Preview

Australian Society of Exploration Geophysicists

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ASEG finances
– Page 10

Minerals exploration software
– Page 11

New Zealand mineral exploration
– Page 14

Australian geothermal resources: special feature
– Page 18

Geophysicists at war: mines and magnetism
– Page 36

South Australia – more petroleum and geothermal opportunities to explore

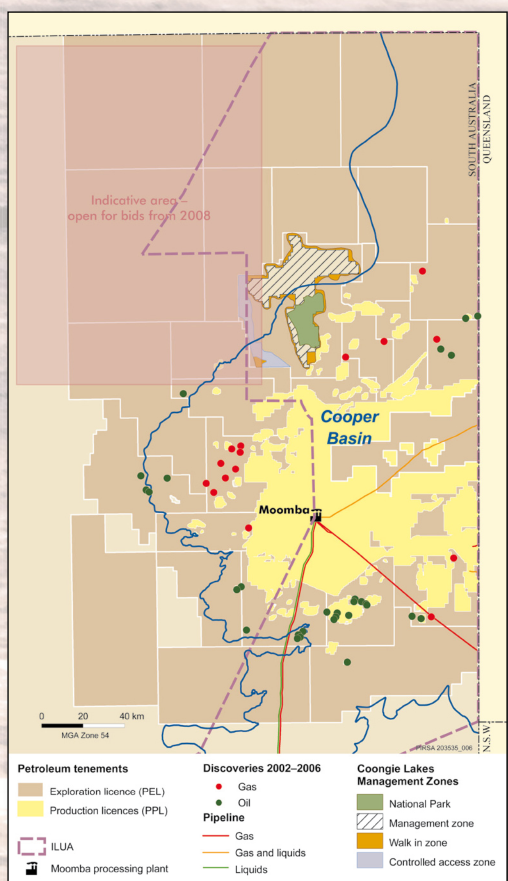
ACREAGE RELEASES PLANNED FOR 2008–09

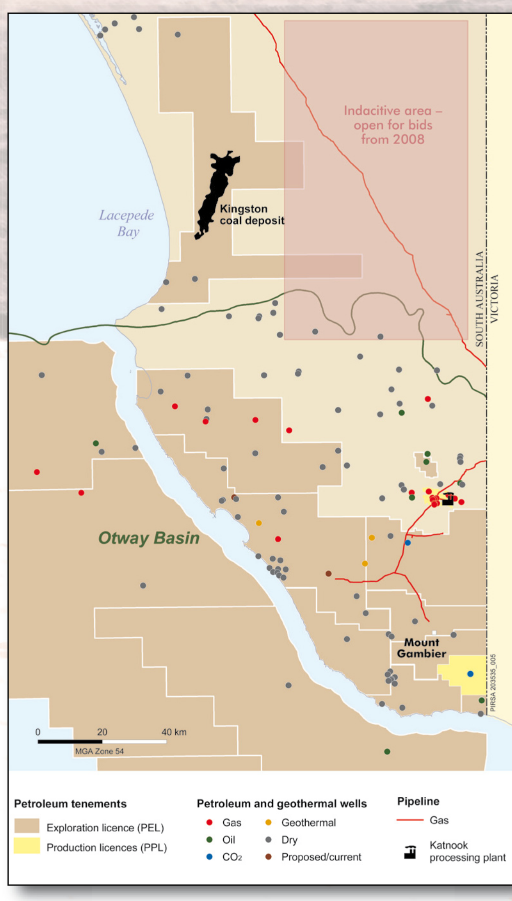
COOPER BASIN

- 19 150 km^2 will be available for work program bidding
- 4–5 large blocks ~4000 km^2 each
- First Indigenous Land Use Agreement in place, more in negotiation.

OTWAY BASIN

- Total release area 5640 km^2 (70% of the onshore basin)
- Cretaceous oil and gas plays.





NEW DATA PRODUCTS

- Workstation-ready data for the Cooper, Officer and Otway Basins
- Free Cooper Basin regional isopach and isolith data for key formations now available
- More online petroleum and geothermal GIS via SARIG.

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Primary Industries and Resources SA
GPO Box 1671 Adelaide SA 5001
Phone 08 8463 3204 Fax 08 8463 3229
www.petroleum.pir.sa.gov.au email pirsa.petroleum@saugov.sa.gov.au

Government of South Australia
Primary Industries and Resources SA

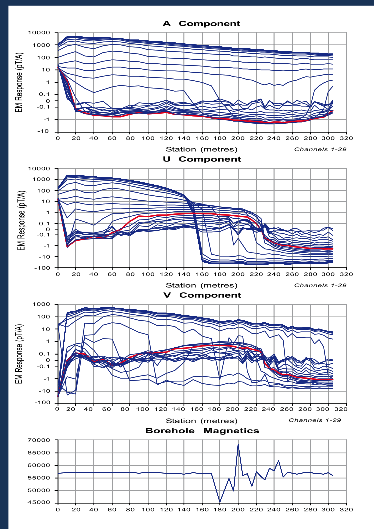
EMIT

ElectroMagnetic Imaging Technology Pty Ltd

Industry Standard Products for Mineral Exploration

Atlantis borehole system

- A low-noise 3-component magnetometer in a slim probe for TEM, MMR and geomagnetic surveys.
- Superior to dB/dt for detecting good conductors further from the borehole.
- The cross-hole components have the same noise level as the axial component.
- Automatically measures the rotation of the probe and the borehole orientation.
- Measures off-time and on-time response.
- Automated interface with SMARTem.
- The same sensor commonly used in surface EM.



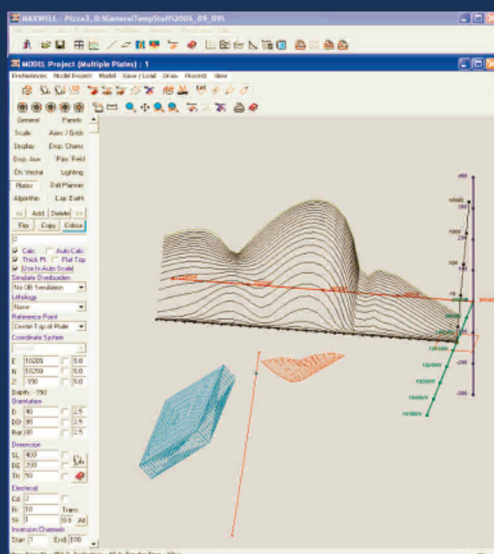
Data courtesy of LionOre Australia

SMARTem receiver system

- 8 Channel multi-purpose receiver system for EM, IP & other electrical geophysical techniques.
- PC-based system with hard disk, VGA graphics, QWERTY keypad, USB and Windows OS.
- User friendly QC software – display profile, decay, oscilloscope, spectrum analyzer, and more.
- Record and process full time series.
- Powerful signal processing for noise reduction.
- Use with any transmitter system and receiver antenna.
- Industry standard file formats.
- Optional transmitter controller with crystal sync.
- Comprehensive PC processing & display software.

Maxwell EM processing software

- Processing, visualisation, interpretation and plotting software for any type of EM geophysical data - ground, airborne, borehole, time and frequency domain.
- Constrained multiple plate inversion and approximate prism modeling.
- Display profile, decay, spectrum, plan, 3-D model and primary fields.
- Compute B-field and on-time response.
- Import/export industry-standard file formats for EM data and interface with Geosoft's OM6 and EMAX.
- Drill planning, decay analysis, MMR modeling, database of system configurations, gridding, contouring, extensive online help and many more features.



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CONTENTS

The front cover shows Geodynamics new drilling rig undergoing tests in Texas before being shipped to Australia. This was purchased for $32 million and starts drilling this month at the Habanero geothermal prospect in South Australia.

Preview is published for the Australian Society of Exploration Geophysicists. It contains news of advances in geophysical techniques, news and comments on the exploration industry, easy-to-read reviews and case histories, opinions of members, book reviews, and matters of general interest.

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Deadlines

Preview is published bi-monthly in, February, April, June, August, October and December. The deadline for submission of material to the Editor is the 15th of the month prior to the issue date. Therefore the deadline for the October issue is 15 September 2007.

Advertising copy deadline is the 22nd of the month prior to issue date. Therefore the advertising copy deadline for the October issue will be 22 September 2007. A summary of the forthcoming deadlines is shown below:

***Preview* issue**	**Text and articles**	**Advertisements**
130 Oct 2007	15 Sep 2007	22 Sep 2007
Conference Handbook 131 Nov/Dec 2007	10 Sep 2007	21 Sep 2007
132 Feb 2008	15 Jan 2008	22 Jan 2008
133 Apr 2008	15 Mar 2008	22 Mar 2008

David Denham

Geothermal focus

Exploration for geothermal resources has taken off in Australia during the last five years. There is now a committed exploration program in excess of $700 000 over five years in place, with more than 95 percent of this investment taking place in South Australia. So when the other States and the Northern Territory catch up, this number can only grow. In this issue of Preview we are reviewing the progress that has been made throughout Australia.

Coincidently, in July, Geodynamics acquired the largest onshore rig in Australia. After a frustrating six months, in an unsuccessful global search for a drilling rig to meet its requirements, they took the plunge and purchased a new rig from the US. The 'Lightning Rig' was bought from Texas-based Le Tourneau Technologies™ at a cost of $32 million. It can drill to a depth of six kilometres and after arrival in Brisbane on 2 July 2007 proceeded to the Habanero Geothermal Field in South Australia to start drilling Habanero 3. The plan is to drill another six holes to establish circulation cells in the hot granite. The picture on the cover shows the rig being tested in Texas, before being shipped to Australia.

I would like to thank all the State and Territory Geological Surveys and Geoscience Australia for co-operating so readily in the preparation of this article.

The drivers for geothermal exploration are two-fold. Security of future energy supplies, with the increased cost of petroleum products, and global warming, as a result of people burning fossil fuels at ever increasing rates.

Carbon storage

It was good to see that Santos is tackling greenhouse gas emissions by developing the Moomba Carbon Storage (MCS) Project. The plan is to store in excess of 400 million tonnes of carbon dioxide in various depleted reservoirs in the Cooper Basin. Interestingly, the Moomba Field is only about 50 kilometres southwest of Geodynamics' Habanero Field. Santos estimates that the demonstration phase will cost about $700 million, and they are hoping to obtain some government assistance in the initial phase.

In this issue

In this issue we also have more about New Zealand geophysics – in this case a summary of mineral exploration; a review of the Geomodeller 3D modelling package and a historical article about the demagnetisation of ships during the Second World War. I would like to draw your attention our Treasurer's report to the 2007 AGM. It is always good to see how the ASEG is travelling financially.

Joe Cucuzza
joe.cucuzza@amira.com.au

Quo Vadis: mining geophysics research in Australia?

Over the years Australia has enjoyed a significant leadership role in geophysical research. Many examples of home-grown developments can be cited, including important developments in EM hardware and software, interpretation of magnetics and radiometrics, and the application of image processing techniques. Much of this work, although not exclusively, has been carried out by CSIRO and a significant part through the support of industry. AMIRA International, operating then under the name the Australian Minerals Industries Research Association, played an important role in much of the geophysical research in Australia. However, over the last decade there has been a steadily declining emphasis on geophysical research in Australian institutions. I am only aware of a few individuals who are involved in any original research in exploration geophysics. This decline in research activity has come hand-in-hand with the decline of earth sciences in many of our institutions and has important implications for Australia's capacity to do research of this nature in the future.

Mining technology

Exploration expenditure is soaring. The latest MEG survey of world non-ferrous mineral exploration budgets for 2006 shows that the total expenditure increased for the fourth consecutive year to almost US$7.5 billion, 47% higher than in 2005. This was also significantly more than the US$5.2 billion achieved in 1997 at the peak of the last exploration boom. However, it is well established that the recent discovery rate in many commodities has not kept pace with the level of production. Consequently the overall industry cost per discovery, particularly in mature areas like Australia has been steadily going up. Indeed according to many in industry, exploration success, measured by both costs per discovery and overall discovery rates has been declining for years. It's not clear if the latter is so for Brownfields exploration.

The most common explanation of this paradox – where increased spending produces diminishing results – is that most sizeable near-surface deposits have now been found, forcing the industry to look for deeper, more expensive and more elusive targets. Of course an obvious response is to move way from mature terranes to less explored but hopefully equally prospective ones.

Greater depth equates to greater discovery costs for a number of reasons, but the most significant is the increased drilling cost. On average, drilling accounts for about 40% of total exploration expenditure and though there has been important incremental improvement in drilling technology in recent decades this has not been sufficient to offset the increasing costs of going deeper.

In the current production-led boom there is a need to bring on stream new mining developments much earlier and more cost effectively. Technologies that can assist in this endeavour along with improving the extraction of ore are of particular interest to industry.

To meet this challenge a consortium of leading mining companies from around the world recently came together, under the auspices of AMIRA International, to develop a Drilling Technology Roadmap which documents the industry needs and defines the research paths to address these needs.

The first step towards this goal was to conduct workshops where invited representatives of mining and drilling companies along with research institutions with expertise in the field participated in a review. The list of areas where improvements could be made was extensive with more than 100 individual R&D needs identified, covering the main application areas from exploration to production drilling. The R&D needs that were identified can be readily grouped into the following three key areas:

- Enhanced current drilling technologies and practices,
- New sensors to maximise high value geoscience data acquisition, and
- Novel drilling technologies.

But what of the role of geophysics in meeting the challenge?

There is a view amongst some industry geophysicists that we have at our disposal all the tools necessary to turn things around. According to this view the problem is not about new technologies *per se* but the smarter application of existing technologies and applying them in the right place. By smarter application they presumably mean applying the right tool for the right job in the right way. In Brownfield environments we know that we are in the right place so presumably success rates are dependent on optimal use of the right technology.

However, when we consider Greenfield environments there is no doubt that having access to the best technology in the world will not help unless we are exploring in the 'right place'. So the challenge here to ensure that we recognise the terranes with the best endowment characteristics and then use appropriate techniques to reduce the search area. I don't believe we have fully cracked the former as yet but clearly geology, geochemistry and geophysics together play a critical role in developing a predictive understanding of well endowed terranes. Much research is being done around the world on this very issue.

In considering the nature and state of the technology in our toolbox an obvious question arises. Have we reached a plateau in technological capability or is there any room for the further development both incremental and breakthroughs? I think everyone would say yes to incremental developments but most would be pessimistic about the latter. In my view the most recent true breakthrough in geophysical technology was the airborne gravity gradiometer. Now we could get mired in semantics about what constitutes a breakthrough but it is my expectation that future developments of this technology will be characterised by small scale improvements focusing on enhanced resolution and better processing capability. The former could potentially come about through some new enabling technology. Some eight years ago I was involved in a truly exciting project involving CSIRO and the University of Melbourne. The aim of the project was to develop proof of concept for a gravity gradiometer based on atomic interferometry. I cite this example to highlight that occasionally radically different enabling technologies may become available that could help expand the operational envelope of existing technology. I will leave it to those interested in such things to debate whether this would constitute a breakthrough or incremental improvement.

I think most will agree that there is plenty of scope for the incremental development

Continued on p. 6

News from the ASEG 19th International Geophysical Conference and Exhibition

The Perth 2007 Conference, to be held at the shiny new Perth Convention and Exhibition Centre this 18–22 November 2007, is shaping up to be one of the best to date. The Organising Committee has been putting in overtime to ensure that exhibitors and sponsors who are clamouring for the attentions of geophysicists during the boom get a chance to show their wares. At present over 250 abstracts have been received for oral and poster presentations.

As for the attendees, a record crowd is expected, with one of the biggest and best petroleum technical programs ever, featuring a minimum of two parallel oil and gas technical streams during the entire conference. A once-in-a-lifetime tour of Barrow Island and a Burrup field trip are also on the agenda for those with hydrocarbon proclivities.

For gold geophysicists, November can be a memorable month, as on the Thursday and Friday preceding the ASEG Conference they can attend the NewGenGold Conference in Perth, then take a tour of the Kalgoorlie goldfields on a pre-conference weekend tour, and return to enjoy a full technical session on gold case histories on Monday.

There is even something for instrumentation aficionados as the Tuesday afternoon technical session is shaping up to be a must-see event focusing on instrumentation. This will be augmented by an interactive forum on the next generation of geophysical instrumentation – the hows, whys and whos.

The response in the run-up to the November Conference has been spectacular, with sponsors, exhibitors and technical presenters turning out in force. As registration opens we encourage all those interested in the profession and industry of geophysics to register early to ensure an opportunity to be where all the action is in November 2007.

Brian Evans and Howard Golden
Co-Chairs, Perth 2007 ASEG Conference and Exhibition

Calendar of Events 2007/2008

2007

9–12 September
5th Decennial International Conference on Mineral Exploration (Exploration 07)
Theme: Exploration in the new millennium. Exploration 07 will review the current state of the art in geophysics, geochemistry, remote sensing, data processing and integration.
Venue: Toronto, Canada
Website: www.exploration07.com

23–28 September
SEG International Exposition & 77th Annual Meeting
Venue: San Antonio, Texas, U.S.
Website: http://seg.org/meetings/calendar

27–30 September
4th International Symposium on 3D Electromagnetics (3DEM-4)
Venue: Freiberg, Germany
Contact: Klaus Spitzer (klaus.spitzer@geophysik.tu-freiberg.de)
Website: http://www.geophysik.tu-freiberg.de/3dem4

2–5 October
Greenhouse 2007
Venue: Sydney, New South Wales, Australia
Contact: P. Holper, CSIRO
Tel: 61-3-9239-4661
Email: info@greenhouse2007.com
Website: www.greenhouse2007.com

22–26 October
2007 SAGA Biennial Technical Meeting & Exhibition
Theme: Making Waves
Venue: Wild Coast Sun Resort, Durban, SA
Contact: events@rca.co.za
Website: http://www.sagaonline.co.za/2007 Conference/2007conference.htm

18–22 November
ASEG's 19th International Conference and Exhibition
Venue: Perth, WA
Contact: Brian Evans (brian.evans@geophy.curtin.edu.au)
Website: http://www.promaco.com.au/2007/aseg
Email: promaco@promaco.com.au

25–29 November
5th International IAHS Groundwater Quality Conference
Venue: Fremantle, Australia
Contact: W. Whitford
Tel: 61 8 9333-6273
Email: Wendy.Whitford@csiro.au
Website: www.clw.csiro.au/conferences/GQ07

10–14 December
American Geophysical Union, Fall Meeting
Venue: San Francisco, California
Website: http://www.agu.org/meetings

2008

6–9 April
2008 APPEA Conference & Exhibition
Venue: Perth Convention & Exhibition Centre
Contact: Julie Hood
Tel: 07 3802 2208
Email: jhood@appea.com.au

9–12 June
70th EAGE Annual Conference & Exhibition
Venue: Rome, Italy
Website: http://www.eage.org/events/

20–25 July
19th AGC, The Australian Earth Sciences Convention 2008
Joint Geological Society of Australia and Australian Institute of Geoscientists Meeting, Perth, WA
Website: http://www.gsa.org.au/events/calendar.html.

5–14 August 2008
33rd International Geological Congress
Venue: Oslo, Norway
Contact: A. Solheim, Norwegian Geotechnical Institute
Tel: 47 2202 3000
Email: as@ngi.no
Website: www.33igc.org

9–14 November
SEG International Exposition and 78th Annual Meeting
Venue: Las Vegas, Nevada, U.S.
Website: http://seg.org/meetings/
Contact: meetings@seg.org

15–19 December 2008
American Geophysical Union, Fall Meeting
Venue: San Francisco, California
www.agu.org/meetings

Continued from p. 4

of geophysical technology, and here I include hardware, processing and interpretation. Much of this work will be done by contractors in their quest for continuous improvements in hardware and processing, eager to secure an edge over competitors.

If we are going to be looking for deeper and possibly lower grade deposits, geology is still going to be important in the getting us in the right place, but in many cases it will be geophysics that will help to narrow down the location of the target, assuming that the target is in fact amenable to geophysics, but it will be through drilling that we will confirm discovery. I believe therefore a lot more research needs to be undertaken to develop better geophysical imaging techniques and in particular techniques that can be applied cost effectively not only in drive but also in the hole. The need to get high quality, real time data from fewer holes and to quickly extract useable knowledge from this, is a critical issue and will be increasingly so as we go deeper. The development of new sensors that could be integrated with drilling along with new interpretation and visualisation techniques could revolutionise how we drill for economic mineralisation. There is an important role for geophysics here. I also feel that a lot more research is required to fully exploit the synergy between different geophysical and geological datasets, including the development of 3D constrained inversion.

I do not exclude further breakthroughs in surface geophysics. For some, the next 'holy grail' is airborne IP. There are some formidable, potentially intractable, technical difficulties associated with the development of such an airborne tool but if the demand is sufficient and someone is prepared to fund such research, now is the time to do it. Certainly AMIRA International is eager to see whether industry is interested in forming a consortium to look at this.

So is Australia well placed to be able to undertake the necessary research to address the challenges? I am not convinced that it is – it's arguable whether we have the people, we certainly do not have the necessary critical mass and little support of the institutions and we do not appear to have the funds. It's not to say that we can't build up the necessary capacity. It will take commitment from universities and industry to develop the right supporting environment. I believe we require the establishment of a critical mass of personnel under an appropriate operating umbrella dedicated to the development of the new science necessary to address the challenges. Such an environment will act as a magnet for talented people eager to work here. However, in my view, for this to happen industry must take a more proactive role.

Federal Executive 2007/08

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[1]Webmaster is not an Executive position but Wayne is listed here because of his new appointment.

New Members

The ASEG welcomes the following new members to the Society. Their membership was approved at the Federal Executive meetings held on 30 May and 27 June 2007.

Name	Organisation	State
Hamish Kenneth Adam	The University of Adelaide	SA
Edward Alexander Bowen		Qld
Barrett Cameron	UTS Geophysics	WA
Brendan Martin Corscadden	Anglo American	WA
Owen Robert Davis	Woodside	WA
Fabien Gilbert	AFMECO Mining and Exploration Pty Ltd	SA
Duncan Lee McIntyre	Coffey Geotechnics	NSW
Sarah Monoury		UK
Regis Angelo Neroni	Zonge Engineering	SA
Kay Philip	University of Sydney	NSW
Camilla Sorensen	Geoscience Australia	ACT
Lincoln Fraser Tovey	PGS Australia	WA
Glenn Wilson	BP	TX USA
Chrisantha Xavier	Geological Survey of Qld	Qld

Congratulations to the following people who are now active members of the ASEG

Name	Organisation	State
Gregory John Armstrong	Consultant	WA
Mark Browne	Stuart Petroleum	SA
Steven Carroll	Woodside Energy Ltd	WA
Roberto Guerini	PGS Geophysical	WA
James Jensen	Fugro Ground Geophysics Pty Ltd	WA
Gary Koo	Fugro Seismic Imaging	WA
Michael Bernard Mills	Velseis Processing	Qld
Seragio Netto	RML Reservoir Management	Malaysia
Tara Siobhan Reilly	Tap Oil Limited	WA
Andrew Hamilton Tucker		SA

Lindsay Thomas receives Distinguished Service Award from SEGJ

Congratulations to Lindsay Thomas, the Managing Editor of *Exploration Geophysics*. He was awarded a Distinguished Service Award by the Society of Exploration Geophysicists of Japan (SEGJ) at its annual general meeting in Tokyo on 29 May 2007. He is the fourth recipient of this award since its inauguration in 2002.

The citation reads: ***To Dr Lindsay Thomas for his long-time contributions and achievements as managing editor of the ASEG, KSEG and SEGJ's English language joint publications.***

These unique issues of the of the ASEG, KSEG and SEGJ journals started in February 2004, with the volume 57(1) issue of Butsuri-Tansa (Geophysical Exploration) of SEGJ. The fourth issue was published in 2007.

Lindsay has been the Managing Editor of the joint issues from the beginning. He reviewed all the manuscripts submitted by the authors from SEGJ and KSEG to improve the English texts. His reviews were always very considerate, sincere, precise and appropriate. This enormous task involved a large number of interactions with many authors for each issue. He tirelessly carried out this difficult and time-consuming task, with enthusiasm and patience, and made the necessary and appropriate corrections to all the manuscripts.

Many of the papers written by SEGJ members can now be read outside Japan and are enjoying a high reputation internationally; due to the intensive efforts of Dr Thomas. SEGJ, herewith, acknowledges the highly distinguished services by Dr Thomas towards the international activities of the SEGJ.

Koya Suto

Lindsay Thomas receives his Distinguished Service Award and testimonial certificate, from Professor Toshifumi Matsuoka, the President of the SEGJ, at the 2007 AGM in Tokyo.

Obituary: Lawrence A. Drake (29 October 1931–28 April 2007)

Dr Lawrence A. Drake died on 28 April 2007 at St Vincents Hospital Melbourne, aged 75. Lawrie joined the Jesuits in 1949 and was ordained a Jesuit Priest in 1964. He studied Physics at the University of Melbourne, obtained his PhD at the University of California, Berkeley, and was Lecturer and Senior Lecturer in Geophysics at Macquarie University for a period of 20 years, from 1972 to 1993.

On leaving Macquarie he moved to South America to become Director of the Observatorio de San Calixto, La Paz, Bolivia, one of the few remaining Jesuit seismic observatories. He returned to Australia due to ill health in 2002, and spent the last years at Campion House in Melbourne. He had been suffering from lymphoma for some years.

Lawrie Drake was a practical seismologist who enjoyed explaining the often ungainly-looking constructs of weights, wires and rods that made up the older, hand-made seismographs he kept in operation in the Riverview Observatory, on the grounds of St Aloysius College, Sydney, where he was Director. He was equally competent at interpreting the earthquake records, which they scrawled on smoked paper, and explaining them to the groups of visitors – boys from the College, students from the universities, visiting academics and others. But during a period when expensive new seismograph stations were being established by governments eager to monitor possible underground nuclear explosions, with the help of Br. Frank Rheinberger, he had the clout and worldwide reputation to keep the unfunded observatory independent but routinely producing data of the high standard demanded of the new World-Wide Standard Seismographic Network, or WWSSN. He justifiably took pride in doing so.

Observational seismology was only one of his interests. As a PhD student at the University of California, Berkeley, Lawrie worked with another Australian, Prof Bruce Bolt and Prof John Lysmer, to develop finite element methods for modeling the effects of 2D geological structure on seismic surface waves. Bolt was a leader in developing California building codes to withstand quakes and Lysmer was at the forefront of finite element applications in civil engineering. Several landmark publications in earthquake seismology resulted from this collaboration, which made a lasting impression on building codes worldwide. When Lawrie arrived back in Australia, his baggage consisted mainly of a large volume of IBM cards containing programs and data. He continued to work with these for some years. Working with students and postdocs at Macquarie he developed tools for understanding the in-seam seismic measurements adopted by industry for coal mine management.

In addition to the seismic vault, the Riverview Observatory included a small astronomic dome, which was used for occasional knowledgeable lectures to the boys and to the public for special events. His popular lectures at Macquarie University included first year, advanced undergraduate and postgraduate levels, and spanned the range of seismology, structural geology, astronomy and cosmology, fitting well with the broad general educational approach favoured by many in earth sciences.

Lawrie enjoyed tea room discussion of current topics of the day, which often included politics and religion. Far from dogmatic, he added a depth and breadth of knowledge well beyond that of most in the department, making those discussions more interesting than in other tea rooms we have known. He was warm, well-liked by academics, technicians and secretaries, and kept in touch with many of them until the end. He was the only person we knew who could read Latin inscriptions as if they were the morning newspaper. He will be missed by many.

Keeva Vozoff, Jim Tayton and Ted Bowen

Margaret Sheil to head Australian Research Council

The Minister for Education, Science and Training Julie Bishop announced on 11 July the appointment of Professor Margaret Sheil, as the new CEO for the Australian Research Council effective from 17 August this year.

Professor Sheil is currently the Deputy Vice-Chancellor (Research) at the University of Wollongong, a director of the Cooperative Research Centre for Smart Internet Technology, and is a Fellow of the Royal Australian Chemical Institute. She is also a member of the Research Quality Framework Reference Committee, and the immediate past Chair of the Australian Vice-Chancellors' Committee Deputy/Pro Vice-Chancellors' (Research) Group.

I am sure that everyone in the ASEG will wish her well in her new important and challenging role.

Government unlikely to boost geoscience training after Skills Summit[1,2]

Don Larkin
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and

Ray Cas
ray.cas@sci.monash.edu.au

Natural resources consistently generate 40% of Australia's export earnings and a major proportion of this comes from the minerals and energy sectors. Geoscience is therefore a strategically vital as it is one of the main disciplines underpinning our current resources boom and consequent economic upturn. However, although there are huge profits and tax revenues to be made from the resource industries, and although there are well paid jobs to be had, the tertiary geosciences sector is withering away.

Despite the current resources 'boom', university geoscience departments are suffering and continuation of current downward trends will impact significantly on Australia's natural resources sector, on the national economy and on the ability of university departments to meet Australia's geoscience needs. Only nine departments now have a viable geoscience major, whereas in 1990 there were 28. And, only three stand-alone geology and geophysics departments survive – at Monash, Curtin and Tasmania universities.

The adoption of government budget models driven by a nearly linear relationship between student numbers and funding by most universities in the last 10 to 15 years has had a huge and detrimental impact on the health of geoscience departments. Even in the boom times, geoscience has never attracted the large numbers of students of most other disciplines, due to its very limited profile in school curricula. Very few students go to university specifically to study geoscience and 95% of undergraduates 'discover' geoscience by accident when selecting their subsidiary subjects in first year. Hence, enrolments in geoscience will never match levels of mainstream sciences, in spite of their great strategic and economic importance.

Allowing staff numbers to drop below a critical mass endangers the integrity and depth of degree major programs and the value of professional qualifications, and of course means that the fewer staff are spending more time trying to service the needs of a degree program at the expense of research productivity. The effect of a downturn in enrolments in a small discipline such as geoscience can be catastrophic, especially for a discipline that has significant laboratory and fieldwork infrastructure needs. It becomes a vicious downward spiral.

Geoscience departments need long-term stability of budget so that strategic forward planning can be undertaken, rather than drifting from year to year with uncertain budget outcomes. It is essential that industry uses its position as one of Australia's biggest corporate sectors to lobby governments and universities to improve funding for the surviving geoscience departments and the sciences in general.

Industry also needs to commit to a more steady employment policy to hiring a consistent number of new graduates from year to year, rather than the knee jerk, boom and bust mentality that has marked its approach to employment of graduates in the past. If it doesn't provide some assurance of demand and opportunities for graduates more geoscience departments will not survive the next downturn.

It was against this background that the *Engineering and Science Skills Summit – Parliament House* was held in Canberra. As the tertiary education sector becomes increasingly driven by demand (market forces), when should a Government intervene to ensure that 'disciplines of national importance' are met? That is, if we, as a nation, believe that we have national priorities to maintain and grow our standards of living, our security, wealth and other economic goals (GDP growth, balance of trade etc.), whose role is it to fund those disciplines which are essential, but low demand and higher cost to deliver? In a buoyant minerals sector where demand continues to outstrip supply and commodity prices have ensured significant returns to the employers, what is the role of those who seek the skills in funding their supply?

These are fundamental questions which were debated at a National Skills Summit, held in Canberra on 19 June, attended by the major groups representing engineers in Australia. The Australasian Institute of Mining and Metallurgy obtained a seat at the top table and posed the question regarding Governments' role to both the Federal Minister and Shadow Ministers responsible for the tertiary education portfolio. Unfortunately, in my opinion, the answer to the question was left hanging in the air like an elephant in the room. Neither side enunciated a vision for tertiary education, nor addressed the question as to when intervention would be appropriate.

It is clear that Government believes that it has addressed the issue through Universities being encouraged to focus on where they have a comparative advantage on a regional basis, and that the recent 'zero sum' review of cluster funding had addressed the concerns of the science (geoscience) and engineering professions. A survey by The AusIMM of tertiary education providers following the Government's recent changes to cluster funding, which increased funding by less than $1000 per student, showed that this amount fell far short of what is needed. Respondents indicated that the main pressure was maintaining adequate levels of academic staff, followed by the need to update outdated infrastructure.

Respondents also indicated that due to relatively low numbers of students in minerals-related courses, removal of caps on full paying students would do little to improve the situation. Competitive bidding under the Higher Education Endowment Fund was also seen as an uncertain option, due to the tendency of universities to favour infrastructure development for areas of greatest financial gain.

However, the Skills Summit was a great opportunity for the engineering representative groups to get together and highlight their current and ongoing concerns to our national leaders. A website has been set up, on which the Summit outcomes are included, together with papers on the skills shortages and activities/programs and initiatives that are being undertaken. Go to www.apesma.asn.au/summit to sight these papers.

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[1]This contribution was compiled from articles by Ray Cas (part 1) and Don Larkin (part 2), following the Skills Summit held in Canberra on 19 June 2007.

[2]See also p. 10, National Summit on Education

Treasurers Annual Report for 2006[1]

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

The Society's funds are used to promote, throughout Australia, the science and profession of geophysics. In 2006, this was achieved by funding the publications: *Exploration Geophysics*, *Preview* and the Membership Directory; by the payment of capitation fees for the administration of State Branch organisations; by funding the national administration of the Society; by funding continuing education programs; by the provision of loans and grants for conventions; for Branch and Federal meetings; and for the ASEG Research Foundation.

The profit and loss account for the year shows a loss of $43 858. The balance sheet shows a retained surplus of $785 873 as of 31 December 2006. The negative result for the year can be attributed to a decline in membership revenue, increased publication costs and an extraordinary grant by the society to the ASEG Research Foundation.

The major expenses for the Society include:

- publications, after advertising and sales income, resulted in a net loss of $154 510;
- operational expenses of $38 900;
- research foundation, $60 577;

The major sources of income for the society were from publications, membership fees and the AESC 2006 conference. Publications and advertising income was $148 102; total membership fees collected were $105 501 and conference income[2] was $152 310. Figure 1 shows the breakdown in the cash flow.

The costs of running the Society are under continual review and the Society is in a sound financial position going into 2007.

John H. Watt
Honorary Treasurer
30 May 2007

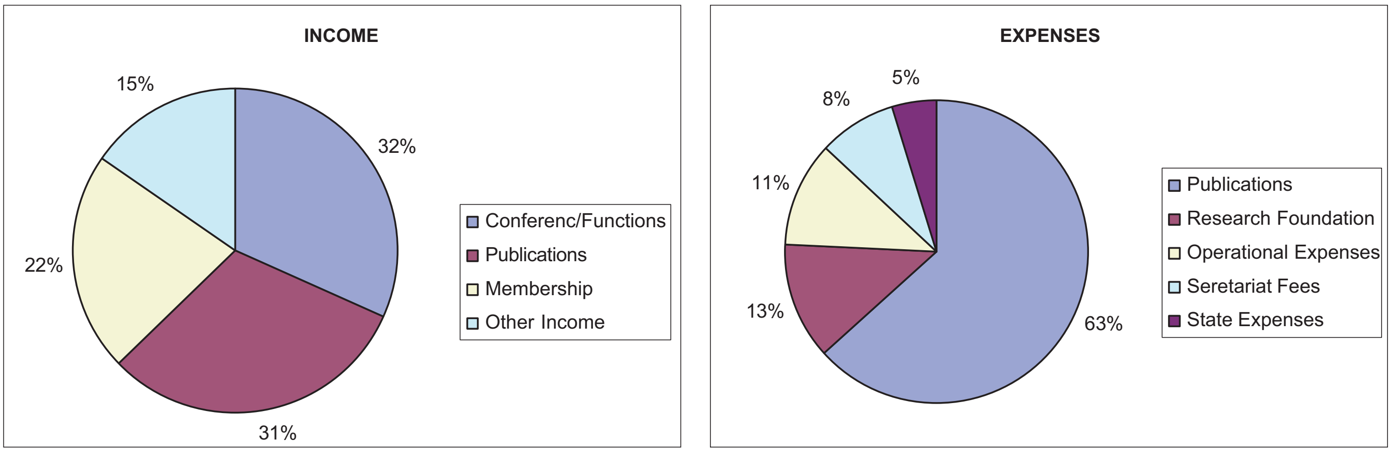

Fig. 1. Total income for 2006 was $520 091, total expenses were $563 949 .

National Summit on "The Plight of University Geoscience Education" 27 September at Geoscience Australia, Canberra

The Australian Geoscience Council (AGC) believes that the current higher educational system in Australia is not able to to provide the geoscientists we need. Highly skilled and motivated geoscientists are required to sustain our resource industries, which provide nearly 40% of our export income, and also to manage our environment. However, it appears that with the demise of earth science departments at universities and falling staffing levels (see Ray Cas, GeoEdLink April 2007 and TAG, June 2007) we are not able to provide the trained graduates required.

To obtain a national perspective, AGC is convening a National Summit in Canberra on 27 September to address this issue. It is currently undertaking a survey and analysis of Tertiary Geoscience Educational opportunities and teaching capabilities across the sector to establish an Australian Tertiary Geoscience Education Profile. This will form a key basis for addressing the education issue.

For enquiries regarding the Summit or to register your interest please contact AGC President Dr Trevor Powell: tpowell@actewagl.net.au, ph: 02 62514128, mobile: 0422 089 532; or AGC Past-President Mike Smith: mike_rpgeo@optusnet.com.au, ph: 02 92522599, mobile 0411 103 761.

[1]This is an edited version of the statement presented by the Honorary Treasurer to the 2007 AGM in May.

[2]This was derived from the 2006 Australian Earth Sciences Convention held in Melbourne.

Lithologically constrained inversion of magnetic and gravity data sets

Summary

A gravity and magnetic potential field litho-inversion scheme that we have used to evaluate and refine 3D geological maps is briefly described. When producing such maps, there are only a limited number of direct geological observations to constrain the distribution of geological units in the volume of interest. A very large number of geological models that satisfy these *a priori* geological constraints could be generated. Using a Bayesian approach to inversion, we reduce the level of uncertainty by identifying a subset of the possible models that can reproduce a set of geophysical observations in addition to the *a priori* geological constraints.

A 3D 'reference' geological model that contains the *a priori* geological knowledge is built. Using supplied estimates of the physical properties associated with each of the geological units, property models are generated that are directly related to this geological model. The gravity and magnetic fields of these property models can thus be calculated. A likelihood is derived for this combination of geological model, property models and geophysical observations by comparing the calculated response with the geophysical observations.

A large sample of the possible geological models is generated in an iterative fashion by making incremental changes to the lithological regions and/or the properties. A likelihood is derived for each new combination. We gain geological insight from the inversion by isolating and statistically analysing the models with high likelihood with respect to the potential field data. As a consequence of generating many different geological models in the course of the inversion, we can begin to explore the geological uncertainty in the inversion results. An overview of a case study for the method is presented for the Bet Bet region in central Victoria, Australia.

Introduction

With increasing demand for 3D geological models, there is a need to produce models more efficiently, and, coupled with this, a need to quantify the reliability of the models. To build and re-build 3D geological models rapidly, an implicit mathematical functions method is used (Lajaunie *et al*. 1997; Calcagno *et al*. 2006). This method allows the model to be constructed directly from a range of geological observations, which also means that the model can be easily revised from time to time as new data become available.

The validity of the 3D geological model can be estimated statistically by inverting complementary geophysical datasets. Gravity and magnetic potential field data are useful in this context because:

(1) the data are a function of the 3D distribution of a source,

(2) the response of the 3D source distribution can be calculated, and

(3) the source distribution in many instances shows a high degree of correlation with geological litho-regions.

Unfortunately, inversion of these data will not return a unique property source geometry solution, nor is it likely in practice that the source geometry will be perfectly correlated with the litho-regions. Despite these limitations, we can still obtain useful information by using a Bayesian approach to inversion. This approach begins with the recognition that direct observational knowledge of 3D geology is imperfect. For any set of geological observations and assumptions (i.e. the *a priori* geological information), there is an infinite number of geological models that could be generated, and perhaps a large but finite number of 'significantly different' models. The number of permissible models can be refined by relating each geological model to a set of independent geophysical observations through observations and/or assumptions about the physical properties associated with each of the geological units (i.e. the *a priori* property information) and the laws of physics, which we assume are correct. We can quantify the likelihood of a geological model (i.e. the *a posteriori* probability) by comparing the calculated and observed geophysical data, with the likelihood increasing as the misfit decreases. If we sample the range of possible geological models, we will be able to identify those that have significant likelihood, and hence have used the geophysical data to gain insight into the likely geological architecture of the model region.

To reduce the non-uniqueness and to increase the geological information that can be recovered from gravity and magnetic data, any number of scalar, vector or tensor components of each potential field can be included in a simultaneous inversion.

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Outline of the inversion algorithm

Although every inversion has a unique workflow, the inversion procedure can be generalised into a sequence of four phases (Table 1).

Phase 1 – initialisation phase

A 3D geological model describing the 3D geometry of geological units is built from a combination of geological observations and inferences. The model is discretised

Table 1. Outline of the steps involved in the inversion algorithm
Phase 1 – Initialisation Phase
(1a) Build the *a priori* geological model (1b) Define the *a priori* physical property laws (1c) Specify any *a priori* geological constraints (e.g. 'shape' and 'commonality' parameters) (1d) Discretise the model to a voxel-based lithologic model (1e) Specify *a priori* 'fixed' voxels (1f) Make a list of the geological-boundary or frontier cells (1g) Compute a unit-response kernel for the gravity and/or magnetic field and/or their tensor components for each voxel at each observation location (1h) Initialise the models of density, induced magnetisation, and remanence, and initialise any values required for the geological tests (1i) Compute the geophysical effects of the model
Phase 2 – Forward Model Checks
(2a) Confirm that the responses from Step 1i reproduce the first order features of the observed geophysical data
Phase 3 – Iteration Phase
(3a) Select a voxel at random and postulate a change to the model (3b) Assess the geological acceptability of the changed model (3c) If geologically accepted, compute the geophysical responses of the changed model (3d) Using the geophysics misfits, compute the likelihoods of the changed model and decide whether to accept the postulated change to the model or revert to the previous model
Phase 4 – Analysis Phase
(4a) Analyse the ensemble of models and generate various statistics (4b) Visualise inversion products in the context of the reference geological model, noting concordant and discordant regions (4c) Modify the reference geological model in the discordant regions if a single representative geological model is required or communicate the full Bayesian outcome that includes an uncertainty assessment

into a 3D matrix of voxels to produce a reference lithological model. There is considerable ambiguity in the way a 3D geological model is constructed from sparse observations. To decide if we have chosen a viable configuration, we evaluate the model with respect to independent geophysical observations through Bayesian inversion.

Phase 2 – forward model checks

The forward model check that is performed in Phase 2 is subjective at this stage. It is carried out to ensure that the basic architecture of the geological model is consistent with the potential field data, and by doing so, ensure that the inversion procedure will be successful in a reasonable period of time. If there is very little correspondence between the major features of the observed and calculated geophysical data, the user needs to return to Phase 1 and re-consider the *a priori* geological model and the *a priori* physical property laws (Steps 1a and 1b).

Phase 3 – iteration phase

A Bayesian inversion approach requires many alternate geological configurations to be generated and examined for consistency with the observed gravity and magnetic data. We limit the variations applied to the geological model by requiring each model to have certain similarities with the reference model. These similarities are expressed as geological constraints, which are a reflection of the geological observations and the geological assumptions that are believed to be true (at least for this exercise). The statistical sampling procedure that is used ensures that we concentrate sampling of the geological models on those that reproduce the supplied gravity or magnetic data to within a desired tolerance level. The adopted strategy is thus a 'guided random walk' around the space of possible models for a given set of *a priori* information. This approach is described mathematically by Mosegaard and Tarantola (1995) and has been applied to potential field inversion in 2D by Bosch *et al*. (2001).

An iterative procedure is used to generate many postulated geological models. At each iteration, we make one of two possible changes (Step 3a).

(1) The physical property values (density and/or magnetic susceptibility and/or remnant magnetisation) for a randomly selected voxel anywhere in the model may be modified. The new physical property values are obtained through random selection from the probability functions supplied by the user to describe the relevant physical property distributions for the lithological unit assigned to the selected voxel.

(2) Alternately, the lithology of a voxel that lies on the interface between two or more units may be modified. The postulated new lithology is obtained by random selection from the set of lithologies assigned to the voxels in the immediate neighbourhood of the target voxel. Since a change of lithology constitutes a small change to geological boundaries of the litho-model, such a postulated revision of the geological voxel model is first examined for consistency with the *a priori* geological constraints. One or more geological constraints or tests may be applied (Step 3b), including:

– ***Fixed cells***, where the geological assignment in certain cells is kept fixed at the reference value throughout the procedure.

– ***Shape ratio***, where the 'shape' of a unit, based on the ratio of that unit's surface area to volume, is maintained statistically between limits.

– ***Commonality***, where the degree of overlap in the distribution of each unit relative to the configuration in the reference lithology model is controlled statistically.

The specification of 'shape' and 'commonality' constraints is guided by our level of confidence in the initial distribution of each unit in the reference model.

At Step 3b, the postulated geological model may be rejected on the basis of any one of the geological tests, in which case the proposed change is discarded and the inversion commences a new iteration at Step 3a. At Steps 3c and 3d, each of the requested geophysics fields are computed in turn, and their likelihood evaluated. If the changed model is rejected on the basis of a computed likelihood, the proposed change is discarded and the inversion commences a new iteration at Step 3a. If the changed model is accepted on the basis of the computed likelihood for all requested geophysics fields components, the proposed change is retained, and this new model is stored. The inversion returns to Step 3a and continues to iterate around this loop. An ensemble of geological and associated property models that satisfy geological constraints and can satisfactorily explain the geophysical signature are (partially) explored by continuing this process for several million iterations.

During the initial part of the Iteration Phase, the data misfit for each field of the current model follows a generally decreasing trend. As the data misfit reaches values more in keeping with the specified data uncertainty values, the rate of change in misfit decreases, and we begin to store the models. By using a Metropolis acceptance test (Metropolis *et al.* 1953), these stored models are an exploration of the higher posterior probability regions of the set of acceptable *a priori* geological models.

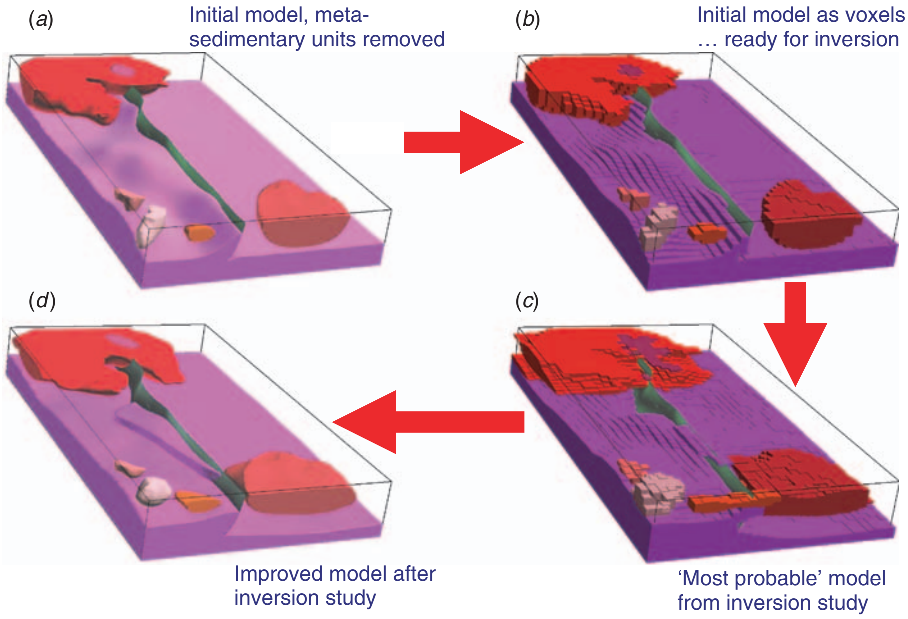

Fig. 1. Summary of the Bet Bet inversion example. Model dimensions are 33 km E/W, 57 km N/S and 7.7 km vertically. (a) Initial geological model with meta-sedimentary units removed. (b) Initial model in voxel format ready for inversion. (c) 'Most probable' composite model from the inversion study. (d) Improved geological model after the inversion study.

Phase 4 – analysis phase

Using this procedure, it is possible to generate a large number of geological models that reproduce the gravity and magnetic observations to an acceptable degree. These models are analysed statistically. For example, the 'most probable lithology' for any voxel can be found by examining the ensemble and determining which lithology was assigned to this voxel more often than any other. A composite 'most probable' model can be compiled by combining the results thus obtained for each separate voxel into a single geological model. The various statistical outputs can be presented as voxel-models, cross-sections, and as horizontal slices. These displays can be combined with the reference geological model to highlight regions of concordance and discordance between the reference model and the statistical products of the inversion.

Application to the Bet Bet Region

A 3D geological model of the Bet Bet region, Victoria, Australia, was built from a combination of field mapping data, drillholes and interpretive inferences (Fig. 1a). The 33 km E/W by 57 km N/S by 7.7 km vertical extent project volume was discretised into 33 × 57 × 77 voxels having dimensions of 1000 m E/W, 1000 m N/S, and 100 m vertically (Fig. 1b).

Eleven geological units were used in the model. For several of these, only limited physical property data were available and we were forced to determine suitable property values by alternate means. The method used to select these values was underpinned by the premise that the geometry for these units in the reference model was approximately correct. The *a priori* geological and property knowledge of these units is too limited to contradict this stance. First, we isolated the region occupied by each geological unit in the reference model. Unit-property response grids were then calculated for each of the geophysical fields and each of the geological units. A bounded least-squares optimisation of a set of formation weights was performed to minimise the misfit between the summed weighted formation signatures to the observed data. The bounds were set using background knowledge of likely property values for the lithological mixtures present in each geological unit. The resultant weights were interpreted as estimates of the optimal physical property values for each geology formation assuming that the reference geometry was correct. These 'optimised' values were used in the inversion work for the formations with limited *a priori* property values.

In terms of geological constraints, the lithology was assumed to be known perfectly ('fixed') for those voxels coinciding with areas of mapped outcrop, and also for voxels pierced by drillholes. The inversion was required to maintain an approximate overlap of 80% in the distribution of each unit relative to the configuration in the reference geological model using the 'commonality' geological constraint. This implies that the reference model was considered to be 'approximately 80% correct'. The shape for each unit was also generally maintained to produce shapes that were within 5% of the shape expressed in the reference mode using the 'shape ratio' geological constraint.

We confirmed through forward modelling that the geophysical response grids associated with the reference geological model reproduced the first order features of the observed total magnetic intensity and vertical gravity gradient data. Several inversion runs were then carried out, generating many tens of millions of stored models in a procedure that took several days to run on a single desktop PC. Through statistical analysis, elements of the geometry that were common to many of these models were identified (Fig. 1c). A revised 3D geological model was build by introducing secondary geological constraints at locations where these common features were significantly different to the original reference configuration (Fig. 1d). The revised 3D geological model was consistent not just with the geological observations but also with the observed gravity and magnetic data. Although not shown, a 3D probability map was produced for each of the geological units to communicate the degree of *a posteriori* uncertainty in the mapping.

Recent and planned developments

The stochastic litho-inversion method described in this paper has been implemented in the GeoModeller software package (GeoModeller 2007). The release of version 1.2 of the software in July 2007 marked the culmination of a 30 month development and commercialisation phase by Intrepid Geophysics and BRGM, supported by a number of government agencies and companies.

Continued on p. 17

Ultra-detailed airborne geophysical surveys applied in an integrated approach to gold exploration in New Zealand

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Introduction

Glass Earth Limited, a junior New Zealand gold exploration company, has changed the paradigm of mineral exploration in New Zealand, championing a region-wide data-driven approach to discovery of new mineral deposits. Key to this approach is the collection of geophysical data sets encompassing whole geological provinces and using this data to derive the most accurate geological and structural models that will guide explorers to areas of significant mineral accumulation.

In the North Island, the Hauraki and Central Volcanic Regions are recognised as epithermal terranes, and are blanketed by a 5–150 m deep ash cover, which has hindered previous surface exploration. The Hauraki Region is host to the ~310 tonne Martha Gold Mine, considered the 'type' epithermal gold deposit. Glass Earth makes aggressive use of geophysics, completing in 2005 a region-wide ultra-detailed magnetic survey (UTS Geophysics) and a regional airborne gravity survey (AirGrav™ by Bell Geospace), followed up in 2006 and 2007 with ground CSAMT (GNS) and DC E-SCAN® (Premier Geophysics Inc.) resistivity surveys on the targets identified through a synthesis of existing geoscientific data and regional geophysics. This process led in 2006 to the drilling of the Tahunaatara prospect and subsequent discovery of a large new epithermal gold system, and it is continuing to define further gold targets.

In the South Island of New Zealand, the Otago Region historically produced ~225 tonnes of alluvial gold and is the host of the ~200 tonne mesothermal Macraes Gold Mine. Throughout 30 years of exploration by numerous companies, only one small 180 km^2 aerial geophysical survey over the Macraes Gold Mine was completed. It was clear, however, that this survey was mapping some of the important structural elements associated with mesothermal gold mineralisation. Glass Earth saw this as an exploration opportunity and recently completed a 12 900 km^2 helicopter electromagnetic (HEM) survey, using Fugro's RESOLVE™ combined EM and gradient magnetometry system (see Figure 1) – this survey is one of the five largest RESOLVE™ surveys ever flown, and the largest airborne geophysical survey conducted in New Zealand. The preliminary results of the survey are very encouraging and are discussed below.

Fig.1. Fugro's RESOLVE™ HEM and gradient array magnetometry system.

Use of geophysics to search for epithermal gold in the North Island

Epithermal gold mineralisation in the Central Volcanic Region (CVR) of the North Island is the manifestation of the intense former and current geothermal activity of the region. The Waiotapu geothermal pools (south of Rotorua) are actively depositing gold at ore grade (16 g/t Au) as gold arsenic and antimony compounds in silica sinter. Waiotapu illustrates the gold potential of the region.

Epithermal gold deposits have a distinctive geophysical signature: the hydrothermal fluid flow occurring during the formation of a fossil geothermal system causes the destruction of magnetite in the host rocks.

Additionally, the silica formed in the shallow parts of hydrothermal systems, after precipitation of the metals/elements due to a sharp change in physical gradients (temperature and pressure) in the hydrothermal cell, is characterised by an increased density of the host rocks. Therefore, the fossil geothermal systems, or epithermal systems, can be pinpointed through a combination of magnetic and gravity anomalies, namely through the concurrence of a magnetic low and a gravity high.

Finally, the formation of silica in the shallow parts of the hydrothermal systems also causes the electrical resistivity of the host rocks to significantly increase. Such silicified zones are associated with high resistivity anomalies, which can be located using ground resistivity surveys.

A number of ranked and scored gold exploration targets were identified by Glass Earth from a comprehensive review and analysis of geoscientific data in the CVR in 2004. Following this legacy data intervention, Glass Earth commenced 40 000 line-km of ultra-detailed airborne magnetic surveying and 6000 km of airborne gravity surveying in 2005. These detailed surveys were designed to resolve the structure and alteration sufficiently to identify individual drill targets, add new potential targets to the existing target banks in areas with poor data coverage, increase high-resolution magnetics in the CVR 4-fold, and provide the first ever substantial airborne gravity data in the region.

Ultra-detailed airborne magnetic survey

The airborne magnetic survey was carried out for Glass Earth by Universal Tracking System Pty Ltd, Belmont, Western Australia (UTS Geophysics). Survey lines were orientated east–west, at 150 m line spacing with survey elevation of 60 m above ground level. The airborne survey was conducted using a fixed wing aircraft equipped with a Scintrex CS-2 Cesium Vapour Magnetometer and a GR-820 Gamma Ray Spectrometer (see Figure 2).

Magnetic field (total magnetic intensity) was digitally recorded at 10 Hz or 0.1 second reading intervals. Radiometric data were digitally recorded at 1.0 second intervals (1.0 Hz).

The airborne magnetic survey covered an area of approximately 5340 km^2 over the CVR (Figure 3).

Airborne gravity survey

The airborne gravity survey was carried out by Bell Geospace Ltd, Aberdeen, Scotland. Survey lines were orientated east–west, at 450 m spacing with survey elevation at 90 m above ground level. Gravity gradient tensor elements were measured with a BGL 3D-FTG system built by Lockheed Martin Corp. This instrument was mounted on a fixed wing aircraft. The aircraft also carried a Novatel GPS system for positioning and tracking the plane's location. GPS signals were differentially corrected to provide accuracy to within ± 1 metre.

The airborne gravity survey covered a smaller area of about 2290 km^2, located within the airborne magnetic survey area (Figure 3). The gravity gradiometer results were verified by flying test lines across the Broadlands geothermal field in the east of the CVR. This field is characterised as having a ground gravity anomaly (previously surveyed by the Institute of Geological and Nuclear Sciences (GNS)). This anomaly was replicated by Glass Earth's airborne survey, with additional resolution apparent.

The result of these surveys was a quantum leap in data density, quality and availability; collation and interrogation of these data allowed the identification and ranking of 127 epithermal gold targets in the CVR. Glass Earth continued in its use of geophysical techniques to further investigate these targets, conducting extensive on-ground CSAMT and E-SCAN® DC resistivity surveys throughout 2006 and 2007.

Fig. 2. Fixed wing magnetic and radiometric aircraft on survey.

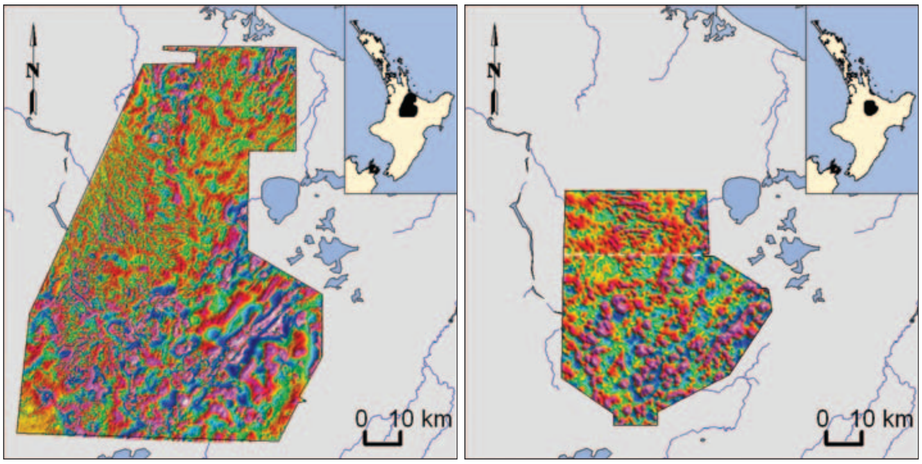

Fig. 3. Glass Earth airborne magnetic (TMI anomalies) (left) and gravity (right) surveys in the CVR. Colour scheme pink/red (high) to blue (low).

Follow-up surveys: CSAMT ground resistivity

The Controlled Source Audio Magnetotelluric (CSAMT) method was selected for ground resistivity surveying mainly for its high resolution and minimal risk to livestock common in the survey areas. The surveys were conducted using a Zonge GDP 32 8-channel receiver and a Zonge XMT 32 transmitter powered by a 16 kW generator. The electric field dipole was maintained at 20 m length (five dipoles per 100 m spread) and the frequency ranged from 4 kHz to 4Hz. Only scalar (TM mode) signals were recorded, using one magnetic coil per spread. The transmitter bipoles were 1–4 km in length and located 5–10 km from each survey area. Operators and equipment for the CSAMT field work were provided by GNS Ltd Wairakei as a contractor to Glass Earth (see Figure 4). Sixteen targets were surveyed between February 2006 and June 2007, with a total survey line length of about 140 km. Line spacing for individual targets ranged from 400 m (reconnaissance) to 100 m (detailed). Figure 5 is an example of CSAMT profile across Glass Earth's Tahunaatara target.

Follow-up surveys: E-SCAN® 3D DC resistivity

Glass Earth engaged Premier Geophysics Inc., Canada to carry out 3D DC resistivity surveys using the E-SCAN® method over several targets in the CVR. It's the first time this method has been used in New Zealand.

Fig. 4. CSAMT survey taking place.

The principle behind the E-SCAN® technique is to take high-density DC resistivity measurements between multiple locations and with different orientations in one set-up. The grounded electrodes are placed in a 300 m spacing grid pattern, over the whole target area (20 km^2 in the case of Glass Earth's first E-SCAN® survey at Ohakuri). This technique allows the generation of a 3D map of the resistivity of the underlying features, as opposed to the 2D result obtained with usual DC resistivity surveys.

Therefore, by conducting an all-direction, high-density true 3D survey approach, the initial guesswork as to the orientation of structure is eliminated, with all orientations tested in a single survey pass. The high resolution of 3D geological features allows direct and effective targeting of potential gold-bearing

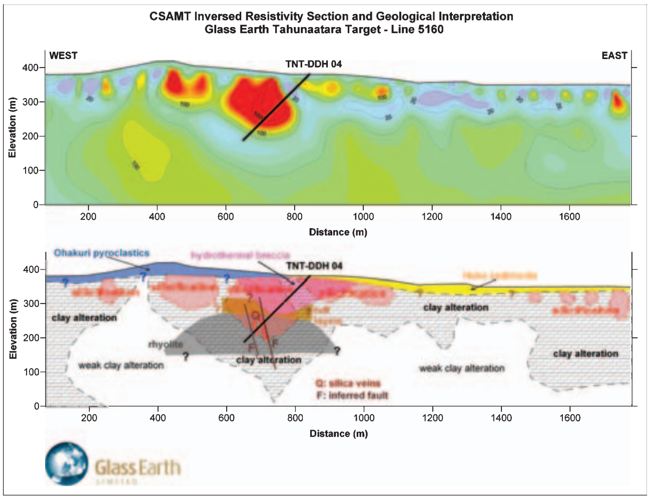

Fig. 5. 2D inversion resistivity section along Line 5160, Tahunaatara target, and geological interpretation shown below .

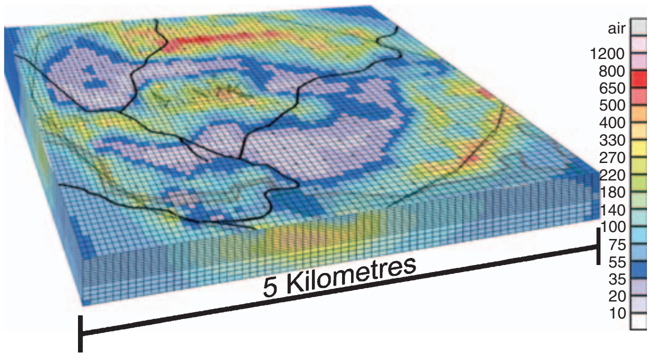

Fig. 6. Preliminary E-SCAN® DC resistivity 3D data view (Ohm-metre) – Ohakuri target.

structures. The E-SCAN® field work was recently completed over the Ohakuri target (see Figure 6), final results are pending.

Results of geophysical surveys in the North Island

The airborne surveys have contributed to further understanding the structural settings of a number of epithermal areas, some of which were unknown or only partly understood. Such areas were made more obvious on images by using appropriate filters such as high pass, various derivatives and analytic signal. Low pass frequency filtering assists in defining structural controls within the CVR. Magnetic and gravity 'worms' have been found to be particularly useful in delineating major regional structural features that may control the emplacement of epithermal systems.

Implementation of petrophysical measurements on drill core (density, magnetic susceptibility and resistivity) assists with data interpretation for successful targeting of geophysical targets.

Use of geophysics in the search for mesothermal and alluvial gold in the South Island

The 200 tonne Macraes Gold Mine, the largest producing mine in New Zealand, as well as 225 tonnes of alluvial gold recovered, attests to the capacity of the Otago Region to host significant gold mineralisation.

Currently, there is no well-understood model for the Otago mesothermal style gold mineralisation, and even less understanding of the geophysical signatures associated with mesothermal gold deposits in the Otago Region. Glass Earth, by reprocessing and interpreting legacy data, has defined the Macraes mine's geophysical signature, therefore opening up the region for exploration of 'covered' gold mineralisation. This was the starting point for Glass Earth's region-wide airborne EM/magnetic RESOLVE™ survey over the Otago Region.

This survey has the potential to directly or indirectly detect regional scale shears similar to the Hyde Macraes Shear Zone, host to the Macraes Gold Mine. It will also allow the delineation of Otago's other mineral and resource potential: untapped ground water, aggregates, coal, coal-bed methane, etc; and to qualify soils, aquifers and hazards, among others.

The Otago Regional Council (ORC) recognised, in this survey, the opportunity to fast-track the region's economic development and provided substantial financial support towards its realisation.

Otago regional HEM survey

From January to July 2007, Glass Earth undertook a large HEM survey over the Otago Region in the South Island of New Zealand. The survey area shown on Figure 7 is 105 km across by 125 km wide and covers an area of 12 900 km^2. Flight lines were orientated northeast-southwest with a spacing of 150 to 300 m. Altogether, some 50 000 line-km were flown, making the survey the largest ever flown in New Zealand in either area covered or line kilometres flown. Prior to this survey, no regional airborne surveys had ever been conducted in the South Island, by either public or private organisations.

The survey was carried out for Glass Earth by Fugro Airborne Surveys Pty Ltd (Fugro) of Australia, using the RESOLVE™ electromagnetic (EM) system mounted in light helicopters. The RESOLVE™ system measures six EM frequencies: 400 Hz, 1800 Hz, 3300 Hz, 8200 Hz, 40 000 Hz and 140 000 Hz and has a ground penetration of approximately 100 m in the relatively resistive country rocks. At the rear of the RESOLVE™ bird was a magnetometer gradient array, which consisted of a 5 m boom with a magnetometer in each end, allowing the measurement of total magnetic intensity (TMI) as well as the horizontal magnetic gradient. The elevation of the RESOLVE™ bird was maintained at a height of 30 m ± 10 m (the helicopter at a height of 60 m). The RESOLVE™ system and the gradient magnetometer array took measurements every 0.1 seconds, which is approximately every 4 m along the survey lines.

Preliminary results of the Otago HEM survey

Figure 7 shows the preliminary Total Magnetic Intensity image from Glass Earth's Otago survey. This figure indicates there is considerably more variation and structural complexity in the Otago Schist than had been previously mapped or interpreted. For example, it can be clearly seen in Figure 7 that there are a set of narrow, strong northwest–southeast trending magnetic features that currently have no explanation. In the northern part of the survey area, there are areas of strongly magnetic schist for which there is also no current explanation. Preliminary

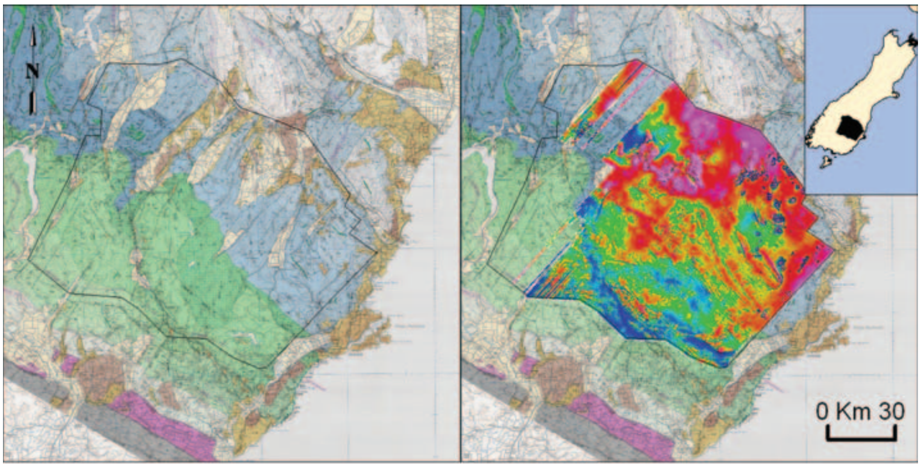

Fig. 7. Otago Region HEM/magnetic survey: left, current geological map (Mortimer 1993); right, preliminary TMI image (colour scheme pink/red (high) to blue (low)).

views of the HEM data show a number of northwest–southeast trending belts of resistive and non-resistive schist indicating some form of lithological variation that has not been recognised as yet.

Conclusion

No publicly funded region-wide geophysical surveys have been conducted in New Zealand in recent times. Such programs remain privately financed, and therefore relatively scarce. Nevertheless, the consequential value of the advanced data collected and combined to legacy data cannot be contested. Glass Earth's airborne magnetic and gravity surveys in the North Island have led to the discovery of a new major epithermal gold system at Tahunaatara, and, associated extensive on-ground resistivity studies are continuing to assist in identifying gold targets for drilling. In the same way, the use of multi-facetted airborne geophysical surveying in the South Island will rewrite the geology of Central Otago, delineating potential world-class mesothermal gold deposits, along with a plethora of other resources.

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The functionality of the software is the subject of ongoing research and development, and the advances in the last year have included development of a process model with a formal schema for forward and inverse geophysical computation, the addition of support for full tensor gradiometry, and improvements to the voxel-based statistical reporting and presentation of inversion results.

There is always an aspiration to represent more complex and realistic geology problems and this requires finer discretisation of the geological model, and hence an increase in the total number of voxels, possibly by an order of magnitude or more. This in turn means that it will take a larger number of iterations to obtain a reasonable sample of the higher posterior probability geological models. A cluster-computer approach that will allow a user to generate a solution for such tasks within an acceptable timeframe is planned.

Acknowledgements

Portions of the work described in this paper were presented by the authors at Workshop W8 of AESC 2006, July 1st, 2006 (*Geologically realistic inversion of gravity and magnetic data*) and the KEGS PDAC 2007 Symposium, March 3rd, 2007 (*Geophysical Inversion: Adding Value to Geological Models*). Contributors to the development of the Bet Bet geological model included John Wilford (CRC LEME, Geoscience Australia), Fiona Watford (Geoscience Australia) and David Moore (Geoscience Victoria). The initial development and commercialisation of 3D GeoModeller mapping and inversion software was a collaborative project between Intrepid Geophysics and BRGM, with support from the Commonwealth, State and Territory geological agencies of Australia, Geological Survey of Namibia, Geological Survey of Canada, Barrick Gold Corporation, and Shell Exploration and Production. The commercialisation project was also proudly supported by International Science Linkages established under the Australian Government's innovation statement, Backing Australia's Ability. Lane publishes with the permission of the CEO, Geoscience Australia.

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The Challenge

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Introduction

The debate about the causes of global warming during the last 60 years or so is really over now. The 2007 reports by the Intergovernmental Panel on Climate Change (IPCC 2007) have shown very clearly that the addition of greenhouse gases to the atmosphere by people burning more and more fossil fuel is the main cause of global warming at this time.

As Kofi Annan said at the UN Climate Change Conference, held in October held in Nairobi in 2006:

A few diehard sceptics continue to deny "global warming" is taking place and try to sow doubt. They should be seen for what they are: ***out of step, out of arguments and out of time.*** *In fact, the scientific consensus is becoming not only more complete, but also more alarming. Many scientists long known for their caution are now saying that global warming trends are perilously close to a point of no return.*

Both the observations of global temperature increases and the climate models are providing consistent results. One of the most compelling diagrams in the IPCC 2007 report is shown in Figure 1, where the effect of the greenhouse gases on the Earth's surface temperature is separated out in the models from other known forcing agents.

So we are looking at a situation where, unless major changes are made to the consumption of fossil fuels, the average global temperatures could rise by up to two degrees above a 1900 baseline during this century.

In an energy hungry world it is no easy task to reduce greenhouse gas emissions. In fact, the IEA (http://www.iea.org/journalists/headlines.asp) forecasts that global oil demand will rise by an average of 2.2% a year from 2007 through 2012 and the demand for coal (http://www.iea.org/textbase/papers/2003/ciab_demand.pdf) is predicted to rise at 2.1% a year for the same period. So the challenge to provide more renewable energy sources is huge. The problem is well illustrated by Figures 2 (for the World) and 3 (for Australia).

Another useful source on future energy use is the 2004 report to the Prime Minister of his Energy Task Force. This lists the Australian energy supply in 2004 as about 5000 petajoules and continuing to rise (see http://www.pmc.gov.au/publications/energy_future/docs/energy_chapter_1.pdf).

For readers confused by energy conversions I can recommend the site www.sei.ie/uploadedfiles/RenewableEnergy/UnitConverterVersion501stOct2003.xls, which provides an excellent conversion calculator.

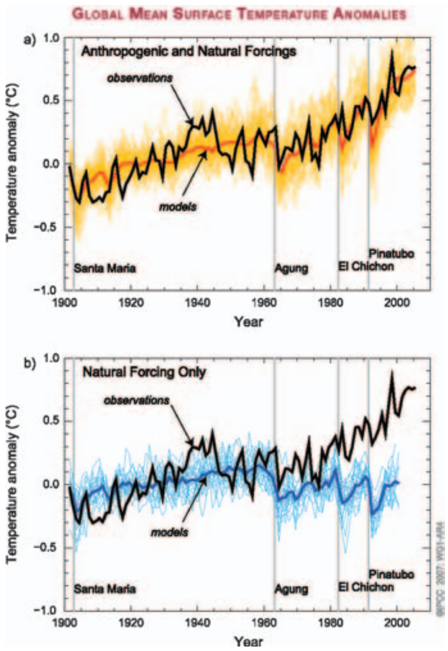

Fig. 1. Temperature modelling from 1900 with and without human actions, from IPCC WG1 report (2007). In each figure the black curve represents the global mean surface temperature anomalies compared to a 1900 base. The red curve shows the average of the models run (yellow curves) including volcanic eruptions and changes to greenhouse gases in the atmosphere. The blue curve shows the forecast without the greenhouse gas effects. Agung, El Chichon and Pinatubo are major volcanic eruptions that took place in Indonesia, Mexico and the Philippines.

Anyway, whether at a global or a national scale, the effort required to increase the renewable energy components is huge, even with the use of nuclear power.

Can geothermal energy help?

So the question is can geothermal energy contribute in providing the energy we will need? And if so, how much? Well the short answer is that geothermal energy can contribute. What we don't know is how much?

In the US, a comprehensive report on *The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems [EGS] on the United States in the 21st Century* was produced by Massachusetts Institute of Technology for the Department of Energy (MIT, 2006). The MIT team concluded that it would be affordable to generate 100 GWe (gigawatts of electricity) or more by 2050, just in the United States, for a maximum investment of 1 billion US dollars in research and development over 15 years.

The MIT report calculated the world's total EGS resources to be over 13 000 Zettajoules of which over 200 ZJ would be extractable, with the potential to increase this to over 2000 ZJ with technology improvements. So we are talking about huge amounts of energy – sufficient to provide all the world's energy needs for thousands of years – if it can be harnessed.

Even if Australia is host to only one tenth of the estimated US resource the generation capacity will be significant. At present, the resource assessment of

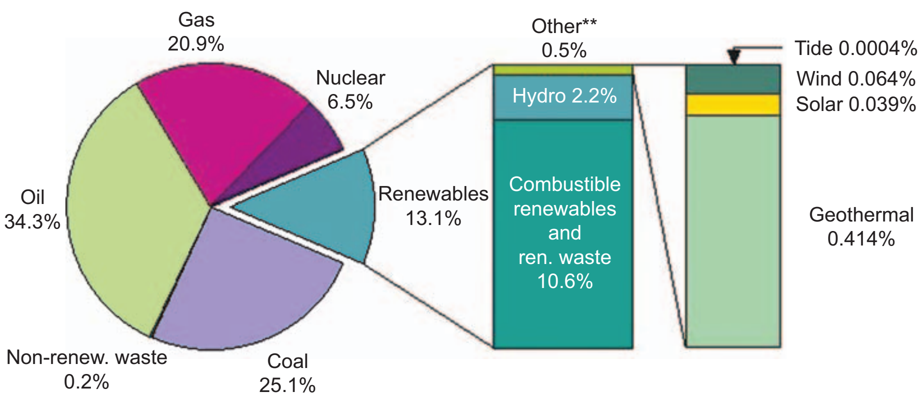

*Fig. 2. 2004 fuel shares of world Total Primary Energy Supply (TPES). TPES is calculated using the IEA conventions. It includes international marine bunkers and excludes electricity/heat trade. The figures include both commercial and non-commercial energy. ** Geothermal, solar, wind, tide/wave/ocean. Totals in diagram might not add up due to rounding. See http://www.iea.org/textbase/papers/2006/renewable_factsheet.pdf.*

Continued on p. 20

The search for Australia's geothermal resources

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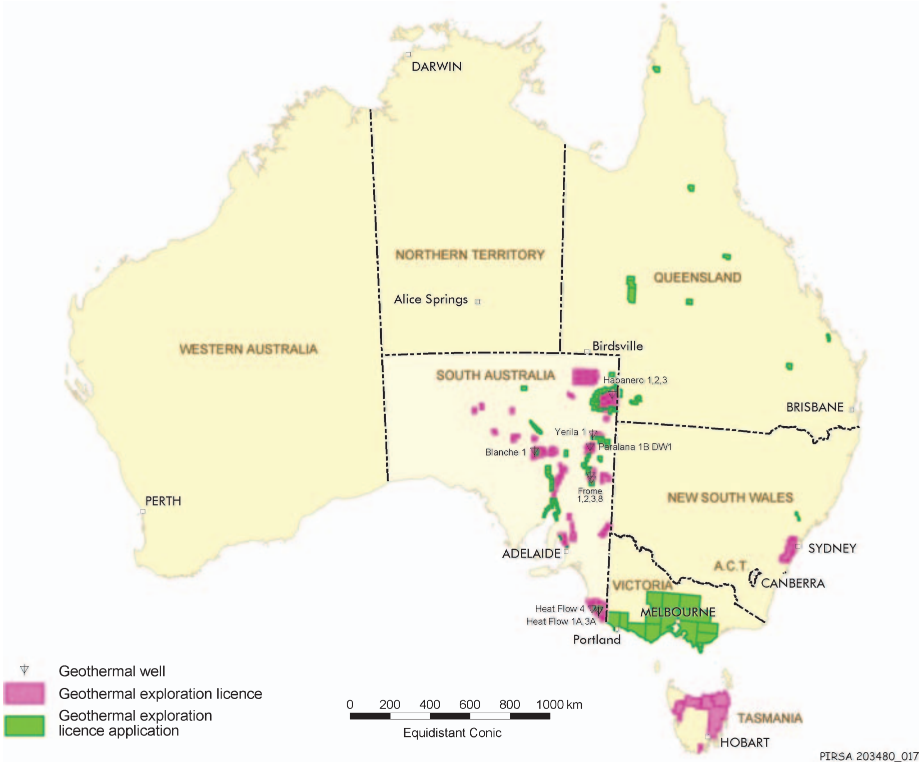

Fig. 1. Geothermal licences, applications and gazettal areas throughout Australia.

Summary

Since the grant of the first Geothermal Exploration Licence (GEL) in Australia in 2001 through July 2007, 27 companies have applied for 197 licences with a 5 year work program amounting to in excess of $700 million (Figure 1).

This represents over a 100% increase in the value of the work programs since 2005. In 2006, an estimated $29 million was spent on surveys and well operations in Geothermal Licences focusing on geothermal resources in South Australia. This is an 11% increase ($3 million) from the previous year and a 97% increase (to $45 million) is forecast for 2007. Ninety-six percent of this is associated with Geothermal Licences in South Australia. Historical, current and projected expenditures for the period 2000–2007 are highlighted in Figure 2.

Five states (South Australia, New South Wales, Queensland, Tasmania and Victoria) have enacted legislation to regulate geothermal exploration and development. Western Australia and the Northern Territory, expect to have legislation in place at the end of 2007.

Both state and federal governments are encouraging the development of low emission power generation. They have invested nearly $30 million in geothermal research, demonstration and development initiatives over the last seven years.

Since the drilling of Habanero 1 by Geodynamics Limited in 2003 through April 2007, 13 geothermal wells have been drilled in Australia by five companies: Geodynamics Limited, Petratherm Limited, Green Rock Energy Limited, Scopenergy Limited and Geothermal Resources Limited, all within South Australia. In addition, Pacific Hydro undertook temperature surveys of water bores to further geothermal exploration drilling is expected to be undertaken by at least Torrens Energy and Eden Energy over the period 2007–2008.

Strong public interest and investment has been sustained in geothermal companies listed on the Australian Stock Exchange (ASX). At end June 2007, the six geothermal explorers listed on the ASX had a market capitalisation in excess of $500 million.

Geodynamics has recently acquired the largest rig to operate in mainland Australia, at a cost of $32 million. It is capable of drilling a 20 cm diameter hole to a depth of 6 km and will be used this year to develop the Habanero Geothermal Field in South Australia.

Based on these results, the future for developing geothermal resources in Australia is bright because the geology, the technical facilities available and the economics are very encouraging.

Introduction

There is now great pressure for Australia to reduce its greenhouse gas emissions to combat global warming. This paper, which relies heavily on the *Australian Geothermal Implementing Agreement Annual Report – 2006* (Goldstein and Hill 2007), outlines the progress made in the last few years to identify and develop Australia's geothermal resources. The original report was prepared for the Australian Geothermal Energy Group (AGEG)[1] , which provides financial and intellectual support for Australia's membership in the International Energy Agency's Geothermal Implementing Agreement.

[1]For more information on AGEG contact Barry Goldstein, the Executive Committee Member for Australia.

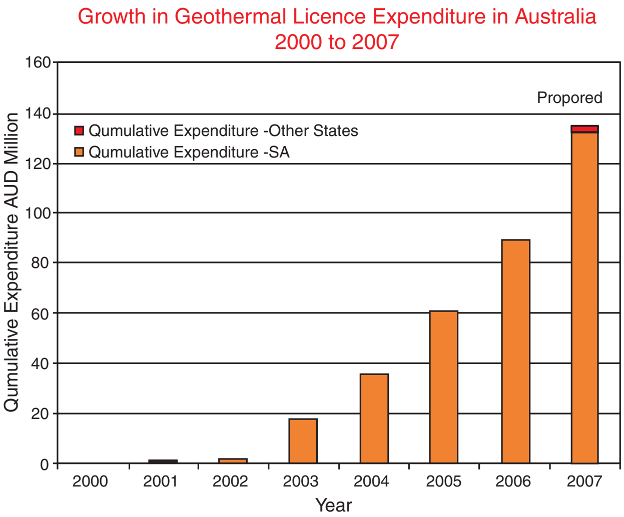

Fig. 2. Continent-wide geothermal licence exploration expenditure, 2000–2007.

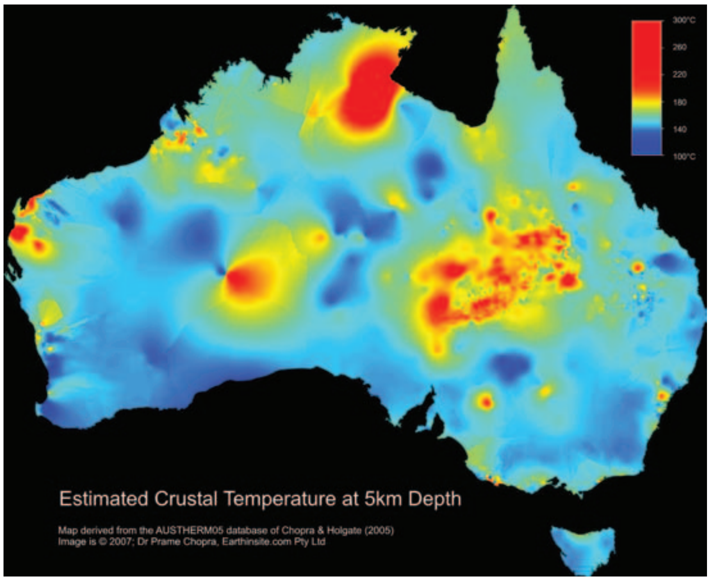

Fig. 3. Map of extrapolated temperature at 5 km depth interpolated across Australia. This map is based on available (in places sparse) data that may not truly reflect geothermal gradients on a regional basis. Image derived from the AUSTHERM05 database of Chopra and Holgate (2005). Image copyright ©2007 Prame Chopra, Earthinsite.com Pty Ltd.

The current 48 member organisations of AGEG include representatives from:

- 27 companies with geothermal licences and pending application for licences in Australia;
- Federal, State and Territory government agencies responsible for investment attraction and licence regulation for the geothermal sector;
- University experts conducting research with implications for the geothermal energy sector;
- Companies providing services to the geothermal sector; and
- An aligned lobby group – the Renewable Energy Generators of Australia (REGA).

All members of the AGEG have a common interest in sharing information to commercialise Australia's geothermal resources at maximum pace and minimum cost. The aim is for ***geothermal resources to provide the lowest-cost emissions-free renewable base load energy for centuries to come.***

Current use of geothermal energy

At present, electricity from geothermal energy in Australia is only produced at one small binary power station at Birdsville in western Queensland, and this is supplemented by diesel powered generators. The fluid is 98˚C and derives from the Great Artesian Basin. The gross capacity of the plant is 120 kW and has 40 kW parasitic losses, which equates to a net output of 80 kW.

Direct use of geothermal waters has been used in Portland in western Victoria, where hot water is pumped from a 1400 m deep bore at a temperature of 58˚C at rates of approximately 60 L/s with a nominal capacity of 3600 kW. It is used to heat many of the municipal buildings and public facilities. Geothermal waters are also used for spas at Moree, Barradine and Lightning Ridge in New South Wales and at Hastings in south east Tasmania. There are also two developments in Victoria on the Mornington Peninsula and another spa resort in Gippsland, Victoria. There are no available estimates of the amount of energy being produced at these locations,

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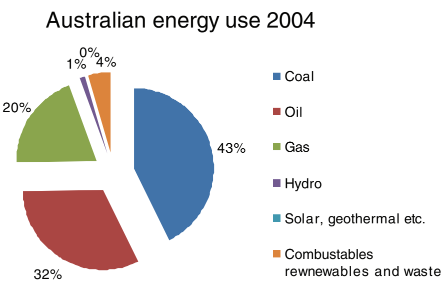

Fig. 3. Total energy use in Australia for 2004 from the website: http://www.iea.org/Textbase/stats/countryresults.asp?COUNTRY_CODE=AU&Submit=Submit. The total energy use was 115775 ktoe (~4850 PJ). Notice how small (~5%) the renewable energy sources were.

geothermal resources, the legislative framework for exploring and the actual investment required to make things happen is just beginning. Hopefully, the contributions that follow will give an up-to-date view on where we are at and also provide encouragement for geothermal explorers.

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MIT, 2006, T*he Future of Geothermal Energy: Impact of Enhanced Geothermal Systems on the United States in the 21st Century*, produced by Massachusetts Institute of Technology. for the US Department of Energy, available from: http://geothermal.inel.gov and http://www1.eere.energy.gov/geothermal/egs_technology.html.

but clearly they only provide very small contributions in the context of the national energy budget. Ground source heat pumps are also finding increased use in Australia in both commercial and residential applications.

The plan now is to expand the use of geothermal energy in Australia by many orders of magnitude.

Australia's geothermal energy resources

Geoscience Australia's Geothermal Energy Project: a national perspective

The Australian Government's 2004 White Paper *Securing Australia's Energy Future* (www.pmc.gov.au/energy_future) classified hot dry rocks as a technology in which Australia was a market leader and the Australian Governments' support for geothermal exploration (research), appraisal (proof-of-concept) and demonstration projects confirms the view that geothermal energy has the potential to contribute significantly to Australia's base load electricity supplies, without generating greenhouse gas emissions.

Included in this policy was the introduction of the Low Emissions Technology Development Fund (LETDF) to provide at least $500 million over a 15 year period for companies to demonstrate new technologies that will significantly reduce long term green house gas emissions.

The Australian Government has also recently committed $58.9 million to the onshore component of the Energy Security Initiative, providing Geoscience Australia funding for five years from mid-2006 to 2011 to improve our knowledge of Australia's onshore energy resources. The program is targeted towards a specific range of energy commodities that include onshore geothermal energy, petroleum, uranium and thorium. Using the latest technology and mapping techniques, Geoscience Australia aims to provide pre-competitive geoscientific information that will help attract companies to explore in new areas by enhancing the chances of discovery and reducing the risks to investors. Geoscience Australia's Onshore Energy Security Program includes the acquisition of new seismic, radiometric, magneto-telluric, gravity, magnetic, AEM, geochemical and drillhole data in support of exploration for the targeted range of energy resources.

Available maps of crustal temperature (Figure 3) clearly illustrate that the geothermal energy resource in Australia is vast. Electricity is expected to be generated from both hydrothermal (hot groundwater *in situ* e.g. the Great Artesian Basin) and Hot Rock plays (e.g. buried hot granites within the Cooper Basin). Significant potential also exists for lower-temperature hydrothermal resources close to population or industry centres which may be useable by direct means.

The Geothermal Energy Project in the Onshore Energy and Minerals Division at GA aims to support ongoing geothermal energy exploration across Australia via the provision of new maps of heat distribution together with a comprehensive national geothermal information system. Heat distribution throughout Australia will be mapped in three ways: (1) new heat flow measurements in existing and new drillholes; (2) a map showing the distribution of radiogenic granites (heat sources) and sedimentary basins (heat traps) to identify potential geothermal plays (Figure 4); and (3) improvements to the 5 km temperature map of Chopra and Holgate (2005). The geothermal information system will comprise a wide range of information including (but not limited to) thermal conductivity, thermal gradient, density, and heat production data. For more information contact: anthony.budd@ga.gov.au; (02) 6249 9574.

State/Territory programs

Five states (South Australia, New South Wales, Queensland, Tasmania and Victoria) have legislation in place to regulate geothermal exploration and development as per the following reviews.

New South Wales

Legislation and policy

Mining Act, 1992 governing geothermal exploration in NSW is on its final review stage for a Bill amendment. Currently, geothermal energy is considered Group 8 – Geothermal Substances. Application for a

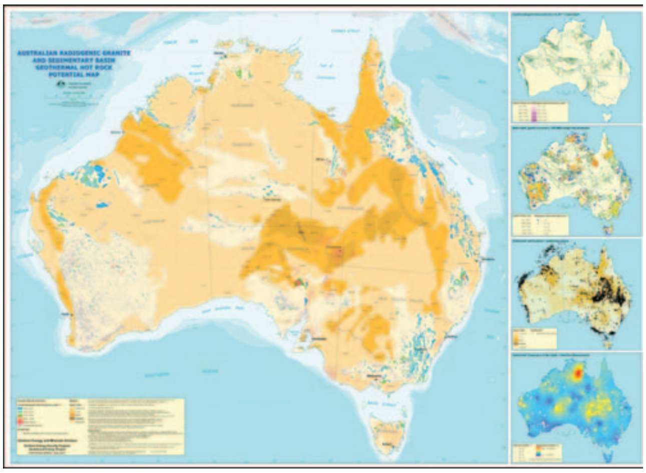

Fig. 4. Map showing schematic distribution of granites and their radiogenic heat production, combined with location and depth of sedimentary basins (main panel). The basins are coloured by their order: the darker basins underlie younger basins which are coloured paler. The granites are coloured red-orange-green-pale blue-deep blue in order of decreasing radiogenic heat production. Right-hand panels include information on distribution of geochemical samples and their U-Th-K contents, distribution of downhole temperature measurements, depth of sedimentary basins, and temperature at 5 km depth. The map can be downloaded at http://www.ga.gov.au/minerals/research/national/geothermal/index.jsp.

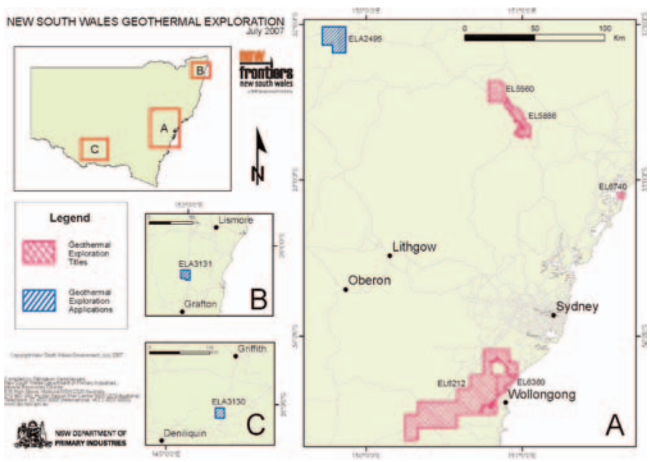

Fig. 5. Location of NSW geothermal exploration leases in July 2007 (see also Table 1).

Group 8 exploration licence requires the Minister's consent especially if it is under mineral allocation areas, usually within coal basins. If successful, a maximum 5-year term is granted based on work program commitments. NSW has not gazetted any acreage for geothermal exploration and accepts over-the-counter applications except those that are under mineral allocation areas, particularly within coal basins, which require the minister's consent. Successful applications are granted a maximum 5-year term based on work program commitments.

The NSW Department of Primary Industries – Mineral Resources Division is a recipient of a renewed government commitment through the New Frontiers Initiative funding. This government support aims to build on the results of previous initiatives which attracted exploration investments and kept NSW competitive. A main focus for this current initiative is the exploration for new clean energy source particularly geothermal.

Current tenure

As at March 2007 there are four existing and recently granted Exploration Licenses (EL) all situated in Sydney Basin, NSW. Three EL applications were received: one in the Clarence-Moreton Basin, another in the Oaklands Basin and one in the western margin of the Sydney Basin. The locations are shown in Figure 5 and the ELs are listed in Table 1.

Prospectivity

The Petroleum Group has initiated a study and data compilation project geared towards mapping and identifying 'hotspots' and potential for geothermal energy (see Figure 6). Bottom-hole temperatures from petroleum wells, water bores, coal and mineral core holes have been extracted, corrected and presented in ArcGIS format. The project results will be presented early next year.

NSW DPI is currently negotiating a collaborative agreement with Geoscience Australia to identify targets for shallow pilot drilling in order to assess geothermal systems in the Sydney Basin.

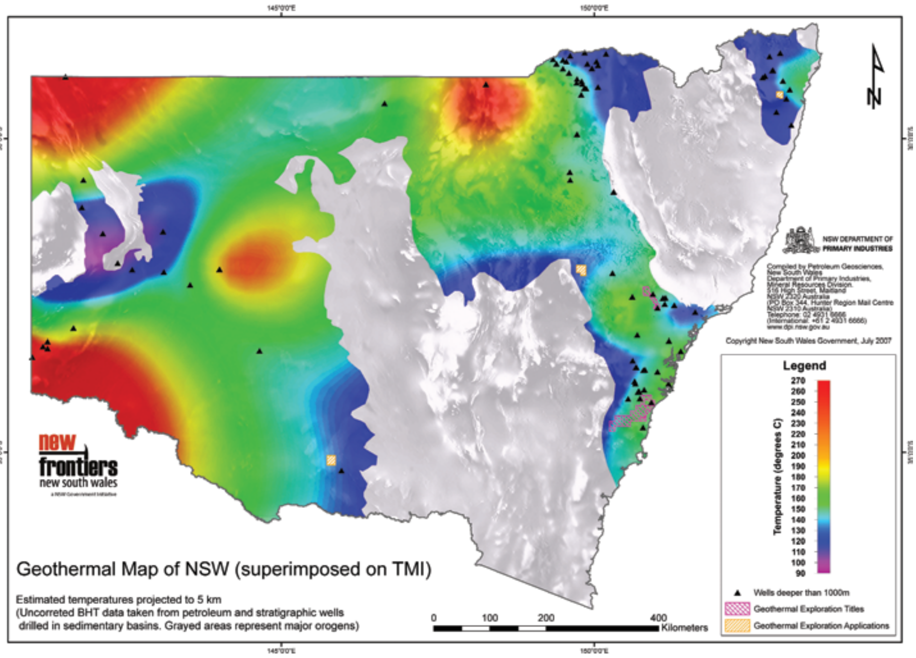

Fig. 6. Geothermal Map of NSW. A 'first-pass' compilation and mapping of the potential geothermal 'hotspots' in the State. Bottom-hole temperatures from petroleum wells drilled in excess of 1000 m were used to give prevalence to thermal centres within sedimentary basins. The most significant anomalous hot spots lie along the south-western corner of the State within the Tararra Trough where possibly Palaeozoic high heat flow rocks have been drilled. Extensions of these hot rocks form geothermal exploration targets across the border in SA. This study is ongoing and data from coal and mineral core holes and water bores will be incorporated. For more information contact Ricky Mantaring on: ricky.mantaring@dpi.nsw.gov.au.

Northern Territory

Legislation and policy

The NT Government is in process of developing a *Geothermal Energy Bill,* which will provide secure tenure for the controlled exploration and development of geothermal energy resources in the Northern Territory. The legislative framework is expected to be in place during the latter half of 2007. The legislation is being adapted from the existing Northern Territory Mining and Petroleum legislation with input from other State geothermal law. It is being developed as a stand-alone law to allow multiple tenure (i.e. mining, petroleum and geothermal) to co-exist.

The proposal is to develop stand-alone legislation that will provide exploration tenure in a similar form to mineral exploration tenure but with the development securities more akin to the NT

Table 1. NSW geothermal exploration leases

EL Titles	Units	Company	Expiry	Status	Min. 2 year expenditure
EL 5560	50	Geodynamics Ltd	22/02/2008	Active	$50 000
EL 5886	63	Geodynamics Ltd	22/02/2008	Active	$50 000
EL 6740	4	Waterflea Pty Ltd	28/03/2007	Pending renewal	$200 000
EL 6212	1912	Hot Rock Energy Ptl/Longreach Oil Ltd	3/03/2007	Pending renewal	$150 000
EL 6360	37	Proactive Energy Developments Ltd	23/12/2006	Pending renewal	$4 480 000
Applications			**Lodged**		
ELA 3131	33	Granite Power	17/05/2007		$56 000
ELA 2495	78	Proactive Energy Developments Ltd	8/03/2005		$118 000
ELA 3130	72	Granite Power	17/05/2007		$36 500

Fig. 7. Location of geothermal exploration permits in Queensland.

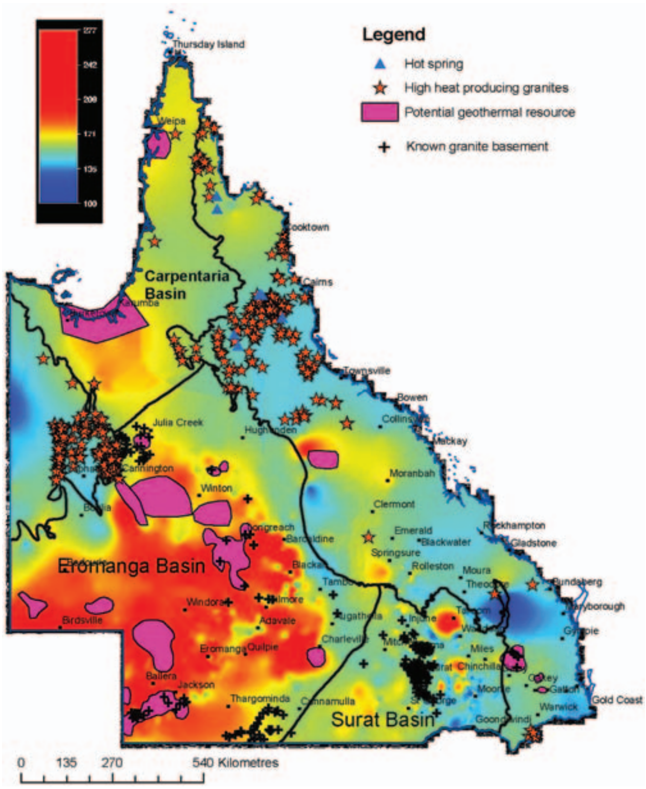

Fig. 8. The Austherm04 image shows the distribution of measured hot areas. The Great Artesian Basin overlies much of the hot areas. Hot springs are known in north Queensland. High heat producing granites are common in outcrop, particularly in the Proterozoic Mount Isa and Georgetown Blocks.

Petroleum Act. That is, the company that discovers and assesses the heat resource will have the right to develop the field.

The legislation will be developed and administered by the Titles Division of the Minerals & Energy Group of the Department of Primary Industry, Fisheries and Mines. It is hoped that the legislation will be passed this year and operative late in 2007.

Resource assessment

A first pass of an assessment of NT geothermal resources will also be completed in 2007 so that explorers will have guidance on which areas are likely to be the most prospective.

On the basis of geology, existing physiography and hot rock potential, an area near Katherine and within the zone covered by the existing major NT power transmission grid looks quite exciting. Hot Springs in the Daly region 100 km north west Katherine and at Mataranka 120 km SE of Katherine coincide with an interpreted presence of a major crustal heat source in the region. For more information contact Tony Waite at: tony.waite@nt.gov.au

Queensland

Legislation and policy

At present geothermal exploration in Queensland operates through *The Geothermal Exploration Act 2004* and the Geothermal Exploration Regulation 2005. The current Act does not cover production. A policy discussion paper *Options for Geothermal Exploration and Production Tenures* was released for public discussion earlier this year. Consultation included a one day workshop involving interested parties. Legislation covering both exploration and development is proceeding following the public consultation.

Geothermal energy forms part of the Queensland Government's *Climate Smart 2050 – Queensland Climate Change Strategy*. Funding for research for geothermal resources near existing transmission lines is included within a $50 million Queensland Renewable Energy Fund. Funding of projects will be on a competitive basis (http://www.thepremier.qld.gov.au/library/office/climate/ClimateSmart_2050.doc). Drilling support and other assistance is available under the Smart Mining – Future Prosperity initiative (http://www.nrw.qld.gov.au/mines/index.html).

Under the present Act, tenure can only be obtained using a tender process. Two rounds of tenders have been held to date with a third planned for later this year. A request can be made to have an area included in the tender process. Such areas are not differentiated from departmental selected areas. Details of the tender process can be downloaded from the departmental website: www.nrm.qld.gov.au/mines.

Current tenure

There are 14 applications for geothermal permits in Queensland at present. Granting of these tenures is subject to the completion of the native title process. The application areas are shown in Figure 7; these include granites in the Cooper Basin area, high heat producing granites at depth south of Mount Isa and at Weipa, hot springs at Talaroo, an anomaly in the Drummond Basin and the Nagoorin Graben near Gladstone.

Prospectivity

The Great Artesian Basin represents a significant geothermal resource with maximum temperatures approaching 100˚C. At Birdsville a small geothermal plant generates electricity from bore water. There is potential for local electricity generation in other parts of the Great Artesian Basin.

A large area of Queensland is underlain by hot rocks. Figure 8 shows the image for Queensland of temperatures at 5 km depth (Austherm04). Most of the southwest of the state is underlain by hot rocks and there are other areas of the state where anomalously hot areas have been mapped. The temperature data are biased by petroleum and artesian water bore measurements and many parts of the state have no or few data points. This applies particularly to eastern and northern Queensland.

There are numerous high heat producing granites exposed in Queensland and in some areas these continue beneath cover. These are attractive targets as they are adjacent to areas with mineral production. Such granites could also provide heat for processing oil shale.

The hot springs in north Queensland have temperatures up to 70˚C. Innot Hot Springs contain meteoric water heated during deep circulation. The hot springs have potential for tourism as well as providing a heat source for other uses.

Queensland contains a range of geothermal resources across a range of temperatures. Non-stabilised geothermal gradients are as high as 58˚C per kilometre indicate the possibility of granites similar in character to that being explored at Habenero.

South Australia

Legislation and policy

The South Australian Government is a strong supporter of renewable energy, as it will make a valuable contribution to reducing greenhouse gas emissions and ensuring a sustainable future for all South Australians. It has developed a sustainability objective as part of South Australia's Strategic Plan, to make South Australia world-renowned for being clean, green and sustainable. It aims to develop renewable energy so that it comprises 20% of the State's electricity production and consumption by 2014. One of the main planks in this plan is the development of the state's geothermal energy resources.

Onshore geothermal and petroleum exploration and development are administered by the PIRSA Petroleum and Geothermal Group under the *Petroleum Act 2000,* which was proclaimed on 25 September 2000 to replace the *Petroleum Act 1940*. The current Act is subject to regular review to ensure that the legislation is achieving its intended objectives.

PIRSA's Petroleum and Geothermal Group is now consolidating stakeholders' submissions on amendments proposed to the Petroleum Act, 2000 in a Green Paper released in December 2006. These submissions will form the basis for the new Petroleum and Geothermal Act to be tabled in Parliament in 2008.

Apart from establishing a legislative framework for geothermal exploration, as early as 2000, South Australia has encouraged geothermal exploration by providing a total of $1.15 million for geothermal research projects in the state.

Current tenure

To end June 2007, 17 companies have applied for 157 geothermal licence applications areas covering more than 70 000 km^2 in South Australia. The

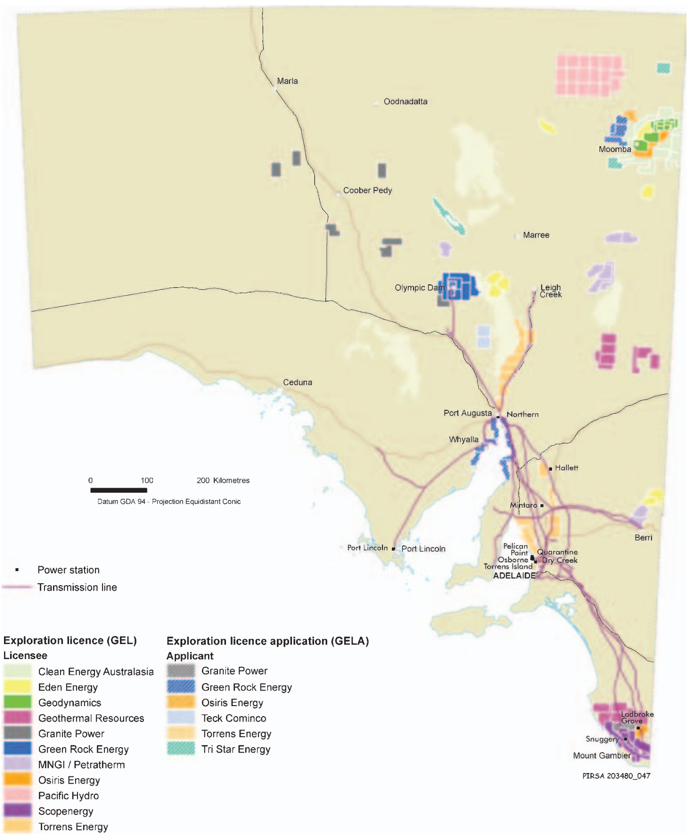

Fig. 9 South Australian tenements and most of the companies involved in geothermal resource exploration.

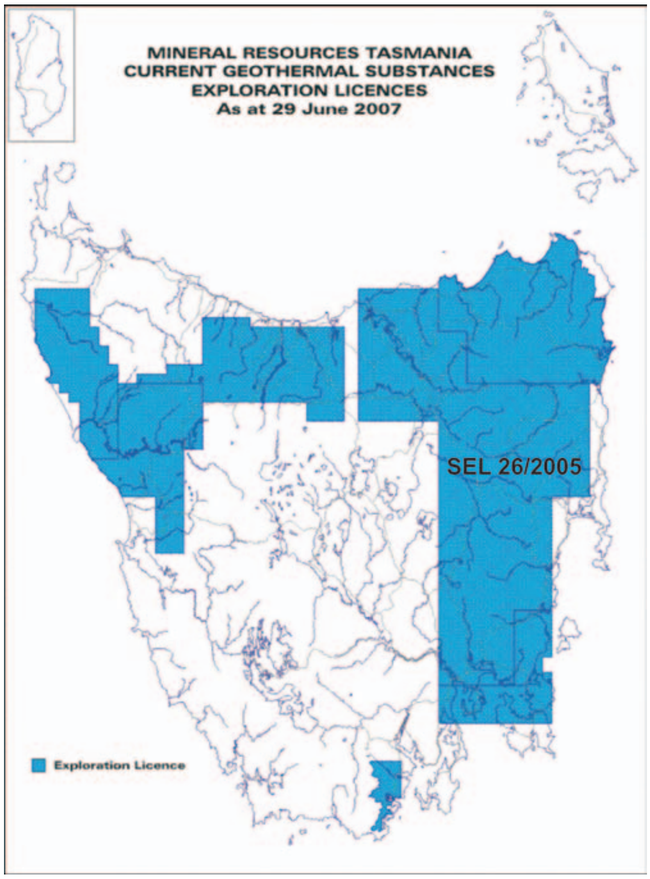

Fig. 10. Current geothermal tenements in Tasmania. One Special Exploration License has been granted (SEL26/2005) to Kuth Exploration Pty Ltd; unlabelled blocks are SEL application areas.

guaranteed and non guaranteed work programs associated with those 157 areas corresponds to an estimated investment of $582 million.

Figure 9 shows the locations of the exploration licences and most of the companies involved. Table 2 shows a list of the companies that have lodged applications in SA as at 12 July 2007. Some of these companies GELAs don't appear on Figure 9 as they are not on the public register. The Appendix gives details of their activities where these could be ascertained. The full tenement information is available at: http://www.pir.sa.gov.au/minerals/sarig.

For further information regarding South Australia's geothermal industry please contact:

Barry Goldstein, Director Petroleum & Geothermal Group, PIRSA on 08 8463 3200 or goldstein.barry@saugov.saogov.au; Tony Hill, Principal Geologist, Petroleum & Geothermal Group, PIRSA on 08 8463 3225 or hill.tonyj@saugov.sa.gov.au; or visit PIRSA's geothermal website: http://www.pir.sa.gov.au/geothermal.

Tasmania

Legislation and policy

Geothermal exploration and extraction in Tasmania is governed by the *Mineral Resources Development Act 1995* (MRDA), administered by the Department of Infrastructure, Energy and Resources. Under the MRDA, 'geothermal substances' (>40ºC) are regarded as one of a number of categories of minerals. Exploration Licenses may be up to 250 sq km in size, and geothermal licenses may overlap with licenses for other categories of minerals. Special Exploration Licenses may be larger than 250 sq km, and are intended to allow for innovative exploration over large, under-explored areas of the State.

Prospectivity

There are favourable indications for Enhanced Geothermal System/Hot Dry Rock prospectivity. Available data indicate a relatively high terrestrial heat flux (>80 mW/m^2) in Tasmania. Devonian granites, some notably radiogenic, are widespread, and particularly abundant in the north-east and east of the State. A thick (up to 2 km) flat-lying cover sequence is widespread in the east, centre and south. There is an extensive high-voltage electricity transmission and distribution network, linked to the mainland by the Basslink cable.

Table 2. Companies with geothermal licences and applications lodged in South Australia
Geodynamics Ltd
Green Rock Energy Ltd
Eden Energy Ltd
Scopenergy Ltd
Petratherm Ltd (MNGI Pty Ltd))
Geothermal Resources Ltd (Havilah)
Pacific Hydro Ltd
Granite Power Ltd (formerly Proactive Energy Developments
Osiris Energy Pty Ltd
Torrens Energy Ltd
Tri-Star Energy Ltd
Clean Energy Australasia Pty Ltd
Allender *et al*.
Teck Cominco Australia Pty Ltd
Touchstone Management Pty Ltd
Inferus Resources/Uranium West
Deep Energy Ltd

Natural warm springs (20–30ºC) are found in several locations, mainly in areas of Ordovician and Proterozoic carbonates, suggesting potential for hydrothermal or space heating applications.

Data availability

No state-wide resource assessment has yet been carried out. Temperature data are available from 35 offshore petroleum exploration drillholes and 10 onshore holes. Forty-eight thermal conductivity determinations of Tasmanian rocks have been carried out. Basic geological data coverage is excellent, and includes a 3D model of the geology of the State. Enquiries may be directed to info@mrt.tas.gov.au.

Current exploration

One large Special Exploration Licence (SEL 26/2005:12 360 km^2) for geothermal resources is held in eastern Tasmania by KUTh Exploration Pty Ltd. Expenditure commitments for the first two years amount to $650 000 for data evaluation and drilling. Five other areas are currently under application, totalling approximately 11 500 sq km, with indicative expenditure commitments totalling $2.1 million (Figure 10). For more information contact Clive Calver at: ccalver@mrt.tas.gov.au.

Victoria

Legislation and policy

The Victorian Government passed the *Geothermal Resources Act 2005* (GER Act) to facilitate investment in geothermal energy and support development of geothermal technology. The Act only applies to major energy investment projects where the temperature of the

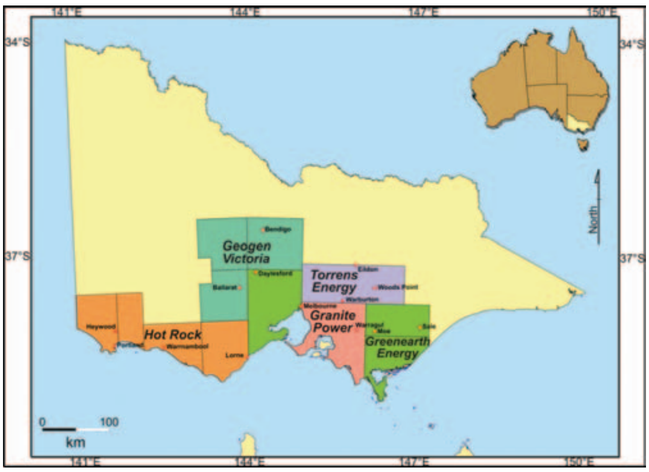

Fig. 11. Geothermal tenements in Victoria, July 2007.

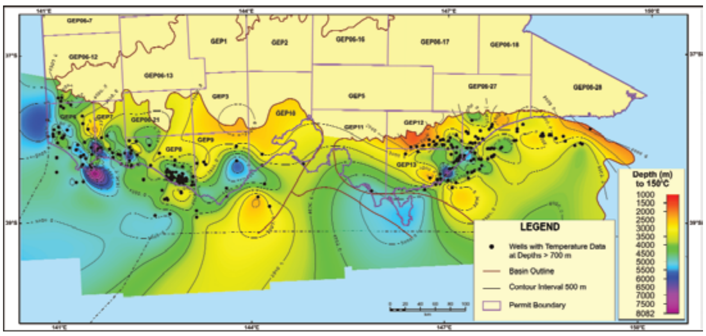

Fig. 12. Depth to 150˚C isotherm in southern Victoria.

resource is greater than 70°C and lies at depths of greater than 1000 m below ground level.

Both the *Regulatory Impact Statement* and *Geothermal Energy Resources Regulations 2006* have come into effect. The primary objectives of the Regulations are to provide commercial certainty and a workable framework to facilitate large-scale, commercial exploration and development of Victoria's geothermal resources. The Regulations also seek to ensure that risks to health and safety and the environment are eliminated or minimised as far as practicable. Secondary objectives of the Regulations are to support the Government's aim of expanding the State's renewable energy sector and to support alternative power generation sources, thereby reducing Victoria's greenhouse gas emissions. The Victorian Government implemented the *Victorian Renewable Energy Target* (VRET) scheme in late 2006, whereby energy retailers are required to purchase a minimum of 10% renewable energy by 2016. This equates to a cut in greenhouse emissions of 27 million tonnes and it is estimated this will lead to $2 billion in new investments and 2200 jobs.

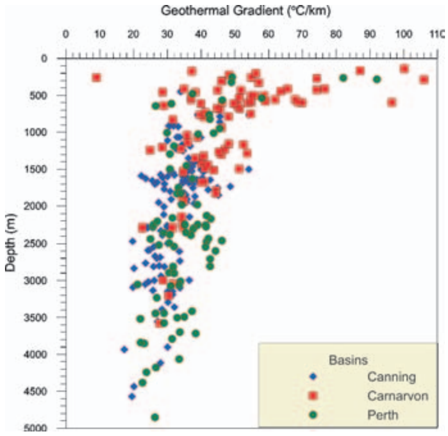

Fig. 14. Estimated present-day geothermal gradients in Western Australia.

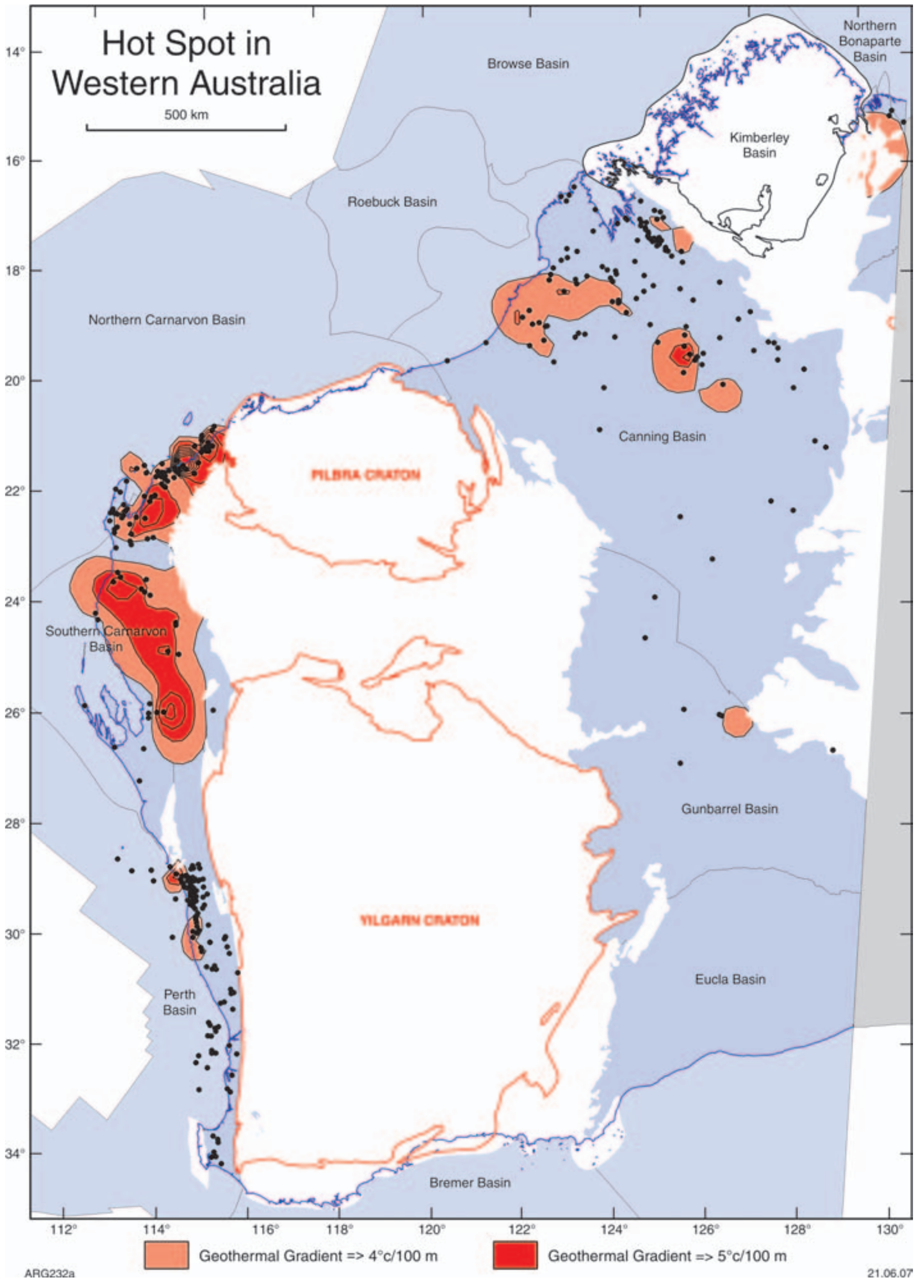

Fig. 13. Western Australian hot spots based on estimated present-day geothermal gradients from existing petroleum drilling results.

Small-scale low-temperature geothermal projects such as fish farms or the heating of municipal buildings are unlikely to be affected by the GER Act. These projects will continue to be developed and managed under existing statutory requirements which include the Water Act 1989, the Environment Protection Act 1970 and reforms emanating from the Victorian Government's White Paper *Securing Our Water Future Together*. Future developments for these projects should consider whether the GER Act will apply. Several low-temperature geothermal schemes are being planned or in the process of being developed in several parts of Victoria including Portland, Warrnambool and Werribee.

Geothermal tenements

The entire State of Victoria was gazetted in April 2006, with a total of 31 geothermal blocks being released for competitive tender. The maximum block size was limited to 10 000 km^2, and the bidding process was open for six months.

Twenty bids were received and were assessed against several criteria including the proposed work program and associated expenditure. A total of 12 geothermal exploration permits (GEPs) were awarded to five companies in April 2007 (Figure 11; Table 3). These GEPs cover much of southern and central Victoria, totalling approximately 73 400 km^2. These companies are exploring for a variety of geothermal targets within their tenements, both shallow and deep hot fractured rock (HFR) and hydrothermal. The combined exploration expenditure, based on each company's work programs, totals $64.2 million over five years. All the permits in Table 3 expire on 13 May 2012.

Table 3. GEP tenement holders in Victoria as of July 2007

GEP	Company	GEP size (km^2)
GEP1	Geogen Victoria Pty Ltd	5788
GEP2	Geogen Victoria Pty Ltd	6969
GEP3	Geogen Victoria Pty Ltd	5585
GEP5	Torrens Energy Ltd	9603
GEP6	Hot Rock Ltd	4559
GEP7	Hot Rock Ltd	3153
GEP8	Hot Rock Ltd	4742
GEP9	Hot Rock Ltd	5840
GEP10	Greenearth Energy Ltd	8440
GEP11	Granite Power Ltd	8362
GEP12	Greenearth Energy Ltd	5000
GEP13	Greenearth Energy Ltd	5355

A data package was released as part of the acreage release process, incorporating a database of temperature readings from over 350 wells in onshore Victoria. This was recently supplemented with data from 61 shallow water offshore wells, and a depth to 150°C map within the Gippsland and Otway basins in southern Victoria has been constructed (Figure 12).

The Victorian Government is currently establishing the criteria for release of fallow geothermal acreage, and this will be announced in due course. For further information regarding Victoria's geothermal industry please contact:

Jim Driscoll, Geologist/Acreage Release Coordinator, GeoScience Victoria on 03 9658 4535 or jim.driscoll@dpi.vic.gov.au.

Western Australia

Legislation and policy

A new era of energy search will commence in Western Australia with the passing of amendments to the *West Australia Petroleum Act 1967*. The new act will be renamed the *Petroleum and Geothermal Resources Act* and will accommodate geothermal resource exploration and production. It is expected that the new act will come into force in 2008. Initially, it is expected that areas with potential for hot dry rocks will be released for competitive bidding once the legislation is in place.

Current data

In 2006 GSWA started investigations into geothermal resources from hot dry rocks (HDR). Current information indicates opportunities for geothermal energy from hot dry rocks in the Canning, Carnarvon and Perth Basins. These 'hot spots' are recognised from present-day geothermal gradients recorded in petroleum wells (Figures 13 and 14).

GSWA is compiling existing data for 580 wells. The compilation includes temperatures, depths of basement, basement rock geochemistry, stratigraphy and lithologies of the sedimentary sections from the drilling. Gravity, magnetic and seismic survey data will also be compiled, synthesised and interpreted to better refine areas of high heat flow and to indicate where and what kind of new data is needed.

Current geothermal tenements

As legislation is still being drafted there are currently no geothermal tenements. For more information contact Ameed R. Ghori at: ameed.ghori@doir.wa.gov.au.

Research programs

Australian Federal and South Australian State government expenditure on geothermal research (exploration), proof-of-concept (appraisal), demonstration and development initiatives, including grants to industry, totalled just over $3.92 million in 2006. There has been a total of more than $28 million in Australian Federal and South Australian State grants for the period 2000 to end June 2007 (Table 4).

Since 2000 the Australian government has provided over $27 million in grants under a range of energy technology support programs. The various grants are listed in Table 4, which also includes $1.15 million in grants provided by the South Australian government.

The following funding schemes have been accessed for geothermal energy research and development, as shown in Table 4. There is a generous amount of money available for good projects in the right areas.

(1) **START Program** – The R&D Start Program was introduced in 2002 by the Australian Government. It is no longer operational.

(2) **Greenhouse Gas Abatement Program (GGAP)**

(3) **Renewable Energy Commercialisation Program (RECP)**

(4) **Renewable Energy Development Initiative (REDI) Program** – This Federal government initiative is a competitive, merit based grants program supporting renewable energy innovation and its early stage commercialisation. The $100 million program started in 2003 and will provide individual grants from $50 000 to $5 million over seven years.

(5) **Low Emissions Technology Demonstration Fund (LETDF)** – The $500 million LETDF is designed to demonstrate break-through technologies with significant long term greenhouse gas reduction potential in the energy sector. The Fund was announced by the Federal government in 2004 and will leverage at least $1 billion in additional private investment in new low emission technologies. It will operate from 2005–06 to 2019–20.

(6) **Renewable Energy Equity Fund (REEF)** – The REEF program was introduced by the Federal government in 1997 and is a specialist renewable energy technology research fund.

(7) **Plan for Accelerating Exploration (PACE)** – PACE was launched in 2004 by the South Australian government and includes funding for collaborative exploration programs to address critical uncertainties in mineral, petroleum and geothermal exploration. The $22.5 million program (of which $10 million has been designated for drilling initiatives) will operate until at least 2009 (http://www.pir.sa.gov.au/sector5.shtml).

(8) **Renewable Energy Support Fund** – Sustainability Victoria offers a Renewable Energy Support Fund that helps to pay 50% of the capital cost for new operations (such as fish farms, horticulture and swimming pool heating, http://www.sustainability.vic.gov.au/www/html/1155-home-page.asp).

(9) **Industry investment** on geothermal research, proof-of-concept (appraisal), and demonstration (pre-competitive development) projects

All Australian geothermal industry field expenditure to date is classed as research and is estimated at $29.1 million for the calendar year 2006. This represents an 11% increase of $3 million from the previous year. A 97% increase to $45.4 million is forecast to be expended in 2007.

Table 4. Federal and State grants awarded for geothermal R,D&D in Australia 2000–July 2007				
Grant	Date	Recipient	Project	Amount
RECP	2000	Pacific Power/ANU	Hunter Valley Geothermal Project	$790 000
START	2002	Geodynamics Ltd	Habanero Project	$5 000 000
REEF	2002	Geodynamics Ltd	Habanero Project	$1 800 000
GGAP	Mar 2005	Geodynamics Ltd	Kalina Cycle to produce 13 MW from waste heat at the Mt Keith Nickel Mine in WA	$2 080 000
REDI	Dec 2005	Geodynamics Ltd	Habanero Project, Cooper Basin, SA	$5 000 000
REDI	Dec 2005	Scopenergy Ltd	Limestone Coast Geothermal Project, SA	$3 982 855
PACE 2	Apr 2005	Petratherm Ltd	Paralana Geothermal Project, SA	$140 000
PACE 2	Apr 2005	Scopenergy Ltd	Limestone Coast Geothermal Project, SA	$130 000
PACE 2	Apr 2005	Eden Energy Ltd	Witchellina Project, SA	$21 000
SA Grant	Jun 2005	U of Adelaide	Induced seismicity Cooper Basin, SA	$50 000
SA Grant	Dec 2005	Geodynamics Ltd	Evaluation of Australian Hot Fractured Rock geothermal energy industry	$40 000
PACE 3	Dec 2005	Geothermal Resources Ltd	Curnamona Geothermal Project, SA	$100 000
PACE 3	Dec 2005	Green Rock Energy Ltd	Olympic Dam Geothermal Project, SA	$68 000
REDI	July 2006	Geothermal Resources Ltd	Frome Geothermal Project	$2 400 000
REDI	Dec 2006	Proactive Energy Developments Ltd	Novel regenerator for adapting supercritical cycles to geothermal power application	$1 224 250
PACE 4	Dec 2006	Torrens Energy Ltd	Heatflow Exploration in Adelaide Geosyncline	$100 000
PACE 4	Dec 2006	Eden Energy Ltd	Renmark (Chowilla) Geothermal Project, SA	$100 000
PACE 4	Dec 2006	Geodynamics Ltd	High Temperature Borehole Image logging of Habanero 3, Cooper Basin, SA	$10 000
REDI	Feb 2007	Petratherm Ltd	Paralana Geothermal Project, SA	$5 000 000
SA Grant	May 2007	University of Adelaide	Induced seismicity protocols – SA	$50 000
SA Grant	June 2007	University of Adelaide	Research posed by the AGEG	$250 000
			Total	**$28 426 105**

Historical, current and projected expenditure for 2007 are highlighted in Figure 2.

Research activities

The principal focus topics of Australian research relate to:

- Identification and targeting of locations with high potential for the development of Hot Rock geothermal;
- Reserve and resource definitions;
- Assessment of technologies (including numerical simulation techniques) with high potential to minimise costs and maximize efficiencies in the development of Hot Rock geothermal resources;
- Environmental impacts of developing Hot Rock geothermal resources, including potential induced seismicity that can be associated with the fracture stimulation of EGS reservoirs; and
- Modelling future energy supply: demand scenarios.

The main, institutions are:

(1) Geoscience Australia

Geoscience Australia has developed a plan to enhance understanding of Australia's geothermal energy resources under the auspices of the Federal Government's five year (2006–2011) Onshore Energy Security Program. Key activities will include: the consolidation of existing geothermal data; the acquisition of additional, infill (precompetitive) geothermal and cognate data (including new thermal conductivity and heat flow measurements); assessments leading to a new detailed hot fractured rock model (map) with refined gridding techniques, and constructing an information system for the dissemination of geothermal and associated data.

(2) University of New South Wales

In 2005, the School developed a numerical simulation technique for characterisation of fracture systems in geothermal reservoirs adopting a geostatistical approach that incorporates field data. Initial results are very encouraging and the School is currently working to advance this work. It has also developed a numerical geothermal reservoir simulator to estimate hot water recovery. An important feature of this model is that it simulates fracture system with spatial distribution and considers fluid flow between fracture and matrix.

(3) Australian School of Petroleum, Adelaide University

PIRSA allocated $50 000 in June 2005 to the Australian School of Petroleum at University of Adelaide to undertake a research study of potential induced seismicity associated with the fracture stimulation of ESG wells in the Cooper Basin and then undertake similar studies in other prospective EGS provinces. The one year study was completed in June 2006 and is currently undergoing peer review on the GIA website: http://www.iea-gia.org/documents/InducedSeismicityRepo rtSHuntDraftOctober2006Malvazos4Jan07 .pdf. In May–July 2007, PIRSA made three tied grants to the University of Adelaide for Hot Rock geothermal energy research, demonstration and development projects. These include:

- $50 000 to extend the findings from Hunt and Morelli (2006) to the Adelaide Geosyncline. This will enable an analysis of induced seismicity risks associated with geothermal reservoir stimulation operations and result in the establishment of peer-reviewed protocols for assessing and managing potential induced seismicity risks arising from these activities. These results will also be relevant to induced seismicity risk management for geosequestration operations.
- $250 000 to initiate Hot Rock geothermal research in the South Australian context. This grant requires project plans to be agreed by the geothermal sector – through the AGEG. The framework specified in the relevant Deed between the University of Adelaide and the Minister for Mineral Resources Development is designed to:
- Enable and stimulate national and international collaboration in geothermal energy research;
- Attract in-kind and financial inputs from government, industry and other research institutes.
- Ensure that funded projects are focused on what Industry considers to be high priority research, with final reports made freely and openly available.

The findings of these research projects will be made freely available, and the experience gained will inevitably be leveraged into further valuable research and the development of a service sector for the geothermal industry.

(4) Monash University –Victoria

Geothermal research has focused on measuring and mapping heat flow and temperature distribution in the crust across South East Australia during 2005.

(5) AGEG Technical Interest Groups (TIGs)

To foster focussed geothermal research, the AGEG has established 10 Technical Interest Groups (TIGs). These TIGs will enable Australian companies, research experts and government regulators to convey and take note of international best practices for the full-cycle of below-ground and above-ground geothermal energy operations and stewardship. The TIGs have active links to the International Energy Agency's research annexes, and all other reputable international geothermal research clusters. The AGEG's TIGs are summarised in Table 5.

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Appendix: Australian Geothermal Licence Holders (Alphabetical Order)

Clean Energy Australasia (http://www.cleanenergy.net.au) is a privately owned company which identifies, evaluates and seeks to invest in geothermal and

Table 5. The AGEG's Technical Interest Groups

AGEG Technical Interest Group (TIG)	Purpose
Land Access Protocols (induced seismicity, emissions, native title, etc)	Mirrors IEA Geothermal Implementing Agreement Research (GIAR) Annex 1. Management of environmental concerns and potential impacts of geothermal energy and devises protocols to avoid or minimize impacts.
Reserves and Resource (Definitions)	Align with similar International forums
Policy Issues: Industry and Whole-of-Sector Forums	Advice to Governments.
Enhanced Geothermal Systems	Mirrors IEA GIAR Annex III Investigate technologies for enhancing geothermal reservoirs for commercial heat extraction.
Interconnection with Markets	Transmission, distribution, network, National Electricity Market issues.
Geothermal Power Generation	Mirrors IEA GIAR Annex VI (Ormat, Italy, Australia). Develop scenarios for comparison of cycles, plant performance and availability, economics and environmental impact and mitigation.
Direct Use of Geothermal Energy (including geothermal heat pumps)	Mirrors IEA GIAR Annex VIII. Addresses all aspects of the technology related to geothermal energy being used directly as heat, with emphasis on improving implementation, reducing costs and enhancing use.
Outreach (Including Website)	Create informed public through accessible information. Provide educational kits for media, all levels of schools and university education.
Data management	Database design, contents and ongoing enhancements.
Wellbore operations	In part Mirrors IEA GIAR Annex VII. Covers drilling, casing, logging, fracture stimulation, testing, etc.

geosequestration exploration and production properties and facilities. The company has been granted 11 geothermal exploration licences (GELs) comprising an area of 5500 km^2 surrounding existing GELs in the prospective Cooper Basin geothermal province in SA. A further eight geothermal exploration licence applications (GELAs) have been submitted in the surrounding area.

Deep Energy Ltd has recently lodged 5 GELAs in SA that are under review.

Eden Energy Ltd (http://www.edenenergy.com.au) was listed on the ASX in 2006. It aims to be a major global player in the alternate energy market, focusing on the clean energy transport market and producing hydrogen without any carbon emissions. Eden is exploring for geothermal resources in SA at Witchellina, northwest of Leigh Creek; North of Renmark, on the Murray River; around Moomba in the Cooper Basin; and at Mungeranie, in the southwest Eromanga Basin. It plans to test a number of different geothermal target types, ranging from, deep hot fractured granite near Moomba and at Mungeranie, to relatively shallow (2–3 km) heat sources associated with buried radiogenic iron oxide and granite at Witchellina; and enhanced permeability zones with elevated heat flows in the Renmark Trough. If successful, Eden will target electricity markets and clean hydrogen production.

Geodynamics Ltd (http://www.geodynamics.com.au) has first mover advantage in Australia with its Habanero project in the Cooper Basin in NE SA. It is the only proponent with a proven resource. Its proof-of-concept Habanero project is located where rocks are claimed to be the hottest in the world in a non-volcanic environment (up to 280ºC at 5 km depth). The company has created the world's largest underground heat exchanger by high pressure water injection in two stages in 2003 and 2005. High rates of injectivity indicate the presence of large volumes of low impedance reservoir where the rock temperature is 250ºC (4.3 km). After completion of the Habanero 2, flows of up to 25 l/s and output temperatures of 210ºC (at surface) were measured in 2005. Since encountering problems with Habanero 2, Geodynamics plans to drill Habanero 3 in 2007, and carry out a 6 week circulation test to complete the proof-of-concept for EGS in the Cooper Basin. Geodynamics' geothermal tenements in the Cooper Basin cover 986 km^2. In addition it has applied for exploration licenses in Queensland and has two geothermal exploration licenses in NSW. The company aims to initially build a 40 MWe power station connected to the national grid based on 7 wells, and then scale up to at least 280 MWe.

Geogen Victoria Pty Ltd is an Australian company formed in mid-2005 to undertake the confirmation of a series of previously unknown geothermal resources in Australia and internationally. Geogen's wholly owned subsidiary Geogen Victoria Pty Ltd has successfully applied for three geothermal exploration permit areas in Victoria, and will begin exploring for shallow high-grade geothermal heat shortly. Please email rbkitch@bigpond.com for further information.

Geothermal Resources Ltd (http://www.havilah-resources.com.au/geothermal_energy.html; http://www.geothermal-resources.com.au) holds two hot dry rock geothermal exploration projects within high heat flow areas of SA. The Frome project lies in the Curnamona Craton, which is characterized by some of the most radiogenic granites in Australia. In the project area a large body of granite is interpreted to lie beneath 2-4 km of younger sedimentary cover rocks. The Crower project, situated in the SE of SA lies along the northern margin of the Otway Basin, where early Palaeozoic granites dip beneath onlapping Jurassic to Cretaceous sediments. Both projects are well located with respect to existing power grids. The Company started an eight hole drilling program on its Frome Project in early March 2007 to establish geothermal gradients and heatflow.

Granite Power Ltd (www.granitepwr.com – previously Proactive Energy Development Ltd) is a private company that plans to explore for hot rocks at intermediate depths near to the existing high voltage grid to Olympic Dam. Granite Power has commenced geotechnical model building in GEL207 Roxby Downs in SA, and field inspection work is planned. The Company has also started geotechnical model research for the Felton EPM in SE Qld. Granite Power has completed a geotechnical model on the Bulli EL6360 in NSW, and is currently seeking funding to drill a 3000+m well there later this year. Granite Power has also been awarded an Exploration Permit of about 8500 km^2 to the southeast of Melbourne.

Greenearth Energy Ltd was recently formed by oil and gas explorers Lakes Oil NL and Victoria Petroleum NL, who combined to form this new Australian geothermal company. It has been awarded a ~10 000 km^2 exploration permit in the onshore Gippsland region of Victoria.

Green Heat Resources Pty Ltd has a 50% interest in Green Rock's licences near Olympic Dam (see below). It is also the operating company for these areas.

Green Rock Energy Ltd (http://www.greenrock.com.au) is listed on the ASX and is undertaking the evaluation and development of a hot dry rock geothermal power plant on its GELs in central SA in preparation for the construction of power plants with a base load electricity capacity of no less than 400 MW. It holds a 100% interest in an area of around 3000 km^2 next to the Olympic Dam mine. It drilled Blanche No. 1 to 1935 m, 8 km from the Olympic Dam mine in 2005. The target granite is interpreted to persist to depths of 6 km over an area of about 400 km^2 and represents a potential geothermal resource in excess of 1000 MWe. Cores and wireline logs from Blanche No 1 indicated natural rock fractures. The company is proposing to conduct a mini- fracture stimulation of the Blanche 1 well later in 2007.

Hot Rock Energy Pty Ltd operates of EL 6212 in the Sydney Basin. This licence area covers approximately 5500 km^2 and was granted in 2004 to Longreach Oil Ltd (50%) and Hot Rock Energy Pty Ltd (50%). It is currently undertaking a technical review of the Sydney Basin, incorporating petroleum, coal and water well data to identify areas of high heatflow. The outcome of the study will lead to the identification of certain areas of abnormally high geothermal gradients for shallow exploratory drilling.

Inferus Resources Pty Ltd is an SA based company mainly focused on uranium exploration.

KUTh Exploration Pty Ltd (http://www.kuthenergy.com) is a private company that was granted Special Exploration Licence (SEL) 26/2005 in 2006. The SEL, which covers an area of 12 360 km^2, has been granted for 5 years and covers a large area of Tasmania known to contain high heat flux granites, a cover sequence including coal measures and is on the Tasmanian power grid, which is connected to the National Grid via Basslink. A variant geothermal target within the SEL is the Tamar (electrical) Conductivity Zone, which, if caused by the suspected deep, brine filled fracture zone, could provide a good geothermal target where it intersects granite. The company is undertaking an active field program in 2007 including heat flow measurements in existing drill holes and corresponding thermal conductivity measurements, plus magneto-tellurics and perhaps seismic in order to refine the geothermal map of Tasmania and the topography of the granites under cover. Slim hole drilling to ~1 km on targets generated will follow. The company is planning a float on the ASX either late 2007 or in early 2008.

MNGI Pty Ltd has six geothermal licences with a total area of about 3000 km^2 and is linked with Petratherm. Contact: admin@minotaurexploration.com.au.

Osiris Energy Pty Ltd (http://www.osirisenergy.com.au) is a private Australian company that aims to locate, define and exploit geothermal resources suitable for power generation and other ancillary uses requiring energy in the form of heat. Osiris has received two geothermal exploration licences in SA (GEL 220 and 221) in the Cooper Basin in the northeast of the State and will be offered the Otway Basin GELA 223 in 2007. It plans to list on the Australian Stock Exchange in 2007.

Pacific Hydro Ltd (www.pacifichydro.com.au) is exploring for sediment-hosted geothermal resources in the SA part of the Great Artesian

Basin to support a 400 MW conventional geothermal project. Pacific Hydro holds 18 GELs covering 9000 km^2 in SA and has successfully completed Year 1 of its GEL work program to delineate the resource and define exploration targets. In Year 2 (2006), downhole temperature logging in existing water bores confirmed thermal gradients of 50ºC/km. These are some of the highest thermal gradients recorded in Australia, with an indicative resource temperature of about 133ºC at 2 km depth. Further temperature upside is expected from exploration wells targeting the Hutton/Poolowanna reservoir package in the area of a pronounced gravity low, inferred to reflect underlying high heat production granites.

Petratherm Ltd (http://www.petratherm.com.au) listed on the ASX in 2004. In 2006, a successful drilling program was completed at Paralana with the geothermal test well extended from 485 m to 1807 m. Temperature logging of the well confirmed a world class thermal resource with temperatures of approximately 200˚C expected at a depth of 3.6 km. In January 2007, Petratherm announced a Farm-In agreement with Beach Petroleum to develop the Paralana Geothermal Site. The initial drilling and stimulation of the two wells will create a heat exchanger involving circulation of water between the wells through rock fractures – to demonstrate a commercial 'hot rock' energy resource. Petratherm's Paralana Project aims to initially provide electricity to the local market – the growing needs of the neighbouring (10 km) Beverley Uranium Mine, from around 7.5 MW building to 30 MW – and then to expand to around 520 MW to supply the National Electrcity Market, via two entry points, namely, Port Augusta and Olympic Dam.

Proactive Energy Developments Limited holds GEL 207 a ~400 km^2 lease near the Olympic Dam mine. In a partnership with the University of Newcastle, this company was awarded a $1.2 million Renewable Energy Development Initiative grant in 2006 (see Table 4). An additional $1.2 million will be provided by PED Ltd, bringing the total funding for the project to $2.4 million.

Red Hot Rocks Pty Ltd (RHR) is the geothermal subsidiary of Mobius Resources Australia Pty Ltd. RHR was formed in 2006 to examine potential commercial geothermal projects. The company participated in the 2006 applications for Geothermal Tenements in Queensland and was offered three of the available areas. Finalisation of these offers is pending resolution of land access issues. RHR policy is to seek involvement in the industry either as operator of specific projects or in joint venture with partners. Further information is available from Domain Capital at Level 16, 379 Collins Street, Melbourne.

Scopenergy Ltd is focused on searching for hot water in sedimentary rocks near recent volcanic activity in the southeast of SA near Millicent. The company holds contiguous GELs totalling 2634 km^2 covering substantially Australia's most recently active volcanic province (5000 years BP). It started a slim hole (100 mm) drilling program in 2006, seeking to confirm several large scale heat flow anomalies previously measured in 19 petroleum exploration wells and 26 water wells in the vicinity of its tenements. This program found that poor core recovery from unconsolidated sediments impeded reliable heat flow estimation. The company is now considering a production scale hole to reservoir depth and/or a 3D seismic program to better define drilling targets. Scopenergy's business model seeks to generate hydrothermal power from water at or above 170°C hosted in a deep aquifer of the Otway Basin. For further information, Tel: 02 9250 0133.

Teck Cominco Ltd (http://www.teckcominco.com) is a diversified mining and metals company, headquartered in Vancouver, Canada. Its core business is the production of zinc and metallurgical coal as well as being a significant producer of copper, gold and specialty metals. It has two GELAs situated about 120 km south east of Olympic Dam.

Torrens Energy Ltd will explore for HFR/EGS Resources in the highly prospective SA Heat Flow Anomaly (SAHFA). The Company has been granted 15 GELs covering over 6700 km^2 and has lodged a further six GELAs. The existing power grid runs through, or is adjacent to, all of Torrens' Project areas, and major roads, towns and the city of Adelaide are located nearby. There are three project areas: the Torrens, Barossa-Clare and Adelaide Projects. Torrens has engaged the services of Hot Dry Rocks Pty Ltd and GeothermEx Inc, Australia's and the USA's leading geothermal consultants. It has also been awarded ~10 000 km^2 EP in central Victoria.

Touchstone Management Pty Ltd has two applications in place for leases in the Callabona region in the eastern part of SA.

Tri-Star Energy Company has applied for GELAs 264 and 265 in the western Great Artesian Basin of SA. The two GELAs comprise approximately 1000 km^2 and are located west of Marree in central SA. Upon grant, the work program for each area will include the investigation and review all relevant existing data to determine the geothermal potential of the areas before completing a feasibility and market study. Favourable results will support the drilling of an injection well and a production well during the term to underpin the future development of an electrical generation plant. The company recently submitted a further two GELAs. For further information, please contact Tri-Star Energy Company, in Brisbane (07 3236 9800) or Houston (1 713 222 0011).

Waterflea Pty Ltd is a Newcastle based geothermal exploration company that applied for ELA 2809 about 12 km southeast of the township of Awaba, near Lake Macquarie in NSW Postal address: PO Box 683, Newcastle, NSW 2300.

Geological Surveys of Queensland, Western Australia, Northern Territory, Tasmania and Geoscience Australia

Update on Geophysical Survey Progress (Information current at 16 July 2007)

Tables 1 and 2 show the continuing acquisition by the States, the Northern Territory and Geoscience Australia of new gravity, magnetic and radiometric data over the Australian Continent. Some of the surveys shown in the Tables are very large. For example the Charters Towers gravity survey will acquire over 150 000 new stations and the Canning, South Kimberley and Westmoreland airborne surveys each will acquire over 100 000 km of high quality airborne geophysical data.

The Offshore Canning and the Westmoreland surveys are new and their locations are shown in Figures 1 and 2.

All surveys are being managed by Geoscience Australia. For more information contact Murray Richardson of Geoscience Australia at murray.richardson@ga.gov.au

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (Preview)	GADDS release
North-East Tasmania	MRT	GA	GPX	18 March 07	52 000	200 m 90 m E/W	8600	69% complete @ 8 Jul 07	TBA	123 – Aug 06 (p. 39)	TBA
Flinders Island	MRT	GA	UTS	9 Jan 07	17 900	200 m 90 m E/W	2900	31 Mar 07	11 May 07	123 – Aug 06 (p. 39)	Released 29 May 07
East Isa North	GSQ	GA	UTS	3 Apr 07	113 000	400 m 80 m E/W	39 940	94% complete @ 8 Jul 07	TBA	125 – Dec 06 (p.32)	TBA
East Isa South	GSQ	GA	Fugro	10 Mar 07	145 900	400 m 80 m E/W	51 560	98% complete @ 8 Jul 07	TBA	125 – Dec 06 (p.31)	TBA
AWAGS2	GA	GA	UTS	29 Mar 07	145 350	75 m 80 m N/S	7 659 861	41% complete @ 8 Jul 07	TBA	124 – Oct 06 (p.15)	TBA
Croydon	GSQ	GA	UTS	2 Jun 07	100 320	400 m 80 m E/W	335 310	36% complete @ 8 Jul 07	TBA	127 – Apr 07 (p.27)	TBA
Tanumbirini	NTGS	GA	UTS	16 Jul 07	69 463	400 m 80 m E/W	24 047	TBA	TBA	126 – Feb 07 (p.35)	TBA
Canning Basin Onshore	GA	GA	Fugro	20 Apr 07	102 656	800 m 80 m N/S	70 192	98% complete @ 8 Jul 07	TBA	127 – Apr 07 (p.26)	TBA
South Kimberley	GSWA	GA	GPX	TBA	163 000	400 km 60 m N/S	57 920	TBA	TBA	128 – Jun 07 (p.26)	TBA
Canning Basin Onshore	GA	GA	Fugro	22 Jun 07	44 643	750 m 80 m N/S	32 640	16% complete @ 1 Jul 07	TBA	This issue	TBA
Westmoreland	GSQ	GA	TBA	TBA	59 753	400 m 60 m N/S	21 010	TBA	TBA	This issue	TBA

TBA: To be advised

Table 2. Gravity surveys

Survey name	Client	Project management	Contractor	Start survey	No. of stations	Station Spacing (km)	Area (km²)	End survey	Final data to GA	Locality diagram (Preview)	GADDS release
Isa Area D	GSQ	GA	Daishsat	At end of Isa Area E Survey	4903	4 regular	75 460	31 May 07	25 Jun 07	125 – Dec 06 (p. 32)	Released 2 Jul 07
Isa Area E	GSQ	GA	Daishsat	1 Feb 07	6233	4 regular	97 420	31 May 07	25 Jun 07	125 – Dec 06 (p. 32)	Released 2 Jul 07

(Continued)

Table 2. (Continued)											
Survey name	Client	Project management	Contractor	Start survey	No. of stations	Station Spacing (km)	Area (km²)	End survey	Final data to GA	Locality diagram (Preview)	GADDS release
Tanami	GSWA	GA	TBA	Dependent on land access	3700	2.5 regular	23 000	TBA	TBA	128 – Jun 07 (p. 27)	TBA
Cooper Basin North	GA	GA	Daishsat	TBA	3537	4 regular	56 590	17 Jun 07	TBA	128 – Jun 07 (p. 27)	TBA
Charters Towers	GSQ	GA	Fugro	Aug 07	15 310	2 and 4 regular	133 950	TBA	TBA	128 – Jun 07 (p. 26)	TBA

TBA: To be advised

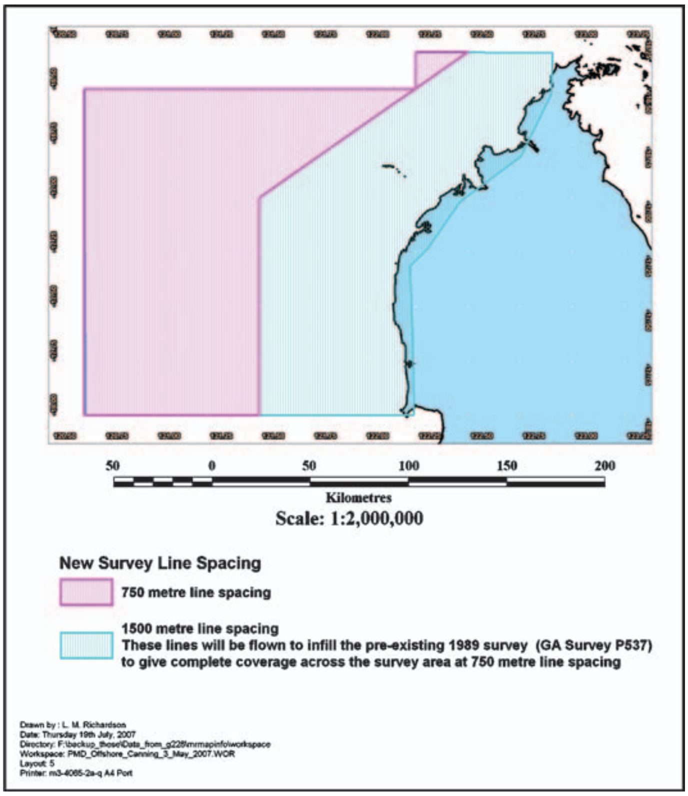

Fig. 1. The location of the 2007 Offshore Caning Basin survey. The survey lines to be flown at 1500 m spacing will interpolate the lines already flown in GA survey P537, which was flown in 1989 with a 1500 m line-spacing. As a result all the coloured areas will be covered by 750 m spaced lines .

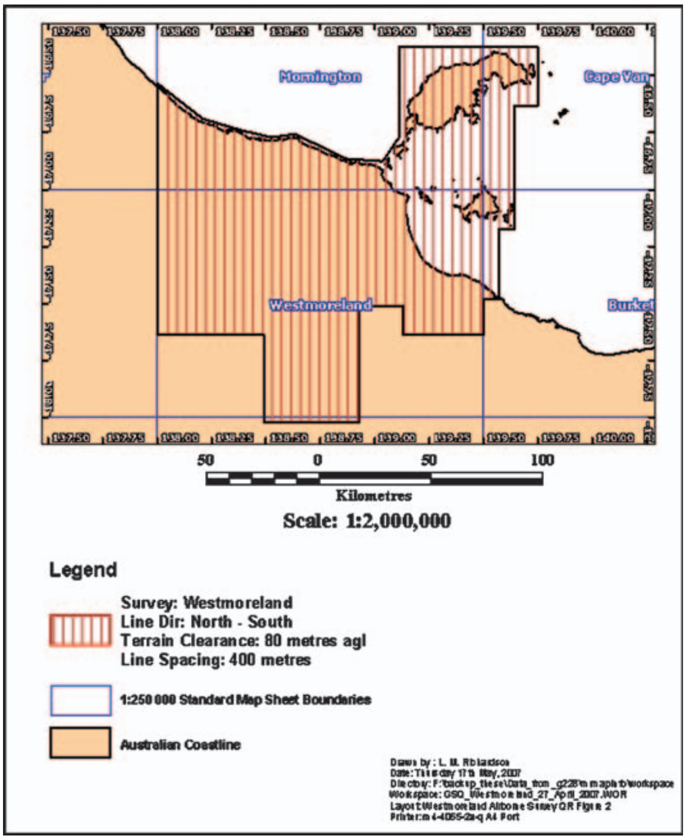

Fig. 2. Location of the Westmoreland airborne geophysical survey. At present the area to be flown is only covered by 1500 m spaced magnetic lines and there is no public-access radiometric data available. It will therefore fill a large data gap in the continental coverage.

Resource stocks surge as BHP reaches $200 billion

July was a big month for BHP Billiton. Its market capital reached more than $200 billion[1] and it climbed to number one on the ASX because Rupert Murdoch's News Corporation moved some stock to the New York SX. It was probably only a matter of time before BHP overtook News Corp on the ASX because it was closing in fast. At the start of 2007 News Corp was listed at $145 billion and BHP at $84 billion. On 13 July BHP had risen to $131 billion and News Corp was $134 billion, before the US move. Figure 1 shows just how fast the top resource companies have been growing. The blue curve is climbing at a prodigious rate, in line with the growth of BHP Billiton. In the last four years the value of the top resource stocks has increased threefold from about $100 billion to over $300 billion – not a bad investment.

Rio Tinto swallows Alcan and the Bear eats the Lion

The huge rise in company values has also resulted in several record-breaking deals, and some market analysts say there's more to come.

Rio Tinto struck a deal to take over Canada's Alcan in a US$38.1 billion deal aimed at forging the world's largest aluminium company, and Brazilian steelmaker Gerdau moved to takeover Chaparral, a US firm, for US$4 billion.

Meanwhile, there is speculation that BHP Billiton could be mounting a takeover for American aluminium group Alcoa. No longer are the resource companies regarded as old-economy dinosaurs being displaced by new high-tech companies. They are fighting back with a vengeance! Much of the surging demand for resources is being driven by the growth of developing nations, especially China, which is seeking metals and other commodities to speed economic growth. However, Russian and Indian companies are also making their presence felt.

In fact the Russian company *Open Joint Stock Company MMC Norilsk Nickel* snapped up the ASX-listed Lionore in May this year. At the time of the takeover Lionore was valued at a cool $6.9 billion. And for those who don't know, Norilsk Nickel is based in Dudinka, a town with a population of less than 30 000, which is situated in Krasnoyarsk Krai – so now you do know.

Minerals exploration keeps growing: a small decline for Petroleum

Minerals Exploration powers ahead

Figures released by the Australian Bureau of Statistics in June 2007 show that the trend-estimate for total mineral exploration expenditure increased by $29.8 million or 7.1% in the March quarter of 2007. The trend estimate of $449.3 million is now 43.5% higher than the December quarter 2005 estimate. Furthermore the level of expenditure, after CPI adjustments, is at $237 million, compared to the previous all time record of $195 million (after CPI adjustments) and $236 million (actual), reached in the March quarter of 1997.

Figure 2 shows the exploration expenditure from March 199 through March 2007. Both the trend and the seasonally adjusted numbers are powering ahead. Figure 3 shows the longer term trends from March 1986. It indicates that in real terms (CPI adjusted) the expenditure levels are at the highest ever.

The largest contributions to the increase this quarter were in Western Australia (up $18.3 million or 9.2%) and South Australia (up $12.2 million or 18.9%). In actual dollars spent, the WA number of $179.9 million was close to half the total of $369.3 million. Western Australia was followed by South Australia with $65.5 million, Queensland with $54.4 million and NSW with $32.3 million.

The trend estimate for metres drilled increased by 3.8% this quarter to a massive 2199 km. The current estimate is now 27.3% higher than the March quarter estimate for 2006, which was also a healthy 1727 km. The Greenfield drilling investment held steady at about 40%, which is very good considering the March quarter is the most difficult for working in remote areas.

In terms of commodities, gold led the way with $103.6 million (28% of the total), followed by iron ore ($54.0 million) and copper at $51.2 million. Uranium exploration is still very healthy with a total of ~$75 million over the last three quarters. The mineral exploration boom just keeps on going.

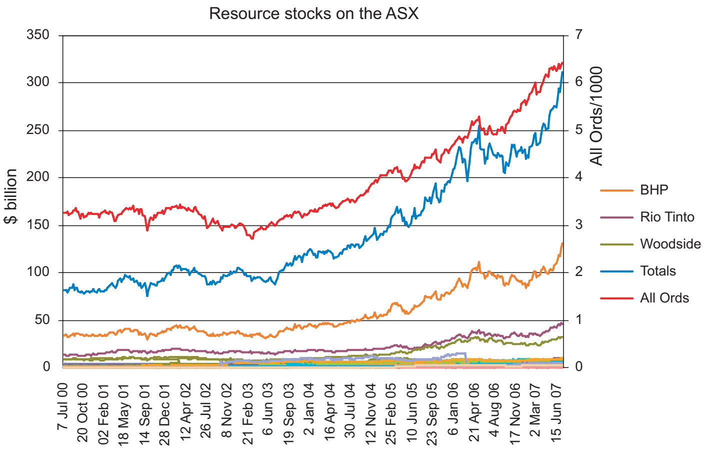

Fig. 1. Plot of All Ordinaries Index on the ASX from July 2000 through June 2007 (in red), total market capital (TMC) in $ billion of all resource companies in top 150 companies (in blue), and the three largest resource companies in $ billion; BHP Billiton, Rio Tinto and Woodside.

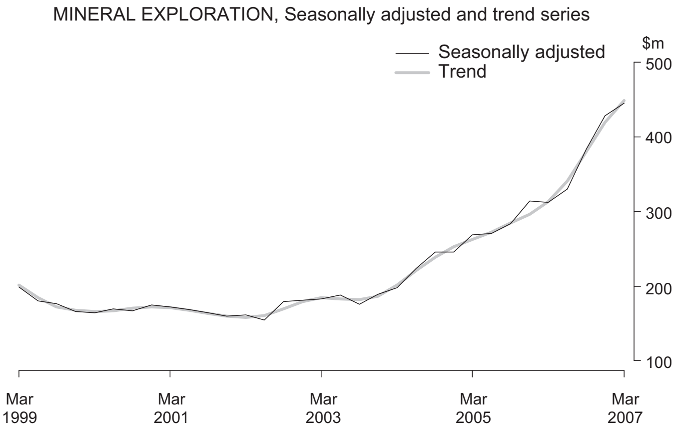

Fig. 2. Trend and seasonally adjusted quarterly mineral exploration expenditure from March 1999 through March 2007 (provided courtesy of the Australian Bureau of Statistics).

[1]BHP Billiton is listed on both the London and ASX. The $200 billion is the sum of both market capitalisations.

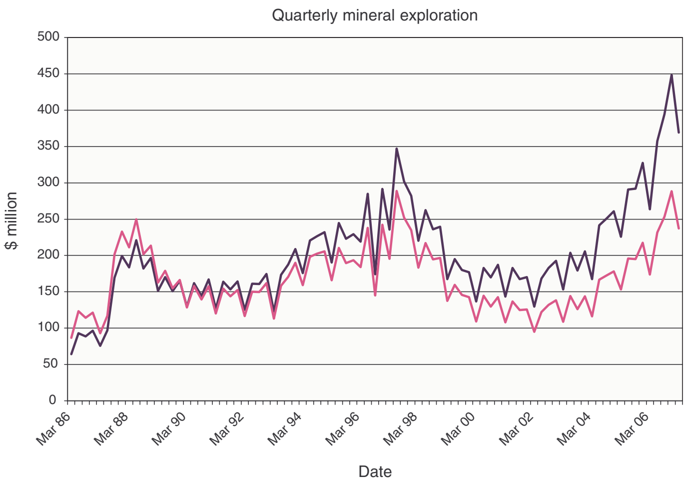

Fig. 3. Quarterly 'actual' mineral exploration expenditure from March 1986 through March 2007 (from ABS data). The black curve represents actual dollars spent in each quarter and the purple curve shows the CPI adjusted number to 1998/99 levels (ABS data).

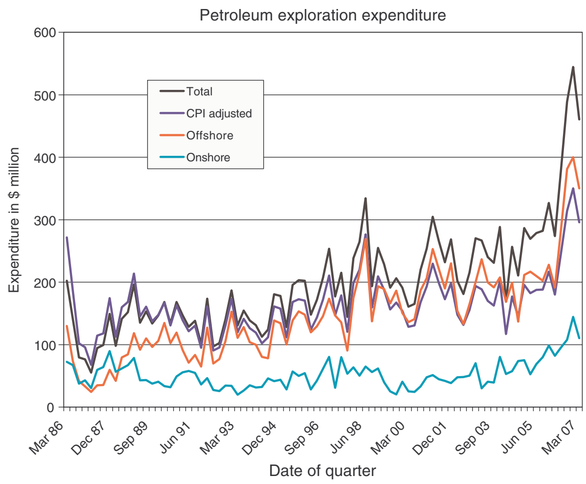

Fig. 4. Quarterly petroleum expenditure from March 1986 through March 2007. The individual offshore and onshore numbers are actual numbers spent at the time, not CPI adjusted. The black graph shows the contemporary dollars spent and the blue curve shows the CPI adjusted number to 1989/90.

Petroleum still at record levels despite small fall

Although expenditure on petroleum exploration for the March quarter 2007 decreased by $84.2 million (15.5%) to $460.3 million, the petroleum sector still turned in a very impressive performance and exceeded all previous December quarters, even when the numbers are CPI adjusted. This is particularly impressive considering the number of cyclones recorded in the main exploration areas. The decrease was across the board. Expenditure on production leases was reduced by $23.1 million while exploration on all other areas decreased by $61.0 million. Off shore expenditure declined by $50 million to $350 million and onshore by $34.2 million to $110.3 million. Figure 4 shows the investment trends from March 1986.

Western Australia continued to dominate with $319.5 million invested, or 69% of the national total exploration expenditure. It was followed by a very distant Queensland at $49.8 million and the Northern Territory next at $49.1 million. In spite of the small fall in spending the situation is still very healthy.

Geophysicists at War: Mines, Magnetism and Memories Part 1: The Background

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Introduction

With the outbreak of the Second World War many Australian geophysicists found themselves caught up in projects that exercised their geophysical skills and knowledge to aid the war effort. The purpose of this two-part article is to outline some of these activities, with a particular emphasis on the degaussing of ships. The article again relies on the papers and my recollections of my late father Jack Rayner together with contemporary naval files as primary sources.

Jack's job application for the position of Chief Geophysicist with the nascent Bureau of Mineral Resources in early 1946 gives some idea of the scope of the activities:

- *The determination of magnetic force components for the Navy in connection with the degaussing of ships.*
- *The development for the first time in this country of the use of fluorescence in prospecting for scheelite and the use of ultraviolet light in connection with the mine on King Island in Bass Strait.*
- *An extensive seismic survey to assess the damage to houses and structures arising from the construction of the Sydney Harbour Graving Dock [Captain Cook Dock, Garden Island].*
- *Preparation of the data concerning magnetic declination and inclination throughout the Western Pacific which is now in use for the Australian and Allied Air Forces.*
- *The development for the first time in this country of electrical methods for prospecting and assaying radioactive minerals containing uranium and thorium.*
- *A long series of researches at the request of the Army into possible methods of detecting non-metallic anti-tank mines.*
- *Advising the Army Inventions Directorate on matters involving geophysical considerations.*
- *Investigations at the request of the RAAF into anomalies at radiolocation stations* (Rayner 1946).

Another major problem was that at the beginning of the War, Australia had no national inventory of its natural resources with respect to minerals and energy resources. For many minerals of strategic importance we did not know how much we had (if any) and where they were located. Minerals of interest included: zircon, rutile, tungsten, tin, copper, mica, quartz and beryl. It may seem surprising that other materials such as lead, zinc and iron were not on the initial list but sources for these materials were already well established (Raggatt 1956). Therefore in June 1942, the office of the Commonwealth Geological Advisor became known as the Mineral Resources Survey with its headquarters in Canberra. Many of the former staff of AGGSNA (the Aerial Geological and Geophysical Survey of Northern Australia), which was wound up in 1940, joined the new organisation. Harold Raggatt, who was the Commonwealth Geological Advisor, was appointed as the director. Subsequently he became the first director of the newly formed Bureau of Mineral Resources, Geology and Geophysics, in 1946. P. B. Nye was appointed as the deputy director, Jack was the chief geophysicist, and Norm Fisher, recently returned from New Guinea, the chief geologist (Crespin 1967). Jim Dooley and Noel Chamberlain were appointed as geophysicists having spent the first part of the War at Mt Stromlo working on optical munitions. Carl Zelman, with his genius for making instruments from bits and pieces, was also on the staff.

During the transition period between the wind-up of AGGSNA and the establishment of the Mineral Resources Survey, many of the geophysicists worked on the problem of protecting allied shipping from the threat posed by German magnetic mines. The geophysicists worked in Sydney and were attached to the Australian Navy to work on the problem of 'degaussing' as it came to be known. Their work is an excellent example of the ability of a group of scientists to transfer their skills and knowledge in one area to the solution of novel problems in a new area, and also provides a case study of the way in which Australian exploration geophysicists adapted to the needs of the War. Part 1 of this article discusses the general principles of the degaussing vessels, while Part 2 will explore the Australian contribution to the solution of this problem.

Magnetic properties of ships and the problem of magnetic mines

A steel ship in the magnetic field of the Earth has significant magnetic properties of two types. *Permanent magnetisation* is due to the initial construction of a steel ship in the Earth's field and the hammering of the rivets that produces a permanent magnet. *Induced magnetisation* is due to the distortion to the Earth's field caused by the presence of magnetic materials. It therefore varies with the heading of the ship with respect to the field and also the ship's location, such as being in the southern or northern hemispheres. Maxwell, in the late 19th century was one of the first people to recognise these effects, and he included a section on 'Ships' Magnetism' in his *Treatise on Electricity and Magnetism* (Maxwell 1892).

The permanent magnetisation consists of three components as shown in Figure 1:

- PVM: permanent vertical magnetisation
- PLM: permanent longitudinal magnetisation
- PAM: permanent athwartships magnetisation.

The induced magnetisation has three corresponding components:

- IVM: induced vertical magnetisation
- ILM: induced longitudinal magnetisation
- IAM: induced athwartships magnetisation.

For a typical vessel, about two-thirds of its total vertical magnetisation is due to induced magnetisation with the rest being permanent magnetisation. Provided that a ship remains in similar latitudes, the IVM remains almost the same as the vertical component of the Earth's field and is roughly constant for a given latitude. The induced horizontal magnetisation (ILM

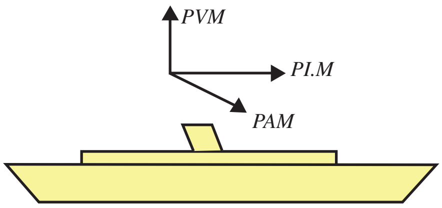

Fig. 1. Sketch of a ship showing the three components of permanent magnetisation.

and IAM), however, depends on the ship's heading with respect to the Earth's field.

During World War I, the British invented an early 'magnetic mine' that would trigger when it detected the magnetic signature of a vessel as it passed over the mine. Small numbers were deployed in 1917 but subsequently little more was done. It was, however, at the beginning of World War II that these mines posed a major threat to shipping. In November 1939, German

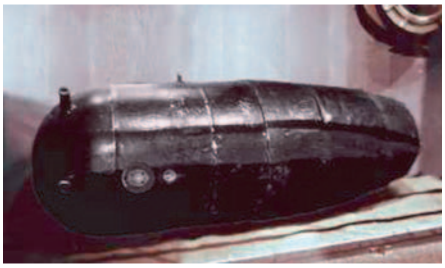

Fig. 2. German mark 1 magnetic mine displayed on HMS Belfast, London (Peter Goodeve, son of Charles Goodeve).

Fig. 3. Firing mechanism for a German mine (Peter Goodeve).

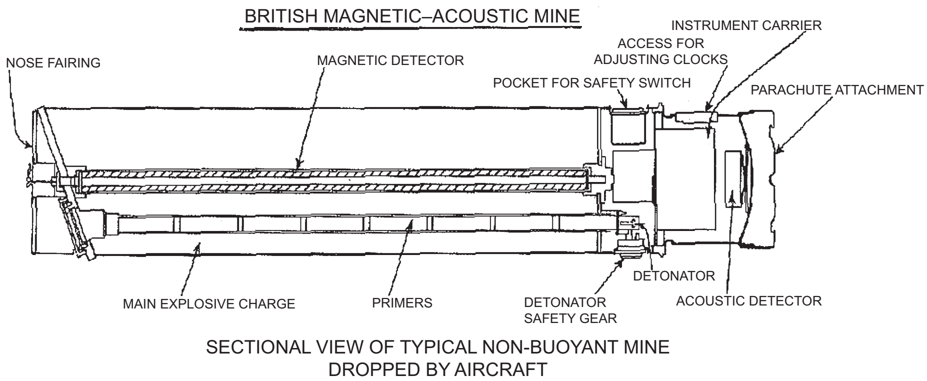

Fig. 4. Sketch of the layout of a British magnetic/acoustic mine (South Kensington Science Museum Exhibition Catalogue, 1946).

magnetic mines sank ~200 000 tons of shipping and the Port of London was nearly closed (Pawle 1967). The British Admiralty assembled a team to devise appropriate counter-measures led by the noted geophysicist Professor E. C. (Teddy) Bullard of Cambridge University, and the chemist Charles Goodeve (Richardson 1981). Fortunately a mine was retrieved from the mud flats at Shoeburyness in the Thames Estuary and dismantled. It was found that the mine's trigger mechanism was a dip circle that responded to the increased north-pole downward magnetic field induced by a vessel in the Earth's field (Pawle 1967). Figure 2 is a photograph of the German Mark 1 mine while Figure 3 is a photograph of the firing mechanism of a somewhat later mine. Figure 4 is a sketch of a British Mine taken from a 1946 catalogue for an exhibition of mines and degaussing equipment at the South Kensington Science Museum. The British mines employed an electromagnetic induction loop, later complemented by acoustic sensors, rather than dip circles.

Degaussing principles

Various counter-methods were devised to overcome the threat from the mines. For large ships with adequate electrical generating capacity 'coiling' or degaussing[1] was employed where a large coil of copper wire, known as the M (or Main) coil was wrapped around the whole ship as shown in Figure 5. The magnetic field due to the coil was adjusted so that the net field was reduced to within safe limits. Thus, for a vessel in the northern hemisphere, the current ran in a counter-clockwise direction when viewed from above, while in the southern hemisphere the current was in a clockwise direction. In addition, many ships carried additional F (Forecastle) and Q (Quarterdeck) coils to help balance the overcompensation provided by the M coil in the vicinity of the bow and stern, and to reduce the longitudinal field. Finally, a number of ships carried A (Athwartships) coils, particularly if they had been laid down initially with an East–West orientation. The degaussing was intended to compensate for both the induced and permanent magnetisation of the ship, with adjustments being made to the coil currents depending on the ship's location.

The British Admiralty also developed a number of other techniques known variously as 'wiping', 'flashing' and 'deperming', designed to reduce the permanent magnetisation of the vessel. They were also effective for the vertical component of the induced magnetisation provided that the ship remained in similar latitudes. These techniques were usually applied to smaller vessels such as those with limited generating capacity, or those that operated over a limited region of the globe. Figure 6, taken from a contemporary publication (Ayliffe 1946) shows a ship rigged for wiping where a heavy copper cable was slung by ropes temporarily around the hull and a large current applied such that a field of

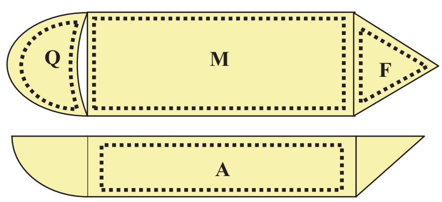

Fig. 5. Sketch of Degaussing Coils.

[1]The term degaussing (DG) is sometimes applied to all of the techniques employed to reduce the magnetic signature of a vessel or in other cases to only the coiling process. In this article I will use the term in the latter sense.

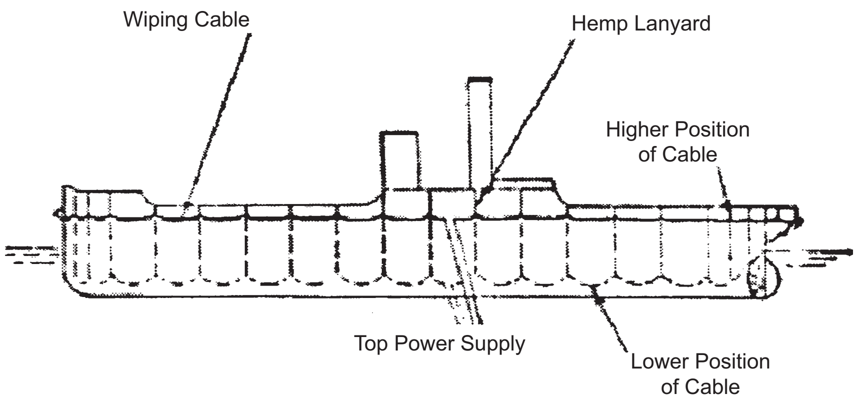

Fig. 6. Ship rigged for wiping (Ayliffe 1946).

opposite polarity to the natural field of the vessel was applied. The cable was progressively lowered or 'wiped' down the side of the hull. In the early years of the War, the German trigger mechanism was designed to respond only to an increase in the North-pole downwards field. Hence, in a frantic effort prior to the rescue of the British forces from Dunkirk, some 400 small ships were wiped to give them a net North-pole upward field.

One of the problems with wiping was that the protection only lasted from one to three months. With the ship's engines vibrating, the steel hull in the Earth's field, the permanent magnetisation slowly returned, making repeated wiping necessary. It was found, however, that the time could be increased by overwiping followed by flashing. This process initially produced a field of the opposite polarity that was ~250% of the original field followed by a large pulse of current of the opposite sense (flashing) that brought the net field back to within safe limits as illustrated in Figure 7.

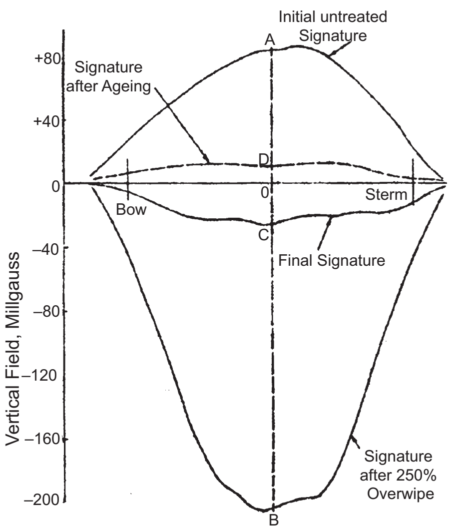

Fig. 7. Graph showing over-wiping and flashing (Ayliffe 1946).

The overall effect was to largely stabilise the magnetic domains. Provided that the ship remained in similar latitudes, it was the PVM that slowly returned as the ship was constantly in the same vertical component of the Earth's field. The PLM, however, tended not to return as over a period of time the ship went through all possible headings with respect to the Earth's field and so its effect was averaged out.

Deperming was designed to reduce the PLM. Figure 8 (Ayliffe 1946) illustrates the process, where the whole ship was wrapped in a temporary solenoid. Large current pulses of alternating polarity were passed through the coil, and progressively decreased until the net field was reduced to within safe limits.

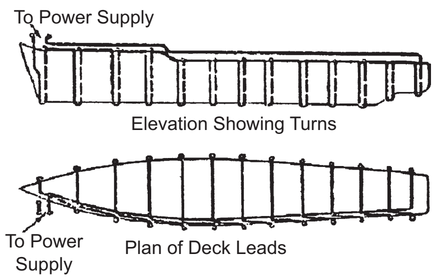

Fig. 8. Ship rigged for longitudinal deperming (Ayliffe 1946).

Endnote

In Australia, exploration geophysicists played a critical role in establishing these techniques under southern hemisphere conditions. Part 2 of this article, to be published in the next issue of *Preview*, explores what happened in Australia in the early years of Word War II, and the contribution made by the geophysicists.

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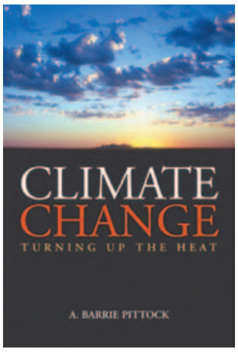

Reviewed by David Denham

Climate Change: Turning up the Heat

A. Barrie Pittock

Publisher: CSIRO Publishing, 2006, 316 pp. (pbk)

RRP: $39.95, ISBN: 0643069313

Barrie Pittock's enthusiasm for climate change and the urgent need to understand it and take appropriate action to mitigate and adapt to its effects, pervades the whole book.

As he says:

> '*The overwhelming body of evidence from relevant scientists is that there is a high probability that human induced global warming, with associated changes in other climatic conditions, is happening. Moreover, the evidence is that warming will continue, at an accelerating pace through the 21st century and beyond, unless urgent measures are taken to slow and eventually reverse the increase in greenhouse gases in the atmosphere.*' (p. 209)

The text was written in 2004–05 before the Stern Report (2006) and the 4th IPCC Report (2007). However, these more recent documents just confirm his conclusions. For example, the expected global temperature increase by 2100 is still in the 1.4–5.8ºC range given in IPCC 3 and the sea level rise range of 0.2–0.7 m still holds. The main difference between IPCC 3 and IPCC 4 is the significant increase in the certainty of the forecasts contained in the more recent report. What is missing from IPCC 4 is some of the 2006 and 2007 data, which indicate that sea level rise may be much faster than estimated earlier. Remember that a 1 m rise in sea level will inundate ~1 million km^2 and impact on at least 100 million people (2006 numbers), and it looks more likely that this will happen in the foreseeable future.

'Climate Change' is a scholarly, well-written book, which paints a broad canvas on the subject. It starts with the evidence of recent climate change, then examines proxy evidence covering the last ~0.5 million years, and goes on to look at what might happen in the future and the uncertainty in the models (*Uncertainty is inevitable, but risk is certain*). Pittock next discusses the impacts of climate change, and how we may be able to adapt to and mitigate these changes in the context of issues like population growth and the sustainability of the planet for human life. This brings us to the last four chapters (10–13): 'The politics of climate change', with a very interesting discussion on the ethical questions that may arise when the poor countries will be affected most by global warming, and yet the wealthy developed countries are those that have contributed most to their demise; 'International concern and national interests'; 'Accepting the challenge', and 'Further information', which contains an extensive list of websites, reading lists and references.

Pittock is particularly savage on the skeptics of climate change and includes a very useful table that deals very effectively with the arguments used by the Australian Government for not signing the Kyoto Protocol.

Most chapters contain a useful summary at the end for those who don't have the time to read the whole text, and each chapter starts with some very interesting quotations. For example, we have John Howard at the National Press Club in June 2004 saying:

> '*Human induced climate change is one of the major challenges confronting the world this century. The potential for climate change is real and addressing it will require changes to the way the world produces and uses energy*.'

And Donald Rumsfeld talking about what we know, what we don't know and what we don't know we don't know.

It should be a must-read for all year 11 and 12 students, all first year university students studying anything to do with resources, the environment and/or economics, and all advisors to government ministers at the State and/or Federal levels.

Finally, for those who want to just sit on their hands and hope that it will all go away let me refer them to the Rio Declaration at the Earth Summit in June 1992.

> '*Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*.'

I hope that Barrie Pittock is working on a second edition to cover the new post-2004 information which is now available. The topic is moving so quickly he could probably bring out a new edition every two years – but that is too much to ask.

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The Revenge of Gaia

James Lovelock

Publisher: Allen Lane, an imprint of Penguin Books, 2006, 177 pp.

Price: $29.95, ISBN: 07139 99268

Global Warming – is it the Revenge of Gaia? In his latest book, 'The Revenge of Gaia', James Lovelock, the founder of the Gaia theory, suggests that the current period of global warming could be Gaia's reaction to our mistreatment of 'her'. In a paper in *Nature* in 1974, Lovelock first proposed the concept that Earth was self-regulating the composition of gases in the atmosphere by a complex feedback mechanism. Whenever the balance was upset by some natural catastrophe, it eventually returned to the preferred state. Lovelock named the concept Gaia after the earth goddess in Greek mythology. At first the concept was met with opposition, especially by biologists, as it was contrary to the accepted wisdom of the time that life only adapted to changed planetary conditions and Earth could not behave like a living organism. However, in 2001, the initial Gaia hypothesis was advanced to a theory when it was ratified by the more than 1000 scientists who signed the Amsterdam Declaration of 2001. That Declaration's main statement was: 'The Earth System behaves as a single, self-regulating system comprised of physical, chemical, biological and human components'. This theory has since been borne out by observations and has allowed for successful predictions based on it. The theory has particular appeal to climatologists recently.

More on the Gaia theory can be found at: en.wikipedia.org/wiki/Gaia hypothesis. Tim Flannery quotes James Lovelock extensively in his book, 'The Weather Makers'.[1] Part 1 is called 'Gaia's Tools' and in Chapter 1, Flannery gives some examples of the fine-tuning of our climate that have given rise to the concept of Gaia.

James Lovelock has previously written three other books on Gaia, 'Gaia: A New Look at Life on Earth', 'The Ages of Gaia' and 'Gaia: The Practical Science of Planetary Medicine'. He has been a Fellow of the Royal Society since 1974 and has authored more than 200 scientific papers. Among his many achievements is his work at NASA to advise on how life on Mars might be recognised if it existed. It was when studying the atmosphere of Mars that he realised how different was Earth's atmosphere and this caused him to wonder why it was so perfectly suited to life. Lovelock has been invited to the Adelaide Festival of Ideas in July this year.

Recently, Lovelock shocked the green movement, of which he was thought to be a strong member, by advocating nuclear energy as the only sufficiently in-time source of energy to not exacerbate the build-up of greenhouse gases. In 'The Revenge of Gaia' he examines all the different sources of energy from non-renewables to renewables with some surprising and controversial arguments for the value of each. In the case of nuclear power, he dismisses the concern of how to safely dispose of the waste by advocating its disposal in places we wish to remain untouched by humans, such as wilderness areas. It would be somewhat ironic and no doubt very disturbing to Senator Bob Brown if the South-west of Tasmania was one such area chosen. Lovelock points out that nuclear waste ponds, such as at nuclear power stations in the USA, have luxuriant vegetation and a richness of wildlife largely because people, who are some of the worst destroyers of habitat, avoid them. Also, he claims our fear of nuclear radiation is unreasonable and that cancer caused by smoking should be of more concern. He argues that the loss of life due to Chernobyl is officially 75 and therefore nothing like the 30 000 stated by the media at the time. It is far less than the million people predicted to be drowned should the new Three Gorges dam on the Yangtze river burst. Lovelock asks what is the more acceptable risk?

In general, 'The Revenge of Gaia' is recommended reading if in parts it requires a strong understanding of chemistry to follow some of the reasoning. The centrepiece of photos in the book includes those of a retreating glacier, deforestation, large-scale farming (which he deplores with a passion), and the luxuriant plant growth at nuclear plants in the USA all of which are treated in the text. Lovelock, perhaps partly because of his age of 87, sounds very upset at what civilisation has done to our planet and pessimistic about our chances of recovering from it. He likens the present situation to that of an addicted smoker who continues to smoke even though the harm being done to him is obvious. In other words, we are leaving it too late. Having studied closely the conditions on Mars, he reminds us that we are heading that way but now faster than we should. Perhaps he could have added that we had better forget the idea of sending people to Mars and instead redirect the huge funds required towards saving Earth.

Maybe some of these funds could be used to advance some of the more way-out schemes now being proposed for the amelioration of climate change some of which Lovelock describes in 'The Revenge of Gaia'. One such proposal is to place a disc, 10 km in diameter, at the Lagrange point to deflect the sun's rays away from Earth. As an engineering feat it is practical and could be effective when Flannery, in his book[1] reminds us that a drop of only 0.1% in solar radiation reaching Earth can trigger an ice age. Of course, this scheme only attacks the consequent temperature increase. Other 'macro-engineering' schemes work at the reduction or absorption of greenhouse gases.

Copies can be ordered from Penguin Group (Australia) Customer Service, Tel.: (03) 9811 2400, Fax: (03) 9811 2620 or email: orders@au.penguingroup.com.

[1]The Weather Makers: The History and Future Impact of Climate Change by Tim Flannery, 2005, Text Publishing, Melbourne, 384 pp.