations are relatively simple, and accompanied by an explanation in the text. I found that the numerous illustrations throughout the text were particularly helpful. While some concepts were difficult to visualise by reading their description in the text, the diagrams often allowed me to quickly come to an understanding of the idea being explained. The text logically works through from basic principles and definitions to more complex interpretations and reconstructions, building on knowledge gained in earlier chapters. Numerous examples and a practical focus make this book a handy reference as well. I think this text will prove valuable for practitioners and advanced students.

Copies can be ordered directly from http://www.springer.com or through your local book store.

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September			**2008**
14–17 Sep	EABS III Energy Security for the 21st Century www.pesa.com.au/pdf/eabs_call_for_papers.pdf	Sydney	Australia
November			**2008**
9–14 Nov	SEG International Exposition and 78th Annual Meeting http://seg.org/meetings/	Las Vegas	USA
24–27 Nov	Pacrim Congress 2008 www.ausimm.com.au/main/events/docs/pacrim2008.pdf	Gold Coast	Australia
December			**2008**
15–19 Dec	American Geophysical Union, Fall Meeting www.agu.org/meetings	San Francisco	USA
February			**2009**
22–26 Feb	**ASEG's 20th International Conference and Exhibition** **www.aseg.org.au**	Adelaide	Australia
March			**2009**
29 Mar–2 Apr	22nd SAGEEP meeting (Symposium on the Application of Geophysics to Engineering and Environmental Problems) www.eegs.org/pdf_files/sageep09_abstractcall.pdf	Fort Worth	USA
April			**2009**
24–27 Apr	CPS/SEG Beijing 2009 International Geophysical Conference and Exposition http://seg.org/meetings	Beijing	China
May			**2009**
24–28 May	American Geophysical Union, Joint Assembly www.agu.org/meetings	Toronto	Canada
31 May–3 Jun	2009 APPEA Conference & Exhibition www.appea2009.com.au	Darwin	Australia
June			**2009**
8–11 Jun	71st EAGE Conference & Exhibition www.eage.org/	Amsterdam	The Netherlands
September			**2009**
7–9 Sep	EAGE: Near Surface 2009 www.eage.org/	Dublin	Ireland
October			**2009**
25–30 Oct	SEG International Exposition and 79th Annual Meeting http://seg.org/meetings	Houston	USA
December			**2009**
14–18 Dec	American Geophysical Union, Fall Meeting www.agu.org/meetings	San Francisco	USA

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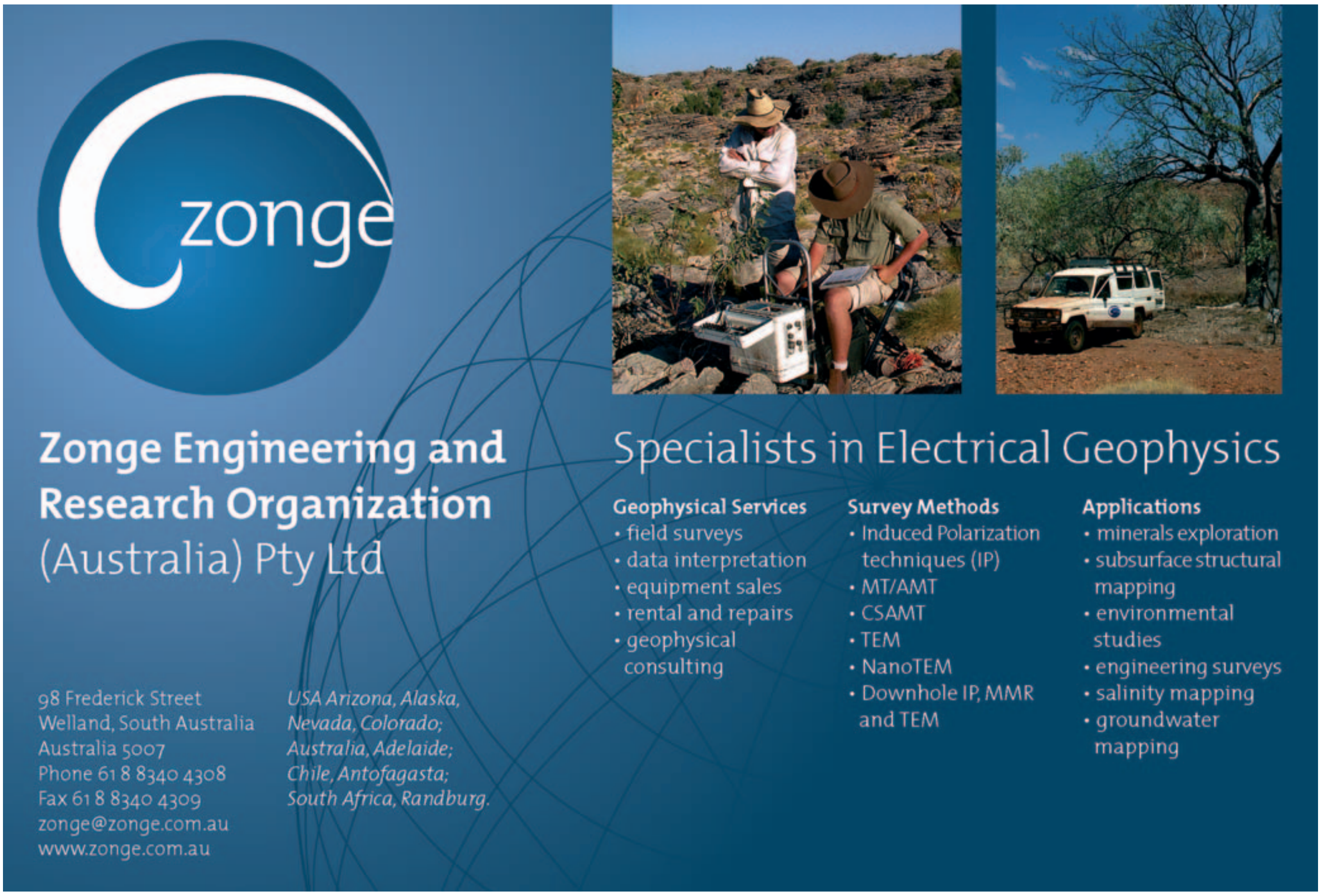
Preview is published bi-monthly in February, April, June, August, October and December. The deadline for submission of material to the Editor is usually about the 15th of the month prior to the issue date. The deadline for the October 2008 issue is 12 September 2008. Advertising copy deadline is usually about the 22nd of the month prior to issue date. The advertising copy deadline for the October 2008 issue will be 19 September 2008.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