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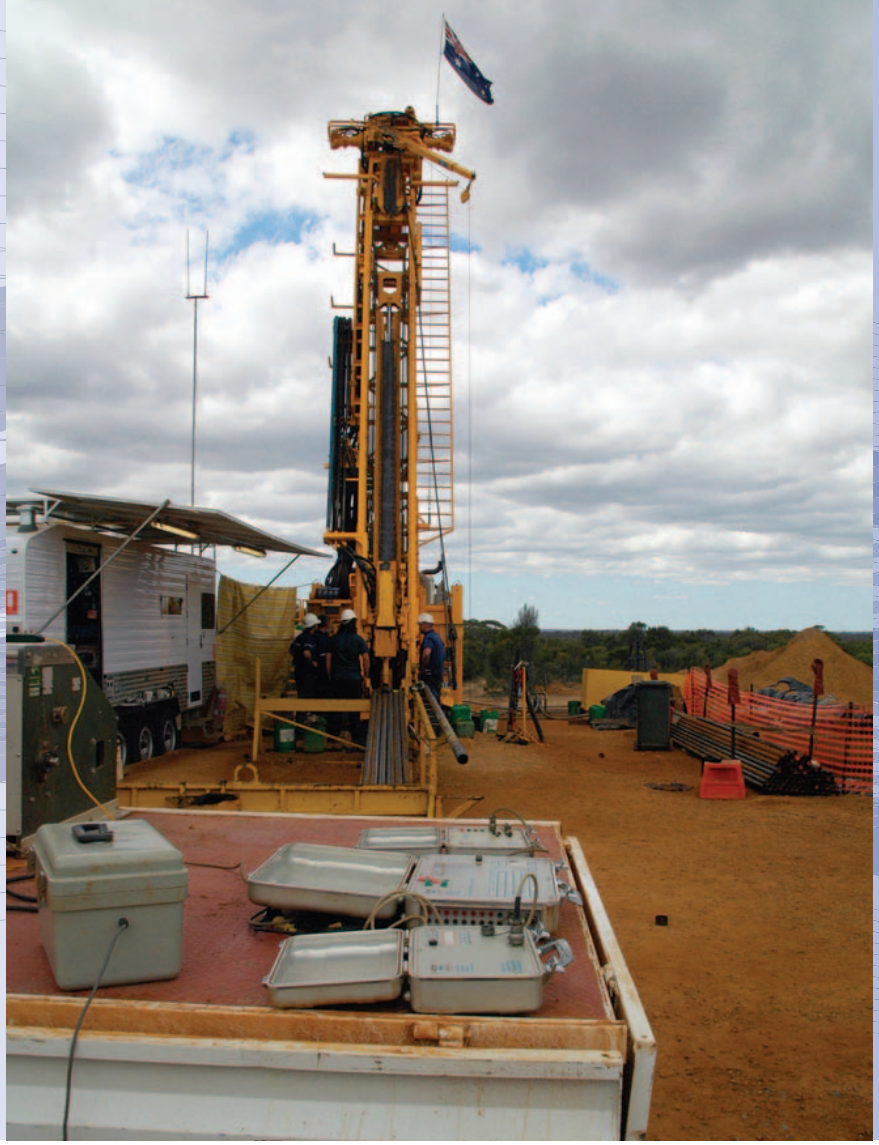
PREVIEW

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

NEWS AND COMMENTARY

FEATURE ARTICLES



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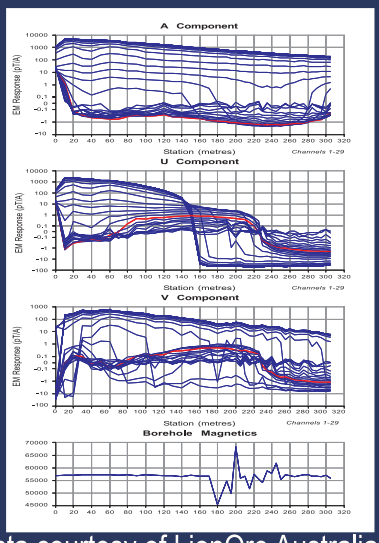

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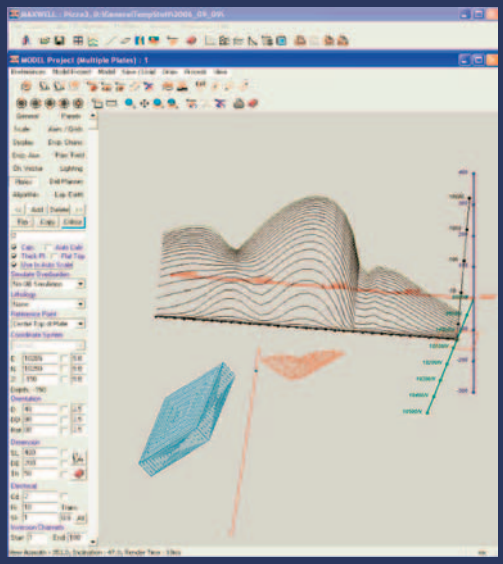

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FRONT COVER

Eighty ton dump truck hauling ore out of Pit #3 at the Ranger Uranium Mine, NT, 1999. Image © CSIRO 2008.

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David Denham

In this Christmas issue

A rallying cry for Geoscience in Australia

Jim Ross, who has been very active in Australian geoscience for many years, has just completed an extensive review of the state of the geosciences in Australia. He examined, among other things, geoscience education, public awareness of geoscience, and the strength of professional societies. We don't have space in this issue of *Preview* for his complete article, so we are publishing his abstract, as a special editorial contribution, to give you some ideas of his arguments, and will be putting the full paper on the ASEG website.

An interesting miscellany

We also have in this issue a review of EM methods in offshore hydrocarbon exploration; the ARC's geoscience grants for 2009 and the ASEG's Research Foundation grants for 2008; Eristicus's comments on climate change and the world economic crisis; two comparing /contrasting book reviews of the same book on climate change, and the usual regular contributions.

Season's Greetings

This is the last issue of *Preview* for 2008, and I would like to take this opportunity to thank our contributors, readers, advertisers, sponsors and publisher for their support during 2008.

I would particularly like to thank Don Emerson who is retiring as Associate Editor after 10 years of work for *Preview*. He could always be relied upon to provide high quality petrophysical contributions for *Preview* and sound advice when the Editor needed assistance, and will be really missed.

Don was also Editor of *Exploration Geophysics* for 16 of the past 38 years. He has made a huge contribution to the Society.

Finally, I wish you all a relaxing Christmas and New Year, and hope to see you in Adelaide at the 20th ASEG International Conference in February 2009.

A rallying cry for geoscience in Australia[1]

Australian geoscience is in decline. This is unacceptable. Geoscience is at the heart of several key national issues. The reasons are systemic, well understood, and have been commented on for many years, yet the decline continues. The key question is: why has the geoscientific community been so ineffective in addressing these systemic problems and what can we do?

A common feature of past analyses has been the focus on the national scale of the problems and proposed solutions. Yet recent encouraging experiences in WA at the secondary and tertiary levels indicate considerable potential for effective initiatives at the institutional and state levels.

Positive change will require concerted action from the professional organisations, industry, alumni and concerned geoscientists at all levels. Existing data indicate that early investment into the two most populous states, NSW and Victoria, will be most rewarding.

The Australian Geoscience Council has made a very important contribution through their 2007 survey and summit, and the new Teacher Earth Science Education Program (TESEP) is a valuable initiative. However, the momentum for change must be strengthened and maintained. For example:

- We must become serious about raising public awareness of our brand; we must promote Earth Science and Earth Scientists at all levels and ensure that our key role in the continuing debates about climate change are recognised and utilised.
- We must become serious at a state by state level about strengthening the teaching of Earth and Environmental Science in our secondary schools (an immediate opportunity for professional organisations is vigorous advocacy of Earth Science to the Year K-12 National Curriculum process).
- We should acknowledge that the current problems with tertiary geoscience in Australia exist at three levels, local institution, state and national, and each requires different solutions.
- We must address the severe fragmentation of our geoscience professional organisations because this blunts our impact at local, state and national levels and diminishes our capacity to address the problems.

A plan to encourage and guide such actions is proposed. It includes: the acquisition of internally consistent data for tertiary and secondary teaching at the institution and state levels; international benchmarking at the tertiary and secondary levels; age profiling of the geoscience workforce; and assessment of the potential for post graduate training of overseas geoscientists. The outcome should be a set of comprehensive, practical and multi-level strategies for strengthening Earth Science in Australia to match our national needs.

These strategies should also pave the way for invigorating our contributions to the three big science issues of today: increasing science participation among our youth, climate change and a sustainable planet. The multidimensional scope of Earth Science can provide rich, contextual, scientific material for schoolchildren at all levels. Therefore it has the potential to be a strong attractor for student engagement with other sciences and, over time, contribute to a more informed community. We should aim for nothing less in this nation at this time.

Jim Ross

[1]This is the abstract of a paper prepared by Jim Ross. Jim is a senior industry geologist who has also been actively engaged at the interface between industry, academe, research organisations and government for 25 years. Since 2003 he has been centrally involved in several initiatives to strengthen geoscience education and research in Western Australia, commensurate with the State's strategic needs. Jim is a part time Technical Director of Berkeley Resources Limited, a Director of Kimberley Foundation Australia Ltd and a member of the GSA Executive. He chairs Earth Science Western Australia, the UWA Geoscience Foundation, and the John De Laeter Centre of Mass Spectrometry and recently was Chair of the Centre for Exploration Targeting. Earlier this year Jim was awarded an Honorary Doctorate of Science by The University of Western Australia for his services to geoscience and the University. Jim can be contacted at jrhross@bigpond.com.

The ASEG completed a full business review in August and September this year. The objective of the review was to determine where we stand as an organisation and how we can improve the way we carry on our activities. One pleasing result of the review is that the ASEG is in a strong financial position and will be able to weather the economic storm that is currently sweeping the globe. The ASEG also has a strong membership base and is growing monthly in membership numbers. Our membership is likely to reach 1400 by the end of this year. A further conclusion from the review is that the ASEG has now come of age (38 years old) and is ready to take the next step in its evolution as an 'Internationally Renowned Society'.

The Business Review highlighted the strengths and weaknesses of the ASEG and as a result there will be additional management tools utilised to improve the administration and management of the society. A possibility that will be considered during the coming months will be the employment of a full time Executive Officer. The EO will be responsible for the day-to-day running of the society and provide continuity between Federal Executive Committees. At present the ASEG depends largely on volunteers to run the society, and this has been adequate up until recent years. However, the ASEG has grown and the environment we operate in has become more complex and demanding on individuals. With increased legal responsibilities and an increasing number of activities, it is essential that the ASEG moves towards a more professional style of management. There will be more on this subject in the next issue of *Preview* once the Federal Executive Committee has reviewed all options.

As a growing society, the ASEG has many opportunities in front of it. These include running a conference every 12 months instead of on an 18 month cycle; improving our professional education facilities along the lines of a DISC; running workshops more frequently; and generally providing better service to our members. The ASEG can also look at itself in a global context and increase its services to overseas members. The ASEG moves into 2009 as a strong and progressive society and I wish all members a peaceful Christmas and the very best for the coming year.

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elliottgeophysic@aol.com

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Penny Sackett, Australia's new Chief Scientist

The Minister for Innovation, Industry, Science and Research, Senator Kim Carr, announced the appointment of Professor Penny Sackett as Australia's new, full-time, Chief Scientist on 30 September 2008. She takes over from Jim Peacock, who occupied the position on a part-time basis, and has already taken up her new post.

As the Minister said:

> 'Professor Sackett will provide high-level advice to Government, foster relationships with science organisations and industry groups and stimulate community thinking on the big scientific issues of our time.
>
> Boosting the role from part-time to full-time demonstrates the store the Rudd Government places in high-calibre, independent, scientific advice.
>
> Professor Sackett comes to the position with a long list of professional achievements and credibility in the innovation, science, engineering and technology communities.'

She was Director of the ANU Research School of Astronomy and Astrophysics and Mount Stromlo and Siding Spring Observatories (2002–2007) and remains a Professor in the School. She is a member of the Australian and American Astronomical Societies, the International Astronomical Union and the Association for Women in Science.

She is an Elected International Fellow of the Royal Astronomical Society and is involved in governance of the Gemini Observatory and the Hubble Space Telescope Science Institute. She is also currently a director of the Giant Magellan Telescope, a project to build the world's most powerful optical telescope.

'Professor Sackett will have a vital role in raising awareness of emerging issues in science, engineering and innovation. She will encourage young Australians to see science as an exciting career option,' Senator Carr said.

She is a physicist by training, an astronomer by profession, and considers herself an educator by inclination.

We wish her well in her new role, where she will need both her scientific skills and her powers of persuasion.

Australia's Chief Scientist, Penny Sackett

Best of SAGEEP

A paper by ASEG members Michael Asten and Andrew Duncan on time-domain EM detection and discrimination of unexploded ordnance was judged one of the best papers at the Symposium on Application of Geophysics to Engineering and Environmental Problems (SAGEEP), held in Philadelphia earlier this year. The authors, together with project manager Gary Hooper, have developed an operational prototype of a novel metal detector which uses an array of fluxgate magnetometers as EM sensors. The project has extended over the past three years and has been funded by the US Army.

The Asten–Duncan paper is one of four from SAGEEP which was represented by invitation at the Near Surface Geophysics Conference of the EAGE, held in Kracow, Poland, in September 2008.

Congratulations to Michael and Andrew.

New members

The ASEG welcomes the following 22 members to the Society. Their membership was approved at the Federal Executive meetings held on 25 September and 30 October 2008.

Name	Affiliation	State	Membership Category
Jerram Adams	Monash University	Vic	Student
Thomas Bodin	ANU	ACT	Student
Raphael Wolfgang Chaise	Khumsup	Thailand	Associate
Borys Data	Hampson-Russell	WA	Associate
Matt Edmonds	Geosensor Pty Ltd	Qld	Corporate
Brendan Terence Frears	Santos	SA	Associate
Scott Matthew Gagen	Woodside	WA	Active
Matthew Laurence Greenwood	Monash University	Vic	Student
Christopher Bernard Harrison	Curtin University	WA	Student
Lachlan Hennessy	RMIT	Vic	Student
Alison Hickson	Woodside	WA	Associate
Joanne Ellen Mary Jago	University of Qld	Qld	Student
Jie Jian Leong	Curtin University	WA	Student
Dina Makarynska	Curtin University	WA	Student
Reece Murrell	Curtin University	WA	Student
Jessica Ness	Lorotech Geophysics Consulting	Vic	Associate
Mohammad Norozi	Western Geco	WA	Associate
Grace Elizabeth Shephard	University of Sydney	NSW	Student
Paul Andrew Sutherland	ANU/Bruce CIT	ACT/NSW	Student
Benjamin Tredrea	Apache Energy	WA	Active
Tim Wiese	University of Adelaide	SA	Student
Jingping Zhe	ZZ Resistivity Imaging Pty Ltd	SA	Associate

ASEG News

New South Wales

In September, Lew Whitbourn from CSIRO Exploration and Mining gave a talk on a physicist's view of building the AuScope National Virtual Core Library Infrastructure. Lew showed us the core logging machine (semi-automated Hylogging) that will be operating in each of the State/Territory Geological Surveys and explained what the loggers are able to do, what the challenges are and what value adding will be done to our geological knowledge.

In October, Craig O'Neill from Macquarie University spoke to us about the tectonics of rocky worlds. Craig spoke about what has happened tectonically on planets and moons other than Earth. Craig showed some impressive images of one of the moons of Saturn, Enceladus and discussed the tectonics that is thought to go on there at the moment.

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

The SA Branch has had two Technical Meetings in Adelaide since the last update. The Annual Industry Night featured three mineral explorers from the Adelaide Fold Belt region. Hillgrove Resources were represented by Richard Bradey, who presented Hillgrove's plans to give the Kanmantoo Copper Mine a new lease of life. David Inkster kindly stepped in at short notice to present part of Copper Range's exploration strategy, investigating for previously unrecognised potential around decommissioned mine sites in the Adelaide Fold Belt. David Tucker wound up proceedings with an interesting look at the complexities of diamond exploration faced by Flinders Mining.

David Robinson, from Geoscience Australia spoke on *Earthquake Risk Modelling in Australia* at the October technical meeting. This provided an interesting complement to the earthquake monitoring talk given by David Love of PIRSA, earlier in the year.

As has come to be expected, the Melbourne Cup Luncheon was a fun-filled event, and competition for best dressed was as tight as the action on the track. As ever, Beach Petroleum was a fantastic sponsor, even extending the tab to ensure a smooth transition into an evening of celebration (for some). The National Wine Centre provided the ideal backdrop, and has been booked again for next year.

Registration for the ASEG's 20th International Geophysical Conference and Exhibition is now open, and both the State Branch and Conference Organising Committee look forward to welcoming you to Adelaide from 22–25 February 2009.

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

Luke Gardiner

Western Australia

This year the WA PESA–ASEG Golf Tournament was played at Burswood Park Resort on 19 October. We've now gone from one extreme to the other, with this year's players facing strong gusts, occasional showers and a cool 20 degrees, but I am pleased to say that didn't stop a single person from playing and having a great time.

Congratulations to all the players for slugging it out and making the day a much remembered event. The final team placements were:

(1) Halliburton 2 (Halliburton) – (53.34) Steve Irvine, Ashley Corbit and Dave Jonkers
(2) O-For-1 (Ophir Energy) – (53.38) Richard Higgins, Alan Stein, Mike Purves and Jane Bond
(3) Black Dogs (ENI Australia) – (53.5) Aaron Bond, Sean Breadsell, Brad Brown and Jamie Garnett.

Special mentions also go out to the last placed team from CGGVeritas (Andy Cairns, Kurt Chambers, John Thornton & Chris Manual) and winners of the varying hole prizes Ashley Corbit, Michael Kay, Ben Tredrea, Neil van Derplans and Greg Turner. Dan Howes received the 'Worst Shot' award donated and presented by Andy Cairns from CGGVeritas for, wait for it, whilst trying to retrieve a ball from one of the many lakes at Burswood, his playing partner decided to drive up behind him and toot the horn to scare him, but instead of hitting the brake he hit the accelerator and sent Dan a few feet into the water. Being soaked on such a cold day, I'll let you be the judge on that one.

I would like to thank the sponsors who contributed to the event, ensuring everyone had a great time: Principal sponsor – CGGVeritas; Gold sponsor – PGS Australia; Silver sponsors – DownUnder Geosolutions, Geoforce, Task Geoscience, IBM Australia & Halliburton; Bronze sponsors – RPS Energy, UTS Geophysics, Ophir Energy, Dynamic Satellite Surveys, BHP Billiton & SpectrumData; Hole sponsors – Fugro Seismic Imaging, E & P IT Solutions, RPS Energy & Phoenix Data Services.

My final thanks go to all those who contributed throughout the year to help organise the event and to those who assisted on the day.

I look forward to seeing everyone again at next year's tournament to be held at the Vines Resort.

Reece Foster

ASEG 09

www.sapro.com.au/aseg.htm

20TH INTERNATIONAL GEOPHYSICAL CONFERENCE AND EXHIBITION

The Australian Society of Exploration Geophysicists (ASEG) and the Petroleum Exploration Society of Australia (PESA) invite you to attend the 20th International Conference and Exhibition

22–25 February 2009

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Academic achievements and honours:			

Please Answer The Following

What are your career plans?	Are you a member of ASEG?
Are you planning to attend the ASEG Conference in Adelaide?	Are you presenting a paper or poster in Adelaide? If so insert title:
Why should you be considered for this subsidy?	
Other factors to be considered?	

Applicant's signature:	Date:

You can view information regarding the Conference on the website: www.aseg.org.au

Economics and climate

Two main issues dominating the Canberra scene during the last month were the ***economic crisis*** and ***climate change***.

Economic crisis

When Alan Bond was at the height of his powers a journalist asked him how much he was worth. 'You have asked the wrong question,' replied AB. 'You should have asked how much could I borrow?'

And this is the paradox at the heart of the economic crisis. Without being able to borrow you can't develop new projects or even buy your home; but if you borrow too much you could go belly-up.

In Figure 1 I have plotted the US GDP in $trillion and the per capita and total Public Debt. Notice how well the growth in the GDP tracks the growth in public debt or alternatively how the growth in the public debt tracks the growth in GDP.

Per capita debt has increased from $8190 in 1969 to $26 225 in 2008. At the same time the ratio Public Debt/GDP has risen to about 70%.

So, what started off as a decline in US property values led to sub-prime mortgages of dubious value and toxic loans, which very quickly embroiled the whole world. As a result, since the all-time closing highs in October 2007, the All Ordinaries Index on the ASX has fallen 43% (equivalent to ~$400 billion) and the Dow Jones has declined by 41% (at the time of writing).

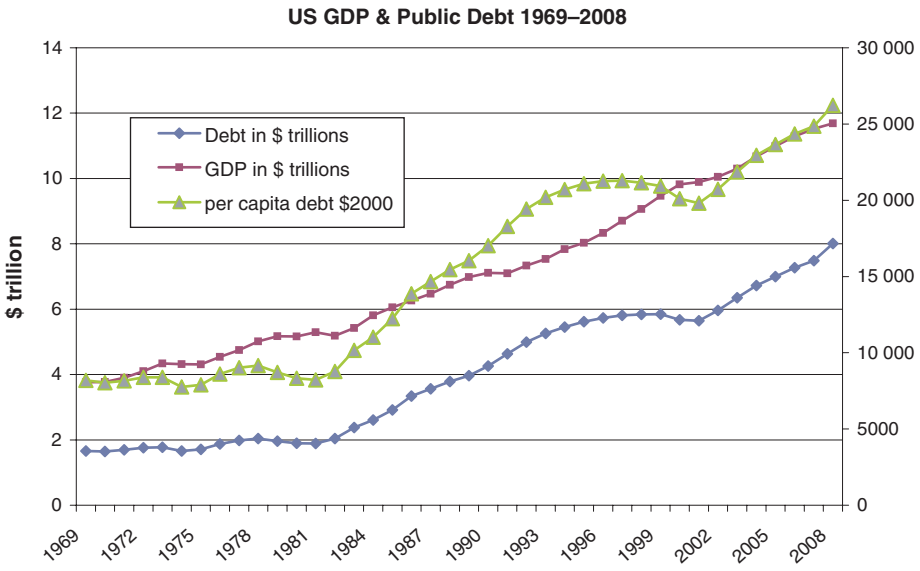

Fig. 1. *US GDP, Public Debt in $trillions (LH vertical axis) and the per capita US Public Debt in dollars (RH vertical axis), from 1969–2008. All values are in current dollars. From: http://www.ers.usda.gov/Data/Macroeconomics/ and http://www.treasurydirect.gov/govt/reports/pd/histdebt/histdebt_histo3.htm.*

I am not convinced that anyone really knows what to do about the current global economic implosion. Worse still, with bad debts around the world at the $trillion level, confidence in the banking and most other sectors is being undermined as the ability to raise money for new projects becomes very difficult. So, in the short term we will experience higher unemployment and governments printing money to try and stimulate growth.

In the long term we will need better regulation of the banking sector. The selling of 'things' that you do not have (short selling) and the whole issue of hedge funds must be better controlled. And the whole issue of growth in the GDP as the economic Holy Grail will have to be abandoned as a goal, because we live on the finite planet with finite resources.

Climate change

Although the global economy has taken centre stage, climate change is still there as a vital long term issue.

In October, Ross Garnaut, released his 680-page final report: *The Garnaut Climate Change Review* and Wayne Swan and Penny Wong released the 271-page Treasury report *Australia's Low Pollution Future: The Economics of Climate Change Mitigation*. I will not attempt to analyse and review these two monster documents, but the Garnaut Report is as much text book on climate change as a policy document recommending government actions.

He starts with the premise that: 'The weight of scientific evidence tells us that Australians are facing risks of damaging climate change due to warming of the climate system'. He also supports the IPCC conclusion that there is a greater than 90% chance that 'the global average net effect of human activities since 1750 has been one of warming'. He then argues that although it would be desirable to bring CO_2-e levels in the atmosphere down to 450 ppm, the practical reality of the global situation is such that 550 ppm CO_2-e is a more realistic immediate target.

Five general themes that are connected to the Review's policy recommendations run through the report. These are:

(1) **Domestic policy must be deeply integrated into global discussions and agreements**. Only a global agreement has any prospect of reducing risks of dangerous climate change to acceptable levels.

(2) **Strong mitigation must be consistent with prosperity**. Global and national mitigation is only going to be successful if reductions in emissions can be made and demonstrated to be consistent with continued economic growth and rising living standards.

(3) **Policies must be practical**. The climate change policy discussion has been bogged in delusion, in Australia and elsewhere. Mitigation targets are defined, and sometimes agreed internationality, without the difficult work being done, to make sure that the separate numbers add up to desired solutions, and to make sure that there are realistic paths to where we commit ourselves to go.

(4) **Policies must be equitable**. While there will be no satisfactory solution to the global warming problem without active participation of developing countries from an early date, equity requires developed countries to accept a major part of the costs in the initial years.

(5) **Good governance is critical**. There will be no success in mitigation, at a national or international level, without

> good governance in relation to climate change policies. Strong vested interests will be at work and fair transparent governance is essential.

These themes are hard to dispute, but the politics of introducing an Emissions Trading Scheme are fraught with difficulty. Humans are noted for focusing on short term goals and individual wellbeing and the next election will loom large in the forthcoming debates.

The ***Treasury report*** focuses on the economic modelling of an Emissions trading scheme.

The main conclusion is that:

> *The Treasury's modelling demonstrates that early global action is less expensive than later action; that a market-based approach allows robust economic growth into the future even as emissions fall; and that many of Australia's industries will maintain or improve their competitiveness under an international agreement to combat climate change.*

However, as the assumptions in the modelling are likely to be wrong, this report is bound to be contentious. For example it assumes that:

> *From 2010 to 2050, Australia's real GNP per capita grows at an average annual rate of 1.1 percent in the policy scenarios, compared to 1.2 percent in the reference scenario. By 2020, real GNP per capita is around 9 percent above current levels, compared to around 11 percent in the reference scenario. By 2050, real GNP per capita is 55–57 percent above current levels, compared to 66 percent in the reference scenario.*

These assumptions are really pie in the sky; but then you have to start somewhere! The bind the economists are in is that they have to put numbers into equations, knowing that these numbers are only best guesses but at the same time if they don't do the modelling they will be open to the criticism that we will be going down an unknown path. Not exactly a win-win situation!

The full reports can be found at: http://www.garnautreview.org.au/CA25734E0016A131/pages/all-reports-resources and http://www.treasury.gov.au/lowpollutionfuture/. They are worth a quick skim.

Eristicus

Research Foundation supports four new projects in 2008

The ASEG's Research Foundation received six proposals for support in early 2008. All were worthwhile and students and supervisors are to be congratulated on the quality of the projects submitted. After careful consideration by the technical committees, the Foundation elected to support four of them, two in the area of petroleum geophysics and two in minerals geophysics. They comprise one Honours project, two PhD projects and one MSc project and commit the Foundation to a total expenditure of $37 000 over the next three years. This is in addition to projects committed in previous years that are on-going.

Specifically the projects for 2008 are as follows:

- *The geophysical response and geological characteristics of iron oxide–copper–gold deposits under cover, Gawler Craton, South Australia* by Luke Nuske (BSc Hons, University of Western Australia)
- *Near surface anisotropy in MT resistivity surveys* by Zara Dennis (PhD, Monash University);
- *Investigation of pressure saturation effects on elastic parameters: an integrated approach to improve time-lapse interpretation* by Boris Grochau (PhD, Curtin University);
- *Analysis of Converted refractions for shear statics and near surface characterisation* by Alan Meulenbroek (MSc, University of Queensland).

We wish all of these students well with their research and look forward to hearing about the results of their work at the completion of their studies.

Support of these projects is typical of the role that the Foundation has played over the years since its inception. While relatively low key, funding is specifically directed towards facilitating the field work and data acquisition necessary to make such projects worthwhile and meaningful.

At the beginning of each year the Research Foundation seeks proposals in exploration geophysics from students and their supervisors in various Australian tertiary institutions. The level of support depends on two main factors, the quality of the projects submitted and the capacity of the Foundation's financial resources.

The Research Foundation is funded from several different sources including corporate membership fees, grants from the ASEG Federal Executive and, importantly, generous donations from the ASEG membership. We are always looking for additional funding so that we can continue this very worthwhile activity of the ASEG.

A successful fundraising drive at the 2007 ASEG conference in Perth helped to underwrite support for the projects in the current year and has encouraged us to pursue a similar activity at the Adelaide conference in 2009. I look forward to catching up with attendees in Adelaide and hope that people will visit the ASEG stand and generously support the Research Foundation through tax deductible donations.

Alternatively donations may be made to the Foundation at the time of membership renewal or at any time through the ASEG executive in Perth.

Phil Harman
Chairman ASEG RF Committee

Australia's R&D investment now more than 2% of GDP

Australia's spending on research and development (R&D) in 2006–07, increased for the eighth consecutive year to $21.0 billion and more than 2% of GDP for the first time, according to a data released by the Australian Bureau of Statistics (ABS) in October 2008.

However, according to FASTS, 'Australian expenditure remains below the OECD average of 2.26% in 2006–07 although the gap has closed considerably from 2002–03 when Australia invested 1.69% of GDP in R&D and when the OECD average was 2.24%'.

The increase represents an increase of $5.03 billion or 31% of the 2004–05 figure (ABS only analyse these numbers every alternate year). The biggest change was in the business sector with a $3.36 billion or 39% increase to $12.0 billion. Universities also increased substantially from $4.3 to 5.4 billion or 25%.

Meanwhile the Commonwealth and States contributions over the 14-year period dropped from 0.26% to 0.19% and 0.15% to 0.10% respectively.

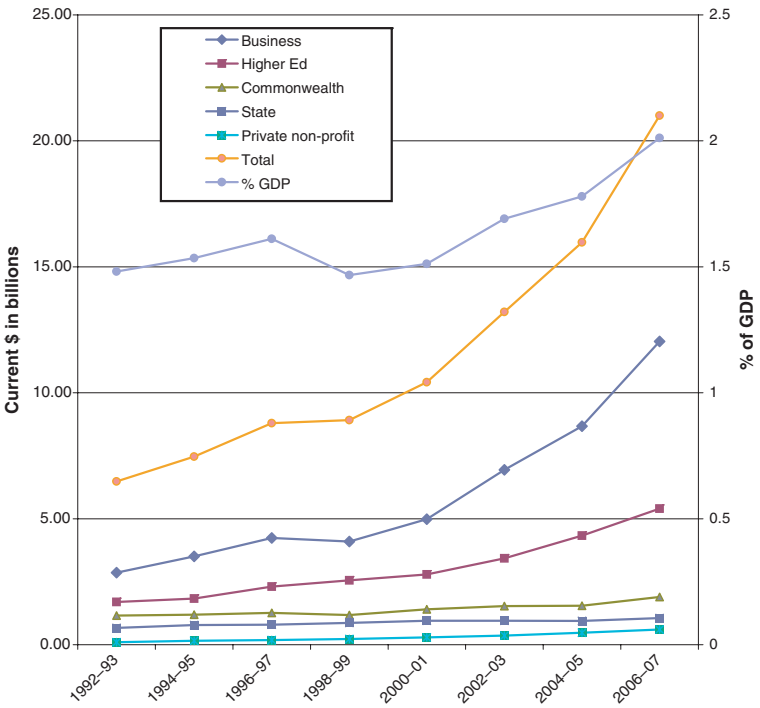

Fig. 1. *Australian R&D trends from 1992–93 through 2006–07. All the plots are in current dollars (not CPI adjusted) in $billion except for the percentage of GDP curve. Notice how the Business and Higher Education trends increase, while the Commonwealth and States trends are very flat.*

Figure 1 shows the results for the five main sectors.

The Mining and Information media and telecommunications industries reported the largest growth in R&D expenditure, increasing by $746 million and $341 million, respectively, although the Manufacturing sector at $4 billion or 31% remains the largest single sector.

The increase in the Mining sector is most impressive. Figure 2 shows the R&D investment made over the last 14 years and it is evident that the increase in the last two years is very impressive. In ABS parlance Mining includes coal mining, oil and gas extraction, metal ore mining, non-metallic mineral mining and quarrying and exploration and other mining support services. Interestingly 81% of the $2.54 billion was invested by businesses employing 200 or more people. In other words the large companies are dominating the R&D resource expenditure.

As to be expected, the curves follow the exploration expenditures for petroleum and minerals shown in the October 2008 *Preview* (pp. 19–20).

In spite of the large increases in business expenditure on R&D (BERD) in the last few years, Australia is still a middle ranking OECD country for this index.

The table below shows how we compare with other OECD countries

In summary, although Australia's businesses have improved their performances in R&D investment in recent years, there is still a long way to go to catch up with the leaders.

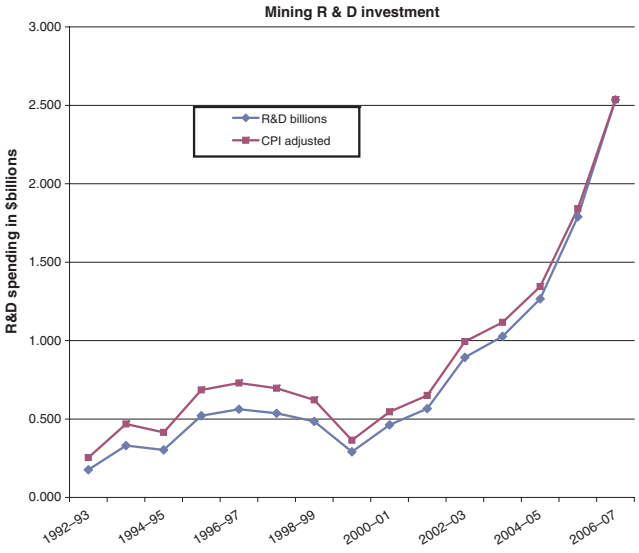

Fig. 2. *Mining sector R&D investment from 1992–93 through 2006–07. The total business investment is now over $2.5 billion per year. The CPI curve is adjusted to A$2006–07. There is a strong correlation between the R&D investment and the resource exploration spending during the same period (see Preview, October 2008, pp. 19–20).*

BERD/GDP ratios in % for selected OECD countries*

	2002–03	2003–04	2004–05	2005–06	2006–07
Sweden	na	2.86	2.67	2.81	2.79
Japan	2.36	2.40	2.38	2.54	2.62
Korea	1.90	2.00	2.18	2.29	2.49
Finland	2.34	2.42	2.42	2.47	2.46
USA	1.86	1.84	1.79	1.83	1.84
Germany	1.72	1.76	1.73	1.72	1.77
Austria	1.42	na	1.51	1.64	1.66
Denmark	1.73	1.78	1.69	1.67	1.62
France	1.41	1.36	1.36	1.33	1.34
Belgium	1.37	1.31	1.29	1.25	1.24
Australia	**0.89**	**0.92**	**0.97**	**1.07**	**1.15**
United Kingdom	1.18	1.13	1.07	1.08	1.10
Canada	1.17	1.16	1.16	1.12	1.06
Netherlands	0.98	1.01	1.03	1.02	0.96
Ireland	0.76	0.79	0.81	0.82	0.89
Norway	0.95	0.98	0.87	0.82	0.82
Spain	0.54	0.57	0.58	0.60	0.67
Italy	0.54	0.52	0.52	0.55	0.54
New Zealand	na	0.48	na	0.49	na
Average for all OECD	**1.51**	**1.51**	**1.49**	**1.53**	**1.56**

**Ranked by 2006–07 BERD/GDP ratio*

$363M for new ARC research projects –$7M less than even 2005 commitment

On 15 October, Senator Kim Carr, the Minister for Innovation, Industry, Science and Research, announced funding of over $363 million for 1103 new research projects awarded under the Australian Research Council's National Competitive Grants Program (NCGP).

This is almost the same in dollar terms to the amount allocated in 2007 and less than the $365 million committed in 2007 by the Howard government and even below the 2005 figure of $370 million. So the total money for this program is certainly not keeping up with inflation and is not consistent with the Minister's statement that: 'The Australian Government is committed to advancing Australian research and innovation nationally and internationally for the benefit of the Australian community'.

For this funding round, applications were submitted to four funding schemes under the NCGP. These schemes are the *Discovery Indigenous Researchers Development, Discovery Projects, Linkage Projects and Linkage International (ARC International Fellowship)* schemes.

Of these four schemes the Discovery Projects captured the bulk of the money with $288 million or ~79% allocated to 845 projects; followed by $72 million for 218 Linkage Projects.

Discovery Projects still hard to get

Discovery Projects aim to:

- support excellent fundamental research by individuals and teams;
- enhance the scale and focus of research in the National Research Priorities;

- expand Australia's knowledge base and research capability; and
- foster the international competitiveness of Australian research.

They are the main vehicles for basic research at tertiary institutions.

Table 1 summarises the funds provided since 2004 for Discovery Projects. There are several worrying trends. The first is that in real terms (CPI adjusted) the total funding provided for Discovery Projects has declined by 15% since 2005. The second is that the success rate of 20.4% remains very low and the third is that the number of Discovery grants awarded is much lower than it was in 2004–05. What this means is that the investment in basic research at Australian universities through the ARC is in decline.

Only seven universities received funding of more than $10 million for Discovery Projects starting in 2009; compared to eleven for projects starting in 2008. Table 2 shows the Top Ten from this round of funding and also how these universities fared last year.

Sydney University has now taken the top spot from Melbourne, and Queensland University has pushed the Australian National University down from third to fourth. As expected the Group of Eight Universities occupies most of the top positions in the table but Wollongong has displaced Adelaide from eighth. Maybe it will be invited to join and turn the G of 8 into the G of 9!

National research priorities

Of the 4152 Discovery Projects considered in this round, 3663 (88.2%) were identified by the applicants as addressing a National Research Priority. Of those 3663 proposals, 760 (20.7%) were approved for funding, representing 89.9% of the total 845 proposals approved for funding. The overall commitment for proposals addressing National Research Priorities is $264 478 524 (91.7% of the total indicative funding). The largest amount ($134 348 588) was for projects in the area of Frontier Technologies for Building and Transforming Australian Industries. Table 3 summarises the proposals and success rates.

Linkage Grants deliver better success rates

The Linkage Projects scheme funds collaborative projects between university

Table 1. Discovery Project funding 2004–09*

	2004	2005	2006	2007	2008	2009
Applications received	3260	3441	3766	4047	4121	4164
Withdrawn	20	28	24	14	9	12
Applications funded	**875**	**1053**	**917**	**822**	**878**	**845**
Success rate (%)	27.0	30.9	24.5	20.4	21.4	20.4
Average total grant size	$271 939	$282 030	$298 350	$334 267	$342 593	$341 344
Total funds requested (million)	$1160.6	$443.7	$496.1	$502.1	$532.0	$2106.3
Total funds approved (million)	**$238.0**	**$295.5**	**$273.6**	**$274.8**	**$300.8**	**$288.4**
Average first year funding	$84 060	$94 340	$103 768	$105 019	$106 469	$116 055

None of the dollar numbers have been adjusted for inflation

Table 2. Top ten universities for Discovery Grants starting in 2009

Administering Organisation	Proposals considered	Proposals approved	Success rate (%)	Funding over project life (approved proposals)	2007 comparison
The University of Sydney	417	124	29.7	$45 847 060	$34 497 035
The University of Melbourne	387	104	26.9	$37 471 712	$38 004 295
The University of Queensland	359	93	25.9	$35 780 231	$28 724 683
The Australian National University	319	86	27.0	$32 017 007	$30 827 792
The University of New South Wales	385	78	20.3	$27 310 860	$26 004 779
Monash University	349	66	18.9	$20 123 948	$27 659 169
The University of Western Australia	174	32	18.4	$11 771 610	$13 089 935
University of Wollongong	126	23	18.3	$8 649 575	$11 337 105
The University of Adelaide	144	25	17.4	$7 630 943	$14 143 514
Macquarie University	143	21	14.7	$6 807 035	$11 048 597

Table 3. Numbers of proposals and success rates for Discovery Projects by National Research Priority

National Research Priority Area	Proposals considered	Proposals approved	Success rate (%)	Indicative funds over project life
None selected	489	85	17.4	$23 957 059
An Environmentally Sustainable Australia	742	122	16.4	$42 634 772
Promoting and Maintaining Good Health	768	164	21.4	$52 778 392
Frontier Technologies for Building and Transforming Australian Industries	1,583	357	22.6	$134 318 588
Safeguarding Australia	570	117	20.5	$34 746 772
Total proposals	4152	845	20.4	$288 435 583
Total priority proposals	3663	760	20.7	$264 478 524
% within priority areas	88.2	89.9		91.7

researchers and Partner Organisations. These projects encourage and develop long-term strategic research alliances between higher education organisations and other organisations, including within industry, in order to apply advanced knowledge to problems and/or to provide opportunities to obtain national economic, social or cultural benefits.

Of the 441 Linkage Projects proposals considered, 218 were approved for funding and represent an ARC commitment of $71.7 million over the life of these projects. The total partner contributions in cash and kind amount to approximately $129 million, so Linkage Projects should be very effective as far as tax payer investment is concerned. Table 4 summarises the results; the success rate of 49.4% is more than twice the success rate for Discovery Projects – so these are the ones to go for!

The average first year funding allocation for approved Round 1 2009 Linkage Projects is $110 082 which represents 71.2% of the average first year request. The average first year funding allocation has increased from $87 217 in Round 2 2006 to $110 082 in Round 1 2009.

The Top Ten Universities are shown in Table 5. For these grants the Group of Eight universities fill the first eight places, with The University of Melbourne at the top of the list.

Table 4. Numbers of proposals and success rates for Linkage Projects Round 1 by Discipline Panel

Panel*	Proposals considered	Proposals approved	Success rate (%)	Requested funds over project life	Approved funds over project life
BSB	85	37	43.5	$42 209 729	$14 422 502
EE	100	55	55.0	$42 221 107	$17 049 460
HCA	32	18	56.3	$11 985 968	$5 310 210
MIC	45	24	53.3	$18 161 993	$8 265 420
PCG	39	16	41.0	$14 150 304	$6 917 420
SBE	140	68	48.6	$50 086 557	$19 739 675
Total	**441**	**218**	**49.4**	**$178 815 658**	**$71 704 687**

**BSB = Biological Sciences and Biotechnology; EE = Engineering and Environmental Sciences; HCA = Humanities and Creative Arts; MIC = Mathematics, Information and Communication Sciences; PCG = Physics, Chemistry and Geoscience; SBE = Social, Behavioural and Economic Sciences*

Table 5. Top Ten list of proposals, success rates, and Partner Organisation contributions for Linkage Projects Round 1 2009

Administering Organisation	Proposals considered	Proposals approved	Success rate (%)	ARC funding over project life	Partner contributions (cash & in-kind)
The University of Melbourne	40	26	65.0	$9 843 100	$18 195 352
The University of Sydney	29	19	65.5	$8 107 042	$10 836 490
The University of Queensland	35	19	54.3	$6 937 000	$12 886 514
The Australian National University	21	16	76.2	$6 505 341	$10 022 248
Monash University	34	19	55.9	$6 098 033	$12 505 940
The University of New South Wales	38	20	52.6	$5 860 524	$10 491 807
The University of Adelaide	15	12	80.0	$4 329 082	$9 659 227
The University of Western Australia	19	8	42.1	$3 140 000	$5 465 834
Griffith University	13	8	61.5	$2 778 000	$4 279 221
Queensland University of Technology	16	8	50.0	$2 610 680	$6 758 518

Geoscience-related Discovery Grants

The successful geoscience-related Discovery Projects are listed below. Out of the 845 grants awarded only 16 could be considered as relating to the geosciences. This is the lowest percentage ever recorded. It probably reflects the tight labour market for new graduates as well as the demise of several Earth Science departments in Australian Universities.

Congratulations to ASEG members Nick Rawlinson and Malcolm Sambridge for their success in being awarded a grant for seismic tomography research.

Seismic tomography using signal and noise: a new window into deep Earth

Researchers: N Rawlinson, H Tkalcic, M Sambridge and RA Glen.

Funding: 2009: $130 000; 2010: $85 000; 2011: $85 000.

Administering Organisation: The Australian National University.

Project Summary: This project will combine traditional imaging techniques based on earthquake records, and state of the art ambient noise tomography, which exploits oceanic and atmospheric disturbances, to construct detailed models of the crust and upper mantle beneath southeast Australia. The national benefits of this research include: a vastly improved understanding of the deep architecture of the Australian Plate, and how it has evolved over time; a paradigm shift in the interpretation of seismic data, which will enhance Australia's reputation in the international scientific community; and important new constraints on the broad scale geology of prospective regions that host world class mineral deposits.

Resistivity of typical rocks at crustal pressure and temperature conditions from combined laboratory and magnetotelluric measurements

Researcher: K Selway.

Funding: 2009: $130 000; 2010: $120 000; 2011: $88 000.

Administering Organisation: The University of Adelaide.

Project Summary: Magnetotelluric surveys are playing an increasing role in Australian geoscience, including academic research, data collected by geological surveys (including a role in Geoscience Australia's $58.9 million Onshore Energy and Security Program), mineral exploration

and geothermal exploration. This project will enable the results of these surveys to be interpreted more accurately and meaningfully by constraining the expected resistivities of crustal rocks at various pressures and temperatures. This research is vital if the investment currently being put into MT surveys is to be capitalised upon.

The early evolution of the Earth system from multiple sulphur isotope records of sediments and seafloor mineral systems

Researchers: ME Barley, SD Golding and M Fiorentini.

Funding: 2009: $70 000; 2010: $70 000; 2011: $70 000.

Administering Organisation:
The University of Western Australia.

Project Summary: This project addresses the early evolution of the Earth system that is one of the most important questions in Earth Sciences. It will use Australia's unique rock record and analytical techniques developed in Australia in collaboration with leading international researchers. The National Research Priority area 'An environmentally sustainable Australia: developing deep Earth resources' will benefit through the development of better exploration models for Archaean submarine metal deposits. Students will obtain a high level understanding of the early Earth system, ore deposits, stable isotope and transition metal geochemistry, which are directly applicable in both pure and applied research and mineral exploration.

Biogeochemical characterisation of Archaean microfossils, biomarkers and organic matter: probing the nature and diversity of early life on Earth

Researchers: B Rasmussen, IR Fletcher and A Bekker.

Funding: 2009: $100 000; 2010: $90 000; 2011: $80 000.

Administering Organisation: Curtin University of Technology.

Project Summary: Recognising biological signatures in ancient rocks poses the single greatest challenge to our understanding of the origin and evolution of life. This Project will use new advanced technology to reveal when and where life first appeared and assess its impact on the environment, atmosphere and climate. Results are essential for understanding the transformation of our planet into a suitable habitat for humankind. The work will place Australia among world leaders in one of the most exciting topics of current scientific research, raising Australia's reputation in this high profile and competitive field. The Project tackles profound questions and seeks to attract, inspire and train future scientists in an ideal location and research environment.

Origin of the New England contorted mountain belt: implications for plate tectonics, magmatism and mineralisation

Researcher: G Rosenbaum.

Funding: 2009: $80 000; 2010: $80 000; 2011: $80 000.

Administering Organisation: The University of Queensland.

Project Summary: The southern New England mountain chain in eastern Australia is characterised by a tight curved geometry. This research will reconstruct the formation of these, hitherto unexplained, mountain curves, unravelling their driving mechanisms and tectonic processes. Results will provide a plate tectonic model for the formation of economic resources, thus facilitating future discoveries of ore deposits in the New England belt, or energy resources in the associated sedimentary basins. The project will foster a pool of highly trained professionals and researchers in the fields of structural geology and tectonics, and will enhance Australia's scientific reputation, maintaining its leading international standing in plate tectonic research.

Modelling fluid flow and mineralisation at crustal interfaces

Researchers: TG Blenkinsop, NH Oliver, DJ Sanderson and JG McLellan.

Funding: 2009: $100 000; 2010: $100 000; 2011: $85 000.

Administering Organisation:
James Cook University.

Project Summary: Several types of mineral resources, including some uranium, iron and base metal ore deposits, may be created by fluid flow through and around interfaces in the Earth's crust. By understanding how, where and why such deposits form, we will assist exploration for future resources of these metals. Insights will also be gained into petroleum resource generation and extraction, the distribution of seismicity and volcanoes in time and space, the problems of underground nuclear waste disposal and sequestration of CO_2, and the potential for geothermal energy, with benefits in resource identification and/or hazard assessment in these areas.

Building the thermodynamic framework for modelling the Earth

Researcher: R Powell.

Funding: 2009: $79 000; 2010: $80 000; 2011: $83 000; 2012: $79 000; 2013: $79 000.

Administering Organisation:
The University of Melbourne.

Project Summary: The Earth holds resources essential for society, such as metals and petroleum, but it also presents risks to society, such as earthquakes and volcanoes. To understand these, we need to understand how the Earth works, and not just at or close to the Earth's surface where these things are found or are felt. This fellowship aims to provide the framework and the tools for modelling the processes involved in how the Earth works. Such tools will, for example, dramatically improve our ability to understand, and therefore to find, ore deposits.

The Cosmogenic 21Ne Exposure Dating Method: calibration for application to volcanic chronology, landscape evolution and paleo-climate change

Researchers: D Phillips and M Honda.

Funding: 2009: $75 000; 2010: $60 000; 2011: $60 000.

Administering Organisation:
The University of Melbourne.

Project Summary: Accurate calibration of the Neon 21 cosmogenic dating method will provide a powerful tool for dating young volcanic rocks, eroded or buried surfaces and glacier/ice retreat. This research will have considerable social, national and economic benefits for volcanic hazard assessment, studies of ore systems buried beneath thick soil cover, landscape evolution, soil erosion and paleo-climate change. In addition, this research will position Australian science at the forefront of cosmogenic dating research and provide essential training for the next generation of Earth Scientists.

Three-dimensional evolution of the Banda Arc: effects of the collision of the Indo-Australian Plate with the active Banda Volcanic Arc

Researcher: MS Miller.

Funding: 2009: $80 000; 2010: $70 000; 2011: $70 000; 2012: $60 000.

Administering Organisation:
The University of Melbourne.

Project Summary: National benefits are associated with the advance of basic science by addressing fundamental tectonic problems on the geodynamics of convergent plate boundaries. In particular, the specific study area would provide a better understanding on the tectonic environment of Australia in the context of the Asia-Pacific region. In the future, outcomes of this research could potentially be used to reconstruct the tectonic history of Australia using the Banda region as a modern analogue.

Thermal structure and evolution of the Australian continent

Researchers: SN McLaren and MA Sandiford.

Funding: 2009: $206 000; 2010: $160 000; 2011: $155 000; 2012: $157 000; 2013: $157 000.

Administering Organisation:
The University of Melbourne.

Project Summary: Australia contains 40% of the world's known uranium resources. Uranium, with thorium and potassium, are heat-producing elements which affect the way temperature varies within the Earth. Outcomes from this project will lead to a better understanding of the potential for geothermal energy in Australia and provide a framework for assessing Australia's uranium resource. Understanding the crustal thermal regime is also fundamental to our knowledge of many earth processes. The project will enhance Australia's international research standing, provide training for an early career researcher and contribute to the development of an environmentally sustainable Australia, a National research priority.

Coupled subduction dynamics and continent deformations: understanding the Asian and Red Sea tectonics

Researchers: FA Capitanio and C Faccenna.

Funding: 2009: $95 000; 2010: $80 000; 2011: $80 000.

Administering Organisation:
Monash University.

Project Summary: Modelling slab pull forces and lithospheric deformation provides a new insight in the dynamics of plate tectonics. Unravelling the self-consistent formation of faults, rifts, shear zones and up to passive margin will further the understanding of our planet. Furthermore the application of these models to specific geological contexts will support the exploration and assessment of inaccessible Earth's resources, such as hydrocarbons pools, located along the deep Australian continent margins, and diamonds and ore deposits, associated with continental shear zones, which potential is still to be fully discovered.

The Origin of Australian Opal Deposits: unlocking the secrets of an Australian icon

Researchers: PF Rey and A Dutkiewicz.

Funding: 2009: $80 000; 2010: $75 000; 2011: $70 000.

Administering Organisation:
The University of Sydney.

Project Summary: Opal is the National Gemstone of Australia. With over 95% of world's precious opal being mined in Australia, this precious mineral is not only one of our major export earners but also the life blood of many central Australian townships. Despite its economic significance and long history of mining little is known about the formation of opal. Consequently, exploration is still based on old-fashioned prospecting methods rather than on genetic exploration models that have made base metal exploration so successful. The aim of this project is to investigate the processes controlling the formation of Australian opal and to use this information to construct an exploration model that will lead to more effective and efficient exploration methods.

A new paradigm for the geochemistry of mineral precipitation and dissolution in aquatic systems: polymer-based numerical modelling

Researchers: AL Rose and JC Rose.

Funding: 2009: $110 000; 2010: $70 000; 2011: $70 000; 2012: $65 000; 2013: $65 000.

Administering Organisation:
Southern Cross University.

Project Summary: The ability to predict the formation and dissolution of solids (minerals and precipitates) in aquatic systems is currently constrained by limitations of the traditional thermodynamic approach. A new approach based on the kinetics of the underlying chemical reactions is expected to overcome these limitations and greatly improve the ability to describe these processes. This new fundamental knowledge will be useful in many diverse fields including aquatic geochemistry, soil chemistry, water engineering and nanotechnology. The new approach will be specifically applied to improve understanding of processes related to the globally significant environmental issues of marine iron fertilisation, ocean acidification and acid sulphate soils.

Application of very short-lived Uranium-series isotopes to constraining Earth system processes

Researchers: SP Turner, A Dosseto and M Reagan.

Funding: 2009: $98 000; 2010: $98 000; 2011: $98 000; 2012: $103 000; 2013: $103 000.

Administering Organisation:
Macquarie University.

Project Summary: This proposal is directly concerned with the continuing aim of building a sustainable Australia through knowledge of deep earth resources. Uranium series isotopes are relevant to the very recent history of the planet (<350 000 years) – time scales which are often over-looked. The more we know about the rates of processes the better we will be able to inform models for volcanic hazard mitigation, soil sustainability and resource exploration and safeguarding. It is to these techniques we must look if we are to understand the immediate past as a clue to the immediate future of our planet.

Partial melting in natural metal-silicate and silicate systems: rheological and geochemical implications for the Earth and other planets

Researcher: TA Rushmer.

Funding: 2009: $70 000; 2010: $55 000; 2011: $60 000.

Administering Organisation:
Macquarie University.

Project Summary: Understanding how fluid and melts migrate through the Earth's crust is vital to predicting how important minerals, metals and oil can be concentrated. Understanding fluid-rock

systems therefore contribute to an environmentally sustainable Australia. Furthering our knowledge of permeable networks through the use of dynamic experiments is an innovative way to study their development within naturally evolving crustal systems as they respond to changing physical and chemical conditions. Thus, this proposal is also directly concerned with the continuing aim of building a sustainable Australia through knowledge of deep Earth resources.

Diamond genesis: cracking the code for deep-Earth processes

Researchers: WL Griffin, SY O'Reilly, NJ Pearson, T Stachel, O Navon and JW Harris.

Funding: 2009: $157 000; 2010: $120 000; 2011: $20 000.

Administering Organisation:
Macquarie University.

Project Summary: The project will provide new insights into the processes by which diamond crystallises in the Earth's mantle, and will deliver information directly relevant to interpreting the diamond prospectivity of the Australian continent. The development of a new diamond mine in Australia, or by Australian companies abroad, would be a major addition to the economy and Australian-based industry. Another outcome of this research will be further development of methodologies for identification of sources of individual diamonds, relevant to the international Kimberley Process for reducing theft and illegal diamond trade. The project will be a highly visible Australian contribution to this global social and economic problem.

Geoscience-related Linkage Grants

The successful geoscience-related Linkage Projects are listed below. Out of the 218 grants awarded only three could be considered as relating to the geosciences. This is the lowest percentage ever recorded. It probably reflects the tight labour market for new graduates as well as the demise of several Earth Science departments in Australian Universities.

Congratulations to ASEG members Peter Wolfgram and Howard Golden for being part of a successful bid to develop new EM sensors and magnetic gradiometers.

Advanced electromagnetic sensors and magnetic gradiometers for natural resources exploration and future space missions

Researchers: DG Blair, L Ju, A Veryaskin, P Wolfgram and H Golden

Funding: 2009: $180 000; 2010: $220 000; 2011: $200 000

Collaborating/Partner Organisations:
Gravitec Instruments (AU) Pty Ltd; Fugro Airborne Surveys Pty Ltd

Administering Organisation:
The University of Western Australia

Project Summary: Australia will benefit from the long-standing world-class mining exploration industry. The new magnetic gradiometer system would greatly enhance their arsenal of geophysical exploration tools, especially for the detection of both magnetically and/or conductive minerals like nickel sulphide. Due to the inherent skin depth issues of conductive cover, a unique condition in Australia, a low frequency electromagnetic survey system is one of the best methods to penetrate the cover and investigate deeper geological structures. The low frequency isolation system developed in this project will improve the survey instrument performance down to 4 Hz, providing capability to explore resources about 50–100% deeper than existing instrumentation allows.

Environmental change in northern Cenozoic Australia: a multidisciplinary approach

Researchers: S Hand, M Archer, SA Hocknull, TH Worthy, JD Woodhead, DI Cendon J Zhao, IT Graham, JD Scanlon, GJ Price and AR Chivas

Funding: 2009: $300 000; 2010: $300 000; 2011: $300 000.

Collaborating/Partner Organisations:
Xstrata Copper North Queensland; Queensland Museum Outback at Isa Mount; Isa City Council.

Administering Organisation:
The University of New South Wales.

Project Summary: The Intergovernmental Panel on Climate Change (IPCC) warned that by 2020 to 2050, Australia will suffer significant biodiversity loss and water shortages. Our research will document and date the evolution of Australia's biota through three cycles of climate change over the last 25 million years to quantify and thereby better anticipate the nature and dimension of threats facing our natural and cultural communities. We will develop innovative techniques to date prehistoric biotic and climatic events and, using a range of tracers, characterize ancient environments and groundwater. This project will assist rural and regional Australia through education and job creation in geotourism and natural resource interpretation, and provide a mechanism to combat generational skill shortage.

A highly resolved chronostratigraphic and palaeoenvironmental framework for Pre-Salt Brazilian core basins

Researcher: JD Stilwell.

Funding: 2009: $220 000; 2010: $150 000; 2011: $100 000.

Collaborating/Partner Organisations:
Shell International Exploration and Production Inc.

Administering Organisation:
Monash University.

Project Summary: Hydrocarbon production and exploration today support viable economies. The engagement of industry with higher learning institutions will advance and enhance the discipline of petroleum geology, with a resultant spectrum from new sources of oil and gas to significantly reducing CO_2 emissions (and decreasing the impact of global warming). National and community benefits are diverse: training and research support for many graduate students and staff in Australia, a better understanding of ancient greenhouse climates, testing and refinement of new techniques (e.g. bioevents, biosteering) in petroleum studies and practical experience of integrating data from frontier exploration wells.

Sub-prime crisis spreads to resource industries

What started as a problem of falling property values in the US has now engulfed the entire planet, including Australia's resource sector. Figure 1 shows how the market capital of the largest Australian resource companies has fared since the boom started in early 2003.

Three points to note:

(1) The All Ordinaries Index started falling about 6 months before the market capital of the resource companies started to decline.
(2) The resources index fell much more rapidly when eventually the value of the shares in that sector started to fall.
(3) The percentage fall of the resource stocks (50.0%) was larger (at the time of writing) than the fall in the All Ords index (43.3%).

Fortunately, 'things' are never as bad as people think they might be, or for that matter as good as they could be imagined!

Anyway, Mitch Hooke, the CEO of the The Minerals Council of Australia, gave an upbeat assessment earlier this month, forecasting that the industry in Australia will need another 58 000 workers by 2020 despite the global economic downturn. As he said: 'Even with growth easing in China, the country will continue to urbanise and industrialise, creating a demand for Australia's natural resources. They're still going to building something like 40 000 to 50 000 skyscrapers in the next 20 years' – and then there's always India.

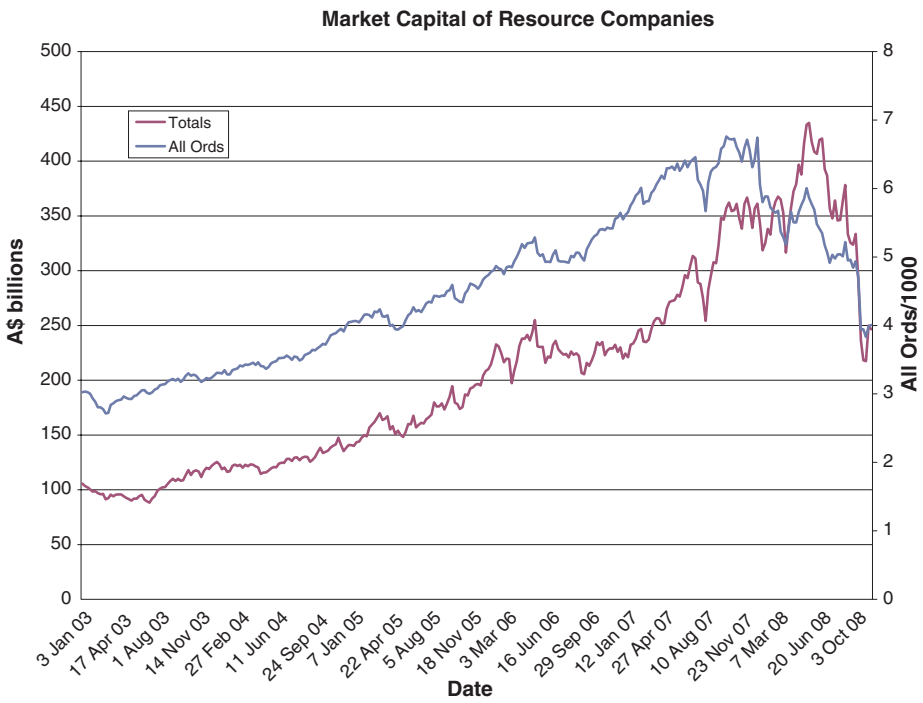

Fig. 1. *The All Ordinaries Index/1000 on the ASX, in blue, from January 2003 through 7 November 2008 and the total market capital in A$ billions of resource companies listed in the top 150 companies during the same period, in red.*

The world today is more volatile than it used to be and also much more interconnected. Some people may claim that we work in a cyclic industry, but that over-simplifies the situation, because we can never go back to where we were.

In the very recent past we have experienced the 1970s nickel boom, the 1973–74 bear market, the 1980s gold boom, the 1987 crash, slowdowns in 1994 and 2002, the late 1990s Asian financial crisis, the recent 'resources boom' and now the 2008 meltdown.

Nevertheless, the world is going to need resources for the foreseeable future, and we are the people who have to find them.

Coal Seam Gas is booming

In spite of the financial crisis, Coal Seam Gas (CSG) companies, particularly those in Queensland, have been booming. In October 2008, Origin Energy entered into an agreement for ConocoPhillips to acquire 50% of Origin subsidiary Origin Energy CSG Limited and establish a CSG to LNG joint venture to be known as Australia Pacific LNG.

The arrangement includes an up-front cash payment of US$5 billion (A$6.9 billion) received on 30 October 2008, an additional fixed contribution of A$1.15 billion to carry Origin's share of costs to Final Investment Decision (FID) expected by the end of 2010, and up to four additional payments of US$500 million to be made at the point that each of the four proposed LNG trains is approved.

It's not surprising that Conoco Phillips was prepared to pay these huge amounts for Origin. In the last six years the market capital of Origin has risen from about $1 billion to $15 billion and the September 2008 Production Report painted a very optimistic picture. There was:

- Record Quarter production of 33.9 PJ, up 13% on previous Quarter.
- Record Quarter sales volumes of 35.2 PJ, up 17% on previous Quarter.
- Record Quarter sales revenues of $198.1 million, up 38% on previous Quarter.

The portfolio of resource projects covers eight fields in six states and almost half the gas production comprises CSG. So it is in good shape to meet rising demand for cleaner energy.

The Queensland Gas Company (QGC) has also done well in recent months. It triumphed at a prestigious awards ceremony for the resources industry, beating majors including BHP Billiton and Rio Tinto, to be judged Australia's Producer of the Year.

It has had an incredible rise in the eight years since it listed, claiming the front-running as Australia's leading coal seam gas producer with its Surat Basin reserves expected to supply about 20% of Queensland's domestic gas market in 2009.

As a result UK's BG Group plc has obtained majority control of QGC, with a relevant interest in 495 million shares at $5.75 per share, representing 52.06% of the issued share capital of the Company.

As at September 2008 QGC's gas reserves (proven {705 PJ} and probable) amounted to 2703 PJ, a rise of almost 12% over the last quarter.

Sunshine Gas was another Australian hydrocarbon exploration company with extensive holdings of prospective Coal Seam Gas (CSG) acreage in Queensland, in varying stages of exploration, appraisal and development. The holdings comprised 12 Authorities to Prospect and three production licenses covering ~30 000 km^2 in the Bowen, Surat and Cooper Basins. It had a market capital of about $1 billion earlier this year but then it was taken over by the Queensland Gas Company in November 2008.

So the big fish swallow the small fish, the giants swallow the big fish, and CSG is still on the menu.

News

Update on geophysical survey progress from the geological surveys of Queensland, Western Australia, Northern Territory and Tasmania and Geoscience Australia (Information current at 10 November 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. There are no new surveys but the Pine Creek AEM survey has now been split into two surveys.

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	June 08	124 – Oct 06, p. 15	Dec 08
South Kimberley **2**	GSWA	GPX	24 Jan 08	163 000	400 m, 60 m N/S	57 920	100% complete @ 3 Oct 08	Nov 08	128 – Jun 07, p. 26	~Dec 08
Cooper Basin East	GSQ	UTS	8 Jan 08	214 352	400 m, 60 m N/S	76 980	100% complete @ 13 Sep 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	91.6% complete @ 2 Nov 08	TBA	130 – Oct 07, p. 29	TBA
Normanton	GSQ	Thomson	25 Apr 08	114 487	400 m, 80 m E/W	74 410	100% complete @ 26 Sep 08	TBA	132 – Feb 08, p. 23	TBA
Cooper Basin North	GSQ	GPX	29 Sep 08	166 373	400 m, 80 m E/W	59 480	23.1% complete @ 2 Nov 08	TBA	134 – Jun 08, p. 22	TBA
Offshore NE Tas	GA	TBA	TBA	29 262	800 m, 90 m E/W	18 750	TBA	TBA	This issue (see Fig. 2)	TBA
South-West Catchment Council – Dumbleyung **3**	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)	100% complete @ 17 Oct 08	TBA	132 – Feb 08, p. 24	TBA
Byro **4**	GSWA	GPX	3 Apr 08	83 855	400 m, 60 m E/W	29 750	100% complete @ 7 Sep 08	25 Sep 08	133 – Apr 08, p. 20	~Oct 08
Balladonia **6**	GSWA	UTS	~24 Nov 08	43 449	400 m, 60 m E/W	14 960	TBA	TBA	134 – Jun 08, p. 22	~May 09
Esperance **6**	GSWA	Thomson Aviation	19 Sep 08	82 674	400 m, 60 m E/W	29 200	36.7% complete @ 26 Oct 08	TBA	134 – Jun 08, p. 22	~May 09

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 **1**	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	100% complete @14 Sep 08	TBA	130 – Oct 07, p. 30	~Dec 08
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 (Kombolgie)	GA	Geotech Airborne	21 Aug 08	9350	1666 & 5000 m for GA; 200 m–1000 m company infill; E/W flight lines; Flying height 30 m	30 710	100% complete @ 16 Oct 08	TBA	133 – Apr 08, p. 21	TBA
Pine Creek (Woolner & Rum Jungle)	GA	Fugro	11 Oct 08	20 820	1666 & 5000 m for GA; 200 m–1000 m company infill; E/W flight lines; Flying height 120 m	44 689	34.9% complete @ 2 Nov 08	TBA	133 – Apr 08, p. 21	TBA

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	April 08	5977	4 regular	95 620	100% complete @ 17 Aug 08	TBA	133 – Apr 08, p. 21	TBA
Central Arunta	NT	Atlas Geophysics	6 May 08	9958 in Area A & a possible 1128 in Area B	4 regular with selected areas for infill at 500 m to 2 km	97 600	100% complete @ 7 Aug 08	Nov 08	133 – Apr 08, p. 21	TBA
Windimurra **5**	GSWA	Atlas Geophysics	30 Jul 08	6066	2.5 km regular	~30 000	100% complete @ 17 Sep 08	Nov 08	135 – Aug 08 p. 16	~Nov 08

TBA: To be advised

Northern Territory

Final data for Central Arunta Gravity Survey has been delivered. Full coverage of the area has been achieved at 4 kilometre spacing (see also GA report above). Point data for these 7224 stations are now available for download at: http://www.nt.gov.au/d/Minerals_Energy/Geoscience/index.cfm?header=2008%20-Central%20Arunta%20Gravity%20Survey. A further 4000 stations at finer spacings were acquired in joint ventures, which set an embargo of 3 months, 23 January 2009, when they also will be released on the same website.

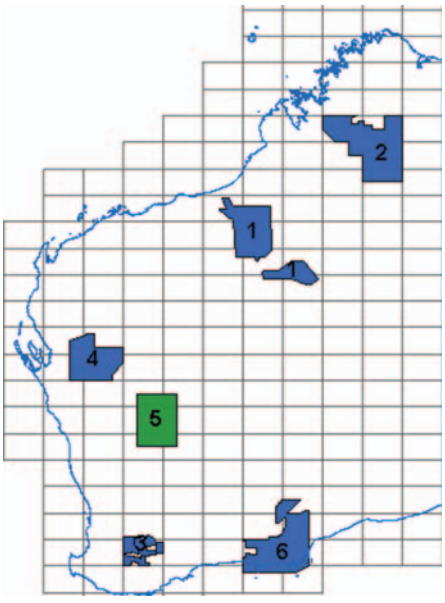

Fig. 1. *Locations of Western Australian geophysical surveys listed in Tables 1–3 above. The numbers on the map identify the surveys in the Tables.*

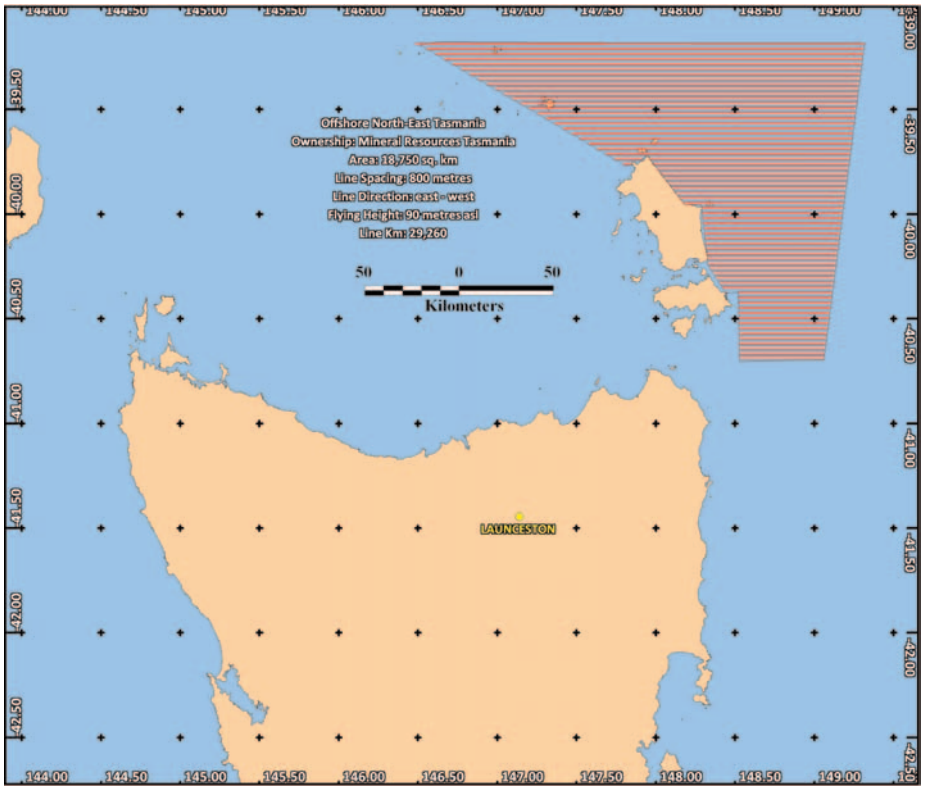

Fig. 2. *Location of North-East Tasmania airborne magnetic survey (see Table 1 for details).*

Western Australia

The locations of the Western Australian Surveys are shown in Figure 1. The numbers on the Figure correspond to the numbers of the surveys in Tables 1–3. Final data releases can be downloaded from the Geoscience Australia Data Delivery System at www.ga.gov.au/gadds. Preliminary and final grids and images can be downloaded from the GSWA website (www.doir.wa.gov.au/GSWA).

To subscribe to the WA data releases see www.doir.wa.gov.au/GSWA—News and Events page and for more information, contact David Howard (david.howard@doir.wa.gov.au).

New seismic survey: Gawler–Officer–Musgrave–Amadeus seismic survey

Geoscience Australia is currently conducting a seismic survey in northern South Australia. The aims of this survey are to provide new insights into the crustal architecture of two Neoproterozoic sedimentary basins in Central Australia and their tectonic relationship to older, Mesoproterozoic basement terranes. The survey may also identify structural elements in the basinal sections, which may host hydrocarbons that were generated before the Alice Springs Orogeny.

The survey consists of one continuous north-south traverse beginning 350 km northwest of Port Augusta. The line crosses from the Gawler Province, over the Officer Basin to the Musgrave Block and then into the Amadeus Basin in the Northern Territory (Figure 3).This traverse is planned to be approximately 634 km and is jointly funded by Geoscience Australia through the Onshore Energy Security Program, AuScope and PIRSA.

Acquisition started at the northern end of the traverse approximately 25 km southeast of Erldunda in the Northern Territory on 1 November. This traverse follows the Adelaide to Alice Springs railway line utilising the railway access road, and it is planned to conclude in late December near Tarcoola in South Australia.

Fig. 3. *Location of the traverses for the Gawler–Officer–Musgrave–Amadeus (GOMA) seismic survey.*

Onshore Energy Security Program seismic survey data releases

Rankins Springs seismic survey

As part of the Onshore Energy Security Program and in conjunction with the New South Wales Department of Primary Industries, Geoscience Australia conducted a deep crustal seismic reflection survey in the Rankins Springs and Yathong Troughs of the Darling Basin in western NSW. Two traverse lines, totalling 234 km, were acquired in March 2008, and the SEG Y data and uninterpreted sections are now available to industry (Figures 4 and 5).

Gawler–Curnamona–Arrowie seismic survey

Geoscience Australia has also undertaken acquisition of seismic reflection in South Australia as part of the Onshore Energy Security Program in June/July 2008. This survey comprised three traverse lines, one across the Gawler province (253 km), one across the Curnamona province (262 km) and one in the Arrowie Basin (60.4 km). Due to high industry interest, the unprocessed basic data for these traverses are now available. Geoscience Australia will start processing these data in 2009 with the aim of releasing to industry mid-2009.

To obtain more information on these surveys or to request data contact Jenny Maher, Project Leader, Seismic Acquisition and Processing, Tel: 61 2 62499896 or email: jenny.maher@ga.gov.au.

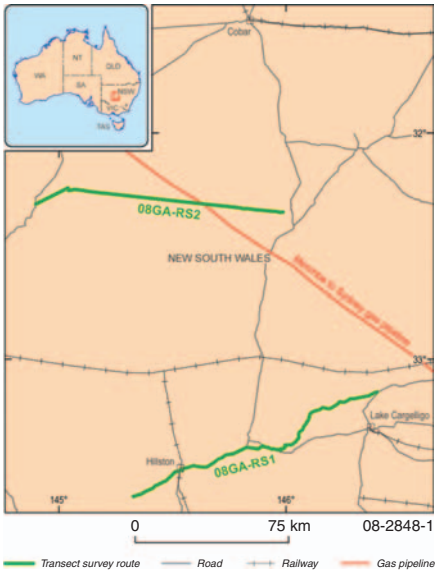

Fig. 4. *Rankins Springs seismic survey traverse line location map.*

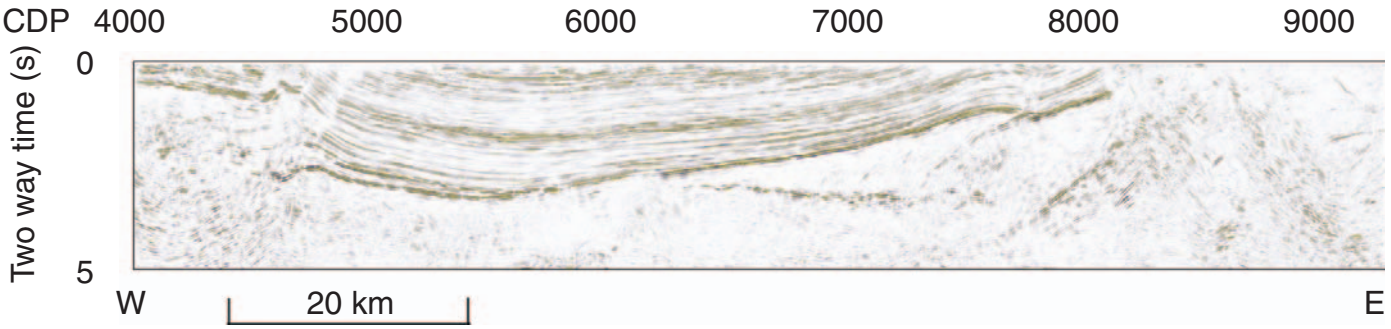

Fig. 5. *Rankins Springs deep crustal seismic survey – 08GA-RS2 processed section, showing the Darling Basin and a possible underlying older basin. The image shows data down to 5 seconds recording time (http://www.ga.gov.au/servlet/BigObjFileManager?bigobjid=GA11274).*

Australia's Identified Mineral Resources 2008 (AIMR) – online release

The latest edition of Australia's Identified Mineral Resources (AIMR 2008) is now available online. The AIMR report is compiled annually by Geoscience Australia to provide governments, the resource industry, the investment sector and the general community with an informed understanding of Australia's known mineral resources and the level of Australia's exploration activity. One of the report's most important objectives is to monitor whether resources are being discovered and developed for production at rates sufficient to maintain Australia's position as a major supplier of mineral commodities. For further information, email: aden.mckay@ga.gov.au or phone +61 (0) 2 6249 9230

Continued on p. 27

Uranium: why, where and how we look for it (part 1)

Why we look for uranium

Historical reasons

Unlike gold, which humans have searched for for thousands of years, large scale exploration for uranium has only been undertaken in the last ~80 years. Uranium oxide (pitchblende) was used by the Romans for colouring glass and ceramic glazes, and since the Middle Ages it has been extracted from the Habsburg silver mines (near Jáchymov in the Czech Republic) for use as a colouring agent in the local glass making industry. However, these historic uses were very small.

All this changed in the 20th century with the discovery of radioactivity, X-rays and fission to produce energy. The experiments leading to the discovery of uranium's ability to fission (break apart) into lighter elements and release the binding energy were conducted in Otto Hahn's laboratory in Berlin in the 1930s. Soon after, Fermi hypothesised that the fission of uranium might release enough neutrons to sustain a fission reaction and in December 1942, his team was able to initiate the first artificial nuclear chain reaction at the University of Chicago. For this reaction to work they used 360 tonnes of graphite, 53 t uranium oxide and 5.5 t of uranium metal. Later researchers found that such a chain reaction could either be controlled to produce usable energy or could be allowed to go out of control to produce an explosion more violent than anything possible using chemical explosives. And the rest they say is history – uranium became in high demand.

Current reasons

Military uses

The major application of uranium in the military sector is in high-density penetrators. This ammunition consists of depleted uranium (DU) alloyed with 1–2% other elements. At high impact speed, the density (19 t/m^3), hardness, and flammability of the projectile enable destruction of heavily armoured targets. Tank armour and the removable armour on combat vehicles are also hardened with DU plates.

During the later stages of World War II and during and to a lesser extent after the Cold War, uranium was used as the fissile explosive material to produce nuclear weapons. There are currently thought to be nine countries armed with nuclear weapons, ranging from Russia and the United States, with approximately 5000 active warheads each, down to North Korea which has less than 10.

Due to its high density, uranium is found in inertial guidance devices and gyroscopic compasses, because it is easily machined and cast.

Civilian uses

Major uses for uranium are as fuel in nuclear power reactors to generate electricity, in the manufacture of radioisotopes for medical applications and in nuclear science research using neutrons from reactors. Nuclear power currently supplies 16% of the world's electricity from 439 nuclear power reactors providing 372 gigawatts (electrical) of generating capacity, which is more than seven times Australia's total production from all sources.

Uranium is a very condensed source of energy. By the time it is completely fissioned, 1 kg of uranium-235 can theoretically produce about 2×10^{13} J, which is roughly equivalent to burning 1500 t of coal, and there are very small greenhouse gas emissions from a nuclear power station. The United States has the largest number of reactors with 104, followed by France with 59, Japan with 55 and Russia with 31. Thirty-two countries were producing electricity from nuclear reactors in 2008. As at mid-2008, a further 35 reactors were under construction in 12 countries, notably in Russia, China, India, South Korea, Japan and Slovakia (http://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm). So there is an increasing demand for uranium.

Where we look for uranium

Global statistics

Uranium is widely distributed throughout the world. According to the World Information Service on Energy (http://www.wise-uranium.org/umaps.html), the global Reasonably Assured Resources (RARs) amounted to 2 598 000 tonnes[1] U at December 2006. If the Inferred Resources are added to this number the total world resource amounts to 4 456 400 tonnes, for a price of US$80/kg. Those countries with RARs of more than 50 000 t are shown in Table 1 below.

Table 1. Global distribution of uranium in December 2006

Country	RARs (t U)
Australia	714 000
Kazakhstan	344 200
Canada	329 200
South Africa	205 900
Russia	172 400
Brazil	157 400
Namibia	145 100
Ukraine	126500
USA	99 000
Jordan	67 800
Uzbekistan	55 200

The annual global production of uranium for 2007 was estimated at 41 279 t (http://www.wise-uranium.org/umaps.html), 1/60th of the current RARs. Table 2 below shows those countries producing more than 1000 t U. Sixty percent of the world's production came from mines in Canada, Australia and Kazakhstan, with Canada producing ~13%.

After a low in world uranium production in 1993–94 of about 31 500 t U, the annual production rate has increased gradually during the past 15 years to 41 300 t for 2007. The price in $US/kg remained relatively constant at about $US20/kg U until 2004 when it increased dramatically and reached a record $US115/kg U in June 2007. It has since settled at about $US40/kg U. Figure 1 shows the price variations during the last 18 years and also the

[1] 1 tonne U = 1.178 U_3O_8.

Table 2. World production of uranium in 2007

Country	Production (t U)
Canada	9476
Australia	8611
Kazakhstan	6637
Russia	3413
Niger	3153
Namibia	2879
Uzbekistan	2320
USA	1654

production figures for the world and the three largest producers. As can be seen from the graph, if current trends continue, Australia will overtake Canada as the leading uranium producer, with Kazakhstan catching up rapidly.

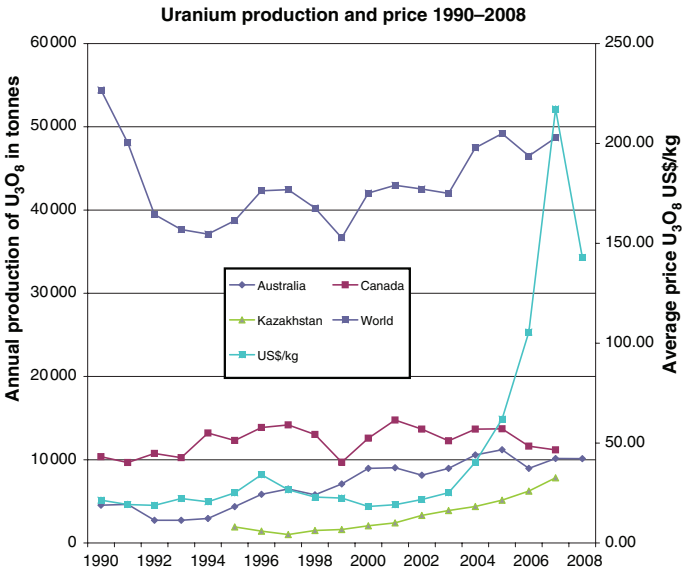

Fig. 1. *Uranium production and price, in current $US from 1990–2008. The data were mainly obtained from The Ux Consulting Company, LLC (http://www.uxc.com), which also provided detailed weekly price information for that period. Note that all figures are for U_3O_8.*

Australian resources[2]

Australia's economic demonstrated resources at December 2007 were estimated to be 983 000 t U, which represented an increase of 38% over the estimates (Table 1) for December 2006 (714 000 t U). This was due mainly to a large increase in resource estimates for the Olympic Dam deposit (SA), the Ranger 3 deposit (NT) and the first estimates of resources for the Four Mile deposit (SA). Australia now has approximately 34% of world resources in this category. Seventy-nine percent of Australia's total uranium resources are in South Australia, with 13% in the Northern Territory and remainder in Western Australia, Queensland and New South Wales. Figure 2 shows the location of Australia's uranium resources and Table 3 shows how South Australia, with Olympic Dam, dominates the resource picture.

Continued from p. 25

New gravity survey data added to the Australian National Gravity Database

Geoscience Australia recently added 8347 more open-file company gravity stations from Western Australia and 7667 more open-file company gravity stations from the Northern Territory to the Australian National Gravity Database. Data from the surveys are situated on the 1:1 million sheets areas for Alice Springs, Darwin, Hall Creek, Lake Mackay, Newcastle Waters, Roper River in the Northern Territory and Esperance, Hamersley Range, Kalagoorlie, Meekatharra, Perth and Wiluna in Western Australia. These data have been supplied to Geoscience Australia by the respective State or Territory Geological Survey. All data in the National Gravity Database can be obtained free-of-charge using the Geophysical Archive Data Delivery Systems (GADDS). For further information, email: mario.bacchin@ga.gov.au or phone +61 (0) 2 6249 9308.

[2]Most of the information in this section was derived from Geoscience Australia http://www.australianminesatlas.gov.au/aimr/commodity/uranium.jsp, and from discussions with Aden McKay.

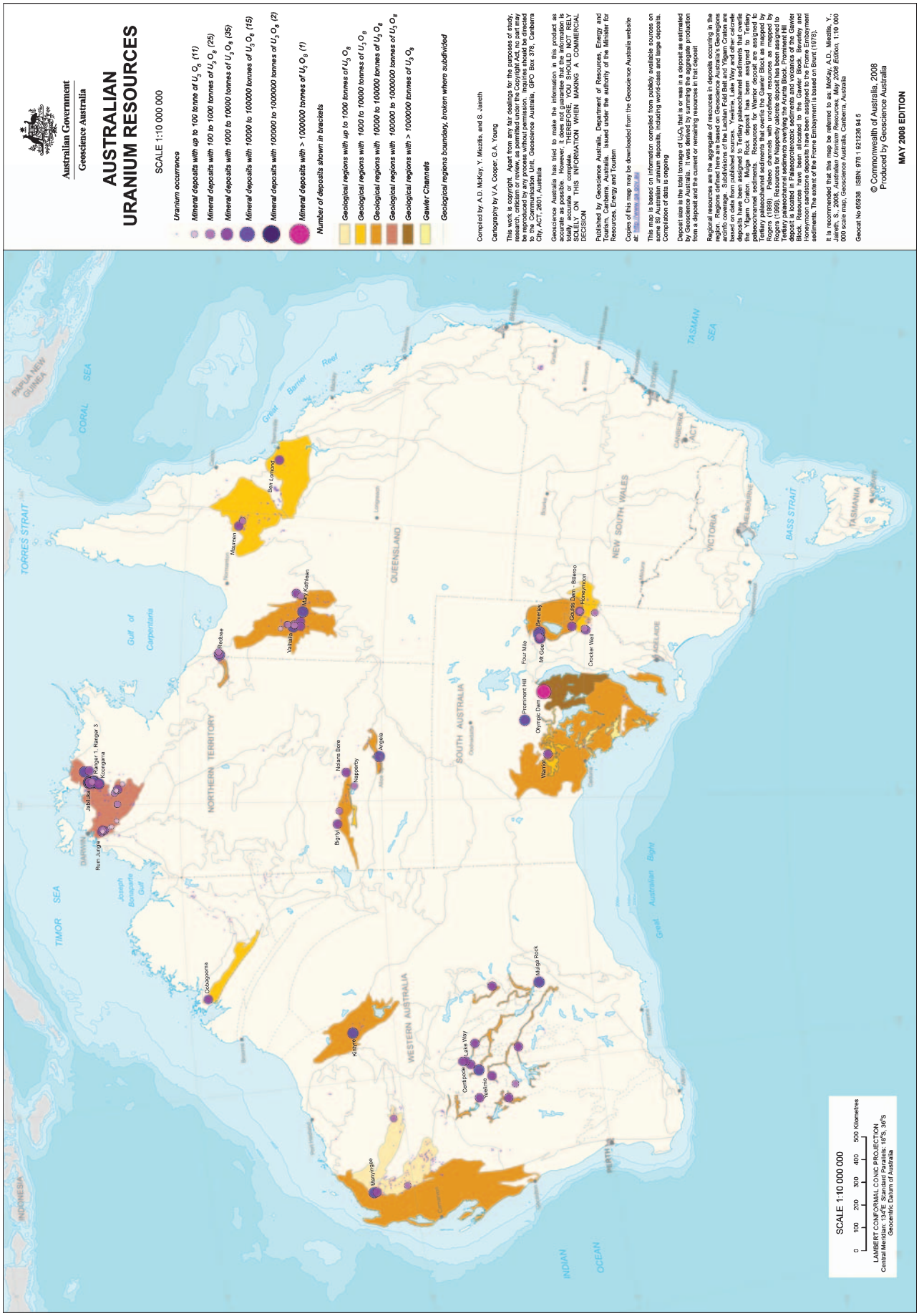

Fig. 2. *Australia's uranium resources from Geoscience Australia's website http://www.ga.gov.au/image_cache/GA11404.pdf. The map is based on information compiled from publicly available sources on some 89 uranium deposits. Deposit size is the total tonnage of U3O8 that is or was in a deposit as estimated by Geoscience Australia. It was derived by summing the aggregate production from a deposit and the current or remaining resources there. The reference is McKay, AD, Miezitis, Y, and Jaireth, S, 2008, Australian Uranium Resources, May 2008 Edition, Geoscience Australia, Canberra Australia.*

Table 3. Uranium resources in States and NT at December 2007

State/Territory	RARs recoverable at <US$80/kg t U	Percentage of Australia's total resources
South Australia	759 456	79
Northern Territory	139 923	13
Western Australia	59 595	5
Queensland	21 269	3
New South Wales	2968	<0.5
Total	**983 211**	**100**

Approximately 95% of Australia's total uranium resources are within six deposits: Olympic Dam, which is the world's largest uranium deposit, Ranger, Jabiluka, Koongarra in the Alligator Rivers region (NT), and Kintyre and Yeelirrie (WA). Production for 2007 from Australia's three uranium mines was 5412 t U_3O_8 from Ranger, 3985 t from Olympic Dam and 748 t from the *in situ* leach operations at Beverley in South Australia, for a total Australian production of 10 145 t U_3O_8 (8602 t U). This is 13.3% higher than for 2006.

Australian exploration

Uranium exploration expenditure in Australia has increased progressively since 2003 mainly because of the significant increases in spot market uranium prices in recent years (Figure 3). Unlike the gold results (see *Preview* 135, June 2008), which show very little correlation between price and exploration investment, the uranium situation indicates a very close alignment. In 2007, uranium exploration expenditure increased to a record level of $181.4 million, which is more than double the 2006 expenditure ($80.7 million). The majority of expenditure was in SA (55%), followed by the NT (23%), Queensland and WA (each 11%).

During 2007 significant uranium discoveries and major extensions to existing deposits were announced at Olympic Dam (SA), Ranger 3 (NT), and Four Mile deposits (SA).

Main exploration areas (in terms of expenditure) during 2007 were:

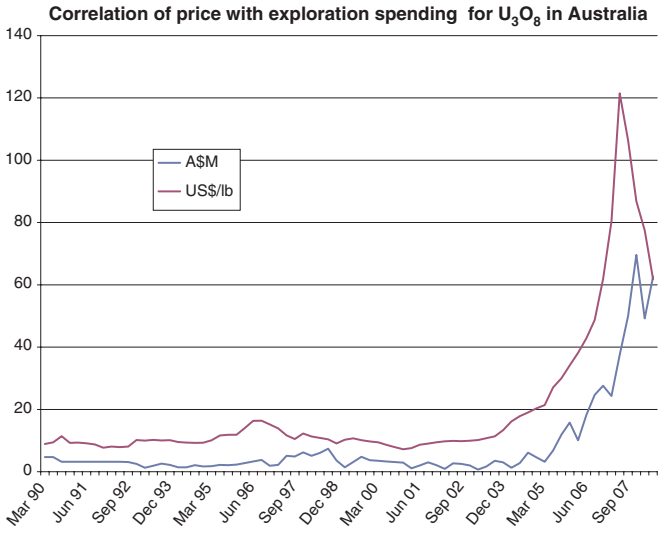

Fig. 3. *The red curve indicates the average quarterly price of U_3O_8 in current $US/lb and the blue curve shows the quarterly expenditure for uranium exploration in A$ million.*

1. South Australia – the Gawler Craton-Stuart Shelf region, Palaeogene sediments of the Frome Embayment and palaeochannels overlying the Gawler Craton;
2. Northern Territory – the Alligator Rivers region and Western Arnhem Land, Rum Jungle area and Ngalia Basin; and
3. Queensland – the Mount Isa Province.

The future for uranium looks sound and in the April 2009 Preview we will conclude this feature with the ***How we look for uranium*** segment.

Key websites

Most of the information for this article was derived from the following websites: http://en.wikipedia.org/wiki/uranium; http://www.australianminesatlas.gov.au/aimr/commodity/uranium.jsp; http://www.ga.gov.au/image_cache/GA11404.pdf; http://www.uxc.com http://www.wise-uranium.org/umaps.html; and http://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm.

Marine controlled source electromagnetic methods for hydrocarbon exploration

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Summary

Application of marine controlled source electromagnetic methods (MCSEM) to deep water hydrocarbon exploration is one of the most exciting recent developments in exploration geophysics. The method offers exploration managers an entirely new data set (i.e. electrical resistivity distribution) that can act as a key hydrocarbon indicator. Under suitable conditions MCSEM can provide quantitative estimates of the hydrocarbon resource. Although the method is increasingly accepted as an effective exploration tool, both misconceptions and a degree of apprehension remain. We hope we can identify and to some extent clarify the central issues in application of MCSEM for hydrocarbon exploration in this overview of a rapidly evolving technology.

Introduction

Low frequency controlled source electromagnetic methods applied in the oceans and seas are not particularly different from the controlled source electromagnetic methods (CSEM) routinely applied for land based exploration (e.g. minerals, groundwater, coal). From our point of view the term 'marine controlled source electromagnetic methods' (MCSEM) seems to be the simplest and most appropriate to describe the method. Other names that this geophysical exploration technology go by include: deep ocean controlled source electromagnetic method, controlled source electromagnetic imaging (CSEMI) and sea bed logging (SBL).

There has been a phenomenal rate of development in MCSEM over the last 5 to 10 years. The reason for this is partly due to advances in technology but as usual the major driver is economics. Like the stock market, oil prices have recently been on a roller coaster ride with the records prices set in July 2008 (e.g. $US147/barrel) being followed by a recent slide back towards $US60/barrel. Despite these fluctuations, the fundamentals of increasing global demand and decreasing volumes of low development cost oil/gas are unlikely to change. Consequently, hydrocarbon exploration is moving into the deeper oceans (e.g. >1000 m ocean depth). This has played into the hands of the MCSEM technologies as current techniques are best suited to deep water settings (e.g. >500 m water depth).

If MCSEM could be divided into a set of key topics these might include:

- Influential organisations
- Basic mathematics of EM
- How MCSEM works and the condition for success
- The water depth problem
- Propagation of low frequency EM fields
- Basic physics and visualisation
- Transmitter and receivers
- The EM properties of rocks
- Forward, inverse modelling and interpretation
- The future

We briefly examine each topic below.

Brett Harris

Andrew Pethick

Influential organisations

Three organisations immediately come to mind when considering the evolution of modern MCSEM. They include: Scripps Institution of Oceanography (Department of Geosciences), Offshore Hydrocarbon Mapping (OHM), and ElectroMagnetic GeoServices (EMGS). A web search of any of these will yield large volumes of information relevant to MCSEM. Of course other MCSEM systems and research institutions exist and are actively engaged in research and development. A few examples include: The MTEM system at PGS, the CEMI group at the University of Utah, and the OCEANMAG project at CSIRO (www.csiro.au/science/OCEANMAG.html). For a review of current thinking on MCSEM see the annual Electromagnetics Research Symposium's website (http://piers.mit.edu/piersproceedings). Also see Eidesmo et al. (2002, 2002a), Kong et al. (2002) and Johansen et al. (2005) for some early papers on the application of MCSEM to hydrocarbon exploration.

Basic mathematics of EM

Like most geophysical methods, MCSEM owns an extensive list of vector fields, parameters, terminologies and acronyms. While not wanting to diverge into the world of EM mathematics which is loaded with numerical tricks, dead ends and complex mathematical book keeping, we should at least re-state the basics. They are:

1. The electric field is directly related to the force that exists on any charge in that field. This is measured as the voltage between two electrodes.
2. The magnetic field is related to the force that exists on any current carrying circuit in that field. This is measured as a voltage induced in a coil (i.e. the time derivative of the magnetic field) or more directly with a magnetometer (i.e. the magnetic field).

Maxwell's equations are the empirically determined rules with which electric and magnetic fields comply. For most practical situations they are a robust mathematical representation of physics of EM. For those who enjoy finding exceptions to the rules (i.e. Maxwell's equations) see the collection of essays by Lakhtakia (1993) and for numerical solutions to Maxwell's equations see Sadiku (1992).

The most fundamental statement that comes out of Maxwell's equations is that charges in our universe are in constant communication. That is, the movement of any charge causes a new distribution of forces on all other charges. Maxwell's equations are a statement of endless dance (changing distribution of force) between all charges.

Any number of text books will cover the basics; however, the SEG publication *Electromagnetic methods in applied geophysics* (Chave et al. 1991) is a good place to start for geophysicists.

How MCSEM works and the conditions for success

Current MCSEM surveys consist of a moving high power transmitter and stationary magnetic and electric field receivers. The MCSEM transmitter is dragged as close to the ocean floor as is practical (e.g. ~30 m from the ocean floor). The transmitter sends a large amplitude changing current into a long electrical bipole source (e.g. 1000 A at 1 Hz into a 300 m long wire cable). The changing current generates an electromagnetic field (i.e. 4D coupled vector electric and magnetic fields) that 'engulfs' cubic kilometres of the earth and ocean. The magnetic and electric fields circulate around each other with a strict geometry. The mathematical expression of the interactions between electric and magnetic fields is captured in Maxwell's equations. Figure 1 below provides a schematic representation of the MCSEM survey with streamlines representing the circulating electric field. Sediments containing oil or gas are typical electrical resistivity compared to the ocean and brine saturated host sediments. The electric and magnetic field patterns and amplitudes become altered or distorted if an electrically resistive hydrocarbon reservoir is present. There are four conditions under which the MCSEM is most likely to be successful. These include:

1. The hydrocarbon reservoir is not too deeply buried compared to its size
2. Sufficient volumes of electrically resistive hydrocarbons exist.
3. The host sediments are sufficiently uniform
4. The target (i.e. hydrocarbon reservoir) is not too deeply buried relative to the water depth.

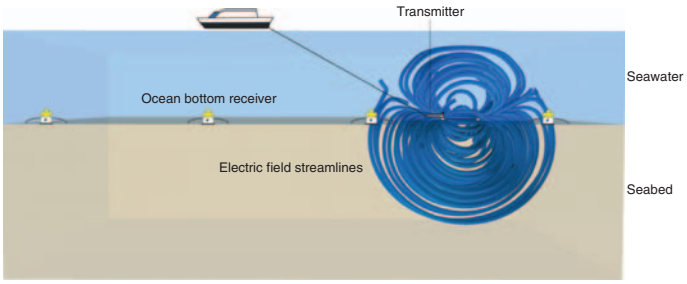

Fig. 1. *A broadside schematic of a typical MCSEM survey with a 2D slice of the electric field from the transmitter. The electric dipole transmitter transmits electric and magnetic fields while the seafloor receivers record subtle variations in the electric and magnetic fields.*

The first two conditions are quite obvious (i.e. the target needs to be sufficiently electromagnetically 'big' compared to its depth). The third conditions says that if the influence of other electrically resistive features (e.g. shallow gas hydrates) is large compared to that of the hydrocarbon reservoir then the reservoir will be difficult to resolve. The fourth condition requires slightly more explanation (see below). A first order quantitative version of the conditions for success (i.e. reasonable target and ocean depths) can be obtained by application the basic EM skin depth equation. That is, skin depth is equal to about 500 multiplied by the inverse of the square root of frequency multiplied by conductivity. However, given sufficient knowledge of both the geo-electrical setting and capabilities of available MCSEM acquisition system, each of the four conditions can quantitatively established by competing suites of numerical experiments with any robust forward modelling code (e.g. Tompkins et al. 2004; Peace 2005; Phillips 2007; Pethick 2008).

The water depth problem

The problem of insufficient water depth compared to target depth is sometimes explained in a convoluted way with unfortunate references to refracted and reflected waves. MCSEM is diffusive, so this type of terminology (as used for typical seismic methods) is inappropriate.

Electric and magnetic fields spread out from the source with a strict geometry. In general the direction of propagation of energy is perpendicular to the direction of both the electric and magnetic fields.

The water depth problem is most simply explained by considering the electrical resistivity distribution. The target reservoir might be as much as 100 Ωm and exist within a host rock of 1.5 Ωm. However, the resistivity of air is more than 1 000 000 000 000 Ωm while that for the oceans is closer to 0.3 Ωm. Clearly if we are looking for an electrically resistive hydrocarbon target, it is a significant advantage to find the target response before the spreading EM fields are strongly influenced by the air ocean interface (i.e. an extreme and more complicated boundary condition).

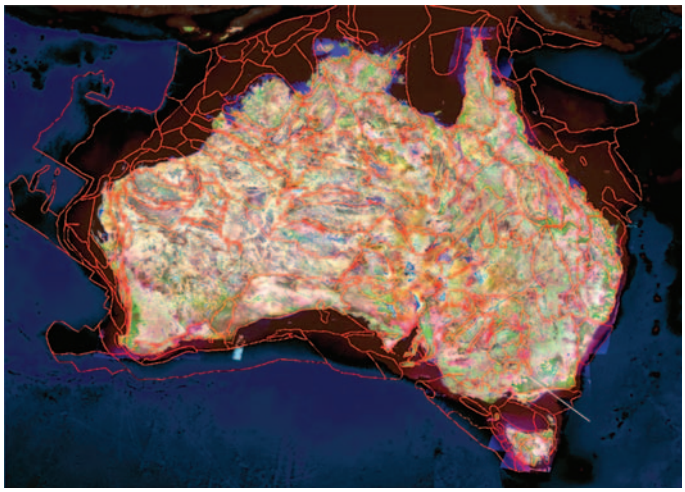

Fig. 2. *Water depth in relation to Australia's offshore basins. Blue areas are greater than 4000 m water depth, lighter brown areas are from 0 to 1000 m and the darker brown to tan areas range from 1000 to 4000 m water depth. Water depth and a host of other images and data can be obtained from the Geoscience Australia website (i.e. http://www.ga.gov.au/map/).*

Many of Australia's offshore basins are ideal for the application of MCSEM. The image below gives some idea of the relationship between offshore basins and water depth around Australia's coast line. That is, many highly prospective basins extend for more than 50 km offshore.

Propagation of low frequency EM fields

The last comment we make about the propagation of EM fields is that for MCSEM one cannot talk sensibly about the propagation of a 'wave front'. With the generation of any time-varying electric and magnetic fields at the transmitter, information travels out at the speed of light. However, it is only when and where the amplitude is sufficiently large to be measured that is of significance. It is the total distribution of energy carried by the measurable coupled vector electric and magnetic fields that provides information about the electrical resistivity distribution. That is, EM is a 'global' phenomenon, so it is the total distribution of fields in time and space that needs to be analysed. The above already hints at the importance and advantages of distributing receivers to cover as much of the 3D volume as is practical.

Basic physics and visualisation

Visualisation can provide a catalyst to understanding MCSEM. We endeavour to give some impression of sheer scale and geometry of the coupled vector electric and magnetic fields generated by the MCSEM transmitter. A software package has been developed by Andrew Pethick to facilitate visualisation and survey planning for MCSEM. It takes MCSEM data (i.e. field or forward modelled data), processes it, then exports it in a number of formats to be used in a range of third party software packages. Input MCSEM data can be quickly visualised as electric and/or magnetic field amplitude shells for any component (i.e. x, y or z), time-varying electric and magnetic field vectors (representation of the fields in time and space), stream lines or polarisation ellipses. Examples of typical visualisations are provided below as Figures 3–7. These show various representations of vector direction and amplitude for the electric and or magnetic fields within a volume of dimensions 20 km by 20 km by 5 km deep.

The electric field is generated by a centrally located single electrical bipole source on the ocean floor, within a three layer earth (i.e. air, ocean, sediment). The shells show four constant vector amplitude isosurfaces, which can potentially be used to identify the spatial extent to which the electrical field detectors can usefully be located (given minimum detectable signal).

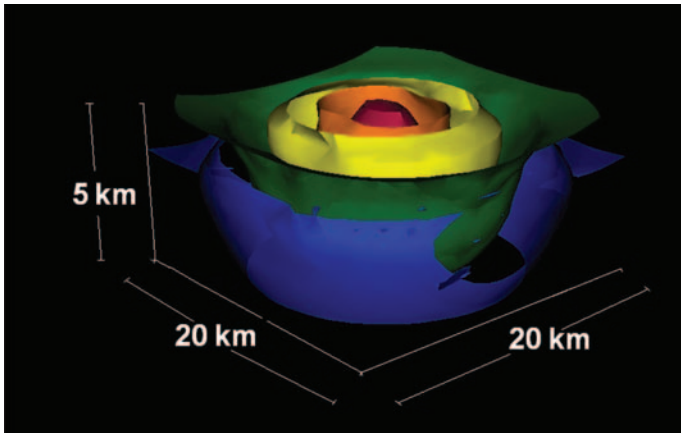

Fig. 3. *Total electric field isosurfaces. Each amplitude shell (i.e. blue, green, yellow, orange and red shells) represents one order of magnitude (blue low to red high).*

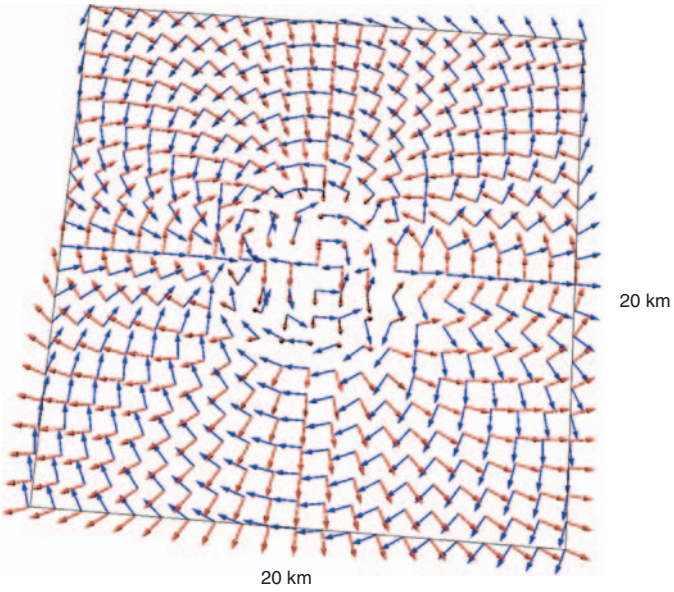

Fig. 4. *A single time interval of the electric (blue) and magnetic field (red) glyphs. Glyphs show direction of the electric and magnetic field for a single time step. Glyphs can be animated to show the changes in direction and amplitude in real time stereo (i.e. a 3D movie).*

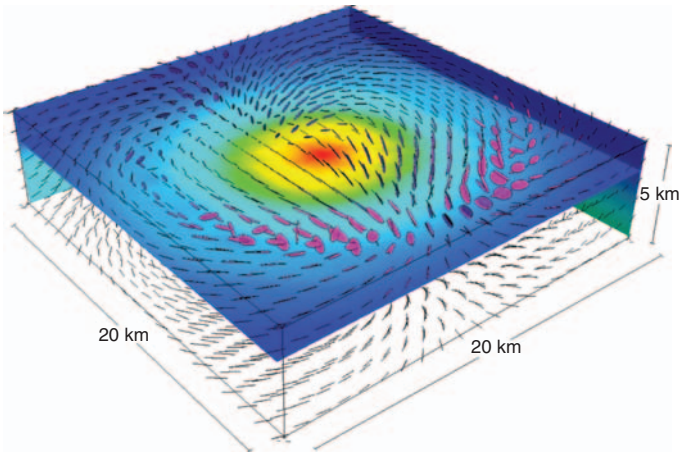

Fig. 5. *Electric field polarisation ellipses and 3D scalar planes. Polarisation ellipses encapsulates the complete 4D animation of the glyphs into a 3D polygon. 3D scalar planes are the 3D equivalent of a 2D grid. Scalar planes can be positioned anywhere in the volume and at any angle to show a single scalar.*

Several points should be clear from the visualisations above.

1. Measurable electric and magnetic fields generated at low frequencies extend through many cubic kilometres of earth and ocean.
2. There is a large overlap in the 'sweep' of the electric and magnetic fields between successive transmitter positions.
3. The fields have a clear geometry, such that some receiver orientations will be optimally coupled and some will be null coupled to the fields generated by the transmitter.
4. The curvature of the fields is high close to the transmitter.

Each of the above has implications for optimal use of the transmitter and receivers to resolve both the background geo-

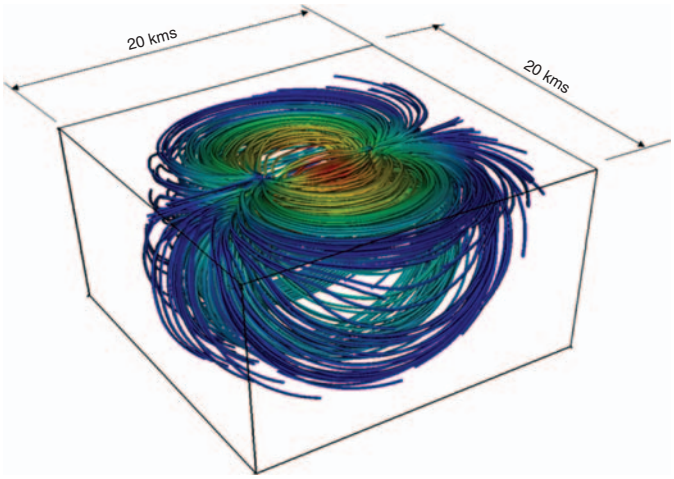

Fig. 6. *Stream lines. Electric fields circulating about a horizontal dipole source. Transmitter frequency is 0.05 Hz. Colours reflect amplitude of the electric field. The red zone around the transmitter is several orders of magnitude larger than blue. The image illustrates just how large the fields are.*

electrical response (i.e. so it can be identified and possibly removed) and the target hydrocarbons response.

Transmitter and receivers

The major contractors have publically accessible images and information concerning the ships, transmitters and receivers (see www.emgs.com/technology/ or www.westerngeco.com/content/services/electromagnetic/index.asp or www.ohmsurveys.com/).

The nature of the transmitted waveform is commonly discussed in MCSEM. Ultimately it doesn't matter what the waveform looks like as long as there is sufficient energy in the frequency range required to resolve the target. The challenges here are very practical. That is, how to build a transmitter that can put sufficient energy in the lower frequencies (e.g. 0.05 to 1 Hz) while still generating information up to more than 10 Hz.

The MCSEM electric field receivers measure voltage between electrodes typically separated by between 5 and 10 m. One practical compromise that must be made is between the degree of 'wobble' (relative movement of electrodes) and receiver moment. The longer the separation between electrodes the greater noise generated by wobble. However a longer receiver dipole will generate a bigger voltage. To counter the above problem contractors often use multiple separations for each receiver dipole orientation.

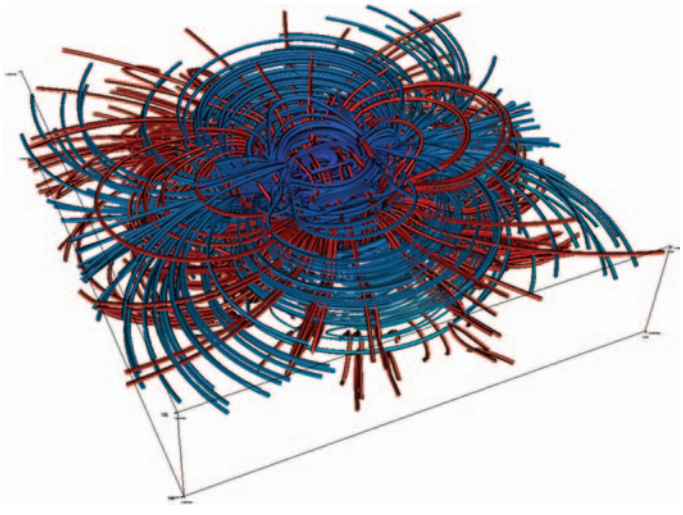

Fig. 7. *Electric (blue) and magnetic field (red) streamlines. The magnetic field is circulating at right angles to the electric field about a central electric field dipole transmitter.*

The EM properties of rocks

The three medium dependent parameters for EM are: (a) electrical permittivity (b) magnetic permeability and (c) electrical conductivity. At the very low frequencies that MCSEM systems operate, the impact of electrical permittivity is negligible. Similarly, variations in the magnetic rock properties are highly likely to provide negligible contribution in a sedimentary setting. So we are left with the electrical resistivity as the dominant medium dependent parameter influencing the way that EM fields 'spread' outside the source domain.

For MCSEM applications, electrical properties of rock are typically considered to be linear with frequency. To a reasonable degree sandstones conform to Archie's law or at least modified forms of Archie's Law, which include hydrocarbon saturation. The electrical resistivities of shales tend to require more complex mathematic expressions. For example, a shale's cation exchange capacity increases its capacity to conduct charge.

Experiments have demonstrated that electrical resistivity of rocks is not perfectly linear with frequency. The EM properties of rock under a broad range of frequencies have been investigated at CSIRO's ARRC facility (Ben Clennel, CSIRO – Dielectrics project, pers. comm.). However, under most circumstances it is highly unlikely that weak frequency dependence in conductivity will have practical significance for low frequency MCSEM. There is still considerable research to be completed in understanding electrical resistivity, both at low and high frequencies, as ultimately it is necessary to correlate MCSEM-derived electrical resistivities with those obtained from wire line logging that spans a wide range frequencies and techniques (e.g. later logs, induction logs).

It should be remembered that electrical conductivity (reciprocal of resistivity) is a tensor quantity. For every direction that current can be driven through a rock a potential difference (i.e. electric field) can be measured in three orthogonal directions and hence nine values of conductivity can be recovered (i.e. a 3 by 3 tensor). Technically we do not need to recover all nine values to fully characterise the conductivity tensor (Bona, pers. comm.). Only six measurements would be required. Further for most common forms of anisotropy three measurements may be sufficient. Electrical anisotropy is a subject that needs further investigation.

Forward, inverse modelling and interpretation

One of the current weaknesses of MSCEM is the lack of any integrated survey planning, processing and interpretation software. There are many packages (i.e. integral equation or finite element codes) that can compute the CSEM responses; however, we are not aware of any that are in final production form that can be purchased off the shelf by oil exploration companies. The common strategies for most companies is to put planning, processing, and interpretation in the hands of the service companies or to join any of a number of CSEM consortiums driven by university or research organisations.

Development in interpretation should move forward on two fronts. The first is development of the tools required to effectively integrate the modelling (forward and inverse) with all other data sets (e.g. seismic reflection, resistivity logs, geological models). The second is access to sets of case studies and field data. For the moment there are relatively few case studies in the literature (see MacGregor et al. 2006; Hood 2006). For us and many other research organisations, the problem is that MCSEM applied to hydrocarbon exploration is relatively new and much of the work (i.e. data analysis to final interpretations) is confidential.

Forward modelling of 3D-MCSEM (given a 3D target) is computer intensive and inversion is orders of magnitude more intensive (Mittet et al. 2004). Issues like influence of complex bathymetry or shallow gas hydrates on the target hydrocarbon response can only be dealt with by 3D forward modelling codes (Li and Constable 2007).

Our strong recommendation would be that a suitable, combined 3D-MCSEM and 3D seismic reflection data set be identified and made available to all organisations actively engaged in MCSEM research. MCSEM (a diffusive method) and seismic reflection should be highly complementary and active research on a common data set would provide benefits to the industry as a whole. It will be interesting to see if any companies will take a leadership role and make such a combined data set available?

The future

The immediate future for MCSEM is to deploy more ocean bottom three component electric and magnetic field receivers and use more transmitter line orientations. As indicated earlier, there is clear advantage in transmitting with the electrical bipole in multiple orientations. That is, current is passed through the earth in a completed range of orientations such that anisotropy or large earth structures are both 'optimally illuminated' and 'null coupled'. This presents advantages for interpretation.

At the moment the best place for receivers is clearly on the ocean floor; however, there is a considerable advantage in spreading receivers more evenly through the 3D volume engulfed by the circulating electric and magnetic fields. For example it may be advantageous to deploy a small subset of receivers that are capable of fixing themselves into the ocean floor. Burrowing devices capable of sending packets of data to the surface may be considered.

Conclusions

The basic technologies required for MCSEM have existed for some time so it is largely economics that have driven the rapid evolution of MCSEM over the last 5 to 10 years. Rising prices and diminishing reserves for low development cost hydrocarbons have pushed exploration into the deeper water settings that are more suitable for application of MSCEM. Deep water settings are electromagnetically quiet and the increased water depth compared to target depth means that any electrically resistive hydrocarbons can be illuminated before the MSCEM response at receivers on the ocean floor is swamped by the strong influence of the air–ocean interface (an extreme boundary condition). Both service companies and research institutions are active in the search for a solution to the water depth problem. Now that potential for MSCEM is demonstrated in deep water, there is strong motivation to develop the technology for application closer to the shoreline. MSCEM has evolved from simple 2D surveys to full 3D multi-frequency, multi-azimuth MCSEM surveys using multi-component electric and magnetic field sensors. In summary, MCSEM is an exciting relatively new hydrocarbon exploration technology, which requires considerable new research and development to realize its full potential. We hope we have been able to provide some direction in the application of this geophysical exploration technology.

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Paleomagnetism 1958 revisited: a Golden Anniversary

Members of the Australian Society of Exploration Geophysicists and the Geological Society of Australia met jointly at the Australian National University (ANU) on 22 October 2008. Beginning with refreshments at 5 pm hosted by the ANU Colleges of Science, the occasion was held to unveil a plaque, and to celebrate major developments in geophysics that took place 50 years ago. An inconspicuous building now amongst storage sheds at the rear of the Research School of Biological Sciences (RSBS) was in the spotlight, as the surviving part of a paleomagnetic laboratory which operated from 1955–64.

In 1955, that part of the ANU campus was an unoccupied bare paddock, and the site was chosen by John C. Jaeger and his research fellow Edward (Ted) Irving[1] of the Department of Geophysics of the Research School of Physical Sciences as ideal for a laboratory needing an undisturbed environment. Rocks of different ages, collected carefully from around Australia, were returned to the laboratory for measurement of their magnetic properties. When the results were compared with similar results from North America and Europe, the demonstration of continental movement was clear, though much debated at the time, as might be expected for such a revolutionary result.

To further complicate the debate, many rock samples were found at the laboratory to be reversely magnetised (i.e. when the rocks were formed, compasses would have pointed south). The understanding of such reversals was greatly advanced when they were shown to occur world-wide, simultaneously. The achievement of this result involved radiometric dating, also then in its infancy. With this knowledge of reversals and later international developments especially in marine geophysics, continental drift became part of the plate-tectonic model for geology which is taught in schools today.

The first part of the paleomagnetic laboratory was a wooden hut built in 1955, constructed to be non-magnetic (Figure 1). An east–west wooden wing was added in 1958 to house demagnetisation apparatus, as these (then-new) techniques were developed. The surviving concrete-block wings date from 1963. These wings are still known fondly as 'the Old Mag Hut', and they belie their origin on a map of the campus by exhibiting an unusual magnetic north-south orientation.

Fig. 1. *The paleomagnetic laboratory 1955, photo by Ted Irving. Black Mountain (without tower) is in the background.*

In 1964 paleomagnetic research moved to a new laboratory in an old quarry on the eastern slopes of Black Mountain, near the ANU campus. The move to Black Mountain heralded a new era in both national and international paleomagnetism, and that laboratory is still in operation today.

Fig. 2. *Kurt Lambeck after unveiling the plaque on 'the Old Mag Hut'.*

The meeting on 22 October 2008 first gathered at the surviving wings of the Old Mag Hut. To commemorate the fundamental discoveries which played important roles in the development of modern geology, a plaque on the building was unveiled by Kurt

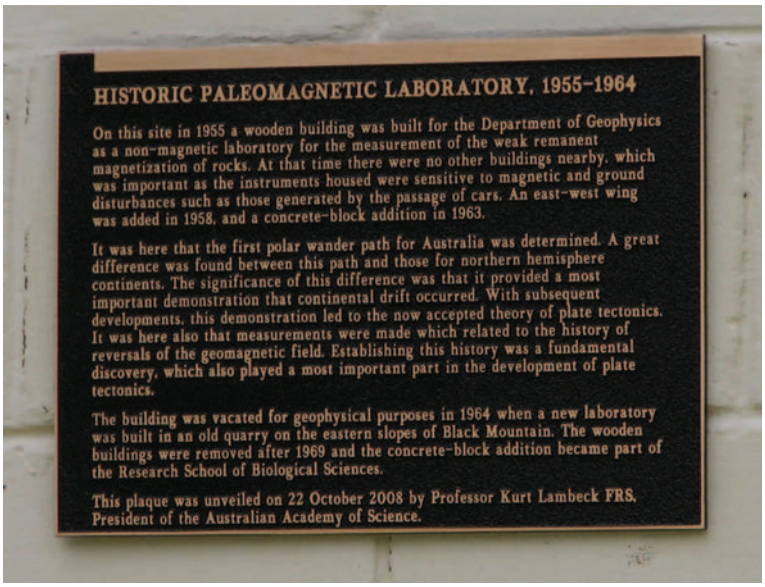


Fig. 3. *The plaque.*

[1]After his arrival in Canberra from the UK, Irving learned that his PhD thesis, describing pioneering paleomagnetic work in England, had not been passed by the University of Cambridge, such was the opposition to this new method and its implication for continental drift. Later, the same university awarded Irving the degree of DSc for his work in paleomagnetism (Editor).

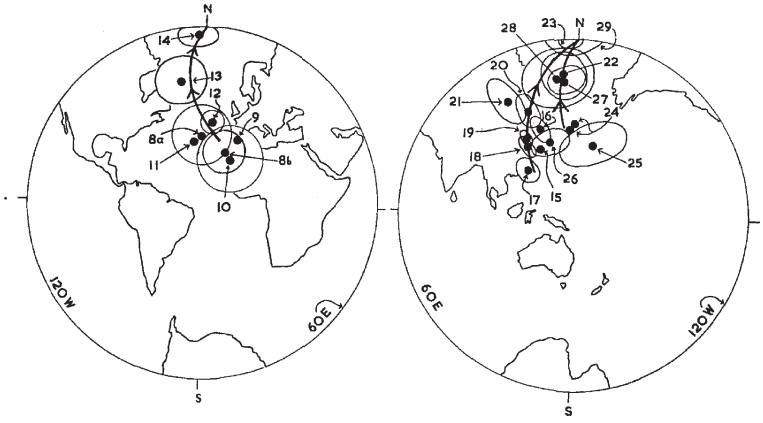


Fig. 4. *Copy of the original Fig. 5. from Irving, E. and Green, R. 1958, Polar movement relative to Australia: Geophys. J. Roy. Astron. Soc., 1, 64–72. The caption read, in part: 'Pole positions obtained from rock formations of Carboniferous and later ages in North America, Europe and Australia (equatorial projection). The large discrepancy between equivalent results from Australia and those from northern continents is illustrated here.' This discrepancy demonstrates relative continental movement and notice how even the North American and European curves were separated – due to the opening of the Atlantic Ocean, not well established at that time.*

Fig. 5. *Results from McDougall, I. 1964, Potassium-argon ages from lavas of the Hawaiian Islands, Bull. Geol. Soc. Am., 75, 107–128. The progressive increase in age towards the northwest indicates migration of volcanism to the southeast at about 10 cm/year.*

Lambeck FRS, President of the Australian Academy of Science (Figures 2 and 3).

The celebrations continued with talks revisiting the historic results of 50 years ago. Chaired by Brad Pillans, the talks were held in the D.A. Brown building (named after David Brown, Foundation Professor of Geology and himself a protagonist of continental drift). Ted Lilley spoke on 'The Old Mag Hut 1955–64, and Australian Continental Drift', in which he showed photos of the early ANU campus; reviewed the paper by Irving and Green (1958) in which the Australian polar wander path is shown to be very different from those of Europe and North America (Figure 4); and concluded with photos taken on a recent visit to the home of the Ted and Sheila Irving on Vancouver Island, Canada.

Then a message from Ted Irving was read by his colleague Carmel Lowe, visiting Canberra from the Pacific Geoscience Centre, British Columbia. Ian McDougall spoke on 'Establishing Geomagnetic Reversals', recounting especially how he and Don Tarling (a student of Ted Irving) had collaborated on dating recent geomagnetic reversals found in lava flows on the Hawaiian Islands. These results provided the steps taken in developing a global geomagnetic reversal history and also provided evidence for crustal movement relative to a mantle 'hot spot' (Figures 5 and 6).

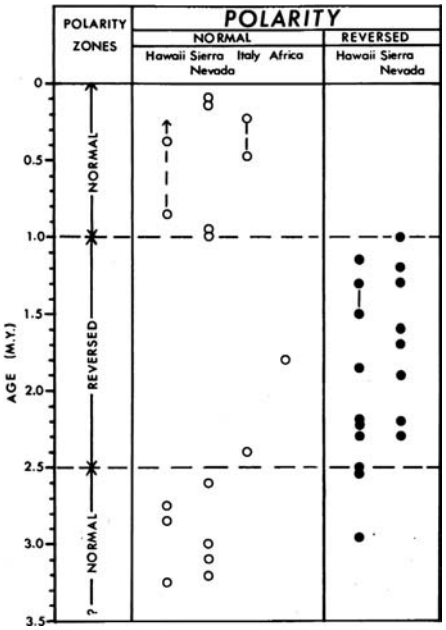
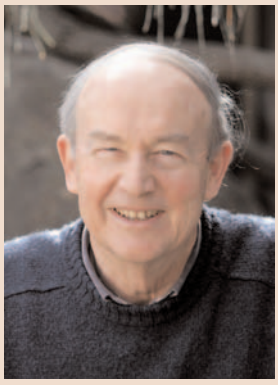


Fig. 6. *Combining Hawaiian ages with magnetic polarity determinations, McDougall and Tarling showed a zonation of normal and reversed polarity, providing strong evidence that the Earth's magnetic field changed polarity, a contentious issue at the time. The figure is from McDougall, I. and Tarling, D.H. 1964, Dating geomagnetic polarity zones, Nature, 202, 171–172.*

The talks concluded with Ron Green addressing the audience informally, with accounts of his experiences in geophysics at the Bureau of Mineral Resources and at ANU 50 years ago.

The celebrations ended with dinner at the nearby Teatro Vivaldi Restaurant. During the evening the 48 diners were welcomed, and greetings were received from well-wishers around the world. A toast to 'The early paleomagnetists' was proposed by Charles Barton. Later, Ronald Green responded 'On behalf of all early paleomaggers', recalling the popular term of the time.



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The Deniers: The world renowned scientists who stood up against global warming hysteria, political persecution and fraud[1]

by Lawrence Solomon

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Does society benefit from a fear-driven science-funding policy that threatens the livelihood of scientists with the courage to argue against 'orthodox' and established 'beyond doubt' views on climate? The media drives this fear with increasingly hysterical messages that the earth is getting hotter, that this is being caused by human CO_2 emissions and, that without radical social and economic surgery, we will face a myriad of global catastrophes, the like of which have not been seen since the dawn of our history. We are told that all serious scientists agree with this and that those few who dissent are either charlatans or are funded by the fossil fuel companies. Other dissenters are regarded on a par with creationists, Holocaust deniers or supporters of tobacco companies. But is this true? Is the science really settled?

To answer this, Lawrence Solomon, the Canadian environmentalist and anti-nuclear campaigner, sought to find well-regarded scientists who disagreed with the AGW (anthropogenic global warming) hysteria promoted by Al Gore and the IPCC. The result was astonishing in that for all of the headline issues of the AGW hypothesis, he found dissenting scientists who were consistently the most accomplished and eminent people in their respective fields of expertise. In fact, the more he searched, the more there seemed to be, complete with data and analysis to support their positions. Chillingly, several of them, despite their substantial expertise and reputations, declined on-record interviews for fear of losing their funding and, in some cases, their jobs.

Solomon's book, *The Deniers*, is a tour-de-force of expert opinions organised into chapters corresponding to the headline issues of AGW. It starts with a chapter on the famous 'hockey stick' graph, created by Michael Mann from temperature proxies such as tree rings and ice cores. The graph purports to show that for the past 1000 years, temperatures had been declining until about 1900 when they began rising alarmingly in correlation with the growth of human-induced CO_2 emissions. It showed the 1990s as the hottest decade and 1998 the warmest year of the millennium. This graph of northern hemisphere temperatures for the last 1000 years appeared seven times in the IPCC report of 2001.

Curiously, the 'hockey stick' graph failed to show a well-known period of warming in the 1930s and essentially contradicted records from Russian naval log books that noted substantial Arctic warming during the period 1920–40. It also contradicted information from British naval log books that showed a period of rapid warming in Europe during the 1730s similar to that recorded during the 1990s. Most astonishingly, it failed to show the well-established existence of the Medieval Warming Period of 800–1300 CE.

Amongst many other critics, a Canadian statistician, Steve MacIntyre, recognised the graph as being similar to the deceptive graphics used by mining promoters to hype risky hard-rock mineral exploration projects based on isolated results. After analysing the statistical process used by Mann, he concluded that even when applied to random data, it would produce a 'hockey stick' graph. The Energy and Commerce Committee of the US Congress asked Edward Wegman, a man with a long, distinguished career, including being a past chairman of the Committee on Applied and Theoretical Statistics of the National Academy of Sciences, to examine the controversy. After he corrected Mann's errors in statistical methodology, the hockey stick disappeared. Along with the panel of prominent statisticians that he had recruited (pro bono) to help him, Wegman concluded that, at most, Mann's graph was valid for less than half of those 1000 years. As a result, despite its prominence in the IPCC's 3rd AR (Assessment Report) of 2001, the graph was dropped from their 2007 4th AR.

Another chapter of *The Deniers* discusses the work of Richard Tol, one of the world's leading environmental economists and an author for chapters from all three IPCC Working group contributions. A holder of multiple prestigious academic appointments, he was highly critical of the Stern Review on the Economists of Climate Change. Tol said that the Stern Report was a mishmash of bad mathematics and bad faith and had treated worst case scenarios with the unwarranted likelihood of being correct.

A lot of the alarmism connected with climate change is associated with the predictions of various climate modelling programs, sometimes referred to as GCMs (general circulation models). *The Deniers* contains a long chapter on the limits of predictability of these programs and how their simplifications do not begin to capture the complexity of climate processes. To quote Freeman Dyson, one of the world's most eminent physicists: 'The models solve the equations of fluid dynamics, and they do a very good job of describing the fluid motions of the atmosphere and the oceans. They do a very poor job of describing the clouds, the dust, the chemistry and the biology of fields and farms and forests. They do not begin to describe the real world that we live in.' Solomon notes that Richard Lindzen, a professor of meteorology at MIT, consultant to NASA and recipient of many professional society honours, testified that numerous problems had been found with the way the models treated clouds and water vapour, two very critical drivers of climate. He states: 'It isn't just that the alarmists are trumpeting model results that we know must be wrong. It is that they are trumpeting catastrophes that couldn't happen even if the model results were right.'

One example of this was Lindzen's observation that if the model results were correct, global warming would reduce temperature differences between the poles which would decrease rather than increase the energy in tropical storms. Nevertheless, fuelled by Hurricane Katrina and several other storms in 2004, many doomsayers predicted an apocalyptic increase in the number and ferocity of hurricanes due to global warming. Dr Christopher Landsea, of the Atlantic Oceanographic & Meteorological Laboratory, one of the world's top experts in hurricanes and a contributing author to the IPCC's 2nd and 3rd ARs, disagreed strongly because his work was showing the direct opposite. He resigned his involvement in the 4th IPCC report after the lead author of the chapter in which hurricanes were discussed had made a speech supporting the increased hurricane hypothesis. Solomon devotes several pages

[1]Climate Change and Emission Trading Schemes are certain to be newsworthy and will probably be controversial for many years, so for interest we have included two reviews from different viewpoints of the same book, *The Deniers*.

describing the efforts of Landsea, Lindzen and others to combat this falsely generated hysteria. These efforts eventually succeeded, partially due to the failure of subsequent hurricane seasons to live up to prior billing. The latest IPCC *Summary for Policymakers* stated: 'There is no clear trend in the annual numbers of tropical cyclones'.

The Deniers discusses another of the apocalyptic predictions of AGW, the rise of sea levels and the concomitant flooding of low-lying heavily populated areas. After analysing satellite data from 1992 to 2003, Prof. Duncan Wingham, director of the NERC Centre for Polar Observation & Modelling and principal scientist of the European Space Agency Cryosat Satellite Mission, found that there was a net growth of the Antarctic ice sheet of 5 mm per year. This includes the well-publicised melting on the Antarctic Peninsula that juts so far to the north. Since Antarctica contains about 90 percent of the world's ice, the fact that it seems to be a sink rather than a source of sea water would indicate that concerns of rising sea level are misplaced.

Another headline issue discussed in *The Deniers* is the predicted catastrophic spread of malaria and other mosquito-borne diseases with increasing temperature. Prof. Paul Reiter, head of the Insects and Infectious Diseases Unit at the Pasteur Institute, chairman of the American Committee of Medical Entomology and contributing author to the IPCC 3rd AR regards this as utterly without foundation. He notes that until the second half of the 20th century, malaria was widespread throughout the world including Europe, the US, Siberia and with major epidemics as far north as the Arctic Circle. Malaria was an important cause of death in England during the Little Ice Age and only began to decline there in the 19th century when the present warming trend was well underway. It was largely eliminated through the use of insecticides, anti-malarial drugs and sound public health and land management practices. Reiter notes that the rapid recrudescence of mosquito-borne diseases is due to inept government public health policies and resistance to insecticides and drugs.

The Deniers features extensive discussions by prominent scientists of aspects of the greenhouse effect of CO_2. The technical details are difficult to summarise in a short book review but they include discussions of atmosphere–ocean interactions, radiative transfer, ice core measurements and the lifetime of CO_2 emissions in the atmosphere. All basically conclude that cultural CO_2 concentration has very little effect on global temperature. Several prominent researchers note that the graph in *An Inconvenient Truth* showing a 600 000 year correlation between increased atmospheric CO_2 concentrations and rising temperature is somewhat dishonest in confusing cause and effect. Temperature rise led rather than lagged the CO_2 increase, typically by a few hundred to a thousand years. In the same vein, Dr Syun-Ichi Akasofu points out that the dramatic fall in temperature from 1940 to 1970 doesn't correlate with increasing CO_2. Moreover, the IPCC's own models point to the irrelevance of CO_2 as a driver of climate change because different geographic regions were warming at different rates while others actually cooled.

Has the earth actually warmed during the 21st century? This is a contentious issue because of the problems associated with trying to define an average global temperature, especially from ground-based measurements. Although 70% of the earth's surface is ocean, 90% of the ground-based measurement stations are on land. Moreover, as urban centres have expanded, these are now disproportionately located near heat sources. The IPCC says that the data has been corrected for this but this is contentious. By contrast, satellite temperature measurements, which can sample the entire globe, show a cooling trend so far this century. Is this temporary or is it possible that the earth is starting to cool?

Dr Habibullo Abdussamatov the head of the Space Research Laboratory at the Pulkovo Astronomical Observatory, a man at the pinnacle of Russia's space-oriented scientific establishment, is a strong critic of manmade CO_2 as driving global warming. *The Deniers* presents his observation that parallel global warmings on Mars and Earth can only be due to a long term change in solar irradiance. He has identified a 200-year cycle in solar activity that has peaked and is now decreasing. He believes that a protracted cooling period will begin in the period 2012–15 leading to a deep freeze around 2055–60, similar to that of the Little Ice Age. His hypothesis is now the focus of Russian experiments on the International Space Station. Project Astrometria has been given high priority by the Russian and Ukrainian Academies of Science to try to identify the likely duration and depth of the predicted global cooling period.

The effect of solar cycles on our climate goes beyond the total solar irradiance reaching Earth. Periods of high solar activity result in high solar wind velocities and magnetic fields that shield us from the cosmic ray barrage from the rest of the cosmos. This shielding attenuates significantly during periods of low activity. *The Deniers* presents the science that links increased cosmic ray flux with global cooling because it promotes an increase in low altitude cloud formation. As shown by Project SKY at the Danish National Space Centre, this happens because the passing muons in the cosmic radiation release electrons that promote the formation of molecular clusters, the building blocks for cloud condensation nuclei. A follow-on study of this crucial effect, the CLOUD experiment has been established at CERN, with an interdisciplinary team of scientists from 18 institutes in nine countries, comprised of atmospheric physicists, solar physicists, and cosmic-ray and particle physicists.

The Deniers is a fascinating journey through leading-edge climate research. The experts cited by Solomon are clearly neither charlatans nor pandering to any particular funding channel. Rather, these eminent scientists present cogent reasons, strongly supported by data, for questioning the accepted 'truth'. One is left with astonishment and indignation that their work is largely ignored by the media.

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The Deniers: The world renowned scientists who stood up against global warming hysteria, political persecution and fraud

by Lawrence Solomon

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There is a story, perhaps apocryphal, that a US Senator once wished plaintively for 'a one-armed scientist'. The Senator was tired of hearing from cautious scientists who would offer an opinion, but then say 'On the other hand ...'

Science does not deal in certainties. The life of policy makers might be simpler if it did, but nothing else in life is certain so really they don't have much reason to complain. Perhaps the distinctive thing about scientists is that they are more often honest about uncertainties. Come to think of it a politician might not be able to comprehend that, and might therefore find it frustrating.

In my assessment this book carries messages at several levels. Level One is that it's not proven that humans are the cause of global warming. Level Two is that policy makers should not do anything about global warming unless and until it's proven that we're the cause. Level Three is that there is a conspiracy to suppress debate about the causes of global warming.

I hesitate to put my view on Level One in writing, for fear it will appear out of context on the websites of sceptics. I think it is not proven that we are the main cause of global warming, but then I don't think it can be proven rigorously that the sun will rise around the time my clock next says 6 am.

So to Level Two. A great deal of the public discussion of global warming concerns whether or not it is proven that we are the cause of it, and thereby a great deal of mischief is done, because it should no longer be the issue preoccupying our policy makers. This may well seem contentious so I will explain. We have known for decades that the effect, if any, of our greenhouse gas emissions would be delayed by decades. Climate scientists have also assembled a long list of potential positive feedbacks that could be triggered by our emissions, any, some or all of which could swing our climate uncontrollably and irreversibly into a dramatically different state. Together, these points mean that if we are to act effectively to avoid human-caused global warming we have to act before we have a high level of confidence that we are the cause. Simply, if we wait that long it will be too late.

What to do? The only thing to do is to ask those most familiar with the climate for their considered professional judgement. We have that, and the message is very clear: in the considered professional judgement of a large majority of climate scientists, it is 90% sure that we are causing global warming. That is not at all the same thing as saying human-caused global warming is proven. It is a professional judgement on the state of the science. I think policy makers would be irresponsible to ignore a warning like that. They do have to consider the safety of their citizens.

Yes, there are plenty who argue the IPCC exaggerated this or that, or got the other thing wrong, and by now there are probably just as many, myself included, who think the IPCC was irresponsibly conservative and unduly influenced by political considerations. The IPCC is, after all, created by governments and its members are nominated by governments.

Thus I think we must act to reduce our greenhouse gas emissions. At the very least it's an insurance policy, and not a very expensive one. Even those economic modellers who are unsympathetic are only claiming that growth of GDP would be slowed by a percentage point or so, and other modellers suggest much less.

There are studies, frankly much more credible because they're only summarising things already being done, that show we can cut a lot of our emissions for little or no cost if we go about it the right way, which is to stop using energy so wastefully. For example, the McKinsey Institute estimates Australia can cut emissions by 20% by 2020 for zero net cost. In other words we'd be smart to do it anyway, regardless of global warming. Why, then, are the sceptics making such a fuss?

So we come to Level Three, the conspiracy. I think this charge has little going for it. I've been on the minority side of a major scientific dispute, so I'm personally acquainted with the frustration, but there's nothing to do but keep plugging away. So my advice to the sceptics is, if you want to debate the science, then do it in the scientific fora. If, on the other hand, you want to debate policy, then get clear what the issues are for policy makers.

So let the scientific debates continue, but do it in the responsible way. Sceptics who are out to prove a point actually have a strategic advantage. It's relatively easy for one person to trawl through a scientific discipline and find diverse bits that challenge the prevailing view of the time. It's much harder for one person to have the breadth and depth of knowledge to respond to the full range of questions raised. Thus it's easy to sit on the sidelines sniping. It's harder to reach a broadly well-informed view.

I'll finish by mentioning one issue in the book that I happen to know about in more detail. In the record of glacial cycles CO_2 fluctuations lag temperature fluctuations by hundreds of years. This is claimed by sceptics to prove CO_2 can't be the cause of the current global warming. A study by Hogg (*Geophys. Res. Lett.* 35, doi:10.1029/2007GL032071, 2008) shows that in the glacial cycle CO_2 is a major amplifier, accounting for the striking asymmetry of the fluctuations. But CO_2 can cause a lot of warming on its own too. Thus there is no contradiction between CO_2 lagging during the glacial cycle but leading in the present episode of warming.

Reviewed by Geoff Davies
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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**
4 June	North Queensland Exploration Conference lantana@beyond.net.au	Townsville	Australia
8–11 Jun	71st EAGE Conference & Exhibition www.eage.org/	Amsterdam	The Netherlands
10–11 Jun	AusIMM International Uranium Conference 2009 http://www.ausimm.com.au/content/wsc.aspx?ID=28	Darwin	Australia
August			**2009**
16–19 Aug	AAPG/SEG/SPE Hedberg Research Conference http://www.aapg.org/education/hedberg/vancouver/index.cfm	Vancouver	Canada
24–28 Aug	11th International Congress of the Brazilian Geophysical Society http://congresso.sbgf.org.br/	Salvador	Brazil
September			**2009**
7–9 Sep	EAGE: Near Surface 2009 www.eage.org/	Dublin	Ireland
13–18 Sep	2009 SAGA Biennial Technical Meeting and Exhibition http://www.sagaonline.co.za/2009Conference/index.htm	Swaziland	South Africa
October			**2009**
12–14 Oct	9th SEGJ International Symposium http://www.segj.org/is/9th/	Sapporo	Japan
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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All editorial contributions should be submitted to the Editor by email at denham@webone.com.au. For style considerations, please refer to the For Authors section of the Preview website at: www.publish.csiro.au/journals/pv.

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