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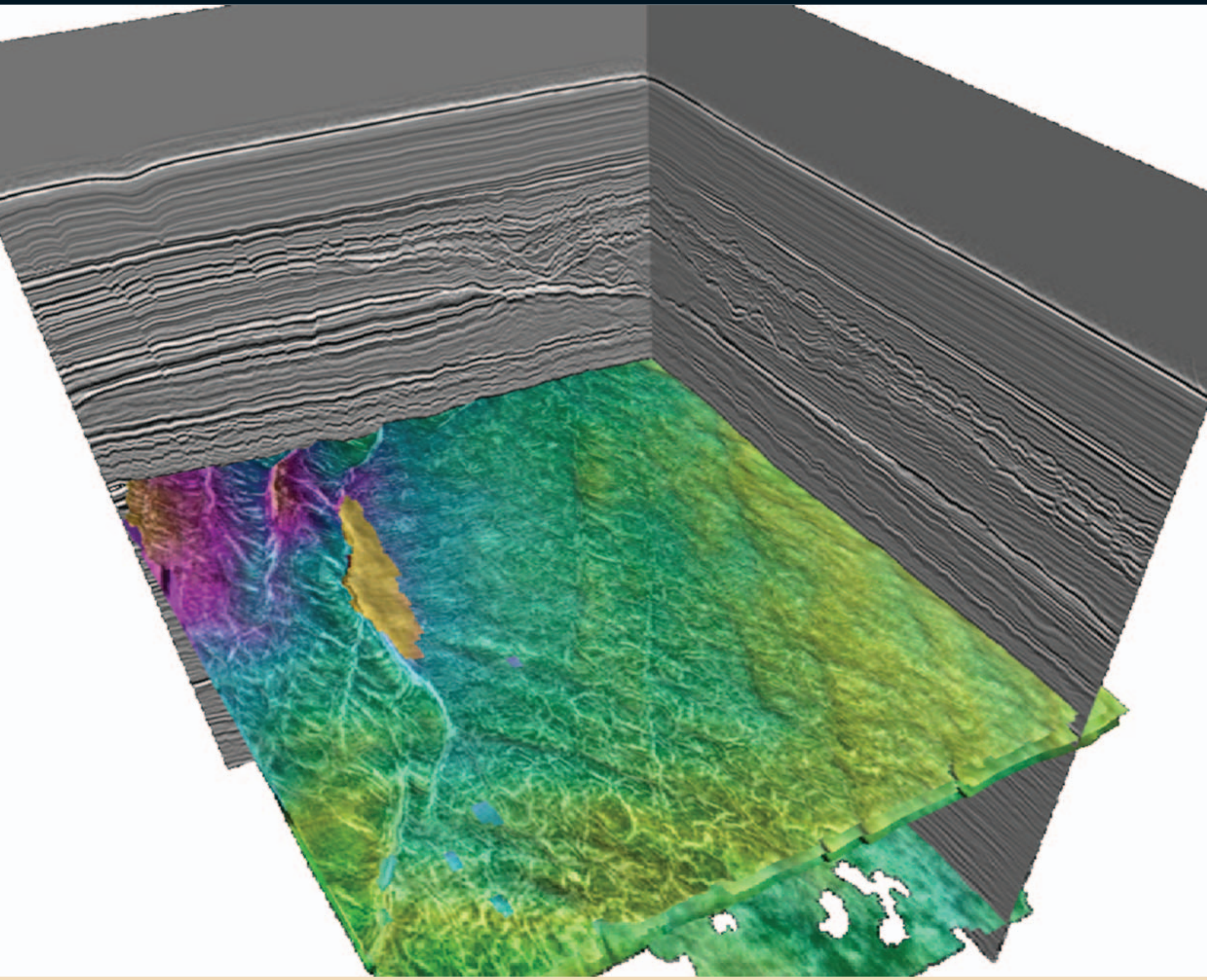
PREVIEW

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS



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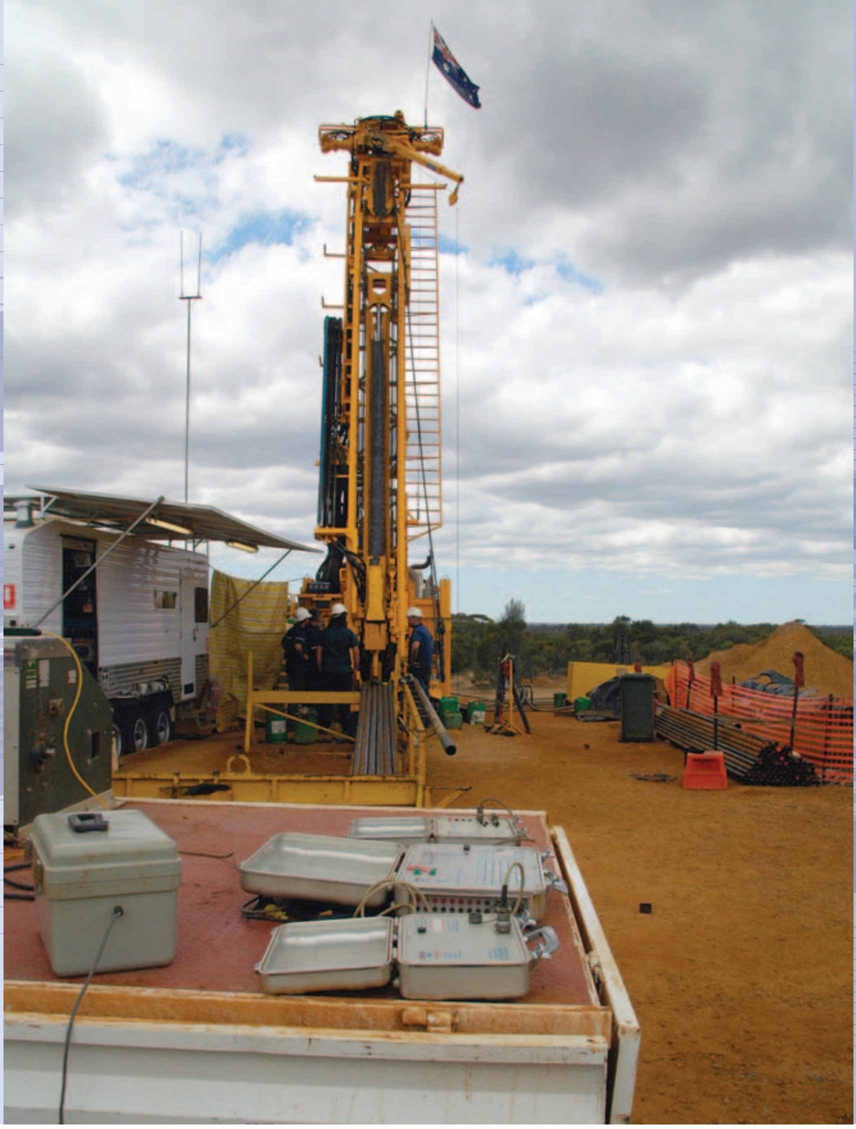
FEATURE ARTICLES



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FRONT COVER

Image taken from the visual database of GeoPopulations™ from the Chandon 3D volume (see p. 34 of this issue).

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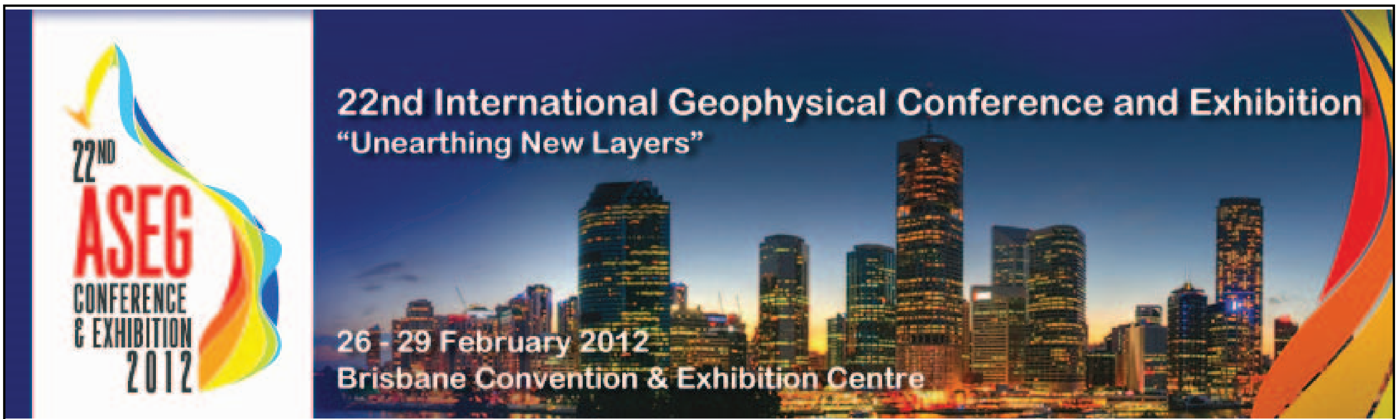
Women in geophysics

Ann-Marie Anderson-Mayes

Kelly Keates, Managing Director of Zonge Engineering, is the subject of this issue's People Profile. After preparing her interview, I became more attuned to issues associated with women in science. Some of you will know that this is a topic of some interest to me – I was Coordinator of the Women in Science and Engineering Project (WISE) at UWA for a couple of years in the early 1990s. The purpose of the programme was to encourage more women into physical science and engineering courses. So, it was with some amusement that I spotted the following item in the '50 & 100 years ago' column of *Nature* (vol. 469, p. 480, 2011) based on a report from *Nature* (vol. 189, pp. 253–4, 1961).

> *The report of an enquiry into the employment of qualified women scientists and engineers in private manufacturing industry shows clearly that, in general, industry in Britain is a man-dominated world and is likely to remain so for many years to come ... From the survey one conclusion is inescapable. Employers are reluctant to employ educated women scientists and engineers mainly because, on economic grounds, they are a bad risk ... From the employer's point of view, their years of useful service before beginning full-time duties in their homes is very limited. All the well-meaning protestations by women's organizations will not make young women scientists and engineers anything but a bad industrial investment compared with their male counterparts. Most educated women know this and accept this.*

In another recent item in *Nature* (vol. 470, p. 153, 2011), it was noted that whilst overt discrimination has largely been removed, there continues to be a persistent gap in the number of women in



CALL FOR PAPERS

Key Dates

- Abstracts to be submitted by Friday, 29 April 2011.
- Notification of acceptance by Friday, 17 June 2011.
- Submission of Extended Abstracts by Friday, 30 September 2011.

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maths-intensive fields such as physics, computer science and engineering. It would be fair to say that geophysics sits firmly in this group. The article reported that the barriers to women's participation in these fields were likely multiple and more invisible – social, biological and institutional.

So, why is geophysics still a male-dominated discipline? I really don't know the answer. As a matter of interest, Curtin University has the only dedicated *Exploration Geophysics* department in Australia. On their web page, no women appear in the list of academic staff, and amongst 22 PhD students, only 5 are women. In a fact sheet published by the American Geological Institute in May 2010 (www.agiweb.org/workforce/Currents/Currents-033-GenderOccupations.pdf), statistics for 2006 showed that only 16% of geoscientists were women.

When I studied Physics at UWA over 20 years ago, I was the only female Honours student in our class. At the time, I really didn't think too much about it – I was studying something I enjoyed and the question of gender was irrelevant to me. It was only with hindsight and my experience working at WISE that I began to question why a choice which was completely natural for me, was not of interest to the majority of my female friends (in fact I have a good friend now who delights in introducing me as a 'the one who likes maths!' as though this were something truly extraordinary, or just plain weird). I suspect most of my female colleagues in geophysics feel the same – the question of gender simply didn't arise in our choice of career, and you will read in Kelly Keates' profile that this is certainly true in her case as well. But this still leaves me wondering, why do women choose our profession in relatively low numbers when compared with many other branches of science? And is there anything as a professional society that we can or should be doing to improve the gender balance?

Alongside all the regular contributions in this issue, we have two feature articles that look at different aspects of analysing data. Anya Reading *et al.* advocate using a mix of both deterministic and inferential data analysis techniques to maximise the extraction of useful geological information from geophysical data; and Dirstein and Fallon apply genetic algorithms to the interpretation of 3D seismic data.

Western Australia Geothermal Energy Symposium (WAGES)

In late March, WAGES is being held in Perth over two days and I believe that it is appropriate that the ASEG is supporting this conference. I have been following developments in this space for a number of years. Geothermal energy has been promoted by many as our way to the carbonless future and on paper it sounds terrific.

Over the last ten years around $640 million has been raised on capital markets and a number of companies have been floated. The Federal and State Governments have contributed in excess of $150 million. Some companies are targeting deep (3–4 km) hot granite that would be fracture-stimulated to allow the circulation of water and create steam at the surface, whereas the other approach is to find hot ground water close to basement that can be pumped to the surface for the recovery of heat.

It is a sad fact that many of the companies currently have market capitalisations that are well below the total money that has been invested, indicating that investors are far from convinced about their future. So far as I know, not one Watt of electricity has been generated commercially in spite of early bullish promises. This says everything about how risky the geothermal business is and how difficult it will be for small players. So why is this so?

My personal view is that the development of this industry is beyond the capability of start up companies because of the geological risk and the impatience of risk markets. If governments are serious about this technology as one way to a carbonless future in Australia, it will take billions of dollars to develop, not a few hundred million.

Most of the presentations that I have heard over the years have focussed on the surface infrastructure side…generation, proximity to markets, powerlines etc., yet these are the easily definable risks. The geological side of the story has been downplayed to simple cartoons yet this is where the real risk lies….3 to 4 kilometres below our feet. It involves questions about rock type and structure, temperature, thermal conductivity, rock mechanics, porosity, permeability, fluid composition and many others. Measuring these both from the surface and below the surface around drill holes will be a future challenge for the geophysical profession.

Final words

This is the last President's Piece that I will be writing for *Preview*. I have tried to keep my bimonthly ramblings relevant to our profession and I take full responsibility for any opinions that I have expressed.

Against a buoyant resources sector, the past year has been a good one for the ASEG. Thanks to the great efforts of the Sydney organising committee our conference in August was a success with a large number of technical papers. It also made a healthy surplus that will help the ASEG to continue pursuing its activities on behalf of its members. At the conference we signed a memorandum of understanding with the Chinese Geophysical Society that I hope will lead to closer cooperation between the two societies in the future.

After a lot of hard work by Koya Suto, Phil Schmidt and Mike Asten, we have signed an agreement with the Society of Exploration Geophysicists of Japan, and the Korean Geophysical Society, to jointly publish our main technical journal, *Exploration Geophysics*. Our hope is that this will allow us to attract a broader range of high quality technical papers and increase the international standing of *Exploration Geophysics* as an academic publication.

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Dr Toshihiro Uchida
President
The Society of Exploration Geophysicists of Japan
uchida-toshihiro@aist.go.jp

Dear Dr. Toshihiro,

On behalf of my colleagues and their families in the Australian Society of Exploration Geophysicists, I would like to express our very grave concern for your members and their families during the recent chain of events in Japan. The images of the earthquake and the resulting tsunami that we have seen on our televisions in Australia have been truly terrifying. Not to mention the follow-up concerns about the nuclear power stations. The scale of the loss of life is truly unbelievable.

I know that Japan is one of the countries in the world best prepared to handle such geological disasters, but this one is beyond what anyone could have imagined. I also know that the people of Japan show great strength in the face of such disasters and once you are over the immediate impact of the current events, the drive to rebuild a new life in the areas affected will be unparalleled anywhere else in the world.

As fellow earth scientists we understand better than most the nature of such geological events and their causes, but in no way does this diminish the personal impact that they have on us.

Our thoughts and hopes are with you all.

Kind regards,

Phillip Harman
President - The Australian Society of Exploration Geophysicists

My greatest disappointment is that I still get phone calls and emails about the website. We are living with an interim solution and are jointly developing a new website in cooperation with PESA. I understand everyone's frustration over the past year and hope that we will have a lasting solution soon.

On a more general front, during the past year I was somewhat relieved to find that the opinion storm raging over climate change and mankind's potential role in it took a breather. With the current situation in Federal parliament, it is clearly back on the agenda with the doomsayers voices saying 'we'll all be ruined' being heard again. Climate change aside, during the past year the world has seen serious natural disasters, some fairly close to home for all of us. These included the drought breaking floods and destructive cyclones in Australia, major volcanic eruptions in Iceland, earthquakes in New Zealand and as I write this piece, the tragic events and huge loss of life in Japan.

None of these events were particularly unusual but the popular press made a real meal of them. Some of the climate change promoters will try to slate the weather events down to the human race, but the volcanic eruptions, the earthquakes and the subsequent catastrophic tsunami, just show us that we are forever at the mercy of earth and its inner rumblings. Nevertheless our hearts go out to all of those who have lost loved ones or been severely impacted in other ways.

My year as President has flown past and I feel privileged to have had the opportunity. I would like to pass on my personal thanks to everyone who has assisted me with their contributions to the ASEG, in particular the members of the Federal Executive and Branch committees along with Ron Adams and his team at CASM. Also, thank you to the editors of our publications, in particular Ann-Marie Anderson-Mayes who is the life blood of *Preview*.

Finally, I wish the incoming president Dennis Cooke all the best for the coming year and look forward to working with him on the next Fedex committee.

Phil Harman
President
phil.harman@bigpond.com

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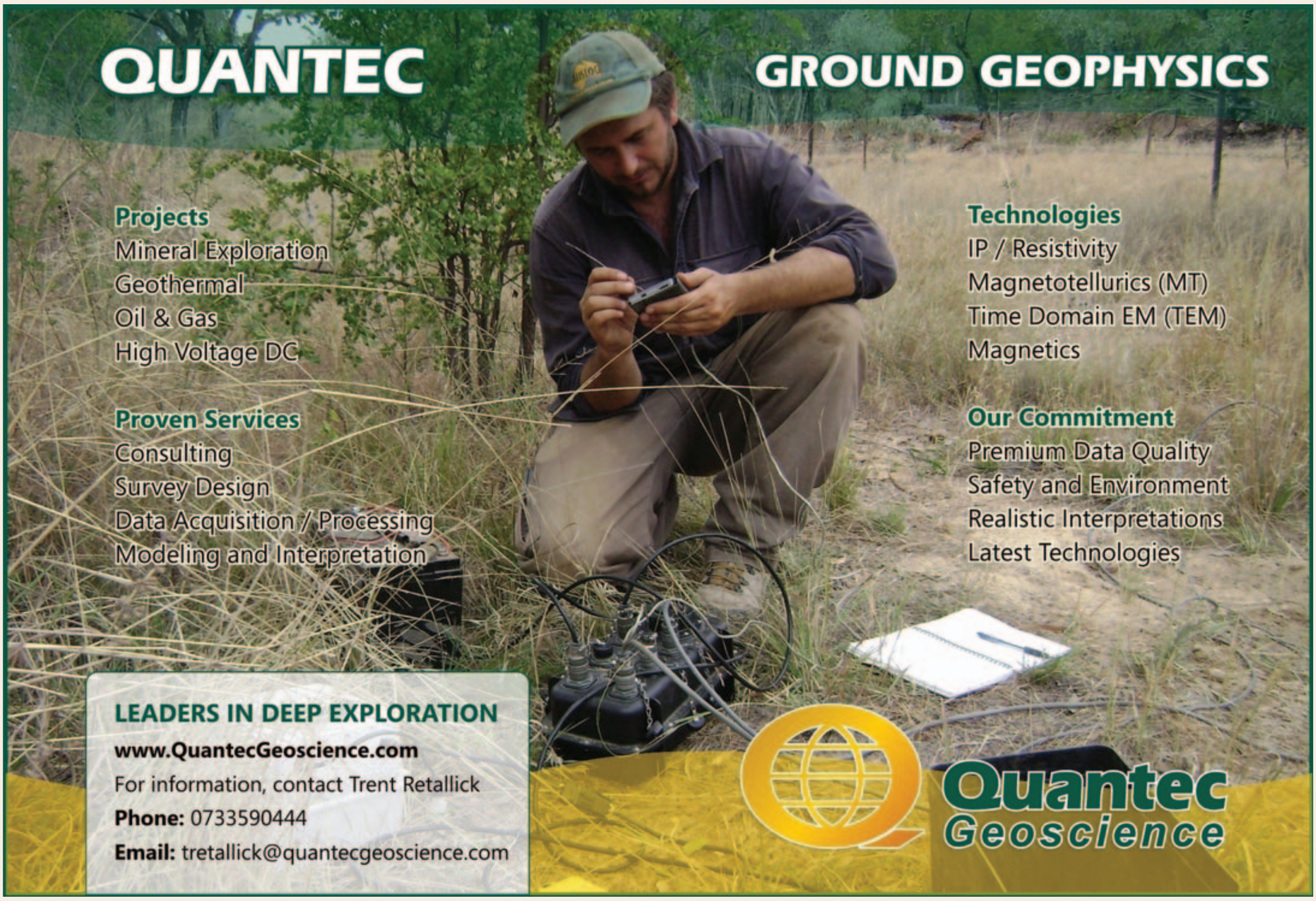
New members

The ASEG extends a warm welcome to 23 new members to the Society (see table below). These memberships were approved at the Federal Executive meetings held on 27 January and 24 February 2011.

Name	Organisation	State/Country	Member grade
Sasha Banaszczyk	University of Western Australia	WA	Student
Mark Alexander Bell	Ground Probe	QLD	Active
Katherine Elizabeth Charlton	University of Melbourne	VIC	Student
Christian Cintolesi	Schlumberger Water Services	WA	Associate
Arjen Johan Dales	GroundProbe Geophysics	WA	Active
Neil Godber	Vale	QLD	Active
Anthony Richard Hallam	Origin Energy	QLD	Active
Lachlan Hennessy	Newexco Services	WA	Active
Troy Richard Hewitt	Pangaea Resources	NSW	Active
Thomas Edward Hoskin	University of Western Australia	WA	Student
Susan John	Nautilus Minerals Niugini	Papua New Guinea	Associate
Kledy Koloa	Nautilus Minerals Niugini	Papua New Guinea	Associate
Stephen John Lee	AGS Advanced Geophysical Systems	Germany	Active
Tarrant Gwylim Meehan	University of Melbourne	VIC	Student
Gavin Trevor Mogensen	Griffith University	QLD	Student
Tyler Raleigh	Fugro Ground Geophysics	WA	Active
Craig Alan Smith	Fugro Airborne Surveys Pty Ltd	WA	Associate
Katherine Allison Stoate	University of Adelaide	SA	Student
Konstantin Tertyshnikov	Curtin University of Technology	WA	Student
Dave Toni	Resource Potentials	WA	Active
Nick Walton	IR Consulting	United Kingdom	Associate
Andrew Mark Weatherstone	Geophysical Resources and Services	NSW	Active
Scott Weber	Adelaide University	SA	Student



ASEG News

Australian Capital Territory

The ACT branch held its AGM on 16 March. Tim Jones, recent Honours graduate from Macquarie Uni and now a Geoscience Australia graduate, kicked off proceedings with a short talk on his numerical modelling work looking at the influence of the post-perovskite phase transition on mantle plumes and lower-mantle thermomechanical piles.

During the AGM, Ron Hackney and Marina Costelloe were voted to continue as President and Secretary, but after many years in charge of finances, Leonie Jones decided to take a breather from the Treasurer's role. Matt Purss was voted in as the new Treasurer. General committee members include Leonie Jones (she didn't escape completely!), Eva Papp, Nick Rawlinson, Ned Stolz and Ray Tracey. Thanks are due to long-serving Treasurer, Leonie Jones, to retiring committee member Malcolm Sambridge, and to enthusiastic student representative Paul Sutherland.

The ACT Branch now looks forward to hosting Richard Lane for his South Pacific Honorary Lecture on 13 April (a week earlier than previously announced). At about the time that you read this, Richard will have made the long journey from GA to ANU for his lunch-time presentation.

Ron Hackney

New South Wales

In February we held our AGM and the usual suspects (myself, Bin Guo and Roger Henderson) were elected to the roles of President, Secretary and Treasurer. Following this, Roger Henderson, gave a presentation on 'The birds and the bees do it…but can humans?'; the talk was about the latest theories on 'magnetoreception' by the animal kingdom. Roger discussed how it is now thought that birds, at least, can not only sense the variation in the intensity of the magnetic field for use in their navigation but also 'see' the declination of the field. Roger reported on 'cryptochromes' and how this makes some animals sensitive to the magnetic field.

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

The speaker for May will be Julian Vrbancich from the Department of Defence and the speaker for June will be Clive Foss from the CSIRO on 'Down-hole tensor magnetic gradiometry'.

Mark Lackie

Queensland

The Queensland Branch has kicked off 2011 with the SEG Pacific Honorary Lecturer Richard Lane presenting 'Building on 3D geological knowledge through gravity and magnetic modelling workflows at regional to local scales'. This was successfully held as an informal lunch, a departure from the usual evening drinks and nibbles.

Geokinetics also invited the Brisbane ASEG branch to a presentation in February by Mr Bill Pramik of Geokinetics on the onSEIS seismic energy source Geokinetics has brought to Australia. The Queensland Branch is currently on the lookout for some presenters to fill the 2011 program. If you can help or have any suggestions, please contact Fiona Duncan (fiona.duncan@bg-group.com).

Fiona Duncan

South Australia/Northern Territory

The SA/NT branch has hit the ground running this year with the AGM and first technical meeting of the year being held on the 8th of February. Philip Heath, Mike Hatch and Tania Dhu remain as President, Secretary and Treasurer respectively. Our guest speaker – David Dewhurst from the CSIRO in Perth – presented a talk entitled 'Strength prediction and rock physics response in shales'.

Our second talk was held on the 8th of March and we welcomed Richard Lane on his SEG Honorary Lecture tour of the South Pacific. His talk on 'Building on 3D geological knowledge through gravity and magnetic modelling workflows at regional to local scales' was well received, with questions continuing into the night. The photograph below shows Richard presenting his talk.

We have numerous events planned for the remainder of the year, including a barbecue at the University of Adelaide, to introduce students studying geophysics to the ASEG. Later in the year the SEG Distinguished Lecture and Distinguished Instructor Short Course will be visiting Adelaide and I invite local members to come along. Dennis Cooke will be giving a talk in April on the history of Shale Gas, and we still have room for a couple of talks if anyone is interested for later in the year.

Richard Lane on the SEG Honorary Lecture South Pacific tour in Adelaide.

We will also hold our regular social events, including the Melbourne Cup lunch and Christmas Party. The wine offer will be on again this year. **Please ensure your email addresses are up to date so you don't risk missing out! (If you are an ASEG member and are not receiving emails please contact CASM (aseg@casm.com.au) to ensure your email address is up to date.)**

The SA branch holds technical meetings monthly, usually on a Tuesday or Thursday night at the Coopers Ale House beginning 5:30 pm. New members and interested persons are always welcome. Please contact Philip Heath (philip.heath@sa.gov.au) for further details.

Philip Heath

Victoria

On 25 October 2010 at the Kelvin Club in Melbourne, the Annual General Meeting for the ASEG Victorian Branch saw the election of new committee members: Asbjørn Christensen – President, John Theodoridis – Secretary, and Kent Balas – Treasurer. We say 'thank you' to Richard Macrae and Phillip Skladzien who with much enthusiasm had served the latter two positions respectively.

A technical talk followed the AGM in which Prof. Alan Green of the Swiss Federal Institute of Technology (ETH), Zurich, Switzerland issued his ASEG/SEG 2010 Distinguished Lecturer Presentation, entitled 'Mapping active major faults using 3D ground penetrating radar and 2D and 3D high resolution reflection seismology – examples from New Zealand'.

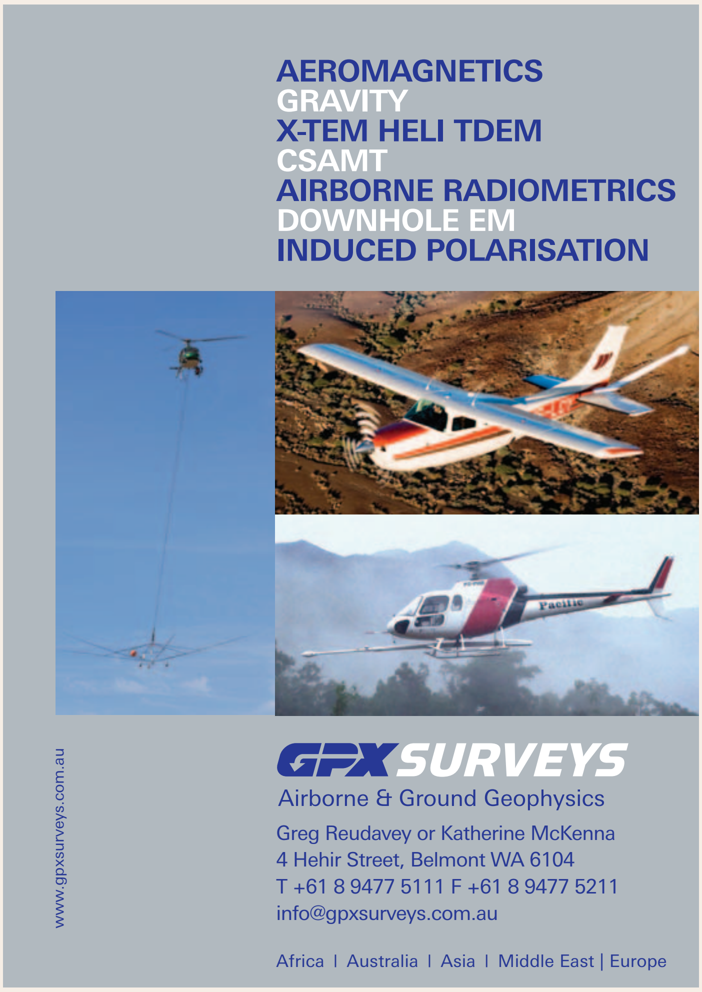
Subsequently Prof. Alan Green held a one-day Distinguished Instructor course, entitled 'Application of seismic and geo-electric geophysical methods to near-surface and engineering related studies' at Monash University – Clayton Campus on 12 November, attracting near thirty professionals all of whom benefited greatly from Prof. Green's unique expertise.

On 8 December 2010 Victorian ASEG members attended the combined PESA–SPE–ASEG end of year technical meeting held at The Victoria Hotel. Whilst treated to a generous three course meal, participants gave audience to a slide show entitled '16 years of Papua New Guinea experiences' presented by the special guest speaker – Roger Thornton. Utilising his 40 plus years experience in the oil and gas industry, Roger Thornton canvassed the many difficulties of exploration in a challenging mountainous terrain, whilst reconciling it with the sensitive cultural needs of the indigenous people of Papua New Guinea; all of which was presented in both a fascinating and entertaining manner. Inter-society events such as this reflect the ongoing relationship between PESA and the ASEG.

With great privilege to the Victorian Branch of the ASEG, Richard Lane commenced his tour of Australia, on 24 February at the Kelvin Club in Melbourne, as the 2011 Pacific South Honorary Lecturer. Sponsored and supported by Shell and the SEG, his lecture entitled 'Building on 3D geological knowledge through gravity and magnetic modelling workflows at regional to local scales' explored the renewed interest in researching potential field modelling techniques in light of advances in 3D software tools and lower cost processing abilities using distributed networks. Richard's presence at our first technical meeting for the year drew a significant audience, which culminated in a lively philosophical discussion relating to the characterisation of model uncertainty and its final relationship with geological actuality.

Finally, on Wednesday 30 March at the Kelvin Club, the ASEG Victorian Branch will be hosting the Annual Student Night, giving local graduating students an opportunity to present their research in a professional forum. Contributing students are anticipated from Melbourne, Monash and RMIT universities. Not only should this prove to be an exciting night for all, but a unique opportunity to extend a warm welcome to our new graduates into the geophysics profession.

John Theodoridis



ASEG 2012 22nd ASEG International Conference and Exhibition News Update (04)

CALL FOR PAPERS

It's all systems go in the lead-up to the ASEG 22nd International Conference and Exhibition. The Call for Papers has been released and the sponsorship and exhibition documents have also been published. The conference has been promoted at the EAGE in Vienna. We are particularly looking for papers that address the conference theme with the application of geophysics in the exploration of unconventional resources.

Please visit our website at www.aseg2012.com.au to lodge an expression of interest.

Co-Chairs: Wayne Mogg & Andrea Rutley
Technical: Binzhong Zhou
Sponsorship: Ron Palmer & Position vacant
Exhibition: Gary Butler & John Donohue
Finance: Noll Moriarty
Workshops: Koya Suto
Publicity: Henk van Paridon
Students: Shaun Strong
Social: Janelle Kuter

Anyone able to help (urgent request for people to help with papers) should contact Binzhong Zhou (binzhing.zhou@csiro.au). You don't need to be in Brisbane.

Our conference theme of 'Unearthing new layers' recognises that transformational change within our industry remains achievable, and as such we invite contributions from all geophysical and related disciplines, highlighting the application of geophysics in diverse industries from resource exploitation to environmental and engineering applications.

Henk van Paridon

Update on Geophysical Survey Progress from the Geological Surveys of New South Wales, Queensland, Tasmania, Western Australia, and Geoscience Australia (information current at 10 March 2011)

Tables 1–3 show the continuing acquisition by the States, the Northern Territory and Geoscience Australia of new gravity, airborne magnetic and radiometrics, and airborne EM over the Australian continent. All surveys are being managed by Geoscience Australia.

This issue reports new surveys which are part of the Queensland Government's Greenfields 2020 Program. There are two gravity surveys (see Figure 1) and four airborne magnetic and radiometric surveys (see Figure 2). The surveys are located in the Longreach area of central Queensland (Galilee surveys – Figures 3 and 4) and in the Cunnamulla–St George area adjacent to the New South Wales border (Thomson surveys – Figures 5–8). For further details please contact Bernie Stockill, Senior Geoscientist, Geological Survey of Queensland on 07 3896 9447 or email bernie.stockill@deedi.qld.gov.au.

An additional new airborne mag/rad survey is being undertaken for the Geological Survey of New South Wales in the Grafton-Tenterfield area (see Figure 9).

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Contractor	Start flying	Line (km)	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
South Officer 1 (Jubilee)	GSWA	Thomson	1 Jun 10	180 000	200 m 50 m N–S	32 380	59.1% complete @ 13 Feb 11	TBA	148 – Oct 10 p23	Survey on hold due to standing water in the survey area
South Officer 2 (Waigen – Mason)	GSWA	Thomson	28 Jun 10	113 000	400 m 60 m N–S	39 890	100% complete @ 5 Jan 11	TBA	148 – Oct 10 p24	QA/QC of final data in progress
East Canning 3 (Stansmore)	GSWA	Thomson	14 Jul 10	114 000	200 m (east) 400 m (west) 50 m N–S	25 934	100% complete @ 2 Nov 10	TBA	148 – Oct 10 p24	QA/QC of final data in progress
Eucla Basin 2 (Loongana)	GSWA	Fugro	20 Jun 10	113 000	200 m 50 m N–S	20 320	100% complete @ 3 Dec 10	TBA	148 – Oct 10 p24	QA/QC of final data in progress
Eucla Basin 4 (Madura)	GSWA	Fugro	1 Jul 10	102 000	200 m 50 m N–S	18 220	100% complete @ 22 Nov 10	TBA	148 – Oct 10 p24	QA/QC of final data in progress
Eucla Basin 5N (Forrest)	GSWA	Fugro	16 Jun 10	75 000	200 m 50 m N–S	13 040	100% complete @ 12 Sep 10	TBA	148 – Oct 10 p25	QA/QC of final data in progress
Eucla Basin 5S (Eucla)	GSWA	Fugro	6 Jul 10	87 500	200 m (onshore) 400 m (offshore) 50 m (onshore) 100 m (offshore) N–S	16 100	100% complete @ 5 Nov 10	TBA	148 – Oct 10 p25	QA/QC of final data in progress
South Canning 1 (Madley – Herbert)	GSWA	Aeroquest	19 Jul 10	95 000	400 m 60 m N–S	33 520	100% complete @ 12 Nov 10	TBA	148 – Oct 10 p25	QA/QC of final data in progress
South Canning 2 (Morris – Herbert)	GSWA	Aeroquest	1 Jul 10	125 000	400 m 60 m N–S	45 850	100% complete @ 11 Jan 11	TBA	148 – Oct 10 p25	QA/QC of final data in progress
North Canning 4 (Lagrange – Munro)	GSWA	Aeroquest	20 Sep 10	103 000	400 m 60 m N–S	36 680	68% complete @ 9 Jan 11	TBA	148 – Oct 10 p26	Survey delayed due to unfavourable weather conditions for survey flying
Southeast Lachlan	GSNSW	Fugro	1 Mar 10	107 533	250 m (NSW) 500 m (ACT) E–W	24 660	100% on 9 Sep 10	TBA	144 – Feb 10 p15	TBA

News

Table 1. *Continued*

Survey name	Client	Contractor	Start flying	Line (km)	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Grafton – Tenterfield	GSNSW	TBA	TBA	100 000	250 m 60 m E–W	23 000	TBA	TBA	This issue (Figure 9)	TBA
West Kimberley	GSWA	Aeroquest	TBA	134 000	800 m 60 m N–S Charnley: 200 m 50 m N–S	42 000	TBA	TBA	150 – Feb 11 p20	Expected to commence April 2011
Perth Basin North (Perth Basin 1)	GSWA	Fugro	TBA	96 000	400 m 60 m E–W	30 000	TBA	TBA	150 – Feb 11 p20	Expected to commence April 2011
Perth Basin South (Perth Basin 2)	GSWA	Fugro	TBA	88 000	400 m 60 m E–W	27 500	TBA	TBA	150 – Feb 11 p20	Expected to commence April 2011
Murgoo (Murchison 1)	GSWA	Thomson	28 Feb 11	128 000	200 m 50 m E–W	21 250	5.6% complete @ 7 Mar 11	TBA	150 – Feb 11 p20	TBA
Perenjori (Murchison 2)	GSWA	GPX	TBA	120 000	200 m 50 m E–W	20 000	TBA	TBA	150 – Feb 11 p21	Expected to commence July 2011
South Pilbara	GSWA	GPX	TBA	136 000	400 m 60 m N–S	42 500	TBA	TBA	150 – Feb 11 p21	Expected to commence May 2011
Carnarvon Basin North (Carnarvon Basin 1)	GSWA	GPX	TBA	104 000	400 m 60 m E–W	32 500	TBA	TBA	150 – Feb 11 p21	Expected to commence April 2011
Carnarvon Basin South (Carnarvon Basin 2)	GSWA	GPX	TBA	128 000	400 m 60 m E–W	40 000	TBA	TBA	150 – Feb 11 p21	Expected to commence February 2012
Moora (South West 1)	GSWA	Aeroquest	TBA	128 000	200 m 50 m E–W	21 250	TBA	TBA	150 – Feb 11 p22	Expected to commence April 2011
Corrigin (South West 2)	GSWA	GPX	TBA	120 000	200 m 50 m E–W	20 000	TBA	TBA	150 – Feb 11 p22	Expected to commence October 2011
Cape Leeuwin – Collie (South West 3)	GSWA	Fugro	TBA	105 000	200/400 m 50/60 m E–W	25 000	TBA	TBA	150 – Feb 11 p22	Expected to commence April 2011
Mt Barker (South West 4)	GSWA	GPX	TBA	120 000	200 m 50 m N–S	20 000	TBA	TBA	150 – Feb 11 p22	Expected to commence April 2011
Offshore East Coast Tasmania	MRT	Fugro	28 Feb 11	30 895	800 m 90 m E–W	19 570	10.6% complete @ 28 Feb 11	TBA	150 – Feb 11 p23	TBA
Galilee	GSQ	TBA	TBA	125 959	400 m 80 m E–W	44 530	TBA	TBA	This issue (Figure 4)	TBA
Thomson West	GSQ	TBA	TBA	146 000	400 m 80 m E–W	52 170	TBA	TBA	This issue (Figure 6)	TBA
Thomson East	GSQ	TBA	TBA	131 100	400 m 80 m E–W	46 730	TBA	TBA	This issue (Figure 7)	TBA
Thomson Extension	GSQ	TBA	TBA	47 777	400 m 80 m E–W	16 400	TBA	TBA	This issue (Figure 8)	TBA

TBA, to be advised.

Table 2. Gravity surveys

Survey name	Client	Contractor	Start survey	No. of stations	Station spacing (km)	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Albany – Fraser North	GSWA	Atlas	21 Oct 10	9200	2.5 km regular	50 980	100% on 30 Jan 11	TBA	146 – Jun 10 p17	QA/QC of final data in progress
Sandstone	GSWA	IMT	Early Oct 10	6300	2.5 km regular	35 640	100% on 17 Dec 10	TBA	146 – Jun 10 p17	QA/QC of final data in progress
South Gascoyne	GSWA	IMT	9 Aug 10	9700	2.5 km regular	55 760	100% on 27 Oct 10	TBA	146 – Jun 10 p17	QA/QC of final data in progress
Galilee	GSQ	IMT	April 11	6400	2.5 km regular	TBA	TBA	TBA	This issue (Figure 3)	TBA
Thomson	GSQ	Daishsat	April 11	7670	2.5 km regular	TBA	TBA	TBA	This issue (Figure 5)	TBA

TBA, to be advised.

Table 3. Airborne electromagnetic surveys

Survey name	Client	Contractor	Start survey	Line (km)	Spacing AGL Dir	Area (km²)	End survey	Final Data to GA	Locality diagram (*Preview*)	GADDS release
Frome	GA	Fugro	22 May 10	34 986	5000 and 2500 100 m E–W	95 450	100% on 31 Oct 10	TBA	146 – Jun 10 p18	QA/QC of final data in progress

TBA, to be advised.

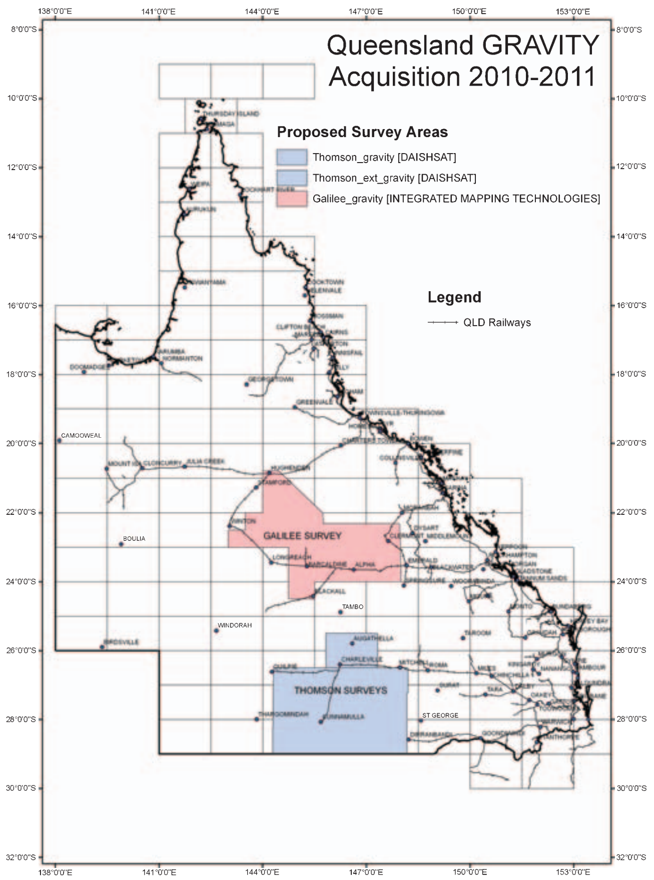


Fig. 1. *Location diagram for new gravity surveys in Queensland.*

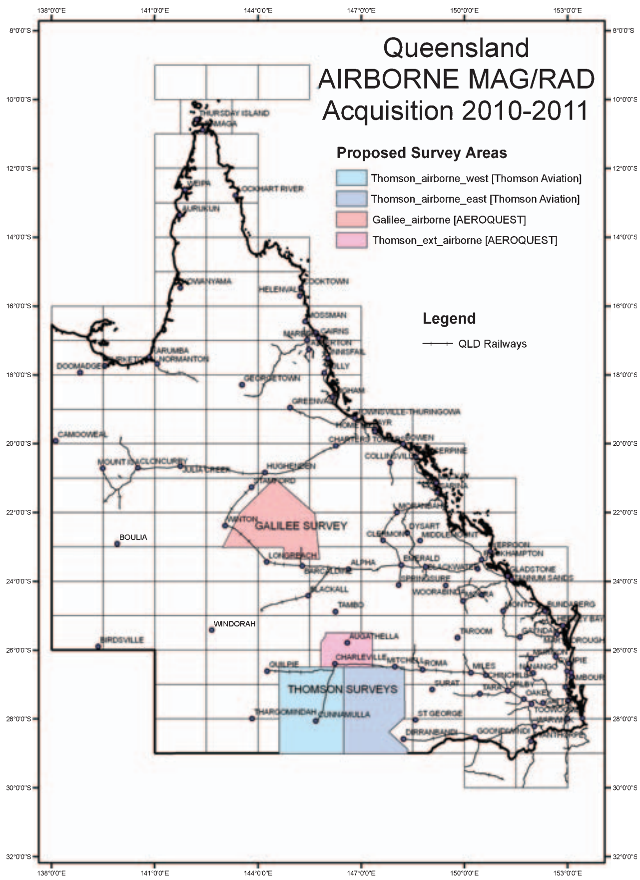


Fig. 2. *Location diagram for new airborne mag/rad surveys in Queensland.*

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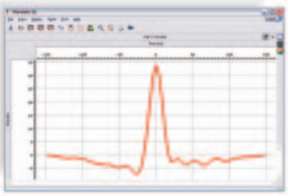

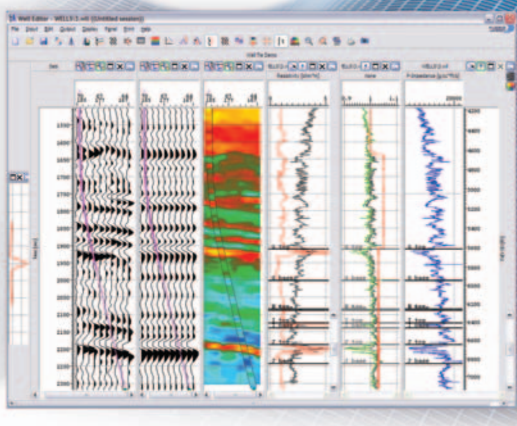

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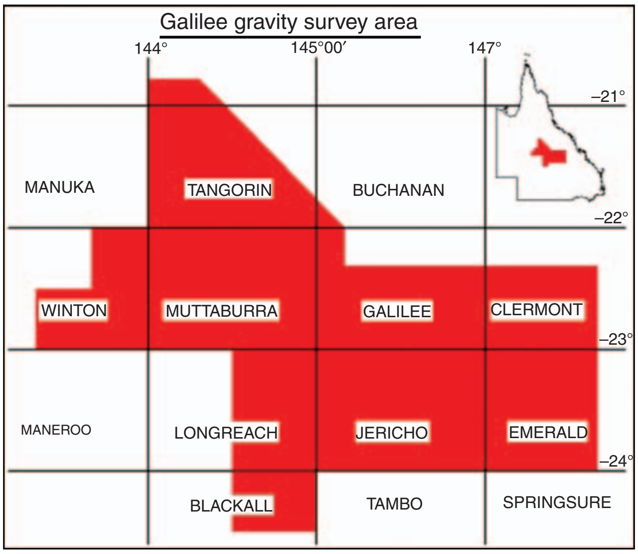

Fig. 3. *Survey area for Galilee gravity survey.*

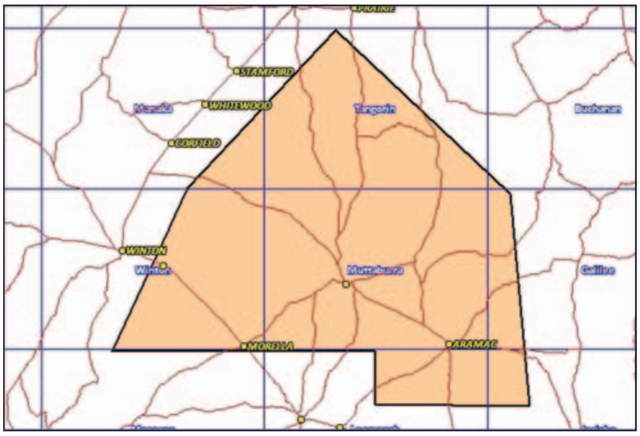

Fig. 4. *Survey area for Galilee airborne mag/rad survey.*

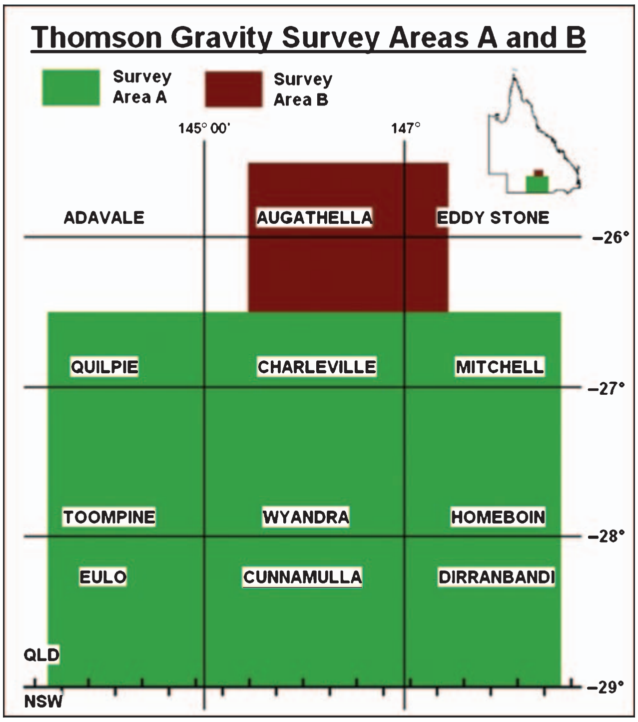

Fig. 5. *Survey area for Thomson gravity surveys A and B.*

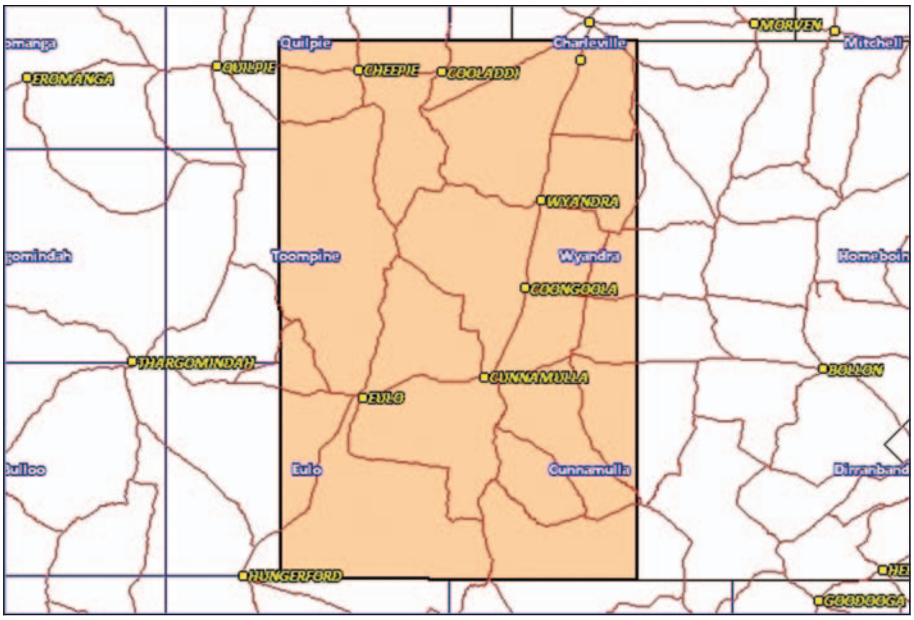

Fig. 6. *Survey area for Thomson West airborne mag/rad survey.*

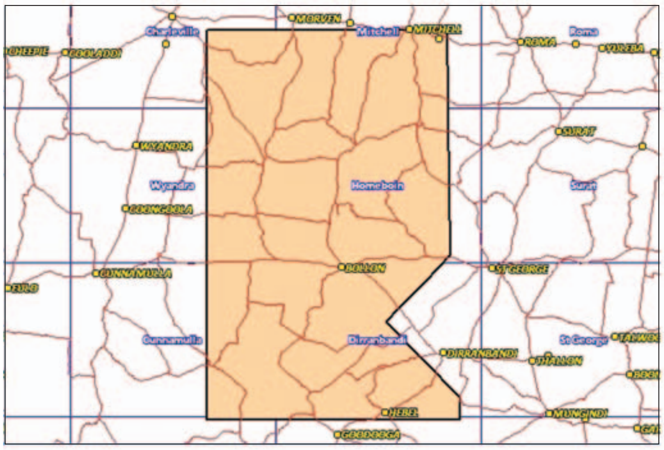

Fig. 7. *Survey area for Thomson East airborne mag/rad survey.*

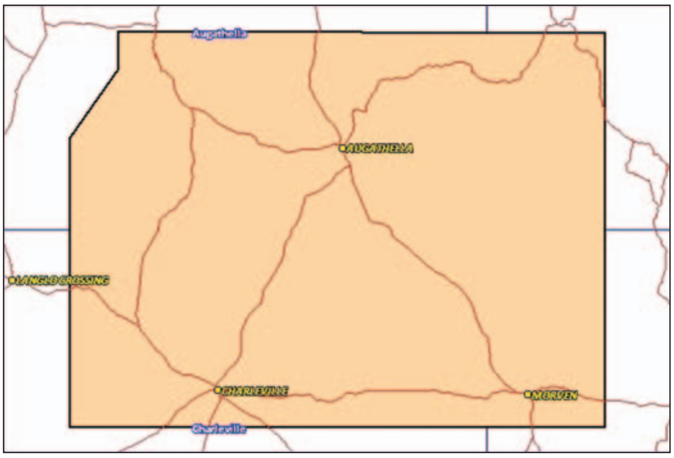

Fig. 8. *Survey area for Thomson Extension airborne mag/rad survey.*

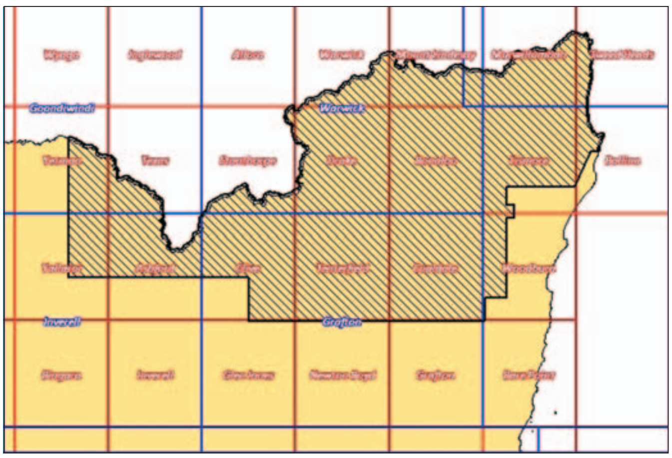

Fig. 9. *Survey area for Grafton-Tenterfield airborne mag/rad survey.*

Geological Survey of South Australia

The 2011 South Australian Resources and Explorers Investment Conference (SAREIC) will be held on the 2nd to 4th of May at the Hilton Hotel, Adelaide. Several new geophysical products will be presented at this conference, including new state gravity and radiometric images, the Cariewerloo AEM surveys and interpretation, and the launch of a new SARIG (South Australian Resources Information Geoserver).

The new version of SARIG is designed to work in a larger variety of Internet browsers. It is easier and faster to use. Floating windows allow a wider view area, and the resolution of the map alters depending on the scale of the view. Searching and downloading geophysical data remains as a standard feature using the Intrepid Jetstream technology. Figure 10 shows a snapshot of the new SARIG.

New state grids have been constructed for gravity and radiometrics (Uranium and Thorium, with the remainder in progress). The gravity grid has been constructed through a process of point selection (many erroneous and duplicate points are removed before gridding), gridding old surveys separately to the new surveys, and merging the grids together. The resultant grid fixes numerous problems of the old grid, notably the ‘dimple’ problem. The radiometric grids have been constructed using a new grid adjustment tool developed at Geoscience Australia (GA). The new grids exhibit fewer breaks between surveys and contain the latest open file surveys.

Four AEM lines were flown over the Cariewerloo Basin in 2010. A new interpretation using these data, Auscope Hylogger 2-3 information, NITON XRF data and all available geology and geophysical data will be presented at the conference and released as a package in order to assess the unconformity uranium potential of the region.

The GA and PIRSA Frome AEM survey data will be released prior to SARIEC, however Ian Roach from GA will be presenting the data and some initial interpretations at the conference.

For more information, please contact Philip Heath (philip.heath@sa.gov.au).

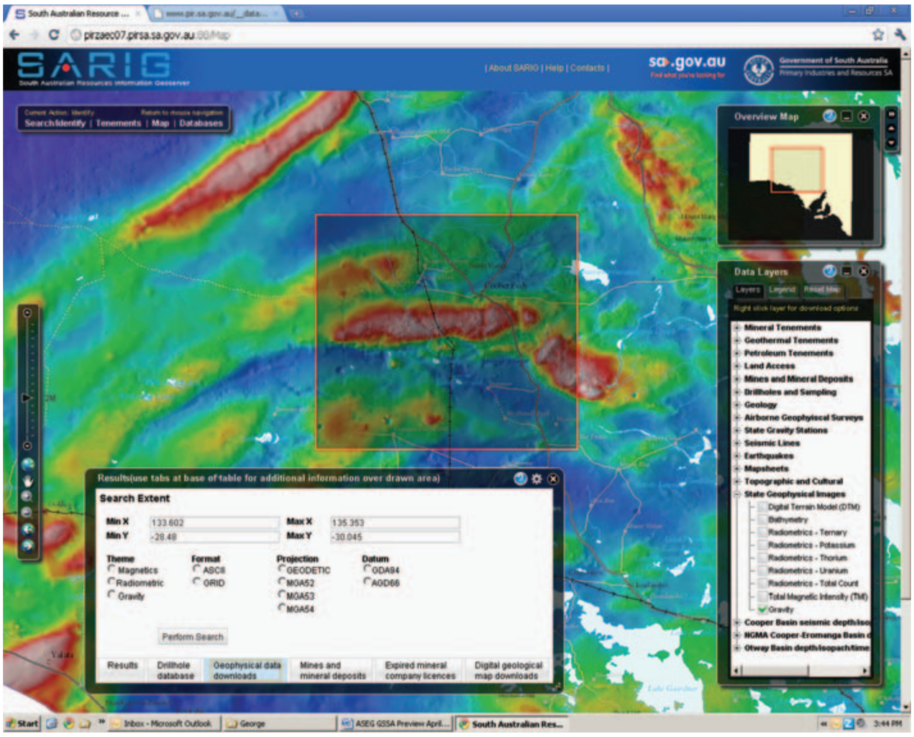

Fig. 10. *The new SARIG will be released at the SAREIC meeting in early May.*

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ERA 2010 assesses Australia's university research output

In February 2008 the Minister for Innovation, Industry, Science and Research, Senator Kim Carr, announced his plans for a new research quality and evaluation system. After two years, and with an allocation of $35.8 million over four years, the first national *Excellence in Research for Australia* (ERA) report has been published (http://www.arc.gov.au/era/outcomes_2010.htm).

The assessment, carried out by the Australian Research Council, examined research quality from approximately 330 000 research outputs, more than 55 000 researchers, and across the nation's 41 universities.

The result is a 314 page tome, packed with statistics over a range of 156 discipline groups. It is a very impressive document, but whether it will serve to improve Australia's research performance only time will tell. And I can't help thinking that perhaps the $35.8 million could/should have been allocated to a few more post docs or research students.

The five objectives of the ERA are to:

1. Establish an evaluation framework that gives government, industry, business and the wider community assurance of the excellence of research conducted in Australia's higher education institutions.
2. Provide a national stocktake of discipline-level areas of research strength and areas where there is opportunity for development in Australia's higher education institutions.
3. Identify excellence across the full spectrum of research performance.
4. Identify emerging research areas and opportunities for further research development.
5. Allow for comparisons of Australia's research nationally and internationally for all discipline areas.

Table 1. The ERA 2010 rating scale (Source: www.arc.gov.au/pdf/ERA_report.pdf – p. 5)

Rating	Descriptor
5	The Unit of Evaluation profile is characterised by evidence of outstanding performance well above world standard presented by the suite of indicators used for evaluation
4	Above world standard
3	Average performance at world standard
2	Below world standard
1	Well below world standard
n/a	Not assessed due to low volume. The number of research outputs does not meet the volume threshold standard for evaluation in ERA.

Table 2. ERA 2010 results for Earth Sciences (Source: www.arc.gov.au/pdf/ERA_report.pdf – p. 267)

University	Discipline Group					
	04 Earth Sciences	0402 Geochemistry	0403 Geology	0404 Geophysics	0405 Oceanography	Physical geography and environmental geoscience
Australian National University*	5	5	5	3	5	5
Curtin University of Technology	5	4	5	3		
Deakin University	2					
Flinders University	3				2	
Griffith University	4				4	4
James Cook University	4	4	4		3	3
La Trobe University	1					
Macquarie University	5	5	5			5
Monash University*	4		4	4		4
Queensland University of Technology	3		3			
Southern Cross University	4	5				
University of Adelaide*	5		5	3		
University of Canberra	3					
University of Melbourne*	5	4	5	4		4
University of New South Wales*	4		4	3	3	3
University of Newcastle	3		3			
University of Queensland*	3	3	3	3	4	3
University of Sydney*	4		4			3
University of Tasmania	4	3	4	3	5	3
University of Western Australia*	5	4	5	5	3	3
University of Wollongong	4		3			4

**Member of the Group of Eight Universities.*

Whether these are useful objectives or whether the report enables the objectives to be achieved, I cannot say. But to my mind the wording is somewhat bureaucratic and it would be difficult to assess whether the objectives are being met or even whether they are worthwhile.

I have three major problems with the process. First, the evaluation appears to be based predominantly on papers published in peer reviewed journals, books published and chapters in books. In other words, the 'publish or perish' criterion is still alive and well. There appears to be no allowance for the original thinkers or impact factors. But then these criteria are very hard to measure. Some of the best science is done by people who are not prolific publishers – how are these catered for?

Second, once a hierarchy of institutions is established these tend to become entrenched. Good students and researchers will be attracted to universities with the higher scores; the good will become better and the poor may well become worse. In biblical terms they will be Matthewed! The Group of Eight will continue to dominate Australia's research efforts in universities. Maybe that is a good outcome, because perhaps we can't and shouldn't have 41 world ranking universities for research. If so then we do not need a review to tell us which are the best institutions.

And third, by the time a student or a researcher is looking at where to study or work, he/she should be aware of the 'good' and 'not so good' places to go to in Australia by networking with peers or simply looking at the ARC results. If businesses were looking for collaborators in universities, they should be able to find out where to look. For example, if BHP or RioTinto wanted a collaborative research project on mineral or petroleum exploration, they would surely know already who to talk to and wouldn't start by looking up ERA results.

Regardless, the analysis finished up with six categories of ratings. These are summarised in Table 1. The results for some of the Earth Science disciplines are listed in Table 2. Of the 41 universities only 21 met the threshold for evaluation and so only these are shown in Table 2.

I am not going to comment on the ratings except to ask a question. Would you agree with them?

David Denham

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Good news for 2010 gold and gas production

Gold production in 2010 rebounds to highest level since 2003

Australian gold production in 2010 rose to 261 tonnes, its highest level since 2003 (290 tonnes) as companies took advantage of increased gold prices. If these are adjusted for inflation they are now at their highest, in Australian dollars, since 1981 (see Figure 1).

Production in 2010 increased by about 17% from the 2009 result of 224 tonnes; but it still has a long way to go to catch the record 314 tonnes recorded in 1997.

Figure 1 shows Australian gold production since 1970, the gold price in Australian dollars per ounce, with cpi adjustments, and the expenditure on gold exploration since 1988. It is interesting to note that in the late 1970s, when the gold price first took off, it took about nine years for the production results to follow; whereas this time it has only taken about four years. The apparent lack of correlation between exploration expenditure and gold production is a bit of an enigma, unless there is a lead time of about 25 years. Clearly if nobody spent any money hunting for gold then none would be found, but the peak expenditure in 1997 did not appear to translate into an increase in production.

According to Sandra Close of Surbiton Associates 'China was number one in the world with reported production of 341 tonnes and it looks as though the United States will come in as number three with an output of around 240 tonnes...South Africa, which produced more than 1000 tonnes of gold in 1970 and for decades was the world's largest producer of the precious metal, is expected to record an output of about 200 tonnes for 2010.' This is South Africa's lowest production for over 60 years.

According to Surbiton Associates the top Australian producer in 2010 was still Barrick Gold's and Newmont's Super Pit at Kalgoorlie but its production fell by 0.7 tonnes in the December quarter. However, Boddington was the star performer with a quarterly production of about 6.4 tonnes, up by approximately 0.8 tonnes from the previous quarter and closing in on the Super Pit's premier ranking.

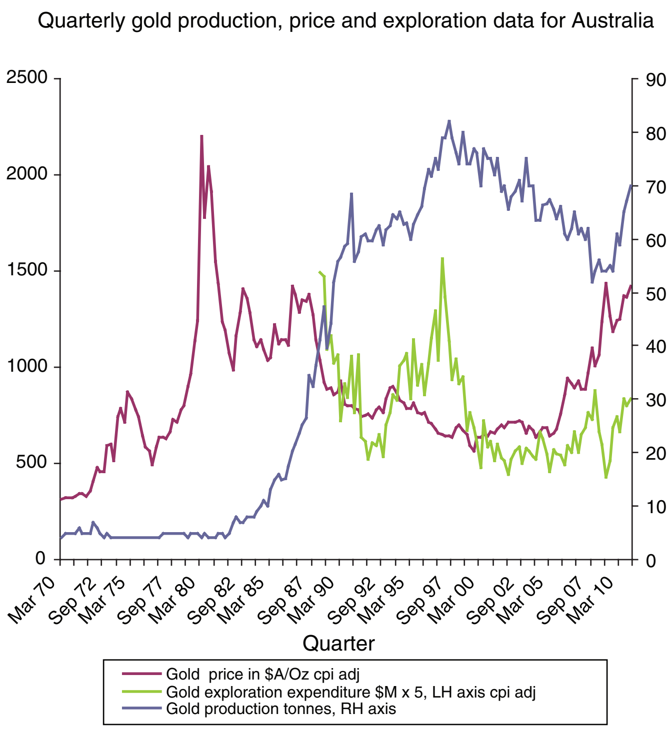

Fig. 1. *Quarterly Australian gold production and gold price (cpi adjusted and in A$) from 1970 through 2010. Gold exploration expenditure (cpi adjusted) from ABS data from September 1988 is also plotted. All prices have been converted to Australian dollars because most of the operating expenses are incurred in that currency.*

Gas production highest ever in 2010

Meanwhile, as a result of increasing global demand for the country's liquefied natural gas (LNG), together with growth in domestic gas-fired power generation, a new natural gas production record was set in 2010, according to EnergyQuest. According to their report, 'Australian natural gas production reached a record 1999 petajoules (PJ) last year, up 5.1% from the previous year's 1902 PJ.'

EnergyQuest reported, 'LNG production grew by 6.2% last year, from 18.6 million tonnes per annum (Mtpa) in 2009 to 19.8 Mtpa due to production from the 'fifth train' of the North West Shelf. The value of LNG exports was a record $9462 million, an increase of 24% over the previous year's $7631 million.'

'The LNG momentum looks set to continue in 2011,' EnergyQuest CEO, Graeme Bethune, said. 'So far this year we have already seen another Gladstone LNG project, GLNG, in central Queensland, reaching sanction and the ConocoPhillips/Origin Energy APLNG project, also situated at Gladstone, reaching major milestones,' he said.

Mr Bethune highlighted the strong growth in natural gas production on Australia's east coast, where coal seam gas production reached a record 222 PJ, an increase of 43 PJ from 2009. 'Gas-use for power generation on the east coast continues to grow and increased by 28 PJ for the year to 209 PJ, with growth of 35 PJ in Queensland.'

And if a proper pollution tax was in place, the use of natural gas for power generating would grow even faster.

David Denham

New report on Radioelement Mapping

The International Atomic Energy Agency (IAEA) has released a new report on 'Radioelement Mapping' that will be of interest to geoscientists working with radioelement data derived from both geochemical and gamma-ray spectrometric surveys. The report was compiled by a group of experts invited by the IAEA to review the current state of radioelement mapping and the development of global radioelement baselines.

The report notes that radioelement baselines are essential for many research applications in the earth and life sciences:

> *'The benefits of radioelement baselines include the effective use of radioelement data for uranium exploration and mining, geological mapping, and mineral (including hydrocarbon exploration) and regolith mapping. Radioelement baselines also benefit land use mapping, and are used in health and environmental applications, for both natural and anthropogenic sources. Also, the regulatory framework surrounding radioactive materials cannot be effectively established without knowledge of the natural variability of radioelements on the Earth's surface. Radioelement baseline data sets are thus crucial for the setting of good public policy in relation to uranium resources discovery and development.'*

The report covers the benefits and uses of radioelement baselines and the methodology to establish such baselines for radioelement concentration estimates derived from both geochemical and gamma-ray spectrometric surveys. It also includes chapters on the global status of radioelement mapping and the application of radioelement baselines to uranium exploration, mining, milling and remediation.

The report is available as a free PDF download from http://www-pub.iaea.org/mtcd/publications/pdf/pub1463_web.pdf.

Brian Minty

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Fugro... Local Presence - Global Perspective

Kelly Keates – Owner and Managing Director, Zonge Engineering and Research Organization (Australia)

Zonge Engineering was formed in the USA in 1972 by Ken Zonge. In 1984 Zonge Engineering (Australia) was established in Adelaide, South Australia. Kelly Keates started working for Zonge in 1991, became a director in 1993 and then purchased the business 13 years later in 2006. I interviewed Kelly via email about her personal path into the geophysics industry, her views on the geophysical contracting industry in general, and the recognition she has received as a woman in business, particularly in an industry that is dominated by men. My very warm thanks go to Kelly for taking the time to share her thoughts on these questions.

Can you give a brief summary of how your career started and how it lead ultimately to becoming Managing Director and owner of Zonge Engineering (Australia)?

In 1991 I applied for an advertised position at Zonge as a field assistant. I had previously completed work experience with Western Mining at Roxby Downs for the Geology Department, doing underground sampling and logging core. I really enjoyed the people and duties at WMC and was focused on gaining employment in the industry. I had completed a Bachelor of Arts and had enjoyed structural geomorphology and remote sensing so geophysics seemed like an interesting field. Van Reed, then Managing Geophysicist at Zonge, thought that I would be better suited to help organise the administration duties, and offered me a part-time one day a week administration position. Although I never made it to the field I enjoyed the challenges of logistics, HR, finances, management, marketing and equipment. Striving to make Zonge a better place to work and provide specialised quality data and safe service to our clients has been a constant goal for me.

A few years after I started, Van moved back to the USA and Ken Zonge asked me to become director of Zonge Australia. Ken was very supportive and had always encouraged me to create vision and direction for the Australian office as it grew over the years. The structure of the company has allowed me to focus on the business and strategy together with a great team of geophysicists. When Ken decided to retire, he similarly encouraged me to purchase the company. It took some convincing for me to think that this would be a good idea as I had a young family, but eventually Ken talked me into it. The change from Director/Manager was significant and unexpected. I had thought there would be no difference as essentially it would be the same role, but I had underestimated the scope for change and perception in myself and others. Initially it was challenging, but it has been a rewarding journey.

Zonge is a well known contracting firm in the Australian geophysics scene. How is business for contractors at the moment?

Zonge was established in Australia in 1984 as a spin off from our work for Western Mining Corporation at the Roxby Downs site. Our business is mainly in the exploration industry although we do also run environmental and engineering surveys. This means we are the first affected by the boom–bust cycle when it downturns and there is less funding for exploration, but on the flip side when the resource demand takes a turn the industry is very quick to respond. We are in the lucky position to have good relationships with our competitors and the general consensus is that there has been a significant increase in surveys over the last half of last year and continued interest into this year for exploration services. Unfortunately the weather conditions are preventing us from accessing some survey sites at present but we expect the next quarter to see a significant increase. We have mobilised a number of crews for overseas work while there is uncertainty in Australia due to the weather conditions.

How has the industry changed over the last ten years?

Increasing safety awareness has had a considerable positive effect on our business over the last ten years. The change of focus in the industry has given us the opportunity to go back to basics, look at what we do and how we do it, and ensure that procedures are in place for all our activities and increased safety for everyone. These safety procedures furthermore help the crew to conduct a more efficient survey.

Additionally there has been a cultural change within the company over the last ten years. We have recognised that there were ways we could improve the conditions for our employees and also deliver better outcomes for our clients. Zonge has faced several challenges in growing the business including managing sales and employment growth, looking at ways to ensure a safe quality end product whilst not increasing production costs, as well as successfully developing new products and integrating process introduction. Of course the changes in technology have made things much easier with increased internet access, affordable communications, and more accurate equipment including GPS.

What are your career highs – the things that make you love being a part of this business? Have there been any lows and what have you learnt from them?

I have had some amazing opportunities over the years and am often thankful that I chose this industry rather than speech therapy. I love the fact that every day at work can be different; there is always a new challenge involving people, equipment and logistics. I love the fact that it is a small friendly industry and that Ken Zonge trusted me with his company from the start. I love that we work in the most remote corners of the globe and Australia. I love to travel so I really enjoy going to the field to spend time working with crews and making visits to clients and attending conferences. Right now I am loving the work we are doing to improve our business through the Enterprise Connect review program and Innovate SA. They recently informed me that Zonge was in the top 5% of businesses in Australia which is something we are all very proud of.

Amazing opportunities to do things like demonstrating equipment for the UN, assisting with environmental water monitoring, taking on big projects with big explorers and small projects with prospectors, and providing them with accurate data to assist with their resource delineation keeps me on a high.

Amazingly the lows happen around the same time as the downturn in the cycle. The hard part is fear of losing staff to another industry in slow periods. The uncertainty and uncontrollability of the downturns are difficult. Although we can do our best to provide accurate efficient surveys, if there is no-one doing exploration…

As a woman heading a geophysical contracting business in Australia, you are part of a very small group. Do you have any suggestions as to why there are not more women in our male-dominated industry? Should we be more actively promoting geophysics to women as a career alternative?

I guess I have managed in my work life not because I am a woman but because I didn't let it get in the way. It is probably best not to focus on the imbalance of men to women in the industry because it might get intimidating. Our work is physically and emotionally challenging and we have and do welcome women to come and join our crews. I think over the years there has been a substantial increase in women in our industry. I do actively promote the industry via Geoscience Pathway events and visits to TAFE colleges, but as a general promotion rather than directed especially to women. As it is such an exciting industry it would be fantastic to see more women consider it as a career alternative.

Recently I realised that in our industry we have unique access to women who could perhaps benefit from items our crews can bring to them in remote areas in the globe and even in Australia. This idea is in its preliminary stages, but the goal would be to help women by providing items that can assist them in their daily life.

You have been involved in a number of initiatives that promote women in business. You were a finalist in the 2007 Telstra South Australian Business Women's Awards;

This nomination was a great opportunity to be inspired by women around Australia in various occupations. It was an honour to be a finalist.

…featured in a book called 'Lounge to Boardroom';

I hope this book can be used by young women starting their career to see how, despite adversity, persistence usually pays off.

…and recently took part in a pilot for the Enterprise Connect program.

This program was a Federal Government trial to assist companies who have taken part in the review move towards implementation of the recommendations. As I do not have a board to answer to I found this process confronting but also empowering.

I also took part in a Path to Vision Trek to assist Young Business Leader Samantha Badcock raise money for the Royal Society for the Blind. The trek was three days and included camping, something of a challenge for me, but also an opportunity to spend time with other business leaders and Duncan Chessell as our inspirational guide.

Can you tell us about your reaction to being a role model for women in business?

I am not really comfortable being a role model for women in business, perhaps I am a role model in persistence and giving things a go. All mothers know there is a huge amount of juggling to be a good worker and mother and I am continually striving to do better at each but could not give up either.

What do you see as the key challenges for geophysics contractors in the future?

Harsher environments, deeper exploration and new technology are all challenges we can't wait to get into. Lack of trained geophysicists is a constant issue. Retaining quality staff through the boom and bust cycle is always problematic, and likewise allowing for a sustainable quality of personal life despite extensive time away from home.

There is an increasing need for innovations that reduce our environmental and cultural impact on the areas we work in, and to remain competitive, we need to bear the cost of innovation and purchasing of up to date equipment.

As an employer of geophysicists, how well do you think we are preparing young geophysicists for a career in our industry? Broadly speaking, are the graduate geophysicists of today well prepared by their university training?

How do you prepare someone for work, can it all be done at University or can it be done from the beginning by parents and friends? I feel our young geophysicists certainly have all the technical knowledge and understanding required for a graduate geophysicist. The things that make these geophysicists fantastic employees are enthusiasm and initiative, which will take them much further and prepare them much better for the challenging life of a geophysicist.

Kelly Keates (right) with Mike Hatch and Lachlan McDonald near Elliston, South Australia for CSAMT/AMT survey.

Turning geophysical data into geological information or Why a broader range of mathematical strategies is needed to better enable discovery


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The goal of exploration geophysics is to infer the nature of buried structure and, in particular, generate drill targets that lead to a mineral deposit discovery or reserve delineation. As a profession, we aim to turn geophysical data into geological information. Most geophysical techniques enable inferences to be made from airborne, ground-based or bore-hole data through a deterministic process whereby a single model 'answer' is generated. Well-founded algorithms include uncertainty estimates for different parameters in the model and/or some form of model validation. This approach has been successful to date, and we advocate the continued use of deterministic algorithms.

We also advocate that alternate strategies for extracting information from data are used alongside deterministic strategies. If we consider two general properties of data inference approaches, that of (1) *assurance* and (2) *opportunity*, deterministic approaches score poorly regarding opportunity: that is, useful answers may be missed. Alternate strategies can be computationally intensive, but several important classes of approach, summarised in this article are now tractable on workstation or high-specification notebook PCs. By using a range of strategies we can maximise both assurance and opportunity for a particular data inference goal and obtain extra, useful geological information from our data.

Keywords: data inference, information, inversion, modelling.

Introduction

Turning geophysical data into geological information presents us with a three-fold set of tasks. As practising geophysicists, we:

1. Carry out the modelling or inversion of geophysical data to find a geological 'answer';
2. Quantify, or represent in some way, the 'strengths' and 'shortcomings' of our model or answer;
3. Explain both the model and its limitations to other geophysicists, and very significantly, also to non-geophysicists.

In this article, we outline some of the strategies for geophysical modelling and inversion that will be familiar and not so familiar to practising exploration geophysicists. Firstly though, we examine a goal for geophysical modelling and inversion, that of mineral deposit target generation. Those targets will subsequently be drilled and hence the geophysical inference, that there is some structure playing host to an ore deposit, can be tested. Importantly, the veracity of the geological information that we have inferred may be tested against geological knowledge (albeit spatially limited) that we obtain from drilling. Two concepts are important here: *assurance* and *opportunity*.

Assurance embodies the extent to which a model answer is likely to be correct, in our example goal: an ore body discovery. High assurance corresponds to low risk. Of course, we wish for highest assurance answers, but constraining our drilling to high-assurance targets will mean that we overlook some targets. We also have to consider that there may be no high-assurance targets.

Opportunity is the idea that targets are generated with sufficiently open criteria that few targets are overlooked. Low opportunity implies that there is a very tight set of rules that map the data to a model. The natural variability of the mineral systems means that a target might still be prospective if one indicator parameter changes, hence a higher opportunity approach might (also) be appropriate.

Exploration geophysics data are often 'inaccurate, insufficient and inconsistent' (Jackson, 1972) and so solution existence, non-uniqueness and the instability of the solution process must all be addressed (Backus and Gilbert, 1970; Aster et al., 2005). At the present time, many established codes handle such difficulties to the satisfaction of their users, yet in a realm that can limit the models available. Moreover, the limitations of the model are not always evident. Fortunately, alternate strategies have become tractable, as computing power and data storage capacity improves. These strategies generally give a more complete set of outputs including alternative models and some measure of the likelihood of different models, or parts of the model. It is important to have in mind that an uncertainty estimate on a single model solution accounts only for noise. It does not account for solution non-uniqueness. Other very different solutions could exist that are equally well supported by the data. In forming single model solutions, we do not fully exploit the information content of our geophysical data.

Alternate strategies are generally more exploratory in character: suggesting answers that are constrained by the data but may not have been imagined by an operator (for example) building a forward model or by a deterministic inverse approach. Alternate strategies all supply material very naturally that assists us in task 2. Finally, so long as we are communicating with a colleague who can accept the inconvenient truth that there is more than

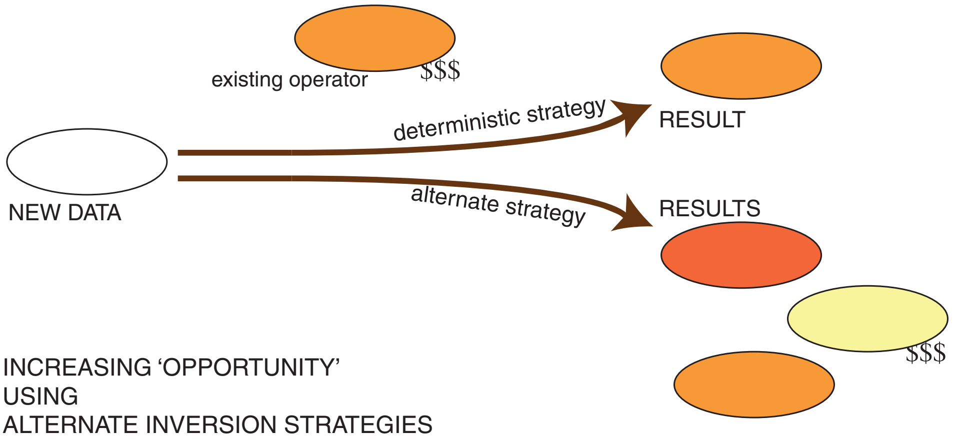

Fig. 1. *An illustration of the difference between deterministic and alternate data inference strategies as applied to new geophysical data. Deterministic strategies provide high assurance results but only provide a single 'answer'. Alternate strategies increase opportunity by suggesting a number of models that are appropriate to the data. A discussion of assurance and opportunity is given in the main text.*

one possible answer, we can do a much better job at task 3, explaining the results and the limitations of the results. Alternate strategies provide us with a much richer range of information from the same set of geophysical data (Figure 1).

Strategies for modelling and inversion

Following the clear exposition provided by Aster et al. (2005) we define task 1 to be: 'find a set of physical parameters which describe a model, *m*'. We do this by collecting a set of observations, the data, *d*. In most cases, *m* and *d* are vectors. We assume that there is a function, *G*, that relates the model values to the data values.

$$G\ (m) = d$$

G is an operator that can take many forms, for example an ordinary or partial differential equations, or a linear or non-linear system of algebraic equations. In practice the data contain noise and we can imagine *d* to comprise some perfect set of noise-free data, d_{true}, plus a noise component, η.

$$d = G\ (m_{true}) + \eta$$
$$d = d_{true} + \eta$$

It is not desirable to fit our model to the noise, although it is mathematically possible: *m* can be influenced strongly by even a small η. In addition, there may be many models aside from m_{true} that fit the data d_{true}. We define the forward problem as calculating *d*, given *m* with the assumption that the true answer lies within the chosen parameterisation of the model *m*. Often this corresponds to finding a set of modelled or simulated data, such as travel times, given an initial test model. Our task is an inverse problem: find a model *m*, given *d*. Many geophysical applications use a finite number of discrete data points, and the model is related to the data (exactly, or as an approximation) through *G* taking the form of a set of linear equations. We are now solving a matrix equation.

$$d = Gm$$

This formulation is broader than it may at first seem as it may also be used to represent 'weakly' non-linear problems, where the data vector, *d*, becomes the perturbations in the data caused by a perturbation, *m*, in a model about some chosen reference model, m_{ref}.

Deterministic methods

Relating *m* to *d* through *G*, gives the sense of these procedures as deterministic. There is a pre-defined physical relationship between *m* and *d*. For example, synthetic seismic travel time data values are determined by the values of the appropriate seismic wavespeed model parameters in *m*. A popular strategy for finding a best fitting solution is then to sum the square of the differences between the observed data values and the synthetic (modelled) data values. Subsequent iterations of the algorithm then seek to find the model which minimises this sum of squared residuals or some other objective function. As developers of deterministic modelling and inversion software know only too well, the necessary matrix inversion operations are usually unstable, hence many approaches to deterministic inversion exist (Rawlinson and Sambridge, 2003; Aster et al., 2005) and underlie most of the geophysical modelling software currently in use. At the present time, we advocate the continued use of these methods alongside one or more of the alternate strategies that follow.

Note that, although we refer to 'deterministic' and 'alternate' strategies, there is often a deterministic component inherent in some part of an alternate strategy: multiple model data inference may use a deterministic forward algorithm; model parameter sampling strategies often use a deterministic optimisation inside

Inversion Strategy	Constrained	Unconstrained
Deterministic e.g. majority of current exploration geophysics software	Widely used High assurance Low opportunity	Less used Lower assurance Increased opportunity
Multiple model ensembles e.g. Monte Carlo (direct search) Genetic Algorithm (adaptive) Neighbourhood Algorithm (adaptive) Stochastic Algorithms	Less used (! computation) Managed assurance Increased opportunity	Less used (! computation) Managed assurance Maximum opportunity
Machine Learning e.g. Naive Bayes, Random Forest	Now tractable Managed assurance Increased opportunity	Now tractable Managed assurance Maximum opportunity
Model parameter sampling e.g. Markov Chain Monte Carlo (MCMC)	Now tractable Managed assurance Increased opportunity	Now tractable Managed assurance Maximum opportunity

Fig. 2. *A summary of selected data inference strategies as applied to geophysical modelling and inversion. Strategies are grouped according to inference style, as outlined in the text. Current usage patterns and assurance/opportunity characteristics are noted.*

a probabilistic approach. Purely deterministic strategies carry out task 1 followed by task 2. Alternate approaches carry out tasks 1 and 2 together such that the limitations of the data are part of the inference process and the outputs include a more comprehensive, and therefore robust, appraisal of the strengths and shortcomings of the model outputs. A range of deterministic and alternate strategies is summarised in Figure 2 together with their usage, assurance and opportunity characteristics.

Multiple model ensembles

One alternate approach to geophysical data inference is to search the parameter space more widely, and in so doing, produce not only one best-fit model but an ensemble of reasonably well fitting models. This style of inversion became known as a 'Monte Carlo' approach with the sense that if you calculate enough models you would find a 'winner' in the end. It has one particular advantage: a linear relationship between the model and data does not have to be assumed. They are therefore appropriate for inverse problems where deterministic methods would fall foul of local minima in the objective function. Computationally very expensive, Monte Carlo approaches have been refined until they have become tractable for modelling tasks with relatively few (10–25 or so) parameters and current research suggests there is hope in extending to much higher numbers of unknowns. This refinement has generally taken the form of making the model calculation adaptive in some sense. Previously generated models inform those that are subsequently calculated. Genetic algorithms are a good example (Sambridge and Drijkoningen, 1992). As the name implies, each subsequent generation of models carries forward successful attributes of the previous generation and therefore guides subsequent search refinement. The precise details of genetic algorithms, and their cousins, evolutionary algorithms, vary considerably between applications. A persistent theme is that each model can be described by a series of properties that can be randomly adjusted or 'mutated' at each iteration. An ensemble of candidate solutions is maintained with 'survival' being tied to the ability of the model to fit the data. As each candidate solution in the ensemble is updated through randomised processes, the population as a whole becomes 'fitter' and the algorithm explores promising regions of the model space efficiently and with high opportunity.

Another ensemble based adaptive search technique is known as the Neighbourhood Algorithm (Sambridge, 1999a, 1999b). Like genetic algorithms, this approach is based on ensembles of models. Simple geometric concepts are used to update the ensemble based on the concept of a neighbourhood. At each iteration, a subset of the current ensemble is chosen (often the n models with the best fit to the data). A random walk is then performed in the neighbourhood of each of the n models to generate a new set. A key point of the algorithm is that the neighbourhoods are automatically and uniquely defined using geometric concepts. As the algorithm proceeds and more models are generated, the neighbourhoods naturally shrink and thereby concentrate sampling of model space in regions of good fit. Again, random decisions guide the algorithm at each stage but the overall effect is far from random with search behaviour being adjustable from explorative to highly adaptive. In this way, assurance and opportunity can be managed. Over the past ten years, the Neighbourhood Algorithm has been applied to a range of inversion problems in the geosciences where derivatives between data and model are either not available or are of little use due to the problem being strongly non-linear. An example of an infrasound beam tuning problem (Kennett et al., 2003) is shown in Figure 3.

Machine learning

Machine learning strategies for inferring useful information from geophysical and geophysics-related data take a different, empirical approach. Machine learning algorithms use sets of related observations that do not necessarily have an obvious physical relationship between each other. They may be described as 'disparate' datasets, related only in that they are observed at the same point on the surface of the Earth. Predictive relationships are then extracted by means of the patterns occurring between the disparate observables. These techniques have been well used across the wider information technology community (Witten and Frank, 2005) and although there are a few examples of such strategies being applied to geoscience data inference problems, there is much scope for wider use in this area.

Machine learning is a 3 stage process: (i) the input data must be prepared to produce matching sets of observations, (ii) the predictive relationships must be deduced or induced, and (iii) the output must be evaluated. Input data preparation (stage i) can involve both geographic and numeric transformations, ensuring that observations from disparate data are spatially coincident. Forming the predictive relationship (stage ii) can take the form of supervised or unsupervised learning. Supervised learning is usually carried out using a training dataset which contains both predictive (input) and dependent (output) variables (*a priori* information). The machine learning scheme is then allowed to deduce the appropriate predictive relationship. Evaluation of the output (stage iii) of supervised learning schemes uses methods such as cross-validation (Witten and Frank, 2005). However, as we may wish to make predictions in areas where observations have not been made, cross validation or other estimates may not provide adequate insight into the ability of a deduced relationship to maximise opportunity when applied to unseen data. This is because the training data may be overly restrictive in its representation of the inference target and, as such, high assurance may be misleading. Conversely, unsupervised learning does not include *a priori* information and predictive relationships are induced from interactions between predictive variables. It is therefore difficult to provide adequate measures of assurance from the outputs of these machine learning schemes. Computational cost incurred when deducing or inducing predictive relationships must be also be considered. For example, a slight increase in assurance due to a large increase in the number of predictive variables may not be practical. Development of these methods in the context of geoscience data inference problems is the subject of ongoing research by the authors.

Model parameter sampling

Data inference approaches that use model parameter sampling produce a solution that consists of a probability distribution for each of the model parameters, rather than a single model. Those probability distributions are found by *sampling* the multi-dimensional posterior model space and a best fit model is constructed at the end of the sampling process in full appreciation of the probability of the occurrence and value of each model parameter. To clarify, the modelling process results, first and foremost, in a full set of probabilistic information which is then used to construct the best fit model. This

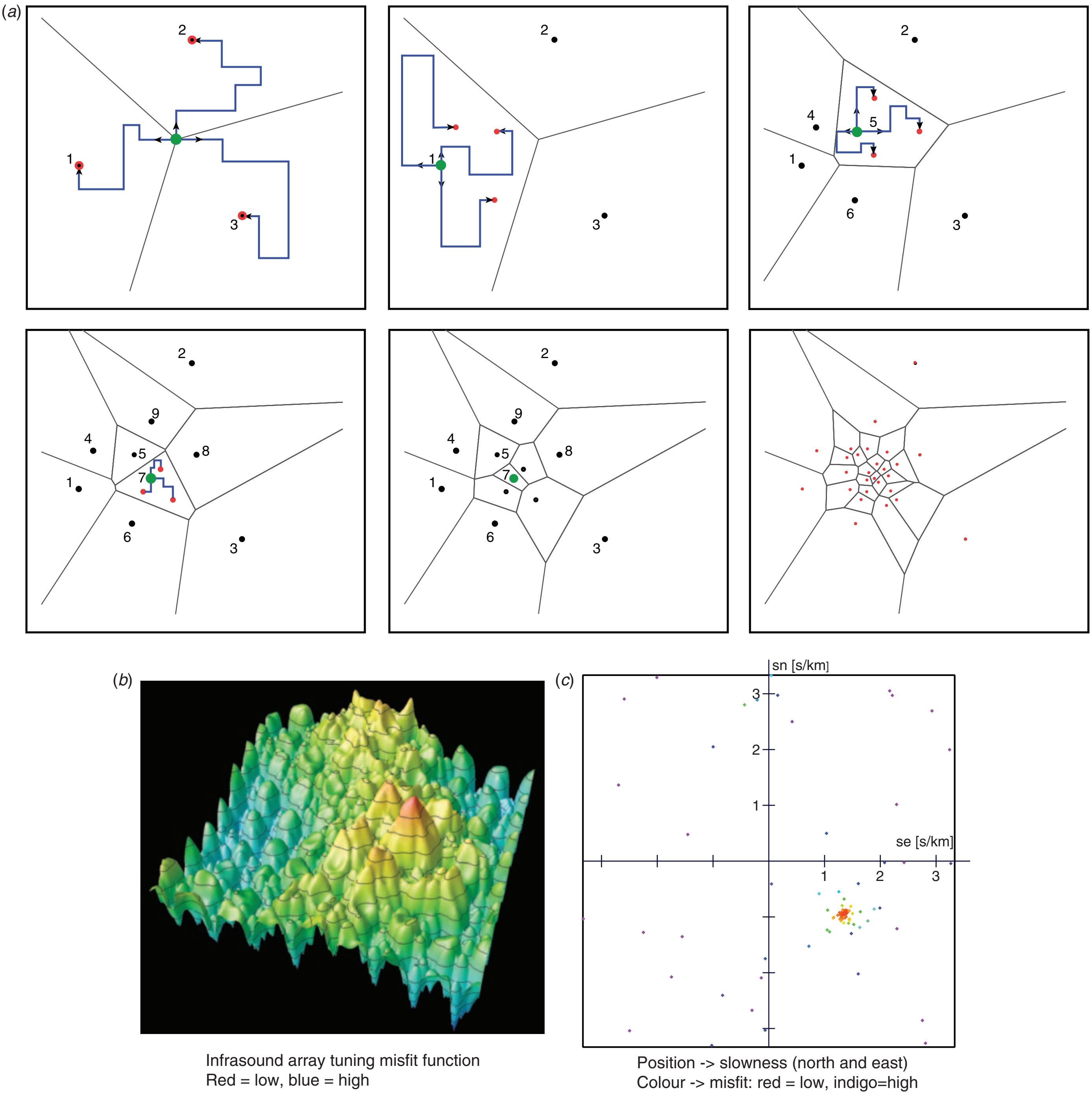

Fig. 3. *An example illustrating a model parameter search using the Neighbourhood Algorithm. (a) Here, a single new random walk is carried out within the neighbourhood (black lines) of the previous best fitting set of parameters. After a few iterations sampling, while locally random, is concentrated in the region of parameter space where models provide a best fit to the data. (b) A misfit surface arising in an infrasound beam tuning problem (Kennett et al., 2003) and (c) the samples produced by the Neighbourhood Algorithm sampling this misfit surface. The peak of the function is located by the algorithm and the complete set of samples can be used for probabilistic uncertainty assessment (Sambridge, 1999a).*

approach falls into the category of 'Bayesian' techniques. Such techniques have met with failure in past usage in exploration applications, and consequent criticism, owing to the lack of understanding of the underlying fundamentals, but used with insight, they facilitate extremely well founded, high opportunity algorithms which are now sufficiently efficient to be of use in a desk-top computing environment. A recent implementation of this approach, illustrated using a geoscience dataset, was developed by Bodin et. al. (2009). They used a Monte Carlo approach to sample the solution space, guided by previous samples using a Markov Chain (MCMC). This work includes an important innovation: that the number of model parameters is allowed to vary. Hence, the model parameterisation is flexible and adapts in the course of the data inference.

A further innovation is that uncertainty in the data need not be known in advance (Bodin, 2010; Sambridge et al., 2010). The data uncertainty is parameterised in the form of one hyperparameter for each of the datasets being analysed together.

The algorithm solves for these values in the same way as for the other model parameters, i.e. by providing a posterior distribution for each. This is made possible by a Hierarchical Bayes regression formulation, HB-MCMC (Bodin, 2010; Reading et al., 2010). In the example we show here (Figure 4a), we investigate change points in wireline data using four logs. It is worth re-stating at this point, that we are not necessarily intending to replace existing wireline software. We find the probability of there being a change in layer character from the patterns inherent in the data and hence allow high opportunity in the data inference. Importantly, Figure 4b shows the relative probability of changepoints existing at different depths. Some depths are highly probable and tightly constrained, some are also highly probable, but their depths are less tightly constrained.

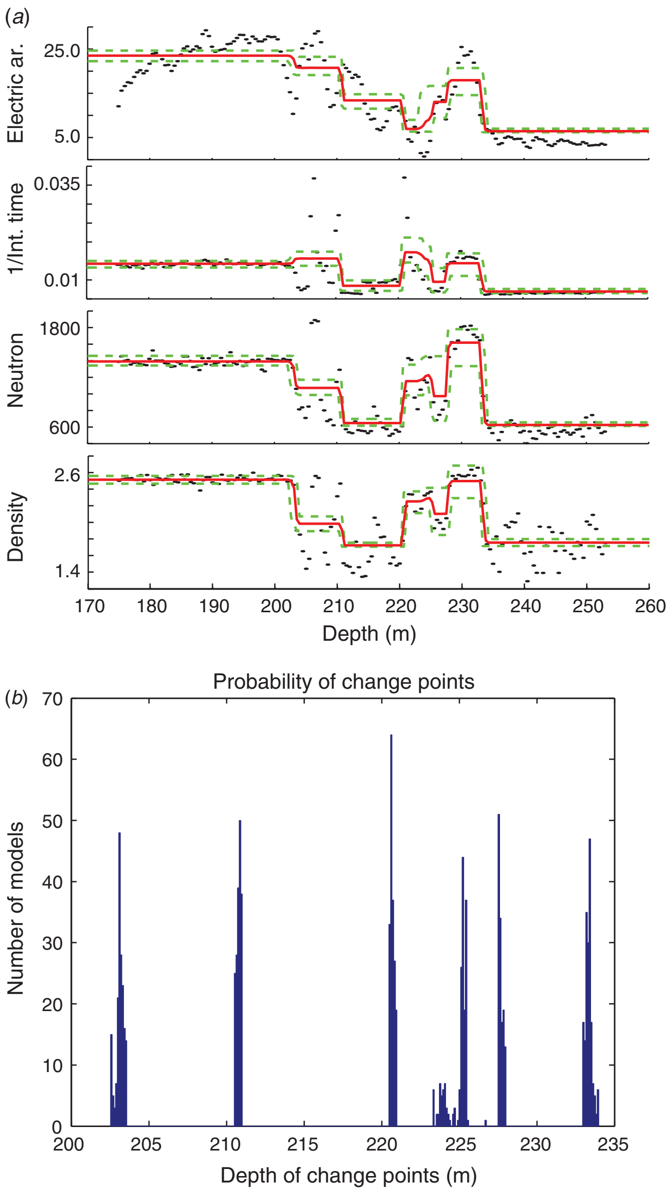

Fig. 4. *An illustration of results from a model parameter sampling data inference example using the HB-MCMC implementation described in the text (Reading et al., 2010). Int. = interval, ar.=array. (a) Input data are points from a wireline log through varied lithologies (blue dots). The final result (see main text for explanation of how this is constructed) is shown by the red solid line with the green dotted lines giving the confidence limits on the final result. (b) The relative probability of change points existing at different depths is indicated by the number of models showing a change point at that depth. While the final result is given as a single 'answer' it is clear from the probability plot that the existence and/or location of some change points is better constrained by the data than for other change points.*

Different strategies play different roles

Deterministic strategies in this discussion are those for which a single 'answer' is found by matching observed to synthetic data where the synthetic data are calculated by the action of an operator, representing an underlying physical process, on a model defined by a set of parameters. The model parameters are modified to find a best fitting model. The advantage of these strategies is that very large and complex models can be accommodated. Where the data inference task is associated with a large amount of well known geological knowledge (for example, borehole intersections), this knowledge may be incorporated at a high level of detail.

In contrast, we define *alternate* strategies as those which provide a deeper insight into the solution space through a variety of methodologies which consider a range of possible 'answers' or show the relative probabilities of various features of the model. These might be provided through the calculation of a large number of models and a subsequent appraisal of the ensemble of possible answers (multiple model ensembles), or by an evaluation of the output (machine learning) or through the statistics of the model parameter space sampling (model parameter sampling).

A frequently misunderstood point in the presentation of alternate strategies is their usage. We do not wish to imply that (for example) a model parameter sampling approach with a comprehensive display of relative probabilities for many tens of thousands of parameters is appropriate in every case. Rather we suggest that, if a constrained, deterministic approach is the primary geophysical modelling strategy for a task, then a simplified version of the model, or particular aspects of the model is/are tested using an alternate strategy to more comprehensively investigate the solution space and quantitatively compare the extent to which important features of the model are constrained by the data. In addition, probabilistic strategies can be used to relax assumptions made in deterministic algorithms. For example, deterministic approaches often require decisions by the user as to the type of parameterisation used (i.e. definition of the model parameters, *m*) and knowledge of the statistics of the noise in the data. In the past ten years, probabilistic algorithms have been developed which allow the model parameterisation and the level of data noise to become part of the inference problem and be constrained by the data. Ultimately, each strategy has its advantages and weaknesses.

A vision for effective exploration

We envision procedures for effective exploration will make use of good deterministic software to produce constrained inversions with suitable error bounds. As well as this approach, we suggest the use of one of the alternate strategies outlined in this article, the investigation of multiple model ensembles, a machine learning approach or a model parameter sampling approach, to enable an increased or maximum opportunity appraisal of the solution space to be made. The alternate approach will be run as an additional inversion and may be conducted on a subset of model parameters or on a simplified model structure. There would be a requirement for this work to be conducted by skilled practitioners with insight into the theory underlying the alternate methods. In this way, we can make use of the advantages of more than one approach.

In closing, we anticipate that as geophysical practitioners become more accustomed to handling output from alternate approaches, these techniques will begin to take the place of purely deterministic methods as their advantages become more widely appreciated.

Summary

We advocate the use of a wider range of strategies for data inference in geophysics. Adding the use of an alternate strategy or strategies to the processing of geophysical data has the following benefits:

1. Alternative geological scenarios are highlighted which are consistent with the geophysical data: increasing the geological information that we extract.
2. Well constrained and poorly constrained parts of the model are clearly presented.
3. Quantitative information is provided that aids the explanation of the model and its limitations to colleagues.

Our ultimate aim is to enable geophysicists to use their data to infer geological information more effectively, thereby providing results with a combination of geological assurance, and enhanced target generation opportunity.

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Automated interpretation of 3D seismic data using genetic algorithms

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Over the past twenty-five years geoscientists have acquired more than 550 000 square kilometres of 3D seismic data (APPEA statistics) over continental and offshore Australia in the pursuit of mineral and petroleum deposits. Whether the target is hydrocarbons of any phase (solid, liquid or gas) or minerals, the information extracted from the 3D seismic data when integrated with other geological and geophysical data helps form models of the subsurface. These models are the foundation upon which decisions are made, directing future exploration, appraisal and development activities. The success of these activities often depends upon the accuracy of these models.

Many advances in acquisition, processing and interpretation methods have been implemented since the first 3D seismic surveys were acquired in Australia during the 1980s. As a consequence of these advances, the geoscientist today is faced with dramatic increases in the volumes of high quality data available for analysis. However, the time available for thorough examination, analysis, extraction and integration of the information from these large, often multi-volume, datasets is always limited and is becoming more problematic. Typically, the geoscientist will spend most of their available time extracting information from small portions of these datasets with a disproportionate amount of time spent thinking about the significance of the results.

Fortunately, geoscientists are not the only, or the first scientists, to face challenges associated with the analysis of large amounts of data. Specifically, ideas developed during the course of the thirteen year Human Genome Project (HGP) have been adapted to help interpret seismic data by automatically segmenting and identifying all surfaces within a 3D volume of data. The results are then stored in a visual database. Using this technology enables the geoscientist to analyse large amounts of data in an unbiased manner and thereby incorporate much more data into their models. The details of this patented technology are discussed and demonstrated on several examples.

Introduction

The use of 3D seismic data is fairly common practice for the evaluation of both coal and hydrocarbon exploration. While considerable effort and budget dollars are spent on the planning, collection, processing and interpretation of this data, the majority of seismic, in most cases, is underutilised. Table 1 shows how the typical interpreter might spend his time working with a 3D seismic volume. For 3D seismic volumes specifically acquired in coal operations the geological interpretation component is a little larger as the effort goes into detailing the characteristics of faults identified in the volume.

Table 1. Breakdown of 3D seismic interpretation time

Activity	Total project time (%)
Analysing data	10
Picking horizons	60
Creating geological interpretation	20
Significance of results	10

Table 1 suggests that the effort required to identify and map individual surfaces within each seismic volume is quite time consuming and limits the amount of data examined within any 3D seismic dataset. By automating the most time consuming element of the process and looking at all the data in an unbiased manner, more time should be available to develop a better understanding of the significance of the results. Given that many auto-tracking algorithms available in commercial workstations struggle to yield high quality surfaces for single horizons without constant corrections in erroneous event tracking, how will the automatic and simultaneous analysis of all surfaces provide a better solution?

Origins

The new technology outlined in this paper finds its inspiration, effectiveness and perhaps future refinements from the Human Genome Project (HGP). Therefore it is appropriate to begin with some background information about the HGP. The HGP was a very ambitious task undertaken by biologists and was perceived to be the last effort needed to conclude work in a field founded by Watson and Crick (1953) with their publication of the double helix model for deoxyribonucleic acid (DNA). Some of the objectives of the HGP were as follows:

- To identify all of the genes in the human DNA (initial expectation of as many as 150 000 genes),
- To determine the sequences of the 3 billion chemical base pairs,

- Store this information in databases and improve tools for analysis,
- Transfer related technologies to the private sector, and
- Address the ethical, legal and social issues (ELSI) that may arise from the project.

Thoroughly conducted scientific investigations generally yield data and insights that are beyond original expectations, and the HGP project was no exception (Baltimore, 2001). A summary of the HGP big surprises were:

- About 24 000 genes were identified in the Human Genome (still not 100% sure),
- Genes are much more complicated than originally imagined (before the HGP a two hour undergraduate lecture was adequate to describe the gene model; after the HGP three months of lectures are required to explain the concept of a Gene (Pearson, 2006)),
- The initial model developed pre-project used only the DNA (ignoring 50% of the mass which was comprised of the encasing protein),
- The 'ignored' protein plays a vital role in the Human Genome (now a new field called Epigenetics),
- The Human Genome has only 2000 more genes than the simple nematode,
- Cautionary insight: an accurate model could not be created using 50% of the data!

Given geoscientists in both the petroleum and coal industry use less than 10% of the surfaces available in 3D seismic data volumes in their analysis, it would be reasonable to assume that additional insights into the subsurface would be possible if all the data could be examined in a timely, accurate and cost effective manner.

Methodology

The analysis system, inspired by the HGP, uses an entirely evolutionary process in the form of genetic algorithms to segment the seismic data. Genetic algorithms are mathematical processes (Grefenstette and Baker, 1989; Michalewicz *et al.*, 1992) that mimic the genetic process of biological evolution. The evaluation of a possible solution depends on the predetermined parameters associated with the "goodness of fit" criteria. The better the fit, the greater the chance of the solution surviving until the next generation of evaluations. Fang *et al.* (1996) and others have demonstrated the effective use of genetic algorithms in geoscience. By applying this approach, the analysis identifies unique waveform segments that relate to surfaces or horizons and are referred to as GeoPopulations™. These are automatically extracted quickly, accurately and in an unbiased manner.

To determine the extent of GeoPopulations™ these evolutionary algorithms apply the principles of natural selection and "survival of the fittest" to grow from disordered and random seed points to groups of genetically related individuals. A wide range of genetic algorithms have been used and proven to be both powerful and effective for a wide variety of optimization problems, such as medical, airline scheduling, stock market trading, adaptive control, military, and so forth.

The genetic analogy with the seismic volume (Figure 1) can be described as follows:

- A chromosome is analogous to a seismic trace.
- The seismic volume therefore, consists of many chromosomes.
- Each chromosome is made up of a group of genes just as each seismic trace consists of a group of waveforms. Therefore, seismic waveforms are considered equivalent to genes.
- Each gene **(waveform)** can be characterized by its own unique suite of attributes (i.e. location, amplitude value, neighbour trace shape, etc.).

Initially, the seismic volume is automatically segmented into a population of individual waveforms (Figure 2). Individuals within this collection of waveforms are randomly selected as new populations. This gene then looks both locally and globally for other genes with the most similar genetic characteristics (amplitude values, trace shapes, frequency or any combination of attributes that are associated to each sample).

As the populations grow (evolve), the common waveform or genotype changes as selection and reproduction continue according to criteria based on both local and global parameters. As the groups of waveforms grow they will eventually encounter other groups. If they are compatible both spatially and genetically they combine forming a new, larger subpopulation (offspring) that inherits the genotype (common waveform) of its two parents. The evolution continues throughout the entire volume until all GeoPopulations™ have been identified and categorised into a database of surfaces.

Like any evolutionary process, some elements evolve faster and others fail to evolve at all (see Figure 3). At the end of processing, each 3D seismic volume has hundreds, of identified GeoPopulations™. This database of surfaces needs to be reviewed, sorted and filtered. Based on the current requirements of the interpreter, a selection of these surfaces will be extracted

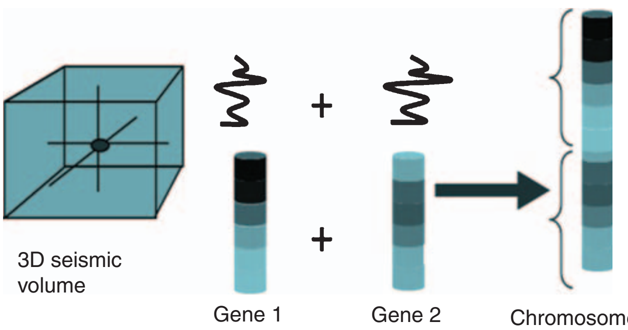

Fig. 1. *Analogy between seismic and the chromosome. Image from Seisnetics LLC, unpublished material.*

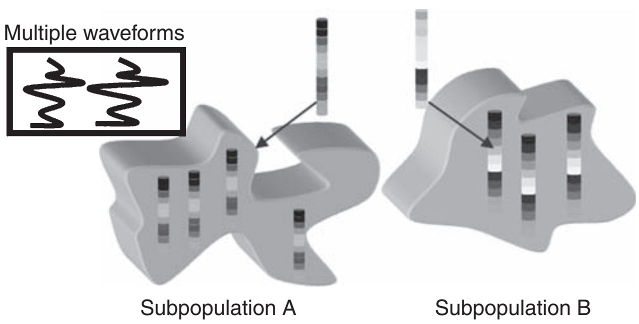

Fig. 2. *The evolution of a GeoPopulation™. Image from Seisnetics LLC, unpublished material.*

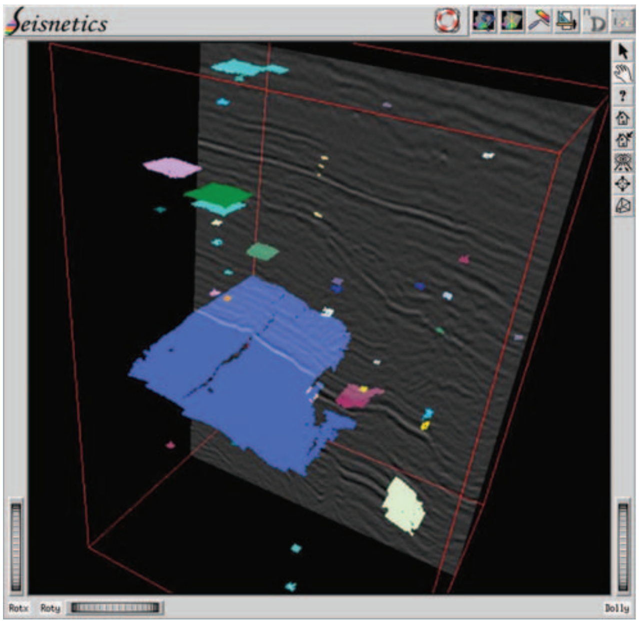

Fig. 3. *Evolution of GeoPopulations™ (snapshot in time). Some populations evolve faster than others (blue horizon). Image from Seisnetics LLC.*

for further analysis. The most effective means of reviewing all the results is by way of a visual database which enables subsets of the GeoPopulations™ to be reviewed and selected for extraction based on a number of statistical and visual criteria. For example, the interpreter might first select the largest surfaces to help develop an initial structural model (Figure 4). Later as objectives change, the visual database can be revisited and queried for other objectives such as a stratigraphic zone of interest, specific seam-roof-floor, shallow overburden assessment, or fault analysis.

The export of selected surfaces into an interpretation, GIS package or modelling software enables further analysis and leaves the integrity of the unbiased GeoPopulation™ database intact. Within the visual database the identification of GeoPopulations™ which match specific criteria can be realised using a number of different filters and sorting techniques (population size, position, quality, etc.).

Each GeoPopulation™ has a set of attributes associated with each member of the population. One of these attributes is called "Fitness" which provides a measure of "genetic likeness" for each member in the population when compared to the common waveform (Genotype) of the same population. This fitness criteria shows individuals that might still be related but are best described as first or second cousins. The best way to assess the genetic variability within a population is to view the fitness values as a map. The fitness map shows areas of high fitness (green) with lower fitness values as blues and reds (Figure 5). Investigation of the lower fitness values which form linear and curvilinear features on the map are predominately caused by subtle faulting with some subtle stratigraphic elements as well. The waveform located in the lower left hand corner of Figure 5 is the common waveform for this GeoPopulation™ and is referred to as the Genotype (shown in red).

A 3D seismic volume is reported to contain many attributes (>150), however most of these attributes are derived from, and dependant on, other attributes: e.g. the gradient is from the Two-Way-Time (TWT) horizon. Consequently, some seismic attributes are useful while others will be redundant or useless and can confuse seismic interpretation more than they help (Barnes, 2007). Using attributes which have a greater degree of orthogonality (or independence) provides better discriminatory power and produces more reliable results. This all clearly assumes the seismic volume has been correctly processed in the first place to minimise artefacts and truly represent the signal and image characteristics at each reflective horizon. Other independent attributes identified for each individual in the GeoPopulation™ are Amplitude and TWT (Figure 6). High quality surfaces will result in more meaningful horizon amplitudes and TWT structure. TWT with Fitness and Amplitude enables a rapid assessment of the volume surfaces.

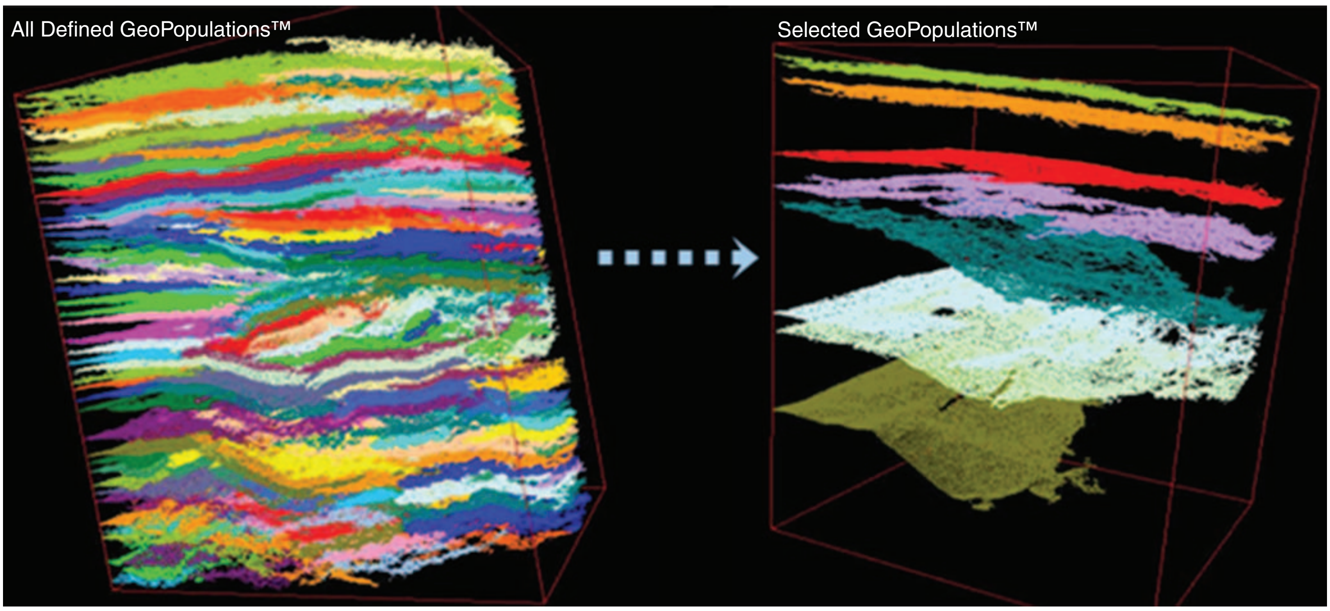

Fig. 4. *Horizons which address the current task are identified and then exported into GIS, interpretation or modelling software. Image from unpublished Seisnetics presentation.*

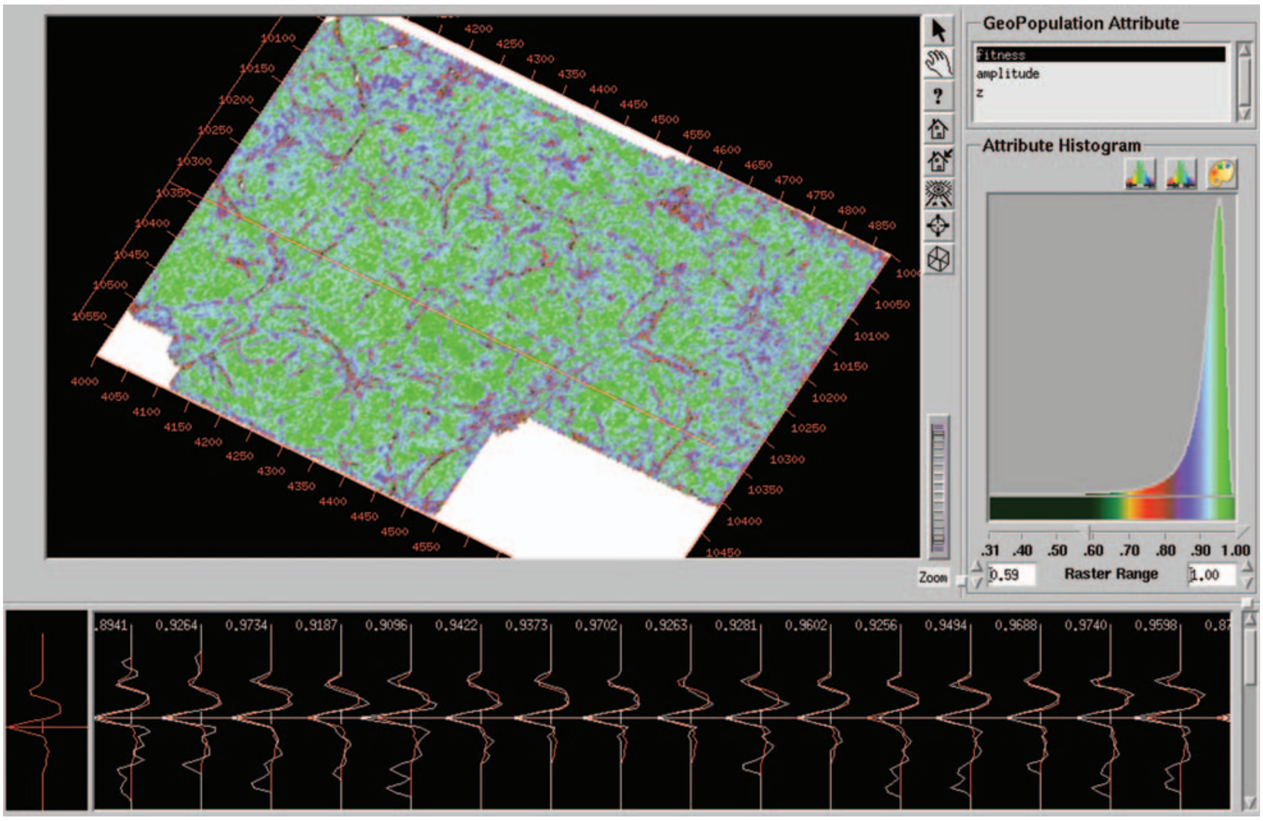

Fig. 5. *The map shows the 'fitness' of a single GeoPopulation™. The common waveform or genotype is shown as the red trace in the lower left hand corner of the image. High fitness values are shown as green on the map meaning these traces have the highest degree of similarity with the genotype. The low fitness values shown are not necessarily an indication of a poor pick. In this case, the areas of lower fitness values identify subtle structural and stratigraphic features.*

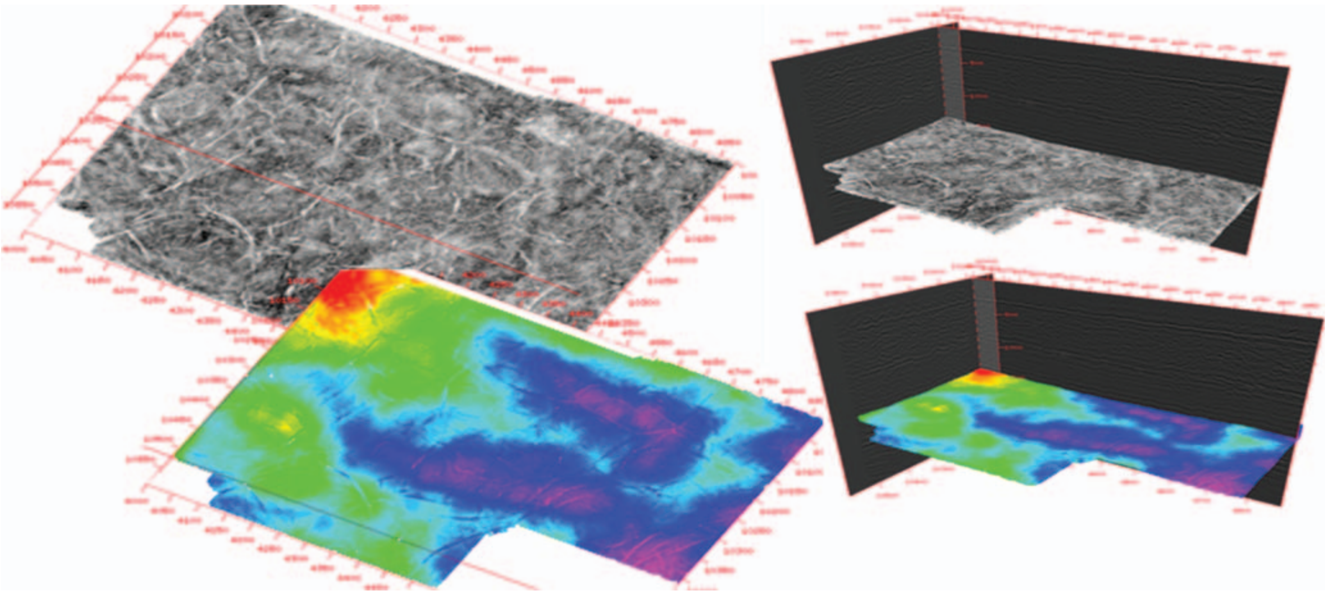

Fig. 6. *Amplitude and TWT when combined with Fitness provide a rapid visual assessment of the GeoPopulation™.*

Results

We have applied the processing algorithm described above to thousands of square kilometres of 3D seismic surveys over both onshore and offshore Australia. In addition to final processed TWT volumes, some other data types processed in this manner include but are not limited to:

- Time, Frequency or Depth Domain.
- Post-Stack (angle stacks, AVO and Inversion attributes, Reflectivity, most seismic attributes).
- Spectral attributes volumes such as Spectral Decomposition and Spectral Attenuation.
- Pre-Stack (gathers, shots for first break or refraction analysis).

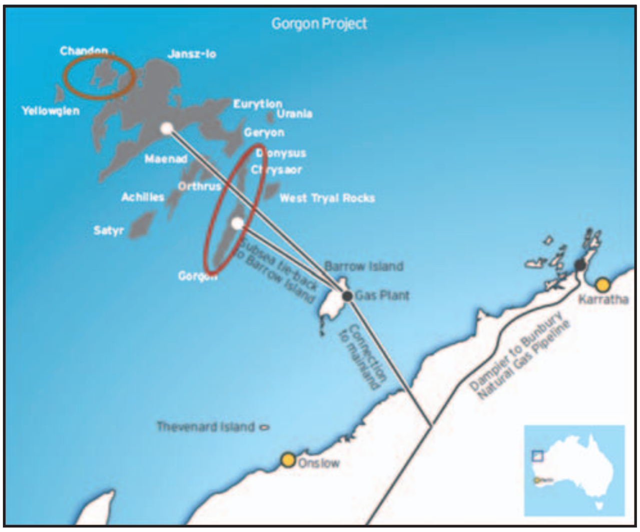

Fig. 7. *Location map for Chandon and Gorgon gas fields. Extract from Chevron Publication 'The Power of Human Energy': http://www.chevronaustralia.com/Libraries/Publications.*

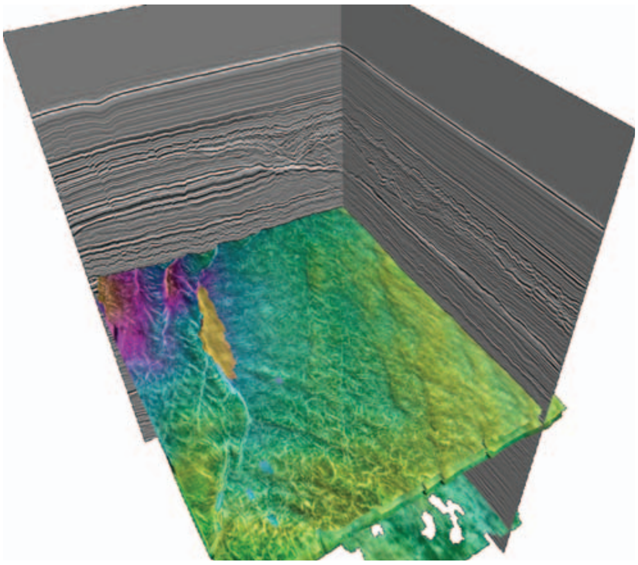

Fig. 8. *Image taken from visual database of GeoPopulations™ from the Chandon 3D volume. The GeoPopulation™ shown is located just above the top of the reservoir section.*

Several examples are shown here from across Australia using datasets collected over the Gorgon Project area, the South Australia portion of the Cooper/Eromanga basin and data collected from a coal minesite in Queensland.

Example 1: the Chandon Gas field (Chevron Operation) reservoir level

The Chandon gas discovery was drilled in 2006 in 1,200 metres of water and is located in the North Carnarvon Basin (Figure 7). This field is one of a number of large gas accumulations which form the Gorgon project area. Chevron reports that these fields contain approximately 40 Trillion cubic feet (TCF) of natural gas and Chevron cites this as Australia's largest natural gas resource (Chevron Australia, 2010). The Seisnetics genetic algorithm was applied to a sub-volume extract from the Chandon 3D seismic volume. The subset processed consists of just under 500,000 traces or about two gigabytes of data. After approximately eight hours of processing more than 700,000 generations of "evolution" identified about 120 million individuals which were assigned to GeoPopulations™. Figure 8 shows a surface near the top of the reservoir section contained in tilted fault blocks. This surface is one of hundreds of high quality surfaces automatically extracted by the Seisnetics processing algorithm. The interpreter then reviews the resulting surfaces to decide which of those surfaces provide the most meaningful geological insight.

Example 2: the Gorgon Gas field (Chevron operation) – outgassing and geohazard

The Gorgon field was discovered in 1981 and is located in the southeast corner of the Gorgon project area. The production lifespan of the project may approach 60 years. In this example, the entire sixteen gigabyte dataset was processed for GeoPopulations™ of both peaks and troughs. As with the Chandon example hundreds of high quality surfaces were automatically extracted after several days of processing. Figure 9 shows an extract from the surface associated with the sea floor. The round circular patterns are pockmarks which are geomorphologic features which are often indicative of upward fluid flow and the venting of gas. The Gorgon field, along with many other gas accumulations offshore from Western Australia, show evidence of outgassing and upward fluid flow. This outgassing has, in places, resulted in both small scale and large scale depressions in the sea floor. While some pockmarks can be small and below the imaging resolution of conventional exploration 3D surveys, many (like those shown here) are much larger and can measure hundreds of metres in diameter. Regionally, areas of higher density of pockmarks have contributed to slumping and sea-floor instability over large areas during the course of geological time.

Example 3: the Cooper/Eromanga basin (South Australia and Queensland)

The Cooper and Eromanga basins, which span northeast South Australia and southwest Queensland, form Australia's largest onshore petroleum province (Fig. 10). Currently, more than sixty 3D seismic data volumes comprising of about 13 000 square kilometres of seismic data have been processed from this area using the automated genetic algorithm from Seisnetics. The initial phase of the project which processed forty volumes was completed within four calendar months. The integration into GIS applications of these high quality GeoPopulations™ with open-file well control, production data, and zones of interest enables both regional and very detailed models to be developed (using much more of the available data). Moreover, these models are entirely data driven and can provide an effective means of extending constrained models into areas which have less data coverage. This type of integration is underway offshore and onshore in every State in the Commonwealth as all seismic data collected eventually becomes open-file.

Example 4: coal mine from the Bowen Basin

This example shows 3D data collected over a Bowen Basin coal mine. The actual location and orientation of the data is withheld at the request of the company operating the mine.

The Bowen Basin in central Queensland is subject to a significant amount of open cut and underground coal extraction.

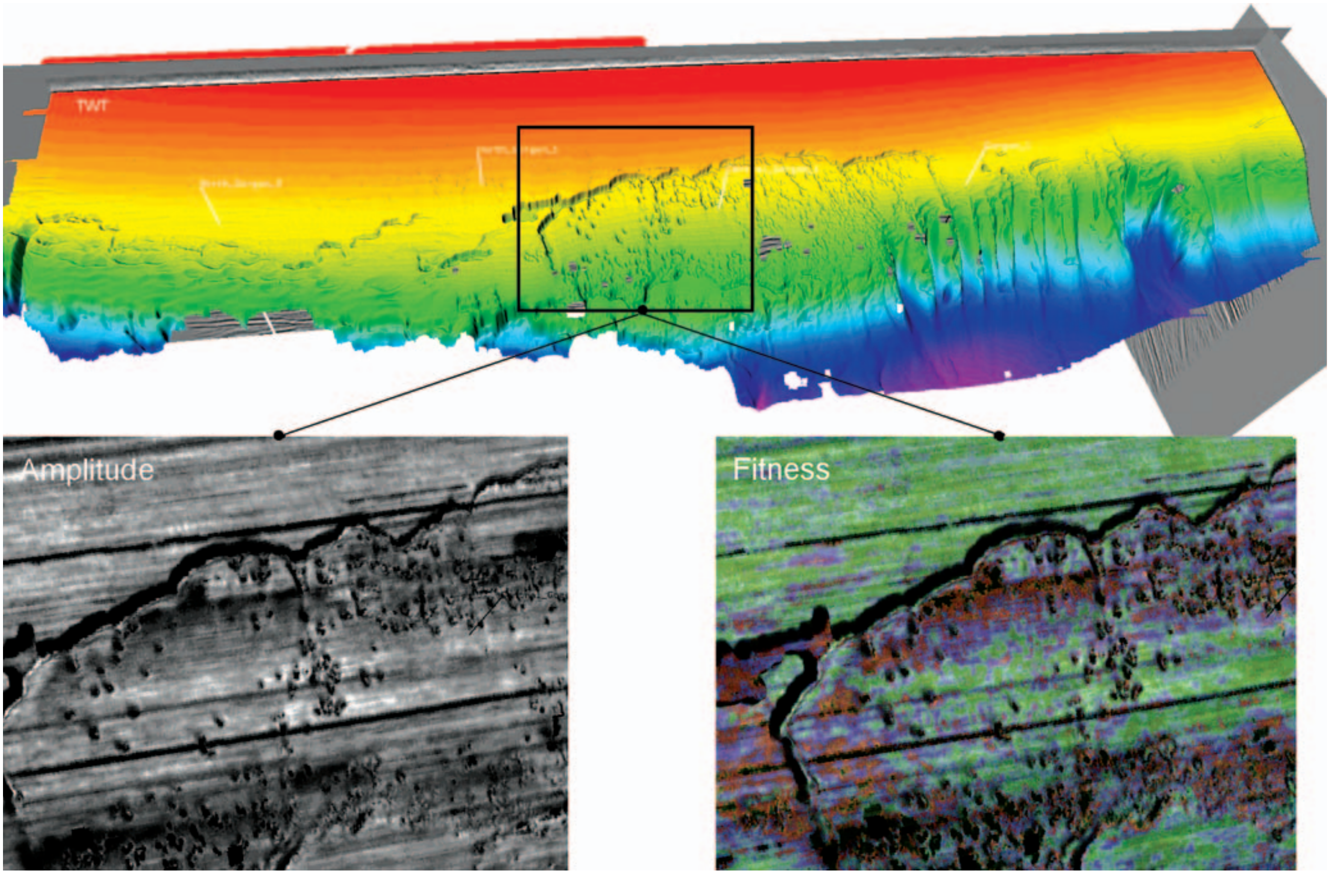

Fig. 9. *Evidence of outgassing over the Gorgon Gas Field offshore Western Australia. While zones of outgassing can reduce the exploration risk and demonstrate areas of active hydrocarbon migration, they can also provide an indication of possible drilling hazards.*

At this site the target coal seam is approximately 210 m below the surface. The seam has an average thickness obtained from the 60 core samples of 2.1 m and the survey area is 7.6 square km. The coal seam of economic interest is the German Creek seam within the Permian Moranbah Coal Measures. There are several much thinner seams existing above the German creek, however these are not of underground economic interest within the project area. The seismic data are derived from a 3D dynamite source survey acquired on a brick acquisition geometry using six geophones grouped into a 2 m array length, spaced 15 m apart, along lines separated by 32 m. A 150 gm PETN booster was used for the charge placed 2 metres below the base of weathering. The dominate wavelength for the final processed signal is approximately 18 to 20 metres. Higher resolution will generate greater detail at or near the target horizon, but this does not necessarily bring greater clarity or certainty to the interpretation. Figure 11 illustrates one horizon of many that can be used by the interpreter to provide an objective starting point to providing a meaningful geological interpretation.

Discussion and interpretation

The ability of an interpreter to provide a geological interpretation that is close to reality depends on a numbers of factors (e.g. experience, survey design, sampling, data quality, noise levels, etc.) If the interpreter focus is only on one or two horizons then the 3D volume has almost certainly been underutilised. Geological events both syn and post depositional combined with lithification can create a complex environment which requires a thorough assessment of the likely hazards associated with placing people and machinery within that world. For the biologists, the initial model of the Human Genome was very wrong, because collectively they had chosen to ignore half of the data when they stripped away the encasing protein to study the DNA molecule. Since geoscientists create models from seismic 3D volumes often using less than 10% of the available data, these models are also likely to be incorrect or heavily biased. To use an often paraphrased quote; 'Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful' (Box and Draper 1987). While the genetic processing technique described above is capable of objectively extracting all the surfaces in a data volume, it is unlikely whether anyone would want to use all data for model construction. However, being able to review all the surfaces in a volume, and to develop an understanding of the variability within the dataset, should enable the geoscientist to develop models that are sufficiently detailed to capture that variability and not be so overly simplified as to render them useless.

From the examples shown, examination of the GeoPopulations™ provided insight into structure, geomorphology, fluid-flow, out-gassing and sea-floor stability at both regional and local scales. These insights can only be made when the volume surfaces can be reviewed in detail (preferably by a multi-disciplinary team). Often different disciplines are able to extract different types of meaningful information from the results. Therefore, by automating the surface extraction process and providing one or two orders of magnitude higher quality surfaces than conventional interpretation techniques, more time can be spent developing an understanding of the results instead

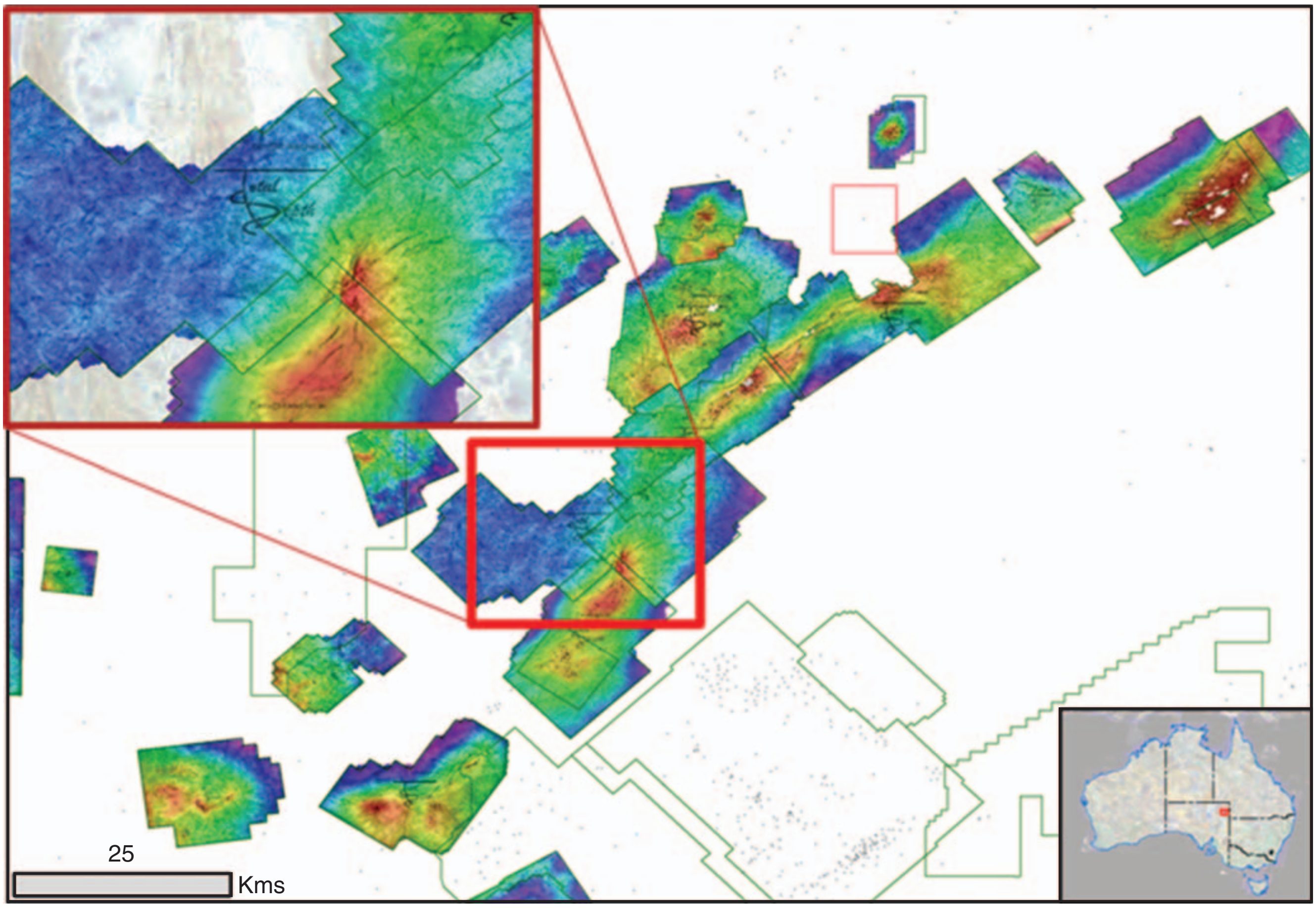

Fig. 10. *The image shows the location of some of the 3D datasets available from the Cooper Eromanga basin. The coloured images show the TWT attribute for the same horizon on all 3D datasets. From the visual database of GeoPopulations™ similar composites could be made at virtually any surface. Colour bars are scaled independently.*

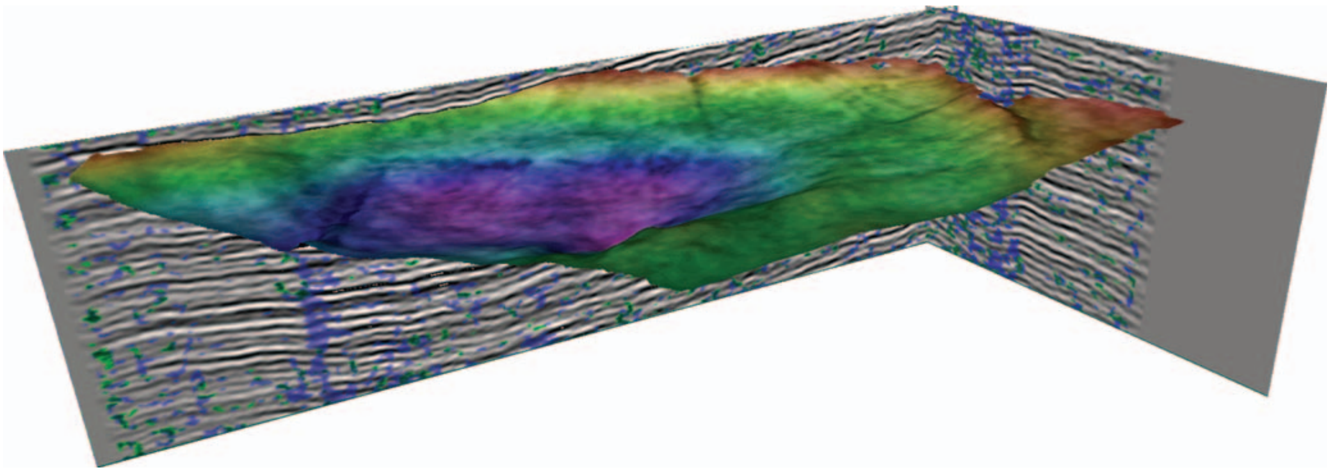

Fig. 11. *TWT GeoPopulation™ with fault zones.*

of losing time in the mechanics of the extraction process. In areas where a horizon is noisy or subject to coherent interference, the ability to rapidly have an objective horizon for critical review by the interpreter can significantly improve the reliability of the interpretation. Moreover, when this analysis is incorporated during the processing of the data, additional information can be used to optimise the processing of the data and get useful data to the interpreter at a much earlier stage. Finally, older legacy data volumes, with the incorporation of geological and engineering data from the sub-surface team into the visual database, will form a knowledge base and provide teaching opportunities for the next project and the next wave of geoscientists. One might also speculate on how this technology would apply to other sets of waveform data collected by the minesite (i.e. analysis of the radar guidance waveforms from the long-wall shearer).

Conclusions

This paper has described and illustrated a mathematical process for objectively providing a series of automatically picked horizons within a 3D seismic volume. The mathematical process emulates biological evolutionary stages whereby an initial population of individuals are randomly identified and given the opportunity to evolve. At the end of each generation, individuals which match the selection criteria, combine with an existing population forming offspring which inherit the genotype of two parents. Through the generations, the fittest have more chance to be selected and to reproduce, which enable them to grow faster than less fit individuals. Typically, the more continuous surfaces evolve first with the more complicated surfaces evolving last. Using this process we have illustrated examples where large multi-horizon 3D datasets can be assessed at either a micro or macro scale for horizon characteristics. The aim of the process is to provide a method whereby the interpreter can rapidly examine all the data, assess the significant aspects of the data then create a meaningful geological model which has been created based on a review of all the data.

Acknowledgements

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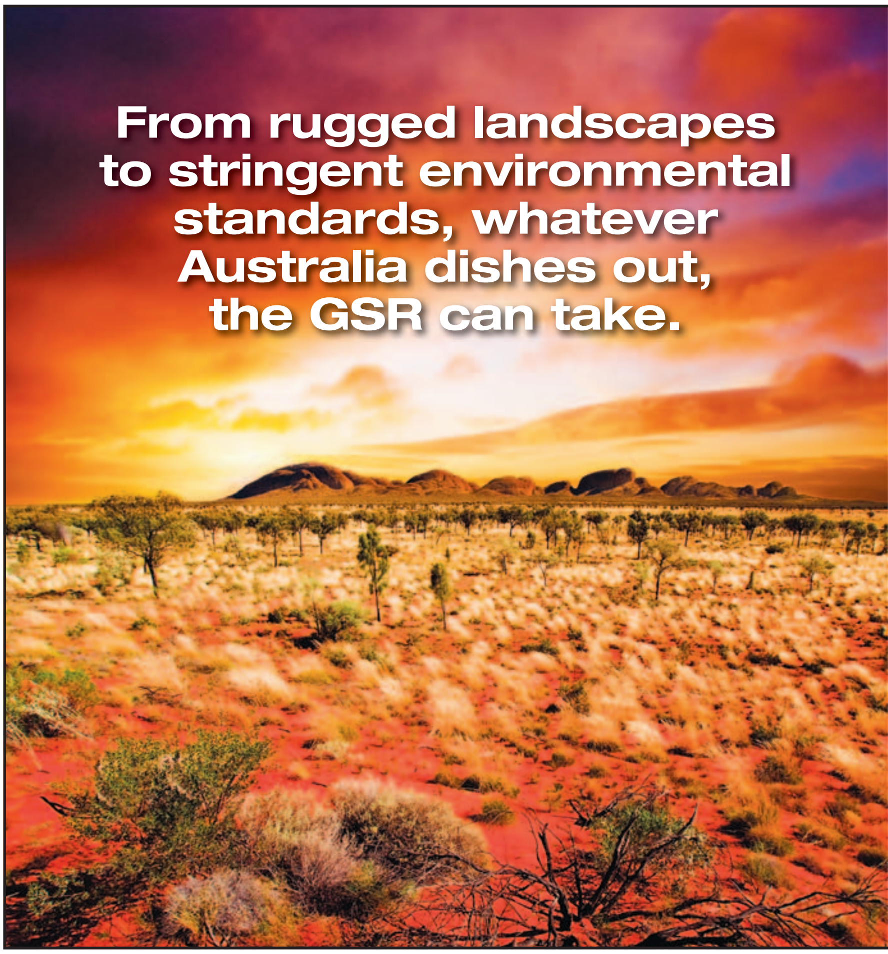

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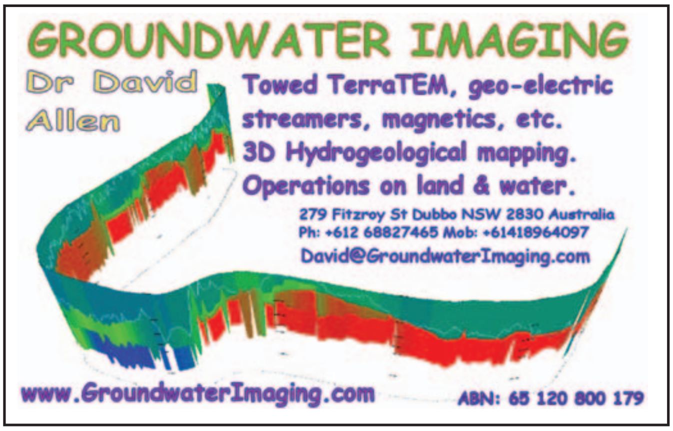

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May			**2011**
9–13 May	Road to Recovery 2011: CSPG, CSEG, CWLS Joint Annual Convention http://www.geoconvention.org/	Calgary	Canada
11–12 May	DEVEX: The Productions & Development Conference & Exhibition http://www.devex-conference.org/	Aberdeen	Scotland
23–26 May	Vienna 2011: 73rd EAGE Conference & Exhibition incorporating SPE EUROPEC 2011 http://www.eage.org	Vienna	Austria
June			**2011**
22–24 Jun	International Workshop on Advanced Ground Penetrating Radar 2011 http://www.congressa.de/IWAGPR-Workshop-2011	Aachen	Germany
28 Jun – 7 Jul	IUGG 2011: Earth on the Edge: Science for a Sustainable Planet http://www.iugg2011.com/	Melbourne	Australia
August			**2011**
28 Aug – 2 Sep	Geosynthesis 2011: Integrating the Earth Sciences Conference & Exhibition http://www.sbs.co.za/geosynthesis2011	Cape Town	South Africa
September			**2011**
12–14 Sep	Near Surface 2011 http://www.eage.org	Leicester	UK
18–23 Sep	SEG International Exposition and 81st Annual Meeting http://www.seg.org	San Antonio	USA
October			**2011**
10–13 Oct	GEM Beijing 2011: International Workshop on Gravity, Electrical and Magnetic Methods and Their Applications http://geophysics.mines.edu/cgem/gem2011.html	Beijing	China
24–26 Oct	IGCP 5th International Symposium: Submarine Mass Movements and Their Consequences http://landslide.jp	Kyoto	Japan
30 Oct – 2 Nov	Society of Petroleum Engineers ATCE 2011 http://www.spe.org/atce/2011	Denver	USA
November			**2011**
8–11 Nov	Sustainable Earth Sciences 2011: Technologies for Sustainable Use of the Deep Sub-surface http://www.eage.org	Valencia	Spain
15–17 Nov	2011 International Petroleum Technology Conference http://iptcnet.org/2011	Bangkok	Thailand
December			**2011**
5–9 Dec	AGU 2011 Fall Meeting http://www.agu.org/meetings	San Francisco	USA
11–14 Dec	First International Conference on Engineering Geophysics http://www.eage.org	Al Ain	United Arab Emirates
February			**2012**
26–29 Feb	22nd ASEG Conference and Exhibition 2012: Unearthing New Layers http://www/aseg2012.com.au	Brisbane	Australia
April			**2012**
2–5 Apr	Saint Petersburg International Conference & Exhibition 2012 http://www.eage.org	Saint Petersburg	Russia
August			**2012**
5–10 Aug	34th International Geological Congress http://www.34igc.org	Brisbane	Australia

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