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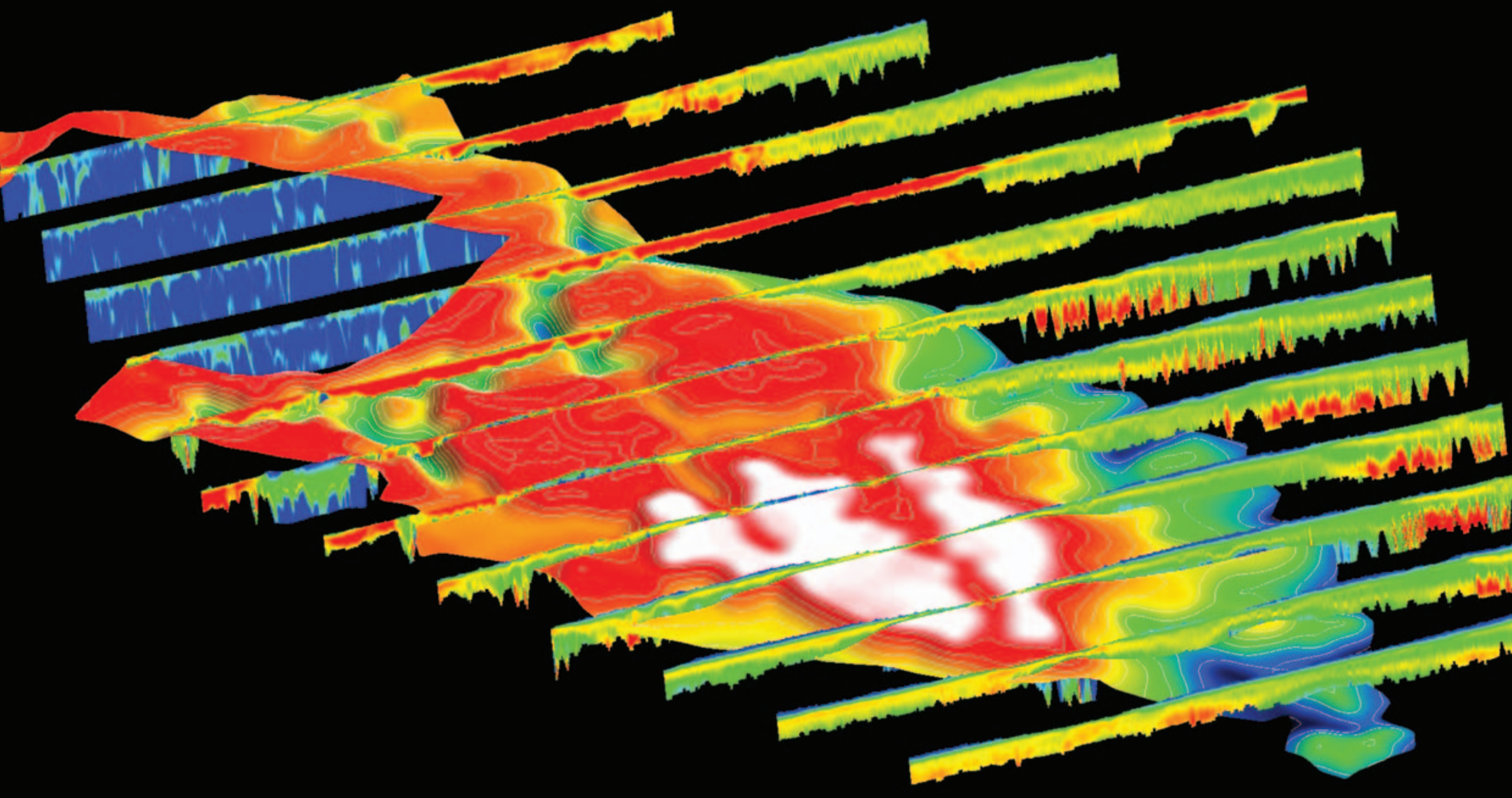
PREVIEW

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS



NEWS AND COMMENTARY

Geophysics on an iPad

Business investment in R&D continues to increase

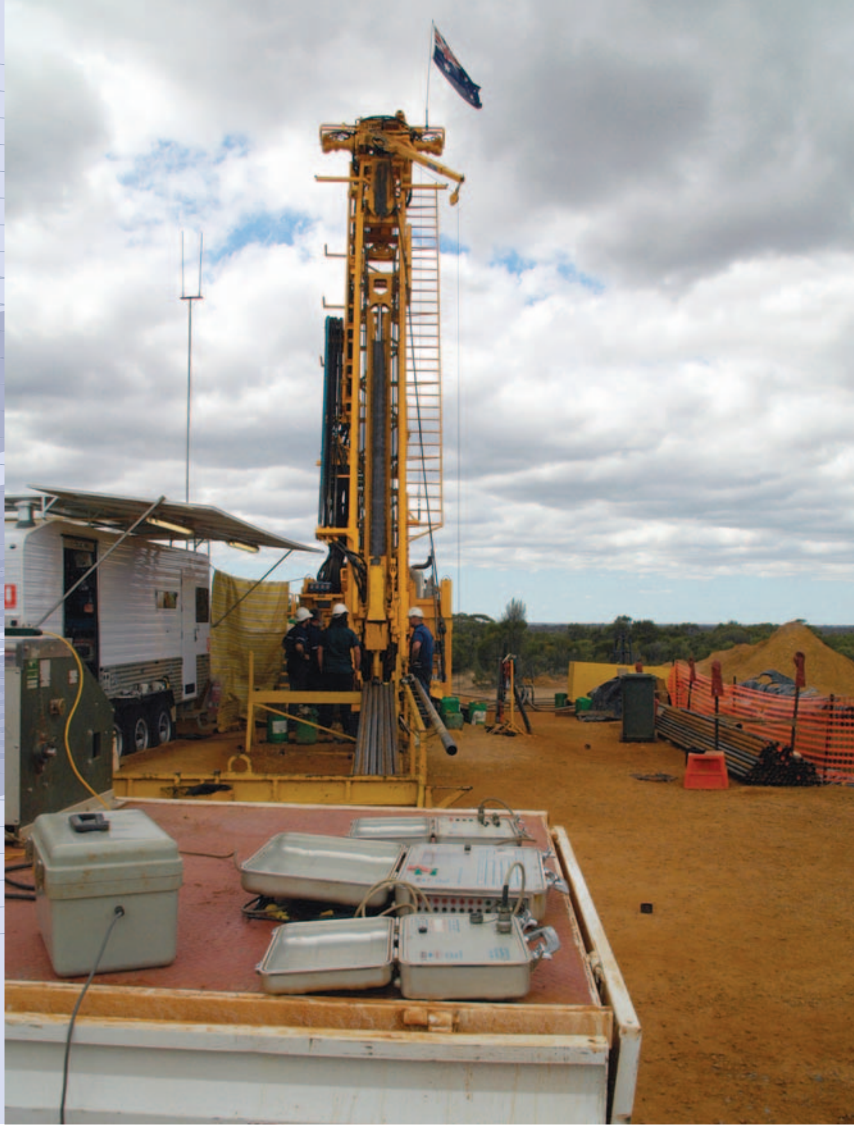
Airborne EM within Cariewerloo Basin

Levelled ship-track gravity & magnetic data for the Capel and Faust basins

FEATURE ARTICLES

Accurate quasi 3D vs practical full 3D inversion of AEM data

Multiple small-aperture TEM system



PREVIEW

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FRONT COVER

A palaeosurface, or unconformity, interpreted from results of the Paterson South AEM Survey. This NW perspective view shows conductivity sections intersecting the modelled palaeosurface between the overlying Canning Basin and underlying Rudall Complex (field of view ~200 km). More detail is available in 'Geological and energy implications of the Paterson Province airborne electromagnetic (AEM) survey, Western Australia' (http://www.ga.gov.au/minerals/projects/current-projects/airborne-electromagnetics.html). Image courtesy of Geoscience Australia.

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Ann-Marie Anderson-Mayes

Online *Preview*

Readers of online *Preview* will have noticed some minor changes in the presentation of last month's issue. In an effort to improve the online presentation of the magazine, readers will now be able to download either a single PDF for the whole issue or individual PDFs of subsections of the magazine. If you think a feature article may be of interest to your colleagues, it will simply be a matter of referring them to a direct link to that article, rather than needing to download a PDF of the whole magazine which may be 20 Mb or more in size.

Preview is freely available online and thus is an excellent vehicle for promoting our profession to a wider audience. Let me know what you think about the new online format and whether you have any suggestions for further improving the digital presentation of our magazine.

A bouquet for Curtin Honours students

It was my very great pleasure to attend the recent Student Night for the WA branch of the ASEG. Seven Honours students from Curtin University delivered short presentations on their research. In my experience there is usually some 'cringe factor' associated with these events because the students are still learning their presentation skills. By contrast, this Student Night showcased a group of students with excellent presentation skills, confidence in their material, and an assuredness in their manner which left me almost dumbfounded. I well remember my own Student Night and how nervous we all were. I suspect these students were no different to us, but they have clearly been given lots of practice in public speaking and this contributed greatly to the effectiveness of their presentations.

We often hear that there is concern about where future geophysicists will come from and how well prepared they are to enter the profession. I am pleased to say that this group of young people gave me confidence in the future of our profession, and in particular in their ability to communicate their knowledge so well. Geophysicists have to be good at communicating with the users of their data, and this newly qualified group of geophysicists are certainly starting out on the right foot. They also exuded a genuine enthusiasm for their topics – not only were they good communicators but they seemed to really enjoy talking about geophysics!

So, a bouquet for the students and congratulations to Dr Andrej Bona, Honours Course Coordinator, and all the Curtin Department of Exploration Geophysics staff, in particular the students' supervisors, who have done an excellent job in grooming these future geophysicists.

Some Christmas whimsy

I felt sure that if I trawled the Internet I would find something funny or interesting that related geophysics to Christmas. I'm afraid to say that the pickings were rather slim. On one site I found advice to the effect that if you wanted a life where you could spend Christmas with your family, then don't bother becoming a geophysicist (!). On another, I found myself reading a Book Review from New Scientist in 1960 about a book called *The World Around Us*, edited by Sir Graham Sutton, which was a collection based on a series of six Christmas lectures delivered in December 1958 as part of the International Geophysical Year. The review commended the book highly, but this was still not quite what I was looking for.

And then I stumbled across this – a science blog going by the name of 'Highly Allochthonous' (http://scienceblogs.com/highlyallocthonous). If you visit the archives for December 2009 and January 2010 you will find an entertaining collection of posts by geologist Chris Rowan under the following titles: 12 folds a-plunging, 11 terranes amalgamating, 10 probes a-probing, 9 isotopes fractionating, 8 streams reversing, 7 glaciers melting, 6 fields a-flipping, 5 focal mechanisms, 4 index fossils, 3 Helmholtz coils, 2 concordant zircons and an APWP. Perhaps next year, we could have the 12 Days of Christmas for Geophysicists.

This issue

In this issue we have two feature articles. The first comes from Viezzoli et al. and was written in response to the article by Wilson et al. in Issue 146 on 'Practical 3D inversion of entire airborne electromagnetic surveys'. The second article comes from China and looks at a novel EM configuration for application to tunnel surveys. These features are complemented by the usual round of ASEG, industry and conference news.

It is hard to believe that another full year of *Preview* is almost complete. I would like to thank all our contributors, readers, advertisers, sponsors and **CSIRO** PUBLISHING for continuing to support the magazine so strongly. I wish you all a very happy and successful 2011, and may you have a wonderful and safe festive season.

Musings on faith and other geophysical foibles

My wife Annie and I recently returned from a rather lengthy visit to the Middle East with two other couples. It was a fantastic experience, while at the same time it was more demanding than any field trip I have ever been on…or maybe that is a reflection of my 61st year. The October timing though did mean that the average temperature every day was plus 35 degrees and reminiscent of field seasons in the Pilbara.

We visited Jordan, Israel, Egypt and Oman, with brief stopovers in Dubai and Qatar. Although it wasn't the main purpose of the trip, unlike many others we met along the way, we covered places important to all manner of religious persuasions from the sun based beliefs of the Pharaohs in Egypt, through Judaism and Christianity to Islam. It struck me how such a small corner of the world is responsible for the beginnings of the great religious philosophies of modern non-eastern religions. It also struck me that many of the holy places are important to more than one of the great religions. They are reasons for either contention such as in some parts of Jerusalem, or agreement, such as in many places highlighted in the old testament, the common book to Jews, Christians and Muslims alike.

It also occurred to me that there is a strong overlap between history, myth and dogma, which brings me back to the word 'faith'. In Israel and Jerusalem in particular, we visited many places that were familiar to me from my Church of England upbringing. They were clearly of great significance to the many pilgrims travelling in the Holy Land but bore no resemblance in my mind to the stories that I was familiar with. Over two millennia since the first Christmas and Easter there is no real historical agreement on the actual site of many of the holy places, so it all comes down to those that have been decreed the holy place or dogma, and faith…what you believe.

So what does this have to do with geophysics? Long ago it struck me that geophysicists are in the business of measuring phenomena beyond the reach of our normal five senses (try explaining 'gravity' to the average person in the street…). We make measurements and turn them into profiles, maps, images or models that allow us to physically 'sense' the variations we are measuring. Over the years we became better at it and created our own history as a profession. We have developed better instruments, better processing algorithms and a greater understanding of the variables that affect the readings. We have developed our own, albeit scientific, 'dogma'. So what about the 'faith'?

To me, the two bases of faith are what we are taught or dogma, and personal experience. The measurements we make and the products we create are of no use unless they are given meaning through interpretation. We have to turn our data into plausible geological maps which lead to meaningful targets. Then we have to convince our peers to believe it or have 'faith'. How many times have we all sat around a map trying to reconcile divergent views of interpretation?

When you work in a large company for a long time, the low success rate often tests the faith of even the most supportive management. It's the same at the small end of the exploration business where we are asking investors to have 'faith' in our experience and knowledge and to back us in a highly risky business. Long periods without success often see the market lose faith in our business and stop investing.

So in fact to me our whole world is about 'faith'. Science takes us so far, but we are still in most part dealing with the unseen and the unknown. Leaps of faith and serendipity still form a large part of our endeavours. As we go further under cover, our challenge will be to make those steps more controlled and rigorous and more importantly, to convince non believers that we can be trusted to know what we are doing. This is the only way we will discover the resources needed to meet the challenge of the emerging world.

Anyway, regardless of your religious persuasions, on behalf of the Federal Executive I wish everyone a happy and safe festive season with your families and a prosperous and successful New Year.

Phil Harman
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ASEG News

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A note of thanks

The ASEG would like to thank Rio Tinto and Origin Energy for their contributions as sponsors in the Student Sponsorship Program for 2009–2010. This program aims to secure the future of our profession by offering subsidised memberships to students interested in careers in Minerals or Oil & Gas geophysics while they study. This year 77 students took part in this program which has contributed to a record number of student memberships in 2009–2010.

Cameron Hamilton
Membership Committee Chairman

New members

The ASEG extends a warm welcome to 49 new members to the Society (see table below). These memberships were approved at Federal Executive meetings held in September and October.

We would also like to welcome a new corporate member to the ASEG.

Quantec Geoscience Pty Ltd was accepted as a new corporate member as of September 2010. Quantec Geoscience has completed more than 2500 surveys globally since 1986. The company delivers high-quality data acquisition, processing, interpretation and other geophysical services to the mining, geothermal, and oil and gas exploration industries. Quantec clients have access to leading and proven technologies that address many earth science challenges – from grassroots and near mine mineral exploration to deep imaging of geothermal host rocks to exploring under volcanic cover or salt for oil and gas. Quantec also provides survey solutions for coal based methane (CBM) and other specialised work.

Quantec uses proprietary technology in their Titan distributed array DCIP/MT system and Spartan MT systems as well as conventional surface and downhole TEM, IP and Ground Magnetics services.

With offices in Canada, USA, Mexico, Peru, Argentina, Chile and Australia as well as agents in India, Brazil and Botswana Quantec can provide services to projects throughout the world.

Contact details for the Australian office are:

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Tel: +61 7 3359 0444
Website: www.quantecgeoscience.com
Contact: Trent Retallick
(Mob: 0410 529 992;
Email: tretallick@quantecgeoscience.com)

Name	Organisation	State/ Country	Member grade
Paul Anderson	Apache Energy Ltd	WA	Active
Toshihiko Ando	Inpex	WA	Associate
Jurin Apisampinvono	Chevron	WA	Active
Maryam Bahrirudsari	Curtin University of Technology	WA	Student
Kira Erika Bruzgulis	University of New South Wales	NSW	Student
Bob Burmaz	PGS Australia Pty Ltd	WA	Associate
John Michael Carew	Southern Geoscience Consultants	WA	Active
Graham Richard Carr	CSIRO	NSW	Active
Shaun Davis	Curtin University of Technology	WA	Student
John David Ellison	Curtin University of Technology	WA	Student
Jamal Ohan Esttaifan	Curtin University of Technology	WA	Student
Gabriela Filomeno	Curtin University of Technology	WA	Student
Reem Freij Ayoub	CSIRO	WA	Associate
Konstantin Alexander Galybin	Schlumberger	WA	Active
Vincent Gruffat	Schlumberger	WA	Associate
Ebrahim Hassan Zadeh	Curtin University of Technology	WA	Student
Bruce Hawkes	Makarra Geotechnical	WA	Associate
David Karel Hutchinson	Geoscience Australia	ACT	Associate
Kent Inverarity	University of Adelaide	SA	Student
Gavin Edward Jones	Curtin University of Technology	WA	Student
Anthony Paul Jumeau	Curtin University of Technology	WA	Student
Vincent Wai Tin Kong	Schlumberger	WA	Active
Aspasia Kouhsen	University of Western Australia	WA	Student
Victor Labson	US Geological Survey	USA	Active
Guhan Manoharan	University of Western Australia	WA	Student
Guhan Manoharan	UWA	WA	Student
Yassily Mikhaltsevitch	Curtin University of Technology	WA	Active
Keith Stuart Myers	Western Geco	WA	Active
Natalie Nguyen	Curtin University of Technology	WA	Student
Eva Papp	Papp Consulting, ANU	ACT	Active
Marina Pervukhina	CSIRO	WA	Active
Andrew Pethick	Curtin University of Technology	WA	Student
Joel Sarout	CSIRO	WA	Associate
Muhammad Shafiq	Schlumberger	WA	Active
F. Hasan Sidi	Woodside Energy	WA	Associate
Paul Christiaan Spaans	Woodside Energy	WA	Active
Henry Reading Steeger	Curtin University of Technology	WA	Student
Linyun Tan	China University of Geosciences	China	Student
Guy Taylor	Woodside Energy	WA	Active
Michael Thomas	Adelaide University	SA	Student
Rebecca Li Jia Tung	Curtin University of Technology	WA	Student
Layne Willem Vanzaanen	Curtin University of Technology	WA	Student
Vicki Louise Ward	PGS Australia Pty Ltd	WA	Associate
Michael Wenz	Curtin University of Technology	WA	Student
Helen Williams	Minmetals Group Ltd	VIC	Active
Takashi Yamatani	Inpex	WA	Associate
Alicia Rebecca York	Curtin University of Technology	WA	Student
Takeshi Yoshida	Inpex	WA	Associate

ASEG News

Australian Capital Territory

The ACT Branch hosted our joint ASEG/SEG Honorary Lecturer, Prof. Alan Green, on the 25th and 26th of October for a talk and short course. On the first day, Alan presented a topical talk on earthquakes and deformation on the eastern side of the New Zealand Alps. His survey area only just missed covering the area ruptured during the recent earthquake that shook Christchurch and surrounds, but the work of Alan and his colleagues from ETH Zurich highlights the danger posed by more obvious faulting closer to the range front. The talk included spectacular examples of how geophysics (primarily shallow reflection seismic and ground-penetrating radar) can image the structures and deformation associated with active faulting.

On Alan's second day in Canberra, around 20 people (including one NSW member and a student from ANU) attended his short course on the 'Application of seismic and geoelectric methods to near-surface and engineering-related studies'. After a refresher on seismic and geoelectric methods, Alan presented a comprehensive set of case studies illustrating the ways in which these methods contribute to studies of slope instability, dam stability, groundwater contamination, archaeology, water-bearing buried valleys, hidden faults and nuclear waste disposal sites – it seems that geophysics suggests the best nuclear waste disposal sites in Switzerland lie immediately adjacent to the German border! The course was well received and the amount of discussion was testament to its success. Thanks are due to Koya Suto for coordinating Alan's tour of Australia.

Events for the remainder of the year include two talks on airborne EM from Yusen Ley and Aaron Davis (24 November) and, as has been the tradition in recent years, a joint Christmas BBQ with the local GSA and AusIMM branches (7 December). Check the branch web site for details!

Ron Hackney

New South Wales

In October, we had our student evening and two students presented their work. Luke Mondy from the University of Sydney spoke about how coupling geodynamic models with synthetic seismic surveys can maximise exploration success. Luke spoke about how to directly compare synthetic seismic sections to real seismic data, to iteratively refine crustal deformation models. He discussed how the methodology is particularly insightful in structurally complex regions, and oil and gas fields containing salt bodies and extended salt layers above hydrocarbon reservoirs.

Tim Jones from Macquarie University spoke about the effects of thermochemical piles and post-perovskite on plume dynamics. He emphasised that understanding the convective processes occurring in the mantle has always been a critical goal of solid-earth geophysics. Tim outlined how he employed numerical simulations to examine the dynamic effect of chemical heterogeneity and a post-perovskite phase transition within the lowermost mantle.

In November, the ASEG/SEG Honorary Lecturer, Prof. Alan Green from ETH Zurich, Switzerland gave a presentation on mapping active faults using 3D ground-penetrating radar and 2D and 3D high-resolution reflection seismology. Alan spoke about examples from New Zealand, comparing geophysical datasets with geomorphological datasets. Alan also gave an update on the recent Christchurch earthquake. Many questions were asked and there was much discussion about how great some of the New Zealand GPR was.

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

Mark Lackie

Queensland

The Queensland Branch has a new President, Fiona Duncan, a new Secretary, Kate Godber, and Henk van Paridon continues in the role of Treasurer. We thank outgoing Branch President, Wayne Mogg, and Secretary, Shaun Strong, for their contribution to running the Queensland Branch.

A busy second half of the year has seen presentations from Natasha Hendricks in July on the topic 'From 4 dry holes to a gas-field'; Wayne Stasinowsky in August on '3D gravity'; Prof. Alan Green, ASEG/SEG Honorary Lecturer in October on 'Mapping active faults using 3D ground-penetrating radar and 2D and 3D high-resolution reflection seismology: examples from New Zealand'; and Kate Godber, also in October, on 'Geophysical studies of the Flying Doctor deposit'.

Fiona Duncan

South Australia

The SA/NT branch recently held a joint luncheon with PESA. The invited speaker – Megan Smith from Woodside energy – presented work on 4D seismic interpretation. This work had been presented at the recent conference in Sydney and was voted as one of the best talks, so this was an opportunity to bring the work to a wider audience.

The Melbourne Cup luncheon is a real social highlight of the ASEG calendar in SA, as geophysicists, friends, colleagues and family get together for an afternoon of networking, fun and good food and wine. This year was no exception, and the function room at the national wine centre was filled to capacity.

Finally, our annual Student night was held on the 16th of November. We welcomed three students from the University of Adelaide who presented their honours work. The audience was (as always!) very welcoming and it was excellent to see some new faces in the crowd.

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

Philip Heath

Western Australia

This year's PESA/ASEG WA 23rd Annual Golf Classic took place on 5 November at the Joondalup Resort and Golf Course. The 144 strong field was treated to a perfect 23 degree day which saw a variety of golfing skills on display.

First place and congratulations went to the 'Andrew Rieu Rocks' team of Len Chia, Rob Healy, Brett McDonald and Neil Shaw with a final score of 58.1258. Second place went to Dan Gillam, Dave Mellors, Denny Rompotes and Llew Vincent (58.5) and the 'Fugro All Stars' of Toby Bridle, Mick Curran, Mike Riha and Simon Stewart took out third spot with a 58.87. Special mention goes the combined PESA/ASEG committee team of Jennifer Wadsworth, Simon Davey, Amanda Nicholls and Anne Morrell who, with a grand total of 70.59375, took out the much coveted NAGA award. We'll be sure to be back defending the title next year!

Many thanks to all sponsors including gold sponsor CGGVeritas, silver sponsors PGS, Woodside, Fugro Seismic Imaging and Searcher Seismic, and bronze sponsors Enigma Data Services, RPS, Ophir, Key Petroleum and Fugro Multi Client Services. Special thanks goes to Dan Beks and the PESA organising committee for an exceptional day enjoyed by all. Organising of next year's event now falls to ASEG and it is certain to be another 'must attend' for 2011.

Anne Morrell

ASEG 2012 22nd ASEG Conference and Exhibition News Update (02)

Preparations are underway for the Brisbane conference. The COC has been in place now for some 5 months and the PCO, ARINEX has been appointed. There are two main foci at this time, marketing and 'theming'.

We will be seeking the assistance of kindred societies. Our 'Ambassador without Borders' Koya Suto has already visited colleagues in the SEG and SEGJ to spread the word. We are also currently looking for certain themed days and workshops that can attract delegates not normally seen at ASEG conferences.

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

Co-Chairs: Wayne Mogg and Andrea Rutley
Technical: Binzhong Zhou
Sponsorship: Ron Palmer and Howard Bassingthwaighte
Exhibition: Gary Butler and Dave Burt/John Donohue
Finance: Noll Moriarty
Workshops: Koya Suto
Publicity: Henk van Paridon
Students: Shaun Strong
Social: Janelle Kuter

Anyone able to help (especially papers) should contact Wayne or Andrea (wayne.mogg@originenergy.com.au or arutley@xstratacoal.com.au)

34th International Geological Congress in Australia, 2012

The ASEG, through the Australian Geoscience Council, is part of the team organising the 34th International Geological Congress. This will be held at the Brisbane Convention and Exhibition Centre, 5–10 August 2012.

The Congress provides an excellent opportunity to enhance the reputation of Australian Geoscience and also to show Australia to delegates from overseas.

The First Circular can be accessed by following the link on the Congress website, www.34igc.org. This website will be the main vehicle for dissemination of updated information and provides the key contact details.

The scientific program will cover all aspects of the geosciences. It will demonstrate how geosciences information, knowledge and applications are contributing directly to meeting societal needs; for example through innovation in the resources and energy based industries, better informed land and water management, enhanced understanding and mitigation of climate change and geohazards, and building major cities and infrastructure.

A major theme will be a GeoHost support program for delegates from low income nations. This will be linked to participation in training workshops, particularly for delegates from Africa.

More details will be provided in the February 2011 *Preview*.

Geothermal energy…the power beneath your feet

West Australian Geothermal Energy Symposium

21 and 22 March 2011
Perth Convention and Exhibition Centre, Perth, Western Australia

CALL FOR PAPERS

The West Australian Geothermal Energy Symposium will bring together scientists, technical experts, policy makers and potential end-users to promote and expand the understanding and utilisation of geothermal energy in Western Australia at all levels. The event will provide a forum to examine the technical, market and regulatory issues critical to the success of the industry and increase public awareness of the opportunities to use geothermal energy.

Our key invited international speaker will be John Lund (USA), who has over 30 years of experience in the geothermal industry and is one of the world leaders in direct use applications and ground-source heat pumps.

The symposium will feature a series of technical sessions sponsored by the Australian Geophysical Exploration Society and supported by the Western Australian Geothermal Centre of Excellence that will focus on the application of geophysical methods to geothermal exploration and development.

Other sessions will focus on identification and development of direct use geothermal projects, ground-source heat pumps, engineering issues and design and building construction considerations.

The **West Australian Geothermal Energy Symposium** is seeking research papers and case studies on the following subjects

- **Exploration for Geothermal Resources**
- **Direct use of Geothermal Energy: district heating/cooling, ground-source heat pumps, sorption chillers, air conditioning and desalination for residential and industrial projects**
- **Power conversion technologies**
- **Business development, funding and economic analysis**

Papers can be presented as talks or posters. In conjunction with ASEG the West Australian Geothermal Energy Symposium provides the opportunity to publish extended abstracts in the conference volume, and peer-reviewed journal articles in Exploration Geophysics.

Extended abstracts
All manuscripts must be submitted as extended abstracts by **15 January 2011** and are expected to be no more than four pages in length, conforming to the detailed instructions on the conference website (www.wageothermalsymposium.com.au), and using the template provided.

Journal articles in *Exploration Geophysics*
Prospective authors are expected to register their interest for publishing scholarly articles in Exploration Geophysics no later than **15 January 2011**. By providing a working title and list of authors in an email to Klaus Gessner (klaus.gessner@uwa.edu.au) or Mike Middleton (michael.middleton@dmp.wa.gov.au). Manuscripts for journal articles must be submitted no later than **15 February 2011**, using the instructions published on the journal website. We expect journal articles to be published 6–12 months after submission. Depending on the volume of submitted journal manuscripts ASEG will consider publishing a Special Volume of Exploration Geophysics.

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Update on Geophysical Survey Progress from the Geological Surveys of Western Australia, New South Wales, Northern Territory and Geoscience Australia (information current at 7 November 2010)

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

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Contractor	Start flying	Line (km)	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
South Officer 1 (Jubilee)	GSWA	Thomson	1 Jun 10	180 000	200 m 50 m N–S	32 380	12% complete @ 7 Nov 10	TBA	148 – Oct 10 p23	TBA
South Officer 2 (Waigen – Mason)	GSWA	Thomson	28 Jun 10	113 000	400 m 60 m N–S	39 890	45% complete @ 7 Nov 10	TBA	148 – Oct 10 p24	TBA
East Canning 3 (Stansmore)	GSWA	Thomson	14 Jul 10	114 000	200 m (east) 400 m (west) 50 m N–S	25 934	100% complete @ 2 Nov 10	TBA	148 – Oct 10 p24	TBA
Eucla Basin 2 (Loongana)	GSWA	Fugro	20 Jun 10	113 000	200 m 50 m N–S	20 320	82% complete @ 7 Nov 10	TBA	148 – Oct 10 p24	TBA
Eucla Basin 4 (Madura)	GSWA	Fugro	1 Jul 10	102 000	200 m 50 m N–S	18 220	82% complete @ 7 Nov 10	TBA	148 – Oct 10 p24	TBA
Eucla Basin 5N (Forrest)	GSWA	Fugro	16 Jun 10	75 000	200 m 50 m N–S	13 040	12 Sep 10	TBA	148 – Oct 10 p25	TBA
Eucla Basin 5S (Eucla)	GSWA	Fugro	6 Jul 10	87 500	200 m (onshore) 400 m (offshore) 50 m (onshore) 100 m (offshore) N–S	16 100	100% complete @ 5 Nov 10	TBA	148 – Oct 10 p25	TBA
South Canning 1 (Madley – Herbert)	GSWA	UTS	19 Jul 10	95 000	400 m 60 m N–S	33 520	96% complete @ 7 Nov 10	TBA	148 – Oct 10 p25	TBA
South Canning 2 (Morris – Herbert)	GSWA	UTS	1 Jul 10	125 000	400 m 60 m N–S	45 850	74% complete @ 7 Nov 10	TBA	148 – Oct 10 p25	TBA
North Canning 4 (Lagrange – Munro)	GSWA	UTS	20 Sep 10	103 000	400 m 60 m N–S	36 680	26% complete @ 7 Nov 10	TBA	148 – Oct 10 p26	TBA
Southeast Lachlan	GSNSW	Fugro	1 Mar 10	107 533	250 m (NSW) 500 m (ACT) E–W	24 660	100% on 9 Sep 10	TBA	144 – Feb 10 p15	TBA

TBA, to be advised.

Table 2. Gravity surveys

Survey name	Client	Contractor	Start survey	No. of stations	Station spacing (km)	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Albany – Fraser North	GSWA	Atlas	21 Oct 2010	9200	2.5 km regular	50 980	17% on 1 Nov 2010	TBA	146 – Jun 10 p17	TBA
Sandstone	GSWA	IMT	Early Oct 2010	6300	2.5 km regular	35 640	33% on 7 Nov 2010	TBA	146 – Jun 10 p17	TBA
South Gascoyne	GSWA	IMT	9 Aug 2010	9700	2.5 km regular	55 760	100% on 27 Oct 2010	TBA	146 – Jun 10 p17	TBA
West Arunta	NTGS	Atlas	6 Jun 2010	12 426	4, 2 and 1 km	89 985	100% on 15 Sep 2010	Oct 2010	146 – Jun 10 p18	10 Nov 10

TBA, to be advised.

News

Table 3. Airborne EM surveys

Survey name	Client	Contractor	Start survey	Line (km)	Spacing AGL Dir	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Frome	GA	Fugro	22 May 10	34 986	5000 and 2500 100 m E–W	95 450	100% on 31 Oct 2010	TBA	146 – Jun 10 p18	TBA

TBA, to be advised.

Levelled ship-track gravity and magnetic data covering the Capel and Faust basins

Levelled ship-track gravity and magnetic data covering the Capel and Faust basins (see Figure 1), offshore eastern Australia, are now available for free download from the Geophysical Archive Data Delivery System (http://www.geoscience.gov.au/gadds). These data were compiled and levelled at Geoscience Australia as part of the Australian Government's Offshore Energy Security Program to aid assessments of the petroleum prospectivity of Australia's remote eastern marine jurisdiction (Hashimoto et al., 2010). Further details on the gravity and magnetic datasets are available in Hackney (2010) or by contacting Ron Hackney (ron.hackney@ga.gov.au).

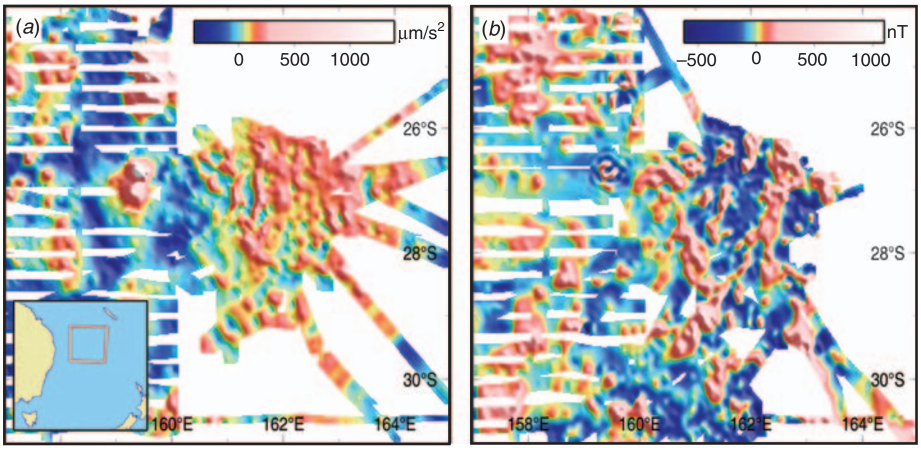

Fig. 1. *Levelled ship-track potential-field data covering the Capel and Faust basins. (a) Free-air gravity anomalies (µm/s²). (b) Low-pass filtered (cut-off wavelength 15 km), reduced-to-pole magnetic anomalies (nT). Note that ringing artefacts are evident in the magnetic image near the Gifford Guyot (centred on 159.5°E/26.7°S), a steep-flanked, basaltic seamount that rises from about 2500 m water depth to within about 300 m of the sea surface.*

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Hackney, R., 2010, Potential-field data covering the Capel and Faust Basins, Australia's Remote Offshore Eastern Frontier: Geoscience Australia Record 2010/34, 40 pp.

Hashimoto, T., Rollet, N., Higgins, K., Petkovic, P., Hackney, R., and Fraser, G., 2010, Integrated geological assessment reveals insights into the prospectivity of remote eastern frontier basins – Capel and Faust basins, offshore eastern Australia: *AusGeo News* 99.

Airborne electromagnetic survey within the Cariewerloo Basin, South Australia – data release

In July and September this year approximately 600 line kilometres of AEM were flown over the Cariewerloo Basin, South Australia (Figure 2) under the Primary Industries and Resources South Australia (PIRSA) PACE 2020 initiative. The survey was managed by Geoscience Australia on behalf of PIRSA and used the Fugro TEMPEST system. The survey addresses dual aims of testing the effectiveness and penetration of this technique in the region and delineating the unconformity surface at the base of the Pandurra Formation within the Cariewerloo Basin.

The Cariewerloo Basin within South Australia is considered highly prospective for unconformity-related uranium (Fairclough, 2005; Fairclough and Curtis, 2007). There are numerous key ingredients assigned to this mineralisation system, many of which are found within this Basin. Faulting, both syn- and post-depositional, and an unconformity at the base of the Pandurra Formation provide pathways for fluid flow. Red-bed sediments within the Pandurra Formation indicate an oxidising environment whilst there are numerous possible sources of reducing environments in the Basin including Hutchinson Group equivalent graphitic schists and Wallaroo Group carbonaceous metasediments (Cowley et al., 2003). Also present are the highly enriched Hiltaba Suite granites with

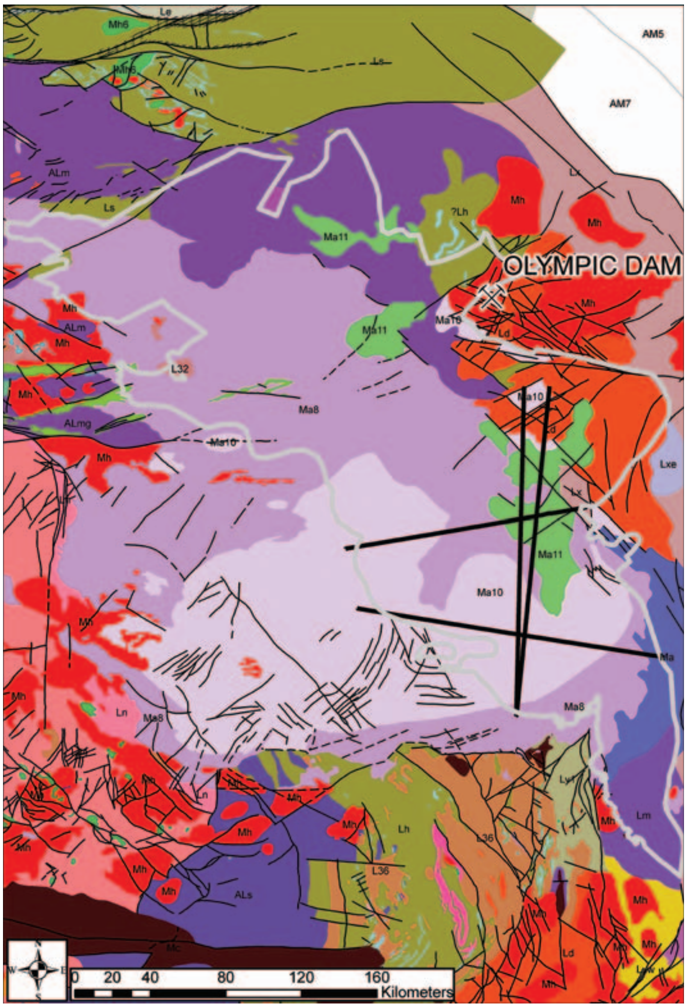

Fig. 2. *Location of the Cariewerloo Basin (outlined in grey) and the AEM lines (shown in black) over the Archaean-Early Mesoproterozoic time slice of the South Australian solid geology map.*

uranium values ~15–20 ppm or greater and co-magmatic volcanics that provide sources of uranium.

The AEM data has been effective within the region with good penetration in most regions excepting the salt lakes. Both Conductivity Depth Images and Geoscience Australia Layered Earth Inversions (are available for the data (Figure 3). Preliminary interpretations of the AEM outlining the unconformity at the base of the Pandurra Formation have also been created. These datasets were released by PIRSA to the public at the South Australian Explorer's Conference on 26 November 2010 and are now available for download from SARIG (www.sarig.pir.sa.gov.au).

The AEM forms part of a larger project that assesses the prospectivity of the Cariewerloo Basin to host unconformity-related uranium. Within this project detailed sedimentological logging of core is being undertaken and integrated with HyLogger spectral analysis. Geophysical potential field models and basement depth estimates have been created and these data are being analysed along with the AEM to create a 3D model of the Cariewerloo Basin which will be released at the South Australian Resource & Energy Investment Conference, May 2011.

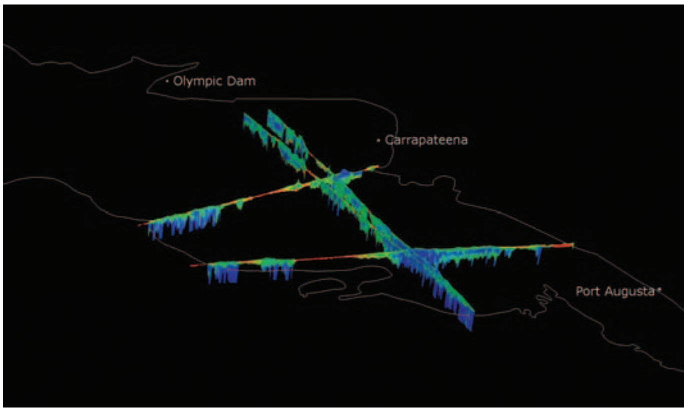

Fig. 3. *Geoscience Australia layered earth inversions.*

For more information please contact Tania Dhu, tania.dhu@sa.gov.au

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Business investment in R&D continues to increase

Australia is in good shape

If a nation's prosperity and future well-being depends on its investment into Research and Development, then Australia is doing well.

Business investment is now at its highest level ever in terms of its percentage of GDP (1.34%) and total investment in all R&D has now increased to $27.7 billion, an increase of $6.0 billion over the 2007–08 levels. This corresponds to 2.21% of GDP, which is also at its highest level (see Table 1).

In 2008–09, business spending on research and experimental development (BERD) in Australia increased for the ninth year in a row to a total of $16.9 billion, according to figures released by the Australian Bureau of Statistics (ABS) on 23 September 2010.

BERD increased by 13% in current price terms and 9% in CPI adjusted terms from 2007–08. Business human resources devoted to R&D in 2008–09 totalled 53 556 person years of effort, an increase of 5% from 2007–08 and an increase of 32% over 2004–05 levels.

Manufacturing and Mining[1] were the largest contributors to BERD in 2008–09, investing $4.35 billion (26%) and $4.24 billion (25%) respectively. Professional, scientific and technical services were next with $2.51 billion (15%) followed by Financial and insurance services with $2.04 billion (12%). Together these four sectors contribute about 80 percent of the national R&D effort.

Of all industries, Mining reported the largest absolute growth from 2007–08, increasing its expenditure on R&D by $860 million – a massive 25% (see Figure 1). This was followed by Financial and insurance services (up $313 million or 28%) and Professional, scientific and technical services (up $233 million or 12%). The Mining R&D results belie those who argue that the resource industries just dig stuff out of the ground. In today's world you have to be smart at whatever you do to be successful and this means investment in R&D.

Australia climbs up the OECD research league

In the past ten years Australia has increased its BERD from 0.74% of GDP to 1.34% of GDP. In the same period it has also risen in the table of OECD members from 18th to 11th. Table 2 shows the results for selected OECD countries. Australia's position with respect to total R&D investment has also risen. It is now 11th in the OECD table compared to 14th four years ago. A good platform for future prosperity.

Further information is in *Research and Experimental Development, Businesses, Australia, 2008–09* (cat. no. 8104.0), and *Research and Experimental Development, All Sector Summary, Australia, 2008–09* (cat. no. 8112.0), published by the ABS.

Table 1. Total investment in Australia on R&D in $ billions[2]

	1996/7	1998/9	2000/1	2002/3	2004/5	2006/7	2008/9
Business	4.235	4.095	4.983	6.940	8.676	12.639	16.858
Commonwealth	1.267	1.179	1.405	1.531	1.544	2.046	2.252
States/territories	0.798	0.864	0.951	0.951	0.942	1.049	1.169
Higher education	2.308	2.555	2.790	3.430	4.327	5.434	6.717
Private non-profit	0.186	0.225	0.289	0.360	0.479	0.609	0.744
Totals	8.794	8.918	10.418	13.212	15.968	21.777	27.740
GERD/GDP	1.66	1.51	1.51	1.69	1.73	2.00	2.21

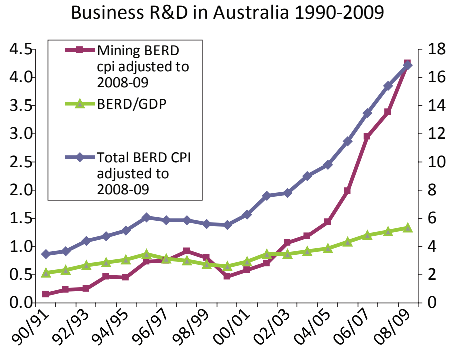

Fig. 1. *Right hand axis shows total business R&D expenditure in Australia (BERD) in $billion (blue curve). Left hand axis shows BERD/GDP in % (green curve) and mining (including petroleum) BERD in $billion. All $s are normalised to 2008–09 values.*

Table 2. BERD/GDP for selected OECD countries

	2002/3	2003/4	2004/5	2005/6	2006/7	2007/8	2008/9
Sweden	NA	2.86	2.66	2.62	2.79	2.66	2.78
Finland	2.34	2.42	2.42	2.47	2.46	2.51	2.77
Japan	2.36	2.40	2.38	2.54	2.63	2.68	2.69
Korea	1.90	2.00	2.18	2.29	2.49	2.65	2.54
USA	1.86	1.84	1.79	1.83	1.89	1.93	2.01
Denmark	1.73	1.78	1.70	1.67	1.66	1.66	1.91
Austria	1.42	NA	1.53	1.70	1.73	1.81	1.89
Germany	1.72	1.76	1.74	1.72	1.77	1.79	1.85
Australia	**0.89**	**0.92**	**0.97**	**1.08**	**1.20**	**1.27**	**1.34**
Belgium	1.37	1.31	1.29	1.25	1.30	1.30	1.32
France	1.41	1.36	1.36	1.30	1.32	1.31	1.27
UK	1.25	1.11	1.09	1.06	1.08	1.15	1.1
Canada	1.17	1.16	1.18	1.15	1.11	1.05	1.00
Netherlands	0.98	1.01	1.03	1.01	1.02	1.03	0.89
Norway	0.95	0.98	0.87	0.82	0.82	0.88	0.87
Spain	0.56	0.57	0.58	0.60	0.67	0.71	0.74
Italy	0.54	0.52	0.52	0.55	0.55	0.55	0.60
New Zealand	NA	0.49	NA	0.48	NA	0.51	NA
Total OECD	1.52	1.51	1.48	1.51	1.56	1.59	

NA, not available.

[1]Mining includes units that mainly search for and extract naturally occurring mineral solids, such as coal and ores; liquid minerals, such as crude petroleum; and gases, such as natural gas.

[2]These numbers have not been adjusted for inflation.

Newcrest swallows Lihir as gold price hits record highs

Australia's top gold miner, Newcrest Mining, finally absorbed Lihir Gold Ltd in September 2010. It raised its offer for Lihir to $9.5 billion, winning the support of its target to create the world's fourth-largest listed gold miner. Lihir operated two gold mining projects; the main one in Papua New Guinea on Lihir Island and the other in Victoria – its Ballarat Gold Mining Project.

Lihir Gold Ltd was first listed on the ASX in October 1995 and since 2000 its market capital has risen from approximately $700 million to $10.6 billion in September this year. During the last decade the price of gold has risen from about US$275 an ounce to about US$1400 an ounce. So, even allowing for inflation and the decline in value of the US dollar, the increase in value of gold has been substantial. This is reflected in the value of both Lihir and Newcrest during the last 10 years.

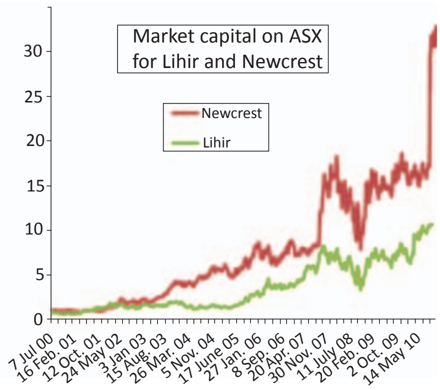

Fig. 2. *Market capital of Lihir Gold and Newcrest from 2000 through October 2010. Notice that the increased value of Newcrest, as a result of the takeover (~$15 billion), was more than the value of Lihir, at its maximum ($10.6 billion).*

Figure 2 shows that both companies were valued at about $1 billion until 2002, when Newcrest really took off. Notice the rise in the value of Newcrest in 2010 from ~$17 billion to ~$32 billion in just one month, when the prospective takeover became public knowledge. It appears that Newcrest negotiated a very good deal, because its market capital rose by ~$15 billion as a result of the takeover, whereas, the value of Lihir was only $10.6 billion at its maximum and its reported offer amounted to $9.5 billion. Stock markets really are unpredictable!

Study and application of the multiple small-aperture TEM system


Guo Wen Bo


Xue Guoqjang

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Nowadays the transient electromagnetic method (TEM) is widely used in ground surface exploration, due to its ease of operation, high precision, large information and sensitivity to low resistance bodies. In the last two years, TEM has begun to be used in underground studies to detect water filled structures ahead of the tunnel. Because of the excellent resolution of low resistance bodies and the secondary field responses directly received by the antenna, TEM has a bright future in tunnel prediction. During a tunnel survey, the scale length of the survey field is so small that it is not possible to lay a large enough loop. Redesigning the optimal survey configuration of TEM is important for improving the detection precision of TEM soundings. In this paper, we introduce a TEM array with multi-aperture survey configuration in which a large aperture single transmitter loop was substituted with several relatively small aperture TEM arrays. Then we study the primary and secondary TEM fields to find a coherent multi-source TEM field. Furthermore, a coherent stack of multiple transmitter sources can improve the intensities of the primary and secondary field. It is shown that the multiple small-aperture TEM system can improve the secondary field response by nearly 31%. A tunnel forecasting TEM system has been developed and a case study shows that it is an effective and successful method for exploring and predicting unfavorable geological structures ahead of the tunnel wall during tunnel drilling.

Keywords: TEM, tunnel, small-aperture, prediction

Introduction

In many parts of the world, fast economic development requires the construction of railways, highways, dams, hydroelectric facilities, as well as mining exploration to identify new resource deposits. Such activities frequently require drilling of extended tunnels through mountain regions with complex geological environments, which in turn introduces potentially dangerous problems, such as water or mud jetting and cave-ins. Consequently, practical geological prediction ahead of drilling is an important and necessary process during tunnel construction. One approach to this problem is to use geophysical prediction methods.

At present in China, to avoid any unnecessary harm to workers and economic losses, the Railway Bureau has decided to make the application of tunnel prediction technologies a routine procedure; similarly the Highway Department is beginning to pay more attention to tunnel forecasting. Based on the above observations, the development of advanced tunnel prediction technologies is an important issue for the future.

Normally, geophysical prediction methods include tunnel seismic prediction (TSP) (Dickmann and Sander, 1996), especially using seismic reflection tomography (SRT) and ground penetrating radar (GPR). This approach is not very sensitive to unfavourable geological bodies, especially when faults, caves and zones of rock fracture are filled with water or mud.

Several popular TEM transmitter-receiver configurations, including long off-set TEM (LOTEM – Spies and Parker, 1984; Strack et al., 1990), coincident loop (Raiche et al., 1985), large loop (Xue et al., 2004), and surface-borehole (Christensen and Sørensen, 1998; Zhang and Xiao, 2000), have been successfully applied in the areas of engineering exploration, mineral investigation and theoretical study. Multi-transmitter electromagnetic surveys (Zhdanov and Tartaras, 2002; Zhdanov, 2006) are widely used in remote-sensing and geophysical exploration. Multi-transmitter multi-receiver surveys have been investigated in the case of marine exploration. However, there are few reports on the study of multi-aperture TEM configurations.

After a modelling test, we developed a special TEM survey configuration, including four small transmitter loops and a receiver antenna. We used this system to measure the field response of a target body. After measuring a decay curve of secondary field voltage corresponding to a survey point, we moved the system to the next survey point until all measurements were recorded. Finally we obtained the data from a tunnel wall, then processed the data and interpreted the results. The case study has indicated that this technique can successfully detect water or mud-filled faults or fracture zones ahead of the front wall of a tunnel during construction.

Laboratory tests of the multi-aperture system

In order to test whether a multi-aperture source produces a larger primary and secondary field response, a conductive copper plate (32 cm × 24 cm × 2 mm) using a single and a multi-aperture transmitter configuration was excited, and the primary and secondary field responses were measured in terms of magnitude and alignment.

The single large-loop transmitter source consists of a square loop (20 cm × 20 cm with 10 turns); while the multi-aperture array consists of four smaller square loops (10 cm × 10 cm with 10 turns each) (see Figure 1). In each small-aperture transmitter source, the current direction was clockwise with a magnitude of 10 A. The transmitting power was 12 V and 50 soundings were stacked with a 25 Hz transmitting frequency during the primary and secondary field survey. The measurements were made on a square receiver loop (10 cm × 10 cm with 10 turns). The field is measured along the diagonal direction in the horizontal plane using a roaming receiver loop at different vertical displacements relative to the transmitter. In Figure 1*a* the current excited in each small-aperture loop is clockwise, so that the corresponding magnetic field is always in the same direction, which is equal to the single-aperture transmitter.

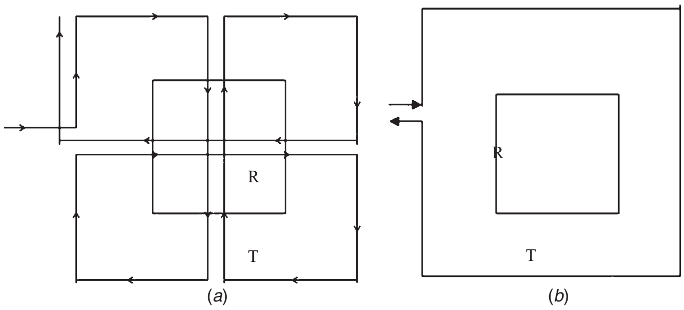

Fig. 1. *Multi-aperture transmitter configuration (a) a special transmitter configuration formed by four small loops; (b) a larger square loop configuration.*

Figure 2 shows the secondary field curves of the single (or standard) and the multi-aperture source without conductance model, where the vertical distance is 6 cm (Figure 2*a*), 8 cm (Figure 2*b*) and 10 cm (Figure 2*c*). From Figure 2 it is clear that the two curves almost agree with a small discrepancy when the conductance plate is non-existing. So we can ignore the difference of self-transients between the two configurations.

The purpose of measuring the primary field is to identify and characterise coherent properties of the multi-aperture field. We generated the primary fields through both the single large-aperture loop and the multiple small-aperture transmitter loops, and measured its strength as a function of horizontal position.

Figures 3*a* and 3*b* show the primary field contour maps, at 6 cm vertical distance relative to the transmitter, excited by the single large-loop source and by the multiple small-aperture array source. In Figure 3*b* it is obvious that in the case of the multiple small-aperture array configuration, the primary field value at the centre is smaller than along the diagonal lines. The maximum value occurs approximately near the centre of the individual loops that make up the multi-aperture antenna. While in the case of the single large-aperture configuration, the primary field value (64.2 mV/a) in the centre of the loop is smaller than that of the value (7.2 mV/A) in the centre of the loop generated by

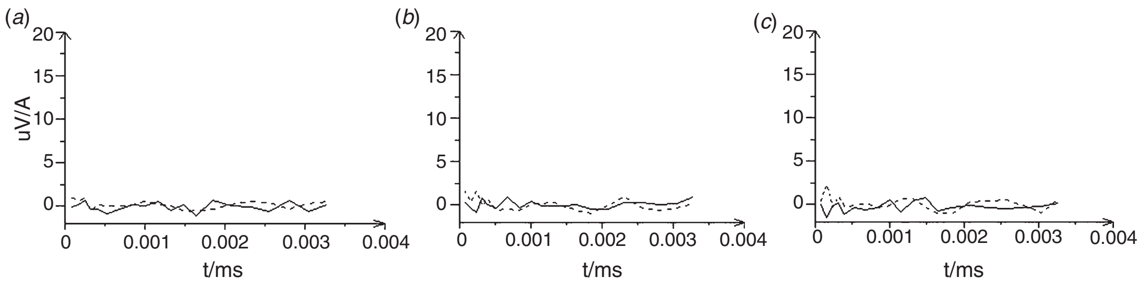

Fig. 2. *Secondary field curves of standard and multi-aperture source without conductance plate. Solid lines represent results with the standard source and dashed lines represent results with the multi-aperture source.*

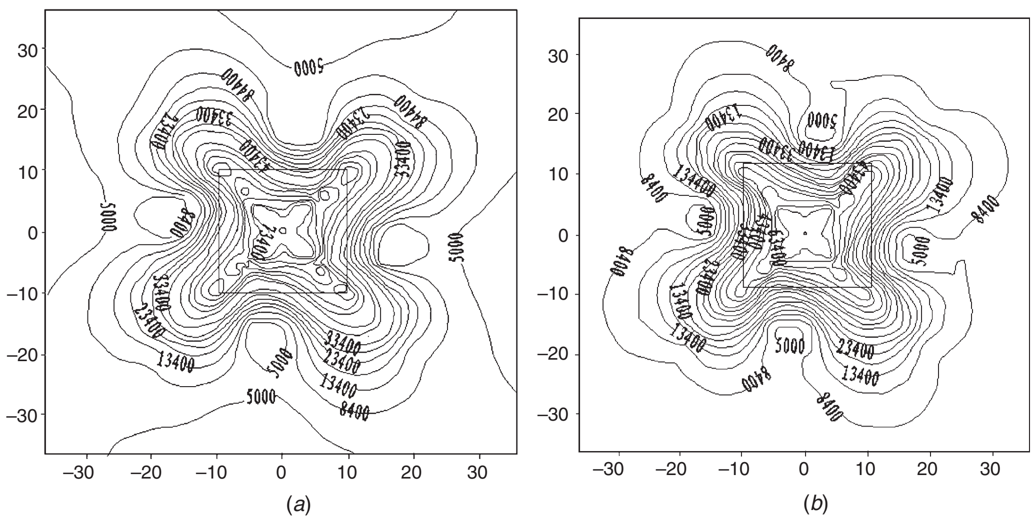

Fig. 3. *Multi-aperture (a) and single-loop (b) primary field contours at a vertical distance of 6 cm from the transmitter. The location of the transmitter loop is illustrated by a square.*

the multiple small-aperture arrays. The latter is approximately 10.9% larger than that of the former.

Figure 4 shows the curves of the field strengths with varied survey points under two different configurations. These results demonstrate that multiple small-aperture sources can generate a more powerful primary magnetic field. Furthermore, the multiple small-aperture transmitter configuration can create a coherent single primary field just as the single large-aperture transmitter configuration does.

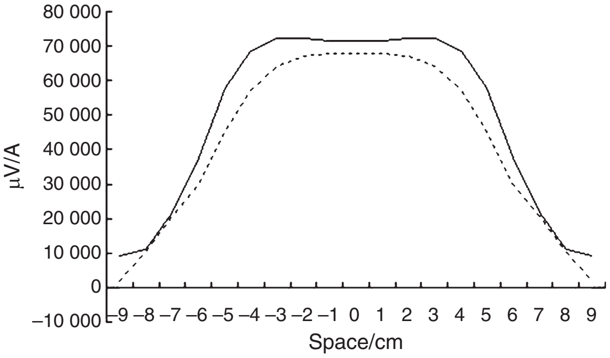

Fig. 4. *Multi-aperture and single-aperture primary field curve for different survey points at a vertical distance of 6 cm from the transmitter. Solid lines represent the primary field with a standard source and dashed lines represent the primary field with a multi-aperture source.*

The purpose of measuring the secondary field is to quantify the improved ability of the multiple small-aperture array sources to detect a low resistivity body compared to the single large-aperture source. We employed a copper plate (32 cm × 24 cm × 2 mm) to simulate a low resistivity body. We used the single large-loop and the multiple small-aperture transmitter sources to initiate electrical currents in the copper-plate at buried depths between 0 cm and 16 cm with 2 cm intervals. The results are shown in Figure 5. The transmitting power was 12 V, the transmitting frequency was 25 Hz and the current was 10 A. The time delay after switching off the two configurations was 0.087 ms, and the survey time range was from 0.087 ms to 7.19 ms.

Figure 5 illustrates that for the same buried depth, the response from the multiple small-aperture transmitter system is greater than that of the single large-aperture transmitter system. When the buried depth is increased from 0 cm to 6 cm the response

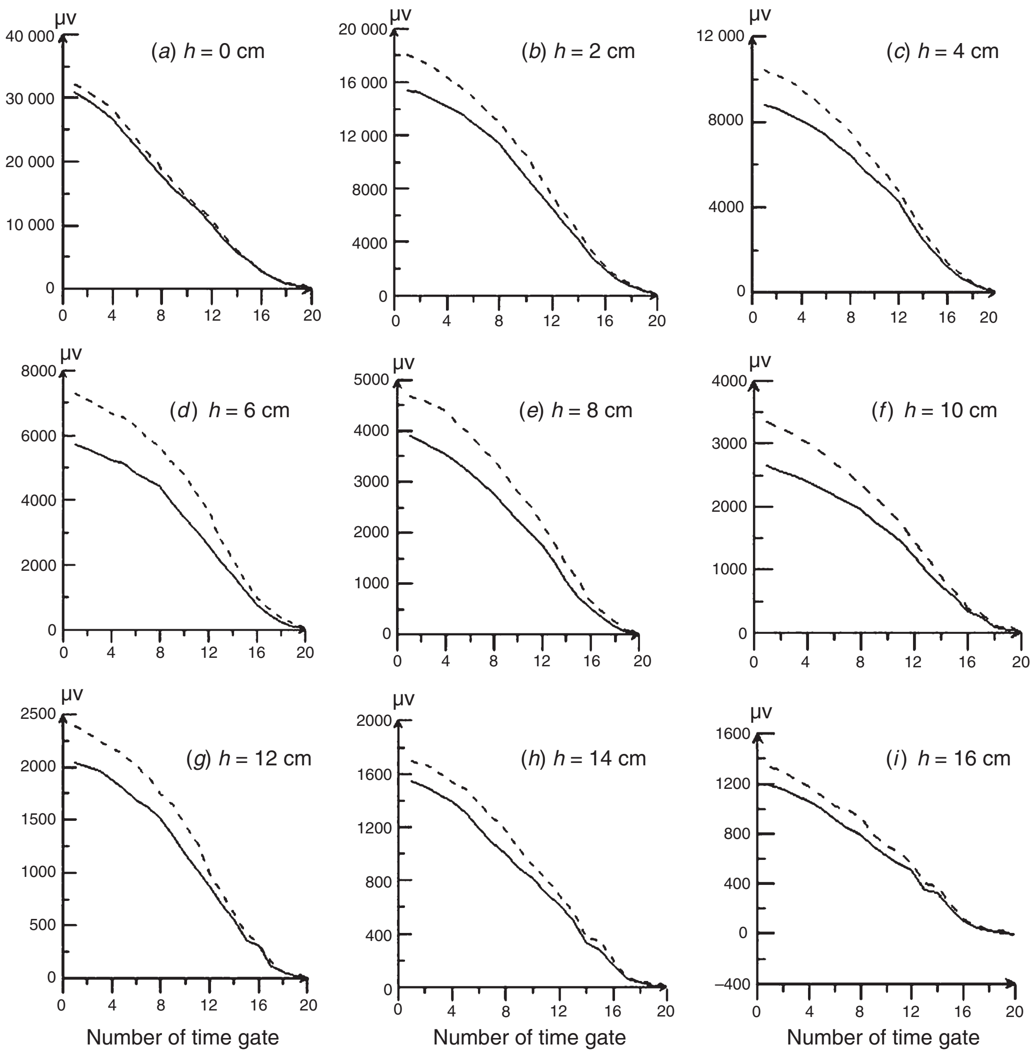

Fig. 5. *Secondary field voltage decay curves for conducting copper plate at different buried depths ranging from 0 cm to 16 cm. The dashed line represents the multi-aperture system response and the solid line represents the single aperture system response.*

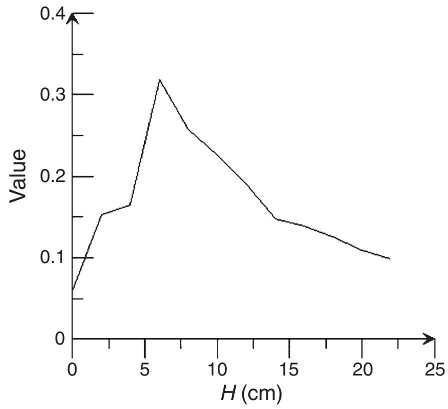

Fig. 6. *Curve of relative difference value between multi-aperture loop and single-aperture loop response to a conductive copper plate at various buried depths.*

difference between the two systems is increased becoming the largest at a depth of 6 cm (Figure 5*a–d*); hereafter the response difference decreases with buried depth from 6 cm to 16 cm.

In order to quantify the relationship between the copper plate response of the multiple small-aperture loops and the single large-aperture loop, we calculate the relative difference, defined as $(V_m–V_s)/V_s$, where V_m and V_s are the voltage for the multiple small-aperture loops and for the single large-aperture loop, respectively. The above relative values for the two systems with varied buried depths are shown in Figure 6, confirming the former conclusion that the largest value was observed at a buried depth of 6 cm, and from that buried depth the relative values decreased both in positive (from 6 cm to 22 cm) or negative (from 6 cm to 0 cm) directions.

We have demonstrated that the magnetic field generalised by the multiple small-aperture array sources (H_m) is greater than that of the magnetic field (H_s) excited by the single large-aperture loop so that we can define the relationship as below:

$$H_m = H_s + \Delta H \quad (1)$$

Table 1. Relative difference between secondary response to the copper plate object using the multi-aperture and single-aperture loop configurations

Buried depth (cm)	Relative difference
0	0.058
2	0.1532
4	0.165
6	0.318
8	0.257
10	0.224
12	0.19
14	0.147
16	0.138
18	0.126
20	0.108
22	0.098

where ΔH is the magnetic field difference. We have compared the differences between the multiple small-aperture sources and the single large-aperture source configurations for both the primary and the secondary fields with different offsets from the transmitter in the horizontal plane or buried depth in vertical extent. The results are summarised in Table 1.

We can see from Table 1 that the relative difference value generalised with two different systems mainly distributes around the range of 0.15–0.31. Based on the statistical data of Table 1, we can deduce the following equation

$$H_m^2 = H_s^2 + \Delta H_2 = H_s^2 + 31\% H_s^2 \quad (2)$$

The above relation indicates that the secondary field response can be improved by nearly 31% when switching from the single large-aperture loop to the multiple small-aperture array sources.

Case study

In order to construct a railway from Hubei province to Chongqing city, a series of tunnels have been designed. The tunnel for this case study is located in the south-west mountain area of Hubei province, in southwest China (see Figure 7). The test area is dominated by very complex geological conditions including tectonic denudation, erosion and corrosion of mountains. The altitude is approximately 400 m to 1400 m. The range of relative heights is 200 m to 1000 m.

The adopted geometry of the system is shown in Figure 8, where Figure 8*a* shows tunnel location. The length of the tunnel is 3.85 km. Figure 8*b* shows the configuration of the in-loop four-aperture TEM. During surveying, we adopted a configuration which fixed the transmitter loop and receiver antenna on a prop stand. A square transmitter loop (3 m × 3 m with 10 turns) was placed vertically on the front tunnel wall, and a small receiver coil (the antenna, see Figure 8*c*) with 210 m^2 in area was placed in the centre of the transmitter loop, with the antenna perpendicular to the plane of transmitter loop. This configuration was used to take soundings at numerous positions across the front wall of the tunnel. Data were recorded in the time delay range from 0.008 ms to 0.96 ms with a sampling frequency of 225 Hz. The output current was 10 A across a voltage of 24 V. The instrument, called terraTEM, was designed and built in Australia. Survey point intervals were 0.5 m.

We measured the parameter $V(t)/I$, where $V(t)$ denotes secondary induced voltage, I is sending current, and the units of $V(t)/I$ are $\mu V/A$. We convert $V(t)$ data into apparent resistivity data by:

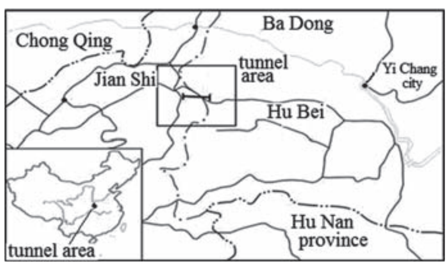

Fig. 7. *Location of the case study survey area.*

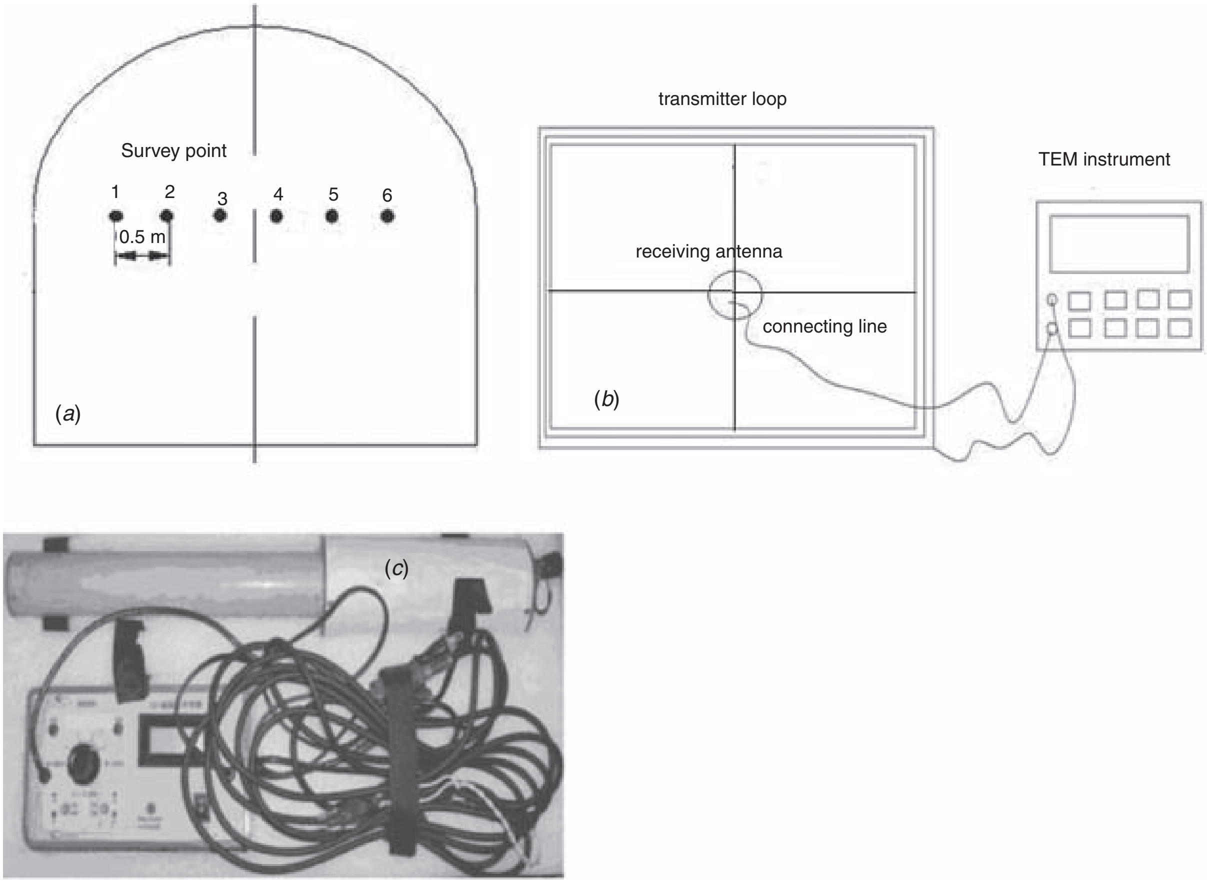

Fig. 8. *A sketch of the TEM configuration located at the surface of the tunnel.*

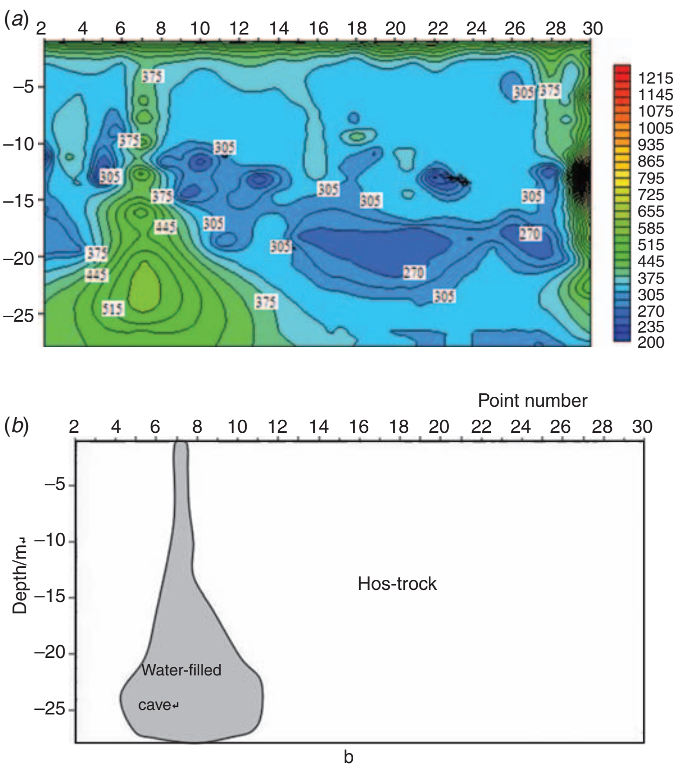

Fig. 9. *Example of interpreted tunnel data: (a) apparent resistivity contour; (b) the interpreted 2-D section and diagram.*

$$\rho(t) = \frac{\mu_0}{4\pi t}\left(\frac{2\mu_0 Mq}{5tV(t)}\right)^{2/3} \tag{3}$$

where M is the moment of transmitter, q is receiver area, and t is time delay.

We also transform prediction depth h_τ from $V(t)$ by

$$h_\tau = \left[\frac{3Mq}{16\pi V(t)\, S_t}\right]^{1/4} - \frac{t}{\pi_0 S_\tau} \tag{4}$$

$$\text{where } S_\tau = \frac{16\pi^{1/3}}{(3Mq)^{1/3}\,\mu_0^{4/3}} \frac{[V(t)]^{5/3}}{[V(t)]^{4/3}} \tag{5}$$

We calculated apparent resistivity and depth according to equations (3), (4) and (5).The results are shown in Figure 9, where Figure 9*a* shows apparent resistivity contours. The horizontal direction indicates the number of survey points, the interval spacing is 0.5 m, and vertical direction represents prediction depth, agreeing with the ex-cave direction. In the surface of the tunnel wall, the resistivity is high, which means that the rock stays well deposited. At survey point 7 and a depth of 25 m, there exists a low resistivity layer (displayed in green), which may be caused by a water filled structure. Figure 9*b* shows the final interpreted results based on available geological information. The interpreted results were tested by an ex-cave recorder during excavation. We found a large cave at a depth of 15 m corresponding to survey point 6. The height of this cave is 10 m and it appears to be a large-scale, full-water, full-mud feature.

Through the interpretation of transient electromagnetic data and comparing the calculated resistivity sections, we can infer the location and scope of a cave. After confirmation of the existence of this cave, we concluded that the transient electromagnetic interpretation was in agreement with the actual geological conditions.

Conclusion

TEM has been used extensively for surface exploration in China over the past few decades. However, there are few reports of TEM being applied in tunnel forecasting. We developed a specially designed TEM configuration, which can be used on a tunnel wall to detect water-filled structures.

The study demonstrates that employing a multi-aperture transmitter configuration can reform the direction of the scatter field, gather magnetic field of the scatter field to the centre of the transmitter loop, and as a result generate a high intensity of primary field in the centre of the loop. It suggests a bright future for the application of this theory and technology to improve the precision and resolution of TEM data. The result of the case study shows that the redesigned configuration can successfully be used to detect water or mud-filled faults or fracture zones ahead of the front wall of a tunnel during construction.

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Accurate quasi 3D versus practical full 3D inversion of AEM data – the Bookpurnong case study

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Introduction

The debate regarding the need for full 3D inversion in semi-layered environments is intensifying, and the issue is the subject of ongoing research (e.g., Ley-Cooper et al., 2010). Along these lines, the May 2010 issue of *Preview* (Issue 146) featured a paper by Wilson et al. entitled 'Practical 3D inversion of entire airborne electromagnetic surveys'. The article describes a novel, innovative approach to 3D inversion of AEM surveys, which the authors argue makes the routine inversion of large datasets a realistic proposition. Their approach uses a moving footprint methodology, which they describe in detail. As an example of the applicability of their inversion method to field data, they present results from the inversion of helicopter time domain (SkyTEM) and frequency domain (RESOLVE) EM data from the Bookpurnong floodplain in South Australia. Specifically they directly compare the results from the 3D inversion of data from these two systems with results from a 1D inversion they produced with *AirBeo* (Raiche et al., 2007). They also make reference to results from the quasi 3D spatially constrained inversion of SkyTEM data described by Viezzoli et al. (2009), and claim that their implementation of a 3D inversion procedure produces results that '…more accurately reflect the known geology of the Bookpurnong area than the results obtained from a variety of 1D interpretations'.

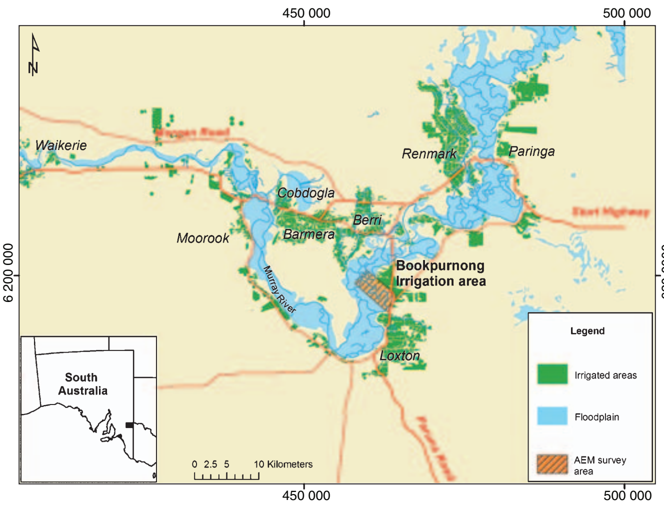

Fig. 1. *Bookpurnong Floodplain in the Lower Murray Region of South Australia.*

We accept that full 3D inversion has an important although, as yet, largely unproven role in the interpretation of AEM data in complex geological settings, and that the moving footprint approach represents a significant step forward towards making it practical. However, we contend that their observation does not adequately reflect the capabilities of accurate 1D inversion methods. We believe that methods based on 1D forward responses have a valuable and continuing role in extracting useful hydrogeological information from the types of AEM data acquired over Bookpurnong, and over other comparable settings, particularly if they use the expected spatial variability as prior information in the inversion. In the interests of encouraging debate and discussion, we take this opportunity to demonstrate the potential of some of these methods with the same data sets, in what is, arguably, as good a 1D environment as you could ask for – a conductive, flat-lying, layered geology which is laterally contiguous and extensive.

Prior to reviewing our results, it's appropriate to summarise the hydrogeology of the Bookpurnong area, not least to provide the reader with an appropriate context for the discussion that follows.

Bookpurnong floodplain hydrogeology

The Bookpurnong floodplain, located approximately 12 km upstream from the township of Loxton in the lower Murray region of South Australia (Figure 1), has been the focus of trials to manage a marked decline in tree health that has been observed along the River Murray in South Australia and elsewhere. The primary cause for this decline is recognised as a combination of floodplain salinisation from saline groundwater discharge, the decrease in flooding frequency, and the recent drought (Jolly et al., 2006; White et al., 2006; Berens et al., 2007). The study area has a hydrogeology characteristic of the eastern part of the lower Murray River and is represented schematically in Figure 2. Floodplain sediments consist of a clay (the Coonambidgal Clay) ranging from 3 to 7 m thick, overlying a sand (the Monoman Formation) which is approximately 7–10 m thick in this area. These sediments occupy the Murray Trench which cuts into a sequence of Pliocene sands (the Loxton-Parilla Sands) up to 35 m thick. These sands outcrop in the adjacent cliffs, and are covered by a layer of Woorinen Sands over Blanchetown Clay, each approximately 2 m thick (Figure 2). The whole area is underlain by the Bookpurnong Beds, which act as an aquitard basement to the shallow aquifer that encompasses the Monoman Formation and Loxton Sands.

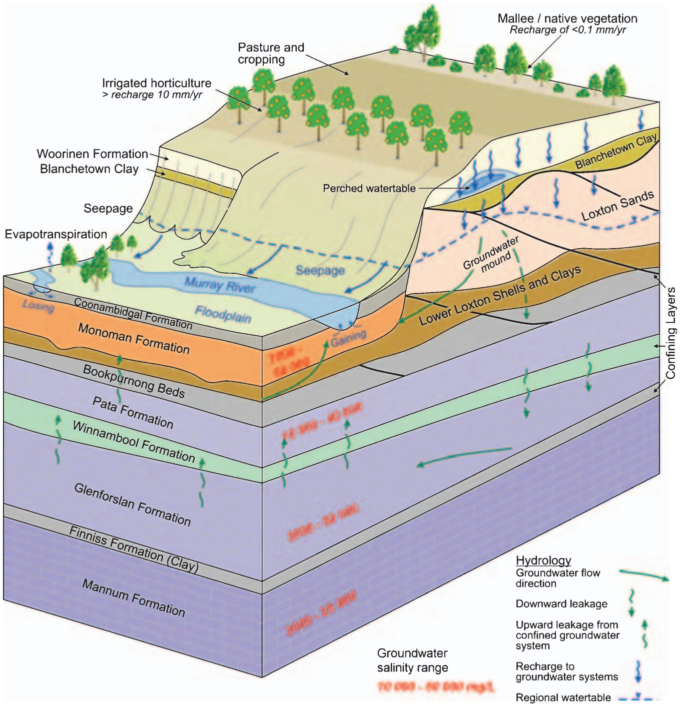

Fig. 2. *Schematic representation of the hydrogeology of the Bookpurnong Floodplain and adjacent highland areas.*

Regional groundwater salinity in the Loxton Sands and Monoman Formation ranges between 30 and 40 000 mg/L, with the high salinities commonly found on the floodplain resulting from evaporative concentration. Irrigation recharge salinity is typically 1000–3000 mg/L (Figure 2). Beneath the Bookpurnong Beds lie limestones and clays of the Murray Group. The regional groundwater salinities in these sediments lie between 15 000 and 30 000 mg/L, that is they are very saline. The above mentioned sedimentary package is sub-horizontal with a very gradual dip in a westerly direction.

High recharge from irrigation on the highlands adjacent to the floodplain results in the development of localised perching and the formation of a groundwater mound in the Loxton-Parilla sands. The mound increases the hydraulic gradient towards the floodplain causing a rise in water levels in the floodplain sediments. Groundwater seepage at the break of slope adjacent to the cliffs may also occur (Figure 2). High water levels coupled with high rates of evapotranspiration, concentrates salt in the near surface across the floodplain. Elevated groundwater levels in the floodplain also promote the discharge of saline groundwater into the Murray River, along what are termed 'gaining' stretches of the river system. Elsewhere along the river, river water discharges into the adjacent banks and we have extensive reaches that are referred to as 'losing' stretches.

AEM over the floodplain

Data from two helicopter EM systems have been acquired on several occasions across the Bookpurnong floodplain. In July 2005, and in August 2008 the Bookpurnong area was flown with the Fugro RESOLVE frequency domain helicopter EM system. In August/September 2006, the area was also flown with the SkyTEM time domain EM system. The repeat survey across Bookpurnong provided a rare opportunity to investigate the relative merits of these systems for surveying the Murray River corridor (Munday et al., 2007). In this paper we examine results from the 2006 SkyTEM and 2008 RESOLVE surveys. The next two sections describe the technical specifications of the two AEM systems employed at the time of the surveys. The SkyTEM system currently in operation has been updated significantly on many of these key parameters when it comes to resolution capabilities.

RESOLVE FDHEM system

RESOLVE is a six fixed-frequency EM system mounted in a 9 m long 'bird' towed beneath a helicopter at a nominal survey altitude of 30 m above the ground, although for the Bookpurnong survey, the nominal altitude was ~50 m because of the presence of tall trees along the river. The bird contains five rigidly mounted horizontal coplanar coils, and in the Bookpurnong survey measured an EM response at nominal frequencies of ~400 Hz, 1800 Hz, 8200 Hz, 39 500 Hz and 133 000 Hz. It also has one coaxial coil pair which measured a response at ~3200 Hz.

SkyTEM TDHEM system

The SkyTEM time domain EM system is carried as a sling load towed beneath the helicopter. Here we describe the SkyTEM system at the time of the survey. Survey altitude of the transmitter in the Bookpurnong survey was ~60 m. The transmitter, mounted on a lightweight wooden lattice frame, was a four-turn, 256 m^2 eight sided loop, transmitting a low moment in one turn and a high moment in all four turns. SkyTEM is capable of operating in a dual transmitter mode (Sørensen and Auken, 2004). In the Low Moment mode, a low current, high base frequency and fast switch off provides early time data for shallow imaging. In contrast when in High Moment mode, a higher current and a lower base frequency provide late time data for deeper imaging. The two modes can be run sequentially during a survey, as was the Bookpurnong survey. In Low moment mode the transmitter base frequency is 222.50 Hz and in High Moment mode base frequency is 25 Hz, which can be lowered to 12.5 Hz. Peak current in the low moment was about 40 A with a typical turn-off time of about 4 µs; while the high moment transmitted approximately 90 A and had a typical turn-off time of about 29 µs. The receiver loop is rigidly mounted at the rear and slightly above the transmitter loop in a near-null position relative to the primary field, thereby minimising distortions from the transmitter. In this survey, the first gate used was at 18 µs after beginning of turn off.

Data acquisition

Twenty-six lines (and 7 tie lines) of RESOLVE data orientated NW–SE were acquired over the floodplain with a line spacing of 100 m (Figure 3). A single calibration line orientated NE-SW over the adjacent highland area was also acquired. Twenty nine lines of SkyTEM data were surveyed on the floodplain in a similar orientation to the RESOLVE data, with 100 m spacing between lines. One line was collected perpendicular to the primary flight line orientation.

1D inversion results and interpretation

The two data sets were inverted using the Spatially Constrained Inversion (SCI) methodology (Viezzoli et al., 2008). The SCI is a

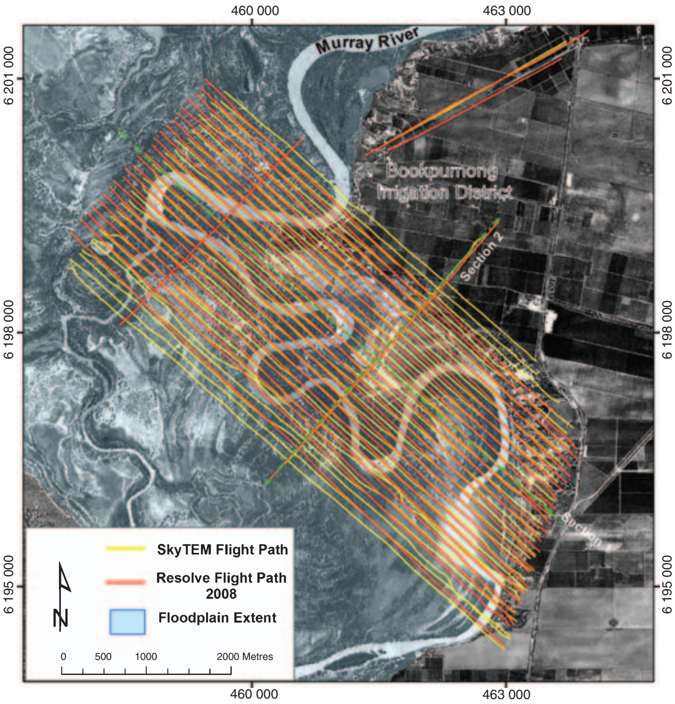

Fig. 3. *Flight line diagram for the RESOLVE and SkyTEM Systems over the Bookpurnong Floodplain. The location of Section Lines 1 and 2, which are discussed in the text, are also shown.*

quasi 3D inversion methodology, based on a 1D forward response, with 3D spatial constraints. The spatial constraints allow prior information (e.g., the expected geological variability of the area, or the downhole conductivity) to migrate across the entire dataset. The output models balance the information present locally within the individual TEM soundings with the ones carried by the constraints. The SCI has a demonstrated applicability in semi-layered environments (e.g. Viezzoli et al., 2009, 2010). We applied the SCI to both the SkyTEM and the RESOLVE 2008 datasets.

The SkyTEM data were fitted within noise levels which were ranging from 3% at early times (nominal) to roughly 20% at late times, based on the stacked data. Data were first inverted with a smooth model with 19 layers, then with blocky discretisation (3 layers for RESOLVE and 4 layers for SkyTEM). The SkyTEM data had both Low and High moment converging locally to the same models. This approach yields the maximum possible resolution of model parameters, as the Low moment contains most information in the near surface, and the High moment on the deeper part of the models. For the RESOLVE dataset, the 2 highest frequencies had a noise level of 15%, whereas for the others it was set to 5%. The data were fitted within noise level over majority of the conductive areas, with exceptions in the more resistive areas, which may be linked to some minor, presently undefined calibration problems.

Figure 4 shows the RESOLVE and SkyTEM SCI results, for conductivity-depth interval of 4–5 and 8–9 m below the ground surface, obtained from the smooth models (19 layers). These images are overlain on a map of the Bookpurnong area, and can be compared directly with the results for the 3D inversion presented by Wilson et al. (2010, figures 3 and 4, p. 31).

The quasi 3D SCI results for both the RESOLVE and SkyTEM data sets show a large degree of medium scale variability, whilst preserving very small scale spatial coherency. For a thorough analysis of absolute conductivity values we refer the reader to the few layer cross sections presented below. However, the near surface conductivity models for both data sets presented in Figure 4 are similar and consistent with the prior knowledge on the soil and groundwater salinities of the area, both in terms of absolute values and spatial variability. A shallow, highly saline aquifer in the floodplains (TDS in excess of 35 000 mg/L, yielding formation conductivities in the order of 1 S/m), is recharged with fresher water in the proximity of the irrigated highlands (see Figure 2). Along the Murray River alternating losing and gaining stretches occur, which are also clearly visible in the SCI results. In-river NanoTEM measurements gave comparable results (cfr Tan et al., 2007 and Viezzoli et al., 2009). The groundwater salinity obtained from shallow boreholes show similar patterns of recharging and discharging areas, and correlate with RESOLVE and SkyTEM results, as shown in Munday et al. (2006) and Viezzoli et al. (2009).

Let us now examine how the SCI recovers the vertical conductivity structure and informs the hydrogeology of the study area. We present the SCI results from both the RESOLVE and SkyTEM data sets (Figure 5 and 6), as vertical sections of conductivity for Section Line 1 (see Figure 3 for location), which corresponds to the profile presented by Wilson et al. (2010) in the Preview article (see Figures 7 and 8). Results from a blocky and smooth model discretisation are presented. In order to assess the absolute values of conductivities, we refer to the blocky model, which, as opposed to the smooth one, has all the degrees of freedom necessary to recover the model parameters correctly, without vertical smoothing or a dependence on the thickness of the starting model. The consistency between the absolute values of modeled conductivity for the 3 layer RESOLVE and the 4 layer SkyTEM data sets is evident, perhaps more so than in the average conductivity maps based on smooth models presented earlier (Figure 4). Flushed (resistive) zones beneath and adjacent to the Murray River are well defined in the near surface for both data sets. Their extent is determined by the proximity to the highland areas, with reaches of the river close to the floodplain-highland boundary more likely to experience the ingress, or discharge of saline groundwater directly into the river, i.e. where the river is gaining. Reaches further away from this boundary show more extensive flushed zones and imply the vertical flux of fresher river water into the adjacent or underlying sediments, referred to as 'losing reaches', although it may be more appropriate to describe them as hyporheic zones. Hyporheic zones are zones along a river or stream where there is mixing of shallow groundwater and river water beneath and next to the river bed, through a process of hyporheic, or through-flow.

To help determine whether the observed variations in measured conductivity reflect changing ground conditions (i.e. the data) rather than model driven changes arising from the inversion process, we also plot an estimate of the depth of investigation (DOI) for both the RESOLVE and SkyTEM systems on cross sections (Figures 5 and 6). The DOI determination is based on the cumulative sensitivity of the actual model output from the inversion (which includes the full system response and geometry) and is described in Christiansen and Auken (2010). It also accounts for the data noise and the number of data points that are integrated into the calculation.

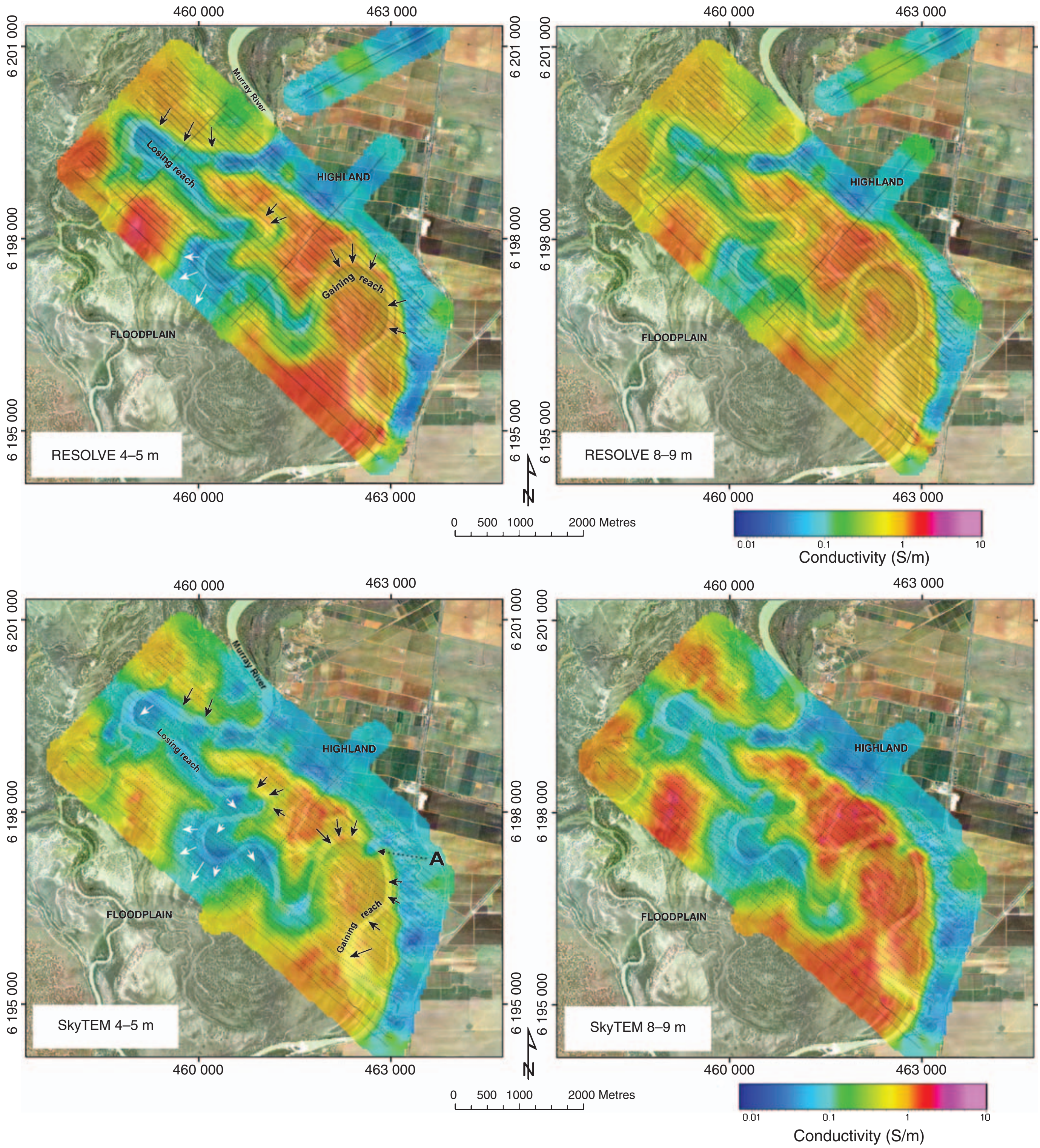

Fig. 4. *Interval conductivity images for the depth intervals 4–5 (left) and 8–9 m derived from 19 layer smooth model quasi 3D SCI inversions of the RESOLVE (top) and SkyTEM (bottom) data sets covering the Bookpurnong floodplain. Black arrows indicate stretches of the river which gain salinity from discharging groundwater, white arrows indicate stretches which lose fresh water from the river into the adjacent floodplain. A wide flushed (resistive) zone is apparent along significant stretches of the river through this area. The resistive zone at locality 'A' (indicated by the dashed arrow on the SkyTEM 4–5 m interval conductivity) may represent a drawdown of fresh river water into the substrate through over-pumping of Salt Interception bores on the adjacent floodplain.*

The DOI suggest an average investigation depth of ~15 m for the RESOLVE system across the highly conductive floodplains at Bookpurnong (Figure 5). Both the smooth and blocky models indicate well defined flushed (resistive) zones in the vicinity of the river, where fresher river water discharges into the adjacent river banks and into the sediments beneath the river. Results from the SkyTEM system (shown in Figure 6) indicate a significantly greater depth of investigation (generally in excess of 60 m) reflecting the High moment capability of that system. A comparison of the modelled conductivity structure for both

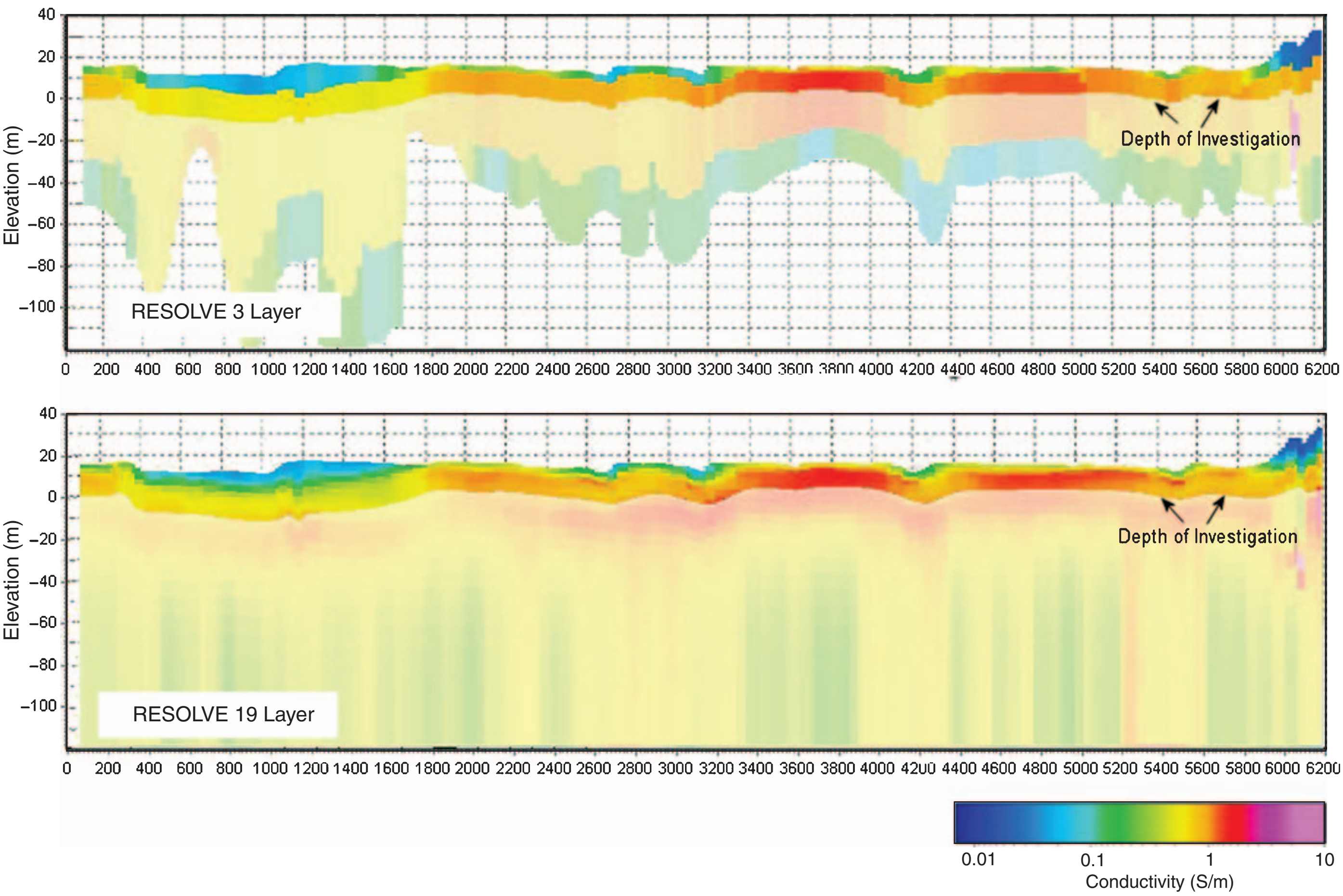

Fig. 5. *2D conductivity depth sections for Section Line 1 from the RESOLVE SCI. Results from a 3-Layer blocky model and a 19 layer smooth model are presented, with the depth of investigation (DOI) marked as a pale-shaded overlay on the 3 layer and 19 layer models are also shown. The cross section has been fitted to topography.*

systems shows that they define similar vertical structure, although RESOLVE, thanks to its higher frequencies, appears to recover finer detail in lateral conductivity variations over resistive areas compared to the SkyTEM system. That said, the extent and depths of flushed zones around the river are comparable for the two systems, and both define the presence of a highly conductive groundwater system at depth. SkyTEM, with its greater depth of investigation, indicates the presence of a fresher aquifer associated with the Limestones of the Mannum Formation at 60–70 m (Figure 6), information which cannot be reliably interpreted from the RESOLVE data set.

We would argue that, in a simple comparison of the SCI results reported here versus those presented by Wilson et al. (2010, figures 7 and 8, p. 32), accurate 1D inversions appear to do as well, if not better, than their 3D inversion procedure in defining finer detail associated with the hydrogeology of the Bookpurnong area. We also contend that the inclusion of an estimate of the system DOI provides further confidence in interpreting the results from the inversions presented here.

The absolute values of conductivity recovered by Wilson et al. (2010) for the SkyTEM dataset (both with 1D code Airbeo and with the 3D moving footprint inversion) are one order of magnitude lower than in the SCI results presented here, and also from what has been determined from bore data in the area. Part of the discrepancy possibly results from their use of the High moment data alone in the inversion. In this and other studies of the Bookpurnong SkyTEM data set, we have included both Low and High moments in the SCI, allowing them to enter the inversion and converge to the same model. The Low moment data is crucial for resolving the shallow parts of the model. However, Wilson's results also differ from the known ground conductivity structure for the area, and from our results. For example the reader is referred to the left hand side of their conductivity cross section reproduced in Figure 8 (p. 32 in Wilson et al., 2010) where resistive areas appear to extend to depth from the surface. Figure 7 shows the effect in the data space (late time apparent resistivity) of changing the conductivity of a half space from 1 to 10 Ohm m. The forward response was calculated modeling the full system transfer function for the SkyTEM system used in Bookpurnong Survey. As expected, the effect on the data of such change in the resistivity (or conductivity) is very large, extending over the entire transient. This means that the results obtained by Wilson et al. (2010), assuming they are fitting the measured High moment data within noise level, are not simply explained by the lack of Low moment data. Another reason for this discrepancy might be linked to the inaccurate modeling of other parameters of the system transfer function, which, as shown by Christiansen et al. (2011), could account for an underestimation of the ground conductivities. We believe that the one parameter that can be ruled out as the cause of the discrepancies in the modeled conductivity structure is the dimensionality of the forward response.

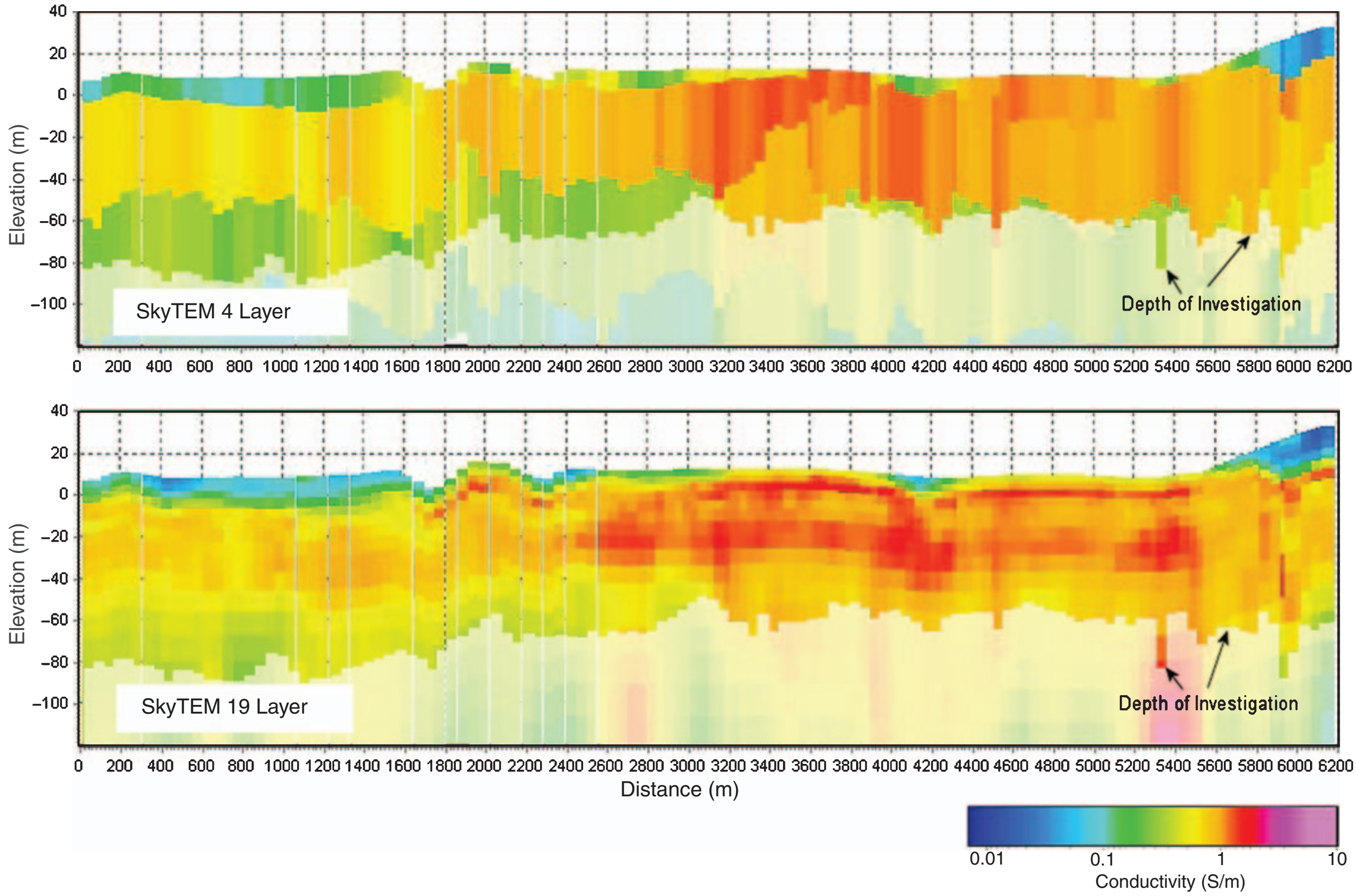

Fig. 6. *2D conductivity depth sections for Section Line 1 from the SkyTEM SCI. Results from a 4 layer blocky model and a 19 layer smooth model are presented, with the depth of investigation (DOI) marked as a pale-shaded overlay on the 4 layer and 19 layer models are also shown. The cross section has been fitted to topography.*

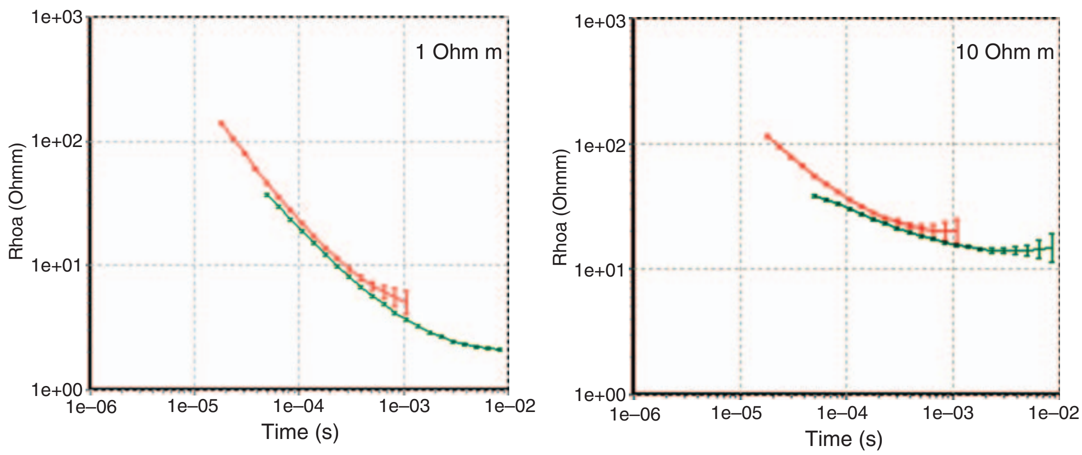

Fig. 7. *The effect on forward responses for the SkyTEM system on changing the conductivity of an half space from 1 S/m to 0.1 S/m.*

As a further test of the value of accurate 1D inversions in understanding the conductivity structure associated with the Murray River trench, we have also examined the applicability of the SCI technique in modelling conductivity structure across the floodplain – highland boundary, a setting where 2 and 3D effects might be more apparent. The interest in this boundary arises from a need to understand the links between irrigation practice occurring on the highlands along the Murray (see Figure 1) and floodplain salinity. AEM systems have the potential to provide a spatial picture of inter-aquifer mixing and surface water-groundwater interaction as it occurs across these physiographic settings (see Figure 8), which could assist conceptual hydrogeological model development and refinement (Munday et al., 2009).

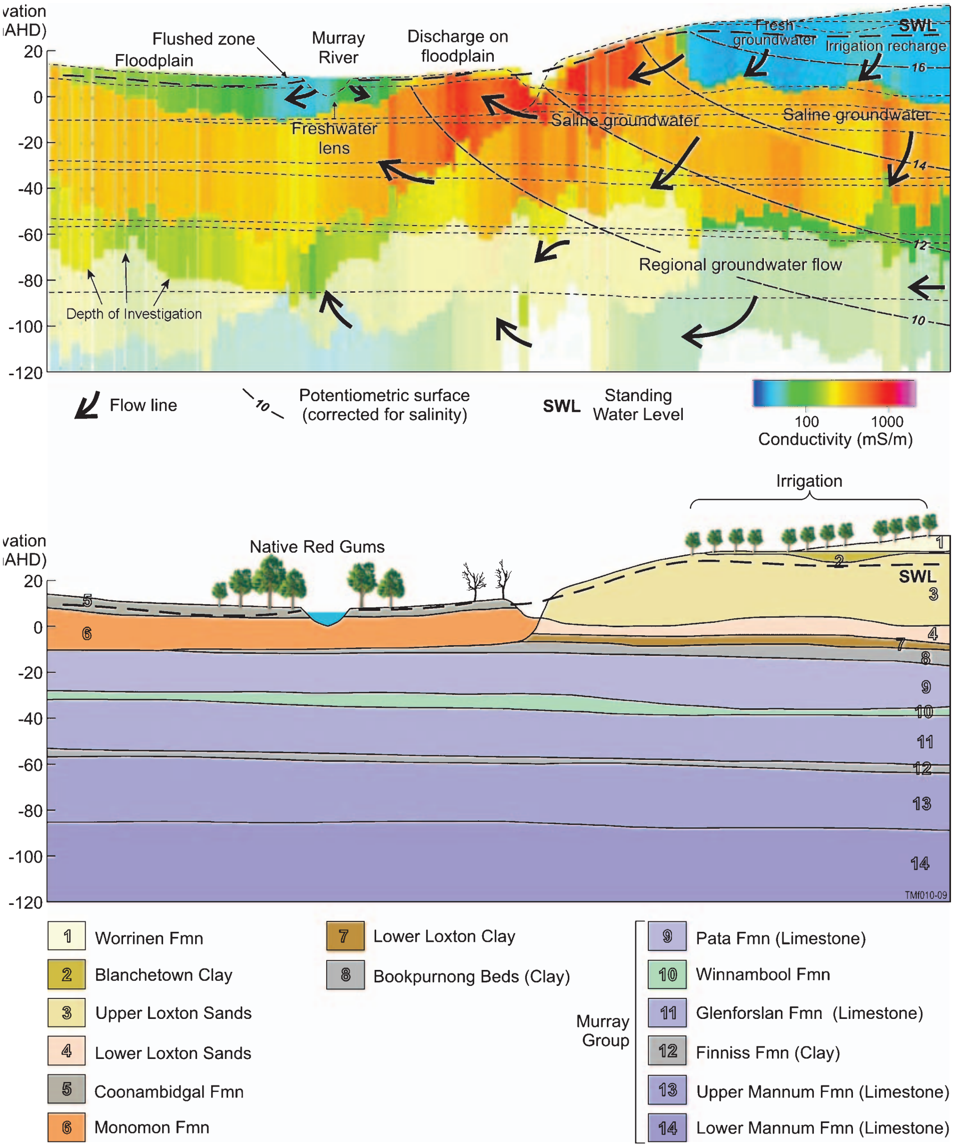

Fig. 8. *Vertical conductivity depth section derived from a 4 layer SCI of SkyTEM data for the floodplain – highland transect shown as Section 2 in Figure 3. The hydrogeology is illustrated in the lower section. Groundwater flow lines have been superimposed over the section and have been derived from an understanding of the potentiometric heads in the different aquifers. Groundwater quality is highly variable, with a fresh groundwater mound developed under the highlands adjacent to the floodplain as a consequence of excess irrigation drainage. The mound sits over a saline groundwater system and the elevated hydraulic gradient to the floodplain encourages an upward flux of saline groundwater across the Bookpurnong Clay aquitard. Groundwater conductivity values from bores in the vicinity of the section line 2 are projected onto the section for reference. The section length represents a distance of ~3.5 km.*

The fluid potential of a groundwater flow system can be determined from empirical observations of hydraulic head distributions. As vertical fluxes are particularly important, we present the distribution of heads (corrected for salinity) as defined by Harrington et al. (2005), in a cross sectional view (Figure 8). Equipotential lines are superimposed on the conductivity depth section derived from the SCI of the floodplain transect line (Section 2) shown in Figure 3. The vertical change in hydraulic heads indicates a potential for downward leakage of comparatively fresh irrigation water (TDS ~<6500 mg/L) from the Upper Loxton Sands aquifer (on the right of the section) into the Lower Loxton sediments. The groundwater mound developed beneath the highland area generates a significant head and flux of the saline groundwater system (that characterises the Pata Limestone at depth) towards the floodplain. On the floodplain-highland boundary groundwater flow is towards the floodplain, and there is an upward head and surface discharge of saline groundwater is observed at that boundary. The observed conductivity structure (Figure 7) indicates that the saline groundwater leaks through Lower Loxton Clays and Bookpurnong Beds and into the floodplain sediments of the Monoman Formation. At depth, in the Murray Group Limestones, lateral flow of the regional saline groundwater system (TDS between 15 000 and 30 000 mg/L) dominates. However, the conductivity structure suggests that under the floodplain, groundwater in the Mannum Formation freshens significantly. Whether this reflects an upward flux of relatively fresh groundwater from the deeper Renmark Group aquifer into the overlying Murray Group sediments remains to be determined.

In the floodplain aquifers, lateral flow of relatively fresh river water occurs in the sediments adjacent to the river. These flushed zones extend a considerable distance: up to a kilometre away from the river (Figures 4 and 8). The moderate conductivities of the Monoman and Coonambidgal Formations, where present, may reflect the presence of relatively freshwater from previous high flow events. The upward leakage the saline groundwater system is apparent in several places, particularly in the lower part of the Quaternary floodplain sequence, with discharge directly into the river noted in some reaches, particularly where the Murray approached the floodplain-highland boundary in the Bookpurnong area as mentioned previously (see Figure 4).

Recent studies by Harrington et al. (2005) in the region around Bookpurnong provide hydrochemical evidence for upward and downward leakage between aquifers, and given the highly saline nature of the lower groundwater system we believe AEM data, inverted with accurate 1D procedures have considerable potential to elucidate the nature of inter-aquifer leakage and the patterns of surface water and groundwater interaction. In the Bookpurnong and Loxton irrigation areas the high moment capability of SkyTEM permits us to investigate variations in the quality of groundwater at depth (>60 m), which in turn allows us to visualise how groundwater may be moving across aquitards and within particular aquifer systems. These data, when combined with bore data, including hydrochemical and environmental isotope data will permit the development of more robust conceptual models for the groundwater system and inter-aquifer leakage. They also provide for better understanding spatial patterns and processes that relate to surface water-groundwater interaction. However, accurate definition of inter-aquifer leakage arguably requires good constraint on aquifer/aquitard geometry and aquifer properties. Where possible information should be incorporated as constraints in the interpretation of the AEM data, if only to remove ambiguity in interpretation.

Conclusions

In the case study presented here, a 'quasi' 3D inversion methodology, the SCI, produces accurate results consistent with prior knowledge over the floodplain and across the floodplain–highland boundary at Bookpurnong. The results are also consistent across datasets acquired at different times, and with different systems.

Whilst recognizing the potential of the practical moving footprint full 3D inversion method described by Wilson et al. (2010) for large AEM datasets, we believe we have demonstrated the value of accurate and innovative quasi 3D inversion methods in landscapes such as those represented by the Bookpurnong case study. In this geological setting, we note that the assumption that each observation can be modeled with 1D forward responses and spatial constraints describing its relation to its neighbours, and that the subsurface is represented as a series of horizontal layers, holds well, particularly at the scale of the footprint of two AEM systems considered. It is worth noting that previous studies by Toft (2001), Auken et al. (2008) and Viezzoli et al. (2008, 2009) have also demonstrated that constrained inversion with 1D forward response can effectively recover the variability associated with a 3D geological structures in sedimentary environments.

Finally we contend that it is critical to ensure the forward responses are locally accurate, particularly for recovering accurate models from AEM data. We believe that, for hydrogeological applications in these and other sedimentary environments, the dimensionality of the forward responses is secondary to the accuracy of the modeling of the system transfer function used in the inversion.

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A brief reply

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We thank the authors for their comments regarding our paper, Wilson et al. (2010).

First of all, we would like to draw the reader's attention to a full paper on 3D AEM inversion with a moving footprint appearing in *Exploration Geophysics* (Cox et al., 2010). This paper independently addresses many of the questions posed by Viezolli et al. (2010) and further elaborates on the Bookpurnong case study. Cox et al. (2010) also provides a more detailed comparison between 3D and 1D inversions for AEM data.

Secondly, the main purpose of the Wilson et al. (2010) paper was to make *Preview* readers aware that 3D inversion of entire AEM surveys is both practical and now available.

Finally, real geological formations are 3D in nature and 3D inversion is required to produce accurate images of the subsurface. We chose to present the Bookpurnong case study in both our publications because it provided the best opportunity for a fair comparison of our 3D inversion results with a variety of 1D methods in the situations where the nearest representation of 1D geology was possible.

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Geophysics on an iPad?

Although not normally an early adopter of consumer electronic gadgets I eagerly registered for the release of Apple's 3G iPad (http://www.apple.com/ipad/) in May this year, hoping the tablet format would be of fundamental benefit to many aspects of my life. Has it lived up to the expectations? The answer is a qualified 'yes', although I believe the potential of the iPad remains fundamentally unrealised.

As widely promoted, the iPad is first and foremost a media consumption device. Provided that you are on a wireless network, the iPad is brilliant for reading e-mails and browsing the web. I also have an Optus pre-paid plan that provides 8 GB of data in a six month timeframe for $80. Four months into the plan and I have only used a few hundred MB, so no problems with data costs. But the fundamental problem is that Australian iPad plans only work within Australia. Travel overseas, as I often do, and you either need a wireless network or a local pre-paid 3G SIM card. I have had a couple of initial challenges when hotel rooms offer no wireless access, so that means no e-mail and web access. The iPad has no ports for telephone or ethernet cables.

I had hoped that the iPad would become my preferred platform for giving presentations to clients, and it almost works. Indeed, I have survived overseas trips with nothing but my iPad, but I cheated by also taking a USB stick of files in case the only solution was a PC running Windows. Apple's VGA adapter cable is frustratingly short, about 20 cm, so it can be difficult to place the iPad (and thus you) far enough away from the LCD projector for comfort. The touch screen operating system has no concept of a cursor, so a bluetooth mouse is incompatible. A bluetooth keyboard, however, can provide minimalist control of presentations (once launched) from many metres away. A great challenge is that very few applications (or 'Apps') have video-out capability. Indeed, the only practical way to run PowerPoint presentations is to read PowerPoint files into Apple's Keynote App, which has greatly reduced functionality compared to the desktop version of Keynote, and then you are away. All types of file exchanges between the iPad and your desktop Apple or PC is done through the (free) iTunes platform. The iPad 25 cm screen has 1024 × 768 (4 : 3) resolution, which translates well onto LCD projectors. My main complaint is that the screen is very sensitive to erroneous finger touches and swipes, and successful iPad presentations can require great physical discipline. Other useful Apps with video-out functionality are GraphCalc HD (graphing), iMindMap Mobile HD (mind mapping and brainstorming), SketchBook Pro (freehand sketching), and GoodReader (read/view most text and graphic file types).

Fig. 1. *Screen snapshot of one of my 'work-related' App collections.*

The physical size of the iPad presents something of a paradox. Whilst a delight to pack for travel, the 730 g unit feels heavy in the hand after a while, and it is not something you readily whip out of a pocket or bag every time you want to check something. There are, however, all kinds of solutions for such challenges, such as the Scottevest (http://www.scottevest.com) travel clothes with 20+ pockets. Steve Jobs was withering in his criticism of upcoming 7″ tablets, equivalent in size to the Amazon Kindle electronic book reader (which my wife swears by), claiming the screen would be impractically small for tablet computing. I think I agree, but I often wish I could easily stash the iPad away like a phone. On the processing side (http://www.apple.com/ipad/specs/ and http://en.wikipedia.org/wiki/Ipad) the unit is surprisingly fast and flexible, although the onboard memory (256 MB DRAM built into the 1 GHz Apple A4 CPU) is too small for heavy computing. I bought the largest storage (64 GB) option, and took only about two weeks to fill that up. Frustratingly, the SD card adapter is programmed to only identify image files from a camera, and will not allow storage expansion. You can 'jailbreak' your iPad very easily, but any warranties are of course immediately void. In contrast to the factory iPad settings, a jailbroken iPad can run multiple applications simultaneously, accept external storage options, and perform a variety of other non-standard functions. But the fundamental capabilities appear to be essentially unchanged. Importantly, the official release of OS 4.2 in mid-November will bring multi-tasking, wireless printing and a few other key functions, so progress is inevitable.

One of the first things we did at PGS when the iPad as released was to build an App version of our internal visualisation platform ('holoSeis') using the software developers kit (SDK) downloadable from Apple. As evidenced in Figure 2, despite the 256 total onboard RAM, a 6 GB seismic data volume can be rendered and manipulated in real time with surprising speed and stability. Again, seismic data volumes are loaded via iTunes. The three

Fig. 2. *A 6 GB 3D seismic volume rendered in real time on my iPad.*

orthogonal planes displayed in Figure 2 are manipulated using the touchscreen, as are any setting changes made from the relevant colour palettes and display parameters.

Admittedly, about half the 173 Apps on my iPad are of superficial value. There seems to be no limit to the ways in which I can remotely control the screen of desktop computers available

Fig. 3. *Dr Steven Ellis (University of Cincinnati) at the Pompeii excavations (courtesy of Apple).*

through a wireless network, stream video and other media in almost real time to my iPad, contact others through online portals, access online news and reference sites, or, naturally, play games. Where I used to read the paper TV guide, open an encyclopedia or magazine, or pick reference books off my bookshelf, now I almost inevitably pick up my iPad.

Probably the greatest current value in the iPad is as a convenient reference portal (e.g. manuals, databases, geophysical data images and presentations) and as a rapid note-taking device. The case study online at http://www.apple.com/ipad/pompeii/ documents the use of iPad for archeological excavations at Pompeii. Indeed, mine goes everywhere, is regularly filthy and frequently dropped (in its ruggedised silicone and plastic protector). That is certainly not possible with my regular notebook PC.

When the iPad can provide an X11 console window (and thus run Unix programs), and Apps become available for essential 'geophysical' tasks such as MATLAB or Mathematica, then my iPad might be considered a true alternative to my notebook PC. The lack of Flash support will apparently remain an irritant when using the web, but overall, Apple are off to a good start.

Disclaimer: I am historically a Windows-based PC user.

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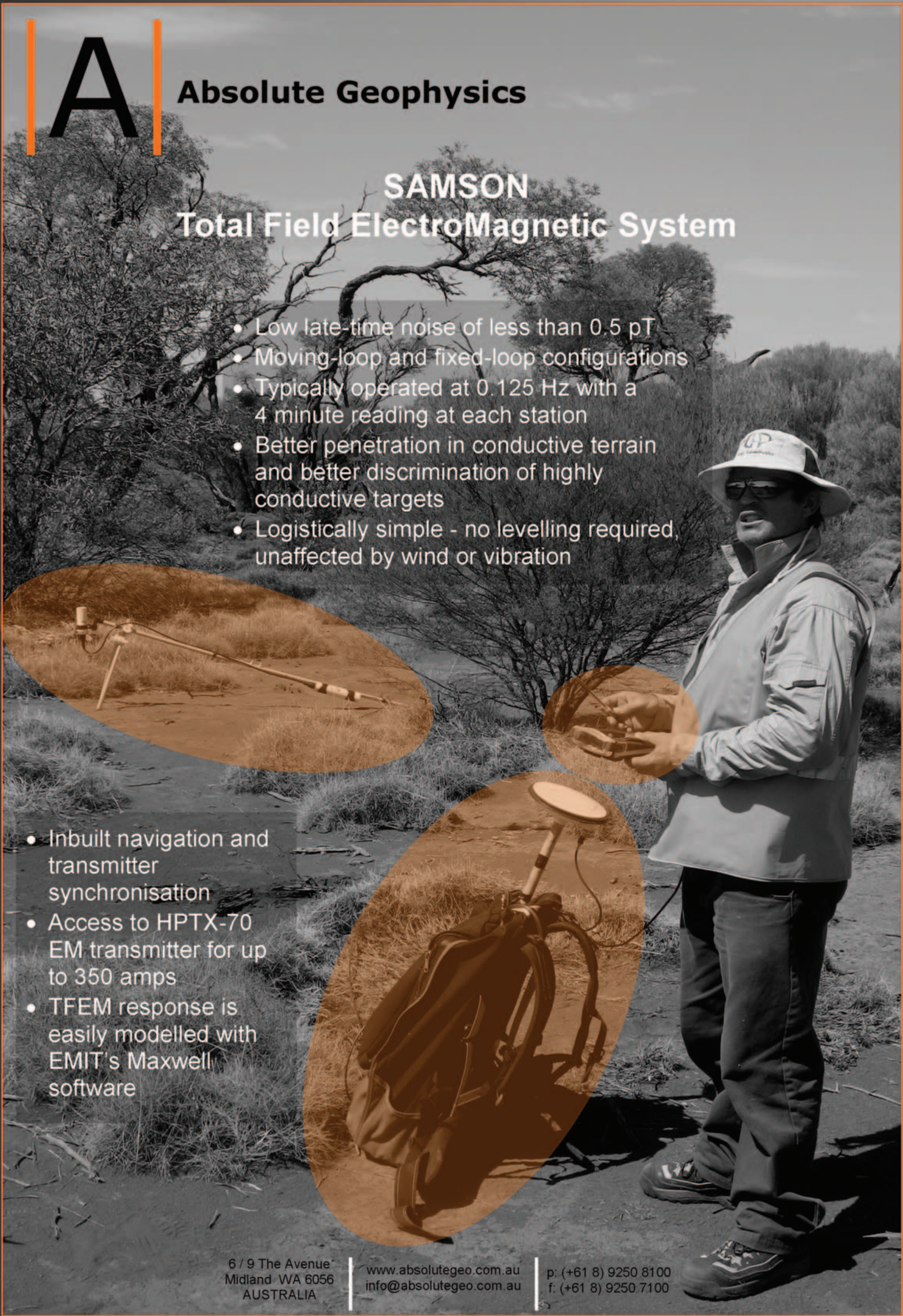
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