Some facts about fracture stimulation

The resource industry is again receiving attention and unwarranted criticism, this time for hydraulic fracture stimulation. Fracture stimulation is not directly related to the work of many exploration geophysicists, but I think that all geoscientists can help explain to the public some of the facts and myths related to fracture stimulation, and perhaps turn the current belief and fear-driven media feeding frenzy on fracture stimulation into an evidence-driven public debate. I offer here some background facts that may be helpful and my opinion on a workable solution.

A good place to start is with the design of an oil or gas well: assume this page is a scaled cross section of the earth with an 'average' 2500 m vertical shale gas well running from the top edge of this sheet to the last line of text. The target hydrocarbon reservoir would be thinner than the last line of type, and shallow aquifers used for town and irrigation supply will normally lie above the title line for this column. Let's consider how those shallow aquifers might be contaminated:

- Can frac fluids leak *directly* from the well into the aquifer? Not likely without a hole in the steel casing that lines the well bore, and that hole would show up immediately as a significant pressure loss during the frac job.
- Can frac fluids leak up the annulus between the casing and the borehole? That annulus is filled with cement and then pressure-integrity tested, so this too is very unlikely.
- But can't the frac job itself create a conduit from the reservoir to the shallow aquifer? This hydraulically created fracture is usually less than 10–30 m high. It normally does not grow higher than this because the high pressure frac fluids will find a lower-stress lithology and stay in it by growing horizontally, not vertically. Vertical fluid movement would require crossing repeated high-stress barriers, which is like water running uphill.

Now it is relevant to point out the important difference between shale gas frac jobs (mostly in North America so far) and coal seam gas frac (CSG) jobs in Australia. CSG reservoirs are shallower than shale reservoirs. The shallowest CSG target might be at 300 m, not the average 2500 m shale well discussed above. This is getting uncomfortably close to aquifers used by towns and for irrigation.

Now let's examine some facts. There have been about 1.5 million fracture stimulation treatments performed since 1947, mostly in North America. There have been about 2500 frac jobs performed in Australia, with about half of those done in deep Cooper Basin targets. Today in North America, approximately 80–90% of all new onshore wells receive multiple fracture stimulation treatments.

The fracture stimulation industry claims that despite the above 1.5 million frac treatments, there has not yet been a documented case of aquifer contamination. The industry's detractors will say that there have been cases of contamination, but these cases are settled out of court with cash payments and non-disclosure clauses.

The New York Times recently found and published the details of one of these out-of-court settlements, a case in Pennsylvania in the late 1980s. In this case (according to preliminary court documents) frac fluids were found in a shallow aquifer above a deep fracture stimulation treatment. And in this case, the frac fluids were able to travel the 'impossible' vertical distance from the target reservoir to shallow aquifer because – unbeknownst to the frac operator – there was an improperly abandoned gas well near the frac treatment well. This improperly abandoned well provided an easy conduit for vertical movement of frac fluids.

What does the above case prove? This case of contamination required a rare set of cascaded errors in well abandonment and regulatory oversight, but it still does not provide a case where a stimulated fracture provides a conduit between a hydrocarbon reservoirs and surface aquifers.

What about frac chemicals and the flaming kitchen tap shown in the documentary film 'Gas Land'?

The flaming kitchen tap seen in 'Gas Land' is caused by a well known phenomenon (well known to coal geologists) explained by Langmuir isotherms. A Langmuir isotherm plot shows how much natural gas will be released from a coal seam as the water pressure in that coal seam is lowered. This is not a rare phenomenon; it is happening by design in tens of thousands of coal seam gas wells in Queensland. And if a rancher completes his water well in a coal seam his water will produce water plus gas as the water pressure is lowered. This is why proper regulation prohibits water wells from drawing water from a coal seam.

Aren't there toxic chemicals released in fracture stimulation?

Yes. The fluids used in fracture stimulation are 99.5% water, but the remaining 0.5% are chemicals that can be harmful and do require regulation. One example: bacteria and algae growth in frac fluids is a potential problem, and biocides are used to preclude that. Biocides are also used for the same reason in public water supplies. I'd like to know that a safe level of biocides are used in my tap water – and if there is ANY chance that frac fluids might leak into aquifers, it would be good to know that the frac fluids do not exceed that safe concentration of biocide(s).

I very recently heard a provider of fracture stimulation saying they are switching from chemical biocides to UV radiation treatment – just as many home owners use in a spa bath. I don't know if this switch from low-level biocides is required from a public risk point-of-view, but this switch could be very important in the court of public opinion.

Perhaps the most attention worthy chemical used in fracture stimulation is a 'friction-reducing agent'. Friction-reducing agents make it easier to quickly pump millions of litres of fluids through the frac pumps, pipes and the well casing. These are hydrocarbon lubricants and go by the acronym BTEX, which is short for benzene, toluene, ethylene and xylene.

I have mixed feelings towards BTEX use in frac fluids. When I fill my car with

Continued on p.4

ASEG Federal Executive 2010–11

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petrol, I'm putting BTEX (among other things) in the tank without *undue* risk to humans and the environment. Shouldn't it be safe to inject BTEX into a *hydrocarbon* reservoir? But I know from experience that uncombusted BTEX fumes make me feel ill, and I understand that exposure to BTEX can cause cancer. Therefore, I would not be comfortable with BTEX in my water supply, even at small concentrations.

Fracture stimulation is an important part of CSG development in Australia, and CSG development is the lowest-cost path of lessening our use of coal and lowering our CO_2 emissions. A sensible solution to the frac stimulation debate would be to allow regulated fracture stimulation using current chemicals and current well design *as long as the frac job is not within 100 m vertically of a shallow permeable fresh water aquifer.* If a frac job gets any closer than 100 m to an aquifer, then it is not unreasonable to ask that the frac job be banned OR that all frac fluids meet food and drinking water quality standards – something that is very doable.

Dennis Cooke
Email: dennis.a.cooke@gmail.com

Research Foundation Update

The Research Foundation was pleased to receive applications to support seven research projects commencing this academic year. Congratulations go to the successful students and their supervisors. After careful consideration and ranking by the technical committees, and also taking account of our financial resources, the Foundation has agreed to support five projects as detailed below.

Project: RF11M01
Title: Constrained magnetic modelling of the Wallaby gold deposit, Laverton, Western Australia
Institution: University of Western Australia
Student: Sasha Banaszczyk
Degree: B.Sc (Hons)
Supervisor: Professor Mike Dentith
Awarded: $5,000

Project: RF11M02
Title: Removing the effects of sensor rotation from EM measurements: a critical need for low-frequency AEM
Institution: RMIT University
Student: Terence Kratzer
Degree: PhD
Supervisor: Professor James Macnae
Awarded: $8,000 (Year 1), $9,200 (Year 2), $1,200 (Year 3) = $18,400 (total)

Project: RF11M04
Title: Modelling down-hole induced polarisation based on the Centenary gold deposit, WA
Institution: University of Western Australia
Student: Jarrad Lachlan Trunfull
Degree: B.Sc (Hons)
Supervisor: Professor Mike Dentith
Awarded: $4,000

Project: RF11P02
Title: Computational rock physics, seismic wave propagation and imaging in complex anisotropic media
Institution: University of Western Australia
Student: James Deeks
Degree: PhD
Supervisor: Professor David Lumley
Awarded: $8,000 (Year 1), $8,000 (Year 2), $8,000 (Year 3) = $24,000 (total)

Project: RF11P03
Title: Seismic anisotropy analysis for estimating reservoir fractures and stress
Institution: University of Western Australia
Student: Lisa Gavin
Degree: PhD
Supervisor: Professor David Lumley
Awarded: $8,000 (Year 1), $8,000 (Year 2), $8,000 (Year 3) = $24,000 (total)

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

Phil Harman, ASEG RF Chairman

New members

The ASEG extends a warm welcome to 17 new members to the Society (see table). These memberships were approved at the Federal Executive meetings held on 28 July and 25 August 2011.

Name	Organisation	State/Country	Member Grade
Craig John Ballington	Queensland University of Technology	QLD	Student
Majid Beiki	CSIRO	NSW	Active
Kyle Robert Blay	CSIRO Materials Science & Engineering	NSW	Associate
Daniel Burton	James Cook University	QLD	Student
Ristch Camille	Macquarie University	NSW	Student
Daniel Robin Eden	Curtin University of Technology	WA	Student
Robert Neil Finnegan	University of Western Australia	WA	Student
Matthew Goldman	Geological Survey of QLD	QLD	Active
Gustavo Hinestrosa	University of Sydney	NSW	Student
Joanna Jago	GroundProbe Geophysics	WA	Active
Emma Louise Johnson	University of Newcastle	NSW	Student
Michael John Nelson	GroundProbe Geophysics	WA	Active
Thomas Phillips	Inova Geophysical	USA	Associate
Ludovic Ricard	CSIRO	WA	Active
Andrew Michael Roberts	Southern Geoscience Consultants	WA	Active
Brent Walker	Macquarie University	NSW	Student
Marlene Woligroski	Southern Geoscience Consultants	WA	Active

We would also like to welcome **Thomson Aviation Geophysical Survey** as a new corporate member of the ASEG. Thomson Aviation offers the highest resolution airborne magnetic, radiometric and digital terrain data available. Advanced acquisition techniques, combined with the best available instruments and in-house processing using the latest software, ensure the best value for money data sets in the industry. Thomson Aviation have over 18 years experience in low level operations and can offer fixed wing and helicopter systems for both domestic and international projects.

The latest addition to Thomson Aviation's fleet of fixed-wing geophysical aircraft is a PAC 750. This aircraft is manufactured in New Zealand and powered by a PT6-34 turbine engine, giving it improved performance over similar piston-engined aircraft. In particular, it has superior climb performance which enables it to maintain close terrain following and in some cases it can do as well as a helicopter. Its features provide for high safety standards, which is always of paramount concern for Thomson Aviation. Its high power-to-weight ratio provides for a big payload. Thus, for example, it is able to carry twice the normal radiometric detector volume, or 66 L. The PAC 750 was obtained deliberately to provide an excellent platform for geophysical operations and this has proved to be the case in practice. The installation of a magnetometer boom and the consoles for magnetic and radiometric measurement were easily accommodated and the compensation quickly achieved. Already, several clients of Thomson have experienced the excellent data quality produced by the PAC 750. Also, its size and payload allows for the future addition of other methods than the current high-resolution magnetic and radiometric installations. More information about this expansion will be available soon.

Contact details are:
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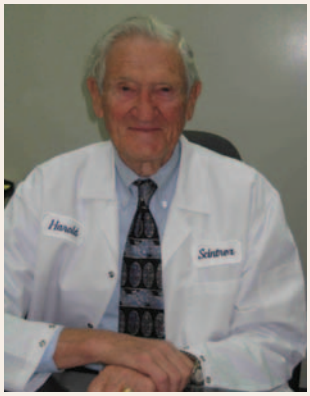
Harold O. Seigel, PhD, O.C.: 1924–2011



Dr Harold O. Seigel, renowned exploration geophysicist, entrepreneur, mentor and Officer of the Order of Canada, passed away on 13 July 2011, in Toronto, Ontario after a short illness, to the great sadness of the global geophysical community. His sudden departure ended an extraordinary career that spanned over six decades.

Harry was born and raised in Toronto. In 1943, Harry, then a first year math and physics undergrad at the University of Toronto, was invited by Lachlan Gilchrist to join a geophysical field crew conducting a magnetic survey north of Lake Huron. Geophysics appealed to Harry's loves of science, discovery and nature, and he had the necessary skills to make meaningful contributions. His PhD thesis on the application of induced polarization for mineral exploration, completed in 1949 at the University of Toronto, included results of the first full-scale field testing of this new method over a porphyry copper deposit in Arizona.

After completing his PhD, Harry spent the next four years working for Newmont in Arizona, collecting and analyzing data and refining the mathematical theory of the IP response, before returning to Toronto in late 1952. The beauty of the desert was firmly set into Harry's heart, and, in later years, he and Marilyn spent the winters in Tucson.

In 1953, a group of geophysicists based mostly in the Toronto area formed the Canadian Exploration Geophysicists Society (KEGS), with Harry as the founding chairman. Harry's active support of KEGS continued through the next 58 years, and he was one of the founding directors of the KEGS Foundation in 1999. In 1987, he served as Chairman of the Exploration '87 conference.

In 1956, Harry started his consulting company, Seigel Associates. He merged this company with E. J. Sharpe Instruments in 1967 to form Scintrex Limited. He remained active at Scintrex until several days before his death.

Over the course of an extremely productive and successful career, Seigel was directly involved in at least nine significant mineral discoveries, authored over 20 patents and published over 40 papers. He was honoured with many awards, including the Canadian Geophysical Union's J. Tuzo Wilson Medal in 1985, a Distinguished Service Award for the Prospectors & Developers Association of Canada in 1987, the A.O. Dufresne Award from the Canadian Institute of Mining, Metallurgy and Petroleum in 1988 and SEG's Maurice Ewing Medal in 1995. In 1995, Seigel was inducted into the Canadian Mining Hall of Fame, and, in 1997, he was appointed as an Officer of the Order of Canada.

Harry also found time to volunteer at the University of Toronto, for which he was awarded the Arbor Award for Outstanding Personal Service to the University in 2002. His legacy at the University of Toronto continues with the Harold O. Seigel Graduate Scholarship, awarded by the Department of Physics for graduate studies in Applied Geophysics. Also in 2002, Harry received a Commemorative Medal in honour of the Queen's Golden Jubilee in recognition of his achievements and distinguished service.

In the late '60s, Seigel recognized significant business opportunities for western geophysical technology in China. He participated in the first Canadian Trade Mission to China in 1972, impressing the Chinese hosts by conversing in Mandarin. He made many return trips to China until 1989, establishing solid relationships for Scintrex in China that continue today.

The challenge to develop effective electrical geophysical methods in Western Australia's highly conductive overburden drew Seigel to Kalgoorlie in 1967. The use of high power transmitters and gradient arrays contributed to the discovery of the Mt Windarra nickel deposit in 1968, and the subsequent Poseidon Nickel boom.

While walking over the Kanowna salt lake in 1968, Harry conceived a method to measure the magnetic rather than electric field on induced polarization surveys in areas of conductive cover. Subsequently, the Magnetic Induced Polarisation method contributed to several significant discoveries across Australia including Elura ('72), South Mt Keith ('77), Sandy Flat ('79) and Mt Pleasant ('83).

Harry was special among his peers in the geophysical business, combining a solid understanding of scientific theory, and engineering with ambition and business acumen. He was a lifelong entrepreneur and scientist who relished the challenge of exploration. Under his guidance, Scintrex focused efforts on instruments that could be successfully commercialized. Many other ideas remain undeveloped. Less than two weeks before his death, Harry spent the morning at Scintrex discussing the potential of magnetic induced polarisation for exploration in the western Athabasca Basin, Saskatchewan.

Harry's love of nature and enthusiasm for outdoor activities were evidenced by his passion for hiking. He was incredibly fit and took the lead on most hikes regardless of the terrain. Those of us who walked with him through the hills north of Toronto or the canyons near Tucson would be humbled the next morning when Harry showed no apparent signs of soreness, while we limped through the day. Our last hike was on 8 May 2011. As usual, Harry was in good shape the next day while the rest of us suffered.

Harry's interests went well beyond geophysics, business and hiking. He was a dedicated and proud husband, father and grandfather. He spoke several languages, travelled extensively and loved music, culture, history and people. He treated everyone equally, respectfully and fairly.

Harry is survived by his wife, Marilyn, his son Joel Seigel, two daughters, Laurie Beckerman and Marcie Seigel, and four grandsons, Mathew, Jordan and Kyle Seigel and Jacob Beckerman.

Chris Nind, with help from Tony Howland-Rose, Norm Paterson, Jerry Roth, Laurie Reed, the Seigel family and the Scintrex alumni.

Nominate a colleague for an ASEG Honour or Award for 2012

NOMINATIONS CLOSING SOON

The ASEG acknowledges the outstanding contributions of its individual members both to the profession of geophysics and to the ASEG, through the presentation of the Society's Honours and Awards across a range of categories. The next Awards are scheduled to be presented at the ASEG Brisbane Conference from 26–29 February 2012.

The ASEG awards are made through nominations of the membership at large, as well as through State and Federal executives. All members are invited to submit nominations according to the 'Nomination Procedure' set out below. Some of the awards carry considerable prestige in the eyes of the ASEG and therefore require some documentation to support the nomination. Please contact the Committee Chairman, Andrew Mutton, if you require further guidelines on what is required.

Recipients selected from these nominations will be presented with their award at the forthcoming Brisbane conference.

Details of the award categories appeared in the previous issue of *Preview* (Issue 153, p. 9). They are:

- **ASEG Gold Medal**
- **Honorary Membership**
- **Grahame Sands Award**
- **Lindsay Ingall Memorial Award**
- **Early Achievement Award**
- **ASEG Service Awards**

Nomination procedure

Any member of the Society may nominate applicants. These nominations are to be supported by a seconder, and in the case of the Lindsay Ingall Memorial Award by at least four geoscientists who are members of an Australian geoscience body (e.g. GSA, AusIMM, AIG, IAH, ASEG or similar).

Nominations must be specific to a particular award and all aspects of the defined criteria should be addressed. To gain some idea of the standard of nomination expected, nominees are advised to read past citations for awards as published in *Preview*. If required, proforma nomination forms are available from the Chairman, Andrew Mutton.

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

Andrew Mutton
Chairman, ASEG Honours and Awards Committee
Email: andrew.mutton@bigpond.com

The deadline for nominations is 15 December 2011.

Australian Capital Territory

A number of events and presentations have kept members of the ACT Branch busy and entertained during the past few months.

Branch President, Ron Hackney, attended the annual Awards Ceremony for ANU's College of Physical and Mathematical Sciences on 6 June. At the ceremony, he presented the local Branch's 2010 'Prize for Geophysics' to Hannah Keal for the best results in the Research School of Earth Science's second-year geophysics course.

After a post-IUGG train/bus trip from Melbourne, Tien Grauch and Jeff Phillips (USGS, Denver) stopped in Canberra on 14 July to share lessons in understanding magnetic anomalies over faulted layers and thoughts on potential-field inversion for constructing and testing geological models. Tien showed that rather than being related to chemical processes modifying the magnetic properties of a fault, the juxtaposition of layers with differing magnetic properties is often sufficient to explain anomaly patterns across faulted layers. Jeff gave a useful overview of the benefits and deficiencies of different inversion techniques that can be used to aid the construction of geological models.

On 28 July, Federal President, Dennis Cooke, was poached and brought to Canberra. Kept from a FedEx meeting, he instead gave a timely and informative presentation to a joint ASEG/PESA audience on the "shale gas revolution". Recognising the significance of this revolution, more than 40 people came to hear Dennis' views on the rapidly changing perception of shales as a gas reservoir. Dennis also provided a good overview of where Australia is at. It seems that we need to move beyond the current status of dominantly vertical drilling and we can still do more with 3D seismic for drill targeting and assessment of geohazards.

During a purple-patch in mid August, we hosted back-to-back talks by Rick Blakely (USGS, Menlo Park) and Clive Foss (CSIRO, Sydney). Rick gave a presentation on 18 August to almost 60 people outlining the use of gravity and magnetic data to link active back-arc and fore-arc faults in the Cascadia subduction zone. Rick not only showcased the benefits of curvature, tilt and Euler deconvolution for mapping active faults, but he also highlighted how the Cascadia earthquake map is a proxy for population density (more earthquakes = more people)!

On 19 August, Clive Foss talked to an audience exceeding 30 people on integrated magnetic field and paleomagnetic studies. The goal of this work is to provide tools to help interpreters deal with oft-ignored remanence. Clive gave an overview of these tools and a soon-to-be-released database containing information (including anomaly images) on remanent anomalies in Australia.

A final point of note is that ASEG member and SEG Pacific South Honorary Lecturer, Richard Lane, presented a Distinguished Geoscience Australia Lecture on 31 August. Richard summarised the impact of his richly rewarding lecture tour around South Pacific countries and shared his insight into the current and future of potential field modelling with his GA colleagues.

Ron Hackney

ASEG News

New South Wales

In July, we held the NSW branch annual dinner. This year it was held at the Belgian Beer Café in the city. Much Belgian beer, the odd bottle of red and many mussels were consumed. Profound geophysical discussion is rumoured to have occurred and a great time was had by all.

In August, Ken Witherly from Condor Consulting gave a talk on the evolution of the use of geophysics in the search for blind volcanic-hosted massive sulfide (VHMS) deposits in the Abitibi greenstone belt in Quebec Canada. Ken spoke about how geophysical technologies have contributed significantly to numerous discoveries of VHMS deposits in the Abitibi greenstone belt since the 1950s when airborne EM technologies were first commercialized. Ken noted that since the mid-1980s however, the discovery rate has dropped drastically even with major improvements to geophysical processes involved in deposit formation and the geochemical signatures associated with deposits. Ken noted that at the regional scale, to develop new Greenfields areas, new data sets such as high resolution gravity need to be acquired and assessed along with traditionally acquired EM and magnetics. Many questions ensued and much discussion about current exploration methodologies.

In September, Bruce Dickson spoke about the geophysical indicators of global climate changes. Bruce outlined how geophysical measurements are the most direct indication of changes occurring across the globe due to the warming climate. Bruce spoke about some of the satellite radar, gravity and radiation measurements and the magnitude of changes that are occurring to the ocean, icecaps and the atmosphere. Bruce even digressed to speak about some isotopes and spoke a bit about the philosophical consideration on the scientific method and extrapolation of trends. Much discussion followed Bruce's talk.

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

Mark Lackie

South Australia

The South Australia and Northern Territory Branch has had a busy couple of months. On 22 August we welcomed Julien Muenier from CGG Veritas who presented the 2011 SEG/EAGE Distinguished Instructor Short Course (DISC). Thirty-eight people attended the full day workshop at the Adelaide Convention Centre.

Our annual wine tasting event was held at Cos Restuarant in early September 2011. Look out for the order form on p. 36 in this edition of *Preview*, and on the website.

Future speakers include Dr Stephan Thiel from the University of Adelaide. Stephan will be presenting his work on magnetotellurics in South Australia with a focus on geothermal exploration.

Our annual Industry night will be held in October and our annual student night in November.

The SA branch holds technical meetings monthly, usually on a Tuesday or Thursday night at the Coopers Alehouse begining at 5:30 pm. New members and interested persons are always welcome.

Please contact Philip Heath (philip.heath@sa.gov.au) for further details. If you are an ASEG member and are not receiving emails please ensure your contact details are up to date by contacting aseg@casm.com.au.

Philip Heath

Victoria

On Wednesday 27 July the ASEG Victorian Branch hosted a technical presentation at the Kelvin Club in Melbourne's CBD entitled **'The shale gas revolution in North America and how it might impact Australia (and you!)'** by ASEG national president Dr Dennis Cooke - Program Manager, Unconventional Resources at the University of Adelaide's Australian School of Petroleum. Attracting a healthy turnout of about 20 geoscientists, Dr Cooke's talk addressed the problems associated with extracting hydrocarbons from shales, canvassing economic viability, shale favourability, drilling and fracturing stimulation technologies and pattern versus sweet spot drilling. Needless to say Dr Cooke's talk gave rise to a lively discussion during question time, inevitably broaching current public concern about this technique.

On Thursday 4 August ASEG Victorian branch members enjoyed a very fine evening of micro-brews, nibbles, and cross-disciplinary banter at the Midwinter Social Evening at the Portland Hotel in Melbourne's CBD. The event, which was a joint meeting of the Victorian branches of PESA, SPE and ASEG, was, as always, a great success.

On Monday 15 August the ASEG Victorian Branch hosted the 2011 SEG/EAGE Distinguished Instructor Short Course (DISC): **'Seismic Data Acquisition from Yesterday to Tomorrow'**, presented by Julien Meunier, CGGVeritas, at the Victoria Hotel, 215 Little Collins Street, Melbourne. This well-received workshop, comprising 18 participants, commenced with an historical account of seismology and its rapid evolution into a valuable exploration tool. Through presentation and course manual, Julien provided a comprehensive description of seismology instrumentation and underlying theory within a practical context. Although discussing some survey design, Julien paid particular attention to consideration of signal and noise – identifying the latter to be either source generated or ambient.

John Theodoridis

Geoscience education turns around at Australian universities

Dr Trevor Powell
Former President, Australian Geoscience Council
tpowell@grapevine.net.au

This article first appeared in the Aug/Sept 2011 issue of PESA News Resources (No. 113). Preview *thanks PESA for permission to republish the article.*

In 2007 in response to increasing concern among the member societies about the health of tertiary geoscience education in Australia, the Australian Geoscience Council (AGC) undertook a survey of Australian universities with 'geoscience departments' to establish an Australian Geoscience Tertiary Education Profile 2007 (AGTEP 2007). Following the initial impact of the Global Financial Crisis, the resumption of the resources boom and the associated skills shortages, it is timely for the survey to be repeated and updated. AGTEP 2010 provides an up to date stocktake of tertiary geoscience education in Australia and the general capabilities of tertiary geoscience institutions. The full report can be accessed at www.agc.org.au.

The principal conclusion of this survey is that the status of geoscience and geoscience education has improved substantially over the last three years (2008–2010) with a marked growth in enrolled students and academic teaching staff reversing the decade-long decline to 2007. In the 2007 survey there had been an increase in enrolment particularly in levels 1 and 2 in some universities and this has now extended to all levels, particularly at the Honours level, and in many institutions (Figure 1). The situation of geoscience in Australian universities is stronger now than at any time over the past 15 years.

Seventeen universities (Table 1) have the capacity to teach geoscience as a major in their undergraduate programs with an additional university offering an earth science major as part of an environment degree. Of these, six maintain distinct geoscience schools. In the remainder, the geoscience discipline is amalgamated into schools of 'earth, geography and environmental science' or schools of 'physical sciences'. The consequence for the structure of the undergraduate majors on offer varies. Some schools have created 'geoscience degrees' from a blend of physical geography or environmental courses and traditional 'solid earth science' courses. Others have maintained a clear distinction between degree types.

Table 1. Australian universities offering Earth Science degrees

University	School	Geoscience staff*
University of Adelaide	School of Earth and Environmental Science Australian School of Petroleum	34.8
Australian National University	Research School of Earth Sciences	72
University of Ballarat	School of Science and Engineering	4.6
Curtin University	Department of Applied Geology Department of Exploration Geophysics	38.9
James Cook University	School of Earth and Environmental Sciences	17
Macquarie University	Department of Earth and Planetary Sciences	14
University of Melbourne	School of Earth Sciences (includes ocean, atmospheric sciences)	35.6
Monash University	School of Geosciences	22.7
University of New England	School of Environmental and Rural Science	2.5
University of Newcastle	School of Environmental and Life Sciences	13.1
University of New South Wales	School of Biological, Earth and Environmental Sciences	16
University of Queensland	School of Earth Sciences	26.6
Queensland University of Technology	School of Biogeoscience	10.5
University of Sydney	School of Geosciences (includes geography, environmental sciences)	25.5
University of Tasmania	School of Earth Sciences	31
University of Western Australia	School of Earth and Environment	43.4
University of Wollongong	School of Earth and Environmental Sciences	16

**Includes teaching and research staff in geoscience only at the time of the survey.*

Contrary to expectations arising from the 2007 survey, geoscience is still being taught as a component of 'environmental science degrees' at the Universities of Canberra and La Trobe and to a lesser extent at University of Technology Sydney. At Flinders University, an earth science major is offered as part of an environment degree. At RMIT University, an Honours course in Physics-Geophysics is offered to eligible physics or engineering students.

The extent to which course work is undertaken for the completion of an Honours degree varies slightly with institution. Eight universities participate in the Minerals Short Course Program at Honours underwritten by the Minerals Tertiary Education Council (MTEC). All institutions offer MSc by research, but there are several MSc degrees being offered predominantly by course work with a lesser component allowed for a dissertation or thesis. These coursework degrees are often specifically aimed at training candidates in the knowledge and techniques required for employment in industry.

In addition to normal curriculum reviews, several universities have taken specific, or are planning specific steps to meet the needs of potential employers by addressing the core skills requirements of graduates:

- they have made (or are in the process of making) specific teaching appointments in resource geosciences;
- they have remodelled courses to meet core skills requirements and the evolution of disciplines including field geology, digital geology, minerals geoscience and petroleum geoscience;

- placements in industry as part of a course of study; and
- provision of specific options and specializations in majors.

Increasingly, sharing of specialist teaching at the Honours and Masters level is becoming more common, active and systematically organized as follows:

- the national Minerals Tertiary Education Council (MTEC) program where eight institutions teach courses into the Minerals Short Course Program;
- three universities collaborate to deliver the MTEC Minerals Geoscience Masters program;
- the Sydney Universities Consortium of Teaching Geology and Geophysics – Honours Course Electives run by the Sydney metropolitan universities; and
- the Victorian Institute of Earth and Planetary Sciences Honours Program run by Melbourne, Latrobe, Monash and Ballarat.

Nationally, student enrolments as measured by Equivalent Full-Time Student Load (EFTSL) have increased 25% over the past 3 years accelerating the level of growth recorded in AGTEP 2007 of 20% over the previous 5 years (Figure 1). Most universities show increases at all levels while others are static, or have decreased in enrolments at some levels.

A major difference from the previous survey has been the substantial growth in the numbers of Honours students (Figure 1), which have increased nationally by 73% to 265 over the period 2008–2010 compared with the 9% decrease in the previous 5 years and the 60% decrease in the 15 years leading up to 2007. However there is a wide variation between institutions.

There is also a wide variation in student load. The total EFTSL across all levels ranges from 53 to in excess of 350 with 12 (10 in 2007) universities having total EFTSL values above 100 and seven (two in 2007) universities in excess of 150 of which two have values above 250. There are five (seven in 2007) universities with values below 100 of which one (two in 2007) has a value below 55.

Whereas in AGTEP 2007 it was not possible to discern any significant trends in postgraduate degrees, the addition of 3 years of data clearly shows some major changes (Figure 2). The output of MSc/MPhil degrees by research has declined by over 50% while the output of MSc degrees based on coursework has seen a dramatic increase, which appears to be accelerating – up 250% in 2010 compared with 2007. In the five years leading up to 2007, the output of PhD degrees had remained generally static, but since 2007 there has been a decline of about 15%.

In 2010, 256 academic staff are engaged in some level of teaching of geoscience in Australian universities whilst there are a further 183 staff engaged in research with no formal teaching commitments. The numbers in 2007 were 170 and 187 respectively. The dramatic difference is dominated by significant change in reporting from the ANU following internal re-organisation. Removing the ANU, nationally there has been an increase in 22 (13%) staff engaged in teaching while the number of research positions has increased by 18 (13%).

Consistent with the increase in teaching positions among the 'geoscience' schools, there are now eight (three in 2007) schools with more than 12 teaching positions, five (12 in 2007) with 8–12 teaching positions, and four (four in 2007) with fewer than eight teaching positions. The EFTSL per teaching academic ranges from below 5 to 20. There are four institutions below 10 (six in 2007), six between 10 and 15 (seven in 2007), and six above 15 (three in 2007).

The combination of teaching and research positions (Table 1) shows a wide range in capability between the 'geoscience' universities with two having in excess of 40 geoscience positions, four having between 30-40 positions, three having 20–30 positions, six having between 10 and 20 positions, and two having fewer than 10 positions.

The survey shows that the Australian institutions vary widely in their viability as teaching institutions although there has been a general strengthening of 'geoscience schools' as student numbers have increased. There is evidence of considerable effort to meet the work force requirements of graduates both at the undergraduate and MSc levels. Funding pressures remain in some institutions. In others the rapid increase in student numbers, although sometimes accompanied by expansion of teaching staff, is causing an increase in teaching loads at a time of turnover of the 'baby boomer' generation of academics. The decline in PhD output must have a financial impact on departments and, if it continues, must be a concern for the

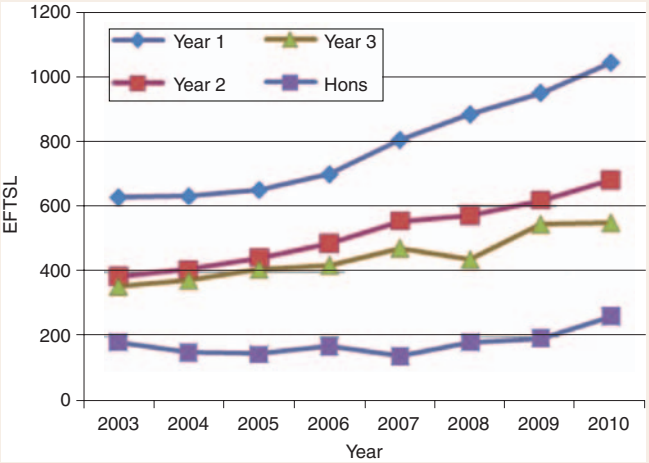


Fig. 1. *Trend in Equivalent Full-Time Student Load (EFTSL) in geoscience at Australian universities 2003–2010.*

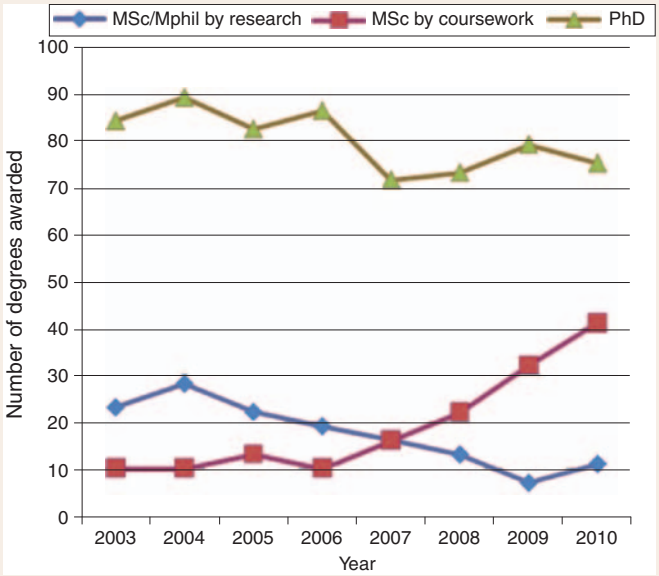


Fig. 2. *Output of higher geoscience degrees in 15 Australian universities 2003–2010.*

long-term viability of geoscience research in Australian universities.

The question asked in the report on AGTEP 2007 remains highly pertinent: 'What is the minimum economic department size that is sustainable in the longer run?' This has to take consideration of government funded student load, fee paying students, academic staff numbers, service teaching to other degrees, external funding for teaching, and research funding. As this survey once again demonstrates these considerations vary from institution to institution and are not easily compared. This is rendered more complex by the changes in the funding arrangements for universities.

In general the position has improved substantially since 2007, but it remains a truism that a critical mass of teaching and research capability that creates a vibrant and attractive educational experience is fundamental to retaining tertiary geoscience educational opportunities in Australia. This survey shows that some larger schools with wide capability are growing from strength to strength, whilst others with lesser capability are static or reducing.