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FRONT COVER

Geotech's ZTEM helicopter system with base station sensor in the foreground, Chile (photo courtesy of Geotech Airborne).

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Science and creativity

Ann-Marie Anderson-Mayes

In my final column as Editor of *Preview* I thought we would look at the issue of science and creativity. This was prompted by a Letter to the Editor from Dr Phil Schmidt (see box), which was published in the *Sydney Morning Herald* on 16 April 2012. Phil clearly makes the point that creativity is vital in scientific breakthroughs – joining the dots and examining data is only part of the scientific process. It seems that for all the emphasis on science communication in recent decades, the scientific profession is still poorly understood by those outside it, and perhaps especially by many politicians.

Science education is largely based on learning a rigid set of mathematical and physical laws. School and university assessments are based on remembering and applying those facts and laws correctly. Even laboratory classes involve running an experiment for which the answer is usually already known, and everyone in the class should get similar results. If your only experience of science is a rigid set of rules and laws that need to be applied in certain ways to pass a test or exam, then perhaps it is understandable that you will not recognise the creativity required to be a practising scientist.

I wonder if you have stopped to think before that geophysicists need to be creative in order to be successful? For example, instrumentation design requires innovative ideas to minimise noise, increase measured signal, operate efficiently and safely, or make measurements over difficult terrain or in harsh environments. These drivers have seen a myriad of different geophysical instruments developed over time to address particular exploration or environmental needs. Similarly, data interpretation constantly evolves. I remember hearing Doug Oldenburg say earlier this year, that developing data inversion methods is an iterative process of deciding what approximations are acceptable for a given problem. We can't invert real world geophysical data exactly, so algorithms are designed to do the best job possible, and these continually evolve and develop as new ideas and approaches are trialled.

Recently I have been reading a book by John D. Barrow titled *The Artful Universe Expanded*. Barrow's book examines the so-called divide between 'art' and 'science' and he makes the following observation:

> *While some people are skilled in the creation of interesting sights and sounds, others are trained observers. They seek out unusual sights, or register events that many of us would never notice. Some, with the help of artificial sensors, delve deeper and range farther than our unaided senses allow* [surely, the perfect description of a geophysicist].

He goes on to say that:

> *…emphasis upon science as just another human activity, rather than a process that involves discovery, can be a subtle manifestation of opposition to the scientific enterprise by downgrading the status of what it does.*

The latter point strikes a chord with Phil Schmidt's objection to Paul Keating's comments (right). Phil is keen to encourage more scientists 'to write letters to dilute the crap that passes for information/debate in our newspapers'. I think we also need to do a better job of educating our future scientists to be analytical thinkers, careful observers, *and creative problem solvers*. Scientific problems have become more complex over time, and the new generation of scientists will need to be adaptive and creative thinkers to meet these challenges.

Thank you

I would like to conclude with an enormous thank you to all the *Preview* contributors and ASEG members who have supported me over the last three years. These people have been so generous with their ideas and time – *Preview* continues to thrive as a result of these myriad contributions. I would also like to thank all those at CSIRO Publishing who have made my role as Editor so much easier.

John Theodoridis will take over the reins as Editor from now on. I know that with your support he will gain as much satisfaction as I have in continuing to produce an important ASEG publication for all members.

Letter to the *Sydney Morning Herald*, 16 April 2012

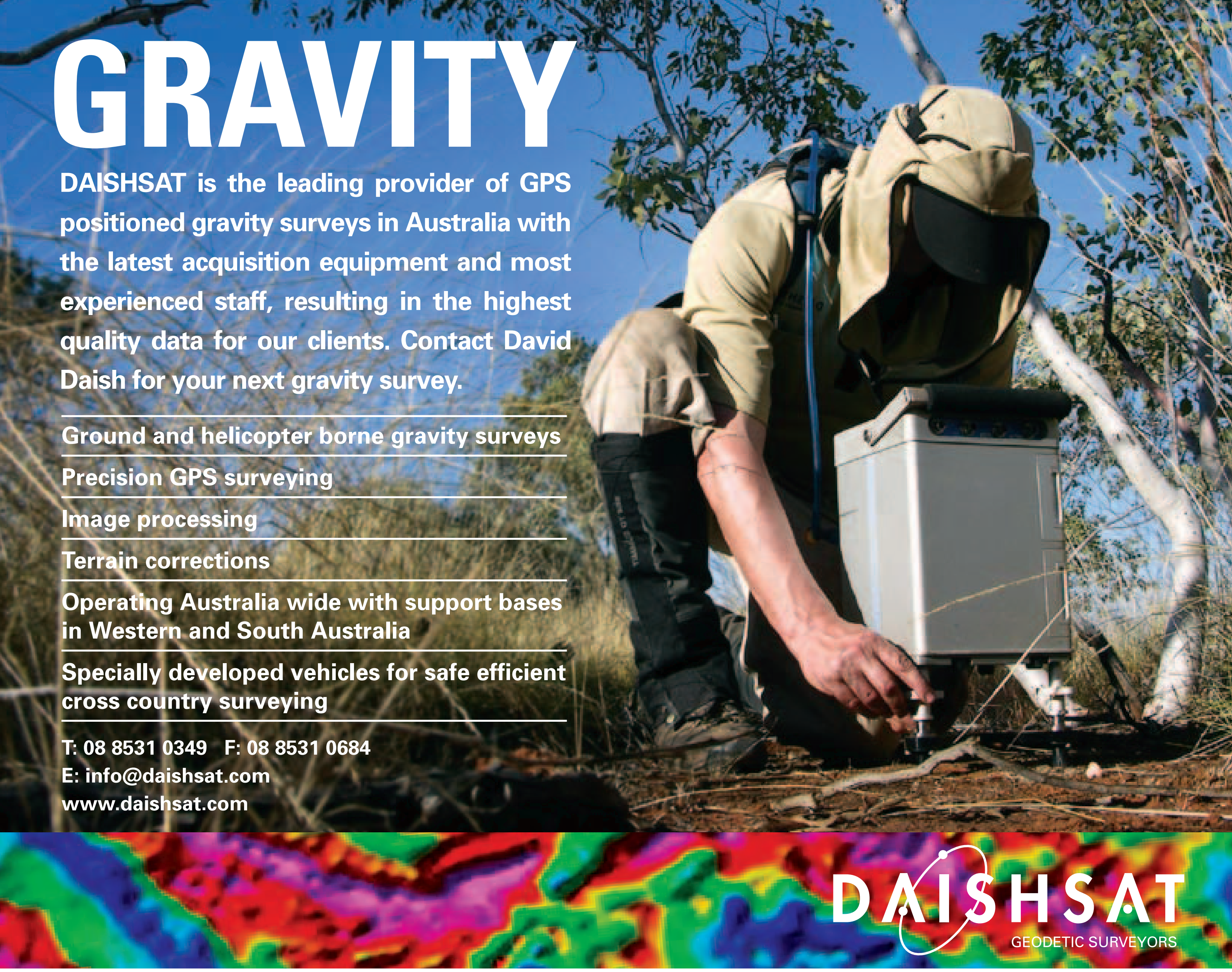
Science maligned

Once again we learn just how little politicians know about science. On Thursday's **Conversations with Richard Fidler** on ABC radio, the former Prime Minister Paul Keating waxed lyrical about music and the arts, and how creative musicians and artists are, making beautiful sounds and images from where there was nothing. On the other hand science was simply observational and joining the dots.

Such a simplistic view is ignorant. Take Erwin Schroedinger's equation, for instance. That was not derived by joining the dots. It was as much a masterstroke as Handel's **Messiah**. Pure genius, as are many scientific and medical breakthroughs.

Interestingly, Einstein's 'Special Relativity' was a case of joining the dots, but not the photoelectric effect for which he won the Nobel Prize.

Phillip Schmidt *North Epping*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ASEG News

Tell me what you really think!

This is my first *Preview* piece as president of the ASEG and I write it while flying back to Perth after a few days in the PNG highlands. A country that has earned number one billing in the collection of customs stamps in my passport and accounts for its fair share of the scars I wear.

I have to confess to not having read a lot of past President's Pieces so for those of you that don't skip this and just jump to the feature articles I apologise in advance if I'm re-telling old tales. I'm sure though that if I do, you'll tell me.

Other than the normal routine business of the Federal Executive (FedEx) we have a couple of big items to grapple with this year, our website and our publications.

As many of you have already noted our existing website is sub-optimal. Staz did a great job in getting it up in short order and maintaining it but it has reached its use by date and we cannot expect volunteers to do the work needed to add the functionality you are asking for. Carina Kemp has replaced globetrotting Staz as our new webmaster and is overseeing the design of a totally new site, which we hope will be online by July. There will no doubt be things you would like to add to this site once it becomes live and I'd encourage your thoughts on how we might improve it. I'm not guaranteeing to implement them all but if you don't ask you don't get. You can send your thoughts to me at my home email, which I use to try and separate ASEG business from consulting business, kfrankcombe@iinet.net.au, or direct to Carina's webmaster email, asegwebmaster@gmail.com. In the interests of Carina's sanity and to save her telling me what she really thinks, you might wait until the new site is live before sending ideas, as we have locked in the specifications for the first pass in order to get something up and running. If we try and adapt as each suggestion comes in then the next President or the one after will be writing the same story in their *Preview* column.

The other major issue facing the FedEx this year is our publications contract, which is up for renewal. The Publications committee, headed by Phil Schmidt, is in the final stages of deciding on a publisher for *Exploration Geophysics*, *Preview* and the *Membership Directory*. At the same time they are juggling with options for increasing our online presence through the SEG web portal and possibly also through Geoscience World. These discussions have the potential to impact on download revenues for our publisher, so are being followed with interest by the final tenderers for the publications contract. The FedEx have also been muttering for some time about the move to digital access only as an option to reduce our publications budget – our single biggest cost. There is no suggestion that we would stop printing paper copies, just that we offer a digital only option for those interested, with the carrot of lower registration fees.

The digital only option then opens up a new set of questions as to whether we should give new members access to old material or make them serve some form of probation and only be allowed to access recent articles for a period. Personally I'm not enthusiastic about that idea and I have not detected much support for it on the FedEx. Another question that arises is how does someone whose membership lapses access material from when they were a member? Added to these is the question of offline access to digital material. This is one of my hobby horses as I spend time working from client's remote field camps where internet access is not always high speed or reliable, despite modern satellite communications. One way to address the latter two issues is for the society to release an annual compilation of our publications on CD with cumulative DVDs produced every 10 years. Again, I personally like that approach – what do you think?

I'd also be interested in understanding how you read *Preview* and *Exploration Geophysics*; direct from the published paper copy, on your screen or e-reader or by the tree hugger's nightmare, downloading the digital version and printing it off? I'm a member of six geoscience societies and for those that I have elected to receive the paper copies of the journal, I read the paper copy but otherwise I tend to print off digital copies. However, I only print off the technical papers, not the equivalent of the more easy reading type of material that is published here in *Preview*. I tend to read the newsy, less technical publications, like this, when I travel while the more solid technical articles either get read while trying to solve a particular problem or also on the plane, but only early in the trip while I can still hold a thought for more than a couple of pages. For those societies that only publish online versions of their newsletters, I tend to scan them quickly with the scroll wheel on the mouse and possibly save a copy in case there is something I later find I need but don't read them in any depth. What do you do and what could the ASEG do that would make you wish you had written and told me what you really think before we decided to do it?

That is probably enough for you to stew over for one edition. I look forward to your emails telling me what you really think. I'll try and find time to respond to those not rejected by the Bayesian junk filter in my mail client!

Kim Frankcombe
kfrankcombe@iinet.net.au

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New *Preview* Editor – John A. Theodoridis

John A. Theodoridis

In 1997, John Theodoridis completed an Honours Degree in Science at Monash University specialising in applied and computational mathematics. His Honours project entitled 'Planetary Magnetism – The Thermal Evolution of Ganymede' explored the hypothesis that the magnetic field of the Galilean satellite, discovered by the Galileo spacecraft in 1996, is an ancient thermo-remnant Jovian-induced field as opposed to one that is generated by magneto-hydrodynamic mechanisms. Then, in 2005, he refined his interests in planetary science and completed a PhD in geophysics entitled 'Borehole Electromagnetic Prospecting for Weak Conductors' – research that investigated survey designs that permitted the detection of mineralisation by electromagnetic methods that are otherwise invisible to traditional inductive techniques. Finally, in 2009, he completed a Graduate Diploma of Education (Applied Learning) in secondary teaching.

John's stewardship toward the ASEG commenced in October 2010 when he assumed his current role of Victorian Branch Secretary, and more recently in February 2012 when he accepted a seat on the ASEG 2013 Conference Organising Committee. He brings to his new role as Editor of *Preview* a dedication to its readers and a desire to promote the science of geophysics by fostering communication, discussions and the entertainment of novel techniques and ideas, along with their possible application within the wider community.

Treasurers Annual Report for 2012 AGM

Audited financial Statements for the year ended 31 December 2011 for the Australian Society of Exploration Geophysicists were presented to the ASEG's AGM on 3 April 2012.

The financial statements refer to the consolidated funds held by the society as a whole, including the State branches. An audited version of the profit and loss statement and end of year balance sheet will be placed on the Society's website.

The Society's funds are used to promote, throughout Australia, the science and profession of geophysics. In 2011 this was achieved by:

- funding the publications: *Exploration Geophysics*, *Preview* and the *Membership Directory*;
- supporting the functions of State Branches;
- funding the national administration of the Society;
- funding continuing education programs;
- provision of loans and grants for conventions;
- provision of subsidies for student members; and
- support for the ASEG Research Foundation.

The Income Statement for the year shows a net deficit of $100 813. The end of year balance shows a Total Equity of $1 009 913 as of 31 December 2011, compared with $1 110 727 to the end of 2010. The result is much better than the budgeted deficit of $144 100, largely due to the additional income from branch events.

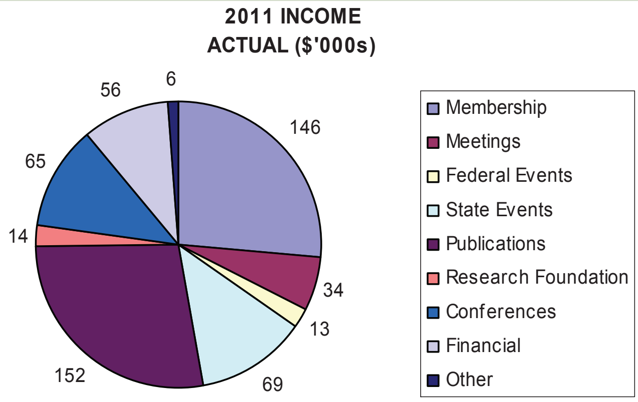
The Society's revenue source continues to be derived from:

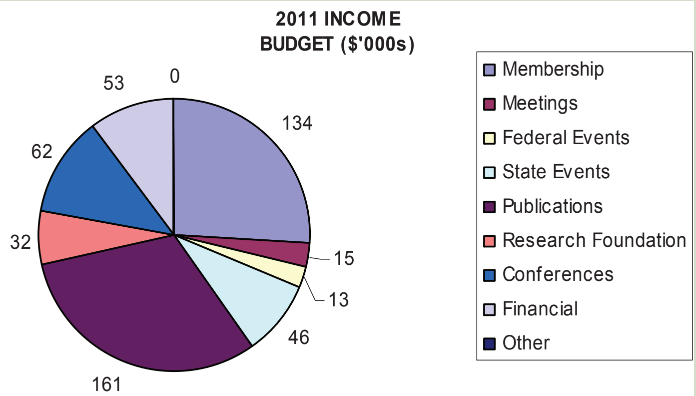
- publications advertising – $152 000 (94% of budget);
- membership subscriptions – $146 000 (109% of budget);
- events and sponsorship – $116 000 (157% of budget);
- conferences – $65 000 (105% of budget);
- interest from accumulated investments – $56 000 (105% of budget); and
- donations to the Research Foundation – $14 000 (43% of budget).

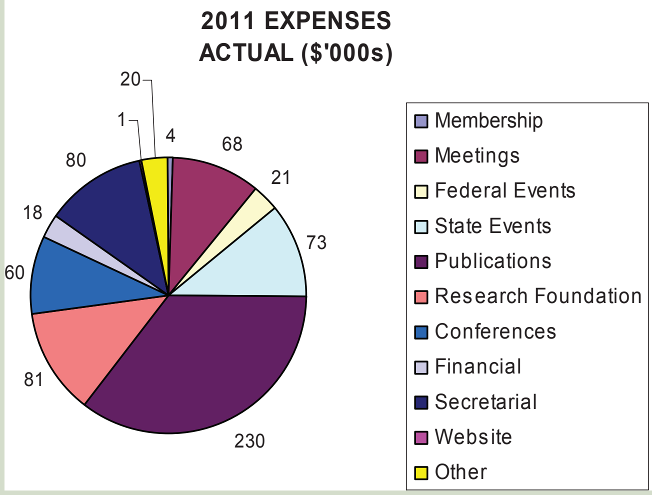
Overall the actual income for the year was 108% of the budget figure. The increase in membership is very pleasing. The additional income from branch meetings and events is also pleasing, although the WA golf day was not identified on the original ASEG budget but is reflected in the actual income and expenditure figures. Income from donations was lower than budgeted for both corporate contributions and fundraising. Although no ASEG Conference was held in the 2011 year, funds continued to come in from the 2010 ASEG conference and the WA Geothermal Energy Conference. Approximately 50% of cash on hand is held in a term deposit to take advantage of higher interest rates.

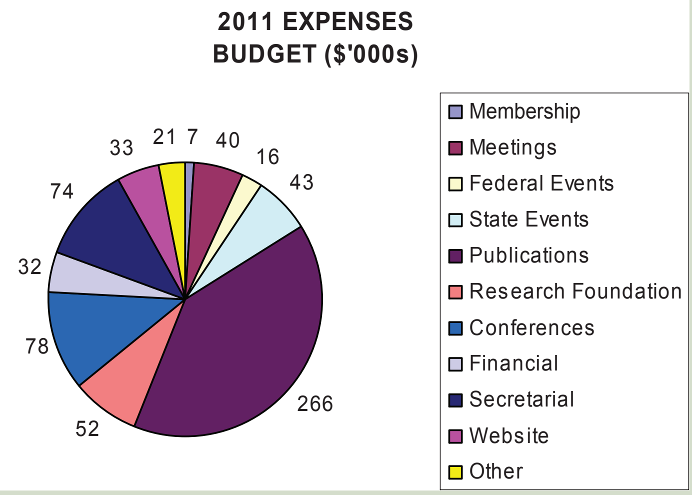
The major expenses for the Society include:

- publications – $230 000 (86% of budget);
- events – $162 000 (164% of budget);









- Research Foundation support – $81 000 (156% of budget);
- secretariat fees – $79 000 (107% of budget);
- conferences – $60 000 (77% of budget); and
- financial – $18 000 (57% of budget).

The overall expenditure was 99% of the budgeted figure. State branch meeting and event costs were higher than budgeted, which reflects an increasing level of support for branches and members. Similarly, contributions to the Research Foundation were also beefed up, which also provides an offset for the tax payable for interest received. This is reflected in the lower financial costs compared with the budget. The publication costs were significantly less than expected, which is pleasing, partially due to the publication on aeromagnetic interpretation by David Isles and Leigh Rankin not being ready in the year and hence calling on the up front financial support from the Society. Conference expenses were also down compared with budget largely due to lack of use of a $20 000 contingency for seed funding for the 2012 EM Induction workshop. There was also a contingency of $33 000 in the 2011 budget for web costs. However, these funds were largely not called on, the web functions being undertaken by our webmaster on a voluntary basis.

A major change to the timing and amount of payments to the Research Foundation has been implemented to provide more clarity and certainty to the management of the Foundation and support for geophysical research.

The Society is in a very sound financial position going into 2012. The equity held will cover the uncertainty of income from future conferences to provide a revenue stream to the society. I would like to acknowledge the help and support provided by CASM staff and in particular the bookkeeping of Jerry Lee Jones and Joy Huang in the management of the financial affairs of the Society.

C. David Cockshell
Honorary Treasurer

New members

The ASEG extends a warm welcome to 58 new members to the Society (see table). These memberships were approved at the Federal Executive meetings held in March and April 2012.

Name	Organisation	State/Country	Member grade
Nicholas John Agnew	Macquarie University	NSW	Student
Adam Henry Edward Bailey	The University of Adelaide	SA	Student
Sasha Banaszczyk	Barrick Gold	WA	Associate
Batbileg Batjargal	Thomson Aviation Pty Ltd	TAS	Associate
Jacqueline Anne Beerworth	The University of Adelaide	SA	Student
Andrew Bisset	Core Geophysics	WA	Active
Joao Henrique Boniatti	Votorantim Metals	Brazil	Associate
Hugo Bonython Burgin	The University of Adelaide	SA	Student
Sito Johan Busman	Shell	WA	Active
Alexander Nicholas Castiglione	Rio Tinto	WA	Associate
Jesse Clark	The University of Adelaide	SA	Student
Dennis John Conway	The University of Adelaide	SA	Student
Norman Cooper	Mustagh Resources Ltd	Canada	Active
Warwick Anthony Crowe	International Geoscience	WA	Active
Millicent Crowe	The University of Adelaide	SA	Student
Aldo De Rooster	Curtin University	WA	Student
David James Eddy	The University of Adelaide	SA	Student
Muhammad Fadhli	Halliburton Australia	WA	Associate
Rafael Fernandez	BHP Billiton	WA	Active
Sam Alex Fraser	The University of Adelaide	SA	Student
Luke George	The University of Adelaide	SA	Student
Kevin Gilbertson	The University of Adelaide	SA	Student
Sally Gregerson	The University of Adelaide	SA	Student
Bradley Grosser	The University of Adelaide	SA	Student
Edward David Heitmann	The University of Adelaide	SA	Student
Liam John Hennessy	Zonge Engineering	SA	Active
Paige Courtney Honor	The University of Adelaide	SA	Student
Brendan David Howe	Barrick Gold	USA	Active
Finn Hutchings	The University of Adelaide	SA	Student
Edwina Sophie Ingham	The University of Adelaide	SA	Student
Martin James	GroundProbe Geophysics	WA	Active
Samuel Kobelt	The University of Adelaide	SA	Student
Cassandra Lazo Olivares	The University of Adelaide	SA	Student
Meng Heng Loke	Geotomo Software	Malaysia	Active
Sharon Jenny Lowe	Fugro Airborne Surveys	WA	Active
Jake Elias MacFarlane	The University of Adelaide	SA	Student
Norberto Matos	The University of Adelaide	SA	Student
Benjamin Kyle McCarthy	Curtin University	WA	Student
Maximilian Milz	Metgasco Ltd	NSW	Active
David Moore	Fugro Airborne Surveys	WA	Active
Daniel Mubake	The University of Adelaide	SA	Student
Philippa Elizabeth Murray	The University of Adelaide	SA	Student
Mitchell Ryan Neumann	The University of Adelaide	SA	Student
Robert Harley Nunn	RHN Consultants Pty Ltd	WA	Active
Jaspher Deo Almerol Olanio	The University of Adelaide	SA	Student

Table 1. *Continued*

Name	Organisation	State/Country	Member grade
Thomas Paten	GroundProbe Geophysics	WA	Active
Sharna Jane Riley	Curtin University	WA	Student
Aixa Maria Rivera-Rios	The University of Adelaide	SA	Student
Kate Elizabeth Robertson	The University of Adelaide	SA	Student
Josh Sage	The University of Adelaide	SA	Student
Sebastian Schnaidt	The University of Adelaide	SA	Student
Jeremy Ryan Schulz	The University of Adelaide	SA	Student
Paul Erhard Soeffky	The University of Adelaide	SA	Student
John Barry Taylor	Solid Energy New Zealand Limited	NZ	Active
Francis Peter Thomson	GPX Surveys	WA	Active
Matthew James Scott Vasey	The University of Adelaide	SA	Student
Ben Williams	Curtin University	WA	Student
Tresor Zaira	The University of Adelaide	SA	Student

George Vernon Keller: 16 December 1927–17 April 2012

George Vernon Keller

George Keller was born in New Kensington PA, USA on 16 December 1927 and passed away on 17 April 2012 in Evergreen CO. Dr Keller received his Bachelor of Science (1949) and Master of Science (1952) degrees in Geophysics and his Doctorate (1954) in Geophysics and Mathematics from Pennsylvania State University. During his career he was employed by the US Geological Survey (USGS) (1952–1963) and by the Colorado School of Mines (1964–1993).

While with the USGS, Dr Keller's assignments included management of studies of geophysical aspects of nuclear weapons testing, the impact of earth properties on communications, surveys of the Arctic Ocean during the International Geophysical Year, and participation in the early USGS planning team for Deep Sea Drilling (AMSOC).

At the Colorado School of Mines, Dr Keller's principal areas of interest were in the development and applications of electrical geophysical methods to exploration for mineral and energy resources. He served as Head, Department of Geophysics, from 1974 to 1983. He retired from teaching 1 May 1993.

He received a distinguished service award from the US Department of Interior in 1959, was awarded the first Halliburton Award for outstanding professional achievement in 1979, served as a senior Fulbright scholar at Moscow University in 1979, was invited on a distinguished lecture tour by the Japan Association for Advancement of Education during the summer of 1986, and served as a Senior NATO Scholar at the University of Pisa in 1991. He has served as a consultant to many companies and government agencies involved in the earth sciences. Most important among the government assignments were: as a member of President Johnson's Blue Ribbon Committee on Mine Safety; as a member of President Carter's Energy Research Advisory Board, subcommittee on Geothermal Energy; and as chairman of the Committee Advisory to the Los Alamos Scientific Laboratory on the Hot Dry Rock Project. In 1996, he was named a Centennial Fellow of the College of Earth and Mineral Sciences at Pennsylvania State University.

Dr Keller formed 'Group Seven, Inc.' in 1970 to provide electrical geophysical services to the energy industries. During the 1970s, Group Seven grew to a company with approximately 60 employees and carried out geophysical surveys for a large number of energy companies and government agencies, including Exxon, Chevron, Union Oil, Phillips Oil, Gulf Oil, the Governments of Indonesia and Nicaragua through the US Agency for International Development, the Government of Kenya through the UN Development Program, the US Geological Survey, the US Department of Reclamation, the US Navy and the US Department of Energy. Group Seven was integrated into United Syscoe Mines (Canada) in 1981.

Dr Keller has published extensively, including more than 200 technical papers in his own name, more than 2000 pages of translations of technical articles, which originally appeared in the Russian literature, and eight books and texts on the electrical methods of geophysical prospecting. He served as translation editor of the journal *Soviet Mining Science*, published by Plenum Press from its inception in 1965 until 1994. During that period he was responsible for supervisory editing of some 15 000 pages of technical articles originally published in Russian.

Most important among Professor Keller's publications are seven books dealing with electrical geophysical methods. One of these books became a classic reference and is regularly cited to this day. The book, first published in 1966, was co-authored with his colleague and friend from the USGS, Frank Frischknecht, and was titled *Electrical Methods in Geophysical Prospecting*. Its popularity is emphasised by the fact that a second edition was published in 1982.

In 1994, Dr Keller began research on the detection and identification of hand guns. This research led to the award of US Patent 5552705 on 3 September 1996.

George Keller married his childhood sweetheart Amber in 1945; she passed away in 1995. He married Liudvika in 1997. George is survived by his wife Liudvika, son George Stephen and wife Chong, grandson Justin, and daughter Susan Diane.

In Dr Keller's honour, a Scholarship has been established entitled: *Graduate Scholarship in Transient Electromagnetics in Honour of G. V. Keller*. Pledges, which will be matched dollar for dollar to a maximum of US $5000, should be sent to Kurt Strack via kurt@KMSTechnologies.com.

Edited by Roger Henderson from text supplied by Charles Stoyer.

ASEG News

Australian Capital Territory

In a relatively quiet period since the last *Preview*, the only ACT Branch event has been Peter Hatherly's SEG Pacific South Honorary Lecture held on 2 May. Peter presented a thoroughly informative overview of coal exploration – arguably the forgotten child of exploration geophysics. Geophysics plays an important role in coal exploration, but its significance seems less prominent than in geophysical exploration activity for other commodities.

Amidst the dichotomy of a desire to reduce CO_2 emissions versus unstoppable demand for coal in an increasingly populous world, Peter talked of the factors driving geophysics in coal exploration and highlighted the differences with better-known geophysical approaches in the petroleum sector. The role for geophysics was made clear, whether it be in identifying dykes and faults, characterising interburden or helping constrain the volume of greenhouse gases likely to be exhumed during mining. Going forward, Peter pointed out that developments in geophysical techniques will be required in order to resolve small-scale faults, perfect the art of measuring seismic through multiple coal seams or basalt, detecting old workings and in guiding in-seam drilling.

Although other events will no doubt eventuate, our next planned event is a visit from ASEG-sponsored lecturer Lucy MacGregor of Rock Solid Images in the UK. Lucy is scheduled to stop in Canberra on 3 August, her last stop before attending the International Geological Congress in Brisbane as a keynote speaker in the symposium 'Putting the geo into geophysics – adding clout through better datasets and joint interpretation'.

The ACT Branch tends to hold meetings on an ad hoc basis as presenters are identified. Any visitors to Canberra interested in giving a presentation during 2012 are encouraged to contact us! For updates, keep an eye out on the webpage or link yourself to the ASEG on LinkedIn.

Ron Hackney

New South Wales

In **April**, Bob Musgrave, from the Geological Survey of NSW gave a talk on remanence and how it is here to stay. Bob discussed how remanence must be quantitatively understood for reliable inversion of targets. Bob also outlined current research into elongate, reversely polarised anomalies around the Benambran orogenic belt in the Stawell Zone, Thomson Orogen, and Lachlan Orogen, pointing out similarities with anomalies associated with orogenic gold in Victoria. Much discussion followed.

The NSW committee would like to acknowledge the following NSW members who received awards at the conference in Brisbane in February.

- Mike Smith – Honorary Membership of the ASEG
- Phil Schmidt – ASEG Service Medal
- Doug Morrison – ASEG Service Certificate
- Mark Lackie - ASEG Service Certificate

NSW Branch awards first student scholarships

The NSW branch has granted the first two scholarships to two tertiary students, Joel Potter from University of Sydney and Ritsch Camille from Macquarie University, to assist with the financial cost of their studies. These awards were presented at the Branch Meeting on 18 April 2012.

The current value of the grant is $1500. The Branch would like the funds to be used to provide facilities or materials that would assist the student's studies but would otherwise be difficult for the student to afford.

To be eligible, the students must satisfy the following criteria:

- Be an undergraduate in second, third or fourth year enrolled in exploration geophysics courses.
- To be judged by the ASEG NSW committee and their supervisor as showing potential to make a worthy career in geophysics.

Successful applicants are expected to make a presentation on their studies to a branch meeting, and to join the ASEG as Student Members, but need not be members at the time of application.

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

NSW Branch President, Mark Lackie, presenting a cheque to Joel Potter of Sydney University.

NSW Branch Treasurer, Roger Henderson, presenting a cheque to Ritsch Camille of Macquarie University.

South Australia/Northern Territory

We welcomed Henk van Paridon from GeoSolve Pty Ltd on 20 March. His presentation 'Coal's dollar dazzler – getting the most out of your seismic dollar' was warmly received. It was particularly nice to welcome some students studying Mining Exploration at TAFE.

Our next event was the student barbecue held at the University of Adelaide on 29 March. Fifty-one people attended, and most of the students signed up to become ASEG members.

ASEG News

On 3 April we welcomed the Federal Executive to Adelaide who held their AGM as part of an evening technical event. Dennis Cooke provided the technical talk: 'Seismic AVO: fluid and lithology attributes de-mystified'. Approximately 30 people attended.

Finally, on 26 April, we welcomed Peter Hatherly from Coalbed Geoscience Pty Ltd in Sydney who was presenting his Honorary Lecturer tour. Peter's talk, 'A role for geophysical methods in meeting the resource requirements of the 21st century', was very well received and generated a lot of discussion.

We hold technical meetings monthly, usually on a Tuesday or Thursday at the Coopers Alehouse in Adelaide beginning at 5:30 pm. New members and interested persons are always welcome. For further details, or if you are interested in presenting a talk to the local group, please contact Philip Heath (philip.heath@sa.gov.au). If you are a SA/NT member and are not receiving emails regarding events, please update your contact details through aseg@casm.com.au.

Philip Heath

Victoria

It has been a couple of busy months in the ASEG Victorian Branch. On 27 March Charles Funk from OZ Minerals presented 'Using geophysics to explore for IOCG deposits: a case study of the recent exploration at Prominent Hill'. Charles showed the attending ASEG Victorian Branch members the results from a wide variety of newly collected data including gravity, airborne gravity gradient, magnetics, induced polarisation, seismic and electromagnetics and discussed their applicability and relevance for IOCG exploration.

On 24 April it was time for SEG Honorary Lecturer Peter Hatherly from Coalbed Geoscience to present 'A role for geophysical methods in meeting the resource requirements of the 21st century'. Peter provided an excellent introduction to the varied applications of geophysical methods in coal mining, which resulted in many questions and comments from the audience.

Finally on 10 May Noll Moriarty from Archimedes Financial Planning presented 'Commodity price forecasting using probabilistic projection of United States dollar'. Noll argued convincingly about the inverse correlation between commodity prices and the US dollar, and certainly challenged conventional approaches to forecasting commodity prices. We will be watching the commoditiy prices with interest!

All events were held at the Kelvin Club, Melbourne Place. We look forward to seeing many ASEG Victorian Branch members at the coming meetings.

Asbjorn Norlund Christensen

Western Australia

The WA branch has hosted two international speakers since our last news update. Glenn Wilson of TechnoImaging in Utah visited Perth following ASEG 2012 and presented on large-scale AEM and potential field inversions, which was well attended. On 27 April, Peter Hatherly gave his SEG honorary lecture on 'A role for geophysical methods in meeting the resource requirements of the 21st century'.

Upcoming events over the next few months include a joint technical night on 13 June with the WA branch of IAH Australia on an integrated geophysical-groundwater case study from Queensland. We will then be welcoming Lucy Macgregor, the European SEG Honorary Lecturer, on 29 July. She will be presenting her lecture on 'Integrating well log, seismic, and CSEM data for reservoir characterisation'. All these talks will be held at our usual venue at the City West Function Centre, Plaistowe Mews, West Perth from 5:30 pm.

The WA committee is also pleased to announce that we will be rolling out our ASEG WA Award program in the next month. There will be two AU$2000 awards on offer to eligible students studying a geophysics-related topic at a WA university. Applications will close at the end of August and the awards will be presented to the successful applicants at our Honours Students technical night in November. Information and application forms should be available on the ASEG website shortly or from our Branch Secretary (asegwa@casm.com.au).

Lastly, we will be holding a practical one-day workshop on airborne electromagnetics in November. This event is targeted at both geologists and geophysicists and will be a seminar series focussed on practical near-surface and minerals applications of AEM. It will include practical theory, case studies and a review of recent and future developments. Watch this space for further details in the coming months.

Anne Tomlinson (née Morrell)

Magnetic Field Sensors for Exploration

Mag-03/Mag 639 3-axis Magnetic Field Sensors

- Noise levels down to 6pTrms/√Hz at 1Hz
- Frequency response to 12kHz
- For use in TDEM or MT
- Land and marine versions

BSS-02B Borehole Magnetic Susceptibility Sonde

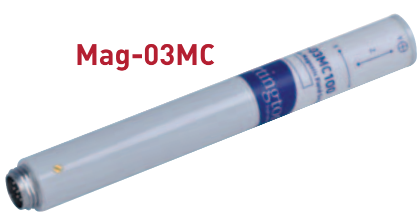
- Measuring range from 10^{-5} to 10^{-1} cgs
- High spatial resolution to 25mm
- Operation to depths of 6000 metres
- Used in stratigraphic correlation

MS3 Magnetic Susceptibility System

- Noise levels down to 2×10^{-6} SI
- Measuring range up to 25 SI
- Sensors for field and laboratory applications
- Used for core analysis in oil and mineral exploration

Mag639

BSS-02B Borehole Sonde



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ASEG News

Launch of *Exploration Geophysics* as joint journal of the ASEG, KSEG and SEGJ

At the 22nd ASEG Conference in Brisbane on 28 February 2012, President Dennis Cooke welcomed President Dr Toshihiro Uchida from the SEG of Japan, and President Professor Ki-Young Kim from the Korean SEG for the official launch of *Exploration Geophysics* (EG) as a joint journal of the three societies. ASEG past-president Michael Asten was asked to speak on the occasion of the launch.

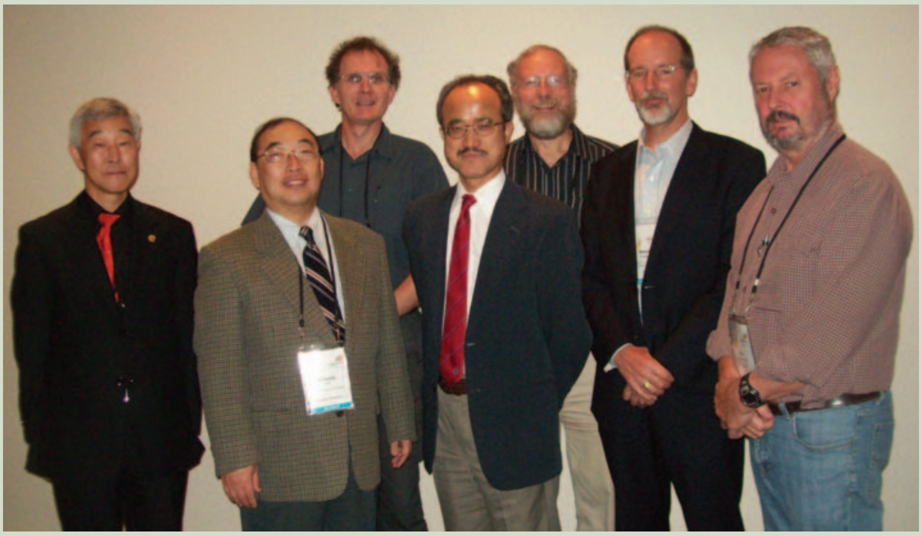
Michael Asten marked the occasion noting the welcome news from CSIRO Publishing that EG has climbed rankings to have an Impact Factor of 0.6 (up from 0.05 four years ago) and likely to reach 1.0 in the next year.

He spoke of the background to the joint issue, and the future challenge ahead.

> *The three societies have collaborated in producing one joint issue per year since 2004, and from 2008 EG went online as a fully searchable and downloadable journal. In June 2009 I asked Publications Director Phil Schmidt, International VP Koya Suto and Managing Editor Mark Lackie to consider the feasibility of expanding the inter-society collaboration into a joint venture producing a joint international journal.*
>
> *Koya Suto explored the concept at the SEGJ conference in Japan in October 2009 and after two more years of negotiations our President Dennis Cooke was able to arrange a signing ceremony to bring the joint venture into being at the SEG Meeting in October 2011.*
>
> *We now have three streams of journal language and editorial oversight. Dr Yoon-Hoo Song of Korea and Dr Toshiyuki Yokota of Japan are regional editors and will receive papers and arrange peer-review in their respective countries. Managing Editor Mark Lackie will receive English-language versions of papers, ensure standards of language and peer review are appropriate, and oversee the publication of the new EG.*

It is possible that the stream of papers submitted to EG will in time increase threefold under the new arrangements.

'That is the kind of challenge we would love to have', Asten commented. 'We wish the Australian and international editorial team well, and promise them every support from the executives of the ASEG, SEGJ and KSEG'.



From L to R: Koya Suto, Professor Ki-Young Kim of the KSEG, Mark Lackie, Dr Toshihiro Uchida of the SEGJ, Michael Asten, Dennis Cooke, Phil Schmidt.

ASEG 2013 Conference in Melbourne: 'The Eureka Moment'

The conference theme for the ASEG 2013 Conference in Melbourne is 'The Eureka Moment'. What does this mean for you?

According to Wikipedia, 'Eureka' comes from the ancient Greek 'I have found it'. The exclamation is famously attributed to Archimedes when he stepped into the bath and noticed that the water rose, suddenly understanding the relation between the volume of water displaced and the volume of his body that had been submerged. This in turn led to the ability to determine the density of objects by the ratio of their weight and volume.

The word 'Eureka' is also strongly associated with the discovery and exploitation of gold, both in California, where it is still the state motto, and in Ballarat, Victoria, where the Eureka Lead was the site for the Eureka Rebellion, an event with national significance to Australia.

Perhaps, like Archimedes, your 'Eureka Moment' comes in the bath as you relax and the ideas floating around in your head solidify into a theory that can be tested. Alternatively, your exploration program is successful and leads to a discovery. Or maybe you are sitting in a lecture theatre or perusing the exhibition at the ASEG 2013 conference and suddenly realise the application of someone else's work to your own. We wish you success in your quest for insight, learning and discovery and hope to see you in Melbourne in 2013.

On behalf of the ASEG 2013 Conference Organising Committee
Suzanne Haydon

Authors show keen interest in resource themes at 34th IGC in Brisbane

Many geoscientists have asked to see the lists of papers to be delivered at the 34th IGC in Brisbane in August 2012, so a status report is appropriate and presented here. The Scientific Program Committee has received over 5000 submissions for oral and poster presentations during the IGC and is currently sorting these abstracts into a coherent structure of symposia using 30 different rooms over 5 days. This is a massive task, which will take some time, so the release of the full scientific program is expected to be available in early June. In the meantime, the revised listing of Symposia and keynote speakers will be available on the website: www.34igc.org. Congress registrations passed 4800 in mid-May.

For those who are interested in the content of the resource-related papers, it is hoped that these themes can be finalised more rapidly in order to assist delegates to make the decision on attending. This will depend on the time available to the volunteer conveners of specific themes and symposia.

This IGC was planned to have a strong focus on commodities that contribute to Australia's favourable economic position and this has been confirmed by the keen interest shown by authors in resource-related themes. This is demonstrated by the statistics provided below for the symposia (these are listed in the 34th IGC Third Circular on www.34igc.org) in selected themes.

In **Theme 7, Mineral Resources and Mining** the first five symposia have received the following numbers of abstracts: 36, 30, 18, 15 and 35. Another two symposia may be combined.

In **Theme 8, Mineral Exploration Geoscience** the five symposia have had the following numbers of abstracts put forward: 39, 35, 25, 43 and 26.

Theme 9, Mineral Deposits and Ore Forming Processes received very strong support in all but one of the nine symposia, with abstract numbers of 58, 61, 29, 23, 26, 8, 90, 34 and 39.

Theme 10, Coal – A Myriad of Resources has two symposia, which received 16 and 23 abstracts.

In **Theme 11, Petroleum Systems and Exploration** five symposia received 15, 45, 44, 30 and 30 abstract submissions.

Theme 28, Groundwater/Hydrogeology was designed with six separate symposia and was strongly supported with abstract numbers for each symposium of 50, 57, 54, 23, 19 and 16.

Several other themes of interest to industry geoscientists such as **Theme 4, Environmental Geoscience,** and **Theme 31, Engineering Geology and Geomechanics**, also received strong support from submitting authors.

It is now apparent that after some re-distribution of abstracts, most of these resource-related themes will have sufficient papers to occupy the full five days of the IGC. Many others will appear as posters. Accordingly, there is an abundance of topics to attract the interest of geoscientists working in the resource sector and we encourage readers to register soon at www.34igc.org.

Mike Smith

News

10th International Symposium of SEG Japan

The Society of Exploration Geophysicists of Japan (SEGJ) held its 10th International Conference in Kyoto from 19 to 23 November 2011. The symposium was held in the Centenary Hall of Kyoto University, the same venue used for the 2006 Symposium. At the symposium 118 papers were presented in two parallel sessions; the Organising Committee said these papers were selected from 179 submissions and the rejection rate was 35%. The record 226 delegates came from 16 countries, mainly from Japan, Korea and China, and six were from Australia. Approximately one-third of the delegates were from outside of Japan.

ASEG representative James Macnae found that the meeting facilitated interaction with scientists from Asia, where a number of geophysical developments in electrical and electromagnetic techniques and instrumentation have taken parallel but different paths to those seen in the West. The ASEG–SEGJ initiatives on joint publication and joint meetings is one that in the future will benefit scientists in both hemispheres, helping to overcome the intellectual isolation that may arise from language and the need to balance local and global interests.

We had a 1-day excursion to Hiroshima after the symposium to see the atomic bomb monuments and Miyajima, a typical tourist route. It renewed our thought of the importance of peace on the earth. Jim's final observation, unrelated to geophysics, is that 'the Shinkansen express trains from Kyoto to Hiroshima travel through many more tunnels than expected; the most interesting sightseeing came not from the train windows as expected but from puttering along in local trams or on foot'.

Koya Suto and James Macnae at the 10th SEGJ Symposium in Kyoto, Japan.

Koya Suto

21st EM Induction Workshop, Darwin, 25–31 July 2012

I would like to invite all ASEG members to the 21st EM Induction Workshop (www.21emiw.com) to be held in Darwin from 25 to 31 July 2012. This Workshop is the premier event for researchers around the world to exchange information on the latest developments in the field of geophysical electromagnetism. The Workshop has historically had a research focus to it, but has proven to be important to industry and government groups that use EM methods and need to know where the science is heading. There will be presentations and posters on mineral, petroleum and geothermal energy exploration; groundwater and environmental resource evaluation; geohazard monitoring, and many other applications. This will be the first time the Workshop has been held in Australia, and follows prior Workshops in Cairo in 2010 and Beijing in 2008.

The Workshop, held over 7 days, is run with a single morning stream of talks that focuses on developments in EM induction science. Afternoon sessions are dedicated to presentations and discussions from the more than 200 posters that are an integral part of the workshop. A key part of the Workshop is the invited reviews from 10 acclaimed international scientists who are experts in their fields. These include people like Richard Smith from Laurentian University in Canada who will speak about innovations in mineral exploration, and Kurt Strack from KMS Technologies in the US who will speak about innovations in petroleum exploration. These invited reviews provide a unique opportunity to hear the state-of-the-art EM methods and applications. As with previous Workshops, articles based on these reviews will be published in *Surveys in Geophysics*.

Also important to the workshop is the social side, fostering further discussion and relationship building (not always about EM). Saturday, 28 July, will be a social day where all participants board a bus charter to the Litchfield National Park. Additionally, on one evening we will visit the world-famous Mindil Beach Markets to watch the sunset over the ocean and do a bit of shopping. On another evening, the Darwin Deckchair Cinema will be ours for a movie night. These social events are as much a part of the meeting and learning processes as the more formal presentations and discussion.

We have received over 270 abstracts, with 250 attendees already registered and 28 sponsoring organisations. If you are at all interested in EM induction, Darwin at the end of July should be in your plans.

This event is proudly held under the auspices of the International Union of Geodesy and Geophysics (IUGG), International Association of Geomagnetism and Aeronomy (IAGA), and is hosted by the Australian Society of Exploration Geophysicists (ASEG).

Graham Heinson
LOC Chair for the 2012 EM Induction Workshop
University of Adelaide

UPCOMING EVENT

The WA Branch of the Australian Society of Exploration Geophysicists

presents

A Practical One-Day Workshop on Airborne Electromagnetics

Targeting geologists and geophysicists, this event will be a one-day seminar series focussed on practical near-surface and mineral exploration applications of airborne electromagnetics. It will include practical theory, case studies and a review of recent and future developments.

WHO SHOULD ATTEND

- Practising geophysicists
- Exploration geologists
- Students

WHEN & WHERE

November 2012
Perth, Western Australia
details to follow

For further information contact Anne Morrell (anne@sgc.com.au) or Chris Wijns (Chris.Wijns@fqml.com)
Sponsorship available

Australian Academy of Science: UNCOVER

The UNCOVER Committee has convened under the aegis of the Australian Academy of Science to address the decline in Australian mineral exploration success through implementation of the 2010 Theo Murphy High Flyers Think Tank recommendations (http://www.science.org.au/events/thinktank/thinktank2010/documents/thinktankproceedings.pdf). The UNCOVER Committee held its first meeting on 28 April 2011 to identify practical steps towards addressing the Think Tank recommendations. At subsequent meetings (18 July 2011, 23 November 2011 and 2 March 2012) the Committee developed a proposal for a coordinated, cross-sector approach to the implementation of the recommendations.

UNCOVER's proposal, 'Searching the Deep Earth: A Vision for exploration geosciences in Australia', can be found at http://science.org.au/documents/SearchingtheDeepEarth.pdf. It calls for

> *Australian earth scientists to cooperate in an innovative, structured and nationally coordinated strategic venture that brings competitive advantage to Australian mineral exploration. The strategy requires research groups, surveys and explorers to participate in a cross-institutional joint research venture on a scale never before attempted.*

Four initiatives have been proposed:

1. The National Cover Map summarising the depth and character of cover. This map will help promote greenfields exploration by highlighting where detection techniques will be most effective; helping to understand the characteristics of the cover and thus the footprint of a buried resource; and showing regions of shallow burial that will enhance a deposit's economic value.
2. The National Map of the Deep Crust and Upper Mantle will be a 3D representation of the modern Australian continental lithosphere with a resolution exceeding 20 km in the crust and 100 km in the mantle. This map will lead to advances in predicting the underlying controls of energetic geological systems and mineral deposits under cover.
3. The National 4D Metallogenic Map will be an interactive continent-scale reconstruction of Australia that provides the geodynamic context for mineral systems through geological time.
4. The National Distal Footprints Map will be a series of interpretive maps identifying the signatures of Australia's mineral systems at a range of scales, to guide exploration into giant new mineral districts under cover.

The goal of these programs is to better understand the genesis and distribution of Australia's mineral wealth and thus lead directly to improved exploration success.

During May 2012, UNCOVER has been holding a series of workshops around Australia to gain feedback and input to further develop these research proposals. The ASEG has been invited to review and comment on the Exposure Draft of 'Searching the Deep Earth: A Vision for exploration geosciences in Australia'. As this issue of *Preview* goes to press, the ASEG is finalising its written submission. The ASEG response is primarily concerned with highlighting the need for the proposed research to translate into exploration success and economic benefits. In particular, the ASEG will highlight a gap that exists in research that can turn geological models of ore deposits, and more significantly mineral systems, into models of physical parameters that can be used predictively under cover. Full details of the ASEG submission will be published in the next issue of *Preview*.

Update on Geophysical Survey Progress from the Geological Surveys of Queensland, Western Australia, Northern Territory and New South Wales (information current at 16 May 2012)

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

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Contractor	Start flying	Line (km)	Spacing AGL Dir	Area (km^2)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
South Officer 1 (Jubilee)	GSWA	Thomson	1 Jun 10	180 000	200 m 50 m N–S	32 380	100% complete @ 22 Jun 11	TBA	148 – Oct 10 p23	Data released via GADDS on 26 April 2012
South Officer 2 (Waigen – Mason)	GSWA	Thomson	28 Jun 10	113 000	400 m 60 m N–S	39 890	100% complete @ 5 Jan 11	TBA	148 – Oct 10 p24	QA/QC of final data in progress
Grafton – Tenterfield	GSNSW	GPX	16 Jun 11	100 000	250 m 60 m E–W	23 000	100% complete @ 6 Nov 11	TBA	151 – Apr 11 p16	QA/QC of final data in progress
West Kimberley	GSWA	Aeroquest	29 Jun 11	134 000	800 m 60 m N–S. Charnley: 200 m 50 m N–S	42 000	100.0% complete @ 11 Dec 11	TBA	150 – Feb 11 p20	TBA
Perth Basin North (Perth Basin 1)	GSWA	Fugro	11 Jun 11	96 000	400 m 60 m E–W	30 000	100% complete @ 18 Dec 11	TBA	150 – Feb 11 p20	QA/QC of final data in progress
Perth Basin South (Perth Basin 2)	GSWA	Fugro	22 Mar 11	88 000	400 m 60 m E–W	27 500	100% complete @ 23 Dec 11	TBA	150 – Feb 11 p20	QA/QC of final data in progress
Murgoo (Murchison 1)	GSWA	Thomson	28 Feb 11	128 000	200 m 50 m E–W	21 250	100% complete @ 16 Nov 11	TBA	150 – Feb 11 p20	QA/QC of raw data in progress
Perenjori (Murchison 2)	GSWA	GPX	21 Oct 11	120 000	200 m 50 m E–W	20 000	100% complete @ 12 Jan 12	TBA	150 – Feb 11 p21	QA/QC of final data in progress
South Pilbara	GSWA	GPX	14 May 12	136 000	400 m 60 m N–S	42 500	TBA	TBA	150 – Feb 11 p21	Commenced 14 May 2012
Carnarvon Basin South (Carnarvon Basin 2)	GSWA	GPX	TBA	128 000	400 m 60 m E–W	40 000	TBA	TBA	150 – Feb 11 p21	Commenced 21 March 2012
Moora (South West 1)	GSWA	Aeroquest	13 Jun 11	128 000	200 m 50 m E–W	21 250	100% complete @ 27 Jan 12	TBA	150 – Feb 11 p22	Data released via GADDS on 26 April 2012
Corrigin (South West 2)	GSWA	GPX	12 Jan 12	120 000	200 m 50 m E–W	20 000	100% complete @ 25 Mar 12	TBA	150 – Feb 11 p22	QA/QC of raw data in progress
Cape Leeuwin – Collie (South West 3)	GSWA	Fugro	25 Mar 11	105 000	200/400 m 50/60 m E–W	25 000	100% complete @ 23 Dec 11	TBA	150 – Feb 11 p22	QA/QC of final data in progress
Mt Barker (South West 4)	GSWA	GPX	24 Apr 11	120 000	200 m 50 m N–S	20 000	52.4% complete @ 6 May 12	TBA	150 – Feb 11 p22	Survey resumed 11 February 2012
Galilee	GSQ	Aeroquest	11 Aug 11	125 959	400 m 80 m E–W	44 530	87.1% complete @ 6 May 12	TBA	151 – Apr 11 p15	Survey resumed 21 April 2012
Thomson West	GSQ	Thomson	14 May 11	146 000	400 m 80 m E–W	52 170	99.2% complete @ 13 May 12	TBA	151 – Apr 11 p15	Survey resumed 13 March 2012

Table 1. *Continued*

Thomson East	GSQ	Thomson	14 May 11	131 100	400 m 80 m E–W	46 730	99.2% complete @ 13 May 12	TBA	151 – Apr 11 p16	Survey resumed 13 March 2012
Thomson Extension	GSQ	Aeroquest	22 Jun 11	47 777	400 m 80 m E–W	16 400	100% complete @ 10 Aug 11	TBA	151 – Apr 11 p16	QA/QC of final data in progress
Thomson North	GSQ	Thomson	11 Mar 12	21 900	400 m 80 m E–W	7543	TBA	TBA	157 – Apr 12 p32	Survey crew mobilised 9 March 2012

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
Eucla Basin SW	GSWA	Atlas Geophysics	19 Jan 12	3798	2.5 km regular	23 030	100% complete @ 9 Feb 12	TBA	154 – Oct 11 p23	Data released via GADDS on 12 April 2012
Eucla Central	GSWA	Atlas Geophysics	28 Nov 11	5704	2.5 km regular	36 100	100% complete @ 18 Jan 12	TBA	154 – Oct 11 p23	Data released via GADDS on 12 April 2012
Eucla Basin East	GSWA	Atlas Geophysics	31 Oct 11	5201	2.5 km regular	31 340	100% complete @ 27 Nov 11	TBA	154 – Oct 11 p23	Data released via GADDS on 12 April 2012
East Amadeus	NTGS	Atlas Geophysics	26 May 12	7560	4 km regular with infill at 2 km and 1 km	101 090	TBA	TBA	This issue	TBA
Esperance	GSWA	TBA	TBA	TBA	2.5 km and 1 km along roads/tracks	TBA	TBA	TBA	This issue	TBA
West Murchison	GSWA	TBA	TBA	TBA	2.5 km	TBA	TBA	TBA	This issue	TBA

TBA, to be advised.

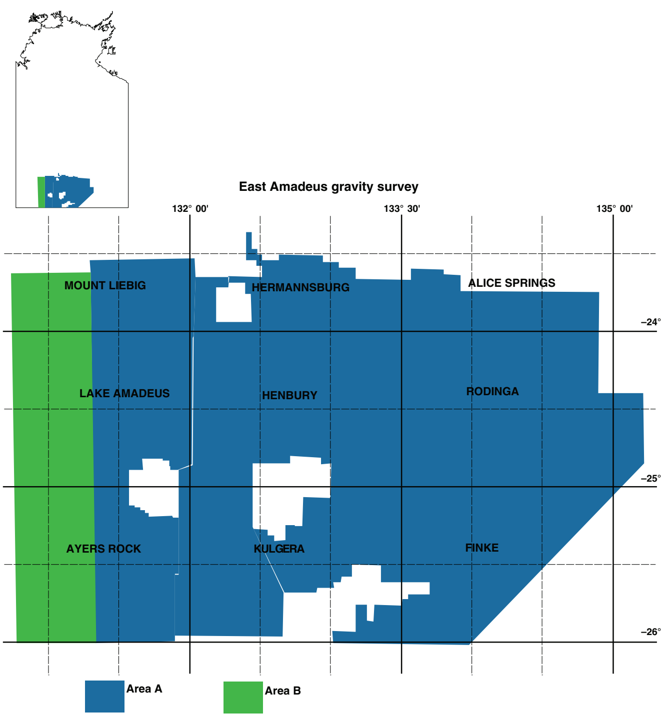


Fig. 1. *Locality diagram for the East Amadeus gravity survey in the Northern Territory.*

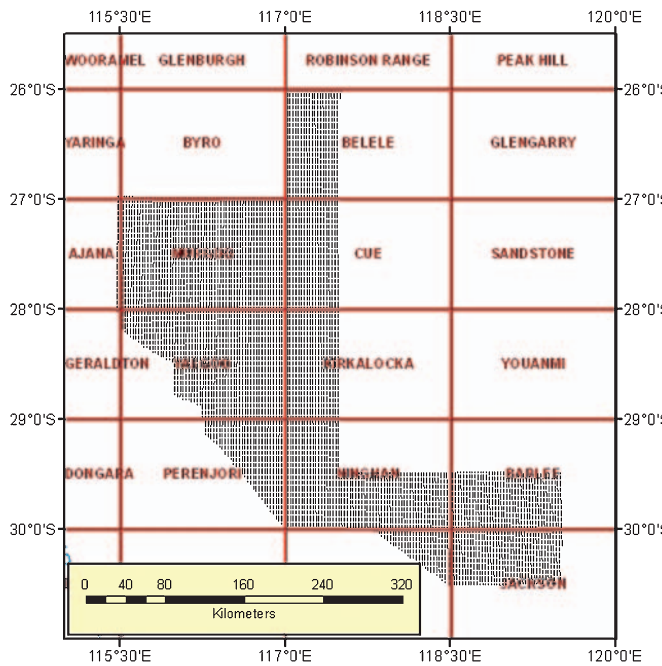


Fig. 2. *Locality diagram for the West Murchison gravity survey in Western Australia.*

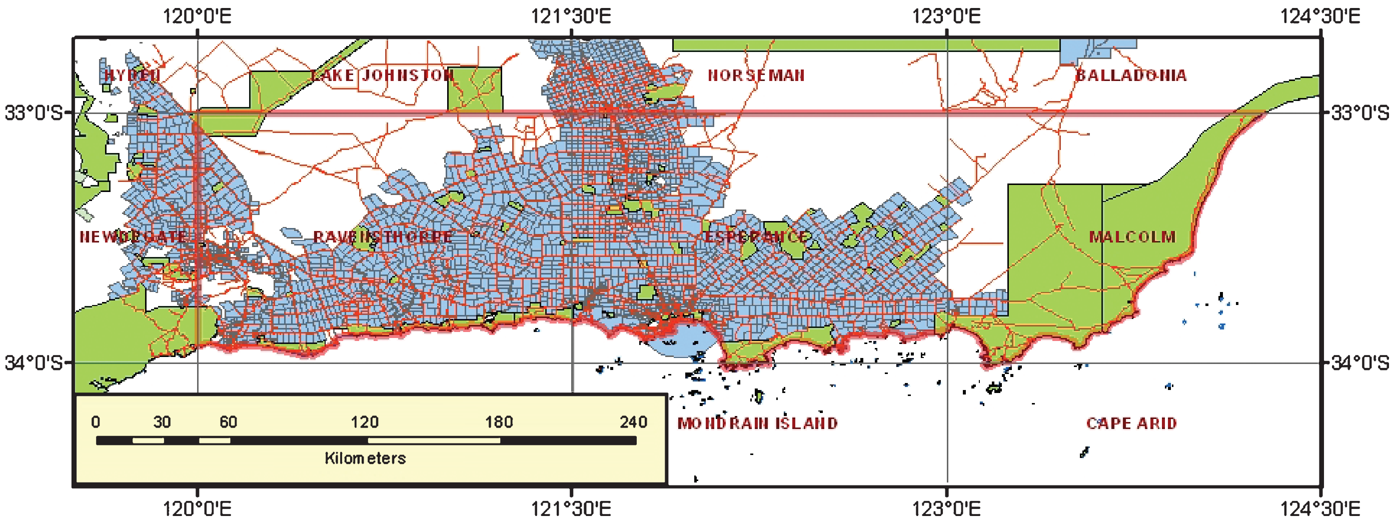


Fig. 3. *Locality diagram for the Esperance gravity survey in Western Australia.*

Three new gravity surveys are reported in this issue. Figure 1 shows the location and survey boundary for the East Amadeus survey in the Northern Territory. The survey will cover over 100 000 km^2 with a 4 km regular grid and infill at 1 km and 2 km spacing. Figures 2 and 3 respectively show the West Murchison and Esperance survey boundaries in Western Australia. The Esperance survey will be on a regular 2.5 km grid with 1 km infill along roads and tracks and the West Murchison survey will be on a regular 2.5 km grid.

The Geological Survey of Queensland reports that after 2 months of rain delays, the Galilee survey recommenced on 21 April 2012. Data collection for the Thomson survey is expected to be completed by 21 May 2012. There will be approximately 6–8 weeks of processing and QA/QC. The data will then be assessed for potential restricted areas before being released to the public. Data release for the Thomson survey is expected in August.

Cross-jurisdictional seismic data compilation for the Tasman Frontier

The Tasman Frontier region is a vast submerged continental fragment of over 3 000 000 sq km between Australia, New Zealand and New Caledonia (Figure 1). It hosts unexplored sedimentary basins, some of which may share a common geological origin with the Taranaki and Gippsland basins, where petroleum production is established.

In order to showcase recent scientific work in this region, Geoscience Australia hosted a Tasman Frontier Petroleum Industry Workshop in Canberra on 8–9 March 2012. The workshop was the first cross-boundary petroleum industry event held collaboratively by the three trans-Tasman jurisdictions, represented by Geoscience Australia, New Zealand's GNS Science and the New Caledonian Department of Industry Mines and Energy (DIMENC). The aim of the workshop was to deliver up-to-date pre-competitive geoscientific information to the petroleum exploration industry as well as to stimulate discussion on the future of exploration in the region.

A highlight of the workshop was the release of the Tasman Frontier Geophysical Database. This database is a first-ever, comprehensive, cross-boundary compilation of all publicly available digital reflection seismic data (~100 000 line km) from the offshore eastern Australian, New Zealand and New Caledonian jurisdictions. It improves data access considerably by offering a single point of access for seismic data from the three countries. The standardised seg-y data format also enables the quick loading of data to interpretation software platforms. Future updates to the product are planned, and it may be expanded to include other data types.

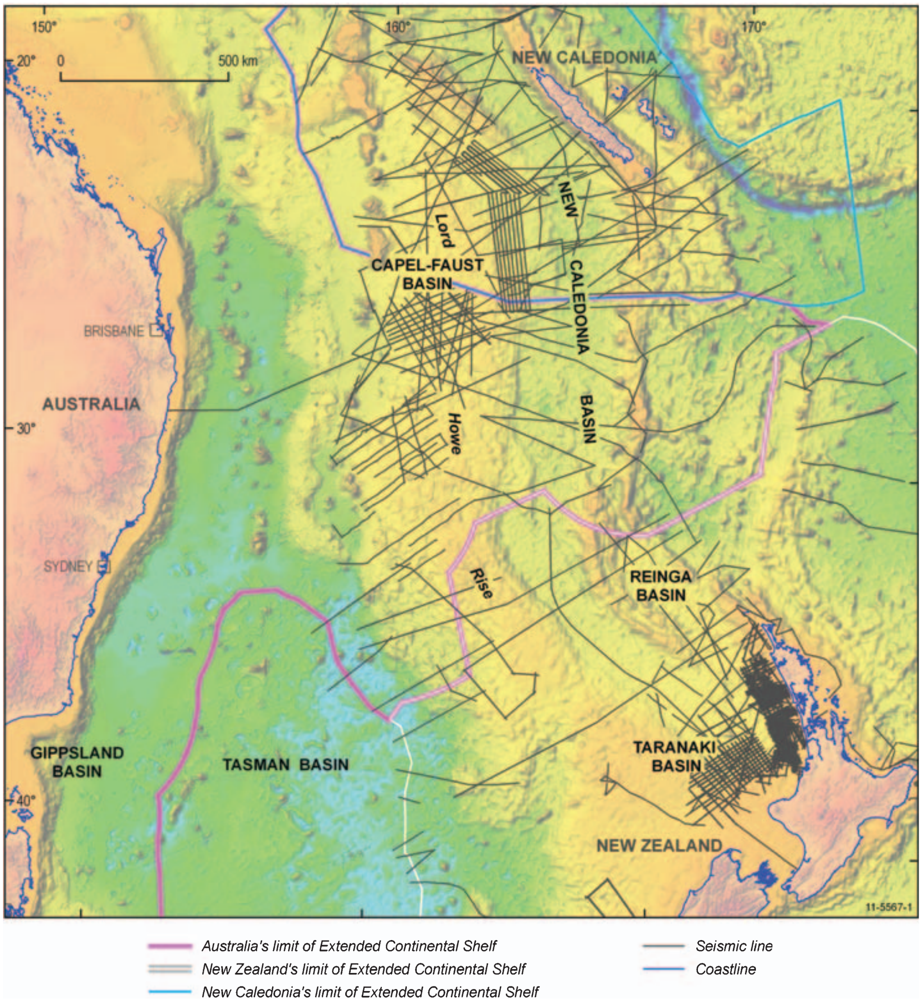


Fig. 1. *Bathymetric map of the Tasman Frontier region showing maritime boundaries and the location of seismic reflection lines included in the Tasman Frontier Geophysical Database (black lines).*

Further information is available at http://www.gns.cri.nz/Home/Our-Science/Energy-Resources/Oceans/Oceans-Research/Tasman-Frontier or by emailing tasman.frontier@gns.cri.nz.

Prospectivity and geophysics: new products to facilitate exploration success

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The Geological Survey of South Australia's (GSSA) Geophysics and Prospectivity Team have been involved in the development of a range of new and updated products, delivered to the public via the South Australian Resources Information Geoserver (SARIG) (www.sarig.dmitre.sa.gov.au) and GSSA section of the Minerals website (http://www.minerals.dmitre.sa.gov.au/geological_survey_of_sa/gssa_projects/mapping_aan_exploration_prospectivity_and_geophysics).

The new and updated information products include new petrophysics and electrical techniques databases; a depth to crystalline basement data package for the onshore Gawler Craton; the full suite of statewide geophysical images in both ers grid and geotiff formats; statewide ASTER mineral maps in ecw format; hyperspectral mineral maps of the Mount Woodroffe region; and a review of the Australian Fundamental Gravity Network within South Australia.

Petrophysical data is available for download as down-hole interval data. Approximately 1500 records populate a database made up mainly of magnetic susceptibility and density measurements, although the system is capable of storing and delivering any petrophysical data type. More data is continually being added to this database.

Magnetotelluric (MT) and Geomagnetic Depth Sounding (GDS) data collected in South Australia since the 1970s by academia, government and industry are now available online. The Electrical Techniques database currently contains over 900 MT and GDS stations in EDI file format. The database is designed to hold any ground electrical or electromagnetic geophysical survey with new surveys being added continually.

Drillholes and surface geology explaining depth to crystalline basement of the Gawler Province have been compiled and are available for download. Figure 1 displays a preliminary interpolated depth to crystalline basement surface, utilising drillhole and surface geology data. Further work will incorporate seismic interpretations and potential field geophysical modelling.

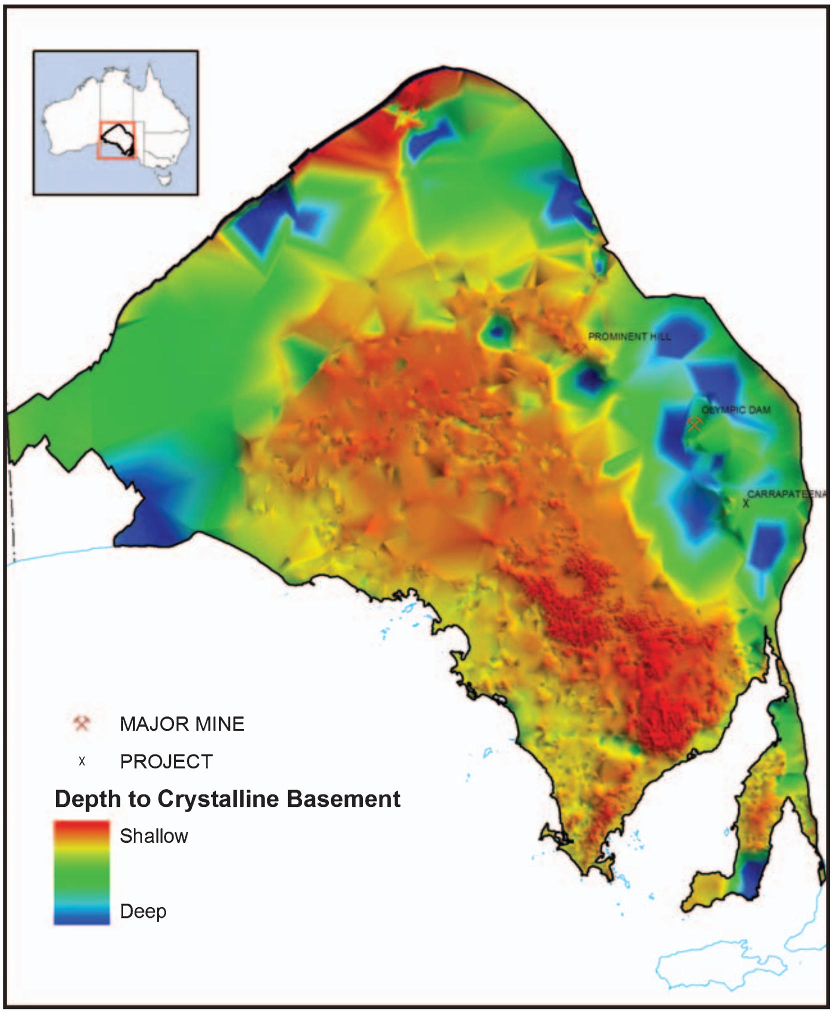

Fig. 1. *Preliminary interpolated depth to crystalline basement surface – Gawler Craton, utilising drillhole and surface geology data.*

The suite of statewide geophysical images is now available for download in both geotiff and ers grid formats. These images include Bouguer gravity, 1st vertical derivative of Bouguer gravity, TMI, TMI reduced to pole, 1st vertical derivative of TMI reduced to pole, uranium, thorium, potassium, ternary radiometric image (tif format only), total count, total dose, and U2/Th ratio. User-defined subsets of gravity, TMI and radiometric data are also available in grid and ASCII formats.

Statewide ASTER mineral maps are available for download in ecw format and 12 hyperspectral data projects are currently being re-processed. The Mt Woodroffe HyMap Survey set of hyperspectral mineral maps are now available for download via the GSSA section of the Minerals website.

Field work has been undertaken during 2011–2012 to assess, photograph and map the South Australian portion of the Australian Fundamental Gravity Network. The result of this work is a new spatial layer available via SARIG and a Report Book (2012/00005) entitled 'The 2012 review of the Australian Fundamental Gravity Network of South Australia', by Philip Heath.

An overview of the ZTEM and AirMt airborne electromagnetic systems: a case study from the Nebo–Babel Ni–Cu–PGE deposit, West Musgrave, Western Australia

Jean Legault

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To improve mineral exploration success, there is an industry-wide consensus on the need to increase the 'discovery space' by exploring under cover and to greater depths. Over the last decade, airborne electromagnetic (AEM) systems have evolved with ever higher moments, and sensor calibration and post-acquisition processing technologies have improved data quality significantly. As an alternative to conventional AEM, the Z-axis Tipper Electromagnetic (ZTEM) and Airborne Magnetic Tensor (AirMt) systems were developed to measure the transfer functions of audio-frequency natural electromagnetic sources from airborne platforms. The ZTEM system measures tipper transfer functions, and the AirMt system measures the rotational invariant of the transfer functions. Ancillary data measured by both systems include radar altimeter, receiver altitude, GPS elevation, and total magnetic intensity. For both ZTEM and AirMt, data are typically measured from 30 Hz to 720 Hz, giving detection depths to 1 km or more, depending on the terrain conductivity. This makes it a practical method for mapping large-scale geological structures. This paper discusses technical specifications of both the ZTEM and AirMt systems, including data processing and interpretation.

Both ZTEM and AirMt capitalise on Geotech's logistical and technical experience from its helicopter-borne Versatile Time-domain ElectroMagnetic (VTEM) system, which has been in commercial operation since 2002 with subsequent generational improvements. The first commercial surveys for ZTEM were commissioned in 2006, and the first commercial surveys for AirMt were commissioned in 2009. Presently, eight ZTEM systems and one AirMt system are in functional operation around the world. ZTEM and AirMt surveys have been flown in Australia, North America, South America, Africa and the Middle East for Sedex, VMS, IOCG, Ni–Cu–PGE, porphyry, uranium and precious metal mineralisation systems for numerous major and junior exploration companies. In this paper, we present a case study for the 3D interpretation ZTEM and AirMt surveys flown over the Nebo–Babel Ni–Cu–PGE deposit in Western Australia.

Background

Since the 1950s, magnetotelluric (MT) surveys have measured horizontal electric and magnetic fields induced from natural sources, which may be treated as plane electromagnetic waves. However, the amplitude and phase of the primary field is unknown. By processing the electric and magnetic fields to a complex impedance tensor, the unknown source terms are removed and the transfer functions are dependent on frequency and the earth's conductivity. Magnetovariational (MV) methods are an extension of the MT concept, whereby the transfer functions between the horizontal and vertical magnetic fields:

$$H_z(\mathrm{r}) = W_{zx}(\mathrm{r})H_x(\mathrm{r}) + W_{zy}(\mathrm{r})H_y(\mathrm{r}),$$

form a complex vector often called the *Weiss–Parkinson vector*, *induction vector*, or *tipper*. Similar to the impedance tensor for MT data, the tipper effectively removes otherwise unknown source terms. Since the vertical magnetic field is zero for plane waves vertically propagating into a 1D earth model, non-zero vertical magnetic fields are directly related to 2D or 3D structures.

This served as the basis for the original development of the audio-frequency magnetic (AFMAG) method (Ward, 1959) whereby two orthogonal coils were towed behind an airborne platform to determine the tilt angle of the plane of polarisation of natural magnetic fields in the 1 Hz to 20 kHz band. The natural magnetic fields of interest originate from atmospheric thunderstorm activity and propagate over large distances with little attenuation in the earth-ionosphere wave guide. Given the

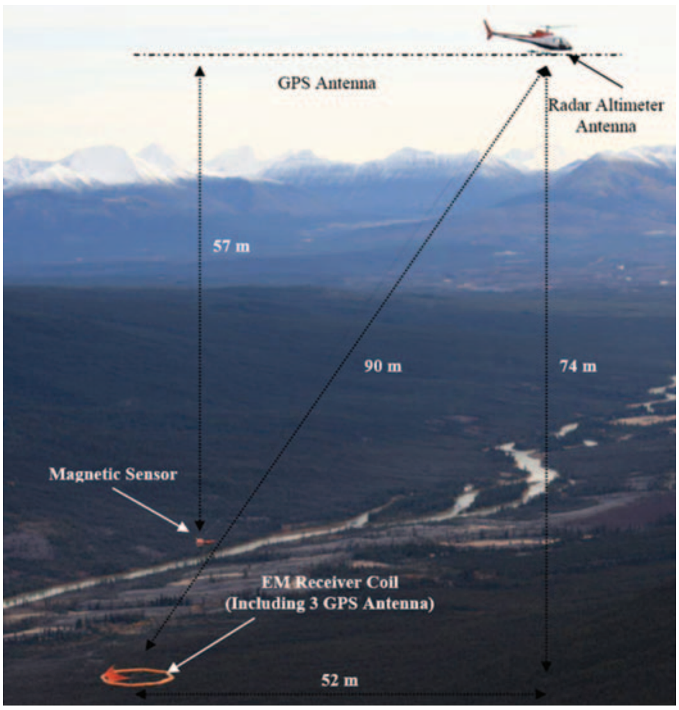

Fig. 1. *ZTEM (Z-Axis Tipper ElectroMagnetic) system configuration.*

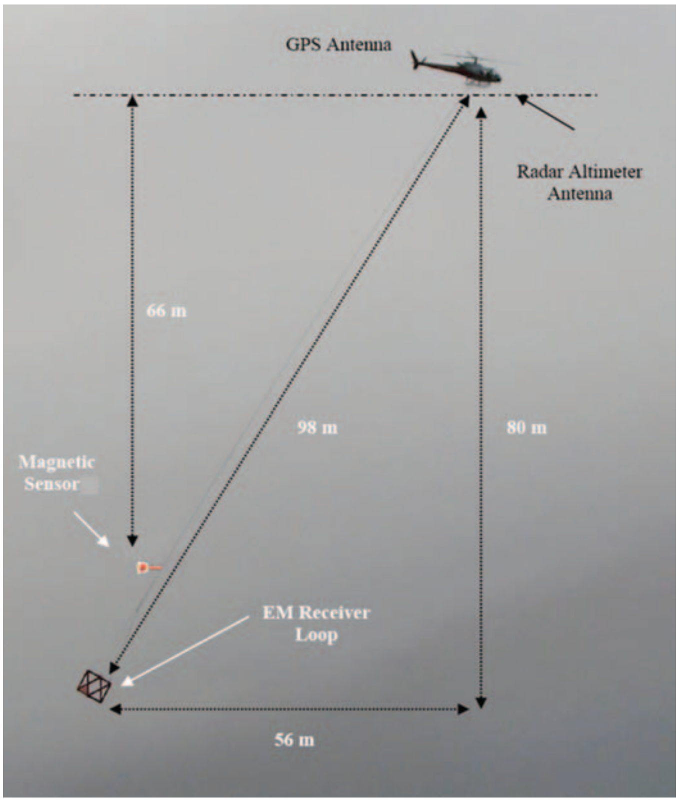

Fig. 2. *AirMt (Airborne Magnetic Tensor) system configuration.*

tilt angle is zero over a 1D earth, the AFMAG method was effective when crossing conductors. However, the direction and amplitude of the natural magnetic fields randomly varies with time and periodically with season, meaning AFMAG data were not repeatable (Ward *et al.*, 1966). By using MT processing techniques for ground-based orthogonal horizontal magnetic field measurements, Labson *et al.* (1985) demonstrated that repeatable tipper data could be recovered from measured magnetic fields.

The AFMAG method of Labson *et al.* (1985) remained largely undeveloped until the recent commercialisation of ZTEM (e.g. Pare and Legault, 2010) (Figure 1) and subsequently, AirMt (e.g. Kaminski *et al.*, 2010) (Figure 2) systems by Geotech. ZTEM measures the tipper components as the transfer function of a vertical magnetic field measured from an airborne receiver (r) to the horizontal components measured at a ground-based reference receiver (r_0):

$$H_z(r) = W_{zx}(r, r_0)\, H_x(r_0) + W_{zy}(r, r_0) H_y(r_0),$$

AirMt directly measures the rotational invariant of the transfer function for the three magnetic fields measured from an airborne receiver to the three magnetic fields measured at a ground-based (reference) location. Generalising the Weiss–Parkinson relationship, the three components of a magnetic field measured at a receiver (r) are linearly related to the horizontal magnetic fields measured at a ground-based reference receiver (r_0):

$$\begin{bmatrix} H_x(r) \\ H_y(r) \\ H_z(r) \end{bmatrix} = \begin{bmatrix} H_{xx}(r, r_0) & H_{xy}(r, r_0) \\ H_{yx}(r, r_0) & H_{yy}(r, r_0) \\ H_{zx}(r, r_0) & H_{zy}(r, r_0) \end{bmatrix} \begin{bmatrix} H_x(r_0) \\ H_y(r_0) \end{bmatrix},$$

If we write W_1 and W_2 as the first and second columns of the transfer function, then we can introduce the variable:

$$K = W_1 \times W_2,$$

and obtain the complex scalar:

$$K = K \cdot \frac{Re(K)}{|Re(K)|},$$

called the *amplification parameter* (AP), which can be shown to be rotationally invariant. (Kuzmin *et al.*, 2010; D. J. Dodds, pers. comm., 2010; P. E. Wannamaker, pers. comm., 2010). Since the amplification parameter does not depend on the orientation of the sensor, it negates the post-acquisition need to correct for sensor orientation.

For both ZTEM and AirMt systems, the time series of the magnetic fields are recorded at fixed sampling rates and the data are binned and processed to generate in-phase and quadrature transfer functions in the frequency domain (i.e. tippers for ZTEM; amplification parameter for AirMt). The lowest frequency of the transfer functions depends on the speed of the airborne platform, and the highest frequency depends on the sampling rate. For helicopter-borne or fixed-wing ZTEM and helicopter AirMt systems, transfer functions are typically obtained at five or six frequencies from 20 Hz to 800 Hz, giving skin depths ranging between 600 m and 2000 m for typical terrain conductivities.

Instrumentation

For helicopter surveys, the ZTEM and AirMt systems are carried as an external sling load, and are independent of the helicopter. The ZTEM receiver measured the vertical magnetic field from a 7.4 m diameter air-core loop sensor. The AirMt receiver measures three components of the magnetic field using three mutually perpendicular, 3.04 m diameter air-core loops. Both ZTEM and AirMt receivers are encased in a fibreglass shell that is isolated from most vibrations by a patented suspension system. The receivers are nominally towed from the helicopter by a 90 m long cable, and are flown with a nominal ground clearance of 80 m. Altitude positioning of the receiver is enabled by GPS antennas mounted on the frame. For both ZTEM and AirMt, the magnetic fields are measured with a 2 kHz sampling frequency. The fixed-wing ZTEM (FW-ZTEM) system is currently deployed from a Cessna Grand Caravan. The FW-

Fig. 3. *ZTEM and AirMt base station sensor.*

ZTEM receiver is a 12 m^2 rectangular loop sensor nominally towed 60 m behind and 80 m below the aircraft. Altitude positioning of the receiver is enabled by attitude sensors and GPS antenna mounted on the frame. The magnetic fields are measured with a 2 kHz sampling frequency. The ZTEM payload is sufficiently light that gravimeters and spectrometers can be simultaneously deployed. The base station for these systems is typically the AirMt sensor, consisting of three mutually perpendicular, 3.04 m diameter air-core loops, as shown in Figure 3. The base station provides a reference field, which when processed with the airborne receiver data produces the appropriate transfer functions.

Interpretation

Given the same plane wave source terms, modelling and inversion for ZTEM and AirMt data is similar to that of MT. However, unlike MT surveys, ZTEM and AirMt surveys typically contain hundreds to thousands of line kilometres of data with measurement locations every few metres, covering areas thousands of square kilometres in size. To be practical, the capacity must exist to generate 3D interpretative products with sufficient resolution in sufficient time so as to affect exploration decisions. Geotech's standard products for ZTEM and AirMt include total divergence and phase rotation grids, and 2D Gauss-Newton inversion based on modifications to algorithms by Wannamaker *et al.* (1987), de Lugao and Wannamaker (1996), and Tarantola (1987). Third parties provide additional products such as 2D pseudo-sections by Karous-Hjelt filters (e.g. Sattel *et al.*, 2010) or 2D Occam inversions based on their own modifications of algorithms by Constable *et al*. (1987) and Wannamaker *et al.* (1987). Holtham and Oldenburg (2010) introduced 3D ZTEM inversion based on modifications of the 3D MT inversion by Farquharson *et al.* (2002). In the subsequent case study for both ZTEM and AirMt, our 3D MT inversion analog is that of Zhdanov *et al.* (2011).

Case study: Nebo–Babel Ni–Cu–PGE deposits

Most world-class deposits of nickel and platinum-group elements (PGE) are found in mafic igneous rocks of Proterozoic age and as part of exceptional large igneous provinces (LIPs). The West Musgrave Block, located in central Australia, is one such example but where most of the prospective grounds are beneath regolith. In previous years, access for explorers was difficult due to restrictions imposed by the traditional landholders. Recently,

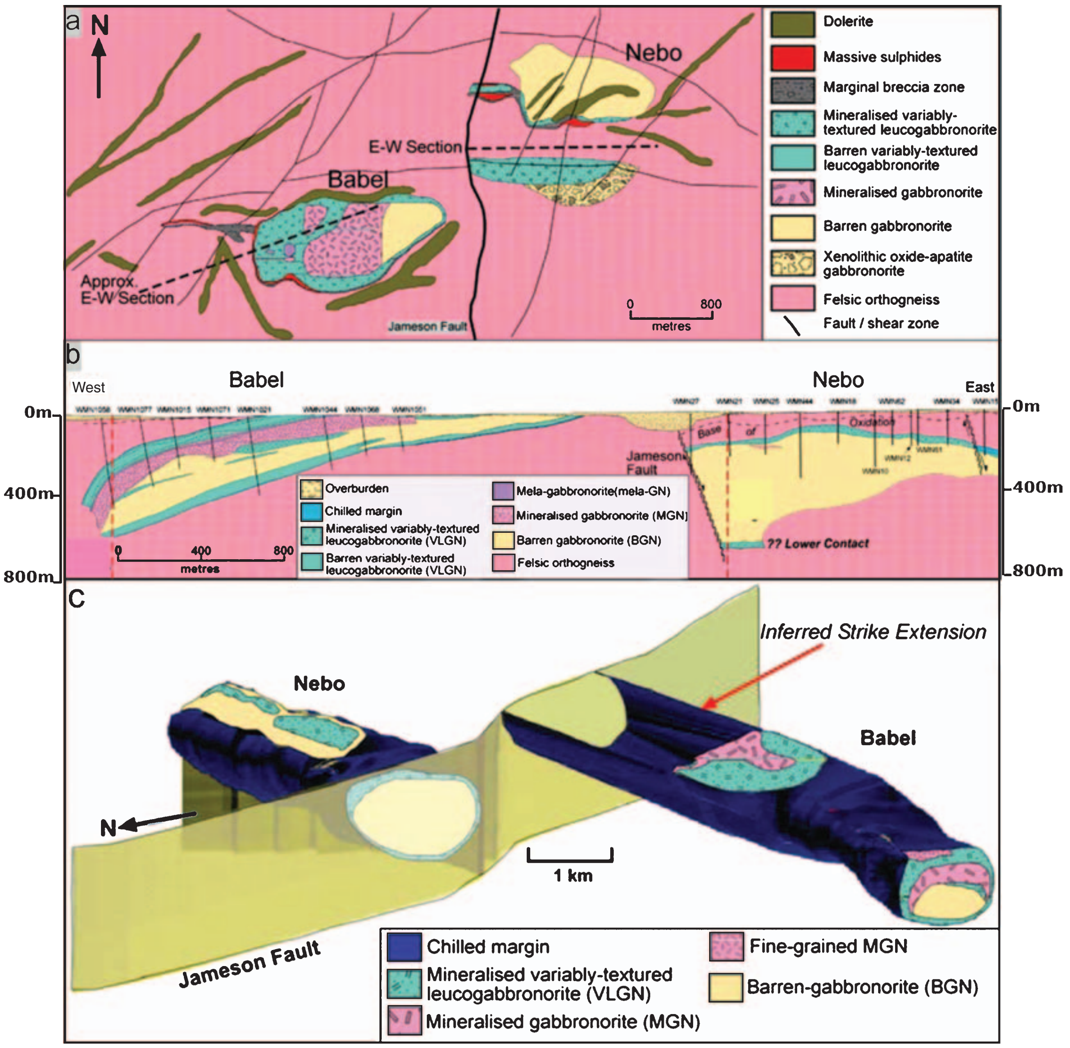

Fig. 4. *(a) Surface projection of the gabbro-norite rock units, mineralised domains, and major structural elements at West Musgrave, (b) longitudinal east-west section though the Nebo–Babel intrusion, (c) south-east facing 3D geological model showing spatial and morphological relationships between the Nebo and Babel parts of the intrusion (after Seat,* et al.*, 2007).*

access has improved with structured agreements between explorers and well organised land councils (Groves *et al.*, 2007). One example of early success in the area was WMC's (now BHP Billiton) surface geochemistry-led discovery of the Nebo–Babel Ni–Cu–PGE deposit in 2000. Nebo–Babel has a number of features in common with other Ni–Cu–PGE deposits hosted in dynamic magma conduits (e.g. Voisey's Bay, Canada), such as multiple magma pulses and sulphide entrainment from depth, rather than *in situ* sulphide segregation (Seat *et al.*, 2007, 2009). Drill intersections include 106.5 m at 2.4% Ni, 2.7% Cu, and 0.2 g/t PGE; and a resource of approximately 1 million tonnes contained Ni and 1 million tonnes contained Cu+Co has been released.

Geology

The Nebo–Babel deposit is hosted within a concentrically zoned, tube-like gabbronorite intrusion (1078 Ma) that has a 5 km east-west extent, a 1 km × 0.5 km cross-section, and a shallow WSW-plunge (Figure 4). The gabbro-norite has intruded felsic orthogneissic country rocks of amphibolite to granulite facies metamorphic grade and is offset along the north-southerly Jameson Fault, which separates the Babel and Nebo deposits that are of similar morphology. Babel is a large, generally EW to SW striking, mainly low-grade disseminated deposit that subcrops through thin sand cover to the east but plunges under more than 400 m of country rock and remains open to a depth of 600 m. Nebo, 2 km to the northeast, is buried under a few metres of aeolian dune sand and is smaller than Babel, but contains a number of high grade massive sulphide pods that are mainly found in the upper part of the intrusion. It extends at least 1.8 km east-west but its eastern limit and lower intrusive contact (inferred at >600 m) have not yet been drill defined. The deposits were discovered using deflation lag sampling on a 1 km × 0.5 km grid drill pattern. However, strong magnetic, electromagnetic, and gravity anomalies highlight the massive and disseminated mineralisation in the deposit. For example, Figure 5 shows the late channel B-field time constant from a GEOTEM survey over the area.

ZTEM and AirMt surveys

Under agreement between Geotech Airborne and BHP Billiton, both ZTEM and AirMt surveys were flown over the Nebo–Babel deposits (Figure 6). A total of 541 line km of ZTEM data and 574 line km of AirMt data were acquired along both east-west and north-south flight lines. The survey area has minimal topographic relief, varying from 460 to 494 m above sea level. The ZTEM receiver was flown with a nominal ground clearance of 78 m. ZTEM data were acquired at six frequencies; 25 Hz, 37 Hz, 75 Hz, 150 Hz, 300 Hz, and 600 Hz. The AirMt receiver was flown with a nominal ground clearance of 78 m. AirMt data were acquired at six frequencies: 24 Hz, 38 Hz, 75 Hz, 150 Hz,

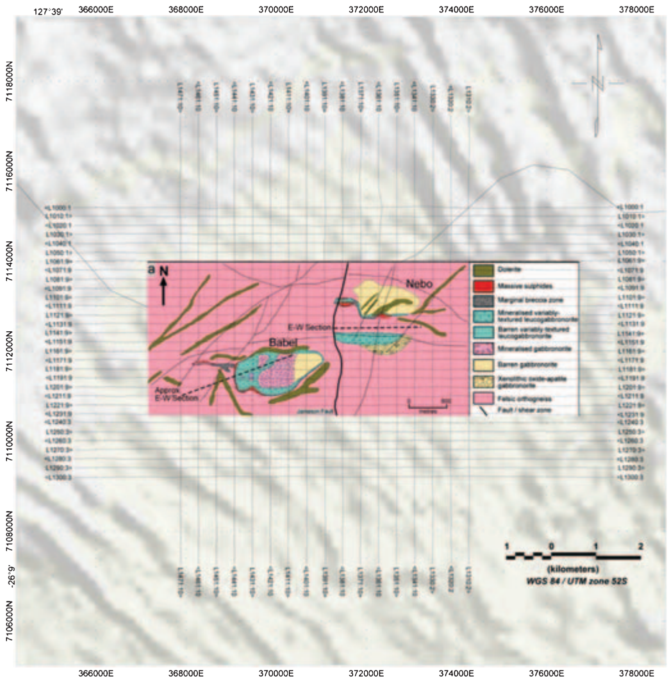

Fig. 6. *ZTEM and AirMt flight lines over Nebo–Babel geology (modified after Seat* et al.*, 2007).*

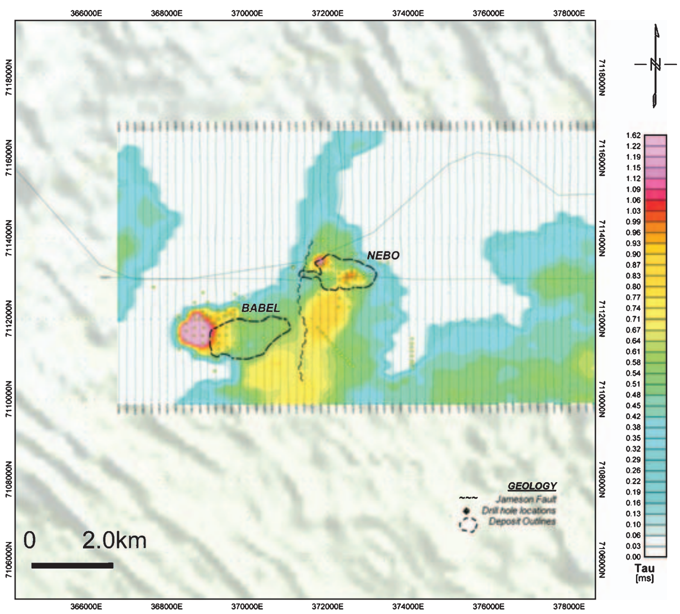

Fig. 5. *GEOTEM late channel B-field time constant.*

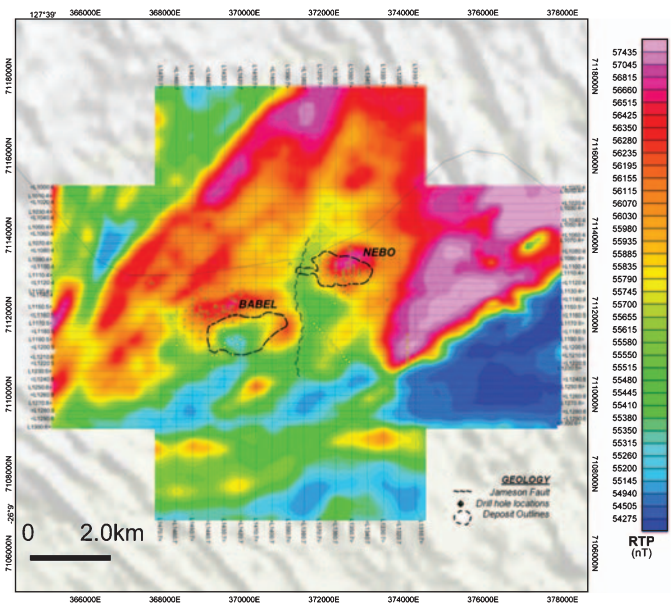

Fig. 7. *Total magnetic intensity (TMI) – reduced to pole (RTP).*

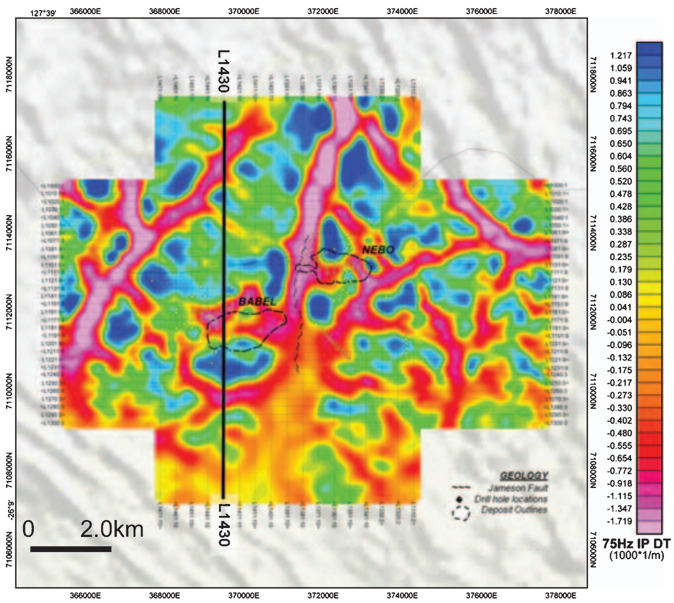

Fig. 8. *ZTEM 75Hz In-Phase Total Divergence (DT).*

300 Hz, and 600 Hz. Total magnetic intensity (TMI) data were also acquired using a caesium magnetometer for both surveys. Figure 7 shows the reduced-to-pole (RTP) magnetic response, which highlights a number of features, including: (a) a linear NS magnetic low over the Jameson fault, possibly due to alteration or overburden fill; (b) NE-trending magnetic lineaments, which mostly correlate with late mafic dolerite dykes; (c) a partial ring-like magnetic high centred on a magnetic low over the Babel deposit, that is likely responding to the increased sulphides on the outer perimeter of the intrusive; and (d) a broad magnetic high mainly centred with the Nebo intrusive that likely indicates increased magnetite content in the gabbro-norite body.

Examples of the 75 Hz ZTEM and AirMt data are shown in plan in Figures 8, 9 and 10. Multi-frequency profiles of the ZTEM and AirMt data are also presented in Figure 11, for a representative north-south flight line (L1430) across the Babel deposit. To present data from both tipper components in one image and to compensate for the cross-over nature of ZTEM data, the total divergence (DT) is introduced as the horizontal derivatives of the tipper components:

$$DT = \frac{\partial T_{zx}}{\partial_x} + \frac{\partial T_{zy}}{\partial_y},$$

and is derived for each of the in-phase and quadrature components at individual frequencies. These in turn allow for minima over conductors and maxima over resistive zones. DT grids for each of the extracted frequencies were generated accordingly, using a reverse colour scheme with warm colours over conductors and cool colours over resistors (e.g. Figure 8). Alternatively, a 90 degree phase rotation (PR) is also applied to the grids of each tipper component. This transforms bipolar (i.e. cross-over) anomalies into single pole anomalies with a maximum over conductors, while preserving long wavelength information. The two orthogonal grids are then added together:

$$TPR = PR(T_{zx}) + PR(T_{zy}),$$

to obtain a total phase rotated (TPR) grid for each of the in-phase and quadrature components (e.g. Figure 9). In contrast to the cross-over behaviour demonstrated by ZTEM tipper data, the AirMt amplitude parameter display peak maxima and minima across conductive and resistive zones, respectively. Hence, no further processing of the AirMt data are required for plan-view presentation, as shown in the 75 Hz AP image in Figure 10.

Comparing the three images in Figures 8 to 10, the ZTEM DT, TPR and AirMt AP results are remarkably consistent and highlight similar geologic features defined in the magnetic results, such as (a) the conductive Jameson fault that extends north and south of the survey area, (b) a ring-like conductive anomaly that partially coincides with the Babel deposit, and (c) a smaller conductive anomaly over the Nebo deposit that appears to coincide with the known massive sulphide lenses. Other ZTEM-AirMt conductive lineaments that are defined, in part, appear to correlate with either magnetic lineations or mapped faults, and may therefore indicate increased porosity or clay in the faults or possible near-surface paleochannel or

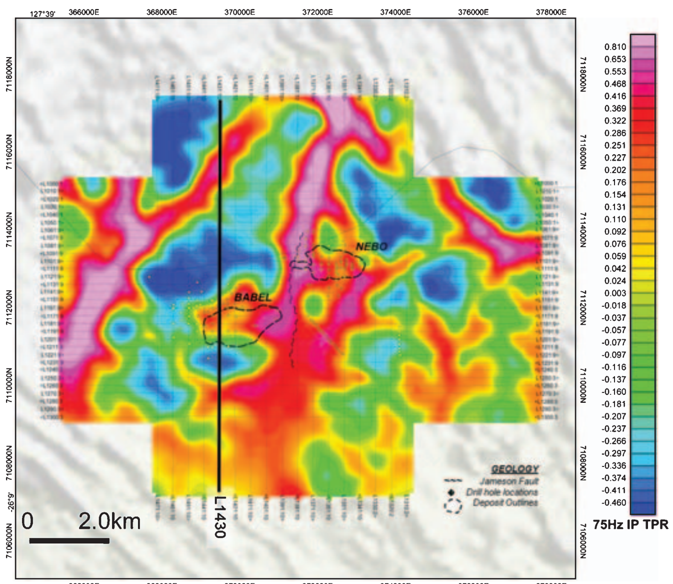

Fig. 9. *ZTEM 75Hz In-Phase Total Phase Rotation (TPR).*

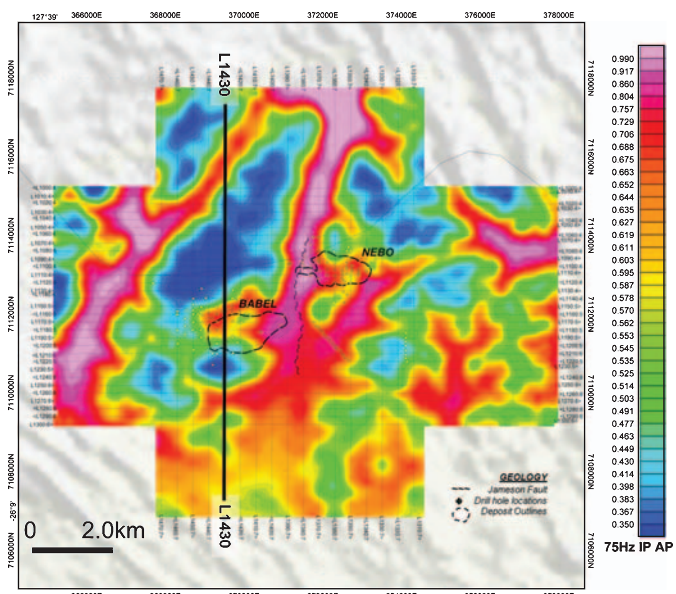

Fig. 10. *AirMt 75Hz In-Phase Amplitude Parameter (AP).*

overburden relief structures (G. Walker, pers. comm., 2011). What is clear from these results is that the cross-cutting behaviour in the ZTEM and AirMt clearly points to 3D geology. While the DT, TPR and AP grids can be used for qualitative analysis, neither they nor the data profiles themselves (Figure 11) are able to easily provide any quantitative information about these 3D structures. For this, 3D inversion is required.

2D inversion

Geotech's 2D inversion is based on modifications to the MT modelling algorithm of Wannamaker *et al.* (1987) with sensitivities by de Lugao and Wannamaker (1996) in an iterative Gauss-Newton method (Tarantola, 1987). The software is serial and runs on desktop computers. Each line is inverted independently. For 2D ZTEM inversion, this software only inverts the inline (T_{zx}) tipper data and assumes orthogonal and infinite strike length of all targets. For 2D AirMt inversion, the software inverts the amplification parameter assuming orthogonal and infinite strike length of all targets. This approximation is reasonable if the geological structures have strike lengths orthogonal to the flight line direction in the order of a skin depth; i.e. greater than the footprint or sensitivity of the ZTEM or AirMt systems. In both cases, the 2D ground topography and the air-layer thickness below the receiver are accounted for; however, the inversions also require *apriori* starting models that are reasonably close to the true half-space resistivity. At Nebo–Babel, 300 ohm-m was chosen for the starting half-space resistivity based on interpretations from a previous ground AMT survey provided by BHP Billiton.

For the Nebo–Babel 2D inversions, model convergence RMS fits of 1.0 or less were achieved in four to five iterations with data errors of 0.03–0.05 for ZTEM, whereas considerably higher data errors of 0.15–0.22 were required for AirMt. This relative inability to properly fit the data in 2D is interpreted to reflect the greater sensitivity of AirMt AP measurement to 3D distortion, relative to the ZTEM in-line component data, but also an indication the 3D geology at Nebo–Babel. Similarly, 2D inversions of data along north-south lines appear to best highlight the Nebo and Babel deposit responses, due to their dominant EW strike, with the ZTEM models seemingly more successful than AirMt. On the other hand, none of the technologies' 2D inversions along east-west lines (not shown) appear to successfully resolve either deposit clearly, due to the dominance of the Jameson Fault. Panels a) and b) of Figure 12 present 2D inversions of ZTEM and AirMt data, respectively, along the north-south L1430 profile, which crosses the Babel deposit – the approximate outline of the intrusion is also shown.

3D inversion

TechnoImaging's 3D modelling is based on the 3D integral equation method (Hursán and Zhdanov, 2002), and the inversion itself uses a regularised re-weighted conjugate gradient (RRCG) method with focusing stabilisers (Zhdanov, 2002). Unlike smooth regularisation, focusing enables the recovery of 3D models with higher contrasts and sharper boundaries. This is an analog of the 3D MT inversion described by Zhdanov *et al.* (2011). The software is fully parallelised for running on cluster computers, meaning that it can be scaled to invert very large survey areas. Panels c) and d) of Figure 12 show vertical cross-sections from the 3D inversions of ZTEM and AirMt data, respectively, along the L1430 north-south profile across the Babel deposit.

Comparing the 2D and 3D inversion cross-sections in Figure 12, at first glance, all four appear to show a reasonably well defined anomalous conductive response over the Babel deposit, with the maximum conductivity generally offset towards the north edge

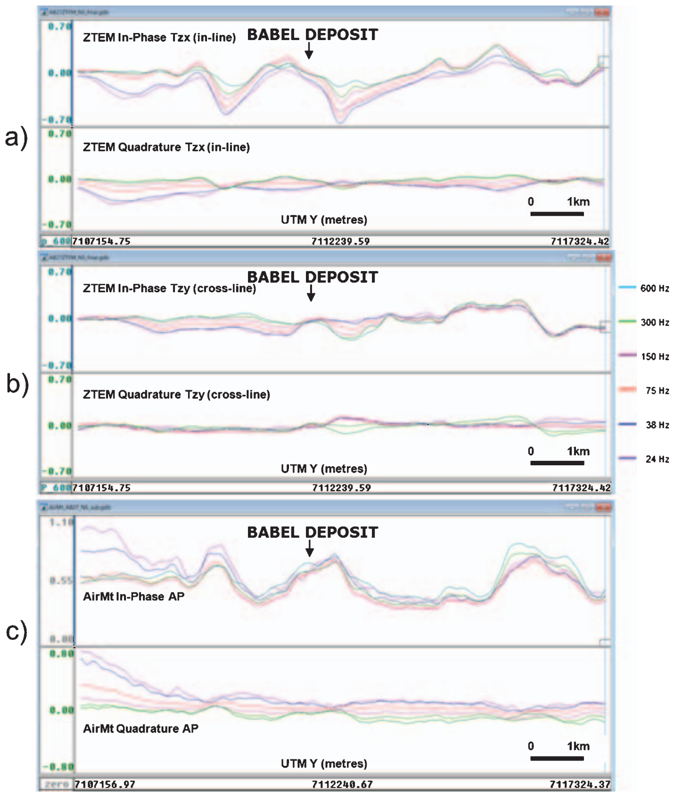

Fig. 11. *Multi-frequency (24–600 Hz) In-Phase and Quadrature data profiles for L1430 (a) ZTEM In-line (Tzx) component (XIP & XQD), (b) ZTEM Cross-line (Tzy) component (YIP & YQD), and (c) AirMt Amplitude Parameter (AIP & AQD).*

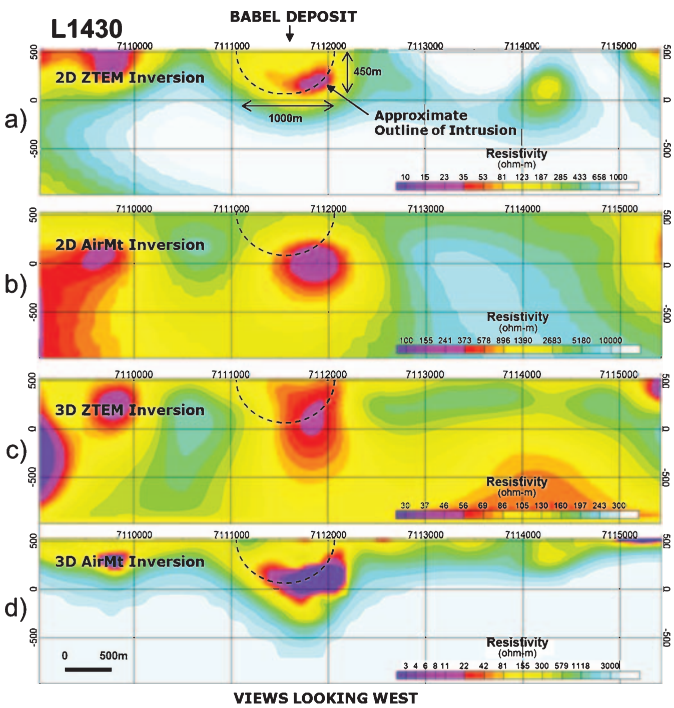

Fig. 12. *2D and 3D inversions along line L1430: (a) 2D ZTEM Inversion, (b) 2D AirMt inversion, (c) 3D ZTEM Inversion, and (d) 3D AirMt inversion.*

and base of the intrusive. Interestingly, this increased conductivity at depth is not easily supported geologically yet is a consistent feature in all four models. However, the overall shape and size extent of the semi-concentric intrusive appear to be better resolved in the 2D ZTEM and particularly in the 3D ZTEM and AirMt models, the lattermost that features the best resolved and most contrasted conductivity anomaly of the four. The generally lower resistivities found in the gabbro-norite are also consistent with ground AMT results (G. Walker, pers. comms, 2011). In contrast, the 2D AirMt model appears to overestimate the target depth, relative to the remaining three inversions, but this may also reflect the poorer quality model-misfits as well. The increased near-surface conductivity observed in all four model sections that extend south of Babel is consistent with heavier overburden cover – as also observed in ground AMT results.

Conclusions

Given global industry trends towards deeper exploration, ZTEM and AirMt represent practical airborne electromagnetic methods for mapping conductivity to depths in excess of 1 km. As natural source electromagnetic methods, ZTEM and AirMt are generated from robust data processing techniques that enable 3D quantitative interpretation. Interpretation of both ZTEM and AirMt data is analogous to magnetovariational (MV) data, and in principle similar to magnetotelluric (MT) data. In this paper, we have presented a review of the current acquisition and interpretation methodologies, including system descriptions, data processing and presentation, 2D inversion, and 3D inversion. We have demonstrated this with a case study involving the interpretation of over 500 line km of both ZTEM and AirMt data from BHP Billiton's Nebo–Babel Ni–Cu–PGE deposit in Western Australia's West Musgrave district.

Acknowledgements

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References

Constable, S. C., Parker, R. L., and Constable, C. G. (1987). Occam's inversion: a practical algorithm for generating smooth models from EM sounding data. *Geophysics* **52**, 289–300.

de Lugao, P. P., and Wannamaker, P. E. (1996). Calculating the two-dimensional magnetotelluric Jacobian in finite elements using reciprocity. *Geophysical Journal International* **127**, 806–810. doi:10.1111/j.1365-246X.1996.tb04060.x

Farquharson, C. G., Oldenburg, D. W., Haber, E., and Shekhtman, R. (2002). An algorithm for the three-dimensional inversion of magnetotelluric data: *72nd Annual International Meeting, SEG, Expanded Abstracts*, 649–652.

Groves, D. I., Groves, I. M., Gardoll, S., Maier, W., and Bierlein, F. P. (2007). The West Musgrave – a potential world-class Ni-Cu-PGE sulphide and iron oxide Cu-Au province? Presented at AIG Conference, Perth.

Holtham, E., and Oldenburg, D. W. (2010). Three-dimensional inversion of ZTEM data. *Geophysical Journal International* **182**, 168–182.

Hursán, G., and Zhdanov, M. S. (2002). Contraction integral equation method in three-dimensional electromagnetic modeling. *Radio Science* **37**. doi:10.1029/2001RS002513.

Kaminski, V. F., Kuzmin, P., and Legault, J. M. (2010). AirMt – passive airborne EM system: Presented at 3rd CMOS-CGU Congress, Ottawa.

Kuzmin, P. V., Borel, G., Morrison, E. B., and Dodds, J. (2010). Geophysical prospecting using rotationally invariant parameters of natural electromagnetic fields: WIPO International Patent Application No. PCT/CA2009/001865.

Labson, V. F., Becker, A., Morrison, H. F., and Conti, U. (1985). Geophysical exploration with audiofrequency natural magnetic fields. *Geophysics* **50**, 656–664. doi:10.1190/1.1441940

Pare, P., and Legault, J. M. (2010). Ground IP-resistivity and airborne SPECTREM and helicopter ZTEM survey results over Pebble copper-moly-gold porphyry deposit, Alaska: *80th Annual International Meeting, SEG, Expanded Abstracts*, 1734–1738.

Sattel, D., Thomas, S., and Becken, M. (2010). An analysis of ZTEM data over the Mt Milligan porphyry copper deposit, British Columbia: 8*0th Annual International Meeting, SEG, Expanded Abstracts*, 1729–1733.

Seat, Z., Beresford, S. W., Grguric, B. A., Waugh, R. S., Hronsky, J. M. A., Gee, M. A. M., Groves, D. I., and Mathison, C. I. (2007). Architecture and emplacement of the Nebo-Babel gabbronorite-hosted magmatic Ni-Cu-PGE sulphide deposit, West Musgrave, Western Australia. *Mineralium Deposita* **42**, 551–581. doi:10.1007/s00126-007-0123-9

Seat, Z., Beresford, S. W., Grguric, B. A., Mary Gree, M. A., and Grassineau, N. V. (2009). Re-evaluation of the role of external sulfur addition in the genesis of Ni-Cu-PGE deposits – evidence from the Nebo-Babel Ni-Cu-PGE deposit, West Musgrave, Western Australia. *Economic Geology and the Bulletin of the Society of Economic Geologists* **104**, 521–538. doi:10.2113/gsecongeo.104.4.521

Tarantola, A. (1987). Inverse problem theory: Elsevier, Amsterdam.

Wannamaker, P. E., Stodt, J. A., and Rijo, L. (1987). A stable finite element solution for two-dimensional magnetotelluric modeling. *Geophysical Journal of the Royal Astronomical Society* **88**, 277–296. doi:10.1111/j.1365-246X.1987.tb01380.x

Ward, S. (1959). AFMAG – airborne and ground. *Geophysics* **24**, 761–787. doi:10.1190/1.1438657

Ward, S. H., O'Donnell, J., Rivera, R., Ware, G. H., and Fraser, D. C. (1966). AFMAG –applications and limitations. *Geophysics* **31**, 576–605. doi:10.1190/1.1439795

Zhdanov, M. S. (2002). Geophysical inverse theory and regularization problems: Elsevier, Amsterdam.

Zhdanov, M. S., Smith, R. B., Gribenko, A., Čuma, M., and Green, A. M. (2011). Three-dimensional inversion of large-scale EarthScope magnetotelluric data based on the integral equation method – geoelectrical imaging of the Yellowstone conductive mantle plume. *Geophysical Research Letters* **37**. 10.1029/2011GL046953.

Design considerations for the development of the HPTX-70 high-powered geophysical transmitter

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Introduction

It is common belief that near-surface mineral resources have probably already been found due to their relative ease of detection. Future exploration will therefore need to focus on finding deposits that are deeper or more difficult to detect. The cost of deep drilling will undoubtedly increase the exploration industry's need for relatively inexpensive geophysical techniques capable of providing quality targets, in order to facilitate more focussed and more cost-effective drilling programs.

Electrical techniques that use a controlled source such as induced polarisation (IP), electromagnetics (EM) and sub-audio magnetics (SAM) use sensitive instruments to measure the earth's response to electrical or electromagnetic signals produced by a geophysical transmitter. The amplitude and quality of the measured response is in turn dependent on the strength and fidelity of the transmitted signal. As explorers search for deeper targets, higher powered transmitters will be required to increase signal amplitudes in order to achieve acceptable signal/noise ratios.

Gap GeoPak Pty Ltd (GeoPak) was formed as a joint venture between Gap Geophysics Pty Ltd and electronic engineering company, Kayar Pty Ltd in 2007. The company's objective was to produce a new generation of geophysical transmitters to meet the increasing demand for higher performance, as well as to accommodate the more stringent safety standards required by the mining exploration industry today.

GeoPak's initial product, the HPTX-70 (see Figure 1), was first commissioned in 2009. The **HPTX-70** is a **h**igh-**p**owered transmitter (**Tx**) capable of output power of up to **70** kW. The system is designed for both electromagnetic and galvanic mode geophysical surveys. It can produce precisely timed, high current waveforms in order to provide a better quality primary signal and consequently allow for high resolution, large scale or deep detection surveys.

The HPTX-70 project involved many design considerations relating to performance, safety and reliability that are described in this article. These may be of interest to the wider geophysical community, particularly at a time when national guidelines for the safe operation of electrical geophysics surveys are being developed.

Development drivers

There were two specific drivers for the development of the HPTX-70.

1. The requirement by Gap Geophysics for a high-powered general purpose transmitter for use with large-scale SAM/HeliSAM and SAMSON surveys. SAM is a total field MMR survey that uses grounded dipoles of up to 10 km separation and may require up to 20 km of loop wire (HeliSAM is a helicopter-acquired SAM survey). SAMSON is a deep search, total field EM technique. In fixed loop EM (FLEM) mode, loops of 1000 m × 1000 m in size or larger are common.
2. The requirement by BHP Billiton – Nickel West for a high-performance EM transmitter to power their FLEM and Downhole EM (DHEM) surveys. Nickel West's defined objective for the system was to achieve 200 A into loops of up to 1000 m × 500 m.

Functional specification

At the outset of the project, a functional specification for the 'ideal' transmitter was defined in collaboration with Gap Geophysics and Nickel West management, geophysicists, engineers and OH&S representatives. Commensurate with the required increases in electrical power and robust design were stated requirements for a very high level of safety.

In developing the HPTX-70, GeoPak endeavoured to construct a functional transmitter with exceptional performance and reliability. Core to its design requirements were also unprecedented security and safety controls.

Overview

Geophysical transmitters are characterised by inherent potential safety issues that include electrical, noise and manual-handling hazards. They are also required to function in hostile environments typified by extremes of temperature, remote locations and rough unsealed roads. In addition to having high performance, the new transmitter also needed to perform safely and reliably in harsh environmental conditions.

Performance considerations

Given the development drivers mentioned above, the HPTX-70 needed to be a general purpose transmitter, capable of

Fig. 1. *The HPTX-70 high-powered geophysical transmitter.*

sufficiently high voltages for galvanic operations and of high currents for EM applications. However, in terms of defining the optimum output power, many factors needed to be taken into account, such as:

- the physical size and weight of the power supply (generator) and transmitter;
- transport logistics – would it need to be trailer or truck mounted?
- fuel consumption (which affects logistics and cost of fuel supply);
- cooling of both a stationary engine and transmitter in Australian temperatures of up to 50°C; and
- operating efficiencies and long term reliability.

Other practical considerations included the output loop characteristics, such as:

- practical loop sizes and configurations;
- loop resistances and inductances;
- electrode resistance for galvanic applications;
- wire sizes and current carrying capacity;
- wire insulation ratings for high voltages;
- wire weights and deployment techniques;
- wire joiners capable of high currents; and
- heat dissipation from the wire.

By modelling the overall system it was determined that around 70 kW was an optimum size for a general purpose, high-powered transmitter. In summary:

- Because of the heat generated, very high currents require high ampacity, low-resistance cable that can be very heavy due to the weight of copper. Heavy wire becomes impractical to deploy and transport without mechanical assistance. For this reason, the output current capability of the HPTX-70 was effectively limited by the practical constraints of wire handling.
- In addition to other Safety and Regulatory considerations, very high voltages require high voltage insulation on the loop wire. This would be prohibitively expensive for the large dipoles being used for SAM and HeliSAM. For this reason, the output voltage capability of the HPTX-70 was ultimately limited by the insulation rating of commonly used, double insulated wire.
- Power (P) is proportional to the square of the current (I). That is, $P = I^2R$ (where R is resistance). This relationship has significant implications for high power outputs. For example, for a given loop resistance, doubling the power output would only result in an increase in current by a factor of 1.4. Doubling the current would require an increase in power by a factor of four. This would be achieved at significant cost in terms of weight, transport, cooling and fuel requirements.
- On a practical note, the transition from 70 kW to 85 kW for an industrial diesel engine usually coincides with an increase from four to six cylinders. This power upgrade increases the physical size and weight of the engine as well as fuel consumption and hence the required fuel capacity.
- The upper weight limit for safely towing a trailer behind a light vehicle on country roads was considered to be around 2.0 tonne. It was determined that the size and weight increase from a four cylinder to six cylinder diesel engine as well the extra fuel capacity required to operate it, would increase the weight significantly beyond that limit. A larger system would therefore need to be mounted on a truck with a minimum load capacity of 5 tonne. The permanent assignment of a truck to the transmitter would therefore result in substantial additional cost.
- A significant increase in power also requires a significant increase in the ruggedness, availability and expense of electronic components in the transmitter. In addition, it results in a dramatic increase in heat generation, which would then require further cooling.

The transmitter design used in the HPTX-70 is scalable and could accept input power well in excess of 200 kW. However, it was decided that a trailer-borne system would be the most versatile, most practical and most cost-effective platform for the initial design. Given the previously described wire constraints on current output, higher power could only be utilised if high voltages were also implemented.

The HPTX-70

Performance

The HPTX-70 has four selectable voltage ranges as shown in Table 1. The maximum current for each range is also shown.

The high current capability means that the HPTX-70 is an ideal transmitter for electromagnetic surveys, particularly for FLEM or DHEM. *Note that high current output requires low resistance loops and appropriate wire capable of carrying the current.*

The HPTX-70 transmitter is also routinely used for galvanic mode surveys such as SAM and IP. *The maximum output voltage of 1200 V will, of course, limit the output power achievable in very resistive environments.*

Internal layout

The internal layout of the trailer is shown diagrammatically in Figure 2. The trailer is partitioned into three main compartments. From front to rear of the trailer, these are referred to as:

A. Dummy load compartment,
B. Engine compartment, and
C. Electrical compartment.

Table 1. Selectable voltage ranges for the HPTX-70

Voltage range	Minimum volts	Maximum volts	Maximum amps
Range 1	100	200	350
Range 2	200	350	200
Range 3	350	700	100
Range 4	700	1200	60

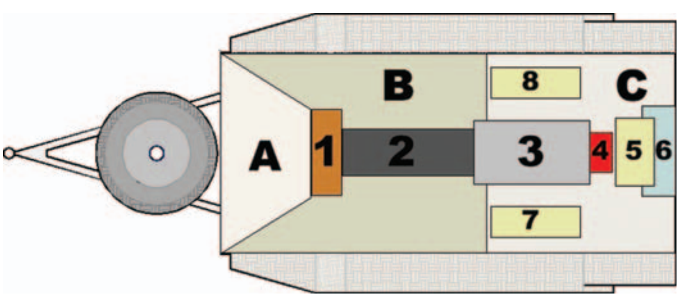

Fig. 2. *Plan view of the HPTX-70 showing the dummy load compartment (A), the engine compartment (B), and the electrical compartment (C).*

The other components of the system are:

1. Radiator,
2. Diesel engine,
3. Alternator,
4. Circuit breakers,
5. Control module,
6. Capacitor box,
7. Switch module, and
8. Transmitter module.

Dummy load compartment

Geophysical transmitters are usually required to produce current waveforms that consist of some **ON** time and some **OFF** time. That is, current may not be transmitted into the loop 100% of the time. Time domain waveforms are typically characterised by a 25 or 50% duty cycle, which means that current is only being transmitted (**ON** time) for 25 or 50% of the time. For the rest of the time there is no output from the transmitter. The variable load on the transmitter therefore results in surging of the engine during the **OFF** time. This may subsequently affect the integrity of the waveforms produced, as well as cause undue wear on the engine.

Fig. 3. *Front view of the HPTX-70 with the door open showing the dummy load protected by an aluminium mesh screen.*

To alleviate this effect, the HPTX-70 has a built-in bank of resistors known as a ‘dummy load’. The dummy load compartment is located at the front of the trailer and can be seen in Figure 3. To balance the load on the engine, the transmitter switches the output current during the **OFF** time to the dummy load. The number of resistors required to balance the load is automatically determined by the transmitter.

Diesel engines also require a minimum load to operate efficiently. The HPTX-70 will also transmit some output current into a portion of the dummy load during the **ON** time if there is insufficient load on the engine.

Engine compartment

A photograph of the engine compartment is shown in Figure 4. The power supply used in the HPTX-70 is a four cylinder, 70 kW, Deutz turbo-diesel engine operating at 1800 rpm and driving a three phase alternator. Direct drive mitigates many of the mechanical drivetrain problems often encountered with gearboxes or drive belts, resulting in less maintenance and greater reliability.

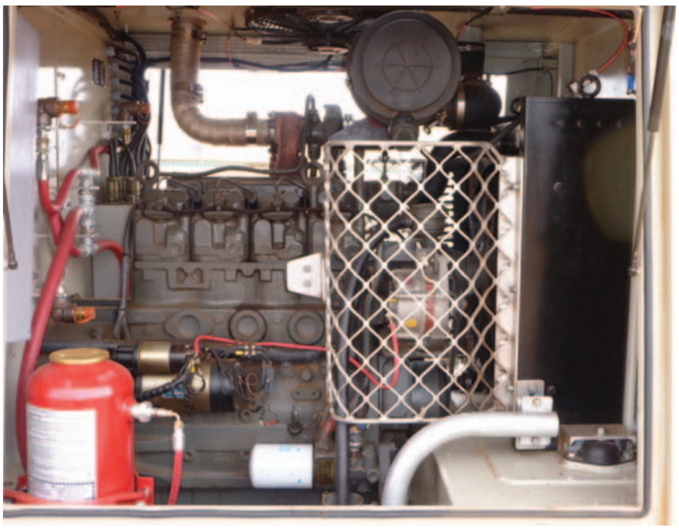

Fig. 4. *The HPTX-70 engine compartment showing the Deutz diesel engine and fire suppression system. The fuel tank is located beneath the radiator.*

Electrical compartment

The electrical compartment can be accessed via the two rear side doors and the rear door. A rear view of the compartment is shown in Figure 5. With reference to the numbering in the schematic in Figure 2, the control module (5) is shown at the top and the capacitor box (6) at the bottom. Directly beneath the control module are the circuit breakers. The grey unit beneath the circuit breakers is the Stamford alternator (3).

To the left of the control module is the switch module (7), showing the circular voltage range selection switch. The transmitter module (8) is visible at the right of the control module.

Cooling systems

The HPTX-70 has been designed to operate in hot environments. It also generates a significant amount of heat internally from

Fig. 5. *Rear view of the HPTX-70 with the rear door open showing the grey alternator, control module at top and capacitor box at the bottom. The switch module (with voltage selection wheel) is located on the left side. The transmitter module is located on the right.*

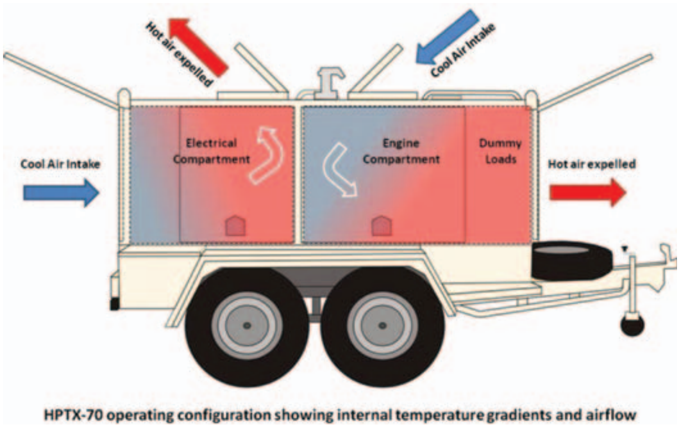

Fig. 6. *The HPTX-70 configured for normal operating mode. The side doors must all be in the closed position. The roof hatches and the front and rear doors must be kept open for optimal cooling.*

both the engine and transmitter compartments as well as from the dummy loads. Consequently, cooling was a major design consideration. By separating the engine and electrical compartments it was possible to design separate, and thereby more efficient, cooling systems for the different sections.

In normal operating mode, the HPTX-70 is operated with its side doors closed and its rear and front doors open. In addition, the two roof hatches must be kept fully open. A diagram showing the HPTX-70 in operating mode is shown in Figure 6. Also shown in this figure is the direction of airflow and the temperature gradient for each of the internal compartments.

Two high-speed fans are mounted beneath each of the roof hatches of both the engine compartment and the electrical compartment. The fans are responsible for volume and direction of airflow throughout the HPTX-70. In addition, there are seven fans mounted on the rear of the transmitter module and two fans mounted on the rear of the switch module.

Output connectors

The output connectors are each comprised of a polycarbonate box containing an aluminium terminal block. The two transmitter cables are terminated with crimp-on copper lugs and attached to the terminals. A photo of an output connector with the lid open is shown in Figure 7.

The loop cables are also terminated with crimp-on copper lugs. They are attached to the terminal block with wing nuts and spring washers for easy removal and attachment. The output connector boxes are also fitted with safety interlocks. The boxes must be closed for the HPTX-70 to operate. Opening the box while the HPTX-70 is operating will result in an emergency shutdown of the transmitter.

Fire suppression system

An automatic fire detection and suppression system is fitted inside the HPTX-70. The control panel, located on the right side of the electrical compartment, is shown in Figure 8. Located beneath the control panel is a bottle of pressurised nitrogen,

Fig. 8. *The fire suppression control panel located in the right side of the electrical compartment.*

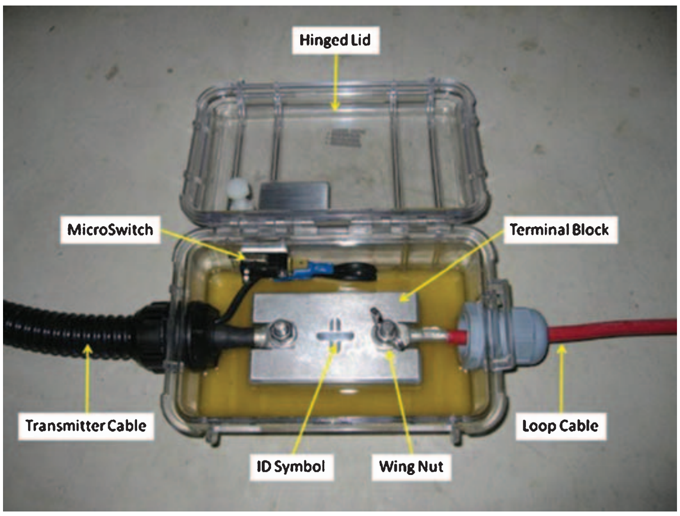

Fig. 7. *Close up of a connector box with lid open showing internal components.*

Fig. 9. *The HPTX-70 control system includes a ruggedised handheld computer and radio modem.*

which acts as the propellant for the bottle of dry powder retardant located in the engine compartment.

Control system

The HPTX-70 is controlled remotely by specialised software (HPTXUi) operating on a handheld computer. The computer may be linked directly by cable to the control panel of the transmitter but is designed to operate via a radio link. The range of the radio link will depend on topography but is usually about 2 km. A photograph of the control system is shown in Figure 9.

HPTXUi

The HPTX user interface software requires the operator to log in to the transmitter via a security password. The operator is then required to review digital checklists prior to starting the transmitter. The alternator and hence the transmitter cannot be started without the use of this software. However, the engine alone can be started manually for maintenance purposes.

All transmitter functions including engine start/stop, transmitter start/stop, frequency, duty cycle and current are controlled on a setup panel (Figure 10). The output status panel provides real-time information on the various operating parameters including output voltage, output current and turn-off time. All internal temperatures, voltages and phases are monitored and broadcast by the transmitter. Abnormal variations in critical parameters will initially result in warnings on the display. Critical errors will be trapped resulting in immediate shutdown of the system. All control and status information is logged to various files for later reference or for auditing purposes.

Computer control of the transmitter also provides the ability to run repetitive or routine procedures. HPTXUi has an inbuilt scripting language for that purpose.

Summary

Three HPTX-70's are now in operation in Australia. Apart from their enhanced performance, the design has been found to have significant implications for many aspects of their operation including safety, logistics, efficiency and reliability.

Safety

- Radio control – the operator does not need to be near the transmitter to operate it. This is a significant safety control as the operator is totally removed from electrical and noise hazards when the transmitter is operating.
- Electrical components are fully enclosed and protected from the environment.
- Electrical and mechanical components are enclosed and inaccessible when operating.
- Safety interlocks are installed on all doors and hatches and will initiate immediate shutdown of the system if they are opened (or closed) during operation.
- No manual lifting – the all-in-one design removes the requirement for manual lifting of heavy generators and transmitters during setup.
- Reduced trip hazards – all of the cabling is internal apart from the output loop and earth wires.
- Safety beacons – two high intensity safety beacons are activated when the HPTX-70 is operating and therefore provide a visual warning to anyone approaching.
- Safety guards are installed on all internal moving parts as well as the dummy loads.
- Steps and grab rails allow three points of contact when opening or closing roof hatches.
- Emergency shutdown – the HPTX-70 may be shut down by activating either of the emergency shutdown switches on the main control panel and near the dummy loads or by pressing the shutdown button on the handheld computer. In addition, shutdown will occur on opening of any of the side doors or by closing the rear or front doors.
- Automatic shutdown – the HPTX-70 also has 32 sensors throughout, which monitor internal temperatures, overcurrent and overvoltage. The transmitter will automatically shutdown if an error condition is detected.
- Open circuit protection – the HPTX-70 will shut down if a change in the loop resistance is detected (i.e. due to a break in the loop such as an open circuit).
- Earth leakage protection – a current of 20 mA or more in the chassis to earth-stake cable will cause shutdown of the motor and transmitter system within 1 ms. A test button allows injection of 20 mA into the earth leakage detection circuitry to enable testing of this function.
- Bunding for the fuel tank – the fuel tank is built separate to the trailer. The trailer base itself is fully sealed so that if any puncture should occur in the fuel tank, the trailer provides internal bunding for the fuel leak.
- Aluminium construction – the HPTX-70 trailer has been built entirely from aluminium in order to minimise weight for towing and manoeuvrability purposes.
- Signage – HiVis reflective tape and appropriate signage is used as required.

Logistics, efficiency and reliability

- Wireless control means the transmitter may be operated and monitored remotely without the operator having to travel to it.
- Cooling system – the HPTX-70 has been designed to operate in hot conditions through implementation of a sophisticated cooling system.
- Reduced wear on connectors due to permanent attachment of all electrical connections apart from the output (constant

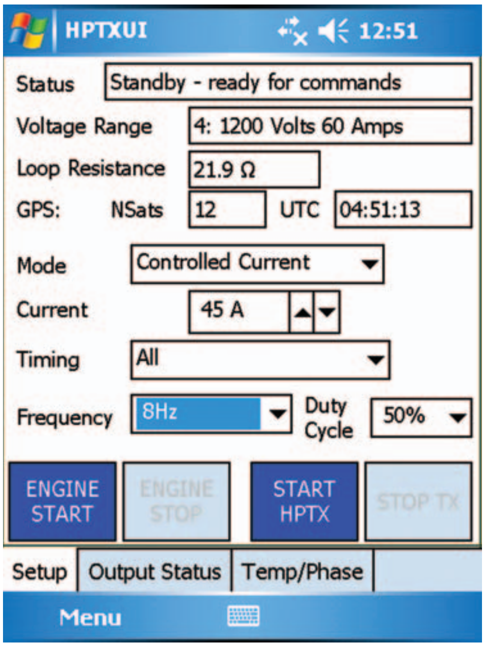

Fig. 10. *HPTXUi – setup panel.*

connection and disconnection results in wear and tear of connectors and is generally one of the major causes of downtime in geophysical surveys).

- Very little setup required – when the HPTX-70 is moved to a new loop, the only setup required is installation of an earth-stake and connection to the loop. This greatly reduces setup time and hence improves survey efficiency.
- Power source – the HPTX-70 uses an industrial quality diesel powered three-phase genset for fuel efficiency, reliability and long life. The engine runs at low speed, thereby extending engine life. Direct drive simplifies power transmission to the alternator as no belts, gearing or hydraulic drives are required.
- Dummy loads – provide a balanced and adjustable load on the engine in order to reduce wear on the engine and help to maintain the integrity of the output waveforms.
- Fuel tank – the large fuel tank (~250 L) is installed for long duration.
- Rhino lining – the trailer base has been sprayed with a protective coating to prevent stone damage and thereby reduce maintenance. It also provides a non-slip surface on steps and guards.
- Rustproof – the HPTX-70 trailer will not rust due to the aluminium construction.

The Frome airborne electromagnetic survey: uncovering 10% of South Australia

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Introduction

The Frome airborne electromagnetic (AEM) survey was acquired by Geoscience Australia (GA) under the Australian Government's Onshore Energy Security Program (OESP). This area is considered to have great potential for uranium mineralisation and includes Australia's only two producing *in situ* leach uranium mines, Beverley and Honeymoon. In contrast to deposit-scale investigations carried out by industry, the Frome AEM survey was designed to reveal new geological information at a regional scale, reducing exploration risk, stimulating exploration investment and enhancing the prospectivity within the region primarily for uranium, but also for other commodities including copper, gold, silver, lead, zinc, iron ore, coal and groundwater. The Frome AEM survey (Figure 1) was flown by Fugro Airborne Surveys for GA, using the TEMPEST™ time-domain AEM system.

In this article we discuss a selection of the Geoscience Australia Layered Earth Inversion (GA-LEI) products that are now available from the GA website free of charge. The inversion data and derived products reveal new geological information including facies changes associated with uranium mineralisation, structures related to uranium and gold mineralisation, palaeovalley architecture, geological surfaces and geology 'under cover'.

AEM system selection and survey design

Geoscience Australia selected the TEMPEST™ system to fly the Frome AEM survey from the various candidates submitted by members of the Panel of AEM contractors after an assessment of the probability of detecting 'type' geological targets in the presence of typical background geology. In this methodology (Green and Lane, 2003) a geological scenario representing the likely background and target conditions is defined and then transformed into an equivalent geo-electric model. From forward model responses, with and without the target unit present, an anomalous response is determined. Then, using the estimated system noise levels, the anomalous response is converted to an anomaly-to-noise ratio, from which a probability of detecting the presence of the target can be derived.

While the usefulness of this method is strongly dependent on the assigned conductivities and system noise levels, it does give an objective measure of system suitability for a particular exploration task. The assigned system noise levels for each AEM system were those specified as maximum allowable noise levels in the Deed of Standing Offer with the GA AEM panel contractors. These are determined from sample high-altitude and repeat-line data (Green and Lane, 2003) provided to GA as part of the requirement of becoming a member of the contractor panel. The geo-electrical models were synthesised from prior knowledge of conductivity ranges for the targeted geological units.

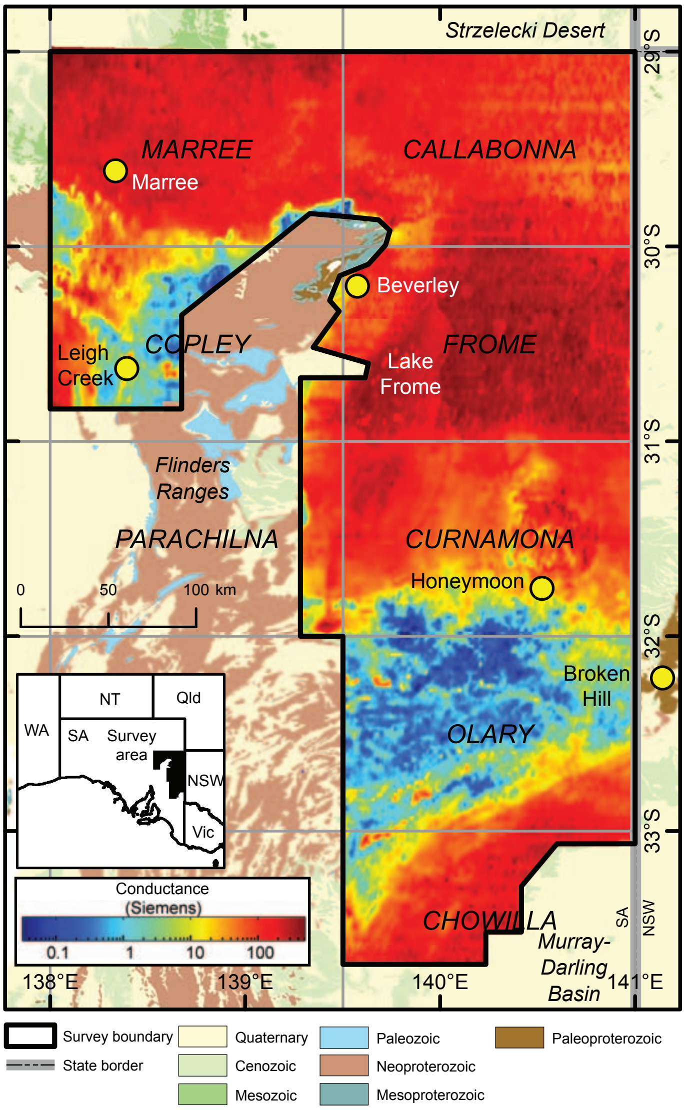

Fig. 1. *The Frome Survey area highlighted with an image of the estimated conductance to 200 m depth and 1:250 000 map sheet names. Geoscience Australia funded 5000 m line spacing across the entire survey and a large infill area at 2500 m line spacing. The Department of Manufacturing, Innovation, Trade, Resources and Energy South Australia (DMITRE) and a consortium led by Callabonna Uranium Ltd. funded infill areas at 2500 m line spacing.*

The geological scenarios representing the aims of the survey can be grouped into three main geo-electric models:

1. Model 1: Sandstone Systems – Paleochannel style; mapping paleovalley architecture.
2. Model 2: Structures – mapping offsets between rock units particularly associated with uranium or other mineralisation.
3. Model 3: Depth of cover – mapping depth to 'mineralised units' and depth to basement.

When all scenarios were deemed of equal relevance, and when other survey factors were taken into account (such as survey logistics, availability, safety and cost), the TEMPEST^{TM} system was assessed as most likely to be effective in the Frome AEM survey area.

Survey boundaries were determined by considering cultural, geological, geophysical, remote sensing and topographic data with the forward-modelling results. Flight line spacing was determined by assessing the extents of known geological units, structures and mineralisation and by assessing the expected footprint of targets. The Frome survey was flown with east–west flight lines spaced at 2500 m and 5000 m, at a nominal 100 m above ground level totalling 32 317 line km of data. The completed survey area was 95 405 km^2, covering 10% of South Australia.

The GA-LEI results

The data from the Frome AEM survey were inverted using the GA-LEI (Brodie and Sambridge, 2006) to create subsurface conductivity models and products, referred to as Phase-2 data (Hutchinson *et al.*, 2011). In previous GA regional AEM surveys, such as Paterson (Roach, 2010) and Pine Creek (Craig, 2011), the data were inverted solely using a GA-LEI sample-by-sample (SBS) inversion algorithm, which inverts each sample independently of its neighbours. For the Frome AEM survey, GA released conductivity models using both the GA-LEI SBS inversion and a laterally constrained line-by-line (LBL) inversion. A detailed description of the LBL inversion algorithm can be found in Brodie and Sambridge (2009) and Brodie (2010). A brief explanation is given below.

The LBL inversion algorithm is based on the same layered earth structure as the SBS inversion, but applies additional lateral constraints. The LBL inversion uses the principle of fitting layered earth conductivity values to match the measured AEM data including the vertical smoothness and reference model constraints. However, a whole line of data is inverted at once using a cubic-spline parameterisation of the conductivity of each layer and each system geometry parameter. This allows along-

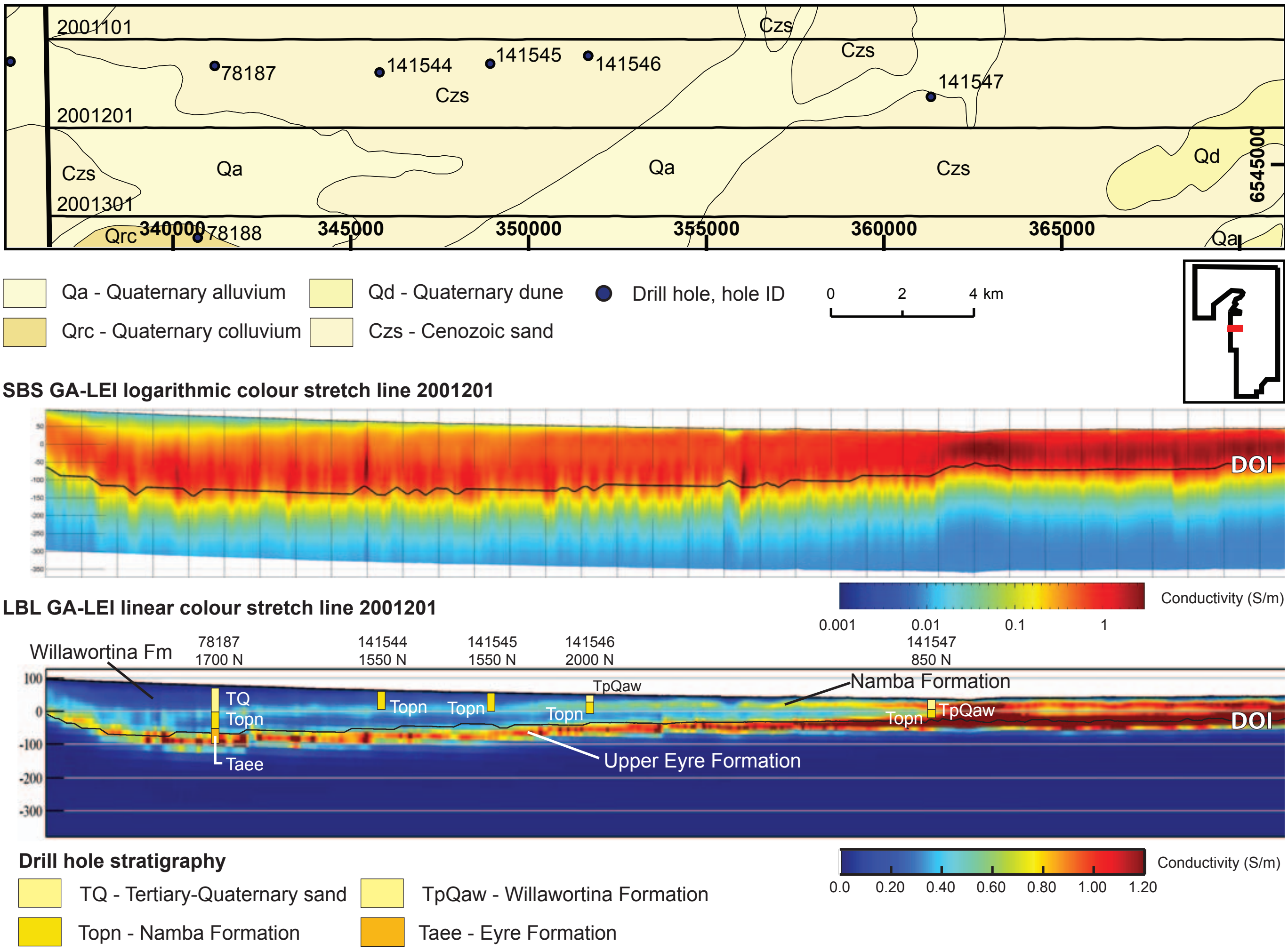

Fig. 2. *Example of surface geology (top), sample-by-sample (SBS) (middle) and line-by-line (LBL) (bottom) inversion products for line 2001201 in the southwestern Lake Frome area. Here, relatively weak to moderate conductors (Namba and Eyre formations) overlie resistive Cambrian basement. The linear colour stretched LBL inversion conductivity section defines the different units in the stratigraphy much more successfully than the logarithmic colour stretched SBS inversion conductivity section, as shown by drill hole logs on the LBL inversion conductivity section (bottom). Drill hole stratigraphic logs are marked with the SARIG drill hole ID and distance in metres north (N) of the flight line.*

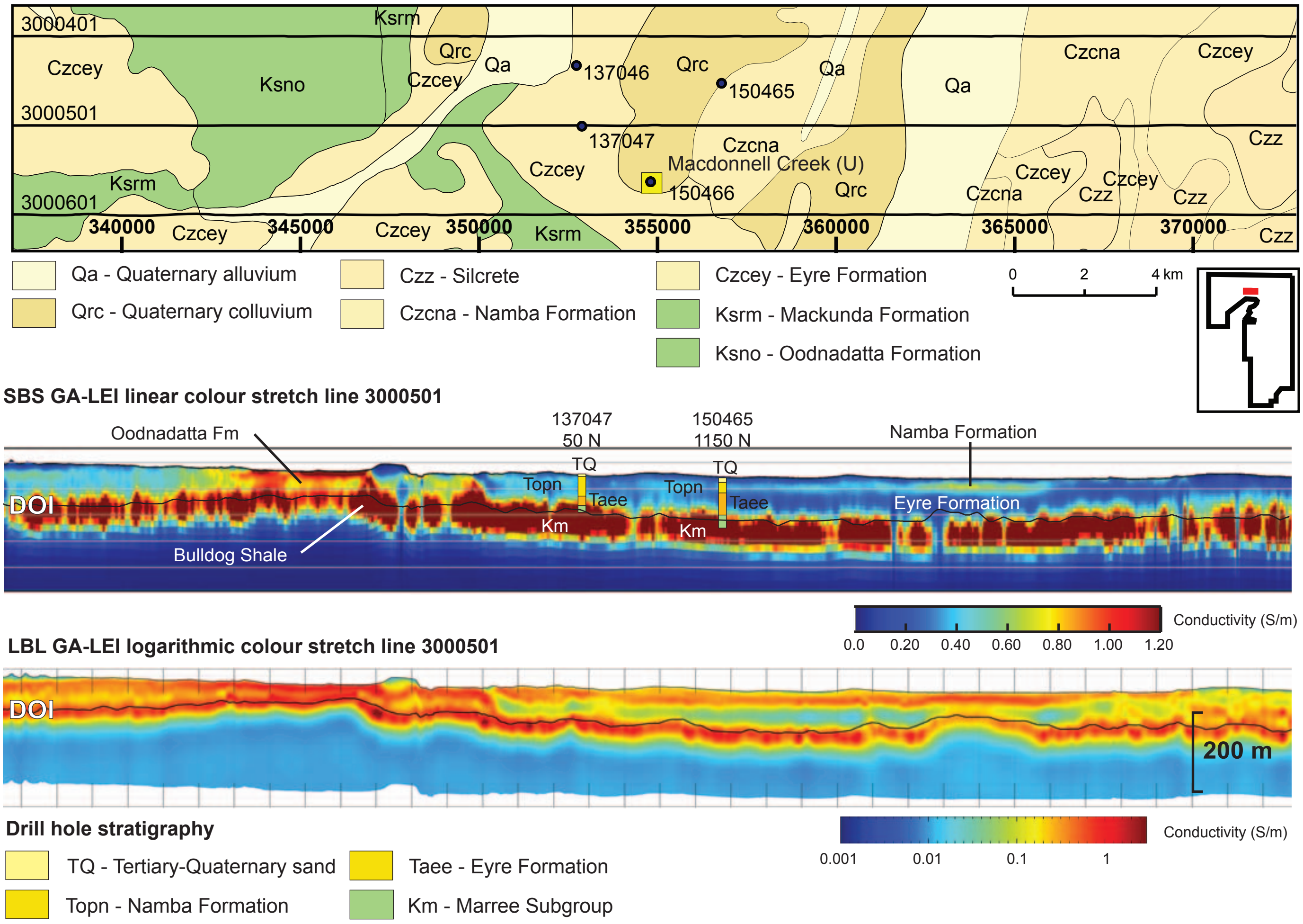

Fig. 3. *Example of surface geology (top) sample-by-sample (SBS) (middle) and line-by-line (LBL) (bottom) inversion products for line 3000501 on the flank of the northern Flinders Ranges. Here, relatively weak to moderate conductors (Namba and Eyre formations) overlie highly conductive Mesozoic basement (Marree Subgroup, including the Bulldog Shale, Mackunda Formation and Oodnadatta Formation). The linear colour stretched SBS inversion conductivity section has been used here to map the top of the Bulldog Shale (basal conductor) and distinguish it from the overlying Oodnadatta Formation. The linear colour stretched LBL inversion can be used to define the top of the Marree Subgroup and top of the Eyre Formation. Drill hole stratigraphic logs are marked with the SARIG drill hole ID and distance in metres north (N) of the flight line.*

line smoothness and continuity constraints to be applied. The solution at a particular sample is influenced by its neighbours.

The horizontal smoothness of the model has the advantage of enhancing layered geological features, making such features more continuous and clearly defined. This smoothing also helps to reduce the one-dimensionality of the SBS inversion, and allows the model to give appropriate weighting to data trends in either a vertical or horizontal direction. Likewise, horizontal smoothing can effectively attenuate discontinuous features in the data, such as discrete conductors. Discontinuous features may still be present in the data, but their magnitudes will be underestimated because of the numerical tendency to reduce the conductivity gradient between neighbouring data points. Examples of SBS and LBL conductivity sections are given in Figure 2 and 3, highlighting the efficacy of each in different parts of the survey area. Figure 2 shows the LBL defining the target stratigraphy more successfully than the SBS inversion. Figure 3 shows the SBS defining the target unit more effectively.

The maximum depth at which the inversion is influenced more by the conductivity data than the reference model is known as the depth of investigation (DOI). The DOI for the SBS inversion was calculated using a variation on the method of Christiansen and Auken (2010). The LBL inversion DOI was calculated based on the method of Oldenburg and Li (1999). The DOI is represented as a black line in the Phase-2 conductivity section products and is utilised as a reliable depth of conductivity results in interpretations. The DOI is also gridded (see Hutchinson *et al.*, 2010) and used as a cutting tool to null data below the DOI in depth and elevation slices to avoid over-interpretation.

Implications for exploration

The outcomes of the Frome AEM survey include mapping of subsurface geological features that are associated with uranium mineralisation including sedimentary facies changes, palaeovalley and basin architecture, faults involved in preserving uranium deposits and depth of cover. The products are also suitable for interpretation focussed on other commodities including metals, coal and groundwater, as well as for landscape evolution studies. The improved understanding of the regional geology for an area that covers approximately 10% of South Australia will be of considerable benefit to mining and mineral exploration companies.

The Frome AEM survey results illustrate a significant improvement in mapping conductivity in greater detail and identifying features such as unconformities (e.g. Benagerie Ridge surface), paleovalleys (e.g. Yarramba and Billeroo palaeovalleys) and major structures (e.g. range front faulting around the northern Flinders Ranges and the Redan Fault Zone in the Murray-Darling Basin) in the Lake Frome area at much greater extent than previously realisable. The Frome AEM survey results demonstrate the effectiveness of AEM for regional geological mapping.

Geoscience Australia Frome AEM survey data releases

Frome Phase-1 TEMPEST™ data and processing report. The complete TEMPEST™ data set and processing report are available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71624

Frome Phase-2 TEMPEST™ GA-LEI 30 layer inversion data and products to 400 m are available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=72589

Frome Phase-2 TEMPEST™ GA-LEI 30 layer inversion data and products to 200 m are available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=73838

Frome Embayment AEM Phase-1 and Phase-2 TEMPEST™ data for the Callabonna Uranium infill area, SA are available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=73839

Frome Interpretation Report. An interpretation report (Roach, 2012) released at the AusIMM Conference in June 2012 is now available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=73713

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References

Brodie, R. (2010). Holistic Inversion of Airborne Electromagnetic Data. Research School of Earth Sciences, Australian National University, Canberra. PhD thesis, unpublished.

Brodie, R., and Sambridge, M. (2006). A holistic approach to inversion of frequency domain airborne EM data. *Geophysics* **71**, G301–G313. doi:10.1190/1.2356112

Brodie, R., and Sambridge, M. (2009). Holistic inversion of frequency-domain airborne electromagnetic data with minimal prior information. *Exploration Geophysics* **40**, 8–16. doi:10.1071/EG08110

Christiansen, A., and Auken, E. (2010). A global measure for depth of investigation in EM and DC modelling. In, *ASEG Conference 2010 Extended Abstracts*, Australian Society of Exploration Geophysicists.

Craig, M. A. (editor) (2011). Geological and energy implications of the Pine Creek region airborne electromagnetic (AEM) survey, Northern Territory, Australia. Geoscience Australia, Canberra. Geoscience Australia Record 2011/18.

Green, A., and Lane, R. (2003). Estimating Noise Levels in AEM Data. In, *ASEG 16th Geophysical Conference and Exhibition Extended Abstracts*, Australian Society of Exploration Geophysicists.

Hutchinson, D. K., Roach, I. C., and Costelloe, M. T. (2010). Depth of investigation grid for regional airborne electromagnetic surveys. *Preview* **145**, 38–39.

Hutchinson, D. K., Brodie, R. C., and Costelloe, M. T. (2011). Frome Embayment TEMPEST™ AEM Survey: Inversion Report. Geoscience Australia, Canberra. GEOCAT #72589, 57 pp.

Oldenburg, D. W., and Li, Y. (1999). Estimating depth of investigation in DC resistivity and IP surveys. *Geophysics* **64**, 403–416. doi:10.1190/1.1444545

Roach, I. C. (editor) (2010). Geological and energy implications of the Paterson Province airborne electromagnetic (AEM) survey, Western Australia. Geoscience Australia, Canberra. Geoscience Australia Record 2010/12, 318 pp.

Roach, I. C. (editor) (2012). The Frome airborne electromagnetic (AEM) survey, South Australia: implications for energy, minerals and regional geology. Geoscience Australia-Geological Survey of South Australia, Canberra. Geoscience Australia Record 2012/040-Geological Survey of South Australia Report Book 2012/00003.

A systematic approach to surface-to-downhole induced polarisation

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This article reports on Jarrad Trunfull's Honours project, which was sponsored by the ASEG Research Foundation in 2011. Jarrad's project was supervised by Mike Dentith at The University of Western Australia and Yvonne Wallace and Lee Sampson at Barrick (Australia Pacific) Limited.

A study was undertaken to investigate the potential use of induced polarisation surveys featuring combined surface-to-downhole electrodes. Two electrode array configurations were investigated, the Axial Gradient Directional Array and the Radial Array. Both were found to provide an advantage over surface IP in close proximity to the target. The Radial Array, however, produced data that allowed for simpler and less ambiguous interpretation. Further research needs to be conducted into the merits of combining both methods, as well as performing successful inversion of acquired data.

Introduction

The purpose of this study is to investigate the feasibility of surface-to-downhole induced polarisation (DHIP) for effective application in the field. This was initiated by identifying DHIP arrays that have a reasonable expectation of returning useful data, which include the Axial Gradient Directional Array and the Radial Array (Sumner, 1976; Mudge, 2004; A. Scott, pers. comm. 2009). These arrays have been investigated via systematically forward modelling different parameters in a static model in order to define the best possible set-up for a given geologic environment. This project used the UBC (University of British Columbia) forward-modelling code DCIPF3D, and also served to assess its ability to forward model DHIP data.

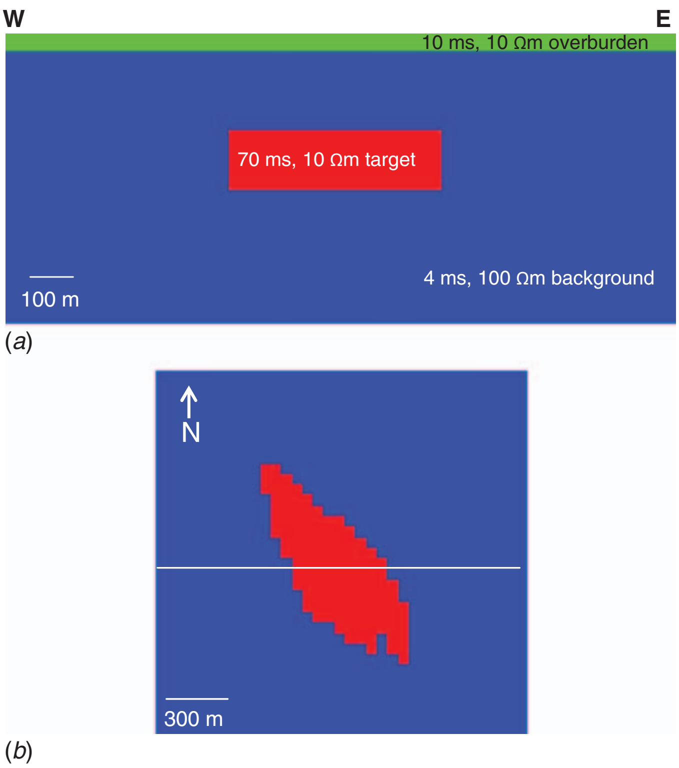

Fig. 1. *Three-dimensional synthetic model of the Centenary gold deposit. (a) A west–east section through the orebody labelled with respective properties of each component. (b) Depth slice at 300 m depicting the shape of the orebody. The white line on the depth slice represents the position of the section.*

The model was based on the Centenary gold deposit, Western Australia, owned by Barrick (Australia Pacific) Limited (Barrick), and consisted of a 250-m-thick chargeable/conductive rectangular body in a neutral/resistive background, with a 50-m-thick conductive overburden (Figure 1). The depth to the top of the target was 250 m. The target was assigned a chargeability of 70 ms and resistivity of 10 Ωm, with the overburden and background assigned values of 10 ms/10 Ωm and 4 ms/100 Ωm respectively.

The study looked at the optimisation of parameters such as target offset (distance between the drill hole and the target body), transmitter distance/depth (distance from and depth of the transmitters with respect to the drill hole), potential dipole size and extent (size and distance covered by the potential dipoles), target depth (depth to top of target body) and whether a target could be detected if not directly intersected by the line of sight between the transmitting and receiving electrodes.

The Axial Gradient Directional Array

The Axial Gradient Directional Array (AGDA) consists of four polar current electrodes located on the surface and transmitting in sequence, and a downhole dipolar array comprising potential electrodes (Figure 2). It measures vertical variations in IP and resistivity, making it ideal for delineating the depth and width of a target.

Testing was initially conducted to determine the operable distance of the array from a target. Forward-modelling results

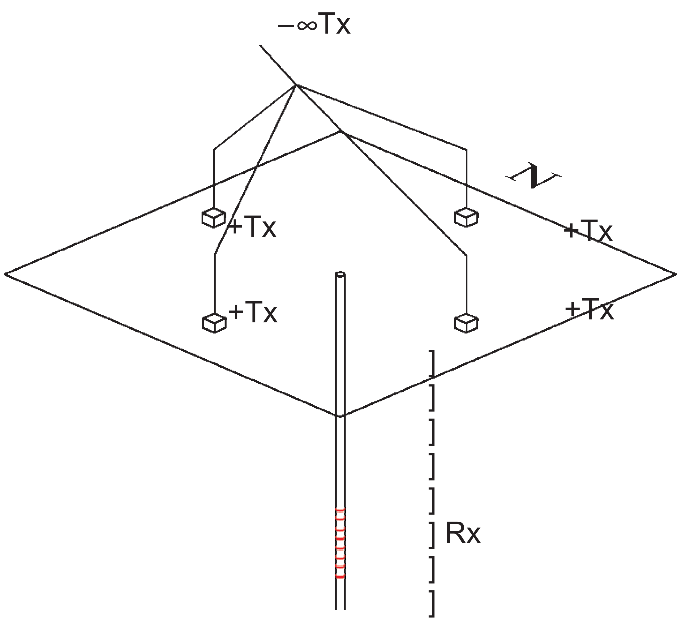

Fig. 2. *Schematic diagram of the Axial Gradient Directional Array.*

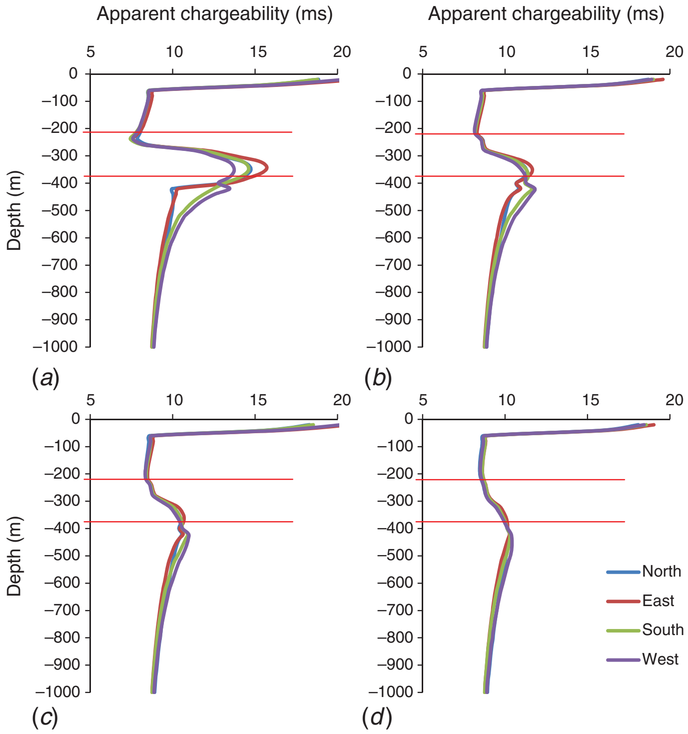

Fig. 3. *Vertical profiles of apparent chargeability from drillholes with (a) 25, (b) 50, (c) 75, and (d) 100 m displacement between the deployed Axial Gradient Directional Array and the target. Red horizon lines denote the vertical position of the target.*

show the AGDA is able to define a large and clear anomaly at a short (e.g. 25 m) drill hole offset from a target, which weakens approximately linearly as this offset is increased; a maximum offset being considered approximately 50 m. The amplitudes of the anomaly vary at the different current electrodes, allowing the data to be used to approximate the spatial location of the target (Figure 3). At a larger drill hole offset (e.g. 100 m) this difference can be masked or overprinted by noise.

The optimal distance of the surficial current electrode from the drill hole was also investigated via forward modelling. Coloured pseudosections were plotted in an attempt to understand the

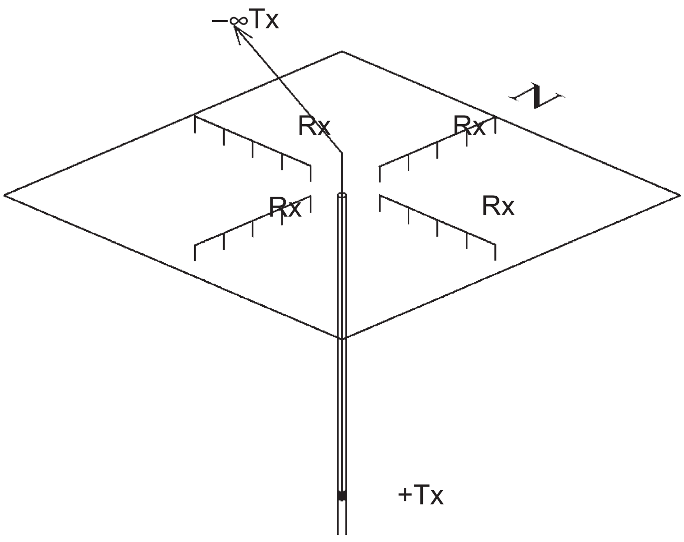

Fig. 4. *Schematic diagram of the Radial Array. Note that only four potential arrays (Rx) are pictured, but the array may include many more at a specified angular interval.*

behaviour of data and identify an optimal distance; however, this was not able to be discretely identified. Various receiver dipole sizes were also investigated as part of this study, with the conclusion being that the dipole size needs to be smaller than the target to allow detection (a smaller dipole size increases survey resolution but is not always necessary.)

The Radial Array

The Radial Array (Sumner, 1976; Mudge, 2004) is, in essence, the reverse configuration of the AGDA, consisting of a downhole polar current electrode and at least four dipolar receiving arrays located on the surface in each quadrant around the drill hole (Figure 4). Snyder and Merkel (1973), along with Asch and Morrison (1989), demonstrated that placing the current electrodes beneath conductive overburden enhances the current density arriving at targets. The Radial Array is best designed to measure horizontal variations in IP and resistivity. This study

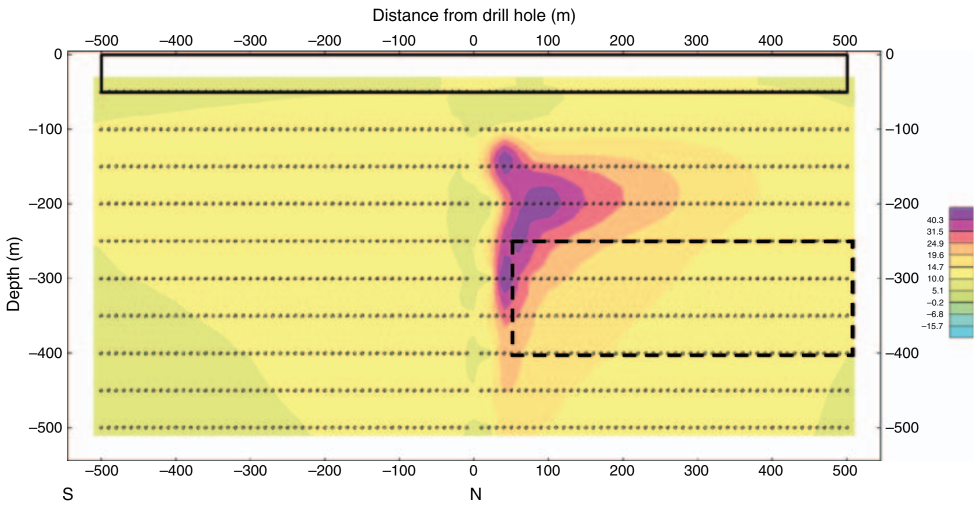

Fig. 5. *Coloured north–south pseudosection of apparent chargeability collected using the Radial Array with an indirect target located to the north-west. A reference colour bar shows apparent chargeability in milliseconds. The drill hole is located in the centre (at 0). Note the strong skewed 'pant-leg' shape; the target is located at the nadir. Black boxes on the diagram represent the position of the overburden and target; the dashed box indicates the relative location of the target where no direct intersection occurs.*

shows that it can also, to a certain degree, recognise vertical differences by using a current electrode at various depths.

Forward modelling was conducted with the Radial Array using the same systematic approach that was used for the AGDA. The optimal distance from the target for deployment of the array was determined to be similar to that of the AGDA, where less than 50 m was ideal. The optimal depth of the electrode was also tested, and in this study observed as coincident with the base of the target – in this case approximately 400 m. A pseudosection of chargeability data was constructed, as for the AGDA, which displayed a discrete anomaly approximately coincident with the location of the body (Figure 5). This means chargeability data can be directly and easily interpreted without relying on inversion.

Further modelling shows that the receiver dipole size has a strong influence on the quality of data, with a shorter dipole producing a stronger and more horizontally constrained anomaly, and a larger dipole producing a broader and weaker anomaly. Interestingly, the model showed an interim value of 50 m produced the largest amplitude anomaly. It was also tested whether more than four receiving arrays would be required on the surface, but a strong anomaly was generated even where the array did not pass directly over the source.

Summary

The results of this study show that DHIP is both feasible and useful (in the case of the AGDA and Radial Array) for a near-miss scenario (i.e. where a target has been missed by 50 m or less). Modelling also suggests that DHIP is useful in overcoming electrical effects associated with clay overburdens. The Radial Array produced the best results in terms of ease of interpretation, but a combination of both AGDA and Radial DHIP approaches ultimately decreases ambiguity. The Radial Array is also logistically harder to deploy due to the need to place the current electrodes downhole. Prior to undertaking field trials it is recommended that the results from this study should be verified and expanded using a second downhole induced polarisation modelling code. Further investigation into inversion of forward-modelling results also needs to be conducted.

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References

Asch, T., and Morrison, H. F. (1989). Mapping and monitoring electrical resistivity with surface and subsurface electrode arrays. *Geophysics* **54**, 235–244. doi:10.1190/1.1442647

Mudge, S. T. (2004). Radial resistivity/IP surveys using a downhole current electrode. *Exploration Geophysics* **35**, 188–193. doi:10.1071/EG04188

Snyder, D., and Merkel, R. (1973). Analytic models for the interpretations of electrical surveys using buried current electrodes. *Geophysics* **38**, 513–529. doi:10.1190/1.1440357

Sumner, J. S. (1976). Principles of induced polarization for geophysical exploration. Elsevier Scientific Publishing Co., Inc, Amsterdam.

Calendar of Events 2012

July			**2012**
22–27 Jul	IEEE International Geoscience and Remote Sensing Symposium: Remote Sensing for a Dynamic Earth http://www.igarss2012.org	Munich	Germany
25–31 Jul	21st EM Induction Workshop http://www.21emiw.com	Darwin	Australia
August			**2012**
5–10 Aug	34th International Geological Congress http://www.34igc.org	Brisbane	Australia
20–24 Aug	Geobaikal 2012: Electromagnetic Research Methods and Integrated Geophysical Data Interpretation http://www.eage.org	Irkutsk	Russia
September			**2012**
3–5 Sep	Near Surface Geoscience 2012: 18th European Meeting of Environmental and Engineering Geophysics http://www.eage.org	Paris	France
11–14 Sep	EABS IV – Eastern Australasian Basins Symposium http://www.EABS2012.com.au	Brisbane	Australia
17–19 Sep	Istanbul 2012: Istanbul International Geophysical Conference and Oil & Gas Exhibition http://www.igcistanbul.com	Istanbul	Turkey
19–21 Sep	KSEG International Symposium on "Geophysics for Discovery and Exploration" http://2012symp.seg.or.kr	Jeju	Republic of Korea
October			**2012**
8–10 Oct	ATCE 2012: Unconventional Wisdom: SPE Annual Technical Conference and Exhibition http://www.spe.org/atce/2012	San Antonio, Texas	USA
29–31 Oct	KazGeo 2012-05-18 http://www.eage.org	Almaty	Kazakhstan
November			**2012**
4–9 Nov	SEG International Exposition and 82nd Annual Meeting http://www.seg.org/web/annual-meeting-2012/overview	Las Vegas	USA
December			**2012**
3–7 Dec	AGU Fall Meeting 2012 http://fallmeeting.agu.org/2012	San Francisco, California	USA
March			**2013**
17–21 Mar	SAGEEP 2013 http://www.eegs.org/AnnualMeetingSAGEEP/SAGEEP2013.aspx	Denver, Colorado	USA
June			**2013**
10–13 Jun	London 2013: 75th EAGE Conference & Exhibition incorporating SPE EUROPEC2013 http://www.eage.org	London	United Kingdom

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