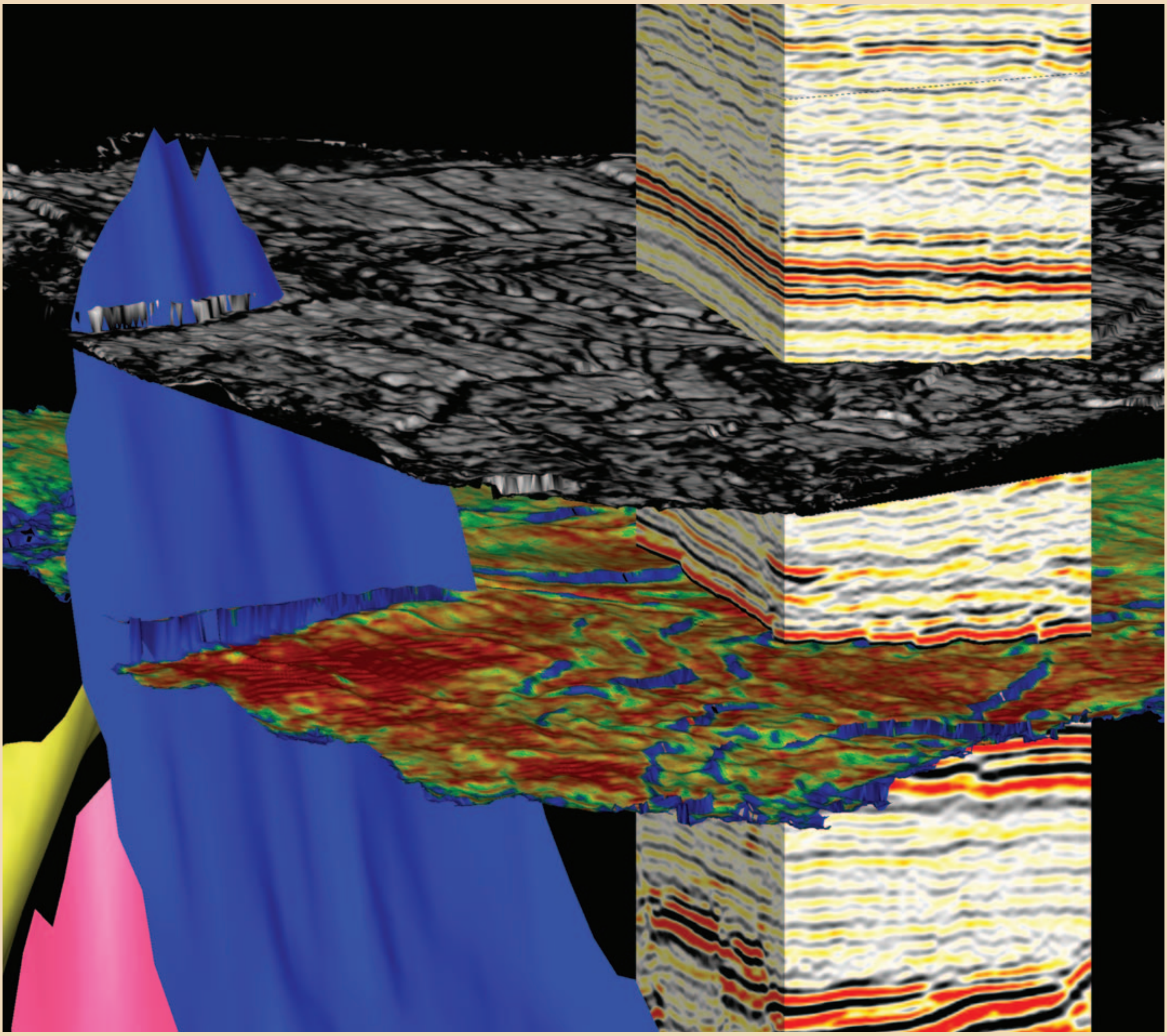
DECEMBER 2011 • ISSUE 155
ABN 71 000 876 040 ISSN 1443-2471

PREVIEW

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS



NEWS AND COMMENTARY

Web Waves: Kaggle style R&D collaboration
Student report on 5th International Earth Science Olympiad
AuSREM: AusMoho and beyond
12th Edition of GA's Index of Airborne Geophysical Surveys

FEATURE ARTICLES

Shale gas in Australia: opportunity and challenges
Production rate variability with shale reservoirs
Eagle Ford Shale exploration: integrated geology, seismic and microseismic

Downhole EM, MMR and IP Surveys

Surface EM and MMR Surveys

Surface IP Surveys including 3D

Geophysical Consulting

Instrument Repair

PREVIEW

ADVERTISERS INDEX

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CONTENTS

FRONT COVER

Visualised view of 250 km² of 3D seismic data across the Eagle Ford formation in South Texas. Image courtesy of Global Geophysical Services, Inc.

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

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Ann-Marie Anderson-Mayes

This issue – shale gas

This issue grew out of a suggestion from ASEG President, Dennis Cooke, to put together a themed issue on shale gas. My thanks go to Dennis for sourcing the three feature articles that are included in this issue: *Shale gas in Australia: a great opportunity comes with significant challenges* by David Warner; *The production rate variability problem with shale reservoirs: what we know and what we don't know* by Dennis Cooke; and *Eagle Ford Shale exploration: integrated regional geology, seismic and microseismic analysis* by Galen Treadgold *et al*. I hope these three articles give you some insight into the developing shale gas industry in Australia.

In this issue we also have a very interesting report from a group of Year 11 students who represented Australia at the 5th International Earth Science Olympiad in Italy in September. Andrew Long's Web Waves column takes a look at Kaggle – a novel approach to data mining challenges that provides an exciting alternative to traditional R&D models. Professor Brian Kennett describes the latest developments with AuSREM – the Australian Seismological Reference Model. And of course, all the usual contributions summarise news of relevance to ASEG members.

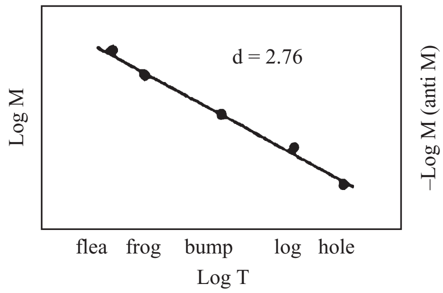
The next issue of *Preview* will be the Conference Handbook for ASEG 2012. The conference program has now been published online, including a full program of workshops for both before and after the conference (more information on p. 10). Make sure you visit the website for all the important details: www.aseg2012.com.au.

A little bit of humour

Another year has rolled around again. We know it is rushing closer when the diary starts filling up with end-of-year functions, school concerts abound and the shops are full of Christmas cheer (way too early in my humble opinion). For readers of this column, I went in search of a little humour … and stumbled across this delightful gem.

In September this year, geologist Kyle House reproduced the following 'deeply insightful abstract' on his blog site, 'Geologic Froth'. It is a joke abstract that was indeed published in 1991 in *EOS Trans. AGU*, 72(44), p. 456. If you haven't come across it before, enjoy…

> ***Fractal analysis of deep sea topography by Marc Spiegelman and Chris Scholz***
>
> *Recent high resolution mapping of deep-sea topography shows clearly that there's a hole in the bottom of the sea. To repeat, there's a hole in the bottom of the sea. There's a hole – there's a hole – there's a hole in the bottom of the sea. Moreover, most careful analysis indicates that there is a multitude of scale lengths in the bathymetric data. For instance, there's a log in the hole in the bottom of the sea. There's a bump on the log in the hole in the bottom of the sea. There's a frog on the bump on the log in the hole in the bottom of the sea. And there's a flea on a frog on a bump on a log in a hole in the bottom of the sea. There's a flea – there's a frog – there's a hole in the bottom of the sea. Figure 1 shows the 5 orders of magnitude inherent in the data plotted in log-log space and indicates a fractal dimension d = 2.76. Plotting in log-frog space gives d = 2.5. No attempt has been made to understand this result.*



On that note I wish you all a very happy and safe festive season. Thank you to all the *Preview* contributors, editors, readers, advertisers, sponsors and CSIRO Publishing for continuing to support our magazine so strongly. I look forward to meeting as many of you as possible at ASEG 2012 in Brisbane in February.

Land rights: the last significant hurdle to Australian CSG development and lower global CO_2 emissions?

I am concerned about global warming[1], and that concern drives my support of the carbon tax.

Over the next 20–50 years, the biggest contributor to increased CO_2 emissions will be the 2 or 3 billion poor in the developing world who will become middle class. These people want the same standard of living the first world has and their current path is to get there by mostly burning coal, which will significantly increase the amount of CO_2 in the atmosphere. China alone is building a new coal-fired electricity plant every 1–2 weeks.

It is not realistic to ask the world's poor to continue going without electricity (i.e. not become middle class), and it is not realistic to ask them to make an immediate transition to expensive renewable energy sources. CSIRO projects that renewables will become cheaper than fossil fuels in 15–35 years, but there are a lot of caveats! (see Fig. 1). This is great news – because if it really happens, short-term economic interests will drive the world to switch to renewables.

If one assumes that economics and innovation (plus a global emission trading scheme) will drive the switch to a renewable energy future, there is still the problem of several billion people burning coal in the 15–35 year period between now and when renewables become low cost. As you have undoubtedly heard before, natural gas is an ideal transition fuel between now and this future world because natural gas has approximately half the CO_2 of coal with a cost increase of ~50%. So one of the best things Australia can do for the world's environment over the near to midterm is to produce and sell more natural gas, which will hopefully displace coal and lead to lower CO_2 emissions.

But there can be a conflict between local and global environmental solutions; for example, wind turbines are good for the environment from a CO_2 point of view but can be bad for the environment from a migrating bird's point of view. A similar environmental debate is brewing (boiling over?) between those who see CSG and shale developments as bad for water supplies and those who see it as good for the environment.

The Greens, who are wary of any development and advocate an immediate switch to renewables, have been fighting CSG development. Their arguments, and the counter arguments, are as follows.

Frac chemicals: The fracture stimulation treatments associated with CSG development will contaminate aquifers. Counter argument: Aquifer contamination has not been observed in over 1.5 million frac jobs performed over the past 60 years. But this contamination may be very difficult to detect, so Australia already has additional protection: our regulator prohibits frac jobs close to aquifers.

Fugitive emissions: CSG wellheads and pipelines leak methane to the atmosphere. This methane is an especially damaging greenhouse gas and makes CSG development worse than coal. Counter argument: These leaks are very overstated. Testing is already done to find and fix them. And economics alone makes it attractive to seal any leaks so the gas can be sold.

Aquifer drawdown: CSG development entails pumping large amounts of water out of coal. The water system in coals is connected to surface aquifers and thus CSG development will drain aquifers. Counter argument: It is unlikely that a given CSG well is connected to the surface aquifer. But if any given well(s) are connected to the surface aquifer, this can be detected early and pumping at those wells can be stopped.

But there is an aspect of CSG development that is difficult to argue against: industrial development may not be welcomed in rural areas. Rural property owners in CSG development areas are asked to live and work around new roads, drilling rigs (only temporarily), well heads, compressor stations and pipelines on their properties.

I have a lot of sympathy for these property owners. They live by choice in the bush far from the industrial development of the city. CSG development almost certainly is good for the state and the economy and the environment. Rural property owners however are directly bearing the biggest burden of CSG development but they are not receiving a share of the CSG benefits that is proportional to their burden.

The Greens (with some interesting support from the opposition parties) have

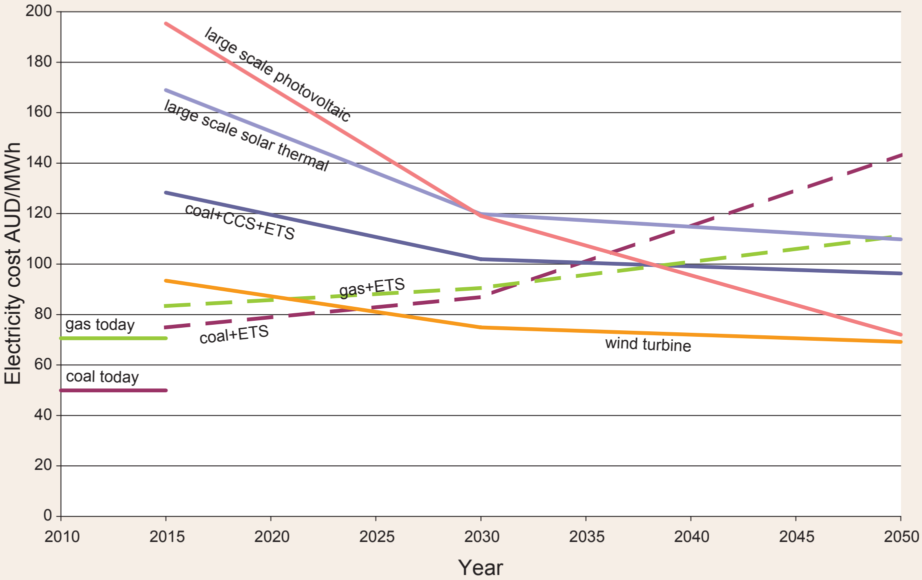


Fig. 1. *Current and future costs of electricity from various technologies. Future estimates include escalating permit costs from an emissions trading scheme plus technical innovation. Not included in the costs above is concept of capacity: 80% for all fossil fuels (plants run 80% of the time – down 20% for maintenance) while solar and wind capacity is 25% ('down' 75% of the time for darkness and no wind). ETS = Emissions trading scheme. CCS = carbon capture and storage. Modified from* Projections of the future costs of electricity generation technologies, *CSIRO Feb., 2011.*

been courting the property owners with proposed legislation that would give them the legal right to stop CSG development on their land. This proposal is trying to take advantage of the disenfranchised property owners and use them to stop CSG development. An alternative approach would be to better reward property owners for living with CSG development on their property.

It is interesting to look at the example of shale gas development in the United States. Shale gas development – which is similar to CSG development as both use dense pattern drilling and fracture stimulation – is proceeding quickly in the US, but there is much more opposition to shale development in the eastern states than in the western states. Why?

In the United States private individuals – not the state – own mineral rights, and those mineral rights may or may not be owned by the surface owner. It is more common in western states that a landowner will own the minerals under his land and thus receive royalty payments from shale gas development. For various reasons, fewer eastern landowners own their mineral rights and receive financial benefit from shale gas development. And thus there is more opposition to shale gas development in eastern states.

CSG development in Australia would almost certainly be less contentious if our surface rights owners received a royalty payment from CSG development on their land. But would that royalty payment be fair to adjacent landowners that don't have CSG wells, but still must deal with the noise and traffic of the CSG development? Or to those landowners who did not receive such a payment in the past? And who would pay such a royalty– the state or the energy companies? And how should that royalty rate be set?

These are tough questions for which I do not have an answer, but I hope they are solved in a way that allows Australia's natural gas to displace coal and lower CO_2 emissions both here and in countries to which we export.

Note: The opinions expressed above are those of the ASEG president and are not meant to represent the opinions of ASEG members or of the ASEG Federal Executive.

[1]See my President's Column for August 2011 (*Preview*, Issue 153, p. 5): Climate change: let's not confuse likelihood with consequence.

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Invitation for candidates for the Federal Executive

In accordance with Article 8.2 of the ASEG Constitution '…*The elected members of the Federal Executive are designated as Directors of the Society for the purposes of the Act.*'

The Federal Executive shall comprise up to 10 members, and shall at least include:

(i) a President,
(ii) a President Elect,
(iii) a Secretary, and
(iv) a Treasurer.

These officers are elected by a general ballot of members. Kim Frankcombe has nominated for the position of President.

In addition, the following offices are required:

(i) First Vice President,
(ii) the Immediate Past President (unless otherwise a member of the Federal Executive),
(iii) the Chairman of the Publications Committee,
(iv) the Chairman of the Membership Committee,
(v) the Chairman of the State Branch Committees, and
(vi) one other to be determined by the Federal Executive.

These officers are appointed by the Federal Executive but nominations for these positions are very welcome.

Please forward the name of the nominated candidate and the position nominating for, along with two members eligible to vote, to the Secretary:

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c/- ASEG Secretariat
PO Box 8463, Perth Business Centre
WA 6849
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Fax: +61 8 9427 0839
Email: secretary@aseg.org.au

Therefore, nominations must be received via post, fax or email **no later than COB Monday 5 March 2012**. Positions for which there are multiple nominations will then be determined by ballot of Members and results declared at the Annual General Meeting, which takes place in Adelaide on Tuesday 3 April 2012.


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New members

The ASEG extends a warm welcome to 14 new members to the Society (see table). These memberships were approved at the Federal Executive meetings held on 29 September and 27 October 2011.

Name	Organisation	State/Country	Member Grade
Eddie Cho	DownUnder GeoSolutions	QLD	Associate
Jamin Anshell Cristall	Vale Exploration	WA	Active
Daniel Card	Southern Geoscience Consultants	WA	Active
Mohammad Emami Niri	University of Western Australia	WA	Student
Hugo Espinosa	Griffith University	QLD	Associate
Victoria Gallagher	Queensland University of Technology	QLD	Student
Valarie Hamilton	DownUnder GeoSolutions	QLD	Active
Sabra Henrik	Avannaa Resources Ltd	Denmark	Active
John Edward Ellis Kingman	Newmont Mining	USA	Active
Russell McChesney	Southern Geoscience Consultants	WA	Active
Omar Adil Mohammad	University of Wollongong	NSW	Student
Frank Nicholson	Nicholson Geophysical	SA	Active
Rebecca Anne Williams	DownUnder GeoSolutions	QLD	Associate
Jillian D. Young-Lorenz	University of Western Australia	WA	Student

ASEG News

New South Wales

In October, we held our student night and four students from Macquarie University and the University of Sydney gave talks on their studies. All the talks were great and invoked much discussion. The speakers and the titles of the talks were as follows:

- *Gravity modelling of the Thomson Orogen, Northwest New South Wales*: Cam Adams, Macquarie University
- *Paleo-environmental evolution of the southern Australian margin*: Megan Holdt, The University of Sydney
- *Jurassic rifting of the northern Australian shelf in the Timor–Banda segment*: Hamish McKay, The University of Sydney
- *Geophysical data mining for opal exploration*: Andrew Merdith, The University of Sydney

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

Mark Lackie

South Australia/Northern Territory

The SA/NT branch held two technical evenings in October. At the first we welcomed our Branch Secretary, Mike Hatch, to talk about nuclear magnetic resonance and its application in downhole geophysics. A small but enthusiastic crowd attended.

The second October event was our annual Industry night. This year our invited speakers were from the South Australian petroleum companies Santos, Beach Energy and Bight Petroleum. The function room at the Coopers Alehouse was filled to capacity and it was particularly pleasant to see some new faces in the crowd.

Our Melbourne Cup luncheon is always popular, and yet again we filled the function room at the National Wine Centre to capacity. Geophysicists, friends, family and colleagues all got together for an afternoon of networking, fun, good food and wine. Congratulations to all the people on the PIRSA table named ‘Last Place Racing’ who won first place!

Our Student night was held on 29 November and featured talks from local students who recently completed their honours work at the University of Adelaide. We also opened the 2012 SA/NT ASEG scholarship to applicants. This scholarship is open to end-of-third year students applying for Honours-level geophysics. There are two awards, both valued at $2000. The two successful recipients also receive a copy of the SEG publication *Encyclopedic Dictionary of Applied Geophysics* by Robert Sheriff.

Finally, our annual Christmas party was held on 8 December. It was an excellent wrap-up to the year and an opportunity for everyone to relax. Many thanks go to our caterer Peter Crettenden and our host Matthew Zengerer.

Our local branch AGM will be held in February 2012. Stay tuned to the website for more details.

We hold technical meetings monthly, usually on a Tuesday or Thursday at the Coopers Alehouse beginning at 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 12 October the ASEG Victorian Branch hosted a technical evening at the Kelvin Club in Melbourne’s CBD. Professor James Macnae presented *Airborne EM system comparison* to an interested audience followed by many questions and a healthy discussion on the relative merits of various commercially available EM systems and developments.

On 7 December the ASEG will co-host an end-of-year technical luncheon with the local chapters of SPE, PESA and GSA at the Victoria Hotel. Dr Mark McLean from Geoscience Victoria will present *Logistics operations and airborne potential field surveying in the Lambert Rift region, East Antarctica*. We look forward to seeing many ASEG Victorian Branch Members at the last meeting for 2011.

Asbjorn Christensen

Western Australia

Well, it’s been a busy few months for the WA branch and Christmas is already on us. We’ve had a great run of quality and well-attended presentations at our monthly technical evenings, as well as several special visits and events.

On 10 August, Chris Wijns of First Quantum gave a talk on the Kevitsa Ni-Cu-PGE deposit in Finland. A multitude of geophysical techniques has been applied at the project since before its discovery in 1987 by the Finnish Geological Survey through to today. Geophysical exploration, particularly MT, downhole EM and seismics, continues to play a major role today in hunting for higher grade zones within and near the current pit envelope.

The annual Careers in Geoscience Night was held at nib Stadium on 16 August and was a resounding success. The event was jointly put on by the WA branches of the AIG, PESA, ASEG and Earth Science WA. High school students attended from late afternoon followed by university students. Over 200 students attended, including 70+ from Perth high schools. They made their way through the exhibition booths and displays, which were occupied by various industry, university and government organisations and were able to chat with geoscience professionals from across all geoscience disciplines. The event was well sponsored with major contributions from Woodside and Integra Mining.

On 18 August, Julien Meunier presented the SEG/EAGE DISC course in Perth entitled ‘Seismic Acquisition from Yesterday to Tomorrow’. The one-day workshop presented the latest developments in offshore and onshore seismic acquisition focussing on the relationship between acquisition parameters and seismic image quality.

Ken Witherly of Condor Consulting was in town from the USA in late August and took time out to present his talk on the evolution of the use of geophysics in the search for blind VHMS deposits in the Abitibi greenstone belt of Quebec, Canada. It was an excellent case study illustrating the need to now expand exploration areas beyond brownfields and develop effective means to discriminate targets of interest within formational conductors.

The September technical night saw Sverre Tresselt of IPRES Norway give a talk on how risks and uncertainties are factored into technical decisions and what the benefits are. This was followed in October with a presentation on a new dimension in fracture recognition from seismic implications for exploration and development of resources by Ralph Opperman.

The November technical meeting on Wednesday 9th was our annual Student Evening where Honours students present their thesis topics. The presentations this year were excellent with the following eight students taking part:

- *Basin scale airborne TEM and seismic reflection for groundwater modelling in Northern Perth Basin, WA*: Robert Martin, Curtin University
- *The use of pseudorandom sweeps to reduce interference noise in simultaneous vibroseis surveys*: Hayan Nasreddin, Curtin University
- *Overburden related amplitude/ frequency decay analysis using VSP data, Exmouth Plateau*: Carolina Pimental, Curtin University
- *Cross well electromagnetic methods for CO_2 injection into brine reservoirs*: Ruan Swanepoel, Curtin University
- *Temperature and gamma-ray logging in the Perth metropolitan area*: Stephanie Tressler, Curtin University
- *Near surface seismoelectric acquisition using a vibroseis source*: Jason Valuri, Curtin University
- *Modelling down-hole induced polarisation based on the Centenary gold deposit, WA*: Jarrad Trunfull, The University of Western Australia
- *Constrained magnetic modelling of the Wallaby gold deposit*: Sasha Banasczyk, The University of Western Australia

We look forward to this time next year when we will be able to present the first awards to successful recipients of the ASEG WA Scholarship Program.

The 24th PESA–ASEG Annual Golf Classic was held on Friday 4 November at Joondalup Resort. The highlight of the day was Wayne Bauer's hole-in-one off the Lake 3 tee. We believe that's a tournament first. First place, and congratulations, went to team 'Geosoft' of Darin Bryce, Chris Bishop, Adam Martin and Ash Johnson with a final score of 58.875. Second place went to the 'Fugro Imagers' of Simon Stewart, Toby Bridle, Mike Riha and Mick Curran with a score of 59.5 moving them up a rank from their third placing last year. And third place went to the 'Individuals' made up of Paul Rheinberg, Dave Christiansen and Bill Warlock with 59.75 on a countback. This year's NAGA award was taken out by the aptly named 'CGGVeritas Hackers' of Andrew Winch, Suzanne Cashman, Rob Elliott-Lockhart and Chris Manuel with a final core of 71.125. Thanks as always to all the sponsors, in particular platinum sponsor CGGVeritas and gold sponsor PGS.

And lastly, we'll wrap up the year on 14 December with the AGM followed by our Christmas function at the Santa Fe Restaurant in Subiaco.

Anne Morrell

News

ASEG 2012 22nd ASEG International Conference and Exhibition: Final News Update

The clock is now winding down to what promises to be the best ASEG ever*. The papers committee, of which I was an unwitting member, has approved over 130 papers for oral presentation. Together with an outstanding selection of keynote presenters the conference program offers something for everyone. There will be five concurrent streams including two petroleum and two mineral streams. Seismic interpreters will have a stream directly catering to them. On the Tuesday of the conference there will be a coal geophysics stream that will include seismic as well as other methods that are now gaining acceptance. The final program (subject to change) is available on the web. Many thanks to Binzhong and his team.

The workshop program has been finalised and is also available on the web. Workshops start on 25 February and continue to 3 March. Ensure you take this opportunity as many of these presenters will not come this way again (well not soon anyway). Prices have been set so that attendees will find them easy to justify. Thanks to Koya and his team.

In a departure from previous conferences we will be giving extended time to more keynote speakers. Check out the keynote speakers on our web site.

Workshops

Petroleum/energy

- AVO Inversion *by Brian Russell*
- Operational Seismic Sequence Stratigraphy *by Robert Kirk*
- Microseismic Monitoring *by Peter Duncan*
- Geothermal Exploration *by Cameron Huddlestone*
- Coal Bed Gas *by Scott Thompson*
- Seismic Imaging: A Review of the Techniques, their Principles, Merits and Limitations *by Etienne Robein (EAGE Education Tour)*
- A Practical Overview of Seismic Dispersion *by Chris Liner (SEG DISC)*

Minerals

- Electromagnetics *by Douglas Oldenburg*
- Natural Electromagnetic (Magnetotelluric) *by Bob Smith*

Industrial workshops on minerals

(Presenters to be confirmed)

- Intrepid Geophysics
- Mira Geoscience
- Ikon Science

Please register for our conference and tell all your colleagues to do the same. No doubt you will find me in the exhibition area networking.

Website: www.aseg2012.com.au

Henk van Paridon

**Product may vary depending on individual usage.*

5th International Earth Science Olympiad, Modena, Italy: a student perspective

Jack Beard, Mehreen Qayyum, Eilidh Cassidy and Nichola Dart

Edited by Bronte Nicholls.

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In September 2011, four students from the Australian Science and Mathematics School in Adelaide were selected to travel to Italy in order to compete in the International Earth Science Olympiad (IESO). It was an opportunity for individuals with a passion for earth science to come together from a vast selection of countries across the globe to share knowledge and ideas on the earth sciences.

The first Australian team ever to participate in the IESO was made up of Eilidh Cassidy, Mehreen Qayyum, Jack Beard and Nichola Dart (Year 11 students from the Australian Science and Mathematics School, Adelaide, South Australia). The team's mentors were Dr Bronte Nicholls (Australian Science and Mathematics School) and Associate Professor Ian Clark (University of South Australia).

The team on arrival at Modena University student accommodation. From left: Mehreen Qayyum, Nichola Dart, Jack Beard and Eilidh Cassidy. (Photograph: Bronte Nicholls)

The team was sponsored by the Australian Geoscience Council, Geological Society of Australia – Federal Division, Australian Society of Exploration Geophysicists, Petroleum Exploration Society of Australia, Beach Energy, Pepinnini Minerals, Geological Society of Australia – SA Division, Flinders University and University of South Australia.

Preparing for the IESO was a joint effort by everyone in the team. We had regular team meetings over the course of the school year and worked through the syllabus provided by the organisers. Working together as a team was a great way to learn new, complex topics. Working with our peers was possibly the greatest contributor to the success of the team in Italy, because we were already accustomed to working through problems with like-minded students. Unfortunately, one of the team members, Nichola Dart, became ill and was unable to participate in most of the event.

The team was successful in gaining the following awards:

Individual Competition: Bronze Medal – *Jack Beard*

International Team Field Investigation: Most Creative Investigation – Winning team member: *Jack Beard*

Best Presentation – Winning team member: *Eilidh Cassidy*

The following reports the IESO experience from the point of view of each of the team members.

Eilidh Cassidy

For me, I felt one of the most beneficial experiences I had at the Olympiad was the International Team Field Investigation (ITFI). I found it was one of those once-in-a-lifetime opportunities that really had an impact on your perspective of learning. The ITFI was based in the Alps, Valle d'Aosta region, where we were split into teams (not based on country).

I stayed in a place called Saint Barthelemy where the topic the team was investigating was Astronomy. The problem my team was given to investigate was to determine the rising time of a star, Algenib, and I must admit I wasn't quite sure if this was something that would interest me.

However, my view quickly changed and I left there with a completely different attitude and a new love and interest in Astronomy. To find the rising time, we first had to design our own instruments as a team, which then allowed us to measure the peak of a mountain where we could calculate angular distance and then eventually determine when the star would be visible.

Saint Barthelemy Astronomical Observatory: one of the sites for the International Team Field Investigation. (Photograph: Bronte Nicholls)

We had to present our findings to a large audience, which happened to be exhilarating and intimidating at the same time. However, my team and I worked hard and put together a PowerPoint and in the end we must have done something right as we came away on the presentation night with the Best Presentation Award.

The Olympiad itself was any geologist's dream and although the exams themselves were very difficult, we took it as a learning experience. I can probably speak for both myself and my team when I say that attending the IESO changed all of us in terms of our confidence and our passion for Earth Science, and although we didn't come home with gold medals, it was a valuable learning experience. If Australia sends a team in the future, they can learn from our journey and maybe one day Australia will do Earth Science proud and come home with that gold medal.

Mehreen Qayyum

I expected the IESO to be very disciplined and thought that the team work referred to the country teams. However, the Olympiad was definitely not what I expected. It was more competitive and covered Earth Sciences of all spheres to a greater extent than what we had studied. Despite this, the atmosphere of the Olympiad was friendly, supportive and encouraging. We studied hard the last few nights in the lead up to the exam to maximise our marks. There

News

were also a few practical examinations, but these were made considerably easier as the guides showed us how to use the instruments we needed for the practical before the examinations. I think as a team we did well according to the amount of knowledge we had in the topics being examined.

Overall, I think being a participant of the IESO was a good experience and I was able to learn a lot from it. We learned how to communicate and interact with people of many nationalities, religious and cultural backgrounds and languages, as well as explore, develop and present ideas to achieve a common goal. Many of the presentation, cultural and earth science skills I have learned will help me in future studies in school and beyond.

Jack Beard

One of the highlights of the trip was the ITFI. I stayed in a place called La Thuile, a small village near the French-Swiss border at the base of Mt Blanc – Mehreen and I were in the same group but different teams.

The International Team Field Investigation site for Group 1: Mt Blanc in the background. (Photograph: Mehreen Qayyum)

Our task was to map the occurrence of gypsum in a valley near the village and what implications it had on the community (such as sink holes and the ability for income through mining).

This was one of the highlights as we really got to know many team members from other countries around the globe. After 24 hours of hard work, we finally presented our findings to an audience of 200 others. Here, the team I was in won the Most Creativity shown during the ITFI award.

The IESO will have a huge influence on me in the future. I will never get the opportunity to participate in such an event again, so this truly was a once-in-a-lifetime opportunity. Not only has it shaped the way I will look at my career plans, but it has also had an impact on the way I interact with others, for example, my peers at school and in other situations.

For further information about the 5th IESO visit http://www.ieso2011.unimore.it/.

Summary of the Australian team IESO and extension activities

Date	Students
5 Sep	Arrival and registration, welcome dinner
6 Sep	Opening ceremony Excursion: Salse di Nirano
7 Sep	Excursion: Venice – Hydrosphere practical exam
8 Sep	Written exam – all topics Excursion: Civil Protection Centre of Modena
9 Sep	Geosphere, atmosphere and astronomy practical exam Excursion: Villa Sorra
10 Sep	Excursion: Valle d'Aosta International Field Trip Investigation
11 Sep	Excursion: Valle d'Aosta International Field Trip Investigation
12 Sep	Local school visit Plenary conference, Terramare di Montale
13 Sep	Modena city centre Award ceremony and farewell party
14 Sep	Departure
15–20 Sep	Australian team post-Olympiad tour to the Bay of Naples and Rome
22 Sep	Return to Adelaide

IESO opening ceremony: flag bearers from each of the 26 participating countries. (Photograph: Eilidh Cassidy)

The Australian team during the Hydrosphere practical examination in the Venice Lagoon. From left: Mehreen Qayyum, Jack Beard, Eilidh Cassidy. (Photograph: Jack Beard)

The International Team Field Investigation teams examining an outcrop at La Thuile. (Photograph: Jack Beard)

The team enjoying the steep climb to the summit of Vesuvius: part of the post-Olympiad tour to southern Italy. From left: Eilidh Cassidy, Mehreen Qayyum and Jack Beard. (Photograph: Bronte Nicholls)

AuSREM: AusMoho and beyond

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The Australian Seismological Reference Model (AuSREM) is designed to capture the wide range of seismological information generated over the last few decades on the structure beneath the Australian region exploiting both natural and man-made sources. The objective is to provide a representation of the 3D structure beneath Australia and its environs in a form that summarises existing knowledge and provides a basis for future refinement from more detailed studies. Potential applications of the model include improved earthquake locations, both within Australia and at the immediate plate boundaries by using better representations of crustal and mantle structure. The AuSREM project is supported by AuScope and the Australian National University.

The AuSREM model is being constructed on a 0.5 × 0.5 degree grid and includes crustal structure and mantle structure to 350 km deep based on Australian specific observations. At greater depth and in surrounding areas, the AuSREM model is linked to S40RTS (Ritsema *et al.*, 2011), which builds on global observations of seismic surface waves and long-period body waves.

The first product from AuSREM is a new map of the Moho Depth for the Australian continent, *AusMoho11*, incorporating a wide range of observations (Kennett *et al.*, 2011). The compilation of Collins *et al.* (2003) used refraction results and receiver function information from about 60 portable or permanent seismic stations across the continent. Since that time much more information has become available, and a further 150 receiver functions have been employed in the new model. Recent years have seen major investments in full-crustal reflection profiling by Geoscience Australia, the State Geological Surveys and the AuScope infrastructure initiative. Many of these profiles provide detailed information in areas with previously sparse coverage. The new Moho map incorporates picks from over 10 000 km of reflection profile, which have been made specifically for the project.

AusMoho11 is represented in Figure 1 in terms of 0.5 × 0.5 degree pixels, together with the locations and nature of the varied observations. The new model provides a good definition of the Moho on the continent and into the surrounding oceanic areas, with only a few remote areas where information is lacking. A detailed description of the data sets used, and the construction of the model is present in Kennett *et al.* (2011).

The patterns of variation in Moho depth show a good general correspondence with the tectonic features of the continent, as noted by Clitheroe *et al.* (2000), but now reinforced by the much increased sampling across the continent particularly from recent reflection profiles. Thus, for example, the thicker crust of the Gawler and Curnamona cratons is now well constrained.

At the continental scale, it is not possible to provide a full representation of the local features such as the sharp Moho jumps (10 km or more) in central Australia that are associated with the major gravity anomalies, even though they show up clearly on reflection sections.

The oldest portions of the West Australian craton, the Pilbara craton and the northern Yilgarn craton, have Moho depths in the range from 30–35 km, whereas in the Capricorn orogen in between the cratons, Moho depths exceed 40 km. Within the Yilgarn craton greater Moho depth is associated with the younger parts of the craton in the west (as noted by Reading *et al.*, 2007). The thicker crust of the Western Yilgarn links across to Central Australia where the greatest crust thicknesses are found.

A very prominent feature in the Moho depth pattern is the strong gradient in Moho depth close to 135 E that juxtaposes 30 km crust in the Lake Eyre region against much thicker material (45 km or more).

Rather thick crust occurs in the Proterozoic parts of the North Australian craton and beneath the southern Lachlan fold belt in southeast Australia. In each case the transition from crust to mantle is

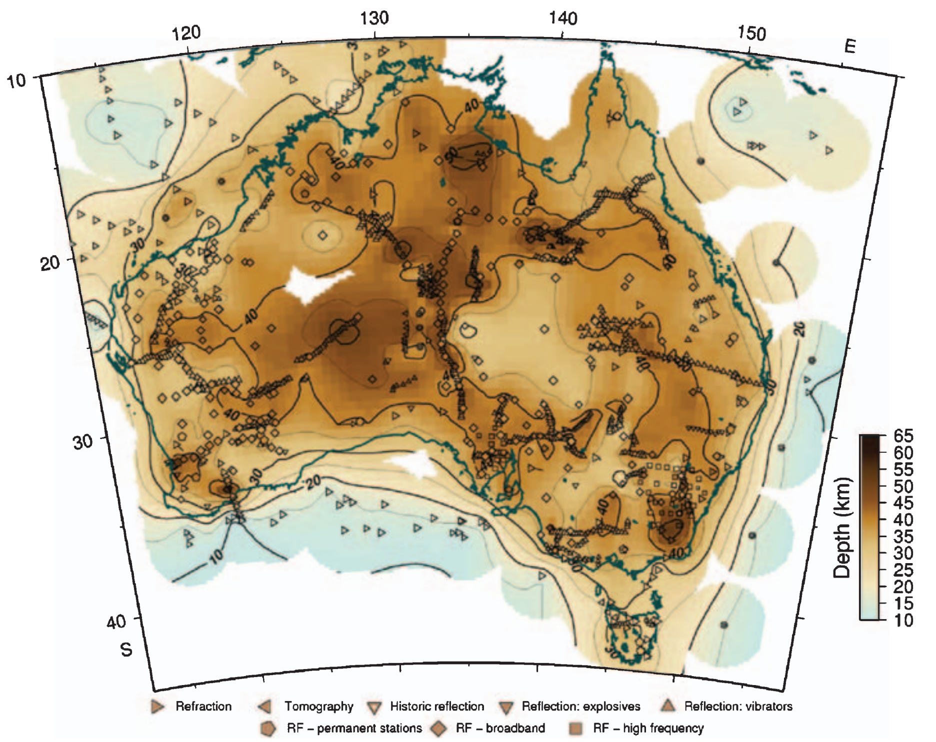

Fig. 1. *The depth to the Moho across Australia derived from a combination of seismic refraction, refraction and receiver function studies (Kennett* et al.*, 2011). The values obtained from different classes of observations are indicated by the colours attached to the distinctive symbols for each data type.*

not sharp and would be consistent with underplating.

The next step in the development of AuSREM is focussed on establishing a crustal model with definition of major crustal boundaries, seismic P and S wavespeed and density on a 0.5 × 0.5 grid. Most of the information comes from refraction experiments and receiver functions, but we are able to use the nationwide reflection profile dataset to provide structural controls.

In parallel with the crustal work, a collaborative project is underway building on prior studies of mantle structure principally based on surface wave tomography (Yoshizawa and Kennett, 2004; Fishwick *et al.*, 2008; Fichtner *et al.*, 2009), but supplemented by other results from body-wave tomography. In the mantle effective resolution is for horizontal scales around 200 km, but a smooth representation will be provided on the same 0.5 × 0.5 grid as for the crust.

A dedicated website has been established at http://rses.anu.edu.au/seismology/AuSREM where further information is presented on the AuSREM project and products such as *AusMoho11* are available for display and download.

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

Tables 1 and 2 show the continuing acquisition by the States, the Northern Territory and Geoscience Australia of new gravity, airborne magnetic and radiometric data over the Australian continent. All surveys are being managed by Geoscience Australia.

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	100% complete @ 22 Jun 11	TBA	148 – Oct 10 p23	QA/QC of final data in progress
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
North Canning 4 (Lagrange – Munro)	GSWA	Aeroquest	20 Sep 10	103 000	400 m 60 m N–S	36 680	100% complete @ 23 Jun 11	TBA	148 – Oct 10 p26	QA/QC of final data in progress
Grafton – Tenterfield	GSNSW	GPX	16 Jun 11	100 000	250 m 60 m E–W	23 000	100% complete @ 6 Nov 11	TBA	151 – Apr 11 p16	TBA
West Kimberley	GSWA	Aeroquest	29 Jun 11	134 000	800 m 60 m N–S Charnley: 200 m 50 m N–S	42 000	77.0% complete @ 9 Nov 11	TBA	150 – Feb 11 p20	TBA
Perth Basin North (Perth Basin 1)	GSWA	Fugro	11 Jun 11	96 000	400 m 60 m E–W	30 000	63.2% complete @ 6 Nov 11	TBA	150 – Feb 11 p20	TBA
Perth Basin South (Perth Basin 2)	GSWA	Fugro	22 Mar 11	88 000	400 m 60 m E–W	27 500	66.2% complete @ 6 Nov 11	TBA	150 – Feb 11 p20	TBA
Murgoo (Murchison 1)	GSWA	Thomson	28 Feb 11	128 000	200 m 50 m E–W	21 250	91.2% complete @ 6 Nov 11	TBA	150 – Feb 11 p20	TBA
Perenjori (Murchison 2)	GSWA	GPX	21 Oct 11	120 000	200 m 50 m E–W	20 000	19.4% complete @ 6 Nov 2011	TBA	150 – Feb 11 p21	TBA
South Pilbara	GSWA	GPX	TBA	136 000	400 m 60 m N–S	42 500	TBA	TBA	150 – Feb 11 p21	Expected to commence March 2012
Carnarvon Basin North (Carnarvon Basin 1)	GSWA	GPX	24 Jul 11	104 000	400 m 60 m E–W	32 500	100% complete @ 20 Oct 11	TBA	150 – Feb 11 p21	TBA
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 January 2012
Moora (South West 1)	GSWA	Aeroquest	13 Jun 11	128 000	200 m 50 m E–W	21 250	65.2% complete @ 1 Nov 11	TBA	150 – Feb 11 p22	TBA
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 January 2012
Cape Leeuwin – Collie (South West 3)	GSWA	Fugro	25 Mar 11	105 000	200/400 m 50/60 m E–W	25 000	75.8% complete @ 6 Nov 11	TBA	150 – Feb 11 p22	TBA
Mt Barker (South West 4)	GSWA	GPX	24 Apr 11	120 000	200 m 50 m N–S	20 000	12.7% complete @ 18 Sep 11	TBA	150 – Feb 11 p22	Survey on hold until January 2012

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
Galilee	GSQ	Aeroquest	11 Aug 11	125 959	400 m 80 m E–W	44 530	39.6% complete @ 6 Nov 11	TBA	151 – Apr 11 p15	TBA
Thomson West	GSQ	Thomson	14 May 11	146 000	400 m 80 m E–W	52 170	66.3% complete at 6 Nov 11	TBA	151 – Apr 11 p15	TBA
Thomson East	GSQ	Thomson	14 May 11	131 100	400 m 80 m E–W	46 730	66.3% complete at 6 Nov 11	TBA	151 – Apr 11 p16	TBA
Thomson Extension	GSQ	Aeroquest	22 Jun 11	47 777	400 m 80 m E–W	16 400	100% complete @ 10 Aug 11	TBA	151 – Apr 11 p16	QA/QC of final data in progress

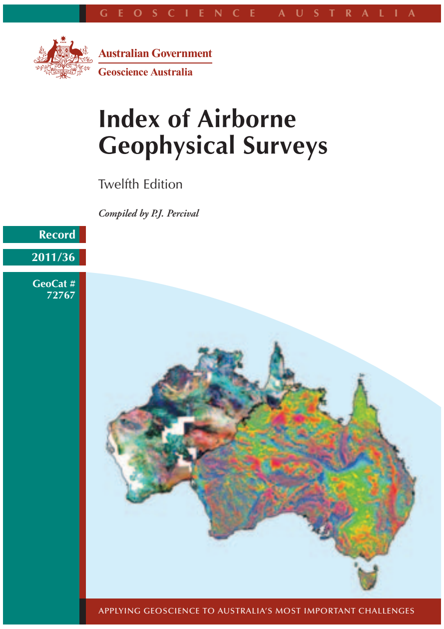
TBA, to be advised.

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
Galilee	GSQ	IMT	3 May 11	6400	2.5 km regular	102 600	100% complete @ 10 Jul 11	October 2011	151 – Apr 11 p15	25 October 2011
Thomson	GSQ	Daishsat	1 Apr 11	7670	2.5 km regular	121 700	100% complete @ 30 Jun 11	TBA	151 – Apr 11 p15	QA/QC of final data in progress
Peak Hill – Collier	GSWA	Daishsat	29 Jul 11	9100	2.5 km regular	56 140	51.0% complete @ 6 Nov 11	TBA	153 – Aug 11 p18	TBA
Kimberley Road Traverses	GSWA	Daishsat	8 Aug 11	7560	400 m station spacing along 2700 km of gazetted roads	N/A	100% complete @ 26 Sep 11	TBA	153 – Aug 11 p20	TBA
Eucla Basin SW	GSWA	Atlas Geophysics	TBA	3798	2.5 km regular	23 030	TBA	TBA	154 – Oct 11 p23	TBA
Eucla Central	GSWA	Atlas Geophysics	TBA	5704	2.5 km regular	36 100	TBA	TBA	154 – Oct 11 p23	TBA
Eucla Basin East	GSWA	Atlas Geophysics	31 Oct 11	5201	2.5 km regular	31 340	24% complete @ 6 Nov 11	TBA	154 – Oct 11 p23	TBA

TBA, to be advised.

GA releases 12th edition of the Index of Airborne Geophysical Surveys and Index Maps



The *Index of Airborne Geophysical Surveys (Twelfth Edition)*, Geoscience Australia Record 2011/36, was released by Geoscience Australia on 14 October 2011. The new edition, which is available for free download from Geoscience Australia's website, is the latest compilation of metadata of Australian open file government airborne surveys and supersedes the previous 11th edition (May 2010). The Index includes specifications of approximately 1080 surveys conducted between 1951 and 2011, which comprise more than 32.8 million line km of mainly total magnetic intensity, gamma-ray spectrometric and land elevation data. Specifications for each survey are presented in tabular format, with four surveys per page and arranged in numerical order, based on assigned Geoscience Australia Project Numbers.

Clients can quickly identify airborne surveys of interest and obtain the relevant metadata by using two lookup tables:

- a table listing survey names in alphabetical order, with corresponding Geoscience Australia Project Numbers; and
- a table listing 1:250 000 map sheet names in alphabetical order, along with Geoscience Australia Project Numbers of surveys located on each map sheet.

Also released are two maps: the 2011 edition of the aeromagnetic and gamma-ray survey index maps, which indicate the standard of data coverage (based on survey line spacing) over Australia in relation to 1:250 000 map sheets. Areas covered by surveys conducted by the States during 2011–12 are also shown on these maps.

Further information or copies of the record and maps in PDF format can be obtained from Geoscience Australia's free download page: http://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=72767.

For more information contact Peter Percival (Email: peter.percival@ga.gov.au or Ph: +61 2 6249 9578).

Shale gas in Australia: a great opportunity comes with significant challenges

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Introduction

The term 'shale gas' is misleading as it includes gas hosted in tight siltstone, sandstone or limestone reservoirs, as well as shales. These non-shale reservoirs are always in close spatial association with the organic rich source rock, often being interbedded with it. It is probably more correct to use the term tight gas; however, the current usage is likely to persist.

Australia could have shale gas resources several times bigger than the existing conventional gas resource base, which is currently estimated at approximately 5300 BCM (190 TCF) by Geoscience Australia (GSA, 2011). The Australian Government currently has no estimate of potential shale gas resources. The US Department of Energy (EIA, 2011) estimated Australian shale gas resources to be 400 TCF. The quantum of this estimate is supported by an Australian study conducted by Advanced Well Technologies (AWT) in conjunction with DSWPET, which estimates resources of 600 TCF. Therefore, in the climate of:

- diminishing Australian self-sufficiency in liquid hydrocarbons,
- the rising cost of offshore gas,
- the worldwide push for carbon abatement, and
- the presence of very large Asian growth economies hungry for gas resources,

there appears to be a real opportunity for large scale development of Australian shale gas resources.

While there are significant technical differences between the shale gas plays in the USA and Australia, it is too early to tell if the technical differences are showstoppers. There are significant differences in the commercial landscape also. The lack of capacity in Australia has led to much higher costs for drilling and fracture stimulation than in the USA. The size of the domestic gas market is much greater in the USA and its existing infrastructure allows for production to come onstream quickly. In Australia this infrastructure is not present in most areas and the domestic market cannot support another large gas development.

Despite these differences, the author's analysis of the current state of the Australian shale gas industry sees no real showstoppers to its development. Similar technical and environmental hurdles have been overcome in the USA. Also extractive industries in Australia such as iron ore and coal seam gas have overcome similar commercial/capacity issues. The gas markets in Asia seem to want more and more gas supporting an industry based on export of gas rather than domestic demand.

Perhaps the greatest challenge this opportunity faces is political. There is a public, hence political, perception that all gas sources have the same 'gasland' problems. These perceptions can be changed. First, the petroleum industry and the Governments need to understand the potential size of the gas resource and the possible strategic opportunity for Australia. Also, these parties need to recognise that the shale gas resources are often located away from areas of high social and environmental impact. Once these factors are understood by these parties, factual information about the environmental impact of shale gas plays in comparison with coal seam methane (CSM) and other alternative gas supplies can be factored into gas resource planning.

It is noted that recent efforts have been made by WA operators and the Australian Petroleum Production and Exploration Association (APPEA) to develop a code of practice for fracture stimulation.

What is shale gas?

Shale gas is defined for this article as natural gas trapped in fine grained sedimentary rocks that contain significant amounts of source material, which has generated the gas and stored some of it. The natural gas can contain significant quantities of liquid hydrocarbons. Shale gas reservoirs are essentially source pods that also store natural gas.

The reservoir sections may be homogenous or have shales interlaminated with other lithologies such as sandstones and or limestones and siltstones. All shale gas reservoirs have very low permeability. For example, the Barnett Shale in the USA is a highly silicious, organic rich shale with an average permeability of approximately 4 nanodarcies. Natural gas is stored in these reservoirs as both sorbed and free gas.

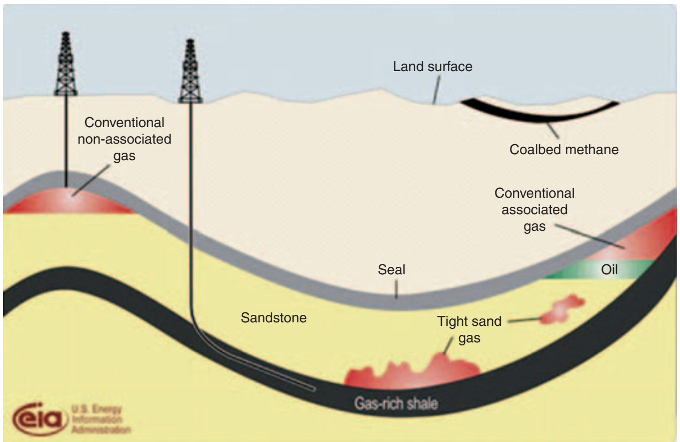

Fig. 1. *Habitat of shale gas plays.*

As shale gas plays are sourced by the reservoirs themselves and hydrocarbon migration plays little to no role in the accumulation process, the size and extent of these plays can be significantly greater than most conventional reservoir plays. Shale gas accumulations can be described as continuous gas accumulations as defined by the United States Geological Service (USGS) in their regional Resource Assessments (Pollastro, 2007). Figure 1 is a representation of one type of hydrocarbon system with a shale gas accumulation and indicates that the continuous accumulation can cover a significant proportion of a sedimentary basin.

Lessons from the US shale gas revolution

Perhaps the first lesson to be learnt from the shale gas industry in the USA is the size of the gas reserves that have been discovered. It is estimated by INTEK Inc. (2010) that reserves of the top seven shale gas plays in the USA could be greater than 700 TCF. The areal extent of the Barnett Shale play in Texas is estimated to be 10 000 km^2 (2.5 million acres) and contains 26 TCF of recoverable gas (USGS estimate), while the Marcellus shale in eastern North Amercia covers 140 000 km^2 (34 million acres) and could recover as much as 84 TCF of gas (USGS, 2011).

The shale gas revolution in the USA has changed the gas industry there greatly, but this revolution came about through innovation and persistence, not following the conventional rule book. The application of innovative completion techniques, horizontal drilling, microseismic and massive fracture stimulation, has unlocked very large volumes of gas. This did not happen overnight and the successful innovations were not pioneered by the major oil companies. The cracking of the code for the Barnett shale took approximately 20 years of constant trial by George Mitchell's team at Mitchell Energy to overcome on a consistent basis a multitude of 'problems'. To quote Dan Steward, the author of *The Barnett Shale Play* (Steward, 2007),

> *At Mitchell, and within the industry in general we've learned that through an integration of technologies and disciplines many of these obstacles can be overcome, and I believe will continue to be overcome in the future. The play was, and still is, dependant on intelligent, open minded, energetic professionals from all specialities.*

So perhaps the second lesson to be learnt from the US experience is that commercial success may not come easily and that it won't come unless we are prepared to innovate and experiment.

According to many of the participants in the US industry, another important lesson coming out of the US experience is that no two plays are alike and that while the drilling and completion techniques may look similar, in detail they can be significantly different. With that in mind, the following are considered common factors for successful shale gas plays in the USA:

- reservoir thickness is greater than 30 m (100 ft);
- target zones are well bounded mechanically for fracture stimulation;
- thermal maturity of the source material is in the dry and wet gas windows;
- average gas content is greater than 3.12 m^3/tonne (100 scf/tonne);

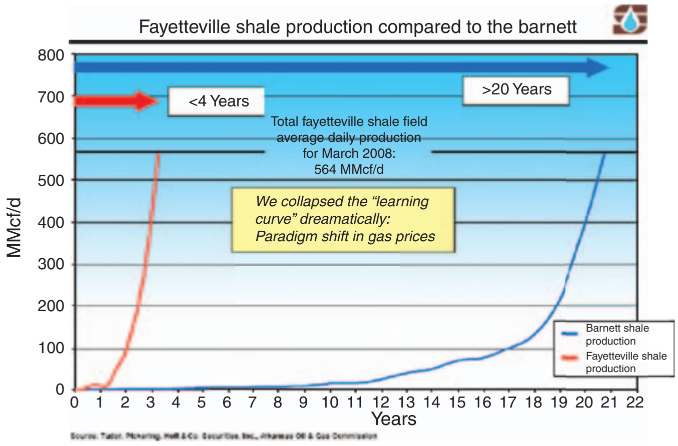

Fig. 2. *Comparison of learning curves in US shale gas plays (from South West Energy website).*

- clay content is less than 40%;
- the rock is brittle;
- the rock fabric and stress regime are aligned to enhance fracture density and connectivity;
- good lateral continuity in commercial reservoir conditions; and
- access to infrastructure and drilling and completion capacity.

It is believed there will be similar requirements for success in Australia.

Following the breakthroughs in commercialisation of the Barnett Shale play, the time between identification of the resource and the establishment of the commercial drilling and completion techniques in other shale plays, such as the Fayetteville and the Haynesville, has occurred much faster. According to South West Energy their solution to the commercialisation of the Fayetteville play took just five years (see Figure 2). So while each play represents an individual challenge to commercialise, the learning period can be successfully reduced by experience gained from precedents in other shale plays.

The success of the shale gas plays in the USA is also attributed to development of a manufacturing model for development. The development of the shale gas play in this mode can drive down cost considerably but involves the utilisation of large amounts of specialised machinery and people (see Figure 3).

It is not within the scope of this paper to outline all the lessons of the shale gas experience in the USA and certainly there are important ones not discussed here. However, the clear message

Fig. 3. *Fracture stimulation of a shale gas well in the USA.*

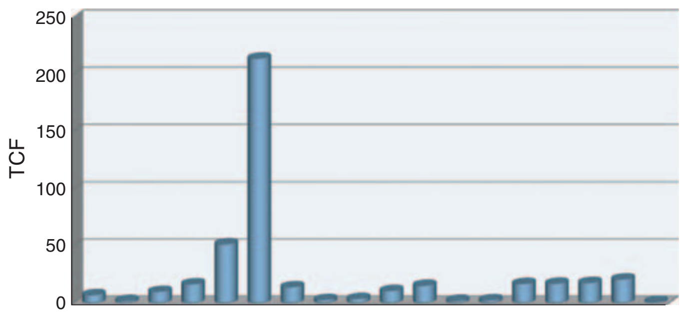

Fig. 4. *Size of potential shale gas plays in Australia (from The Australian Shale Gas Atlas, 2010). This study showed that Australia has shale gas plays ranging in size from 700 km² (175 000 acres) to 200 000 km² (49 421 000 acres) widely scattered across the Australian continent. They range in age from PaleoProterozoic (1600+ ma) to Cretaceous (150 ma).*

is that if a company is prepared to be innovative and patient the reward can be very large. This is demonstrated by the billions of dollars paid by the major petroleum exploration and production companies to acquire acreage in US shale plays established by the early movers such as XTO and Chesapeake.

So in summary, the lessons from the USA are that the key ingredients for success are not all related to just finding a gas saturated shale, but that innovation, patience, industrial capacity, and capital are also necessary.

The shale gas opportunity in Australia: current resource estimates

The US Department of Energy has estimated that Australia may have as much as 396 TCF of recoverable shale gas, ranking it fifth behind China (1275 TCF), the USA (862 TCF), Argentina (774 TCF), Mexico (681 TCF) and South Africa (485 TCF).

A separate study, *The Australian Shale Gas Atlas* by AWT International and DSWPET (2011), has identified 20 potential shale gas plays (see Figure 4) with an estimated recoverable resource of 603 TCF gas and 27 billion BBL oil. The estimated size and number of potential plays in Australia is roughly equivalent to that present in the US where 33 plays have been discovered with an estimated resource of 862 TCF.

Differences between US shale gas and Australian shale gas

While the size and distribution of the potential resource describes a very large opportunity for gas development in Australia, there are some significant differences between the USA condition and that in Australia.

The differences between the Australian and US shale gas plays that can be identified at this time are both technical and commercial and include the following:

1. Source material

While some of the older plays in Australia have source material that is marine (Type I and II) in origin, similar to all the USA plays, Australia is rich in non-marine source rocks (Type II and III). Little is known about whether this will enhance or reduce the gas storage capacity and or fraccability when compared with the marine shale gas plays in the USA.

2. Stress regime

The dominant stress regime in onshore Australian basins (strike slip) is different from that dominant in the USA (normal). As with the source material it is yet unknown whether this will be a blessing, have no effect, or be a curse.

3. Industrial capacity

Currently there is very little drilling or fracture stimulation capacity available in Australia capable of executing the types of programmes used for shale gas in the USA. Presently one large scale frac would consume all the shale frac capability for Halliburton in Australia. Similarly, the number of rigs capable of long horizontal wells at depth is very limited. This lack of capacity means that presently the costs of appraisal are much higher than in the US.

4. Access to infrastructure

The large domestic market for gas in the US is fed by a very large distribution system that covers most areas. As new production comes on it can access this infrastructure quickly and relatively cheaply. This is obviously not the case in Australia.

There is no doubt that as the shale gas plays in Australia mature more differences will become apparent.

Challenges to shale gas play commerciality in Australia

There are significant technical, commercial and political challenges facing the development of shale gas plays in Australia.

Presently there is not enough information available on the shale plays in Australia to be certain what the technical challenges will be. Suffice to say there are likely to be many. The most likely technical challenges are considered to be:

- finding the areas with sufficient gas storage capacity; and
- stress conditions in relation to horizontal drilling and fraccing.

Based on the experience of the USA shale gas industry, technology should be able to overcome these likely challenges, but only time will tell.

The commercial hurdles are related to drilling and fracture stimulation capacity. Currently Halliburton has one shale frac spread available in the whole of Australia. There is a similar shortage of drilling rigs and experienced people who can design and execute the drilling and completion programmes required. In the current phase of exploration in Australia, capacity is not as critical as for the appraisal and development stages. The creation of a manufacturing mode of development is vital to reduce unit costs and provide the steep production ramp up required to maintain commerciality. Again experience, this time with the Australian coal seam gas industry, indicates this capacity can be created in Australia if the demand requires it.

Currently there is a significant ground swell of anti-shale gas development that is present in many parts of the world. Often, and wrongly, shale gas development is seen as the same as the coal seam gas development with the same risks. Such is the concern that presently there is a moratorium on shale gas development in some USA states and in France and South Africa.

Risks attributed by the public to shale gas development, whether correct or not, include:

- chemicals that are used in fraccing may be dangerous and might contaminate groundwater;
- poorly cased wells allow gas to escape into underground aquifers used for human or agricultural purposes;
- waste water returning to the surface during production can be contaminated with salt and radon and may pollute land or streams;
- water used for fraccing depletes a scarce resource;
- exploitation for shale gas can damage amenity and landscape value and competes for agricultural or cropping land; and
- hydraulic stimulation might trigger earthquakes.

It is the author's opinion that all these 'risks' can either be shown to be unfounded or managed and a successful development plan executed. However, until the case is put to the public in a way that can be understood, there will be significant roadblocks to some developments.

An effort initiated by WA operators and supported by APPEA to develop a Code of Practice is a significant and important step toward achieving this (SPE News, December 2011).

Acknowledgements

The author thanks AWT for permission to use parts of *The Australian Shale Gas Atlas* in this paper.

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The production rate variability problem with shale reservoirs: what we know and what we don't know

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Introduction

Our traditional view of shales is that they are usually seals and sometimes source rocks – but never reservoir rocks. But recent improvements in drilling and completion technologies have made production of oil and gas from shales possible. Fracture stimulation treatments can provide the missing reservoir permeability and horizontal wells allow engineers to cluster many fracture stimulation treatments in the somewhat rare shale intervals that make good oil and gas development targets. Shale exploration and development has suddenly become big business; it has added more than 100 years of natural gas supplies in North America. North American LNG import terminals are now being turned into export terminals. Nations and energy companies around the world are asking if their shales can produce oil and/or gas.

But there is an emerging issue: unexplained production variability. Urbina (2011) showed that a small percentage of the wells are producing most of the gas in the Barnett Shale, Haynesville Shale and Fayetteville Shale plays. Baihly *et al.* (2010) showed the same well-to-well productivity variations for the Barnett shale and that there is also a large productivity variation between fracture stimulation treatments within the same horizontal well bore.

Shale gas development programs using 'pattern drilling' with evenly spaced wells drilled in 'factory mode' have been very successful in lowering the development costs in this capital intensive play. Pattern drilling is based on the assumption that the reservoir is uniform in quality and productivity. But the production results quoted above show that this is not the case.

There is considerable potential value in understanding what causes this production variability and developing only the better well locations. Most North American shale gas plays are marginally economic with current gas prices. Australian shale gas plays will probably be sub-economic because our drilling costs are considerably higher than North America's. If the good well locations were predictable, then the economics of shale plays could be significantly improved. Additionally, the ability to predict the good shale well locations offers the opportunity to lower the societal impact of shale development drilling.

Many industrial and academic groups around the world are looking for the explanation(s) of shale production variability. Early in 2012 the University of Adelaide will be starting up research efforts into production variability in shale and other unconventional reservoirs: coal seam gas, tight gas and geothermal reservoirs. Those efforts will be focused on stress and natural fractures for all of the unconventional reservoirs with additional research investigating the geochemistry, stratigraphy and sedimentology of shale reservoirs.

Organisation of this article

This article is written for a general geoscience audience with little or no experience in shale reservoirs who wish to learn more about this quickly growing and very important resource. Discussed below are a number of *possible* causes of production variability in shales. Some of these ideas are rather new and not fully developed – so only time and experience will show what the truly important variables are for shale productivity. The major sections in this article discuss shale geology and geomechanics. Not covered in this article – but certainly related to production variability in shales – are the topics of completion and fracture stimulation design. This article is intended to be a brief summary of many different topics and specialists will find that some parts are sparse in detail.

Geological variability in shales

The following is a brief 'check list' of what makes a good oil or gas shale:

- *Total organic content (TOC)*: should be higher than 2%. TOC values for the 'best' shales may reach 25%.
- *Thermal maturity*: also known as vitrinite reflectance or Ro. For Ro = 0.6–0.8 kerogen will start to crack and create liquid hydrocarbons. Ro = 1.1–1.5 will generate condensate and Ro > 1.5 will generate dry gas.
- *Gas content*: determined by measuring the amount of gas that flows from a pulverised shale core sample. Can range from 40–400 scf/tonne (and higher?).
- *Thickness*: thicker shales may have more gas-in-place. Note that as a shale regionally thickens, its TOC may become lower.
- *Rock properties*: porosities of shales can range up to 15%. A low Poisson's ratio and high Young's modulus indicate that a shale has more gas, more porosity and is easier to fracture stimulate.
- *Structural integrity*: hydrocarbons can migrate out of a shale that is heavily faulted.

Variability in shales is especially confusing given the traditional view that shale is deposited in a deep-water low energy environment where the major depositional process is 'pelagic rain' of organics and clays. Little spatial variability in depositional conditions is expected with this view. But pattern-drilling results indicate a high spatial variability in production rate and recovery factor from shales. Below are some emerging ideas that could explain this variability.

Shale variability driven by sequence stratigraphy and sedimentology

We now understand that the classical thick homogeneous shales are actually comprised of stacked parasequences (Passey *et al.*, 2010). A shale parasequence may only be a metre or two thick but the organic content, porosity, and mechanical properties can change from top to bottom within a sequence. The lower part of sequences is deposited in lower energy and deeper water while the top of a sequence will be deposited closer to shorelines. This can lead to the basal portion being more organic rich with softer rock properties while the top can contain less mud and more silt (i.e. more porosity). This presents a choice when landing a horizontal well in a given sequence; going deep in the sequence may lead to better gas content, but going shallow may lead to better porosity and 'fracability'.

Shales are not just comprised of pelagic rain: spatial changes within a given shale parasequence can be driven by traditional concepts of sedimentology. Flume studies show that muds and clays can behave like coarser sedimentary particles and move along the sea floor as hyperpycnal and/or turbidity current flows (Mulder *et al.*, 2003; Mulder and Chapron, 2011). And it is not just deep water shales that make good 'shale' reservoirs; for example, the Barnett 'Shale' is actually a siltstone. Siltier shales present the risk of lower TOC, but the advantage of better porosity, fracability and deliverability. And with an increase in grain size comes higher energy depositional environments and the associated spatial variability.

As discussed above, shale properties can vary *vertically* within a sequence and certainly between different sequences. *Spatial* variations within a single shale are predicted if the concepts sedimentologists use for coarser grained sediments (turbidity currents and resultant channels and fans) are applied to shales.

High frequency variation in TOC driven by clay type

Kennedy and Wagner (2011) point out that TOC can vary rapidly vertically within a shale. They point out that these high frequency variations are related to clay types; high TOC is associated with smectite and low TOC is associated with illite. They propose that the large mineral surface area of smectite allows it to adsorb the very small organic compounds that result from the bacterial break down of organics. Illite does not have much mineral surface area and thus cannot adsorb organic compounds. These organic compounds concentrated by the smectite may be the pre-cursors to kerogen. Kennedy also proposes that the clay type variations are depositional, not diagenetic, and controlled by climate conditions and clay source provenance.

Porosity types in shales: are spatial changes expected in pore types?

Hydrocarbons can be stored in shales via adsorption, absorption and in conventional pores. Absorption occurs when methane dissolves into the water in shales. Adsorption occurs when methane is densely packed into organic particles (and smectite clays?). Absorption and adsorption will work for small hydrocarbon molecules – i.e. methane – but storage of liquid hydrocarbons in shales almost certainly requires conventional pores.

Our understanding of the different pore types in shales is evolving very quickly and is driven by new microimaging technologies such as argon-ion milling, field emission scanning electron microscopy, and micro 3D CT imaging. These technologies are showing that there can be pores in the kerogen in shales (Walls and Sinclair, 2011), although there are questions on how connected these pores are and thus what sort of permeability they can provide. Slatt and O'Brien (2011) discuss other types of porosity in shales; porous floccules, organopores, fecal pellets, fossil fragments, intraparticle grains and pores, and microchannels and microfractures. In my opinion, the most promising of these is porous floccules. Shales have a 'fabric' that is predominantly caused by stacked parallel clay platelets. Slatt's porous floccules have a different sort of fabric that occurs when shale platelets connect end-to-end to form ring structures. Their pores (centre of the ring structure) are large and can be connected to other pores – i.e. provide permeability pathways.

Important questions about these floccules are:
- How and when do they form?
- Why do they not collapse with burial?
- How common are they in the sub-surface?
- Can they provide the required permeability network to drain adjacent tighter shale fabrics?

Slatt and other authors speculate that floccules are related to turbidity flow in shales, but others speculate that floccules are built by nanobacteria. If flocculated shale porosity is present in sufficient amounts, it would be quite helpful in allowing hydrocarbons to drain from shales. And if that flocculated porosity is controlled by turbidity flows, it could lead to the observed highly variable spatial distribution of shale productivity.

Geomechanical variability: rock properties, stress and natural fractures

Local stress and fracture closure pressure

Shales require fracture stimulation before they can flow hydrocarbons (if present). One of the critical parameters in a frac job is the fracture closure pressure, which is the stress that frac fluids must overcome if they are to fracture the reservoir. Let's consider how the fracture closure pressure might change in the reservoir. The simplest expression for fracture closure pressure is[1]:

$$P_c = \frac{PR}{(1-PR)}\,\sigma_{vert} + \sigma_{h-tect}$$

where P_c = fracture closure pressure, PR = Poisson's ratio, σ_{vert} = vertical stress = integrated density log from surface to this depth, and σ_{h-tect} = local minimum horizontal tectonic stress.

Propagating frac fluids will naturally flow and break into those lithologies and/or regions where the fracture closure pressure is lower. From the above equation, we see that lithologies with lower Poisson's ratio will have a lower fracture closure pressure.

Figure 1 shows how lithology, gas saturation and Poisson's ratio vary in a vertical well with tight gas sands, gas-charged silty shales, coal and shales with little apparent gas saturation. The shale zones with both higher gas saturation (higher resistivity log) and higher porosity from silt (lower gamma log) are the target zones for shale fracture stimulation treatments. Luckily these target zones also have a lower Poisson's ratio and thus tend to take and contain a frac job. Within the red fracture stimulation target zone, siltier intervals decrease Poisson's ratio

[1]More sophisticated versions of this equation include terms that describe the effect of reservoir pore pressure, anisotropic rock properties and strain during a frac job.

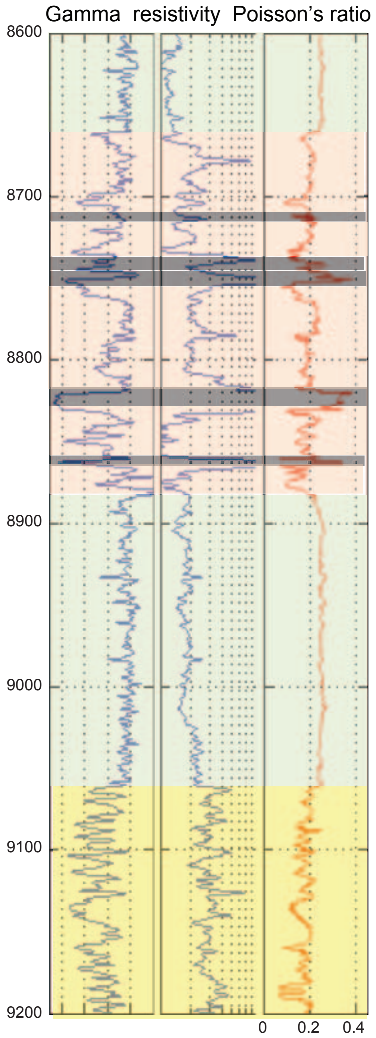

Fig. 1. *Log data for an interval containing tight gas sands (yellow), shales with little or no gas (green), coal (gray) and gassy silty shales (red). Frac jobs will tend to stay in zones with lower Poisson's ratio, i.e. yellow and red.*

while coal increases it. Silt and coal will thus change the result of a frac job (and well productivity) in ways that are difficult to model and predict. Furthermore, there is the issue of lateral changes in lithology (and Poisson's ratio) away from the well bore; if present these probably have a large impact on fracture stimulation results.

Increased quartz and carbonate can be quite helpful if it is from a *depositional* source (i.e. more porosity), but increased *diagenetic* quartz and carbonate can occlude shale porosity and hurt productivity of a frac job. Unfortunately, it is difficult to determine depositional from diagenetic quartz and carbonate from log data – and rapid lateral changes away from the well bore in this important rock property can happen in some shales (Taylor and Gawthorpe, 2003).

The above equation for fracture closure pressure includes terms for vertical and horizontal stress. The vertical stress is just the weight of the earth above the reservoir and thus will not have rapid lateral changes. However, the horizontal tectonic stress could be changing laterally, and if so, would be a major cause of production variability. Figure 2 shows one example of σ_{h-tect} varying rapidly.

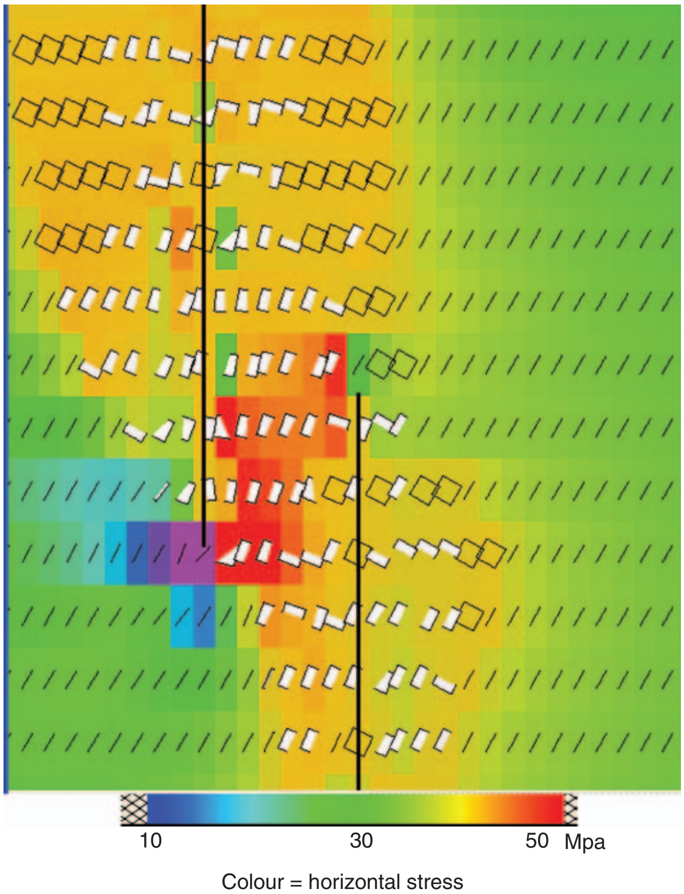

Fig. 2. *Plan view of a geomechanical model showing minimum stress (in colour) and stress orientation (lines and planes) at a fault step-over. Large black North–South lines indicate a step-over in a strike slip fault system.*

Figure 2 shows the map view of modeled[2] minimum horizontal stress in the presence of a strike-slip fault 'step-over' for shale at a depth of 2.5 km in an Australian basin. In this model, the fault has experienced strike slip movement which changes local stress – especially at the fault tips. Figure 2 models the last term in the equation above for fracture closure pressure; it averages approximately 30 MPa with swings of ±20 MPa. Compare this to how changes in lithology and Poisson's ratio impact the first term in this equation. Using frac target Poisson's ratios of 0.15 and 0.22 (see Figure 1 just beneath the coal at depth = 8750) the first term in the equation above will change between 11 and 17 MPa. This says that structure and stress can have a greater impact on fracture stimulation (and resultant production rates) than changes in lithology. Unfortunately, local stress is rarely if ever modelled in this manner as part of optimising fracture stimulation design. Instead, regional stress (obtained from sparse leak-off tests and bore-hole breakout analysis) is used as a proxy for local stress.

Shear movement on pre-existing natural fractures and microSeismic

The above model hints that pre-existing faults can have a considerable impact on local stress and thus on fracture

[2]This is a finite element model that assumes constant rock properties and constant reservoir pressure in the reservoir and allows fault strain to occur when the ratio of tangential to normal stress on a fault exceeds 0.6.

stimulation results. Das and Zoback (2011) document another mechanism by which pre-existing faults and fractures might impact a fracture stimulation treatment. This occurs when a propagating hydraulic fracture causes shear movement on a properly oriented pre-existing fault or fracture.

Das and Zoback (2011) use spectral analysis of microSeismic data recorded during frac jobs to uncover previously unnoticed low-frequency ‘events’. They call these long-period long-duration (LPLD) events and attribute them to shear movement on pre-existing natural fractures, which are seen on image log data in the treated well. These LPLD microSeismic events appear to be very similar in character to traditional earthquake seismology records of large shear tectonic events. Shear movement may be quite important during a frac job as it can create fracture and fault permeability without placing frac proppant in the sheared fault[3].

While Das and Zoback (2011) hint that pre-existing fractures are helpful for fracture stimulation success, other authors point out problems associated with them. Roth (2011) shows that frac stimulation treatments can break into larger faults in the lower Barnett Shale and allow the underlying Ellenburger aquifer to kill the well with an influx of water. A different combination of fractures and stress conspire to give poor frac results in a case presented by Johnson *et al.* (2010). Fracture stimulation treatments almost always create new fractures oriented in the direction of maximum horizontal stress. Johnson attempts to use hydraulic fractures oriented by stress to connect up known pre-existing fractures and create a larger drainage area. Unfortunately in that case, the fracture is initiated in and remains constrained to a single pre-existing fracture and never connects up to other pre-existing fractures. This undesirable hydraulic fracture containment/localisation might have been prevented by ensuring that the frac treatment was not initiated in the pre-existing fracture.

How common are these pre-existing faults and fractures?

The conclusion drawn above is that pre-existing fractures and/or faults can help or hinder fracture stimulation success. And thus a key to optimising fracture stimulation treatments would be to locate wells and frac stages based on the location of faults and fractures. Faults and fractures can been seen on image logs, but these are not normally run on horizontal shale wells due to cost issues – and even if they are run, they will only see faults at the well bore. Even with an image log, it is quite possible (likely?) that an induced hydraulic fracture will grow away from the well bore and be influenced by a pre-existing fault that does not extend to the well bore.

Another method of mapping faults and fractures is to use seismic, which will never have the resolution of logs, but seismic analysis can provide information away from the well-bore and be performed pre-drill. The seismic attribute that offers the most promise for mapping small scale faults and fractures is curvature analysis (Chopra and Marfurt, 2007). My personal opinion is that assuming that subtle seismic curvature signatures are caused by faults or fractures is fraught with pitfalls. That said, Figure 3 from Backe *et al.* (2011) shows a curvature attribute from a Cooper Basin shale whose pattern is

[3]This assumes that the rock properties and fault asperities are sufficient to keep the sheared fault open against the normal stress against that fault, which is another geomechanical control on shale production rates.

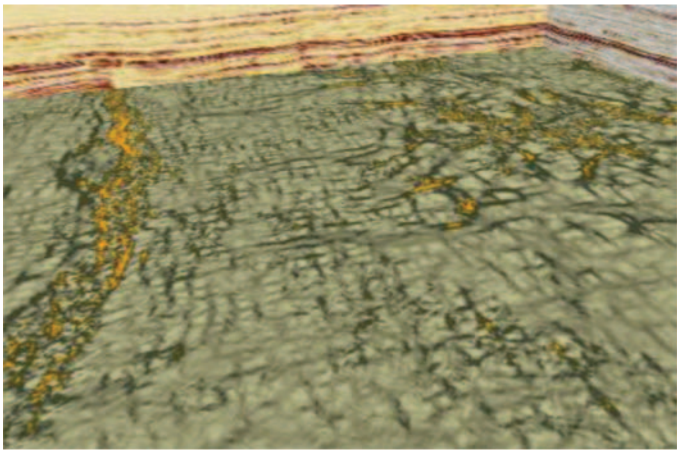

Fig. 3. *Seismic curvature attribute for a 3D seismic cube extracted on the top of a shale reservoir. The dark green cross-hatched pattern is the same pattern expected from a conjugate set of fractures.*

difficult to explain except by invoking a conjugate set of natural faults and/or fractures. If this pattern is caused by faults or fractures, then a pattern drilled shale development program here would have an occasional well that intersects and possibly shear stimulates a pre-existing fault/fracture (leading to a high rate well), but a majority of the wells would miss the pre-existing faults and fractures.

Fractures normally do not have the vertical offset that is required for them to be detectable on seismic. Why might the ‘fractures’ in Figure 3 show up on seismic data? One possible answer is that the Cooper Basin’s highly differential stress regime can cause those fractures to ‘pop’ vertically and thus become seismically visible faults. Figure 3 is actually from a large gas field with many wells and we are currently using that well control in an attempt to validate and understand what causes this pattern.

Which pre-existing faults/fractures might be critically stressed and ready to shear?

Not all pre-existing faults and fractures can shear during a frac job; some of them are ‘critically stressed’ and ready to move as soon as the frac fluids start to inflate that fault and lower normal stress, but others are locked up and will be difficult or impossible to shear stimulate. Zoback (2007) predicts that faults will shear when the ratio of tangential to normal stress on that fault is approximately 0.6 or greater (this will vary with different lithologies). These normal and tangential stresses can be a complicated function of depth of burial, Poisson’s ratio, reservoir pressure, local horizontal stress, frac treatment pressure and leak-off. Figure 4 shows two different numerical geomechanical models of shear displacement on a conjugate joint set. On the left model the East-West faults are ‘locked-up’. The model on the right has a slightly different external stress orientation and that different orientation allows the East–West faults to shear.

Summary and conclusions

This article has briefly discussed some of the geological and geomechanical phenomena that might cause productivity variations in oil shale and gas shale reservoirs. Which phenomena are important? That will probably depend on the shale in question and will require more research and more data

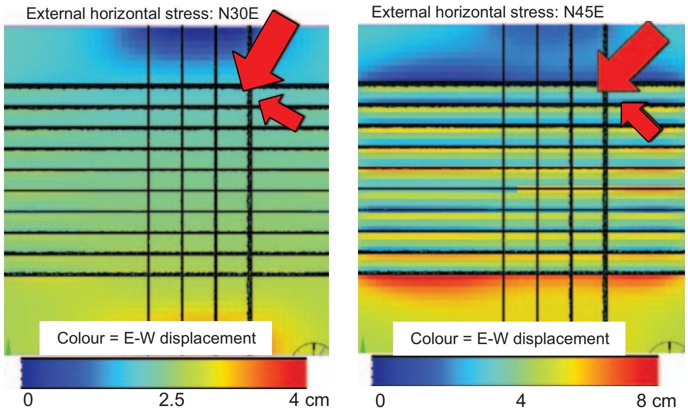

Fig. 4. *Plan view of numerical model of shear displacement on faults. Black lines are pre-existing faults. Colour = East–West shear displacement on those faults. Maximum horizontal stress for the left model is oriented N30E, and the East-West faults do not move (indicated by a lack of colour change at faults). Maximum horizontal stress for the right model is N45E and the East–West faults do move as indicated by the colour changes. Model is built for a shale reservoir in an Australian basin and assumes a frac job can raise pressure in the faults by 10 MPa. Leak-off effects are ignored.*

(i.e. expensive cores, image logs, and production logging surveys) to resolve.

A very useful way to look at productivity variations in shale reservoirs is to use the classical petroleum systems analysis approach. Petroleum systems analysis says that all of the following must be working before a conventional reservoir can contain and produce hydrocarbons: structural closure, seal, reservoir, generation of hydrocarbons in a nearby source rock, and migration of hydrocarbons from the source into the target reservoir. For shale reservoirs, similar aspects must still be working but with some important changes; migration of hydrocarbons out of the source rock must not happen (at least not to all of the hydrocarbons generated) and permeability needs to be successfully created with the fracture stimulation program. The important concept is that if just one of these fail (source, reservoir, seal etc) then the reservoir will not successfully contain and produce hydrocarbons. Applying a petroleum systems approach to shale reservoirs makes us realise that there is not a single silver bullet that can explain production variability; instead we need to use a systematic evaluation of a number of equally important criteria.

One important clue as to which phenomena are important may be contained in the spatial scale of shale production variability. Baihly et. al (2010) show that shale productivity repeatedly turns on and off in horizontal well perforations just 40 m apart. It may be easier to explain radical spatial variability with geomechanics (hydraulic fractures interacting with pre-existing faults) than with changes in TOC or porosity or rock mechanical properties. Note that a fracture stimulation treatment should grow vertically several tens of metres – or over several adjacent parasequences. This would tend to minimise the impact of geological variations. I find it easy to imagine that regularly spaced perforations and frac stimulation treatments in a horizontal well would almost randomly find and shear a critically stressed pre-existing fault – and lead to a large increase in productivity of a few lucky intervals.

In closing, I note that while Australia has a number of possible shale gas and shale oil plays under evaluation, all of them face tougher economic hurdles than comparable shales in North America due to our higher drilling and fracture stimulation costs. If Australia's shales are going to be economically produced, either our cost must be driven lower and/or we need to successfully predict and develop the highly productive well locations.

Acknowledgements

I would like to thank my co-workers at the University of Adelaide who have contributed to the ideas and concepts expressed above: Martin Kennedy, Guillaume Backe, Ros King, Mark Tingay and Hani Khair. I would also like to acknowledge Steve Begg at the Australian School of Petroleum and Stephen Grano at the Institute of Energy and Minerals Research for their support and advice in starting up a research effort into conventional reservoirs.

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Eagle Ford Shale exploration: integrated regional geology, seismic and microseismic analysis

Galen Treadgold

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Introduction

The Eagle Ford Shale in South Texas (Figure 1) is one of the more exciting shale plays in the United States at the current time. Recently published reports of well tests describe initial gas well rates exceeding 17 mmcf/d and initial oil well rates in excess of 2500 bopd. Acreage lease rates continue to climb as additional positive results come from drilling within the trend. A key issue for the exploration companies is finding where to focus acreage acquisition and optimise drilling plans for optimal gas and oil recovery. This paper first considers the geologic context of the Eagle Ford and then examines the geologic drivers for locating economic producing wells. With improved understanding of local rock properties, focus shifts to geophysical techniques, in particular, the use of 3D seismic data and microseismic data from frac monitoring to build an understanding of a successful unconventional play.

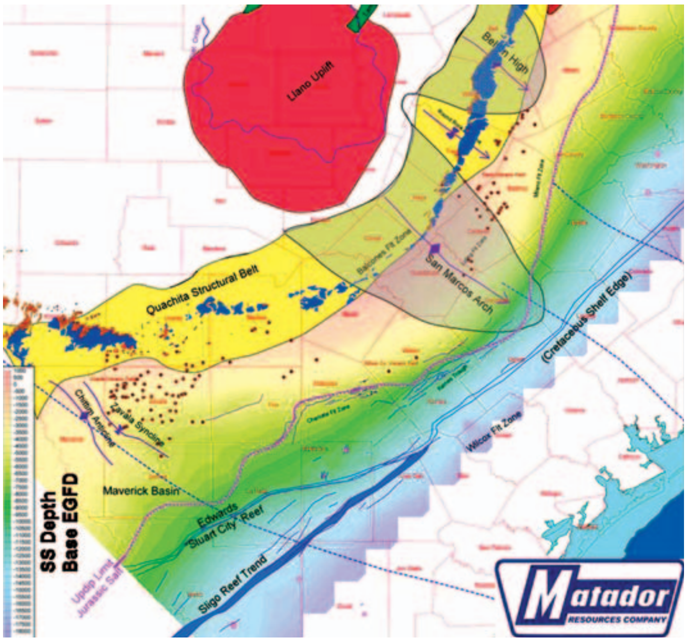


Fig. 1. *Tectonic setting of the Eagle Ford with post 2008 Eagle Ford activity.*

Since the first publicly reported, significant gas shale test by Petrohawk in the Dora Martin #1 on 16 October 2008 (9.7 mmcfg/d), the play has expanded to now cover ~11 000 square miles (~7 mmac). Over 1500 wells are believed to have either been drilled or permitted in the play. What has emerged is a well defined down dip gas play that transitions rapidly up dip into less well defined wet gas and oil fairways. While there are several large independents who have pioneered the play, the extent of the play area has provided ample opportunity for additional small companies to join the exploration effort. The resulting high level of activity has created a rapidly expanding need for viable tools to high-grade areas to reduce economic risk.

Geology

The Upper Cretaceous (Cenomanian to Turonian) age Eagle Ford Shale (Figure 2) was deposited during an extreme marine high-stand that saw marine incursion deep within the North American continent. The depositional framework in the south Texas area resulted in the accumulation of varying thicknesses of deep water, organic rich marine shales. The form of this marine environment was largely controlled by the interaction of basement zones of weakness, underlying carbonate paleogeography, salt tectonics, and eustatic sea level. Deeper stratigraphic successions impacting the paleogeography are the Louann salt, and the paleo reef margin deposition of the Sligo and the Edwards (Stuart City) formations. Tectonically, the local area was relatively quiet with small, but significant gravitational sliding in a south-easterly direction towards what is now the modern Gulf of Mexico. A southern bounding low, the Bisbee–Chihuahua trough was rapidly deepening. Additionally, intrusive and extrusive volcanics occurred in the north and western parts of the basin.

Lowstands preceding and during deposition generated a regional flooring carbonate horizon (the Buda limestone) and an internal carbonate marker (the Kamp Ranch member) that divides the organically rich basal section (lower Eagle Ford or Britton/Pepper Shale) from the overlying leaner and more calcareous member (upper Eagle Ford or Acadia Park). The calcareous source section is down lapped unconformably by the overlying prograding Austin Chalk formation.

Rock property measurements: seismic and wireline

Rock properties of this succession are well suited for seismic analysis. The underlying Buda, a tight, massive limestone, is present regionally in most of the play area and ranges from 40 to 160 ft in thickness. As one would predict, seismic impedance

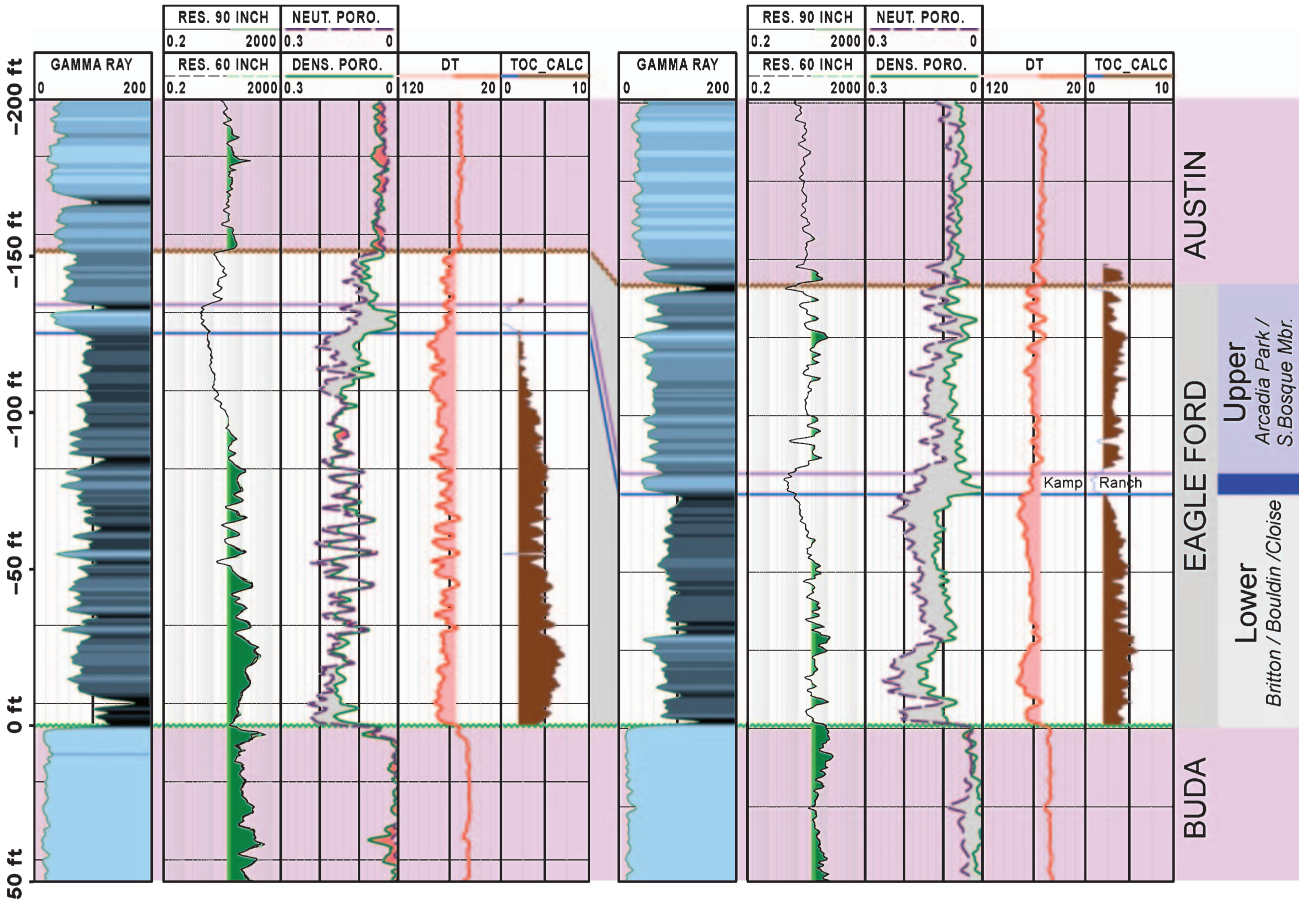


Fig. 2. *Stratigraphic variations within the Eagle Ford. Organics and the associated porosity generally increase toward the base of the section above a tight Buda limestone.*

values for this section are quite consistent and provide an excellent point of calibration for seismic inversion (converting the seismic wiggles into rock property predictions). Immediately above the Buda in the Eagle Ford the organic shales are often the richest (4–7% total organic carbon (TOC)) and most porous (7–15%) of the target interval. Impedance changes in the Eagle Ford commonly relate to changes in TOC and/or porosity. The top of the Eagle Ford is somewhat less well defined as the section grades into the Austin Chalk. The gradual decrease of porosity and organic content at this upper interface generally is not a clear reflection on the seismic data.

What makes the Eagle Ford play work is a thick Lower Eagle Ford interval with high TOC content possessing high porosity. Porosity is a combination of intercrystalline pores between loosely cemented microfossil debris and hydrocarbon expulsion pores positioned within the sourcing organic debris (kerogen). Additionally, evidence suggests that strained but not highly deformed settings enhance performance. Natural fractures of any size provide a larger permeability network.

Understanding the geomechanical properties of this sequence is extremely important in placing the horizontal bore hole within the section. The inter-relationship of the pore distribution, rock strength, and ensuing completion program impacts the ultimate recovery of the well. Advanced suites of wireline logs (Figure 3) designed to measure vertical and horizontal stress, brittleness, and existing fracture development are becoming the standards early on in any shale evaluation program. Data collected from directional sonic tools is key to extrapolating well results into the 3D seismic data.

Geophysical data and the Eagle Ford

Seismic data

Conventional subsurface data, such as wireline logs, cores and cuttings, are limited in availability to many companies currently exploring the play. Interpretation of these data is often ambiguous at best. As a result, thorough understanding of the regional aspects of the play remains elusive to many companies. Matador Resources believes that modern seismic data and interpretation techniques can add significantly to the database and greatly enhance regional understanding of the play. Newly acquired 3D datasets like the Reservoir Grade (RG) Patron Grande 3D from Global Geophysical Services provides a high-resolution characterization of the subsurface, which highlights drilling hazards (faults), and also offers the potential for identifying better reservoir quality intervals (higher TOC shale sections with greater porosity and fractures). Extracting rock properties from the seismic should be the goal of any processing and interpretation effort. Linking the results of well tests to the attributes derived from the seismic will provide operators with a far more reliable predictive capability in any shale play.

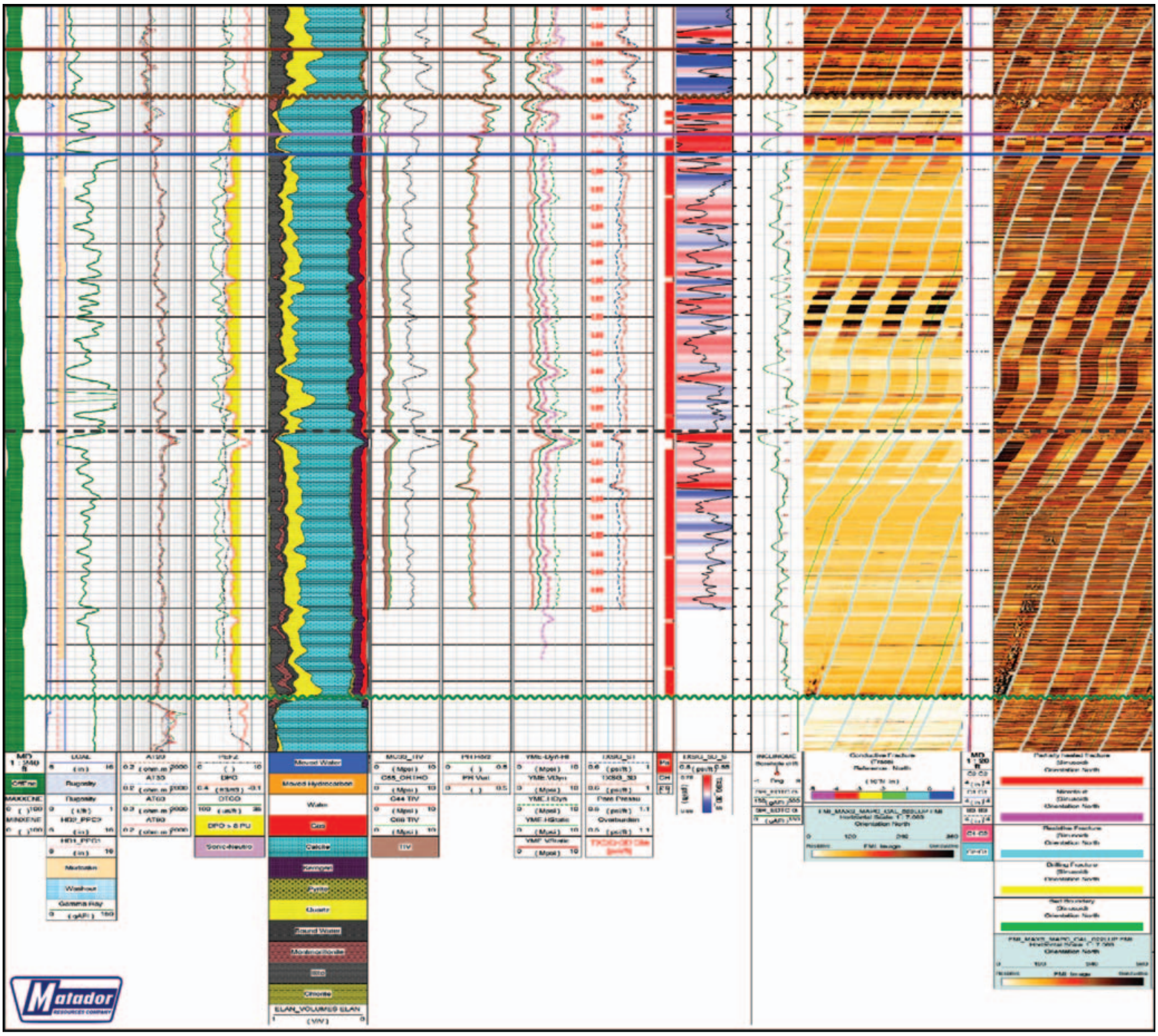


Fig. 3. *Direct rock state measurements (Dipole sonics and FMI) within the Eagle Ford are key to planning horizontal well positions and transferring the well data into a 3D space.*

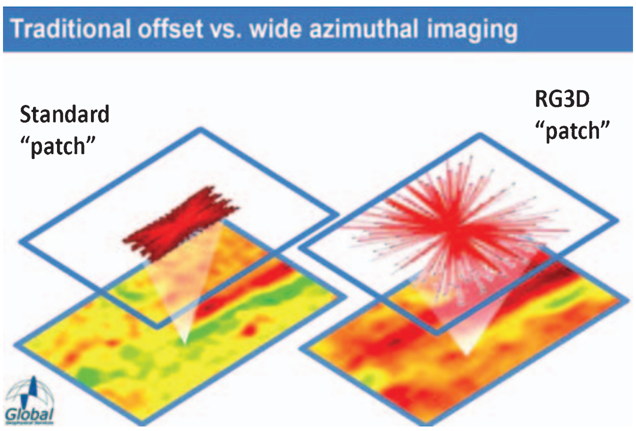


Fig. 4. *Standard versus RG3D (Reservoir Grade 3D) seismic acquisition layouts. The full azimuth, high channel count effort provides additional data for shale assessment.*

Seismic acquisition in the Eagle Ford and other shale plays has changed in the past few years to better accommodate some of the geomechanical goals of the field development (Figure 4). High channel count crews are providing full azimuth, long offset date volumes critical for better subsurface illumination, improved frequency content and improved rock property inversions. Traditional (channel limited, azimuth limited) seismic acquisition techniques under sample the subsurface limiting the use of the 3D dataset. Full azimuth shooting provides a dataset for seismic processing that can feed fracture prediction studies not possible in the older 3Ds.

Data processing

Full azimuth processing for fracture prediction from the seismic involves searching for velocity and amplitude differences in the Eagle Ford that change with azimuth. We expect open fractures and stress field variations to have a subtle impact on the seismic velocities and interface reflections which, with proper processing, can be extracted from the 3D data. Standard

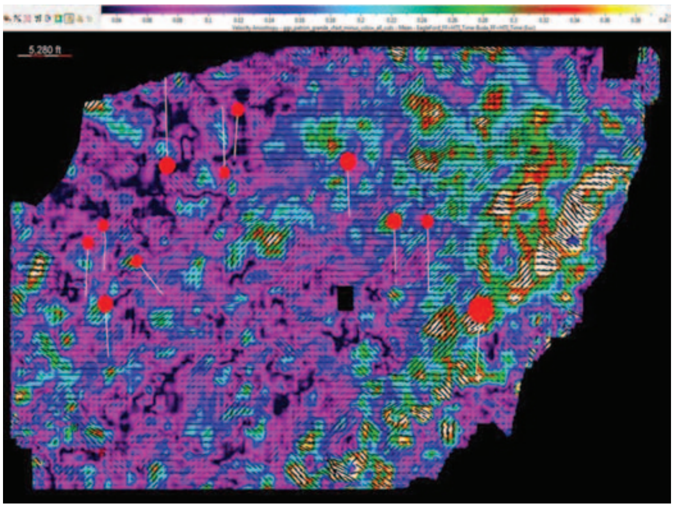


Fig. 5. *Map of azimuthal velocity variations within the Eagle Ford highlighting probable open fracture swarms or stress field variations. Color represents magnitude of azimuthal anisotropy (purple = low, white = high) and vector length and direction represent the orientation of the fast velocity within the Eagle Ford.*

processing assumes these changes aren't significant enough to hurt the final image so the effects are often ignored. Processing the data to highlight azimuthal variations is a relatively new technology in the industry but has shown promise in most US shale plays by highlighting potential open fractures or weak zones that impact fraccing. The most robust product from azimuthal processing is the orientation of the stress field – critical information for planning horizontal well placement.

The primary products of azimuthal processing are a pair of volumes describing areas where the velocity changes as a function of azimuth and a volume that describes the azimuth of the fast velocity. Faster velocity in one direction may indicate the direction of open fractures or the orientation of the local stress field. In the Eagle Ford section we see areas that show little change in velocity with azimuth (purple in Figure 5) and other areas that show strong changes (red-white in Figure 5). Open fractures can be both a positive and a negative factor in developing the resource depending on the response of the shale to hydraulic fracturing. Pre-drill prediction and mapping of potential fracture zones is an added benefit of a full azimuth acquisition and processing effort.

The other positive effect of addressing anisotropy in the processing (both azimuthal and layer anisotropy) is in improving the amplitude information in the far offsets. Elastic inversion involves the conversion of near and far offset seismic data into a prediction of attributes that can infer rock strength. Seismic processing that does not properly preserve far offset amplitudes will lead to less correct rock strength predictions from the elastic inversion. In areas where azimuthal and layer anisotropy are present, it's important to include anisotropy in the actual migration of the data. Unfortunately, the more standard approach in the industry is to correct for anisotropy post migration. Elastic inversion can provide density, Poisson's ratio and 'fracability' or rock strength prediction volumes to help identify sweet spots in the shale – only if the processing is done correctly. Predictions of ductile versus brittle rock behaviour (Figure 6) require careful processing and good calibration with well control to add value to the field development.

Interpretation

Once the processing is completed the seismic data can offer a number of tools for understanding the spatial distribution and quality of the Eagle Ford section. Mapping of the Austin Chalk and Buda horizons yields well constrained thickness maps central to the development of reliable gas or oil in place maps. Acoustic impedance inversion is the simplest and most robust first step in the pursuit of Eagle Ford rock properties. The inversion uses a 3D model, the seismic velocity field, and an estimation of the seismic wavelet to convert the seismic volume to an impedance volume. Rock property studies in the Eagle Ford indicate that impedance and porosity in the Eagle Ford are well correlated. Thus, inversion is an excellent tool for highlighting the best intervals in the shale (based on our current limited well control). Volume and surface attributes help highlight lineaments that may be associated with open fractures or zones of weakness. Figure 7 shows seismic amplitude in gray-scale highlighting small throw faulting at the base of Eagle Ford. These faults have throws of 20–300 ft and will greatly impact the portion of the Eagle Ford drilled in a 4500 foot lateral. Curvature and coherence help highlight more subtle

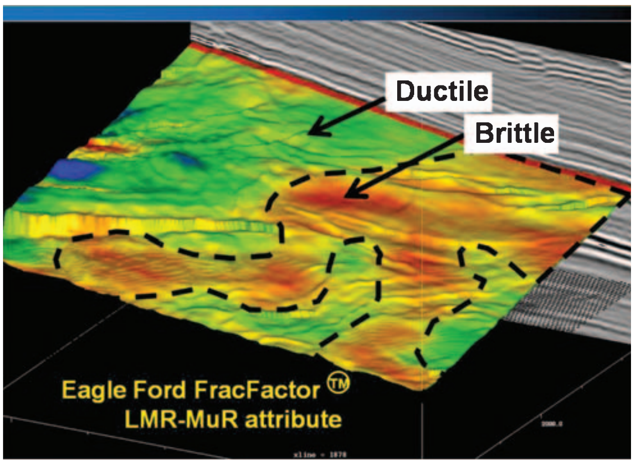


Fig. 6. *Map of the Eagle Ford from an elastic inversion and cross-plot analysis designed to highlight brittle versus ductile rock behaviour.*

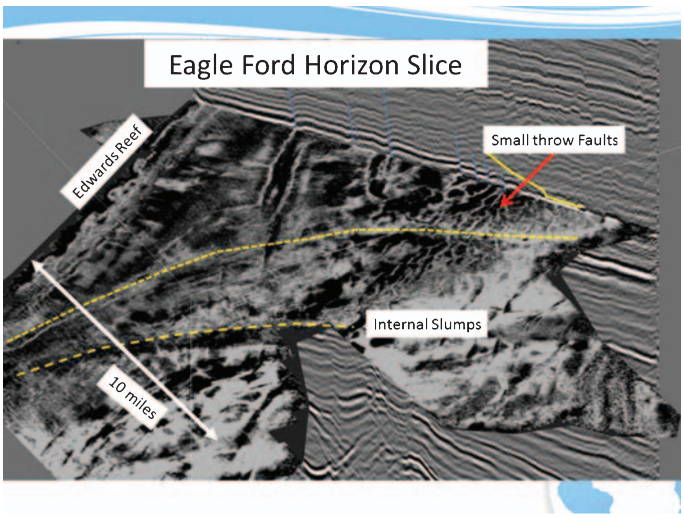


Fig. 7. *Faults and slumps apparent in Global Geophysical's Patron Grande Eagle Ford dataset. The faults impact well placement and frac designs.*

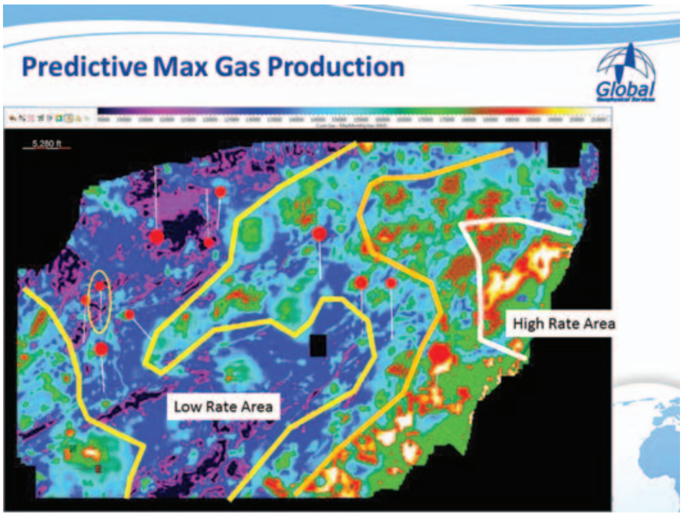


Fig. 8. *Map results from the multivariate statistical analysis predicting areas of higher production potential within the Eagle Ford.*

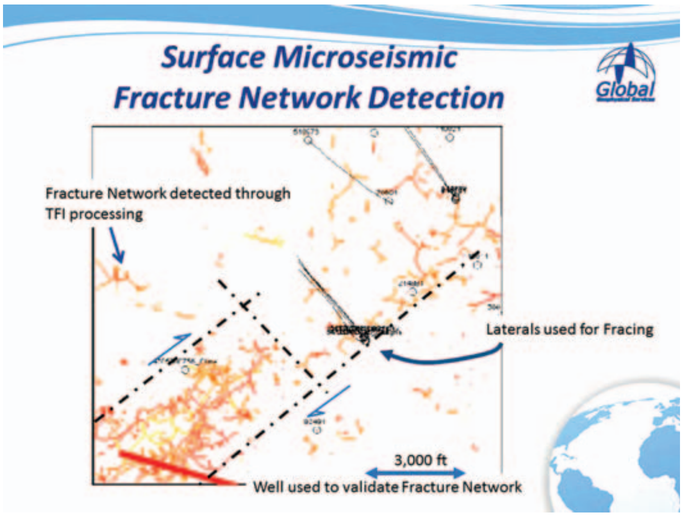


Fig. 9. *Microseismic monitoring can help highlight fracture networks for better well planning.*

lineaments that may be related to open or closed fracture systems.

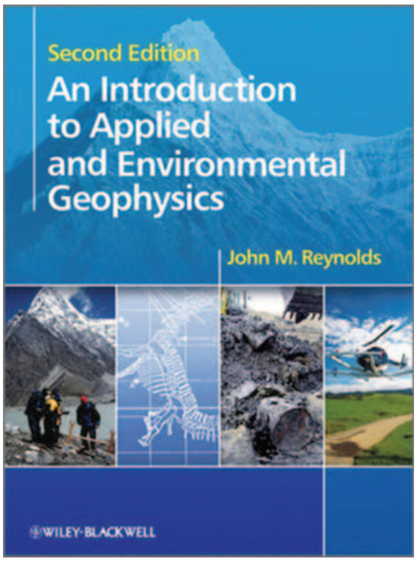
With the completion of the processing and inversion it is time to attempt a link between the well results and the seismic. Multivariate statistical analysis allows us to compare attributes from the seismic to production and ultimately work towards a predictive model for mapping production potential. The work flow involves analyzing seismic and engineering attributes for potential performance indicators. From this work we select attributes that show a positive correlation to performance without showing high correlation to each other. Combining the attributes through a non linear regression allows for the creation of a predictive map for locating areas of better production potential (Figure 8).

With fracture predictions from the seismic processing, rock strength predictions from elastic inversion, and lineament analysis from surface attributes there is still a sizeable gap between what we infer from the seismic and what we know from the well data and regional geology. Frac monitoring to detect and map the microseismic events created by hydraulic fraccing is one way to help link the seismic predictions to the geomechanical properties and eventually to the reservoir performance. Receivers at the surface, in a buried array or downhole in a nearby well listen during the fraccing process to detect where the rock has been broken. Figure 9 shows a fracture network highlighted in a surface microseismic experiment in a non Eagle Ford reservoir. Integration of the frac monitoring with the seismic rock property predictions offers the best chance of high grading the most effective geophysical and geological technologies for the most productive development of the Eagle Ford shale.

Ultimately, the pursuit of Eagle Ford acreage and the designing of an Eagle Ford drilling campaign is best accomplished through a comprehensive understanding of the geological framework coupled with a focused processing, analysis and interpretation of the seismic and microseismic data. Multi-disciplinary integration is key to understanding the risks associated with this complex play. Technical partnerships like the Matador Resources–Global Geophysical Services (Weinman GeoScience) effort permit the shale operators to better position themselves in a rapidly changing play like the Eagle Ford.

An Introduction to Applied and Environmental Geophysics

by John M. Reynolds
Publisher: Wiley-Blackwell, 2011, 712 pp.
RRP: $79.95 (paperback)
ISBN: 978-0-471-48536-0



Like many of us, John Reynolds, the author of this comprehensive introductory geophysical textbook, has struggled with the challenge of teaching geophysics to students possessing only very basic mathematical skills and a limited background in physics. Reynolds found that many of his students struggled to comprehend the mainstream geophysical textbooks and quickly tagged geophysics as a 'hard subject', best avoided. As a consultant, Reynolds also found it difficult to find an appropriate book that demonstrated to his industry clients the many ways in which geophysics could be used in applied and environmental applications.

With these deficiencies in mind, Reynolds states in his Preface that he set out to write a book that addresses these shortcomings and that provides a foundation for further learning. The result is a book that covers the fundamentals of just about every geophysical method (as best I can tell, only paleomagnetism is missing). The inclusion of a multitude of case studies goes a long way towards illustrating the breadth of applications to which geophysics can be applied, particularly in engineering and environmental science.

After thumbing through the first few pages of this book, a couple of features stood out. First, all the figures are in black and white. This would have been disappointing, but having read the Preface first, I knew that the figures are available online in colour. The provided link (http://www.wiley.com/go/reynolds/introduction2e) takes the reader to a 'Student Companion Site' where the figures can be downloaded for viewing in PowerPoint a chapter at a time. To me this approach is novel, but I wonder whether it would become frustrating if the book were used frequently. However, the cost advantage of printing in black and white is no doubt appreciated by many.

The second thing that stood out is the use of Boxes to present key equations. I have to confess that I often find it heavy going to read a text book riddled with equations, so I appreciated the flow of the descriptive text, uninterrupted by equations to think about and understand. This approach allows the mathematical basis to be examined at the end of rather than during the process of absorbing new concepts.

Chapter 1 is an introductory chapter that summarises the uses of geophysics, planning and designing a geophysical survey, the problems of ambiguity and the need to integrate different techniques and constraints from other fields. This chapter should be a must-read for newcomers to geophysics. It was also pleasing to read here that the ASEG is an 'organisation of note' and to see that *Exploration Geophysics* rated a mention as a source of further information!

The introduction is followed by a chapter each on gravity (Chapter 2) and geomagnetics (Chapter 3). The gravity case studies range from mining applications to glaciological studies, while the use of magnetics in mineral exploration, landfill investigations, and detection of unexploded ordnance, to name but a few, is also covered.

Seismic methods are covered over three chapters. The first deals with the principles of applied seismology (Chapter 4). Chapters 5 and 6 deal with seismic refraction and reflection methods. Both outline the general principles behind each method and discuss the processing and interpretation of seismic data and associated pitfalls. In keeping with the goals of the book, the seismic applications and case studies are dominantly focused on shallow targets, an area where Reynolds suggests that there is still limited literature available. The applications and case studies cover topics such as void detection, landfill investigations, high-resolution profiling on land and over water, and even the morbid topic of locating buried miners.

The next three chapters cover electrical resistivity methods in Chapter 7, self potential (SP) methods in Chapter 8 – but not down-hole techniques – and induced polarization (IP) in Chapter 9. SP and IP are methods less familiar to me, so I read through theses chapters in more detail than some. After having done so, I felt that I had filled (or re-filled) some knowledge gaps. This reinforces my opinion that this book will be useful to many. Case studies include geothermal and mineral exploration, hydrogeology, and detection of leaks in dams (like those in a potentially unstable natural moraine dam in Kazakhstan that lies upstream of a nasty tailings dam!).

Electromagnetic methods (EM) are dealt with in three chapters; one on principles (Chapter 10), and two on systems and applications. Chapter 10 includes mention of the rapidly-evolving marine EM techniques. Chapter 11 covers continuous wave and time-domain EM, while Chapter 12 includes very low frequency, telluric and magnetotelluric methods.

Apparently ground-penetrating radar (GPR) is now the most widely used technique in applied geophysics and GPR is also covered in separate chapters on principles (Chapter 13) and case histories (Chapter 14). These chapters highlight the rapid expansion of GPR from sub-ice bedrock mapping into engineering and archeological applications.

The final chapter, Chapter 15, gives a relatively brief but informative overview of radiometrics and its applications. The case histories include well-known applications in regional-scale mapping for uranium exploration, but also in more surprising areas like the detection of engineering structures within 10 cm of the surface.

Reynolds states in his Preface that his goal was to write a book that provided a broad overview of applied and environmental geophysics, a book that illustrates the power (and limitations) of different techniques, while also improving the acceptance of geophysics as a tool and increasing the awareness of the methods available. I would say that he has succeeded in these goals. His explanations of the principles of each method are likely to be well suited to undergraduates newly exposed to geophysics, industry professionals seeking new ways to address problems in engineering and environmental applications, as well as others, like this reviewer, whose knowledge simply needs updating or refreshing.

Reviewed by Ron Hackney
Email: Ron.Hackney@ga.gov.au

New Year data resolutions

Looks like we are at our last *Preview* magazine for 2011. I want to pass on my best wishes to the ASEG team who have done a great job this year getting this publication out on time despite me always being the last minute merchant.

To the readers, I hope you have a great Christmas and New Year. I look forward to next year when I will be putting articles together on some new technology being released, some old technology coming back from the dead, and some technology that never made it into anyone's Christmas stocking – ever. For now, it's the Top 10 Data Storage Resolutions for 2012 as written by Teena Townsend, my close work colleague.

Each year, millions of people form New Year's Resolutions in the hope of making a change for the better. It's that time of year again, and professionally, it is an opportunity to reflect on all the things that you kept meaning to get around to doing last year, but never actually did. With the start of the New Year, take 10 minutes to look ahead with a fresh perspective and renewed sense of determination. Make a new list of data storage and management resolutions for 2012 and resolve to protect your data (and yourself) from life's unknown beasts.

Here are a few ideas to get you started:

1. **Ensure your data is stored correctly**
   Is it in a data vault with the correct environmental conditions? Is it stacked and boxed correctly?
2. **Know and monitor what data you have**
   Keep records or a database of the data you have and where it is. Know what format and media type it is stored on.
3. **Battle the bulge and do your housekeeping**
   Don't let your data centre get cluttered and dirty. Keep things lean and clean and don't use additional space (if you're lucky enough to have some) as a storage space for junk and legacy equipment – it only creates problems later on.
4. **Backup your data regularly**
   Ensure clear guidelines and responsibilities are understood and that it occurs daily, weekly, monthly or as agreed.
5. **Test your backup data and the restoration/disaster recovery plan often**
   Can you restore data quickly when required? Do you know where it is? Do you have the equipment and know how to restore older archive backup data sets?
6. **Automate your backup as much as possible**
   Backup is boring. Find tools (hardware and software) to ensure that your backups happen regularly in a robust and bulletproof way. The right tape automation and backup software are key.
7. **Store your backup data offsite**
   Use an experienced and knowledgeable offsite data storage provider.
8. **Keep up to date and learn something new**
   Ensure you keep abreast of new technology and solutions. Make time to read, attend seminars and conferences, network and attend industry events. You never know what you might gain and there is nothing to lose.
9. **Resolve to be greener**
   Look to how your data centre or data storage can be more environmentally friendly. Can you use more efficient cooling systems? Are you able to reduce power consumption or choose 'renewable' electricity sources? Can you better use space and resources more effectively?
10. **Use data storage experts**
    If you don't have the time, the experience and/or the knowledge, then call in the experts. The relatively little investment in expert knowledge and experience can literally pay for itself a thousand times over in the event of disaster. Don't fudge it – engage the experts to show you the solutions.

Screen grab from www.elfyourself.jibjab.com

For now, Merry Christmas to all, and to all a good night.

Guy Holmes
Guy.Holmes@ovationdata.com.au

An online alternative to academic and government consortia?

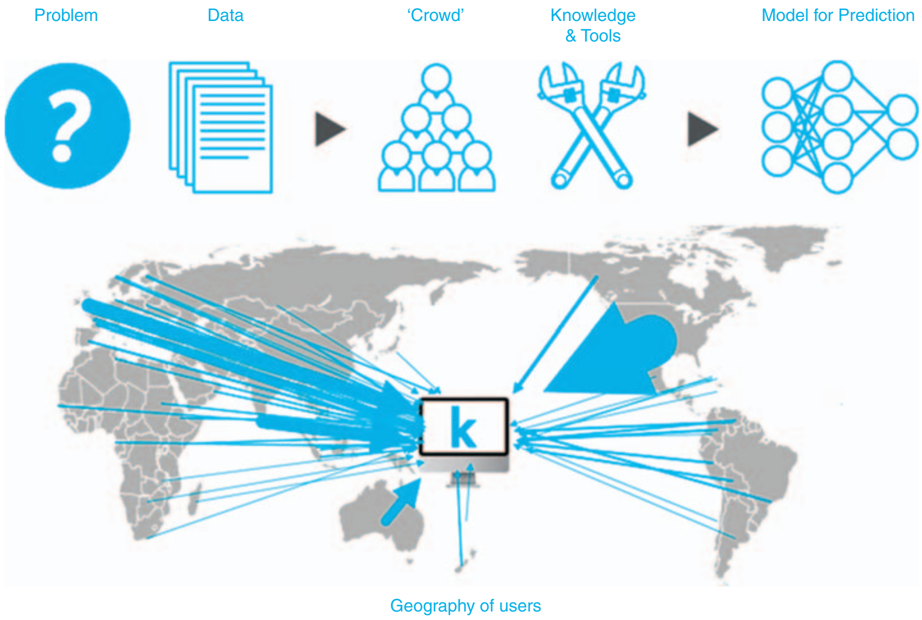
My employer sponsors about 20 academic consortia and university departments worldwide, for a variety of strategic and altruistic R&D reasons. We also participate in a few collaborative R&D projects with government scientific organisations. A common bugbear for all R&D activities is intellectual property (IP). Everyone wants to claim it; such is the universal nature of business these days. The process of making patent applications is arduous even in the simplest scenario where we conceive and develop our own IP, independently of any external personnel or groups. If we choose to pursue innovation with external partners, the contract process involved in formalizing partnerships inevitably becomes bogged down with IP legalese. To quote from the CSIRO website (http://www.csiro.au/multimedia/CSIROandIP.html), 'CSIRO takes the management of its IP seriously. Effective management of IP is important to achieve impact from CSIRO science for the benefit of industry, community and the environment. It is also essential to CSIRO forming productive collaborations.' Most of the aforementioned partners we sponsor maintain a similar ethos.

Academic consortia inevitably dictate that IP is shared between the sponsors of the consortium and the university. My employer maintains a 'portfolio' of consortia based upon their academic specialties, strategic R&D directions and geographical location. It is an expensive process to administer and engage with consortia, their output is rarely aligned with the specific activities of any individual sponsor, new R&D directions occur at best via loose consensus with sponsors, and academia traditionally survives despite layers of bureaucracy and distractions from administrators and the never-ending process of applying for grants. So, consortia sponsorship brings together a small cross-section of academics with conflicting interests and IP restrictions. It's fun working with enthusiastic students, even if we're talking about topics for purely intellectual reasons, but is there a better model to accelerate strategic R&D with rapid commercial payoffs to sponsors? I revisit this question later.

There are typically several other factors embedded within the R&D of publicly funded academia and government organisations that affect their IP rights and the IP rights of any partners (such as my employer). For example, many organisations choose to develop software on the GNU platform (http://www.gnu.org/), and are thus subject to the GNU General Public License, version 2 (GNU GPL v2: http://www.gnu.org/licenses/gpl-2.0.html). CSIRO develops various software on the GNU platform, with one consequence being that the software becomes public domain upon project delivery. So here we see a double IP challenge. Someone wishing to sponsor R&D with an organisation such as CSIRO will inevitably agree to grant various IP rights to CSIRO, and thus any commercial benefits of the partnership will at best (from the perspective of the sponsor) be shared. Alternatively, the sponsor may have no rights at all because, for example, the GNU GPL v2 demands there is no IP. So the sponsorship can be viewed as an altruistic exercise that accelerated the development of a new concept that benefits everyone, not only the sponsor. Please note I only use CSIRO as a representative example of most such organisations. CSIRO do outstanding work, and potential R&D partners should visit http://www.csiro.au/org/Partner.html for more information.

These simplistic and entirely non-exhaustive examples are nevertheless a useful introduction to the dilemma of sponsoring academia and government R&D. How can a sponsor pursue strategic R&D and gain IP rights to any commercial outcomes? In the case of academia, individuals (both faculty and students) can be paid to work within our company, variously via internships and paid projects. This assumes that appropriate personnel, resources and time are available; rarely at best. The competition for bright minds is fierce. And this leads to the key element of this article: Online 'data prediction competitions', a concept that could be extended to wider analytic and computational challenges.

As described at http://www.kaggle.com/pages/about, Kaggle is a platform for data prediction competitions that allows organisations to post their data and have it scrutinized by the world's 'best data scientists'. In exchange for a prize, winning competitors provide the algorithms that beat all other methods of solving a data crunching problem. Most data problems can be framed as a competition. Kaggle is thus an innovative solution for statistical/analytics outsourcing, and claim they are 'The leading platform for predictive modelling competitions'. Kaggle claim most organisations don't have access to the advanced machine learning and statistical



Schematic illustration of the Kaggle model for global online data prediction competitions. Is this a model for future alternatives to traditional consortia and government R&D partnerships?.

techniques that would allow them to extract maximum value from their data. Meanwhile, data scientists crave real-world data to develop and refine their techniques. Kaggle corrects this mismatch by offering companies 'A cost-effective way to harness the 'cognitive surplus' of the world's best data scientists':

> *There are countless approaches to solving any predictive modelling problem. No single participant (or in-house expert, or consultant) can try them all. By exposing the problem to a large number of participants trying different techniques, competitions can very quickly advance the frontier of what's possible using a given dataset.*

A short video that explains how the Kaggle forum works, including a few examples and suggestions on how companies can protect their IP, can be found at http://host.kaggle.com/. Ongoing competitions are listed at http://www.kaggle.com/.

Is this the start of a new model for external R&D? As noted, the competition forum need not be the data mining challenges addressed by Kaggle. 'Any' R&D challenge could be posed to a global online network of scientists with 'cognitive surplus' (and financial deficit). The diversity of solutions that would be returned is an attractive consideration. To return to my opening theme about IP, Kaggle competition data is made anonymous, scrubbed of all personally identifiable information. It can also be masked, so that competitors can develop algorithms to predict results based on the presence or values of variables A, B and C without knowing what A, B and C actually are. This protects proprietary and competitive information, in addition to privacy. Kaggle also hosts private invitation-only challenges in which players undergo background checks and compete under non-disclosure agreements. Participants in private competitions are selected based on their past performance in Kaggle competitions. Every competitor that accepts the invitation to compete wins prize money, with larger prizes for those who produce the best results. Private competitions are an important tool for organisations that want to harness the power of predictive modelling competitions while keeping their data and IP private. In certain scenarios, the Kaggle-type forum may become an exciting and low-cost alternative to traditional R&D structures. Furthermore, the Kaggle-type platform enables many challenges to be tested that would simply not be addressed within the scope of R&D resources and timeframes possible within most companies.

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Calendar of Events 2012

January			**2012**
22–24 Jan	4th International Professional Geology Conference: Earth Science – Global Practice http://www.4ipgc.ca	Vancouver	Canada
February			**2012**
8–10 Feb	Workshop on EM in Hydrocarbon Exploration http://www.eage.org	Singapore	Singapore
16–18 Feb	SPG India, 9th International Conference & Exposition on Petroleum Exploration http://www.spgindia.org	Hyderabad	India
26–29 Feb	**22nd ASEG Conference and Exhibition 2012: Unearthing New Layers** **http://www/aseg2012.com.au**	**Brisbane**	**Australia**
March			**2012**
4–7 Mar	GEO 2012: 10th Middle East Geosciences Conference and Exhibition http://www.geo2012.com	Manama	Bahrain
7–9 Mar	First EAGE/ACGGP Latin American Geophysics Workshop http://www.eage.org	Cartagena	Colombia
22–23 Mar	3rd Unconventional Hydrocarbons Summit 2012 http://www.cdmc.org.cn/uhs2012	Beijing	China
25–29 Mar	SAGEEP 25: Making Waves – Geophysical Innovations for a Thirsty World http://www.eegs.org	Tucson	USA
April			**2012**
2–5 Apr	Saint Petersburg International Conference & Exhibition 2012 http://www.eage.org	Saint Petersburg	Russia
May			**2012**
14–18 May	GeoConvention 2012: Vision http://www.geoconvention.com	Calgary	Canada
27–29 May	3rd International Professional Conference: Geosciences and Environment	Belgrade	Serbia
29–31 May	3rd International Geosciences Student Conference http://www.agserbia.com		
June			**2012**
4–7 Jun	Copenhagen 2012: 74th EAGE Conference & Exhibition incorporating SPE EUROPEC 2012 http://www.eage.org	Copenhagen	Denmark
4–8 Jun	GPR 2012: 14th International Conference on Ground Penetrating Radar http://www.gpr2012.org	Shanghai	China
August			**2012**
5–10 Aug	34th International Geological Congress http://www.34igc.org	Brisbane	Australia
September			**2012**
3–5 Sep	Near Surface Geoscience 2012: 18th European Meeting of Environmental and Engineering Geophysics http://www.eage.org	Paris	France
November			**2012**
4–9 Nov	SEG International Exposition and 82nd Annual Meeting http://www.seg.org	Las Vegas	USA

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All editorial contributions should be submitted to the Editor by email at preview@mayes.com.au. For style considerations, please refer to the For Authors section of the *Preview* website at: www.publish.csiro.au/journals/pv.

Preview is published bi-monthly in February, April, June, August, October and December. The deadline for submission of material to the Editor is usually before the 15th of the month prior to the issue date. The deadline for the February 2012 issue is 9 January 2012. For the advertising copy deadline please contact Wendy Wild on (03) 9662 7606 or wendy.wild@csiro.au.


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