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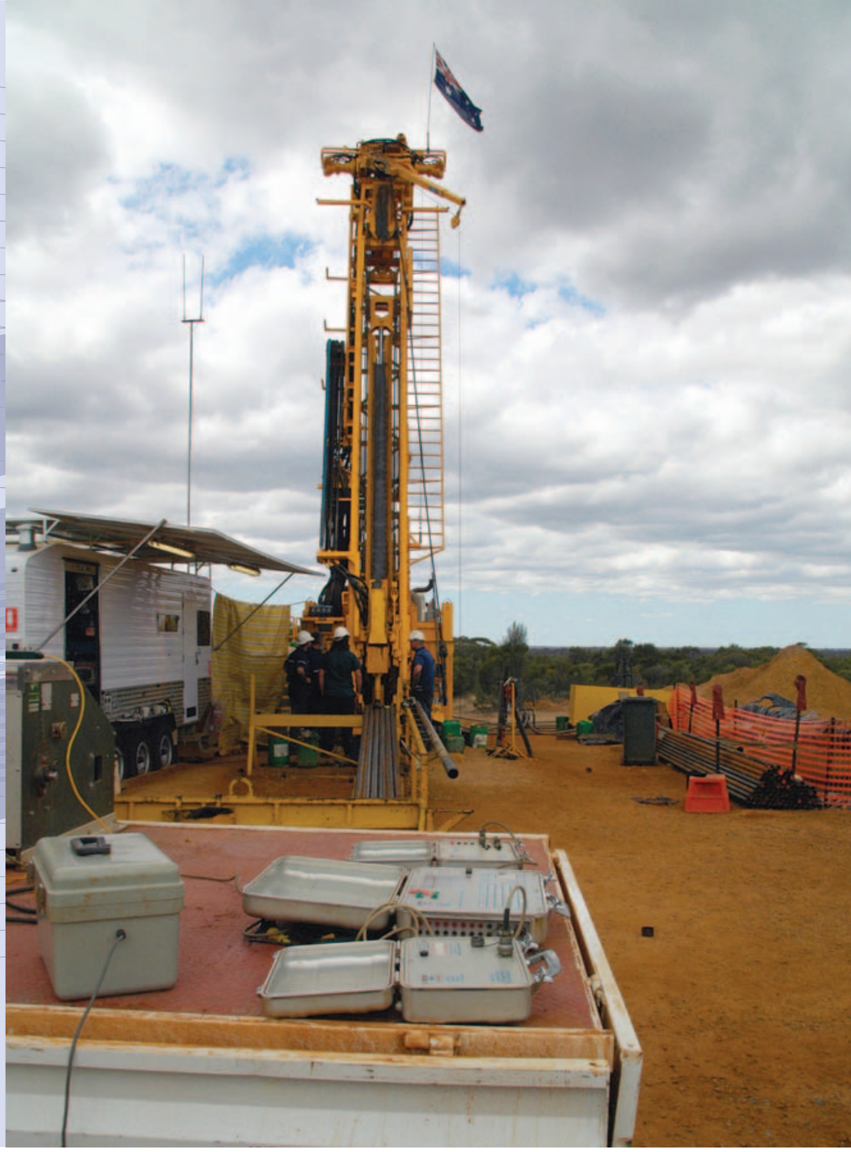
PREVIEW

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

NEWS AND COMMENTARY

FEATURES



PREVIEW

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FRONT COVER

SkyTEM mineral exploration survey near Munglinup, Western Australia, using a 494 m² transmitter loop. Photo: Tristan Kemp, Geoforce, 2007 (see p. 27 of this issue).

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Ann-Marie Anderson-Mayes

This issue has been enormously rewarding to compile. James Reid and co-authors have prepared a thorough review of the SkyTEM system with some Australian case studies. This is complemented by two articles from Geoscience Australia on the Depth of Investigation Grid for regional airborne electromagnetic surveys and results from the Paterson AEM survey. My thanks go to David Hutchinson, Marina Costelloe and Ian Roach for these contributions.

In a new column for *Preview*, we present a profile of Stephen Busuttil who recently joined BHP Billiton in Singapore as Principal Geophysicist, Mineral Exploration. In Industry News, David Denham casts an eye over the state of gold, oil and gas production in Australia. Geophysics in the Surveys contains all the usual summaries plus some information about data and map releases in Queensland and South Australia. And following on from articles published in the last issue of *Preview*, Andrew Long's Web Waves column has taken a look at some websites related to carbon capture and global climate change.

In February of this year, GSWA ran its annual Seminar and Poster Display. The Hon Norman Moore MLC, WA Minister for Mines and Petroleum opened this event and I took the opportunity to invite him to contribute a Guest Editorial to this issue. His article takes a look at the progress of the Exploration Incentive Scheme so far and plans for the future.

Regular readers of this column will know that, since taking over as *Preview* Editor in June last year, I have been urging ASEG members to contribute articles, comments, opinion etc. Issue 144 stimulated a greater than usual volume of correspondence in my Inbox. In particular, the articles on climate change science provoked a range of views and opinions. So, below you will find two responses to Michael Asten's President's Piece on p. 3 of the last issue. Happy reading!

Letters to the Editor

Dear Editor

I found Michael Asten's President's Piece in the February issue (On climate change, the elephant, tusk and tail) a most prescient and thought-provoking summary of the key issues in the so-called climate change 'debate'. For the past few years I have had to read widely about climate science in my role in a major water catchment management authority where I have just completed a climate change impact and adaptation assessment.

During this time I have tried, like Michael, to get across the rich diversity and complexity of climate science, but coming to the realisation that the 'elephant in the room' is in fact the much wider issue of sociology and climate politics fuelled by powerful lobby groups with a vested interest in preserving the status quo. I have been disappointed by the lead taken in the 'sceptics' camp by some of our professorial colleagues in the earth sciences who seem to enjoy the limelight and notoriety of front-page attention in the popular press and talk-back radio.

Science is on attack from all sides. Colleagues from the Bureau of Meteorology's climate group who track media articles are despondent and frustrated by the reporting of at least one major news agency that runs a heavily biased ratio of articles against climate science. It is only in Australia, and to a lesser extent the USA, that this media bias is so evident. The head of CSIRO, Megan Clark felt the need to speak out (ABC radio, 15 March) in defence of climate scientists after attacks on their scientific integrity after publication of the State of the Climate report by the CSIRO and the Bureau of Meteorology.

Climate science, as with any other field of science, does not work by popular 'debate'. Science advances by careful interpretation of experimental or observational data using models and theories within a carefully constrained logical structure, constantly testing challenging via a peer-reviewed process. However there are major vested interests with big stakes aiming to preserving the status quo, and others who seek to win the biggest concessions from the government possible ('rent seeking' as Ross Garnaut calls it). The more discontent and confusion generated in the media the better. Sadly, many of the most voracious opinion-makers are funded by the extractive industries, both in Australia and the USA.

On a local scale, rather than become disillusioned with the state of debate I've decided to become more active in giving public presentations on climate, e.g. at local Rotary clubs. By necessity I have had to expand my first attempts at focussing on climate science to a much broader discussion of political and sociological drivers that fuel the media attention.

Australia's Chief Scientist, Penny Sackett, said on 28 Jan 'it will be very important for the Australian public to disentangle discussions about the science of climate change from the political debate on policies to tackle climate change'.

I couldn't agree more.

Brian Spies
ASEG Past President 1999–2000

In support of science and the scientific method

I write in response to the article published by Michael Asten in the February issue of *Preview*. Given that Michael is the President of a scientific society and one that publishes a peer-reviewed journal, I was astounded and dismayed to see him suggesting as 'references' to climate science, blogs, on-line article and newspapers – no mention of peer-reviewed literature. I am sure no lecturer in geophysics would accept the former as suitable source material for an assignment.

The original idea for scientific societies was for the oral presentation of data and interpretations to be reviewed by one's peers. In this way the acceptable work was separated from the unacceptable. This changed in time into the journals we recognize with the peer-review process still providing a means of stopping publication of work deemed by review to be substandard. Such a process does not occur in newspapers and on-line material.

If those who write in these media feel they have a contribution to make to any branch of science, then there is no impediment to them preparing and submitting a manuscript to a journal. But the reality is that in climate science there are many writers who believe they have the answer but never put it up for scrutiny.

The President seems to suggest that climate science is 'an unshakeable conviction from a partial understanding of the whole truth'. Well all of science is 'a partial understanding of the whole truth', but there is no suggestion anywhere in the published work that climate science or any other science is 'an unshakeable conviction'. Scientists never stop questioning their understanding of any subject. That is almost a definition of a scientist. There are endless of examples of this in every field, including geophysics. Even the finer details of our understanding of gravity are in question due to the 'Pioneer Anomaly'. This is because by training scientists are skeptical, but it is a skepticism that seeks answers. Scientists require repeatability of experiment and accept new ideas only after there is agreement with other related work. The opposite of this is denialism which dismisses the scientific method in favour of beliefs. This is unfortunately the world of blogs and opinion writers – uneducated, untrained and often blatantly wrong. This is not where we should be referring anyone.

I would just like to repeat here a section of a recent submission by the Royal Society of Chemists to the UK Parliamentary Committee looking into the CRU[1] affair and who, more eloquently than me, address the same issue[2].

> *8. With the increased use of electronic media, access to information is widespread for scientists and the public alike. While this is a great benefit to society, the quality and validity of information available raises complex problems as valid scientific information and general opinion are presented side by side. The inability to decipher which information is legitimate, results in confusion, misinterpretation and may lead to mistrust of 'science'. There needs to be a clearer understanding in the public domain of what constitutes a reliable source, including an appreciation for the process that is used for disseminating research and the advantages of peer review.*
>
> *9. The peer review system is central to the credibility of science: its purpose to prevent the dissemination of unwarranted claims and unacceptable interpretations. Formally published scientific research is subject to this authoritative process whereby a community of qualified, impartial experts examine the information and possess the ability to prevent publication. Authors generally protect their data until it has been peer-reviewed and published in a formal publication due to the competitive nature of research.*
>
> *10. The issue of misinformation in the public domain must also be tackled. Just as the scientific community must be open with regard to their evidence base, those who disagree must also provide a clear and verifiable backing for their argument, if they wish their opinions to be given weight. When disagreements occur, the validity of the analysis must be established before credence can be given to any opinion. Increased understanding of the process of scientific research, firstly in the government, but also within the media and general public, is vital in order to foster a more open sharing of information.*

In conclusion, I would hope the ASEG, like the RSC, would be forward in extolling the virtue of peer-review literature as the source of material on any science topic, including climate science.

Bruce Dickson

Michael Asten responds

I thank Bruce for his thoughtful comments. Our point of disagreement appears to be on the role of peer and non-peer reviewed publications in public debate. Of course when we seek to publish a recommendation or view it should be based on peer-reviewed literature, but when we first seek to inform ourselves we will undoubtedly turn to secondary sources. If we didn't, none of us would be reading *Preview*! The books I suggested for reading are both authoritative texts where the primary author is a climate scientist of note. The blogs I mentioned are notable in carrying articles by climate scientists (in addition to much ancilliary uninformed comment which the discriminating reader can ignore). The journalists I mention (Monbiot, Booker) are leading commentators and opinion shapers from either side of the public debate and we may disagree with their views but we can learn from their perspectives.

Michael Asten
ASEG President

[1] The leaking of more than 1000 emails in November 2009 from the University of East Anglia's Climate Research Unit (CRU).

[2] Memorandum submitted by the Royal Society of Chemistry (CRU 42) downloaded 14/3/2010 from http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/memo/climatedata/uc4202.htm

In the next issue...

In the June issue of *Preview*, we are publishing a number of short extended abstracts from the recent seminar, 'Geophysics and Geohazards – Defining Subsea Engineering Risk'. The seminar brought together a range of presenters to examine the application of geophysical techniques to identifying subsea geohazards that present risks both to the safety of offshore operations and ultimately to the marine environment.

We will also be publishing an article on AuScope by Dr Bob Haydon, AuScope CEO. AuScope was established in 2007 to manage the creation and development of a geoscience infrastructure system that would see Australia maintain a leading position in earth science and geospatial research. Delegates at the AESC 2010 in Canberra in July will have the opportunity to find out more about AuScope activities at a 1-day Topical Symposium. AuScope will also be at the ASEG-PESA 2010 conference in Sydney in August.

Exploration Incentive Scheme boosting WA's resources future

Hon Norman Moore MLC
WA Minister for Mines and Petroleum

New information from extensive airborne magnetic and radiometric surveys is set to provide a significant boost to mineral and petroleum exploration in Western Australia. The survey provides 400 m line-spaced, aeromagnetic and radiometric coverage over about 30 per cent of WA which did not have publicly available medium spaced data before. The Department for Mines and Petroleum (DMP) is completing the work under the geophysics program, the largest program in the five year $80 million Exploration Incentive Scheme (EIS) funded by Royalties for Regions (see *Preview*, Issue 140, p. 18 for details).

More than 900 000 km were flown during the past seven months, resulting in the release of nine airborne surveys focused on the Kimberley and Canning Basins in the north and the SE Yilgarn margin and the Eucla Basin in the south east of WA (see Figure 1).

The EIS is also funding a significant regional gravity acquisition program. The recently released Cunderdin survey, covering a large area of the wheat belt provides key information that is not only useful to explorers, but adds to an understanding of the subsurface structures that control groundwater flow and soil salinity. Within the area covered by the Cunderdin survey, the DMP has established an airborne gravity test site with Rio Tinto. This has close-space ground gravity to provide a calibration and experimental test site for airborne gravity gradiometry.

A magnetotelluric traverse, undertaken in collaboration with the WA Centre for Exploration Targeting, has identified major crustal boundaries beneath the mineralized belts of the Yilgarn. Deep crustal seismic traverses will improve the understanding of the crustal structure of WA. Traverses are planned for the Canning and Eucla basins as well as world class surveys providing links from previous surveys in the Yilgarn through the Gascoyne Complex and north to the Hamersley basin.

The State Government will spend $8.5 million by the end of this financial year on capture of geophysics. A further $21.5 million is assigned to these programs in the next three years. The program recognises vast areas of the State that were previously under-explored and provided vital data for potential new discoveries. This is very significant work which can boost new resource discoveries to help unearth tomorrow's mines today.

Mineral and energy exploration in WA has also received a significant boost with the recent call for applications for the 2010–11 Co-funded Exploration Drilling Program. As the EIS's signature program, the Co-funded Exploration Drilling Program supports exploration drilling in the State's under-explored areas. It has been less than 12 months since the EIS was launched by the State Government yet some of the co-funded drilling projects are already showing early indications of potential commercial success.

The program preferentially funds projects which promote new mineral and energy targets. We are targeting innovative exploration concepts and technologies that will encourage industry to drill in areas that have mineral, petroleum or geothermal potential, ultimately helping identify new opportunities. With WA now poised for a surge in mining activity, the State Government wants to identify new opportunities and ensure the prosperity of our resources sector.

Offering co-funding of more than $5 million in the current round, the program is attracting significant interest. The first round of co-funded drilling funding in 2009–10 proved to very competitive, attracting 168 applicants which resulted in 35 projects successfully gaining support from the $3 million in funding offered. The total amount requested from all the first round applicants was more than $15 million. Over the next three years there will be about $5 million per year available.

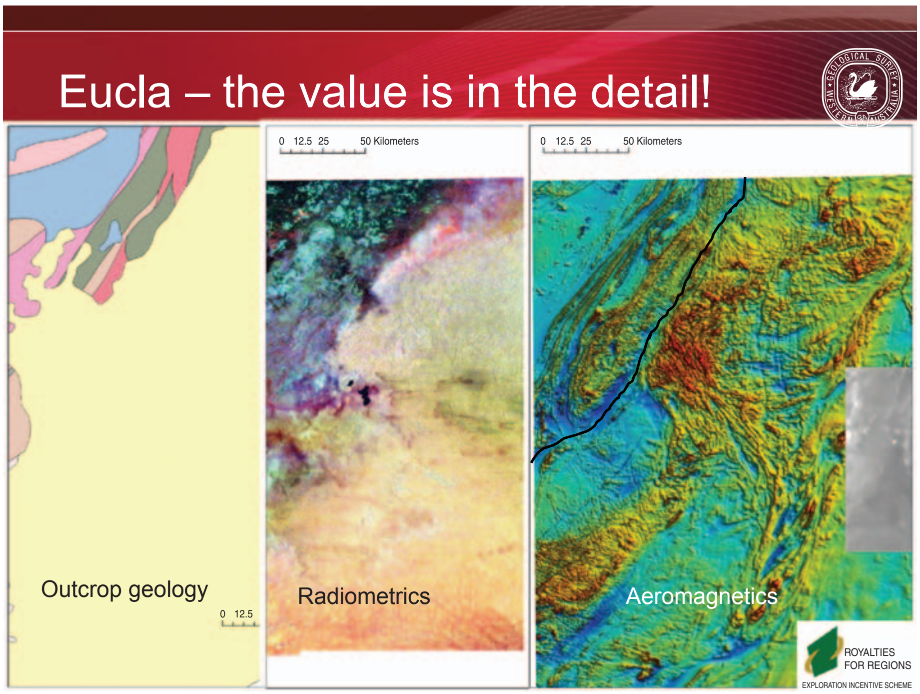

Fig. 1. *Outcrop geology, radiometrics, and aeromagnetics from Eucla, WA. This shows the state of knowledge based on the outcropping geology map. Geology is exaggerated. There is detailed information in the radiometrics that will require careful evaluation. However, the magnetics immediately show complex geology beneath the sand cover.*

The current Co-funded Drilling Program will fund up to 50 per cent of direct drilling costs, with three different caps based on the types of applications. General multi-hole applications are capped at $150 000 while a single deep-hole project can attract up to $200 000 of funding. A special category is available to genuine prospectors with funding being capped at $20 000 per project. The prospector's funding will help support geochemical analyses based on the drilling.

The Geophysics and Co-funded Drilling Program are two of six programs being funded by the EIS focussed on providing new, high quality geoscience information.

To increase the value of the ongoing mapping programs and other data collection undertaken by the Department of Mines and Petroleum, other EIS programs are focussed on value adding through data capture and building and interpreting 3D models and mineral exploration targeting products.

The EIS is an exciting development which was developed in consultation with industry and will go a long way towards keeping WA at the top of the national resources industry. It's a momentous step forward in ensuring the future of this significant part of our economy, particularly following the recent downturn in the economic climate.

WA has fared better than other Australian jurisdictions as the economic climate improves. For the first nine months of last year, the State's mineral exploration spending declined by 22 per cent, in seasonally adjusted terms, from the same period of 2008. This compared with a decline of 30 per cent for the rest of Australia and coincided with the first months following the introduction of the EIS.

The EIS aims to ensure a continuous stream of new resources projects, to replace those already in production. For this reason, it is critical to present this State as a welcoming environment for ongoing investment and this is where the Exploration Incentive Scheme comes in.

I spoke last November about the possibility of enlarging *Exploration Geophysics* into a combined journal of three west Pacific societies, ASEG, the SEG Japan, and the Korean SEG. We have for five years had a very successful collaboration with these groups in producing one combined issue per year titled 'Exploration Geophysics, Butsuri Tansa and Jigu-Mulli-wa-Mulli-Tamsa'. Our proposal for an integrated inter-society journal is evolving through a series of discussions at the SEG Houston last year, with follow-up discussions at inter-society meetings in Japan, Delhi and Melbourne since that time.

Over the financial year to June 2009 EG cost (in very rounded figures) a gross $170 K to prepare electronically and post online, plus a further $30 K to print and post hardcopies. The costs were offset by about $60 K revenue from institutional subscriptions, advertising and pay-per-view downloads of articles. We would very much like to grow the journal, and find that our sister societies are keen to have additional access to a peer-reviewed English language journal, so there is a synergistic opportunity to combine efforts to produce a larger journal, share the costs so that our costs do not grow further, increase the scope and circulation of EG thus giving greater impact to publications of our authors.

How may we achieve this? On the financial side we are negotiating a notional share of costs to be 50 : 35 : 15 ASEG : SEGJ : KSEG, although it may be appropriate to reduce the KSEG share and correspondingly increase the ASEG share in order to assist the smaller society in the start-up years. On the scientific side, it may result in EG having a wider range of papers since some academic authors in Japan and Korea may wish to submit solid-earth geophysics papers; this does not pose a problem since EG has certainly carried such papers in the past although recent years have been limited to mining, petroleum and near-surface applied geophysics. A possible down-side would be removal of automatic printing and mailing of hardcopy; the proposal covers cost sharing to the electronic form of the journal, with each society free to print hardcopy for its members as it sees fit. How would this affect us? How many ASEG members will call for hardcopy delivery if given the option? And how many would dispense with hardcopy if (like the SEG) we charge an additional membership fee for a hardcopy option?

How to maintain editorial standards across the language divides? It would see the appointment of Associate Editors for Japan and Korea who would receive and arrange peer review of papers in the national language, after which a translated paper along with translated reviews would be forwarded to the EG editor who would then assess the paper and have prerogative for calling for additional review/revision as may be appropriate.

We believe it should be possible to provide an enlarged journal, improved opportunity and credit for authors, a greater range of papers for our readership, while containing costs at or below current levels. Before activating any agreement to proceed, we will of course provide a detailed proposal to the membership via State Branches and our website. I encourage members who have comment, advice or questions on the proposal as outlined thus far to contact any member of the Federal Executive, or your State President. We value all feedback.

On another publication front, it is pleasing to be able to report that in the recent review of journal rankings by the Australian Research Council the ASEG, as part of the Australian Geoscience Council, was able to make a strong representation for upgrading the status of several key journals in applied geosciences. The initial ranking published last year rated many applied journals lower than equivalent 'pure geosciences' journals, which had potential to downgrade publication records, access to ARC grants, and promotion prospects for graduate students and academic staff working in mining and petroleum related geosciences.

The following contains examples of changed rankings for two journals each from geophysics, economic geology, hydrology and petroleum geosciences.

Journal title	2010 ARC ranking	Obsolete Feb 09 ranking
Exploration Geophysics	B	C
Geophysics	A	B
Economic Geology	A	B
Mineralium Deposita	A	B
J. Hydrology	A*	A
Hydrogeology Journal	B	B
AAPG Bulletin	A	B
APPEA Journal	B	na

By the time you read this, my Presidential coach will have reduced to the proverbial pumpkin, and Phil Harman will be in the Chair. It has been a privilege to lead the society over the last year, and it is my pleasure to welcome Phil, who has extensive exploration management experience, into the role.

Michael Asten
President
michael.asten@sci.monash.edu.au

From the incoming President

First of all I would like to thank Mike Asten for his work as President over the past year. The ASEG lives in a changing world and many challenges face the Federal Executive and in particular, the President. I was amazed when I joined the Federal Executive just how much goes on behind the scenes that is virtually invisible to the general membership. This is essential not only to the efficient running of the ASEG but is also critical in maintaining our status as a well recognised and effective professional society. Mike has approached the task of President with enthusiasm in a year when there seems to have been a few challenges from 'left field'. On behalf of the Society and the Federal Executive I would like to personally thank him for his dedication and efforts over the past year. I also thank the dedication of the other members of the current Federal Executive and look forward to working with them over the upcoming year.

I have often thought that my grandmother lived in the most interesting of times. She was born in the 1890s and died in the 1980s. During her life she pretty much saw the advent of everything that has given us our modern world. She was born before electric lights, telephones, motor cars, aeroplanes and penicillin and lived to see man walk on the moon. As a geophysicist though, I reckon that I have been lucky to live in times that have been just as interesting.

As a baby boomer born in 1950 and the son of a geologist, I was attracted by the challenge of exploration and 'surely geophysics was the way of the future'. I started my career in the early 70s when many of the fathers of our profession were still very active both on the petroleum and on the minerals side. They had taken technology developed during the two world wars and adapted it to the exploration for petroleum and metals. I was fortunate to meet a number of them and benefit from their generosity in the way they shared their knowledge and experiences. They laid the foundations of a truly exciting profession yet, at the time, none of us could have seen the great strides that would be made over the next 40 years.

However we had a lot to learn! The application of post war geophysical methods during the 1960s nickel boom in Western Australia, demonstrated how little we understood our methods or the earth that we were trying to measure. The credibility of mining geophysicists in the early 1970s when I started was pretty low. However, a commitment by both government and the Australian mining industry, largely through AMIRA, saw the blossoming of research programs that have led to a much greater understanding of the nature of the earth and how we must measure it. More importantly, we have gained a greater insight into background or temporal noise and how to deal with it.

At the same time in the petroleum industry, the advent of digital data processing and the unending drive for computer power has led to an approach and scale to seismic data collection and analysis that was unimaginable even in the early 1990s.

Yet, in spite of all of these great strides one fact remains, the nature of the earth itself is complex both in composition and structure…it doesn't give up its secrets easily…we'd all be out of a job if it did! Taking remotely measured responses and making geological predictions of what is going on at depth remains the fundamental challenge for our profession.

Against all the miserable thinking of the late 90s pundits, the people of the world are getting hungrier for energy and commodities as the poorer nations drive for better standards of living. Unless we believe that the covered earth is barren then that is where the new discoveries will come from. And it doesn't only apply to metals and oil. On the face of it 'hot rock' geothermal energy is a simple concept however, understanding the nature of the earth at 4 km depth is to me the overriding 'elephant' in the room that seems to be relatively downplayed in the presentations by the various promoters.

So, even though geophysics was the way of the future in the 1960s, it still is in the 2010s. I believe that the ASEG has a key role to play in nurturing our profession, through its conferences its publications and through the active support and mentoring of a new generation of enthusiastic geophysical explorers.

I am looking forward to my tenure as President and look forward to your continued support of the ASEG.

Phil Harman
President Elect
phil.harman@bigpond.com

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Australian Capital Territory

The ACT branch held its AGM on 17 March. The event kicked off with a short technical talk by Ned Stolz on Geoscience Australia's efforts to deliver pre-competitive data for onshore energy exploration. Ned covered new applications of GA's nationwide radiometric data and pointed out that since its release at the Adelaide conference last year, the full 100 Gb dataset has already been taken up by 65 clients. Ned also discussed an updated version of the Australian magnetic map (due for release before the middle of the year), initial inversion modelling of new airborne EM data, and the latest on plans for future deep seismic profiling. During the AGM that followed, Ron Hackney was re-elected as president, as was Marina Costelloe as Secretary and Leonie Jones was voted in to continue her marathon run as branch treasurer. Apart from the loss of one member due to an overseas posting, the committee remains largely unchanged and comprises Matt Purss, Nick Rawlinson, Malcolm Sambridge, Ned Stolz and Paul Sutherland (as student representative).

The only other event so far in 2010 was the visit from SEG Pacific South Honorary Lecturer, Ben Clennell, on 12 March. During his pre-lunch presentation at Geoscience Australia, the substantial ASEG/PESA audience heard a comprehensive overview of the theory behind determining the electrical properties of sedimentary rocks and how those properties are determined in the laboratory. Perhaps most importantly, the audience learnt that the physicist's view of rocks is based on no more than circles and ellipses!

The future program for 2010 is still evolving, but the main event in the near future is a visit from Pat Connolly on 18 May to give his SEG Distinguished Lecture on seismic reservoir characterisation.

Ron Hackney

New South Wales

In February, Bob Musgrave, from the Geological Survey of NSW, Department of Industry & Investment, spoke on new ways of extracting depth structure from potential field data. Bob spoke about the need for a visualisation method whereby the anomaly wavelength information related to source depth can be extracted in a form that preserves its map position and trends. Bob has been investigating and developing a number of these approaches, and applying the results in support of recent mapping and interpretation. Bob showed examples of what had been achieved, sparking much discussion amongst the audience.

In March, Ben Clennell, the SEG 2010 Pacific South Honorary Lecturer, spoke on the electrical properties of sedimentary rocks from DC to Dielectric frequencies. Ben introduced us to the high and low frequency realms of electromagnetic behaviour and gave us an insight into how hard it is to take good broadband measurements from DC to GHz and just what parameters you need to consider. Much discussion ensued about the topic and an excellent talk was enjoyed by all.

Do not forget the ASEG–PESA conference in 2010 in Sydney, 22 to 26 August

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. The speaker for the May meeting (17th) is the SEG Spring Distinguished Lecturer, Pat Connolly who will be speaking on seismic reservoir characterisation. The speaker for the June meeting (16th) is John Bishop, who is going to talk about geothermal exploration. Meeting notices, addresses and relevant contact details can be found at the NSW Branch website.

Mark Lackie

South Australia

The South Australia Branch recently held its AGM and first technical meeting of the year. After three years, Luke Gardiner stepped down as President. Philip Heath was elected new President, Mike Hatch returns as Secretary, and Tania Dhu was elected as Treasurer. Ten general committee members were also elected. The AGM also hosted the SEG's Pacific South Honorary lecturer, Ben Clennell. Ben's talk, 'Electrical Properties of Sedimentary Rocks from DC to Dielectric Frequencies' was well received.

The next ASEG technical meeting will be on 25 March, where ASEG President Michael Asten will be giving a talk. Other events for 2010 include Patrick Connolly and Colin Sayers from the SEG, as well as our annual wine tasting, Melbourne Cup lunch, Student and Industry nights.

The SA Branch holds technical meetings monthly, usually on a Thursday Night at the Coopers Ale House, 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

Western Australia

The Western Australian branch looks forward to participating in the SEG's 2010 Lecture program. The Pacific South Honorary lecturer, Ben Clennell, was due to make his presentation in Perth on 14 April. Unfortunately, this presentation has had to be postponed. ASEG President, Michael Asten, has agreed to step into the breech and will be presenting 'Electromagnetic Induction Detection and Discrimination of UXO Using an Array of Fluxgate Magnetic Sensors'. On 26 May, Patrick Connolly, SEG Distinguished Lecturer for Spring 2010, will give his presentation in Perth – 'Robust workflows for seismic reservoir characterisation'.

Reece Foster

ASEG News

The ASEG extends a warm welcome to 27 new members to the Society (see table below). These memberships were approved at the Federal Executive meetings held in January and February 2010.

Name	Organisation	State	Member grade
James Austin	Pangara Resources	NSW	Active
Kent Balas	Monash Uni	VIC	Student
David Chua	Monash Uni	VIC	Student
Guillermo Chutrau	Chevron	WA	Active
Emma-Lee Dellar	Rio Tinto	WA	Associate
Geoffrey Dunn	Geoforce	WA	Active
Russell John Eade	Geoforce	WA	Active
Richard Eden	Petroleum Geo-Services	WA	Active
Mark Grujic	Monash Uni	Vic	Student
Mohammed Hayat	Geoforce	QLD	Active
Laura Ellen Huebner	Terralliance	USA (SEG member)	Active
Stephen Johnson	Monash Uni	VIC	Student
Ward Justin	Zircon Geophysics (Consultant)	VIC	Active
Sam Long	Geoforce	WA	Associate
Antonio Menghins	Consulting Geophysicist	Italy	Associate
Riaan Mouton	Geoforce	WA	Active
Aaron Mullineux	Geoforce	WA	Active
Barry Muprhy	Fractore Pty Ltd	VIC	Active
Robert Nesbit	Schlumberger Australia Pty Ltd	WA	Active
Adrian Noetzli	GPX Surveys	WA	Associate
AJ Pate	ExxonMobil Exploration Co	Texas, USA	Active
Andres Paxton	Schlumberger Australia Pty Ltd	WA	Active
Geoffrey Peters	Geoforce	WA	Active
Takeshi Sato	Geoforce	WA	Associate
Elmar Strobach	Curtin University	WA	Student
Jered Townsend	Barrick Gold Exploration Inc	USA	Active
Maria Woodgate	NT Dept of Natural Resources, Environment, The Arts and Sport	NT	Active

We also congratulate the following members whose Membership was upgraded to Active or Emeritus at the Federal Executive meeting in January 2010.

Name	Organisation	State	Member grade
Justin Mark Anning	Geoforce	WA	Active
Tristan Campbell	Geoforce	WA	Active
Mark Alexander Edmiston	Fugro Survey Pty Ltd	WA	Active
Kate Godber	GroundProbe	QLD	Active
Mahammad Heidarian Shahri	Education University	Iran	Active
Darren Peter Hunt	Teck Australia Pty Ltd	WA	Active
Christopher David MacHunter	URS Australia Pty Ltd	NT	Active
David Benjamin Spence	Beach Petroleum	SA	Active
Hugh Tassell	Geoforce	WA	Active
Adam Michael Wooldridge	New Resolution Geophysics	South Africa	Active
Sam Bullock	Fugro Airborne Surveys	WA	Emeritus
Maxwell Allen		ACT	Emeritus
Papken Zarzavatjian		NSW	Emeritus

Kenneth Reginald Seedsman – 10 October 1929 to 25 January 2010

by Keith Johns

When the Geological Survey of South Australia was established in 1946 the Director of Mines, Ben Dickinson, was aware of the potential for application of various geophysical methods to the search for minerals. Thus, the Geophysical Section was created in 1948 with the appointment of Bill Fenner and Colin Kerr Grant; in the following year Dean McPharlin replaced Fenner.

Ken Seedsman, newly graduated BSc from the University of Adelaide, was appointed Temporary Assistant Geophysicist in January 1951. He was engaged, initially, in making regional gravity observations in the lower south-east of the state to assist in definition of the Moorlands coal field, and traverses were extended along the railway lines of the Murray Mallee with the aid of a South Australian Railways motor quadricycle.

Rather more excitement was on offer when Ken was attached to aerial scintillometer surveys at Radium Hill, in the Adelaide Hills and in the Moonta/Wallaroo area using equipment acquired from Canada and installed in Fairchild and Auster aircraft. This was successful in locating uranium mineralisation at Crocker's Well, Mount Victoria and elsewhere. Regional magnetic and radiometric surveys were undertaken using an Avro Anson aircraft from the British Department of Supply with an RAAF crew on Lower Eyre Peninsula, flying systematic parallel traverses 500 m apart at a height of about 65 m. In December 1953 the plane crash-landed near Big Swamp, west of Port Lincoln – the crew, including Ken, were shaken but not injured. A light aircraft while similarly engaged had been forced to land near Wallaroo; overnight, horses that shared the paddock destroyed the fabric of the wings and fuselage!

Airborne magnetic surveys undertaken by Adastra Hunting Geophysics Ltd and by the Commonwealth Bureau of Mineral Resources, Geology and Geophysics (BMR) resulted in the discovery of a new deposit of iron ore near Iron Knob, which was later quarried by BHP Co. Ltd as Iron Princess. Ken was committed to that work and to the expanded application of geophysical methods adjunctive to the launch of a project in 1953, which would be directed to a complete regional survey of the state. The BMR provided aircraft and equipment while Departmental geophysicists were involved with data reduction and map publication.

The search for oil and natural gas became a new field of investigation in 1955 when equipment was acquired and seismic refraction and reflection surveys were carried out at Wilkatana (on contract to Santos Ltd), on Yorke Peninsula, northern Adelaide Plains, and in the Otway, Willunga and Great Artesian Basins. A seismic party was equipped to undertake work in the Innamincka/Cordillo Downs area in 1958 (on contract to Santos Ltd and Delhi Australian Petroleum Ltd) under the direction of Ken as party leader.

Photo 1. *Ken Seedsman with the Minister of Mines, Sir Lyell McEwin, 1958.*

The growing importance and requirements for seismic exploration led to the creation of the Geophysics (Seismic) Section and Ken was appointed Senior Geophysicist in October 1960. He was sent overseas for nine months in 1961 to gain experience in petroleum exploration and seismic technology in USA, Guatemala, France, Germany and Libya. Reflection recording over anticlines in the Cooper Basin led to drilling at Innamincka, Betoota and the discovery of natural gas at Gidgealpa on 31 December 1963.

Ken resigned from SA Government service in April 1965 to become more widely involved in the search for petroleum and was based in Sydney as Consultant Geophysicist with Australian Exploration Consultants Pty Ltd; he was based in Indonesia in 1975–76.

In May 1976 he returned to live in Adelaide to join newly formed Western Mining Corporation (Exploration) Pty Ltd as Chief Petroleum Geophysicist, engaged in farm-out areas of PEL5 and 6 in the Cooper, Eromanga and Pedirka Basins and on other targets until that office was closed. He continued to undertake casual consultancy work for Santos Ltd and compiling seismic completion reports during the period November 1988–July 2005.

Photo 2. *Ken Seedsman.*

Ken was a long-time member of the Petroleum Exploration Society of Australia and a foundation member of the Australian Society of Exploration Geophysicists. He had an enduring interest in and had been a skilful player of football, tennis, cricket and golf; he occupied the same seat at Adelaide Oval (as for attendance at meetings of PESA) long enough for it to be deemed his own; he was one of the original members of the South Australian Oilmen's Golf Association. He was widely regarded for his intellect, integrity and good humour. A doyen of the oil patch, Ken is survived by his wife, Mardi, and daughters, Sarah and Lucy.

M. Turhan Taner – gentleman, scholar and friend

by Ray and Judy Farrell

Dr M. Turhan 'Tury' Taner, pioneering geophysicist, passed away Saturday, 6 February 2010, in Houston, Texas at the age of 82.

Taner was the recipient of numerous accolades including the SEG's highest award, the Maurice Ewing Medal in 1993 and the EAGE's highest recognition, the Desiderius Erasmus Award for lifetime contribution in 2004. During his career he authored or co-authored several groundbreaking papers on geophysical methods and contributed to the development of many technologies still in use today.

Born and educated in Turkey, Taner earned a Diplome Engineer in 1950 from the Technical University of Istanbul. While a postgraduate student at the University of Minnesota in the early 1950s, Taner ventured into the world of computers for his engineering calculations. In 1959, along with Fulton Koehler, his mathematics professor and lifelong friend, Taner formed Scientific Computing to offer computer-based 'problem solving'. Three years later, he landed his first contract for geophysical research after constructing filters to extract a geophysical signal from a seismic section. As reported by Nina Taylor, Tury's client, Dr McCollum, asked him what he knew about geophysics. Taner humbly replied, 'Nothing, sir.' 'Oh, that's good', responded Dr McCullum 'We know where we start from then'. Tury Taner learned, discovered, innovated, and shared from that point on.

In 1964, Taner co-founded Seismic Computing Corporation, which later became Seiscom Delta, a geophysical service company, where he served as chairman, director of research, and senior VP for technology. In 1980 he started Seismic Research Corporation (SRC), and in 1998 SRC merged with Petrosoft and Discovery Bay to create Rock Solid Images.

Over the course of his prolific career, Taner received numerous awards from ASEG affiliated societies, including Honorary Membership in the SEG (1978) and the Geophysical Society of Houston (1979). He was Distinguished Lecturer for the American Association of Petroleum Geologists in 1975 and for the SEG in 1992.

Readers of *Preview* may recognize processes and algorithms critical to their daily work in an overview of some of Tury's contributions to seismic signal analysis and processing.

He devised an algorithm to measure coherency of reflection events along hyperbolic traveltime trajectories in CMP gathers, displaying this coherency as velocity spectrum.

He designed surface consistent deconvolution operators for transition zones with significant variations in near-surface conditions at source and receiver locations. He devised a method to use the conjugate-gradient algorithm to design single- and multi-channel predictive deconvolution operators.

He developed surface-consistent residual statics correction algorithms to address near-surface imaging problems.

He worked tirelessly to create efficient migration algorithms to handle steep dips and spatially varying velocities with minimal numerical artifacts.

He thoroughly enjoyed isolating various seismic attributes, such as reflection strength and instantaneous phase, and displaying these in color displays.

And these accomplishments take us up to the mid 1970s. Recent work includes data and case study analysis using neural networks and examining seismic attributes with methods employing artificial intelligence. Two weeks before his death, we visited Tury at his home in Houston. His health had been declining for some time and we wanted to reminisce about 'old times'. We thought we could cheer him up. But when we arrived, Tury was poring over a copy of a Fortran subroutine critical to his next project (and probably his next patent), which he graciously set aside to visit with us.

Tury developed all these wonderful algorithms, but also took care to effectively communicate their worth to the geophysical community. Sometimes, the simplest things accomplished this. Back in the 'olden days', when we used Ektachrome slides to illustrate our technical presentations, Tury had the most wonderful photographic equipment in his well-appointed office. While almost everyone else talked from full-scale seismic sections, Tury very effectively communicated the results of his work with close-ups – the details of the seismic sections which proved the worth of his processes. With this technique illustrating the quality of his work, Tury was awarded the SEG Best Presentation Award in 1978.

His engineering training, his mathematical skills, and his ingenuity all meshed to achieve great strides in geophysical software development, in seismic processing and in seismic data imaging.

We offer our sympathies to those in the geophysical community who only knew of Tury and his contributions to our science. We extend our condolences to those who knew Tury, for if you knew Tury, you were his friend. As his friend, you knew he was a true gentleman; an artist; an art collector; a jazz musician; a gourmet chef; and more.

Michael Castelberg, former president of Seiscom Delta United, recalls meeting Tury for the first time in 1968 when he presented a review paper on Seismic Velocity Determination at the EAGE in Salzburg, Austria. 'Afterwards Tury, the inventor of the Velocity Spectrum, and already seated on Olympus in my eyes, came up to me and praised my paper. As I was to learn in later years this was typical of his magnanimity and generosity toward all he met, not just the young and nervous'.

'In subsequent years he became my mentor and one of the most important people in my personal and professional life. Later, as our paths turned in different directions,' recalled Castelberg, 'I would run into Tury from time to time. Always his face would light up and he would greet me as if I were one of his dearest friends; as he was one of mine'.

'Early in my career,' remembers Norman Neidell, 'I lamented to Tury that I could not read Geophysics, the IEEE magazine, etc. each month cover-to-cover and understand it all. He told me not to worry. 'Just read each one until you learn just one new thing.' He assured me 'that over time it would all add up'. He was right. And it did remove a lot of stress...'

'We were all were very lucky to come together at a time when computer science in geoscience was brand new', remembers Kathleen Coburn. 'There was a real feeling of new frontiers and this was very exciting.' Tury mined related technologies (e.g. optics) to find concepts and techniques that could possibly provide breakthroughs in signal processing. Ms Coburn remembers that Tury was tireless in his pursuit of those answers and expected those around him to share in his dedication. She also remembers, 'Sometimes he would start those long Saturdays by cooking us crepes on the hot plate in the library!'

His drive for results, coupled with the patience Tury and Dr Koehler showed toward those working to prove their hypotheses, often succeeded in getting more from those people than they believed themselves capable of.

Robert E. Sheriff praised Tury as someone who 'successfully searched for information content in seismic data'. But, added Sheriff, 'The aspect that really distinguished him was that he was a gentleman, in the classic sense – cultured, honest, loyal, the sort of person one wants to associate with'.

The GSH Spring Symposium in 2007, cosponsored by the SEG as a tribute to Tury Taner and his science, was originally known as the Taner Symposium. Almost immediately it became known as 'TuryFest'. We commend the article in *The Leading Edge* for a light-hearted but amazingly solid look at Tury's contribution to our science (http://www.seg.org/SEGportalWEBproject/prod/SEG-Publications/Pub-The-Leading-Edge/Pub-TLE-Non-Technical-Past-Issues/pdf/pdf-archive-2007/tle2606r07220724.pdf).

Tury is survived by his loving family, including his son Jeffrey Taner, daughter Jane Harris and son John Taner. Jeff, who worked with his father at Rock Solid Images, remarked that Tury was so well regarded at his alma mater, Istanbul Technical University, that he was often invited to lecture – not in the school of Engineering where he learned his degree, but in the school of geophysics where he received an Honorary Doctorate.

Ray Farrell summed it up when he wrote, 'He was the role model for the phrase 'gentleman and scholar'. Tury will be missed greatly by the geophysical community. His contributions to the science do not end with his passing but will remain the basis for substantial future advancement.'

Those wishing to share your own memories of this remarkable pioneer should visit www.rocksolidimages.com/tury. Donations in honor of Dr M. Turhan Taner may be made to the National Parkinson Foundation, 1501 NW 9th Avenue, Bob Hope Road, Miami Florida 33136-1494, or online at www.parkinson.org.

ASEG and PESA Conference 2010 update – Sydney, 22–26 August 2010

The organisation for the next ASEG Conference is progressing well and by the time this article is published, the draft programme will have been finalised and most presenters will have submitted their extended abstracts. The exciting programme covers a diverse range of topics including exploration in PNG, geothermal exploration, basin architecture, development of offshore basins, better delineation of groundwater resources, mineral exploration case histories, innovations and challenges in geophysical inversion, and technical innovation. The demand for exhibition space has been very strong, with 95 booths already allocated. There are still some booths available, but act quickly if you are still planning to exhibit. We will be running 13 workshops before and after the conference. We have had very good industry support for the conference, but there are still sponsorship opportunities available. More details of the conference workshops and technical programme will be available soon on the website.

For more information please consult the website: http://www.aseg-pesa2010.com.au

Mark Lackie and Phil Cooney (Co-Chairs)

For the record

With apologies to David Denham, Figure 1 on p. 16 of February's *Preview* (Issue 144) was printed incorrectly. The correct figure is reproduced here, now including all the important data from May 2008 through to the end of 2009.

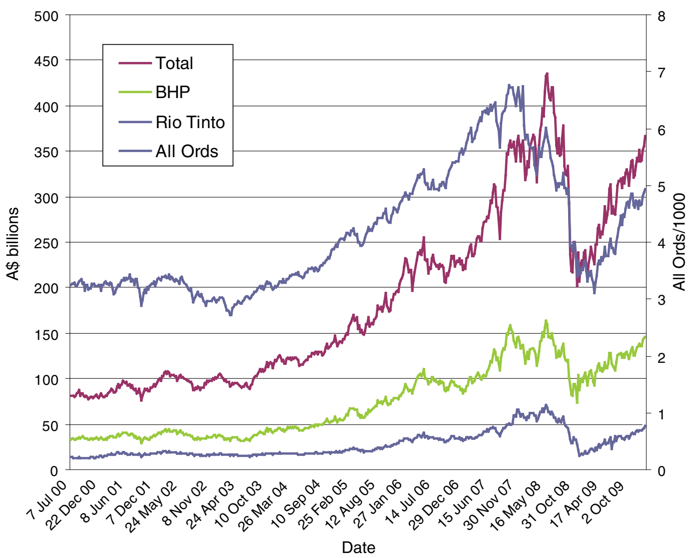

Fig. 1. *Total market capital (in $billions – left hand axis) of the resource companies in the top 150 listed companies on the ASX (red), together with a history of the top two; BHP Billiton (green) and Rio Tinto (blue), and the All Ordinaries Index (AOI) (right hand axis). Notice that the resource stocks crashed well after the AOI did and they recovered more rapidly in 2009.*

News

Update on Geophysical Survey Progress from the Geological Surveys of Queensland, Western Australia, Northern Territory, New South Wales and Geoscience Australia (Information current at 12 March 2010)

Tables 1 and 2 show the continuing acquisition by the States, the Northern Territory and Geoscience Australia of new gravity, and airborne magnetic and radiometrics 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
Crossland – Noonkanbah (East Canning 1)	GSWA	GPX	10 Aug 09	116 700	400 m, 60 m N/S	41 720	100% complete @ 20 Nov 09	TBA	141 – Aug 09 p. 19	4 Feb 10
Naretha (Eucla Basin 3)	GSWA	Fugro	11 Jun 09	123 100	200 m, 50 m E/W	22 090	100% complete @ 4 Nov 09	TBA	141 – Aug 09 p19	4 Feb 10
Eucla Coast (Eucla Basin 6)	GSWA	UTS	24 Sep 09	121 645	200 m (onshore); 400 m (offshore); 50 m N/S	27 400	100% complete @ 26 Dec 09	TBA	141 – Aug 09 p. 19	Anticipated for release 1 Apr 10
Southeast Lachlan	GSNSW	Fugro	1 Mar 10	107 037	250 m (NSW) 500 m (ACT) E/W	24 660	As at Sun 7 Mar the survey was 1.6% complete	TBA	144 – Feb 10 p. 15	TBA

TBA: to be advised

Table 2. Gravity surveys

Survey name	Client	Contractor	Start survey	No. of stations	Station spacing (km)	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
South Yilgarn Margin	GSWA	Fugro	24 Jul 09	6500	2.5 km regular	39 240	100% complete @ 22 Oct 09	11 Feb 2010	140 – Jun 09 p. 17	25 Feb 2010
Southern Cross	GSWA	Atlas	19 Jan 10	7000	2.5 km regular	41 250	100% complete @ 1 Mar 10	TBA	143 – Dec 09 p. 21	TBA
Gascoyne North	GSWA	Atlas	15 Mar 10	7400	2.5 km regular	45 410	TBA	TBA	144 – Feb 10 p. 15	TBA

TBA: to be advised

New solid geology interpretation map, Tallaringa, South Australia

The South Australian Explorers conference was held on 27 November. At this conference a new solid geology interpretation of the Tallaringa and Ooldea magnetic surveys was released. The two surveys, flown in 2005 and 2006 by Fugro surveys, were commissioned by PIRSA and GA. The new solid geology interpretation marks a new step forward for exploration in this area; the previous geological maps of the area only revealed very near-surface geology (Primarily Quaternary and Tertiary sediments). This new interpretation reveals Proterozoic and Archaen structure, and suggests possible sub-divisions of the Mulgathing Complex based on geophysical signature. To obtain a copy of the map, please contact PIRSA customer services through the PIRSA website. Figure 1 shows the map in miniature.

A PIRSA geophysicist was seconded to the Saskatchewan Geological Survey for 3 weeks in December to undertake geophysical interpretation tasks in the Athabasca Basin area. The SGS doesn't employ a geophysicist but has a large amount of geophysical data at its disposal. The output of the trip was a series of improved geophysical grids over the area, gravity and magnetic multi-scale edges, a depth to basement model, and a new solid geology interpretation of the underlying geology of the basin. The next stage of the project involves further secondments, including sending a 3D modelling expert to Canada in early 2010. Further to this, the SGS will be sending a Uranium expert to undertake modelling of South Australian uranium sedimentary systems.

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

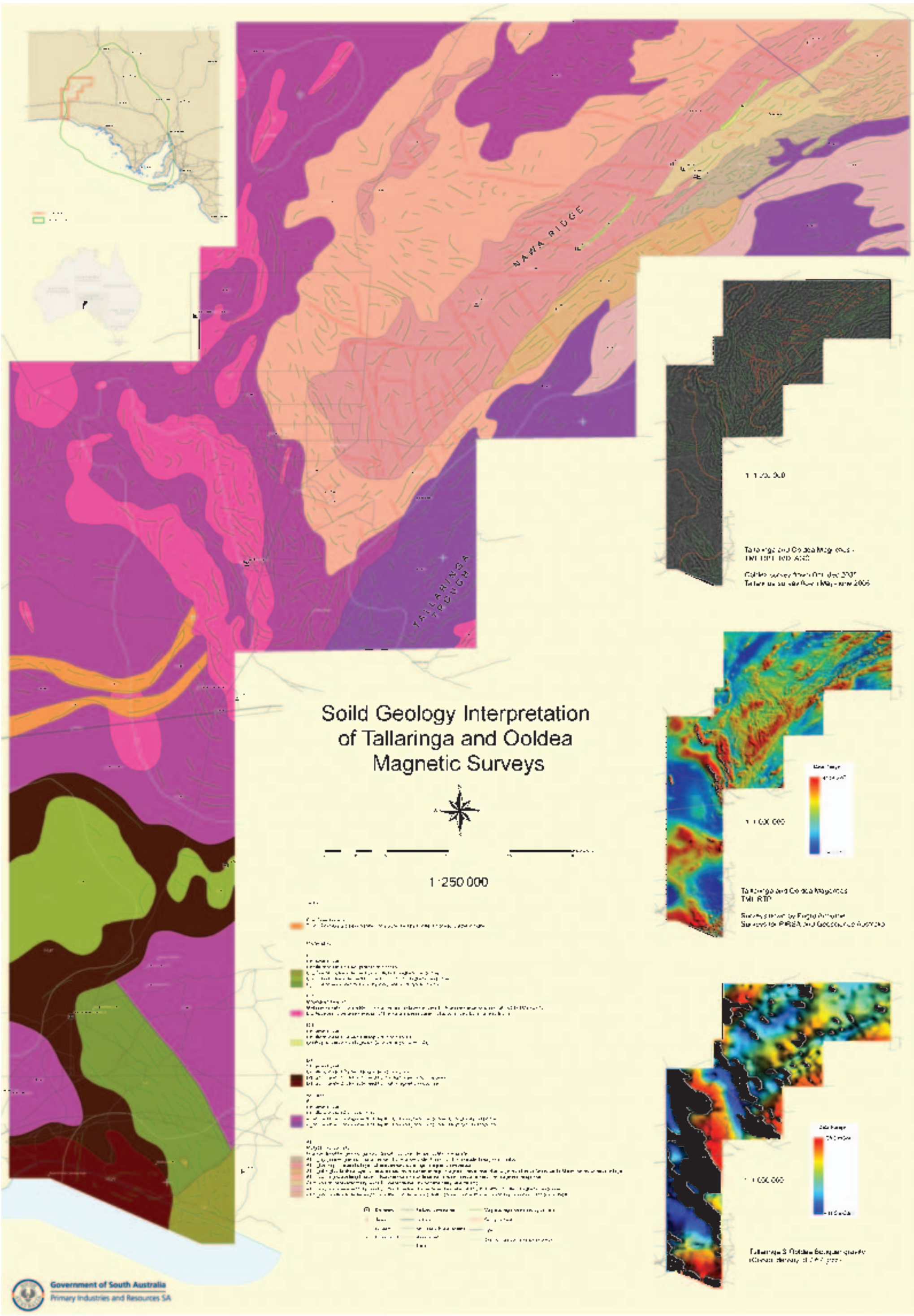

Fig. 1. *Solid geology interpretation of Tallaringa and Ooldea magnetic surveys.*

News

Recent geophysical data releases from the Geological Survey of Queensland

Gravity

Daishsat Pty Ltd carried out a precision GPS-Gravity survey between 11 May and 17 September 2009 on behalf of the Geological Survey of Queensland. The Geoscience Australia project number for the survey is 200940.

A total of 9238 new gravity stations on a regular 4 km by 4 km square grid were surveyed across the Cape York Peninsula region of Queensland. Over 1000 proposed stations were abandoned due to inaccessibility.

Gravity data were acquired using a Scintrex CG-3 automated gravity meter. Position and level data were obtained using Leica 1230GG dual frequency, geodetic grade GPS receivers operating in post-processed kinematic mode. Gravity data were reduced using Geoscience Australia standard reductions on the AAGD07 gravity datum. GPS data were reduced to MGA coordinates with levels expressed as metres above the Australian Height Datum (AHD) as well as metres above the Geodetic Reference System 1980 ellipsoid. Figure 2 shows an image of the gravity data.

Magnetics/radiometrics

GPX Surveys carried out a fixed wing airborne magnetic and radiometric survey in the Cape York Peninsula region of Queensland between 21 April and 10 October 2009 on behalf of the Geological Survey of Queensland.

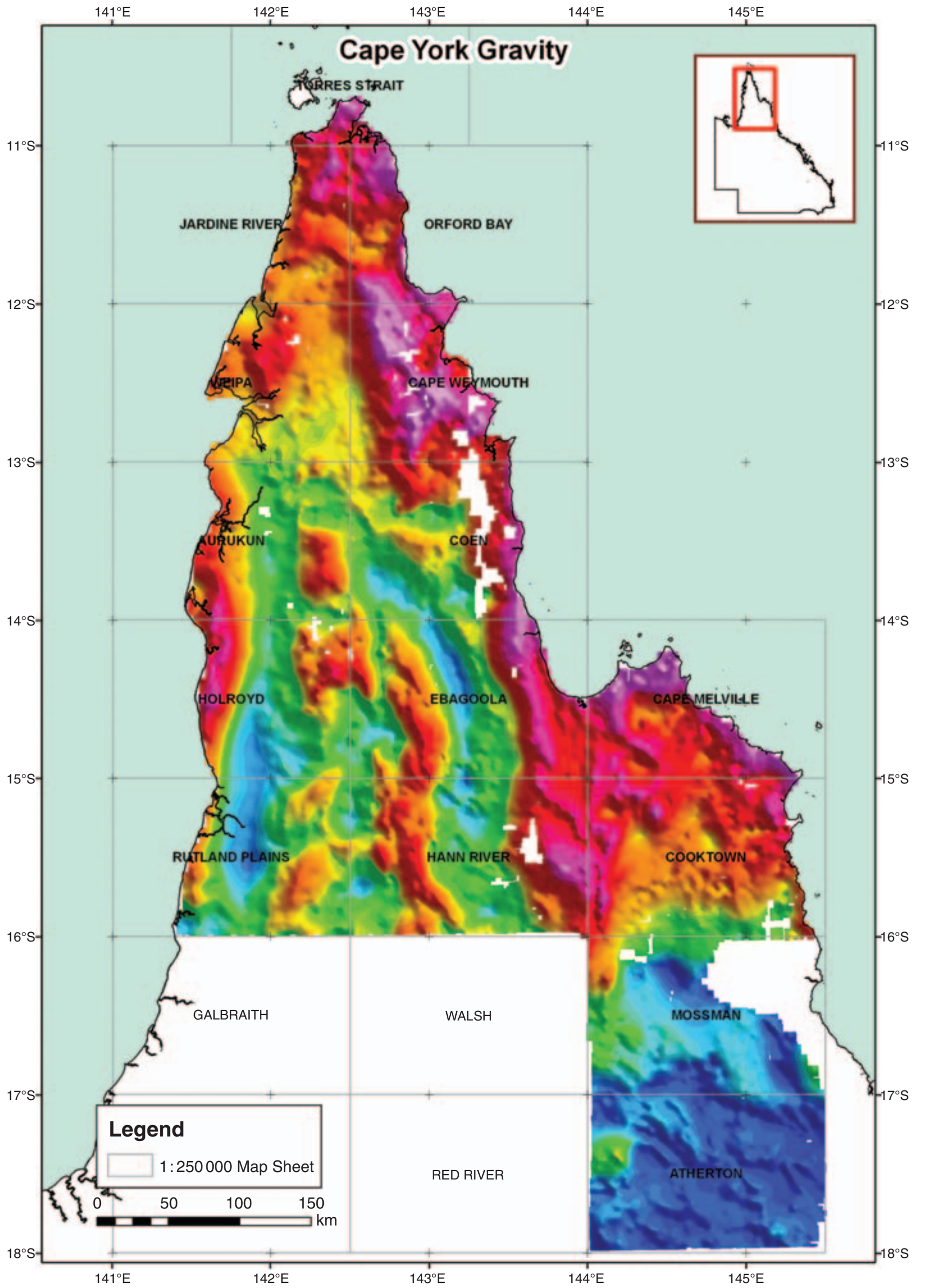

Fig. 2. *2009 GSQ Cape York 4 k Gravity. Image shows colour gravity draped over NE sun-shaded greyscale.*

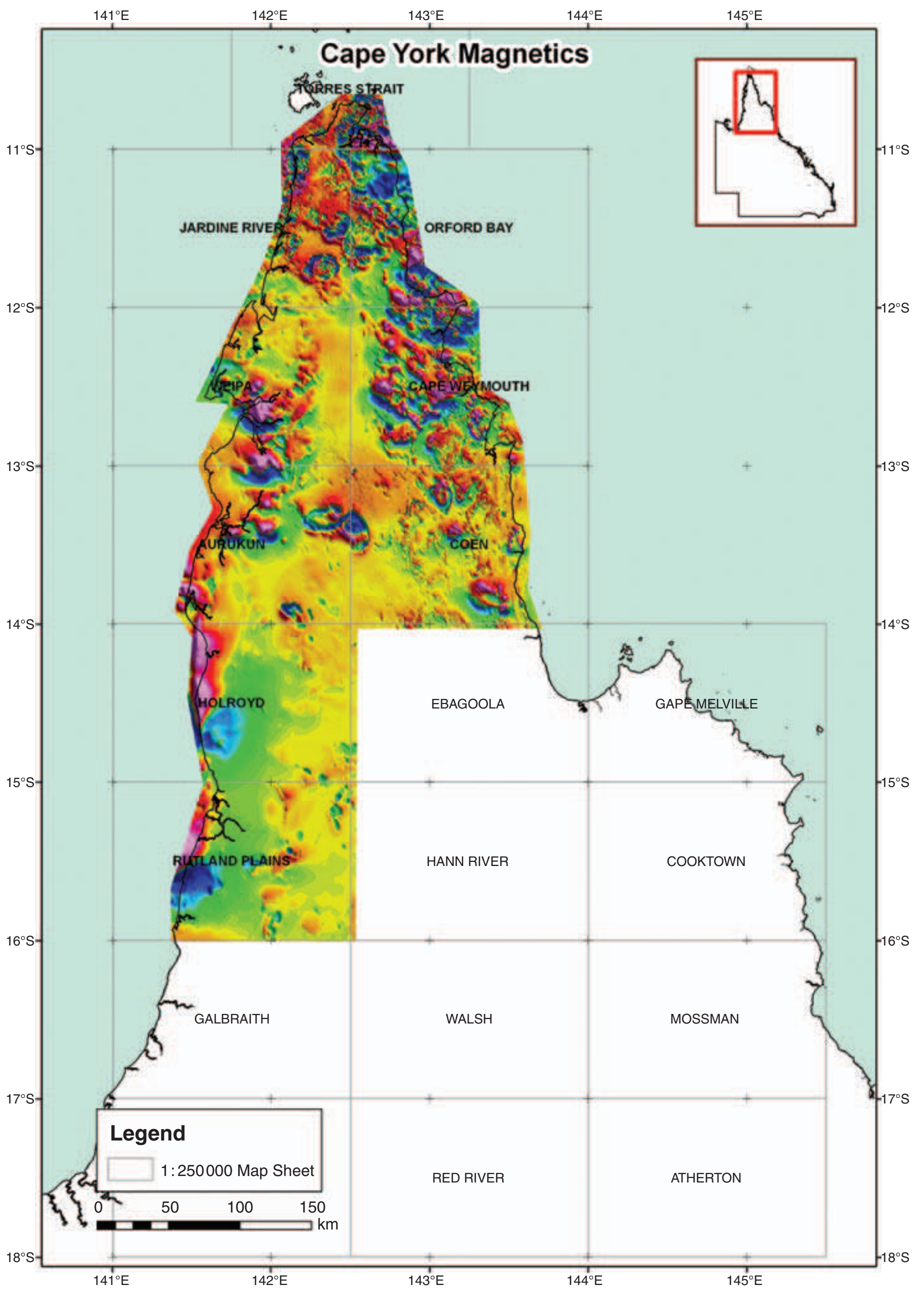

Fig. 3. *2009 GSQ Cape York Magnetics (400 m line spacing data). Image shows colour TMI draped over NE sun-shaded greyscale.*

A total of 239 800 line km of data were recorded along 400 m spaced flight lines at a nominal ground clearance of 80 m. Magnetic and radiometric data were acquired using a Geometrics G-822A Cesium Vapour magnetometer sensor and an Exploranium GR820 (32 litre crystal) spectrometer respectively.

Both located data and final grids are based on GDA94 Datum. Grid products include:

- Digital terrain model (DTM)
- Total magnetic intensity (TMI)
- Total magnetic intensity first vertical derivative (TMI1VD)
- Reduced to pole (RTP)
- Potassium (POT)
- Thorium (THO)
- Uranium (URA)
- Total count (TOT)

Figure 3 shows an example of a magnetics image based on the TMI grid.

Magnetotellurics

Quantec Geoscience completed a Tensor Magnetotelluric (MT) survey in the Millungera, Cloncurry, Dajarra and Mount Isa areas of NW Queensland from 5 August to 2 October 2009.

Seven lines for a total of 240 sites were completed over a frequency range of 0.001 Hz to 250 Hz with site spacing varying between 500 m and 5 km. A number of different inversion algorithms in 1D, 2D and 3D were used to produce maps of electrical resistivity variations of the subsurface.

All basic data, 1D, 2D and 3D Inversions, Survey Operations Report, Quantec and GSQ interpretation reports will be available on DVD in March 2010.

For further information contact Geological Survey of Queensland, Queensland Mines and Energy. Email: geophysics@dme.qld.gov.au

Australian gold and gas production rises but oil slumps in 2009

Gold

Australian gold output rose by four percent in 2009 to 225 tonnes, after several years of declining gold production, according to figures released by the Australian Bureau of Resource Economics (ABARE). The main contributor to this rise was the output from Newmont Mining's Boddington mine. However, there is still a long way to go to reach the 1997 peak of 314 tonnes.

According to Surbiton Associates, Australia is now the world's second largest producer after China, with 314 tonnes, and ahead of the US with 216 tonnes and South Africa with 210 tonnes. Figure 1 shows the annual production of Australia and the world from 1960 through 2009. The world gold production also increased in 2009 by 6 percent, from 2330 to 2470 tonnes. It just goes to show what can happen when the price of gold goes up!

Petroleum

As world gold production increased, petroleum production fell. According to an EnergyQuest report (http://www.energyquest.com.au/EQhome.html) released in March, Australian production of crude oil during 2009 dropped to its lowest level in four decades. It decreased by 17 percent from 120.6 million barrels in 2008 to 99.5 million barrels in 2009.

According to EnergyQuest's CEO, Graeme Bethune, 'The slump in oil production reflects the maturity of Australia's major producing oil fields, together with disruptions due to maintenance and weather'.

'The recent start-up of BHP Billiton's Pyrenees oil field and Apache's Van Gogh field – both situated off Western Australia's north-west coast – will provide a boost in the short-term, however the long-term trend is for production to keep falling', he said.

The fall in oil production was matched by a growth in natural gas production. According to EnergyQuest, 'Natural gas production grew strongly during the year. Total Australian natural gas production increased by 10.1 per cent in the 12 months to December 2009, reaching a record 1897 petajoules'.

Figure 2 shows the fall in oil production from 1975 and the rise in gas production from 1970. Oil production has certainly passed its peak, but the natural gas output looks like increasing for many years to come before the peak is reached.

Peak oil not here yet?

A report by HIS Cambridge Energy Research Associates (CERA) entitled *The Future of Global Oil Supply: Understanding the Building Blocks* (http://www.cera.com/aspx/cda/client/report/report.aspx?KID=5&CID=10720) paints a much more optimistic picture for the arrival of Peak Oil. CERA estimates that global production will be able to rise to as much as 115 barrels per day by 2030, but beyond that date there will be a slow decline. The model assumes that the price of oil will be above the total cost of production until 2030 and that there will be sufficient capital available for investment into the exploration and extraction of oil from new and established fields.

This optimistic view is supported by the results of a survey (www.seismicmicro.com/Survey2009) of geoscience professionals carried out by Seismic Micro-Technology (SMT). The results indicate that respondents anticipate the price of crude will remain between \$50 and \$100 per barrel in 2010, but climb beyond \$100 by 2014.

Sixty percent of respondents indicated that exploration budgets are likely to increase in 2010. This expected increase is substantially higher than the previous

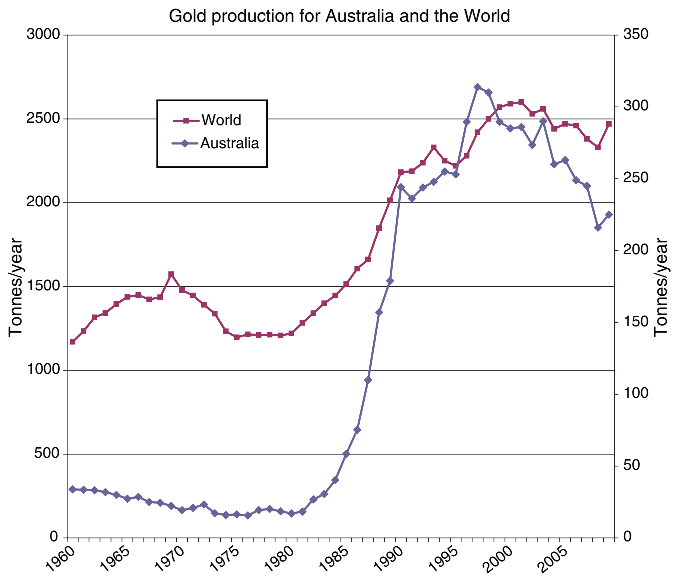

Fig 1. *Annual gold production for Australia and the world for 1960–2009 (data from USGS, ABARE and the World Gold Council).*

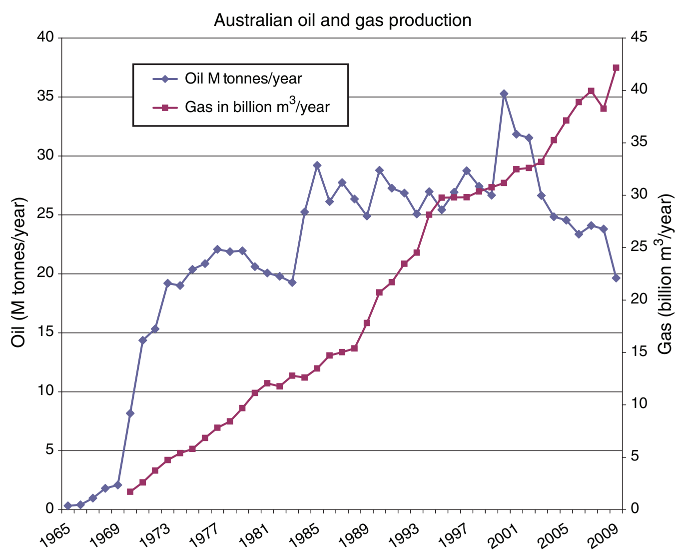

Fig. 2. *Australian oil (from 1965) and gas (from 1970) production. All the figures have been taken from BP's Statistical Review of World Energy 2009 (http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2009_downloads/statistical_review_of_world_energy_full_report_2009.pdf), with the 2009 data added from the GeoQuest report.*

year's survey, in which only 43 percent of respondents anticipated an increase in 2009.

'It's an optimistic assessment', said Indy Chakrabarti, Director of Marketing for SMT. 'It indicates a number of things, including an improved economic climate, an upsurge in competitive strength among exploration companies worldwide, and the benefits of advanced seismic technologies. Today's seismic technologies offer unprecedented visibility of subsurface conditions, and we believe that exploration companies are investing in and better utilizing this technology as a means of minimizing risk and driving business results.'

Approximately 50 percent of respondents predicted global peak oil supply to occur either between ten and twenty years from now, or beyond twenty years. The other 50 percent indicated that it had already occurred, or would occur within the next ten years. Chakrabarti commented that this data would serve as a principal 'hot topic' for industry debates and forums in 2010.

Exploration expenditure holding firm

The optimistic view of the petroleum industry is reflected in the exploration statistics for the December quarter of 2009. Although short of the peak of $1017 million in June 2009, the $827 million reported is still at a healthy level.

Figure 3 shows the petroleum and mineral exploration levels since 1986. It shows that mineral exploration is also encouraging and, at $579 million for the December quarter, is well above the average for the last five years.

In fact, the Global Financial Crisis is a mere blip in the data sets and it puts the 1997 peak back into the noise.

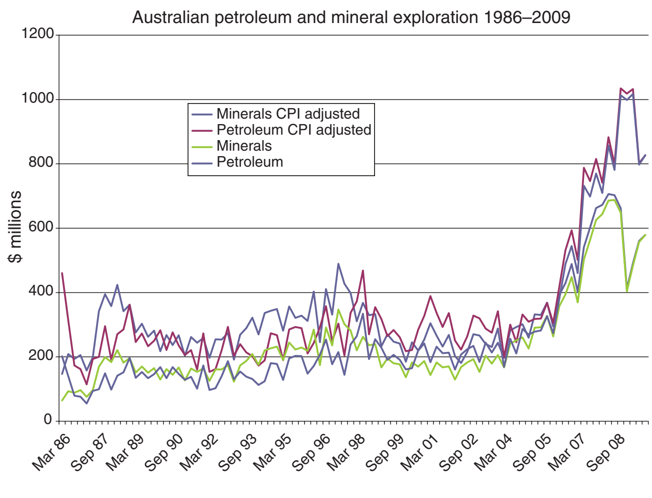

Fig. 3. *Actual quarterly mineral and exploration investment for petroleum and minerals for the period 1986–2009. The raw data and the numbers adjusted to December 2009 dollars have been plotted.*

Steve Busuttil – Principal Geophysicist, Mineral Exploration, BHP Billiton

Steve Busuttil

Steve Busuttil recently joined BHP Billiton in Singapore as Principal Geophysicist, Mineral Exploration. Preview's *Editor decided that this was a good opportunity to commence a new series of People Profiles. Many thanks go to Steve for taking time to participate in preparing this profile. Please contact Ann-Marie Anderson-Mayes (preview@mayes.com.au) with suggestions for geophysicists who could be candidates for these pages in future issues.*

Steve Busuttil first joined MIM in the early 1990s, and was with them for more than a decade. That period was a time of considerable growth in the application of geophysics and hardware development within MIM. It culminated, under the leadership of Nick Sheard, in the development of the MIMDAS system. After MIM and then Xstrata Exploration imploded, Steve became general manager of a spin out group offering MIMDAS and general geophysical services worldwide. He has now moved to BHP Billiton to take up a key strategic position. *Preview* interviewed Steve by email to find out about the highs and lows of his career so far, and to look at the challenges and opportunities presented by taking on a role as Principal Geophysicist for one of the world's largest resource companies.

How did you come to be a geophysicist and what is your educational background?

I have an honours degree from Adelaide and a Masters from Curtin. I'm not sure what the factors were that led me to choosing geophysics. I recall not having any intention of pursuing an earth science career when I first started university. Maybe what swayed me was a combination of charismatic teachers, the adventure of travel and working in remote areas. Having grown up in suburban Adelaide, I think I had a romantic view of that aspect.

For those of us who don't know you, what three key factors characterise Steve Busuttil both as a person and as a geophysicist?

It's always hard to characterise yourself as a person – maybe that's for other people to judge. If I had to pick anything I would say I was someone who enjoyed working in a team environment – in any capacity. I think there is nothing more inspiring than being part of a group of talented individuals who work for a common goal and are successful. It doesn't always work out that way, but when it does it's a good feeling.

I also like to think of myself as a 'hands-on' type of person. Although I should say, that's not always been the case. Working in remote areas and meeting people who live and work there has taught me a few things about the benefits of just getting out there and 'doing it'. I think that's the beauty of working as a geophysicist, you can find yourself in situations that challenge in a number of different ways.

Other than that I'm not sure. Some would say I have a tendency of doing some things to excess but I'm not going to divulge what they are!

Prior to commencing with BHP Billiton, what were the highlights – perhaps both positive and negative – of your geophysical career so far?

I have been quite fortunate to have had the experience of working in both a large company and a small one. Both experiences have in general been mostly positive. MIM had a strong geophysical emphasis during my time there and it was beneficial for me to be part of that. I suppose the negative aspect was that the team was eventually disbanded when MIM was swallowed up. However that provided the opportunity to be a part of a company start up which was a new experience for all of us who were involved at the time.

What is the most interesting or challenging field location in which you have worked and why?

There have been plenty of areas that have been challenging from a logistical point of view. Rough topography always makes life hard. A survey in a reasonably mountainous part of China was the most recent and probably the most difficult area to work in. Although meeting and working with the local people was a great experience.

I think the most interesting projects, technically, are the ones where you're learning new things. Usually these are the ones that provide the biggest challenges. Deeply weathered or covered terrains and complex geology require you to think beyond the routine. One of the benefits of working as a contractor is you get an exposure to many different geological environments which gives you, I think, a better understanding of the methodologies you're working with.

What do you see as the opportunities in your new role with BHP Billiton?

The positive thing about being involved in a large company like BHPB is not being limited by the resources available to you. Large diversified mining companies have a global reach and a wide range of businesses to work in. So there is plenty of opportunity to get involved and make a difference in any number of ways. BHPB, in particular, is in a strong position financially and is looking to grow through exploration success, which is a positive strategy.

What about the challenges?

I think the challenge in any large organisation is to maintain focus, both personally and from a team point of view. There are many demands that an organisation this size throws at you and sometimes it can be difficult to maintain your focus on what's important. The most successful people are the ones that can keep their eye on the ultimate goals and not get bogged down in day to day process.

What do you see as the key challenges for the whole of the exploration geophysics industry?

The biggest challenge, I think, has always been attracting young and talented individuals to the discipline. A low general awareness of geophysics doesn't help our cause here. Although in this area, I think progress is being made. The improvement in our acquisition technologies, our ability to transform data into earth models and display those models in a palatable way to non-geophysicists has contributed to geophysics making it into the public realm. Companies are now, more than ever, before publishing results using geophysical imaging of one sort or another. This can only be a good thing.

We often hear about the worrying trend of declining numbers of new geophysicists graduating from our universities. Based on your personal experience, how would you sell exploration geophysics as a career to the next generation?

I think we do ourselves no favours as technical professionals in bowing to what is our natural tendency to understate or downplay our achievements, particularly to the wider community. Scientific disciplines like ours suffer from a lack of general understanding because our activities are too far removed from the 'real world', i.e. people's everyday lives. However I think we have a good story to tell. I haven't done the research but I'd wager that the vast majority of modern mineral and certainly petroleum discoveries have been in some way aided by geophysics and geophysical technologies. These discoveries have tangible benefits to the real world – economic activity, jobs and improved standards of living. The ability to actually make a difference to the wider community is a positive message that would resonate.

An overview of the SkyTEM airborne EM system with Australian examples

James Reid

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Introduction

SkyTEM is a high-resolution helicopter-borne time-domain electromagnetic system. The system is very versatile and can be very easily configured, with most parameters being software selectable in the field. This versatility makes the system applicable to a wide variety of geological problems.

The principal features of the SkyTEM system are as follows:

- SkyTEM is a calibrated system designed to give quantitative electromagnetic data across a wide time range, as required for detailed investigations where it is often necessary to be able to distinguish geological units with very slight differences in conductivity. Ancillary data measured by the system includes laser altitude, GPS elevation, transmitter loop attitude, and peak transmitter current for each transient, enabling rigorous quantitative interpretation of the electromagnetic data.
- The instrument is uniquely capable of operating in dual moment mode, combining the high shallow and lateral resolution offered by early time data measured at high base frequency and low current, with the large depth of investigation from later time measurements at low base frequency and high transmitter moment. The transmitter can easily be configured to operate at a range of base frequencies and delay times, and the measurements can therefore be optimised for a range of target depths and conductivities.
- The receiver coils measure both vertical (Z) and horizontal in-line (X) components of the secondary voltage response. The X-component provides additional resolution of lateral conductivity contrasts and steeply dipping conductors.
- The receiver coils are placed so as to be null-coupled to the primary field of the transmitter, in order to minimise the self-response of the system. The bias signal from the transmitter is very low, and no levelling of the electromagnetic data is required. As a consequence data can be processed and inverted in the field, allowing rapid assessment of survey results and planning of infill lines etc. whilst a survey is in progress.
- The low flight height provides high lateral resolution and improved shallow depth resolution.
- Advanced quantitative interpretation programs are available. Fast approximate layered earth interpretation using iTEM can be performed faster than the rate of data acquisition, enabling very rapid data turnaround. Full nonlinear laterally or spatially constrained inversion can provide improved resolution of layer depths and allows straightforward application of constraints on the conductivity model both laterally and with depth. Incorporation of additional constraints on the inversion, based on geological considerations or additional geophysical data, can be readily performed.

SkyTEM has been deployed in Australia since late 2006, and is operated by Geoforce Pty Ltd under an agreement with SkyTEM Aps, Denmark. Survey objectives in Australia have included groundwater exploration, salinity mapping, contaminated site and tailings dam assessment, and exploration for a range of mineral commodities, including channel iron deposits, palaeochannel and unconformity-hosted uranium, gold, manganese and base metals. Surveys have been successfully and safely conducted in both remote and urban areas, including around active industrial and mine sites. Australian clients have included Federal and State geoscientific, water resources and environmental organisations, CSIRO, and major and junior mineral exploration companies.

This paper will discuss the technical specifications of the SkyTEM system including a brief summary of the data processing and inversion techniques applied to the data. It will then present results from a number of case studies at locations around Australia (see Figure 1).

Technical

The SkyTEM system has a number of novel design features which distinguish it from other helicopter transient electromagnetic systems operating in Australia.

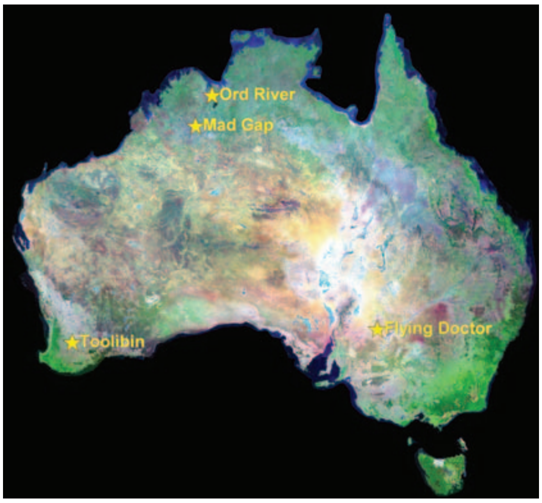

Fig. 1. *Locations of surveys discussed in this article.*

Configuration

The system is carried as an external sling load, and is independent of the helicopter. A small navigation screen is installed in the helicopter, which receives positional and altitude information via wireless link from GPS antennae and laser altimeters mounted on the transmitter loop frame (Figure 2). Other essential operating parameters, such as transmitter current and temperature, battery voltages, pitch and roll of the transmitter loop etc. are also available to the pilot. All navigational and operating parameters can also be received by the ground crew when within radio modem range. The SkyTEM transmitter is powered by a motor generator mounted on the tow cable.

In Australia, surveying is conducted using light helicopters such as AS350BA or AS350B2. Average survey groundspeeds are 80–100 km/h, although the transmitter frame can be rigged for speeds of 60 km/h or lower if required for detailed surveying around built-up areas or in very rugged terrain. In favourable flying conditions e.g., long flight lines and flat terrain, sustained production rates of 400–500 km/day have been regularly achieved.

The instrument geometry is fixed, with the transmitter loop, receivers and all ancillary instruments rigidly mounted on the transmitter loop frame. A 314 m^2 transmitter loop has been used for the majority of surveys conducted in Australia, although a 494 m^2 loop is also available. Ancillary instruments include two independent GPS receivers, two independent laser altimeters and two sets of independent inclinometers, providing redundancy in the case of instrument failure while the system is airborne. The redundant ancillary datasets are also very useful during quality control of survey data. Each inclinometer set measures the tilt of the frame from horizontal both in and perpendicular to the flight direction. The rigid geometry of the system means that the DGPS position and inclinometer information can be used to determine the exact position of all sensors in three dimensions. Tilt information is used to correct measured laser altimeter data to the vertical, and can also be used to perform an approximate correction of the EM data for transmitter attitude (Auken et al., 2009).

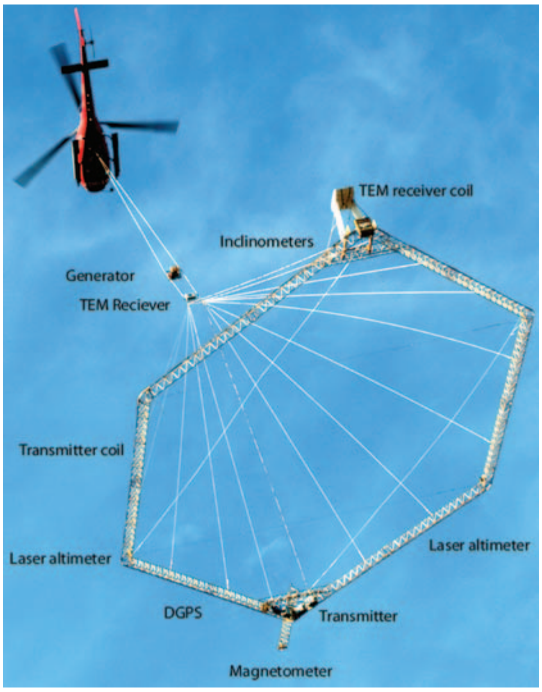

Fig. 2. *SkyTEM system in flight, showing the instrument configuration.*

Transmitter

The SkyTEM system has been designed to provide calibrated electromagnetic data over a wide range of delay times. The SkyTEM transmitter is capable of operating in several different modes.

High-moment (HM) mode uses four transmitter turns and a peak current of ~100 A. Ramp time in HM mode is typically 45 µs. Base frequency may be either 25 or 12.5 Hz in regions with 50 Hz powerlines, or 30/15 Hz where the powerline frequency is 60 Hz. The 25 Hz base frequency uses a 50% duty cycle, and yields gate centre times from the start of the current ramp of between 71 µs and 8.8 ms. The 12.5 Hz base frequency employs a 25% duty cycle, with an on-time of 10 ms and off-time of 30 ms. The maximum gate centre time at 12.5 Hz is 26.6 ms.

Low-moment (LM) mode uses a single transmitter loop turn and a peak current of ~40 A. Base frequency in this mode is 222.2 Hz, with an on-time of 1 ms and off-time of 1.25 ms. Ramp time is typically ~8 µs. LM gate centre times typically range from 14.2 µs to 0.897 ms.

Other transmitter modes, such as Super Low Moment (SLM; Auken et al., 2009) allow unbiased data from 10 µs, but to date have not been employed in surveys in Australia.

Examples of HM and LM current waveforms measured in the field are shown in Figure 3.

The SkyTEM data acquisition script is software controlled, and data may be acquired solely in HM or LM modes, or using a combination of the two (dual moment). In dual moment mode, data is sequentially acquired at HM and LM. Noise measurements with the transmitter off can also be included in the acquisition script – these can provide useful information on background noise levels which may be utilised during inversion of the data. The unique flexibility of the SkyTEM instrument means that acquisition can be optimised for a particular geological objective. The fast turn-off and early sampling times of the LM mode provide high shallow resolution and increased sensitivity to weakly conductive targets, while the higher current and late delay times of the HM mode provide a large depth of investigation.

The peak transmitter current for each transient is recorded and is used in data processing and inversion.

The main transmitter parameters are summarised in Table 1.

Receivers

The sensors are shielded overdamped coils with an effective area after preamplification of 105 m^2 and a low-pass cutoff frequency of 450 kHz. Both X and Z-components of dB/dt are measured, with the coils placed in positions at the edge of the transmitter loop where they are approximately null-coupled to the primary field of the transmitter. Detailed aspects of the signal detection scheme are given by Sørensen and Auken (2004). Note however that some of the waveform and filtering schemes described by them have since been superseded, as described in this article. The receiver electronics have a user-selectable low-pass filter. A value of 300 kHz is often used to avoid distortion of the early-time response, which is critical for providing reliable shallow

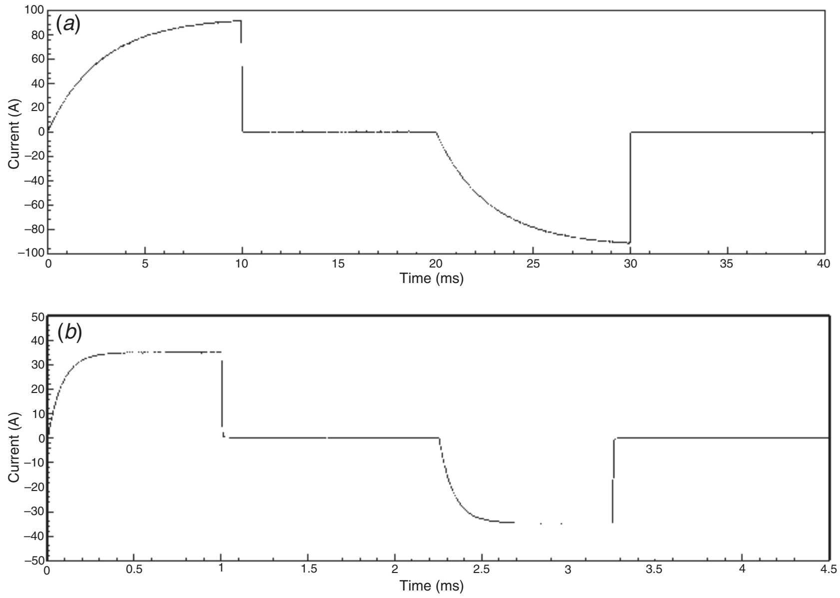

Fig. 3. *SkyTEM (a) high and (b) low moment current waveforms.*

Table 1. Transmitter specifications

EM transmitter – high moment	
Transmitter loop area	314 m^2
Number of transmitter loop turns	4
Average peak current	103.0 A
Peak moment	129 370 A.turn.m^2
Tx loop terrain clearance (nominal)	30 m
Tx waveform – high moment 25 Hz	
Base frequency	25 Hz
Tx duty cycle	50%
Tx waveform	Bipolar
Tx on-time	10 ms
Tx off time	10 ms
Tx ramp time	45 µs
Tx waveform – high moment 12.5 Hz	
Base frequency	12.5 Hz
Tx duty cycle	25%
Tx waveform	Bipolar
Tx on-time	10 ms
Tx off time	30 ms
Tx ramp time	45 µs
EM transmitter – low moment	
Transmitter loop area	314 m^2
Number of transmitter loop turns	1
Average peak current	41.6 A
Peak moment	13 063 A.turn.m^2
Tx loop height (nominal)	30 m
Tx waveform – low moment	
Base frequency	222.22 Hz
Tx duty cycle	44.4%
Tx waveform	Bipolar
Tx on-time	1 ms
Tx off time	1.25 ms
Tx ramp time	8.5 µs

information. Each individual transient is recorded, along with important ancillary data such as peak current.

The main receiver parameters are summarised in Table 2.

Table 2. Receiver specifications

EM Receiver	
EM Sensors	dB/dt coils
Rx coil effective area (Z and X)	105 m^2
Low pass cut-off frequency for Rx coils	450 kHz
Low pass cut-off frequency for Rx electronics	User-selectable
	300 kHz
	100 kHz
	30 kHz
	10 kHz
Z-component Rx coil position	
Behind Tx loop centre	12.62 m
Above plane of Tx loop	2.16 m
X-component Rx coil position	
Behind Tx loop centre	13.88 m
Above plane of Tx loop	0 m

Data processing

An important aspect of the SkyTEM design is that the receiver coils are null-coupled to the primary field of the transmitter. This minimises transmitter bias and means that regular excursions to high altitude to monitor the bias response are not necessary during each flight. In practice, high altitude flights are only required at the start of a survey to confirm correct operation of the instrument, and at approximately weekly intervals thereafter. The transmitter bias measured at high altitude can be compared with the response measured at survey altitude. Rather than attempt to correct for the bias by subtracting the response measured at high altitude, channels where the bias is >2% of the earth response are not used for subsequent processing and inversion. For surveys where the dual transmitter mode is employed, the LM mode provides unbiased data at those high moment channels for which the bias signal is strongest, so there is no loss of information when biased early-time HM channels are excluded.

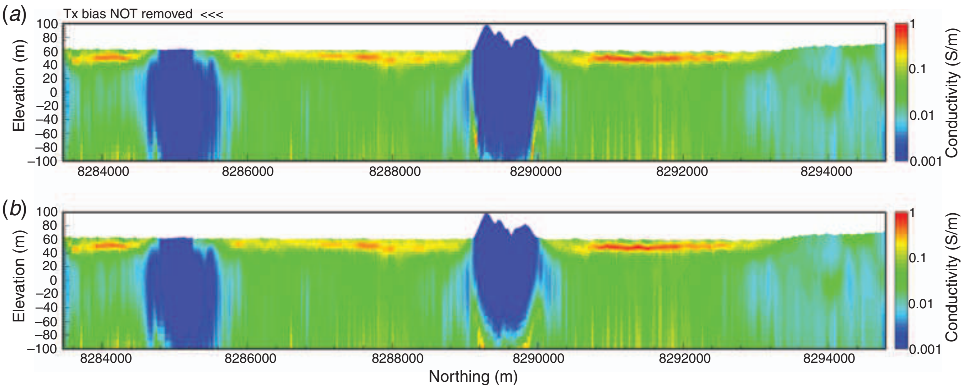

Fig. 4. *30-layer iTEM fast approximate layered-earth inversions of SkyTEM high-moment Z-component data from the Ord River survey. (a) Raw data; (b) data with transmitter bias subtracted. The similarity between the two sections indicates that the transmitter bias is negligible.*

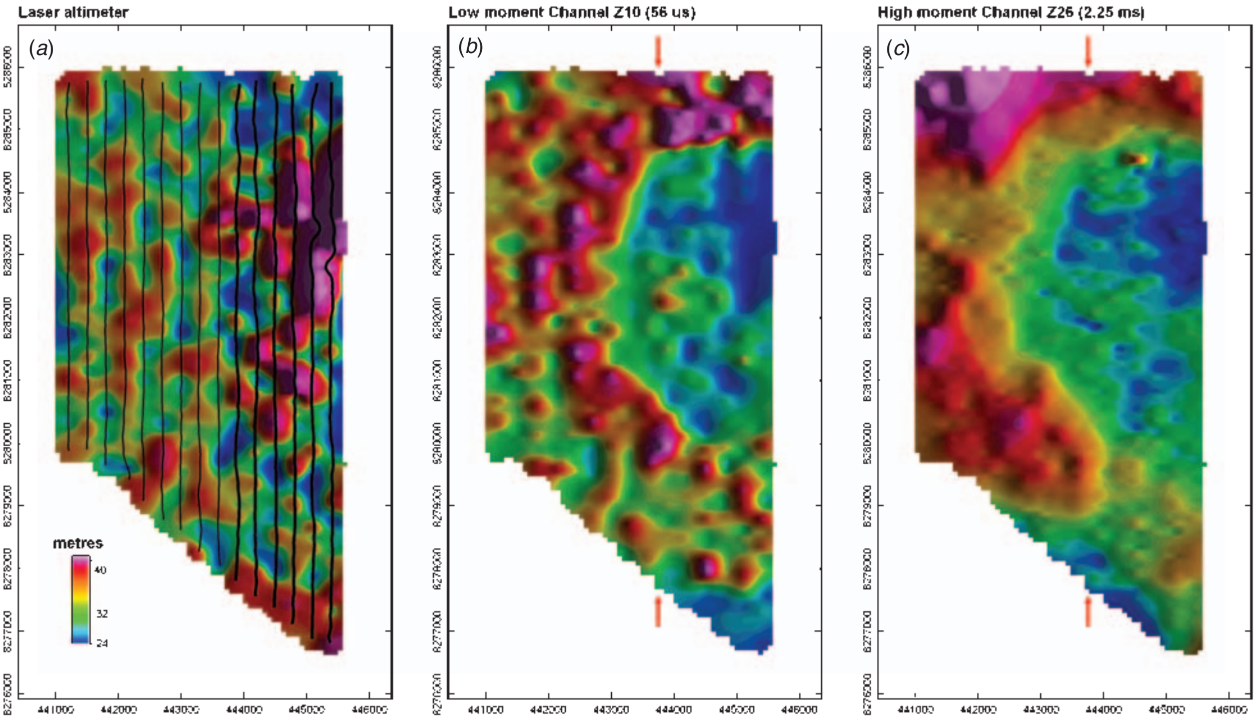

Fig. 5. *Images of raw SkyTEM data from two flights conducted 17 days apart at Ord River, Western Australia, illustrating that levelling of SkyTEM data is not required. (a) Terrain clearance and flight lines. The two individual flights are indicated by heavy and fine flight paths. (b) Stacked Z-component data from low moment channel 10 (56 µs). (c) Stacked Z-component data from high moment channel 26 (2.25 ms). Arrows on (b) and (c) mark the boundary between the two flights. The images have been sunshaded from the east, perpendicular to the flight line direction.*

Figure 4 shows comparsions of iTEM fast approximate layered-earth inversions of the data from a large survey at Ord River, Western Australia. The inversion was performed on data without (top panel) and with (lower panel) the bias removed. There are only very minor differences between the two cross-sections, even at shallow depths where the effect of any bias should be largest. The similarity of the inversion results demonstrates that the bias is negligible in comparison with the earth response in this example.

The very small bias signal means that preliminary presentation and inversion of SkyTEM data can be performed without the need for any substantial data processing or levelling. Figure 5 shows plan images of SkyTEM data from two abutting survey flights conducted during the Ord River survey, which were flown 17 days apart. No processing other than stacking of the data has been performed. Images of the Z-component EM data at LM Channel 10 and HM Channel 26 show that data from the two flights stitches together seamlessly, even when sunshaded from the direction perpendicular to the flight lines. The minimal data processing requirements for SkyTEM mean that inversions can be performed on field-processed data, which yield results very similar to those from final office-based processing, as illustrated by Figure 4. Using the iTEM fast approximate layered-earth inversion code (Christensen, 2002; Christensen and Tølbøll, 2009), inverted SkyTEM data is now routinely delivered the morning after data acquisition.

Quantitative interpretation

A number of quantitative tools have been applied to SkyTEM data, including EMaxAir CDIs (Fullagar and Reid, 2001; Fullagar et al., 2008); iTEM fast approximate layered-earth inversion (FA-LEI; Christensen, 2002; Christensen and Tølbøll, 2009; Christensen et al., 2009) and the full nonlinear laterally constrained inversion (LCI) from Aarhus Geophysics (Auken et al., 2005, 2009; Viezzoli et al., 2009).

iTEM

iTEM is a fast, robust, approximate inversion that yields smooth multilayer layered-earth inversions (LEI) in a fraction of the time required for conventional nonlinear inversion. Each individual sounding is inverted independently (as in conventional LEI). Layer thicknesses are fixed and the data is inverted for the layer resistivities only. The iTEM LEI is now the standard method used to invert SkyTEM data in Australia, due to its extremely fast computation speed and parallelised processing. A standard field laptop with a single CPU is capable of performing iTEM inversion of SkyTEM data faster than it can be acquired. During office-based processing on computers with 8–16 CPU, an entire day's worth of field data can be inverted for a 30-layer model in less than 30 min. Despite the approximations made in the algorithm, iTEM yields smooth conductivity models comparable to those obtained via full nonlinear multilayer inversion.

LCI

In LCI (Auken et al., 2005), a group of TEM soundings are inverted simultaneously using 1D models. Each sounding yields a separate layered model, but the models are constrained laterally on a number of model parameters such as resistivity, layer thickness and/or depth to layer boundaries, i.e. these parameters are permitted to vary only gradually along a profile. The degree of lateral constraint can be set by the user depending on the local geology. The result of the LCI inversion is a quasi-2D model section that varies smoothly along the profile. The LCI inversion is also capable of simultaneously inverting the interleaved HM and LM measurements, yielding a conductivity model that combines the very good shallow depth resolution offered by the low moment data and the larger depth of investigation from the HM data. HM and LM models are linked via the lateral constraints, meaning that the well-resolved shallow information derived from the LM data provides a shallow constraint on the neighbouring HM inversions, and the deep information from the HM data constrains the deeper part of the adjacent LM models.

The LCI code can be run in two basic modes: in few-layer inversion, both the model resistivities and thicknesses are allowed to vary during the inversion, as in a standard LEI. The multi-layer, smooth model mode is similar to that used by iTEM, i.e. the layer thicknesses are fixed and the data are inverted only for resistivity. The LCI smooth-model inversion typically uses fewer layers (12–19) than iTEM. Smoothness constraints are applied on the variation of resistivity with depth, in additional to the lateral constraints between adjacent models. Few-layer LCI inversion gives sharp resolution of layer boundaries and is faster to compute because of the small number of model parameters. However, few-layer inversion can fail if there are insufficient layers in the model to fit the observed responses. Multi-layer smooth-model inversion is slower to compute, but is usually able to provide a very close fit to the observed data. Precise depths of subsurface interfaces are more difficult to determine from smooth-model inversion results.

Figure 6 shows a line of SkyTEM data from Mad Gap, Western Australia, which has been inverted using the iTEM LEI, 17-layer smooth-model LCI, and a 4-layer LCI with additional constraints on the layer resistivities. The profile consists of 588 HM soundings and 237 LM soundings. iTEM inversion of this dataset required a total of 152 s of CPU time on a single processor. This is faster than the time taken to collect the data (165 s was taken for the helicopter to physically fly the line). Note that the computation time can be further reduced by parallel computation on multiple CPU, as is routinely done with larger datasets (i.e. ~20 s computation time for the same line using 8 CPU).

The 17-layer LCI has yielded a result quite similar to that obtained from iTEM, although deep artifacts (vertical striping)

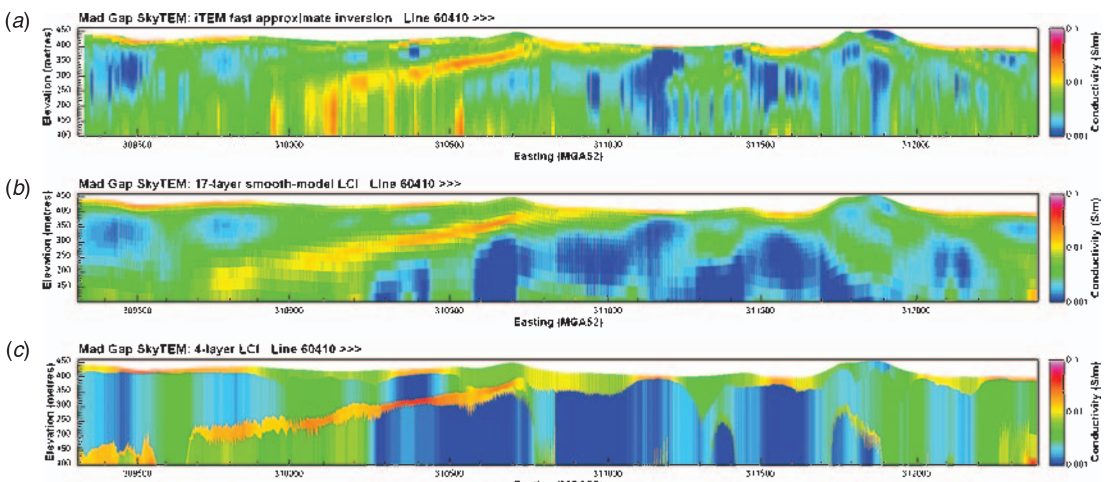

Fig. 6. *Three different inversions of SkyTEM data from Mad Gap, Western Australia. (a) iTEM fast approximate layered-earth inversion with 30 layers. (b) Full nonlinear laterally constrained inversion with 17 layers. (c) Four-layer laterally constrained inversion with layers 1 and 3 constrained to be conductive, and layers 2 and 4 constrained to be resistive.*

in the iTEM section have been removed. The main west-dipping conductive layer also appears to have been somewhat better resolved at depth by the LCI. The 17-layer LCI required 14 760 s to compute on a single CPU, or 97 times the time required for the iTEM inversion. As for iTEM, the computation time could have been reduced by invoking the parallel computation capability in the Aarhus Workbench software (~30 min computation time assuming 8 CPU).

The iTEM and 17-layer LCI inversions suggest that the geoelectric structure in the vicinity of the main west-dipping conductor generally comprises four layers, with three layers (conductor, resistor, conductor) overlying a resistive basement. Constraints were applied to the layer resistivities in order to reflect this conductivity structure, with the aim of improving resolution of the main dipping conductor. Starting layer resistivities were estimated from the smooth model LCI results, and the first and third layers were constrained to be conductive and the other two layers to be resistive. The final 4-layer model shows very good agreement with both iTEM and the 17-layer LCI. The 4-layer LCI model appears to provide the best definition of the main dipping conductor, particularly at depth where the conductor appears to be more laterally continuous than in the other inversion sections. The time required to compute the 4-layer model was 2580 s on a single CPU, or 17 times that required for the iTEM inversion.

Field examples

Toolibin Lake

The initial field trial of SkyTEM in Australia was conducted at Toolibin Lake, Western Australia (Reid et al., 2007). The hydrogeology of Toolibin Lake has been extensively studied, and the area has been the subject of two previous airborne electromagnetic surveys (SALTMAP and TEMPEST) as well as numerous surface and downhole geophysical surveys. The extent of the 2006 SkyTEM survey is shown in Figure 7.

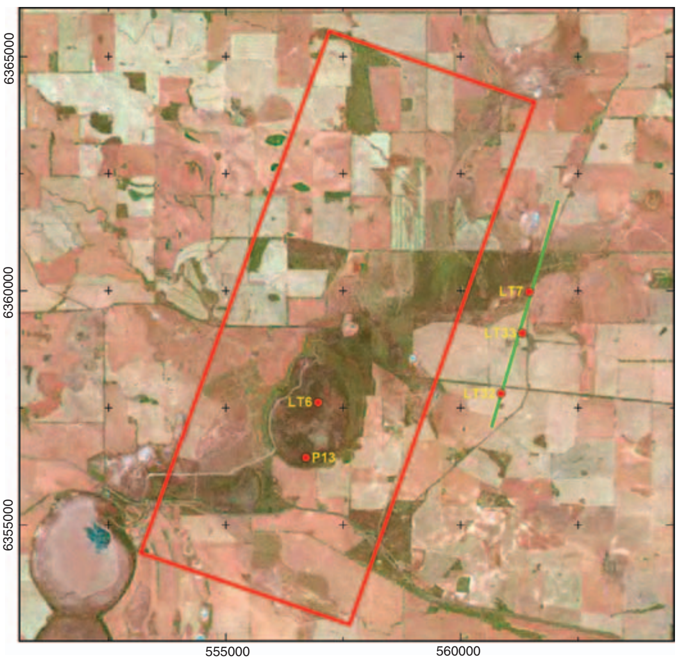

Fig. 7. *Location map for the Toolibin Lake SkyTEM survey, showing the main survey block (red rectangle), 5 km test line (light green), and selected boreholes.*

The geology in the survey area comprises Quaternary and Tertiary alluvial sediments overlying weathered Archaean granite and granite gneiss cross-cut by Proterozoic mafic dykes. The unweathered Archaean basement is generally highly resistive. Regolith thickness ranges up to 60 m and averages 25 m. Groundwater is highly saline (up to ~36 000 mg/L), and in-situ conductivities of sediments and weathered bedrock determined by previous geophysical surveys range up to 700 mS/m.

The TEMPEST AEM survey conducted in 1998 revealed the presence of an extensive palaeochannel system beneath Toolibin Lake, and extending to the northeast (Lane and Pracilio, 2000). The palaeochannel sands and gravels exhibit slightly lower electrical conductivity than surrounding saprolitic clays and overlying lacustrine clays.

The SkyTEM survey at Toolibin Lake repeated the earlier TEMPEST survey. The survey was flown with dual moment (HM and LM). Line direction was north-northeast at a spacing of 150 m, as for the earlier TEMPEST survey. Nominal terrain clearance was 30 m.

A number of different inversions of the Toolibin Lake SkyTEM dataset have been conducted, including both 6- and 15-layer LCI (Reid et al., 2007), and a laterally constrained fast approximate approach (Christensen et al., 2009). An interval conductivity slice derived from the LCI model for the depth range 16–20 m

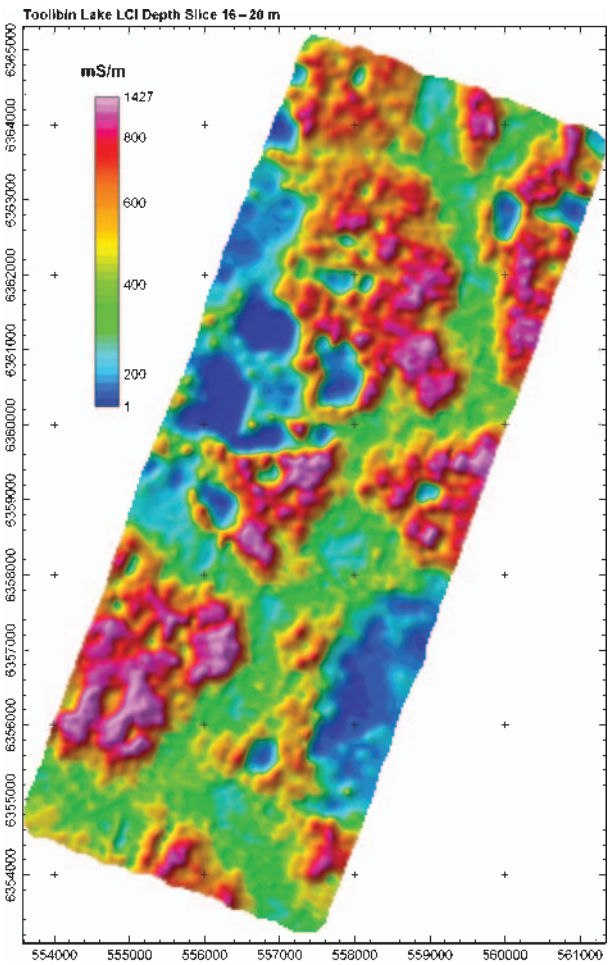

Fig. 8. *Toolibin Lake interval conductivity slice for the depth range 16–20 m below surface, derived from 15-layer smooth-model laterally constrained inversion.*

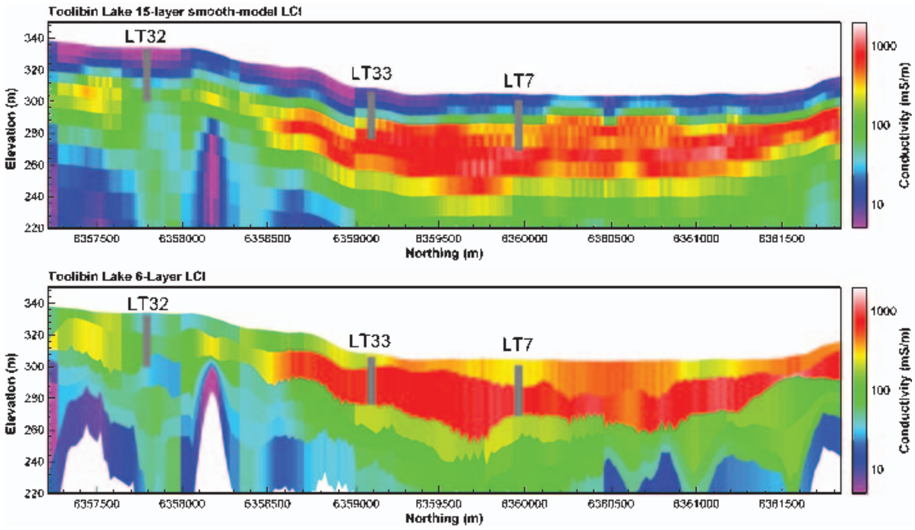

Fig. 9. *Comparison of 15-layer and 6-layer laterally constrained inversion results from the 5 km test line shown in Figure 7. The auger holes shown were terminated upon encountering bedrock. All drillholes shown lie within 70 m of the flight line.*

below surface is shown in Figure 8. The relatively resistive palaeochannel sands extend from the NNE of the survey block to the SSW to its SSW extremity, and appear as light-green to light-blue on the image (300–400 mS/m). In addition to the main channel, a number of smaller tributaries have also been defined.

Figure 9 shows a comparison of 15-layer smooth-model and 6-layer LCI from a 5 km long testline flown outside the main survey block at Toolibin Lake (Figure 7). A number of drillholes have been superimposed on the LCI conductivity cross-sections. These were auger holes, which were terminated upon encountering consolidated material, and so the depth of the holes provides an indication of the depth to competent bedrock. Depth to bedrock is extremely well mapped by the 6-layer LCI in the central part of the line (drillholes LT33 and LT7), where the granite bedrock is overlain by highly conductive clays and saprolite, and there is an abrupt decrease in conductivity at the bedrock interface. The smoothness constraints applied to the vertical variation of conductivity in the 15-layer LCI do not allow rapid conductivity changes with depth, with the result that the saprolite–bedrock boundary is not imaged as well in the smooth model. The effectiveness of SkyTEM in mapping the depth to bedrock in this instance stems from the high sensitivity of EM measurements to the conductivity and thickness of the highly conductive layer immediately overlying the resistive bedrock.

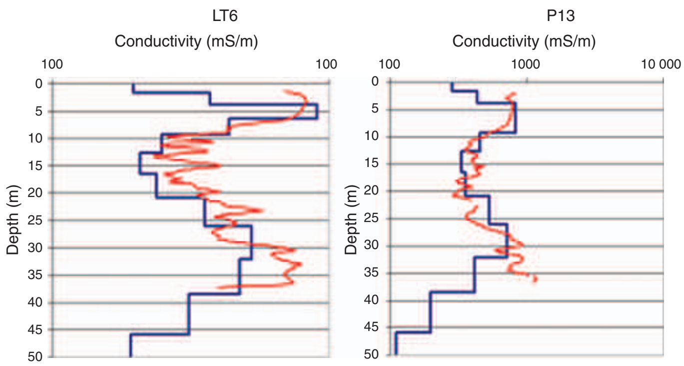

Fig. 10. *Comparison of EM39 downhole conductivity logs with the closest SkyTEM 15-layer laterally constrained inversion models for drillholes LT6 and P13 at Toolibin Lake (Figure 7). The nearest SkyTEM soundings were 42 m from LT6 and 51 m from P13.*

Figure 10 shows a comparison of EM39 inductive conductivity logs from drillholes LT6 and P13 located within Toolibin Lake with the closest 15-layer LCI models. The LCI results show excellent correspondence with the conductivity logs, illustrating the good calibration of the SkyTEM system. The agreement between the borehole logs and the SkyTEM models suggests that the geoelectric structure is laterally homogeneous within the lake, i.e. that the geology is fairly uniform over the SkyTEM footprint.

Ord River Survey

The Ord River Valley SkyTEM survey was flown to help inform groundwater and salinity management practices in the current Ord Irrigation Area (ORIA) and future proposed irrigation developments, and to examine surface–groundwater interactions in neighbouring environmental wetlands. The airborne survey acquisition was undertaken as part of a collaborative project between the Ord Irrigation Cooperative, Geoscience Australia and CSIRO (Lawrie et al., 2010).

The survey encompassed the areas of ORIA Stage 1, Parrys Lagoon, Carlton Hill and Keep River areas (Figure 11). A total of 5936 line km of data was acquired between July and August 2008, using a dual moment (HM and LM) configuration.

The HM and LM SkyTEM data for the Ord survey were inverted using a 1D LCI (Auken et al., 2005).The resultant conductivity model can be presented as plan form, either depth below surface or elevation slices, vertical cross sections or stitched together to produce quasi-3D models. An example of conductivity-depth plan for 4.2–6.7 m below the surface is shown in Figure 12.

A total of 45 boreholes within the survey areas were logged with an induction tool to support the validation of the SkyTEM data. An example of comparing individual induction logs against the smooth model SkyTEM conductivity model is shown

Fig. 11. *Location map for the Ord River SkyTEM survey, © Commonwealth of Australia (Geoscience Australia) 2005.*

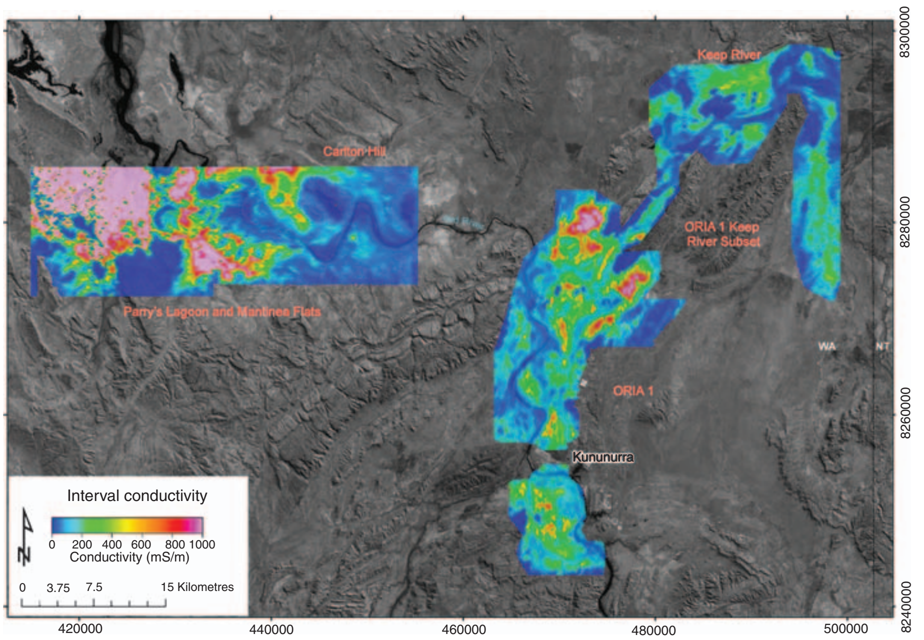

Fig. 12. *Interval conductivity for depth slice 4.2–6.7 m below surface, Ord River SkyTEM survey.*

in Figure 13. Generally, for all 45 boreholes the modelled conductivity structure defined from the SkyTEM smooth model LCI matches that defined from the bore data, except in the fine detail. The models derived from the SkyTEM data provide a reasonable approximation to 'true' ground conductivity, as defined by the borehole conductivity tool.

The SkyTEM LCI conductivity model can also be compared to ground NanoTEM data collected using a 20 × 20 m transmitter loop by Lawrie et al. (2006) within the Ord Irrigation Area 1 (ORIA1). The NanoTEM data was inverted using Zonge's STEMINV1D (MacInnes and Raymond, 2001) program to produce a smooth model conductivity model. The equivalent SkyTEM section was extracted from gridded data at 80 m cell size, and thus is expected to smooth conductivity features horizontally. The modelled conductivity structure defined from the SkyTEM smooth model LCI closely matches that defined from the NanoTEM smooth model (Figure 14). The comparison highlights the excellent vertical resolution that can be achieved by SkyTEM. In this example a conductive layer 6 m thick has been imaged at depths of only a few metres.

The conductivity model produced from the Ord Valley SkyTEM survey appears to be well calibrated and accurate

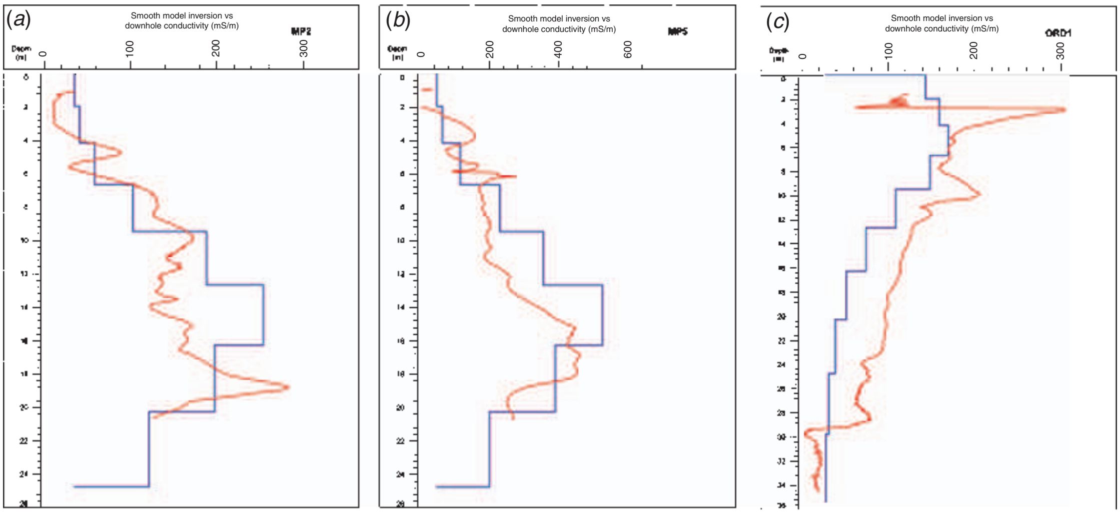

Fig. 13. *FID point comparison of borehole conductivity data against SkyTEM smooth model laterally constrained inversion (LCI) for bores MP2, MP5 and ORD1. Red line, borehole conductivity; blue line, SkyTEM LCI conductivity.*

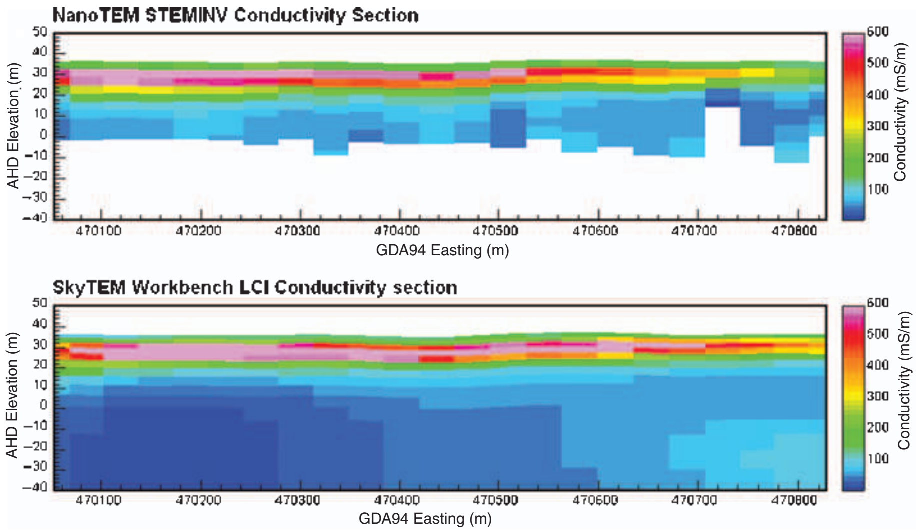

Fig. 14. *Comparison of 20 × 20 m ground NanoTEM conductivity model and equivalent SkyTEM laterally constrained inversion conductivity model.*

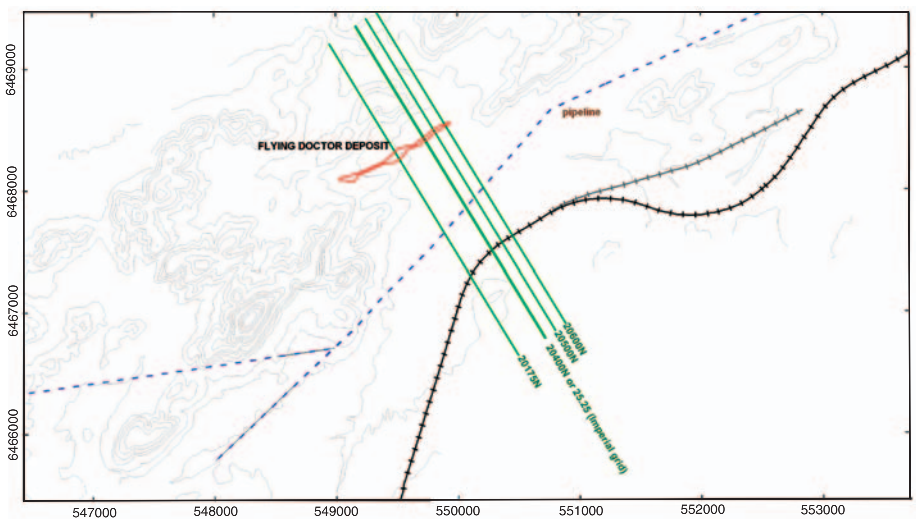

Fig. 15. *Location map for the Flying Doctor SkyTEM survey (MGA 54 coordinates). The surface projection of the Flying Doctor mineralisation is shown by the red polygon. The locations of nearby metallic infrastructure (grounded pipeline and railway line along road) is also shown.*

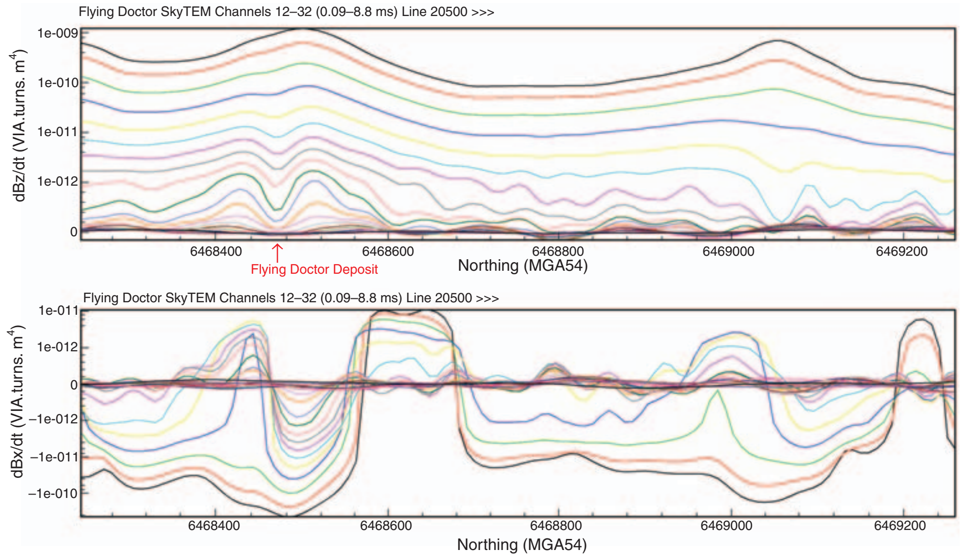

Fig. 16. *Subsection of SkyTEM line 20 500 over Flying Doctor, showing a double-peaked Z component anomaly and crossover X-component anomaly at ~6 468 475 mN, characteristic of a steeply dipping thin-sheet conductor. The slightly larger amplitude of the northernmost peak indicates that the conductor dips toward the northern end of the line. The location of the mineralisation is indicated by the red arrow.*

when compared to borehole and ground EM data. This provides confidence in using the resultant model to accurately interpret the 3D hydrogeological framework of the study area and identify salinity risks. Interpretations of this dataset have been used to populate 3D hydrogeological models to help inform groundwater and irrigation management of the Ord Valley area.

Flying Doctor

The Flying Doctor deposit is a Pb–Zn–Ag deposit near Broken Hill, NSW, which has been used as a geophysical test range over the last few decades (e.g., Boyd and Wiles, 1984; Cattach and Boggs, 2005). Numerous surface, downhole and airborne electromagnetic and electrical surveys have been conducted over the deposit. The detailed geometry of the mineralisation is quite complex (see cross-sections in Cattach and Boggs, 2005). In summary, the thin lenses of mineralisation strike roughly northeast and dip steeply (80º) to the northwest. The main mineralisation lies at depths of 10–150 m. In long section, the mineralisation is 'boomerang' shaped, and is shallowest (10–15 m) at its centre (~flight line 20 400 in Figure 15) and deepest at its southwestern and northeastern ends.

Figure 16 shows a subsection of flightline 20 500, showing well-defined Z- and X-component anomalies from the Flying Doctor mineralisation at ~6 468 475N. The X-component anomaly is well-developed (i.e. shows a clear crossover) by Channel 16 (226 µs), at which time the double-peaked Z-component anomaly is just starting to appear. The presence of both X and Z-component anomalies improves confidence in both identification of the anomaly and in interpretation of the response. The mineralisation is only moderately conductive, presumably as a result of high sphalerite content, and the anomaly only persists in the Z-component until Channel 25 (1.79 ms). Exponential fitting of the later-time part of the decay yields a time constant of 0.42 ms (Figure 17). Boyd and Wiles (1984) obtained a time constant of 1.5 ms, from Newmont EMP downhole electromagnetic (DHEM) data measured to later delay times than used for the SkyTEM survey.

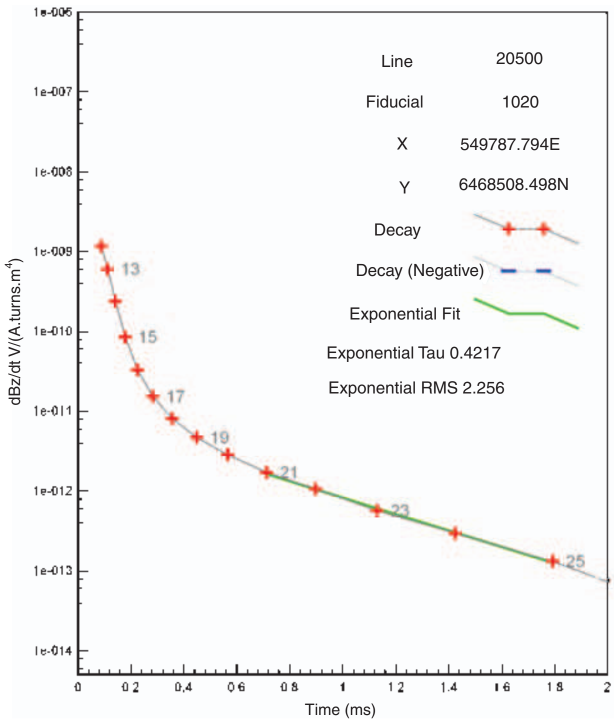

Fig. 17. *Time constant analysis of a decay from the northernmost peak of the Z-component anomaly in Figure 16 (~6 468 500 mN), indicating a time constant of 0.42 ms for the Flying Doctor mineralisation.*

Figure 18 is a multiplot showing the measured Z-component SkyTEM response on a 1 km section of line 20 500, the iTEM fast approximate LEI computed from the Z-component, and a plate-in-free-space model obtained by fitting the observed Z- and X-component anomalies using Maxwell. The Maxwell model shows that the observed anomaly can be explained by a single plate-like body dipping steeply to the northwest. The modelled plate has a depth to top of 40 m, dip of 85º to 327º, strike extent of 350 m, depth extent of 100 m and conductance of 50 S,

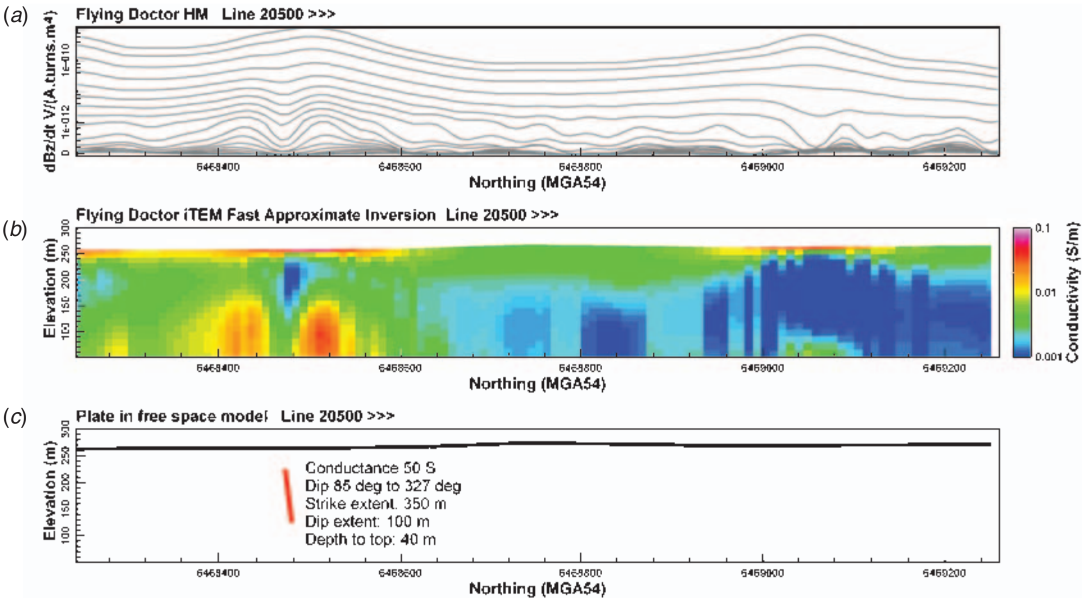

Fig. 18. *Multiplot for line 20 500 at Flying Doctor, showing (a) observed Z-component response, (b) 30-layer iTEM LEI calculated from the Z-component and (c) Maxwell plate in free-space model.*

and is consistent with the known location of the highest-grade mineralisation on this line. The modelled conductance is in reasonable agreement with Boyd and Wiles (1984), who derived a conductance of 110 S based on their DHEM data.

The iTEM LEI was able to achieve a good fit to the observed Z-component data, but has resulted in two strong conductors underneath the peaks of the Z-component anomaly at 6 468 425 mN and 6 468 510 mN. The iTEM conductors also lie considerably deeper (65–90 m) than the Maxwell plate model. This example clearly illustrates the inapplicability of one-dimensional conductivity-depth transformation (e.g., LEI or CDI) in strongly 2D or 3D geology. Layered-earth transformations of SkyTEM data have been found to yield reasonable results for dips up to approximately 30º. For more steeply dipping targets, one-dimensional models incorrectly represent the conductor geometry and overestimate the depth. Rapid layered-earth inversion of mineral exploration data is still considered useful both for fast identification of conductors and for determination of parameters such as overburden thickness and conductivity, which may influence the plate modelling.

Conclusions

SkyTEM is a quantitative electromagnetic system designed to be able to resolve small differences in conductivity. The system provides calibrated electromagnetic data over a wide time range and has excellent lateral and shallow resolution and a depth of exploration of up to 400 m in favourable geological settings. Measurement of transmitter altitude and inclination, and well-established filter parameters and transmitter current waveform mean that rigorous quantitative interpretation is possible. Comparisons with drilling results and borehole conductivity logs presented in this paper demonstrate the calibration of the system.

As with all airborne electromagnetic systems, SkyTEM is continuously evolving. Current active areas of hardware and software development are focussed on improving both the depth of investigation and near-surface resolution.

Acknowledgements

Andrew Bisset from U3O8 Ltd is thanked for permission to publish the Mad Gap example. The Ord River project was co-funded by the Australian Government in partnership with the Western Australian Government and undertaken under the auspices of the National Action Plan for Salinity and Water Quality, and managed by Ord Irrigation Cooperative (OIC) for the WA Rangelands Natural Resource Management Group. Perilya Ltd kindly provided access to their tenements for acquisition of the Flying Doctor dataset. JR would also like to thank Max Halkjaer and Per Gisselø of SkyTEM Aps, Denmark; Esben Auken and Andrea Viezzoli of Aarhus Geophysics Aps Denmark, and Niels Christensen of EMModel, Denmark for technical discussions over the last few years. Tim Munday (CSIRO), Dean Rogers (Perilya Ltd) and Max Halkjaer are thanked for their comments on an earlier draft of this article.

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Depth of investigation grid for regional airborne electromagnetic surveys

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We describe a new method of presenting the depth of investigation (DOI) for an Airborne Electromagnetic (AEM) Survey of the Paterson region, Western Australia. The DOI is derived using the Geoscience Australia Layered Earth Inversion (GA-LEI) algorithm of Lane *et al.* (2004), which includes conductivity reference model constraints. Thus the inversion is influenced by both subsurface conductivity and reference model assumptions. The DOI is chosen to be the maximum depth to which the inversion is more influenced by data than the model assumptions. A 2D grid of the DOI across the survey area illustrates clearly how the depth penetration of AEM varies across this regional-scale survey. This information about the depth penetration can be used by the mineral exploration industry when planning detailed AEM surveys.

Introduction

Airborne electromagnetic (AEM) surveys are commonly used for investigating ground conductivity for a range of geophysical purposes, including mineral exploration and groundwater studies (Lawrie *et al.*, 2000; Meyers *et al.*, 2001). Airborne electromagnetic surveys can provide subsurface geophysical information about rock and water properties at depth scales from tens to several hundreds of metres. The method can reveal features such as paleotopography, subsurface ore deposits, faults and other boundaries between neighbouring rock formations.

While the application of the technique is common, AEM surveys are generally limited to small target areas, due to their high cost compared to other geophysical techniques. In addition, the depth of penetration of the AEM signal is highly variable; in resistive areas a high-power system may penetrate to depths of the order of 500 m, whereas in conductive areas penetration may be limited to less than 100 m. Thus an inherent risk of conducting AEM surveys is that the extent of the information they provide is not certain until after a given survey is flown, even if extensive *a priori* information is available.

Geoscience Australia (GA) is conducting a program of flying regional scale AEM surveys in the Paterson region of WA (2007–08), the Pine Creek region of the NT (2009) and the Lake Frome region of SA (planned for 2010). The surveys are funded by the Australian Government's Onshore Energy Security Program, and cover much larger areas than previous AEM surveys flown in Australia. They are designed to provide pre-competitive AEM data on flight lines spaced several km apart. These regional-scale surveys aim to highlight targets for more detailed investigation by the mineral exploration industry. A key point of interest in these surveys is to show where smaller scale AEM surveys could be effective, so that further exploration using AEM (or ground-based EM) surveys will have reduced risk in locating exploration targets.

Here we present a new method for determining and imaging the depth of penetration of the AEM technique. A map of the depth of investigation (DOI) of the Paterson survey is presented. This DOI map provides a new means of visually determining the utility of the AEM method based on regional data and will be applied to future regional surveys to help determine the likely effectiveness of more detailed investigations.

Determining the depth of investigation

The data presented here have been inverted from airborne measurements to form a conductivity depth model using the GA Layered Earth Inversion (GA-LEI) algorithm of Lane *et al.* (2004). This algorithm uses an assumed conductivity reference model as a starting point and iteratively adjusts the model until the measured AEM data are fitted. Since the inversion solution is non-unique, a reference model is used to constrain the solution. Note that the reference model used in this study is a half-space of uniform conductivity. Where the model is unresolved (or ambiguous) the solution will tend toward the reference model.

A key step is to estimate how much the inversion is influenced by the assumptions fed into it. To do this we compare two inversions with a large difference in their reference models and measure how much the inversion changes as a result of the different assumptions. This measure is known as the Percent Data Influence (PDI):

$$\mathrm{PDI} = 100\left(1 - \frac{\log(\sigma_{i1}) - \log(\sigma_{i2})}{\log(\sigma_{r1}) - \log(\sigma_{r2})}\right)$$

where σ_{i1} and σ_{i2} are the two inverted conductivities at a given point, and σ_{r1} and σ_{r2} are the corresponding reference model conductivities. We define the PDI using the logarithm of the conductivity, since this is the quantity used in the inversion process. This definition of the PDI is used by Lane *et al.* (2004), which was adapted from Oldenburg and Li (1999).

If the PDI is greater than 50%, then the inversion is deemed to be more influenced by the AEM data than the reference model, whereas if it is less than 50% then the reference model is deemed to be dominant. The DOI is defined as the depth at which the PDI is 50%. Thus the DOI marks the depth to which the inverted conductivity is relatively robust. Note that the 50% PDI threshold is somewhat arbitrary, and a different threshold could be chosen.

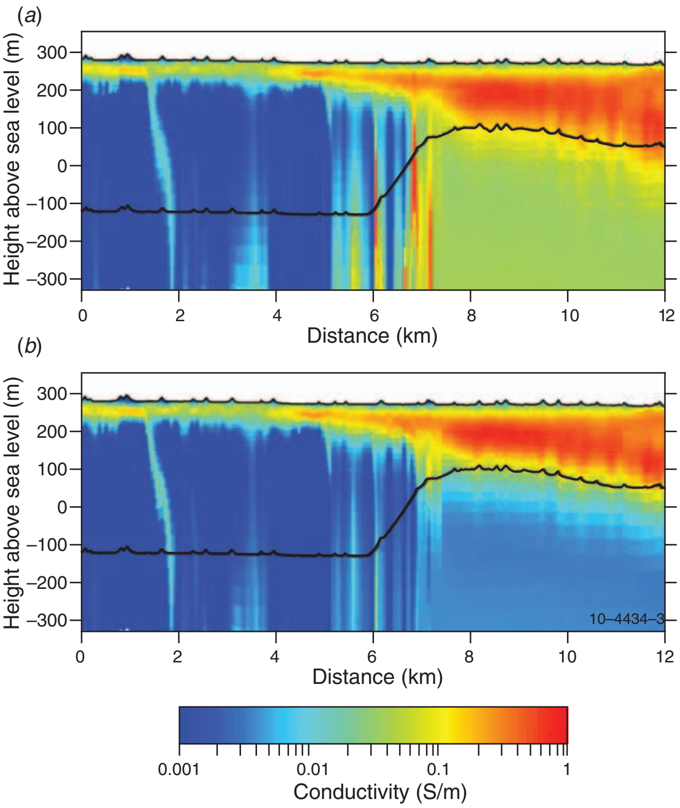

Fig. 1. A sample conductivity depth section, comparing the results of inversions using reference models of (a) 0.04 S/m and (b) 0.004 S/m. The black line marks the depth of investigation (DOI) in each case. Above the DOI, the results are similar for both inversions, whereas below the DOI, the conductivity differs according to the reference model value.

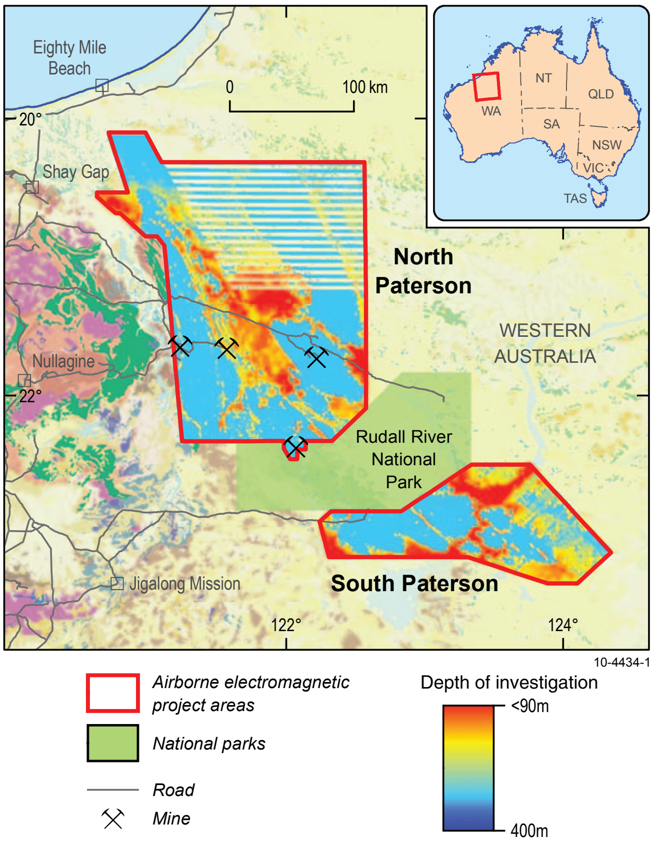

Fig. 2. Depth of investigation (DOI) grid across the Paterson Survey. We have chosen not to interpolate between the lines of 6 km spacing in the north-west of the survey, since this may create misleading results.

An illustration of the DOI along a conductivity depth section is shown in Figure 1. Two inversions of the same line are shown, using reference models of (a) 0.04 S/m and (b) 0.004 S/m, with the DOI line shown in black. Above the DOI line, the two inversions show approximately the same results, whereas below the line, the results are heavily influenced by the reference models.

Depth of investigation grid

The DOI was calculated along each of the individual lines of the survey, and the DOI from each point was combined into a 2D grid, shown in Figure 2. The DOI ranges between 91 and 400 m, illustrating that the depth of penetration of the AEM survey is highly variable across the survey area.

Discussion

The DOI grid is a useful tool for planning the location of further exploration work in the area using airborne or ground-based EM surveying. This grid clearly illustrates the variability in the depth of penetration of the AEM signal across the survey area. The shallower DOI values correspond with conductive areas, while the deeper DOI values correspond with more resistive areas of the survey. Note that the precise DOI is system dependent, but this grid is indicative of how the DOI would vary across the survey for other AEM systems.

This grid can be used to refine the location of further EM surveys, or to estimate the effectiveness of EM in a given area of interest. The DOI grid can thus be interpreted as an AEM 'go-map'. AEM surveys are relatively costly, and carry an inherent risk since the depth of penetration is highly variable. This DOI grid can reduce the risk of exploration using EM surveys in the Paterson region, making EM surveying a more attractive tool for mineral exploration.

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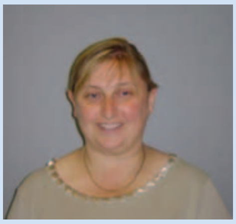
Paterson AEM survey directly detects major unconformity near Kintyre, WA



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Introduction

Geoscience Australia flew a regional Airborne Electromagnetic (AEM) survey across the Paterson Province of Western Australia in 2007–08. The AEM data acquisition, processing and interpretation were funded by the Australian Government's Onshore Energy Security Program to reduce exploration risk and encourage exploration for energy resources in frontier areas. Flight lines were acquired at 200 m, 1 km, 2 km and 6 km spacings using Fugro's TEMPEST system for a total of 29 000 line km. The aim of the survey was to improve the understanding of the region's geology and potential for uranium exploration.

One of the main interpretation objectives of the Paterson AEM survey was to map the unconformity between the Neoproterozoic Coolbro Sandstone and the Paleoproterozoic Rudall Complex (the Coolbro–Rudall unconformity). This unconformity is an important exploration target in the region as it features strongly in unconformity-related uranium deposit models and is related to the Kintyre uranium deposit, Australia's fifth largest deposit by weight of contained U_3O_8. Other uranium prospects near the unconformity include Sunday Creek and Mt Sears to the east of Kintyre. Mapping the unconformity in this area with pre-competitive AEM data will assist in reducing the risk for uranium explorers in the region.

The application of electromagnetic methods for mapping unconformity-related uranium deposits is not new; however, in the Paterson Region there is no documented evidence of such an achievement.

Forward modelling indicated that the probability of detecting the Coolbro–Rudall unconformity was low as:

- both the Coolbro Sandstone and the Rudall Complex are resistive (less than 1 mS/m) and it was unclear whether there would be an adequate conductivity contrast between the two units to allow detection;
- the unconformity may potentially lie deeper than the anticipated depth of investigation (greater than 500 m for Fugro TEMPEST in this area);
- the unconformity was anticipated to have a complex structural nature because of post-depositional tectonics; and
- reports indicated that the alteration zone at the unconformity may not have sufficient conductivity to be measured.

Evidence for the Coolbro–Rudall unconformity

AEM data were interpreted using an integrated approach incorporating the Geoscience Australia 1 : 1 000 000 Surface Geology of Australia map (Stewart, 2008), solid geology (Czarnota, *et al.* 2009), publicly available drill hole logs (Roach, 2009) and the results of the layered earth inversion process developed by Geoscience Australia (GA LEI; Lane, *et al.* 2004). The investigation focused on areas where surface mapping indicated that the Coolbro–Rudall unconformity was expected to lie under cover.

Figure 1 shows GA LEI conductivity depth sections for three consecutive 200 m spaced flight lines proximal to the Coolbro–Rudall unconformity, as geologically mapped near the Kintyre uranium deposit, which lies about 4 km off-section to the east. The depth of investigation line, which normally features on conductivity depth sections, is below the data depicted in these sections. The interpreted Coolbro–Rudall unconformity appears in the LEI conductivity sections as a thin, weakly conductive, sub-horizontal feature at the top of the resistive Rudall Complex on the western side of the sections. The interpreted Coolbro–Rudall unconformity surface has substantial relief of several hundred meters, interpreted to be the result of tectonics after the deposition of the Coolbro Sandstone. The interpreted Coolbro–Rudall unconformity appears to be a zone several tens of metres thick, possibly because of sub-aerial weathering of the Rudall Complex followed by post-burial diagenetic or hydrothermal alteration of the palaeo-weathering profile. The interpreted Coolbro–Rudall unconformity in Line 40 360 extends sub-horizontally about 200 m under the surface for a distance of about 3 km. The elevation of the interpreted Coolbro–Rudall unconformity falls away rapidly between line 40 360 in the south and line 41 860 in the north. The interpreted Coolbro–Rudall unconformity is projected to lie largely beneath the depth of investigation in the western portions of line 41 860.

It is difficult to identify the Coolbro–Rudall unconformity on the ground because it is largely covered by Permian glacial till and Quaternary valley fill. However the position of the interpreted Coolbro–Rudall unconformity correlates well with publicly available historical drilling logs. The closest drill hole to the imaged Coolbro–Rudall unconformity is a CRA exploration hole (number 91WYRC003), about 2 km south of line 40 360 (CRA 1991). This hole was logged to contain Quaternary sand to 5 m, Permian glacial till to 35 m, Coolbro Sandstone to 69 m, weathered magnetite-bearing Rudall Complex to 78 m and fresh Rudall complex to 106 m. The calculated slope of the interpreted Coolbro–Rudall unconformity in the LEI sections correlates well with the logged position in hole 91WYRC003.

Analysis of the magnetic signal shows there is no magnetic signature related to the conductivity signature at the Coolbro–Rudall unconformity. Thus the Coolbro–Rudall unconformity is not mappable using aeromagnetics, but is detectable using AEM

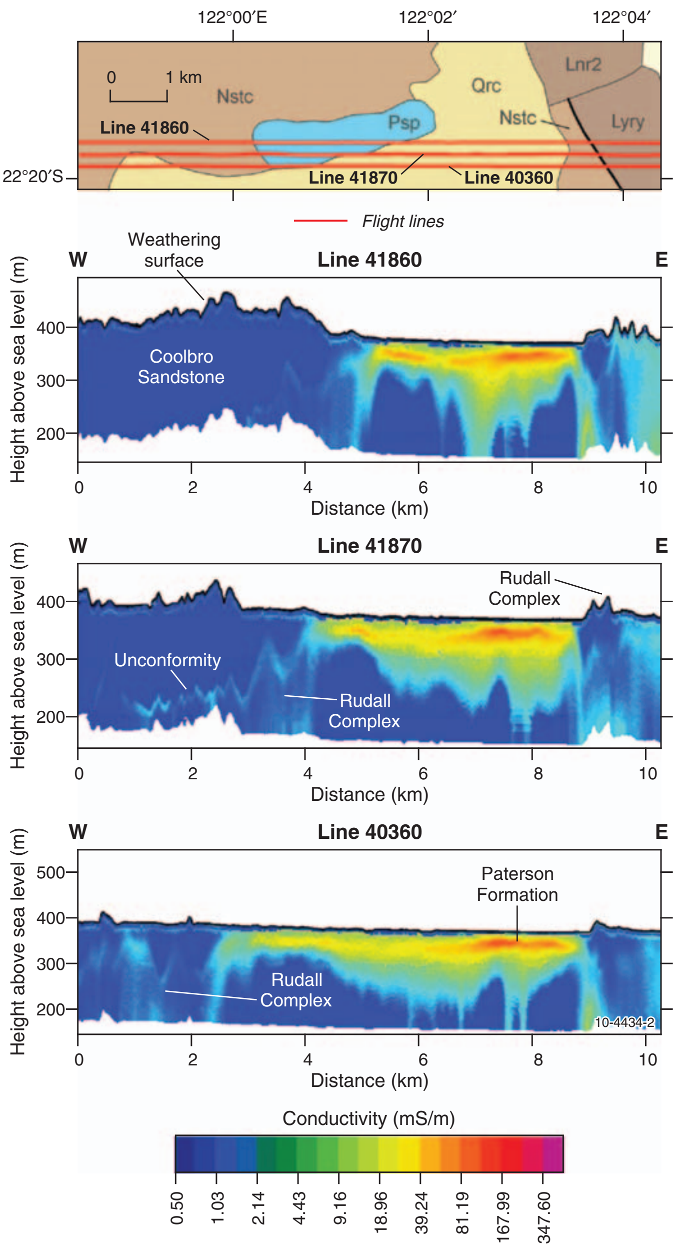

Fig. 1. *Geoscience Australia Surface Geology of Australia map and GA LEI conductivity depth sections showing the Coolbro–Rudall unconformity. Map symbols: Qrc, Quaternary colluvium; Psp, Permian Paterson Formation; Ntsc, Neoproterozoic Coolbro Sandstone; Lnr2/Lyry, Paleoproterozoic Rudall Complex.*

data because of the conductivity contrast caused by alteration, including small amounts of magnetite, below the Coolbro–Rudall unconformity surface.

Implications for exploration

Interpretation of the Paterson AEM data indicates that the Coolbro Sandstone and Rudall Complex have different electromagnetic signatures because of their contrasting conductivities. The Coolbro Sandstone is uniformly resistive at less than 5 mS/m whereas the Rudall Complex has subtle conductors at depth giving it a conductivity range between 1 and 20 mS/m. Further interpretation has mapped basement conductors in the Rudall Complex and significant faults that penetrate the Rudall Complex, e.g. the Kintyre Fault. These key minerals system features are mappable with AEM because of weathering and possible hydrothermal alteration, and are not necessarily evident in magnetic and gravity data. There is potential to image the unconformity in areas where the Coolbro–Rudall unconformity exists in other parts of the Paterson AEM data set, including in the South Paterson area. There is also potential for further unconformity-related uranium systems in the Paterson region that may be mapped using AEM data; these could constitute exploration drilling targets.

Phase 2 Paterson data release

Geoscience Australia has prepared enhanced GA LEI products for the Paterson area. This package will include ASCII datasets containing conductance, depth slice and elevation slice data with the depth of investigation estimate contained within. Grids of total conductance, elevation and depth slices will be provided with data below the estimated depth of investigation nulled out. Georeferenced conductivity sections and a basement anomaly map for the Rudall Complex will also be provided.

Paterson AEM Phase 2 Data is available for free download in May 2010 from the Geoscience Australia Website. Geoscience Australia's 'Geological and energy implications of the Paterson Province airborne electromagnetic AEM survey, Western Australia' interpretation report will be available in July 2010.

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Carbon capture and global climate change

I enter this topic with trepidation, as there seems to be no more polarizing public debate going around. Unfortunately, science and scientists are quoted and abused in an appalling manner, by both sides – advocates of anthropogenic global warming and skeptics. My own viewpoint is that as scientists we have a responsibility to educate ourselves and share our scientific skills with the community around us. Rather than leaping to conclusions, a most unscientific behavior, we should be advocating rational debate and analysis.

It would seem fair to observe that just as our atmosphere and biosphere is an inconceivably complex and dynamic cocktail of chemical processes, the many aspects of the entire climate change debate are confusing and difficult to collectively judge. Attempts by governments to adopt, for example, international agreements on controlling emissions, seem to create even more debate. Is it fair to measure carbon emissions by capita rather than by country? Are there workable carbon trading models that can reduce our commercial burden as already-highly taxed developers of natural resources? What time scales should we examine to separate planetary vs anthropogenic contributions to carbon levels in the atmosphere? How do carbon levels in the atmosphere really affect short and long-term weather behaviour? How do we discriminate between the validity of atmospheric temperature measurements taken in urban, rural, oceanic, and satellite-based settings? On it goes.

A quick search of 'global warming' websites reveals the nefarious antics used by some of both sides of the debate. For example, http://www.globalwarming.org/ is clearly produced by skeptics under the guise of being a reference site, and although http://www.skepticalscience.com/ might appear to be taking a skeptics viewpoint, it is in fact 'Getting skeptical about global warming skepticism'! In other words, dirty tricks are too often getting in the way of objective debate. Other sites such as http://www.worldviewofglobalwarming.org/ are of reference value, but seem to have an implicit acceptance that anthropogenic climate change is an established fact. Likewise, the EPA in the US has quite a vast climate change section at http://www.epa.gov/climatechange/, including a section on CO_2 at http://www.epa.gov/climatechange/emissions/co2.html. Again, it is explicitly accepted that climate change since 1700 is of significant anthropogenic origin.

The reporting itself of climate change news is rapidly becoming a major business, as evidenced for example at http://www.climatechangecorp.com/. Fortunately, there are more credible resources available. The Center for the Study of Carbon Dioxide and Global Change (http://www.co2science.org/index.php) was created 'To disseminate factual reports and sound commentary on new developments in the world-wide scientific quest to determine the climatic and biological consequences of the ongoing rise in the air's CO_2 content'. What scientists like me are looking for, however, is better met by websites such as that provided by the University of California, San Diego, where a two-part course is available at http://earthguide.ucsd.edu/virtualmuseum/climatechange1/cc1syllabus.shtml. This type of content is the platform that we should look to be building upon.

There must be enormous scope for our talented and diverse membership in the ASEG to contribute to our community understanding of the issues involved. For example, enough of us understand that complex systems often do not have linear behavior, and the principles within chaos theory have application. How does our global climate reach a critical tipping point in response to rising carbon levels, if indeed that is a realistic scenario?

Returning to more tangible discussions, the capture and disposal of carbon dioxide is a rapidly developing industry, and Australian scientists are at the forefront. Irrespective of the commercial merits in the long term (I am not passing judgment, apart from stating that I hope our natural resources industry is not forced into premature investment by those with vested interests in carbon capture and storage (CCS)), the science is very interesting, and promises to be a true 'melting pot' that will allow the integration of the many different geophysical disciplines – seismic, remote sensing, geochemistry, and so on. The business of CCS will grow quite dramatically in profile and scale of investment in the coming decade, offering many scientific and career opportunities. Introductory information on CCS in Australia can be found on Wikipedia at http://en.wikipedia.org/wiki/Carbon_capture_and_storage_in_Australia. The obvious next destination is the CSIRO CO2CRC resource at http://www.co2crc.com.au/, noting again that anthropogenic climate change mitigation is implicitly accepted by the CO2CRC as not only being feasible, but also necessary. The position of the Australian federal government on climate change and CCS is well known, but those seeking greater programmatic specificity can visit http://www.austrade.gov.au/Invest/Opportunities-by-Sector/Clean-Energy/CCS/default.aspx

These are still early days in the debate over anthropogenic effects and climate change. May the debate advance with less animosity on all sides.

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