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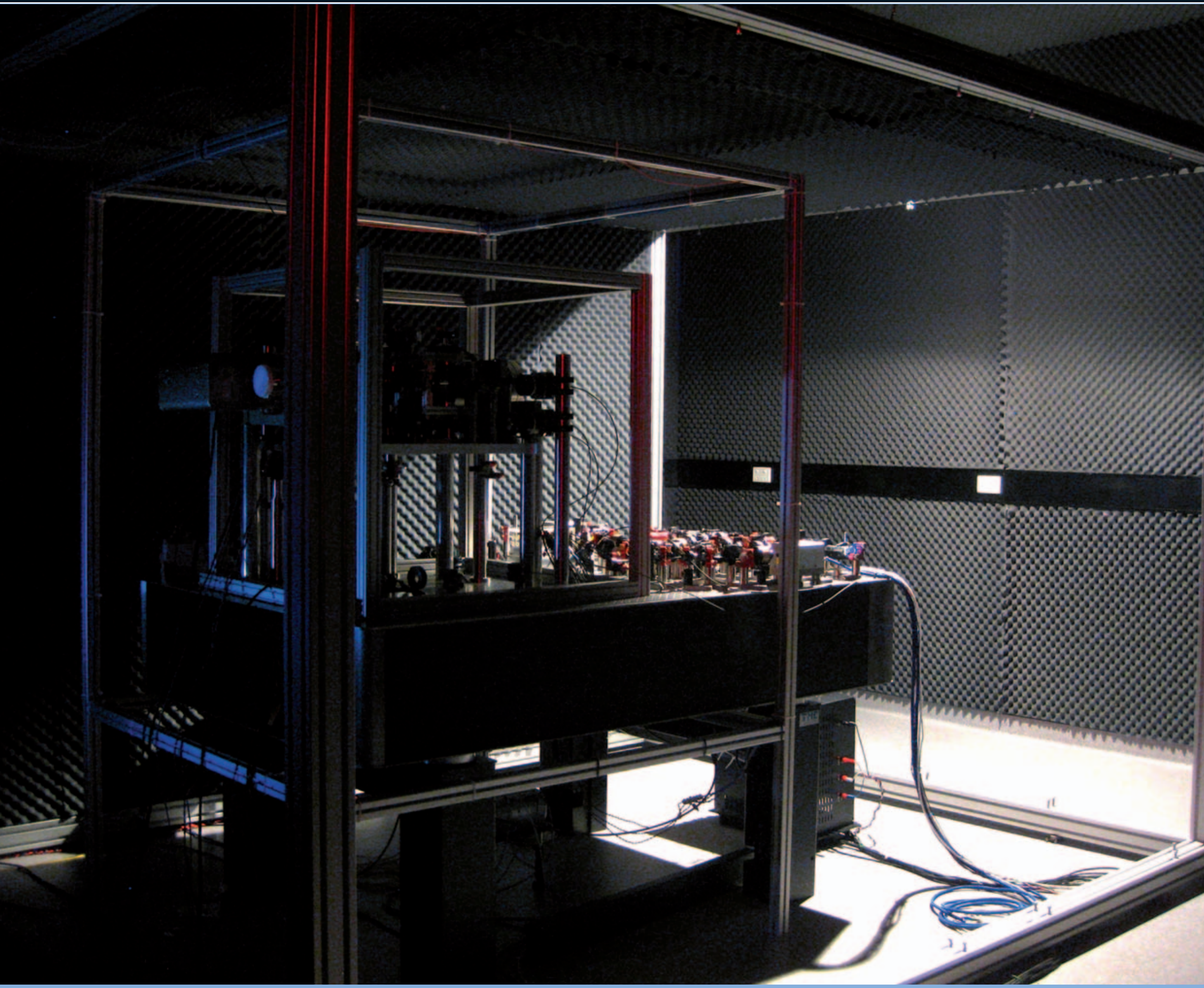
PREVIEW

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS



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FRONT COVER

High precision gravimeter laboratory (see article p. 30 ; image courtesy of Quantum Sensors and Atom Laser Group, Department of Quantum Science, Research School of Physics and Engineering, ANU).

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John A. Theodoridis

To commence, I wish to congratulate the former editor of *Preview* Ann-Marie Anderson-Mayes in receiving an award in recognition of her fine services to the ASEG (see p. 12). In true professional conduct, she did so with understated modesty.

On another matter, do make the most of the opportunity to hear SEG Distinguished Instructor (DISC) for 2013, David Johnston, presenting the practical applications of time-lapse (4D) seismic technology. The SEG DISC programme in general should not be taken for granted as it comes to us at significant expense to the SEG. By showing an active interest in the SEG DISC we can help ensure that this valuable programme is not discontinued through under patronage.

On Thursday 16 May I had the pleasure of meeting Koya Suto, our newly elected ASEG president, for the first time. I did so at our Victorian Branch meeting where he delivered his final technical talk in a tour entitled 'Multichannel analysis of surface wave (MASW): a tool for investigation of ground competence'. For those of you who have not yet had the privilege of meeting Koya I encourage you to seek out an opportunity to do so. His infinitely polite and amiable personality makes him quite approachable, but also you will enjoy his proactive leadership style. To me, Koya comes across as an extremely resourceful and capable man who can unite the practical with theoretical to produce solid outcomes. My statement is both literal and metaphorical. In casual conversation after the talk, Koya explained to me how he cobbled together, or rather handcrafted, his seismic survey equipment from mostly off-the-shelf parts obtained largely from DIY stores. This included his electromechanical drop weight seismic source and the receiver tow line made by carefully stitching each geophone to the tow ribbon – I admire his ingenuity! Yet, he applied this same philosophy as his expounded his aspirations for the ASEG in the meeting that followed. Among the charts, mission statements and strategic plans I could see immediately that Koya is seeking to identify and gather the available resources within the society, alongside consultation, to foster mechanisms that will yield viable outcomes. This quality is captured succinctly in his unusual alternating portrait within his President's Piece that features a 'magic mirror'; to paraphrase Koya – he is a geophysicist, so although you may see him in a suit at meetings and conferences his presence is backed up by his work in the field.

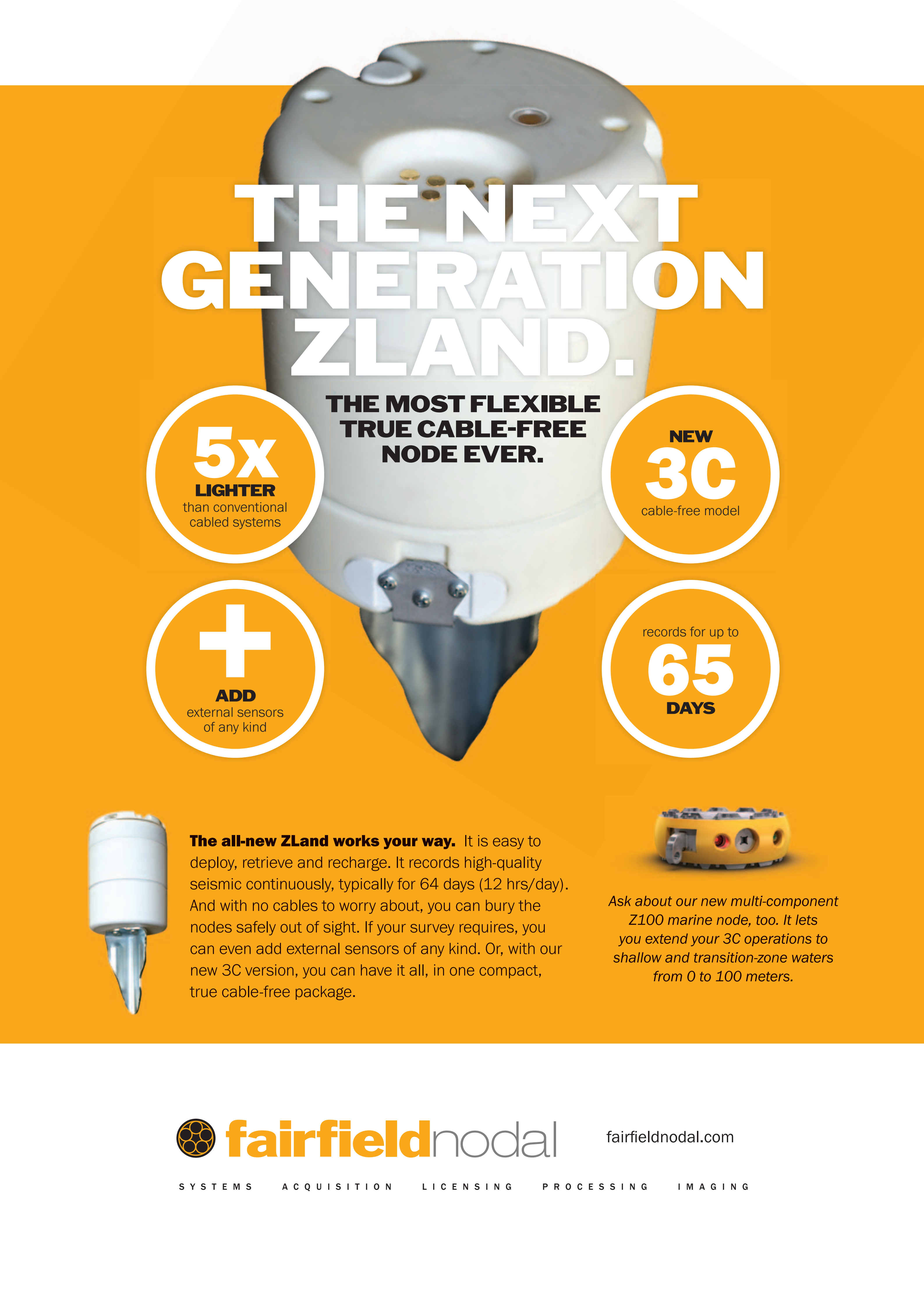
After the meeting I came home with four distinct points for reflection, which I would like to share with you my fellow ASEG members:

Education – Is the teaching of geoscience merely strategic so as to create the next generation of geophysicists; or perhaps provide an interesting training ground for students to apply skills acquired in other subjects; or even more to enhance the understanding of geoscience within the general community?

Membership – How do we perceive the ASEG and our individual roles within it? Is it merely a place where we can gather our expertise within a welcoming social environment to benefit members or something greater?

Application – My favourite point to ponder. As a game, place the resource industry aside and try to compile a long list of geophysical applications that are either currently in place or novel. Now, map out a line of research to advance each application and consider the possible outcomes whether they are practical or theoretical.

Society – Finally, what is our role as geoscientists within society? Is it acceptable to be insular and focus only on our careers or should we exercise greater stewardship? In a sense we come full circle on reconsideration of education. For education empowers people and creates an inclusive society, which in turn permits informed and fruitful debates to flourish – particularly on contentious issues such as resource exploration and management. This surely is to the benefit of all.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Bridging the gaps

By the time this article reaches your eyes, I should have met many of you at your state branch meetings in May. (I am writing this while preparing for the trip).

At the Annual General Meeting, when I was elected, I introduced myself as a 'Bridge'. I like this comparison, and I will repeat it in my first President's Piece.

I was born in Japan and lived through university age. My first thesis was at Akita University, Japan; the subject was on tidal variation of gravity. I came to Australia for the first time during my Master's study. I continued studying at Adelaide University after the Master's degree in airborne magnetics and radiometrics under Professor Boyd. It was at that time that I joined the ASEG. When I looked for employment, the minerals industry was depressed and the petroleum industry was booming. I worked for oil companies as a seismic geophysicist. One of the companies I worked for was the petroleum arm of a large mining company. There I got acquainted with many minerals geophysicists. My past study of airborne geophysics helped in communicating with them. Now I service the construction industry with seismic surveys for geotechnical engineering. I would be a bridge between the minerals, petroleum and geotechnical industries.

My contact with SEG Japan came much later. Several Japanese geophysicists came to ASEG conferences and we discussed the possibility of collaboration. The association agreement was exchanged in 2001. With the Korean SEG joining, the first joint issue of *Exploration Geophysics/Butsuri Tansa/Mulli-Tamsa* was published in 2003, which has now become an international joint journal. Through the ASEG Federal activities, particularly looking after travel arrangements of DISC and Distinguished Lecturers (DL) of the SEG and EAGE's Education Travels (EET), I made friends among the SEG and EAGE. I became a bridge between the ASEG and international societies.

In the past 20 years in the ASEG committee, I looked after membership and education committees of the ASEG. These committees required close communication with the state branches and members of the ASEG. I have been acting as a bridge between ASEG members and executives.

At the Annual General Meeting on 17 April, four new directors were elected: they are Greg Street as President-Elect, Reece Foster re-elected as Treasurer, Barry Drummond also re-elected as Hon. Secretary, and myself as President. On the following day, a new Federal Executive Committee was formed. The members are: Kim Frankcombe, immediate Past President; Mike Asten, Past President; Phil Schmidt, Vice President – Publications; Mark Tingay, Vice President – Education; Phil Heath representing State Branches; Carina Kemp, Webmaster; Katherine McKenna representing the Membership Committee; and Wendy Watkins organising Continuing Education. We welcome Katherine and Wendy, two new members of the Federal Executive Committee. With this strong team, I hope the Society will be run and progress in the next 12 months.

The treasurer reported a healthy financial position of the ASEG after successful conferences in 2012. With this backing, we can enhance membership service in many ways. To start with, the capitation to the state branches has been increased. This enables the branches to plan and carry out more ambitious technical and social programs. We encourage all members to participate in the branch activities. After all, if you do not participate in these, you are subsidising the benefit of other members, rather than receiving the membership benefit for yourself.

An initiative of the Federal Executive is the ASEG's own DISC, of which we still don't have a name. As announced in the last issue of *Preview*, there will be two one-day courses: one for petroleum and the other for minerals. While a specific topic is addressed in the lectures, the scope of these courses is to fill some gaps between academic studies and industry practices, the study of geology/geophysics and exploration application, and geologists and geophysicists. Our past presidents, Dennis Cooke and Mike Asten, have been selected as the first lecturers of these courses. These courses will bridge these gaps.

The Federal Executives is currently drafting a strategic plan for the next five years, led by Barry Drummond. The last strategic plan was made in 2001 after an intensive membership survey when Brian Spies was president. Some of the plans were accomplished and others were completely forgotten. Since then, the environment around the ASEG has changed. Our conferences and publications are running smoothly as the experience and dedication of those concerned maintain a high standard. Both are well recognised in the academic and industry arenas internationally. For the strategy, we recognise three areas to work on: (i) education; (ii) membership; and (iii) involvement in geoscience debates. These will benefit the science of geophysics and the industry as a customer of geophysics and ultimately benefit members. We will keep this discussion going in state branches for the next few months, and hope to finalise at the council meeting in Melbourne in August. We welcome input from members.

During the state visits, I had a series of meetings with state branch committees. One of the messages I wanted to deliver was that the state branches are the ASEG entity closest to the members. It is state branches that can have face-to-face contact among the members, and the member's voice is best heard through the branches. Although many overseas lecturer's tours are organised at the Federal Executive level, the state branches arrange the on-site work of preparing venues, promoting to local members and meeting travelling lecturers. Some branches have social events such as dinners, excursions and sporting meetings. These help the members and their families to see each other in a relaxed environment. These events are posted on our website and notices are sent directly to branch members by email. So it is important to keep your email addresses current with our membership database. Again, I urge members to contribute to their state branches. Federal Executives maintain close contact with the state branches and are prepared to support their activities. Together with the State Branch Representative to Federal Executives, Phil Heath, I am committed to being a bridge between Federal Executives and State Branches.

Federal Executives recently approved this year's commitment of funding of the ASEG Research Foundation for supporting seven Honours and postgraduate projects to the value of $106 500. This is funded by the donation included in the corporate membership fee and voluntary donation from members as well as ASEG's ongoing support. We thank the generous donors. This forms the vital construction material of a bridge towards the future of geophysics in Australia.

The new ASEG website has been running for about half a year and some parts are still under development. There has been an awkward connection between the membership data entered in the website and the main database, causing some delay in updating the information. This should have been fixed and improved by the time this issue of *Preview* is in your hand. The website continues to evolve and will enhance the flow of information of the ASEG. Thanks to our webmaster, Carina Kemp, for her excellent work in constructing this electronic bridge.

On the web front, there is another development in digital publication. *Exploration Geophysics* and *Preview* will be accessed from the SEG's website soon (if not already, by the time of this issue). This will expand the exposure of our publication to the wider geophysical community in the world and improve the credit rating (the impact factor) of *Exploration Geophysics*. Phil Schmidt and Mike Asten have been tirelessly negotiating with the SEG for several months. This is another bridge created.

Finally, I would like to thank my predecessor, Kim Frankcombe, for his hard work as president in the past year. My task as President-Elect in the past was to support him and learn the skill of leading the Society. He looked after this 'President's Apprentice' very well by guiding me. He has been a great bridge between ASEG's past and present. I will continue bridging the present and future.

In my work as a geophysicist for geotechnical application, I sometimes investigate the foundations of bridges. Bridges need a strong base. In the Society, this essential foundation is members. I hope to have members' support my function as a bridge.

Koya Suto
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President's Report: Brisbane, 17 April 2013

The 2012–13 year has been a busy one for the Federal Executive committee. It started with a fairly dire financial outlook with our budget forecasts having us in deficit in a conference year. The Brisbane Conference Organising Committee had warned us not to expect the usual surplus that the society has come to rely on in order to deliver services to you, its members. The society might appear to have adequate funds under investment, indeed we are sometimes accused of sitting on too large a balance. However, at current expenditure levels it would only take two consecutive Conferences to break even before we would be close to exhausting those funds and have to make a call on our shareholders...you. Such is our reliance on Conferences to sustain the society. We were therefore delighted when the Brisbane Conference committee told us that we could look forward to a typical surplus figure.

My thanks to all those in the Brisbane Conference team that made a successful technical and networking event also a successful financial event, no small feat when dealing with the most expensive conference venue in Australia. It was a great result.

Brisbane hosted two major geoscience conferences in 2013. The 22nd ASEG Conference and Exhibition and just a few months later, the 34th International Geological Congress (IGC). The IGC was organised through the Australian Geoscience Council (AGC) of which the ASEG is a member. Each of the member societies contributed to a fund to underwrite the conference and provide sufficient working capital to allow the organising committee to run for several years before sponsorship money would come in. Initial budget projections from this conference were also fairly dour with an expectation that we would get our seed capital back but not a lot more. The reality was quite different and the IGC committee delivered a spectacular surplus that was split three ways, one-third to a student travel scholarship fund to be administered by the Academy of Sciences, one-third to the seed contributors to be split in proportion to the initial seed investment and one-third to the AGC. The organising committee did an outstanding job in not only organising a successful conference but also in creating an environment where the Australian geoscience community has the means to support projects and ideas that would have previously just been distant visions.

Not to be outdone by 'the other mining state' the Western Australian geothermal community ran their second Symposium, WAGES. Again, the Federal Executive was not expecting anything more financially than a break-even event. However, the WAGES committee surprised on the positive side and delivered a small but significant surplus.

These three events combined to transform a bleak financial outlook for 2012–13 into a much rosier one. It would not have been possible without the hard work of those volunteers on the organising committees, our thanks to you all.

Investing in the future

How have we invested this change in our fortunes? The additional financial security has allowed the Federal Executive to sign off on something we have been discussing for some time, the ASEG's own travelling lecturer programme. We currently have the SEG Distinguished Instructor Short Coarse (DISC) and Distinguished Lecturers who travel the world, or at least part of it, delivering professional development courses to members. The EAGE run their own successful EAGE Education Tour (EET) on similar lines to the SEG DISC. Both groups fund the course to come to Australia and allow for it to be run in two cities. The ASEG provide additional funding to enable the courses and lectures to travel to all those branches that want it. Both of the SEG and EAGE programmes are aimed at relatively experienced audiences and the Federal Executive saw an opportunity to deliver high-end content to a more junior audience and to cross disciplines and attempt to educate geologists about the use of geophysics. The first two courses will be run this year and preparations are already underway to lock in times and venues.

The executive have also decided to support the state branches in providing scholarships to students. On the condition that they have a transparent application and selection process, approved previously by the executive, each state will be given up to $4000 to provide scholarships for university students. These can be travel scholarships to ASEG conferences or scholarships to help needy students complete their course.

Since before the time Roger Henderson was in shorts, branch capitation has been set at $10/head. That is a long time! Capitation is the money that the state branches are given to run their activities. This is clearly inadequate and the result was that branches had to come to the treasurer on a regular basis seeking funding for particular causes. This was nearly always given but the process created a disconnect between those spending the money and the money supply. Sounds a bit like our governments! To try and give the branches the power to control their own finances without having to come to the treasurer cap in hand, we have decided to increase the capitation to $40/head. Based on state expenditures over the past couple of years this should see all states living within their budgets and reduce the requirements for top ups from the treasurer. Importantly nearly half your annual dues payment is coming back to your state branch committee. Get involved in your local branch and make sure you get your money's worth!

Working smarter

As well as defining new ways to invest the society's reserves the Federal executive has reviewed the way we do business and decided some changes are needed. To that end we have started a strategic review. A discussion paper will be going out to the state branches to gain their input prior to the council meeting in Melbourne in August. This is your chance to have a say in the future direction of the society and I would encourage you to do so.

We are also undertaking a review of the contract with our secretariat, the current version of which is now over six years old and does not adequately cover what we expect of the roll.

In order to make savings that come directly off the bottom line and which could be handed back in the form of reduced membership fees the executive approved a category of membership that only receives digital copies of *Exploration Geophysics*. This is expected to considerably reduce the cost of printing our flagship journal. That saving has been passed back to you in the form of reduced fees. This measure particularly impacts on our overseas members who pay a postage surcharge along with their membership dues.

Projects completed

Although not strictly completed yet, the principle achievement of the past 12 months has been the launch of the new website. Carina is still working with the developers to add new functionality and fix bugs as they appear. The state branches will soon have access to it and be able to add content. Our membership database, which is currently sub-optimal, will be revamped to remove a lot of the manual data entry and hopefully provide a more accurate record of our membership.

We have reached agreement with the SEG to provide SEG members with online access to *Exploration Geophysics* just as they currently do with Geophysics. This opens our journal up to a huge geophysical audience and in doing so increases its visibility and citation index. The citation index of *Exploration Geophysics* has increased steadily over the past two years largely due to the efforts of our publishers CSIRO Publishing. To those working in the publish or perish business, citation index is everything and a journal with a high index attracts more high quality papers than one with a lower index.

After a few years in gestation, the long awaited book from Dave Isles and Lee Rankin on aeromagnetic data interpretation is with the publisher. It was originally intended that it be published as a book; however, technology has caught up with it and it is now being published as an e-book, our first but hopefully not last. It will be jointly published by the SEG, which will expose it to a wider audience.

Other achievements

For our main publications, *Exploration Geophysics* and *Preview* we have signed a new five-year contract with CSIRO Publishing to produce the journals. This comes after a long and complicated tender process, which saw our requirements changing as time passed because of negotiations with the SEG and the move to digital publications. There was considerable relief on both sides when the final agreement was signed.

After trialling a joint issue of *Exploration Geophysics* with the Japanese and Korean Geophysical societies we have formalised the arrangement so that future editions of the journal will be jointly produced. This provides us with a larger pool of authors and instantly increases our readership numbers. This agreement was a long time in the making and the Publications Committee is to be congratulated for their perseverance.

In July last year, having worked hard for three years to build on the work of

ASEG News

previous editors, Ann-Marie Anderson-Mayes handed on the *Preview* editor baton to John Theodoridis. John has some big shoes to fill but is already starting to put his stamp on the magazine.

Our conferences might only come around every 18 months but it takes at least two years to pull a conference together and the Melbourne organising committee is nearing the home straight on their journey. In Perth, a committee has just been formed to plan the following conference in 2015. The Melbourne Conference organisation is well underway and a draft programme and workshop outline has been released. If you have not already registered I would encourage you to do so soon and hope to see as many of you as possible there.

The ASEG has joined forces with the Chinese, Korean and Japanese Geophysical societies along with the SEG to create a pan-Pacific Near Surface Conference. Although there has been a considerable amount of discussion as to what Near Surface really means the ASEG has held the view that it relates to the fields of engineering, environmental and archaeological geo-science. On their own, none of the groups involved has sufficient membership in this category to hold a significant international event. However, when combined, we can offer a platform to showcase the very best in near surface geophysics from around the Pacific. The first event is scheduled to be held in China in July, the next in Hawaii and at this stage the third one will be held in Australia in 2017.

At the other end of the geophysical depth spectrum is the group working on deep exploration under Australia's formidable noise blanket of cover. The UNCOVER initiative sprang from the Academy of Sciences and to some extent has already been adopted by our national and state surveys. However, its work extends beyond that and will require the input of industry users to guide the process so that we can improve Australia's relatively poor recent greenfield's discovery rate, particularly in the world class deposit category. This will not be possible without geophysics but it is unlikely that doing more of what we have previously done is the answer. New tools and new ways to use those tools will have to be developed to leverage the physics so that we can better image the geology – that is what we do! There is an informal UNCOVER session as part of the Melbourne Conference and a special workshop later in the year run by the UNCOVER group. I encourage you all to get involved and make sure the organising committee understands the importance of planning for improved geophysical input to their mapping and how they might achieve that.

The ASEG has for many years supported the work of the postgraduates and researchers who will be in the box seat to develop any new technologies required by UNCOVER. It does this through the ASEG Research Foundation who each year provide recurring grants to postgraduate students to help defray logistical expenses in completing their project. Last year the executive approved a record $112 000 in grants, up from around $70 000 the previous year. This grant from the ASEG includes individual donations from our members and our corporate members. You may not know that 80% of the corporate and corporate plus membership fee goes direct to the research foundation. Our corporate members deserve a great thank you for their help and to those of you who have donated individually a special thank you.

During the year the Technical Standards Committee of the ASEG generated a new standard format for the digital transfer of electrical geophysical survey data, ASEG-ESF. This is designed to form a new standard for the transfer of all electrical survey data including those from IP, EM, CSAMT and ERI surveys in particular. It is in the process of being ratified by the state surveys as an acceptable format for data submission and is intended to capture all the information about a survey in a well defined format accessible to all. It is available for download from the ASEG website.

Concurrent with the development of a data transfer standard, a small group of contractors formed the Ground Geophysical Survey Safety Association (GGSSA) to develop a standard safe operating procedure for the high-powered transmitters used on these electrical surveys. It is intended that the standard they have developed will be certified by Standards Australia and used as the basis for operating under State Mines Acts. In a literal reading of these acts as they currently stand, the use of equipment we have previously operated without major incident in Australia is not permitted and so various ad hoc processes have been developed to allow the surveys to continue.

The ASEG is one of a global group of learned societies representing a regional group of geophysicists. We already have sharing arrangements in place with the South African, Indian, Chinese, Korean and Japanese societies as well as special arrangements with the EAGE and SEG. This year we added the Brazilian Society of Geophysicists SGBf to the list of societies we share with. This gives each society a free booth at each other's conference to promote our region and importantly for you as members it gives you access to publications from those societies at member rates. The Brazilian Society will join the others in the group above in exhibiting in Melbourne and we welcome them.

Losses

Something I had not prepared for when taking on the role of President was to be writing obituaries for members who died much too young. This year we lost Pete Elliot and Jodie Gillespie a few months apart. Our sympathy and hopes for the future go out to both families. I hope that Koya does not find himself writing similar articles and that we have a serious accident and illness free year.

Acknowledgements

In closing I would like to acknowledge those people who left the executive in the past 12 months. Cameron Hamilton left early last year to travel the world, Dave Denham handed over his position of secretary last year but stayed on the executive until the IGC in Brisbane. Dennis Cook steps down from his position of immediate past president to take up a role on the SEG executive at this AGM and Mike Asten who has been Past President for three years and has overseen the publications agreements with the SEG and between the ASEG and the KSEG and SEGJ is taking a well earned rest but offered to stay on until the Melbourne Conference to keep the executive up to date with progress there. On behalf of all our members I thank these volunteers for the time they have given, over many years, to make the society work better for us all.

Thank you for the opportunity to be your President for 12 months and I wish Koya all the best for the next 12.

Kim Frankcombe – Immediate Past President
kfrankcombe@iinet.net.au

Treasurer's Annual Report for 17 April 2013 AGM

Audited financial statements for the year ending 31 December 2012 for the Australian Society of Exploration Geophysicists are presented. The financial statements refer to the consolidated funds held by the society as a whole, including the State Branches.

The Society's funds are used to promote the science and profession of geophysics throughout Australia. In 2012 this was achieved by:

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

As of 31 December 2012, the Income Statement for the year shows a net surplus of $272 386 and a Total Equity of $1 282 299. The result is much better that the budgeted deficit of –$79 900, largely due to the additional extraordinary income from Conferences.

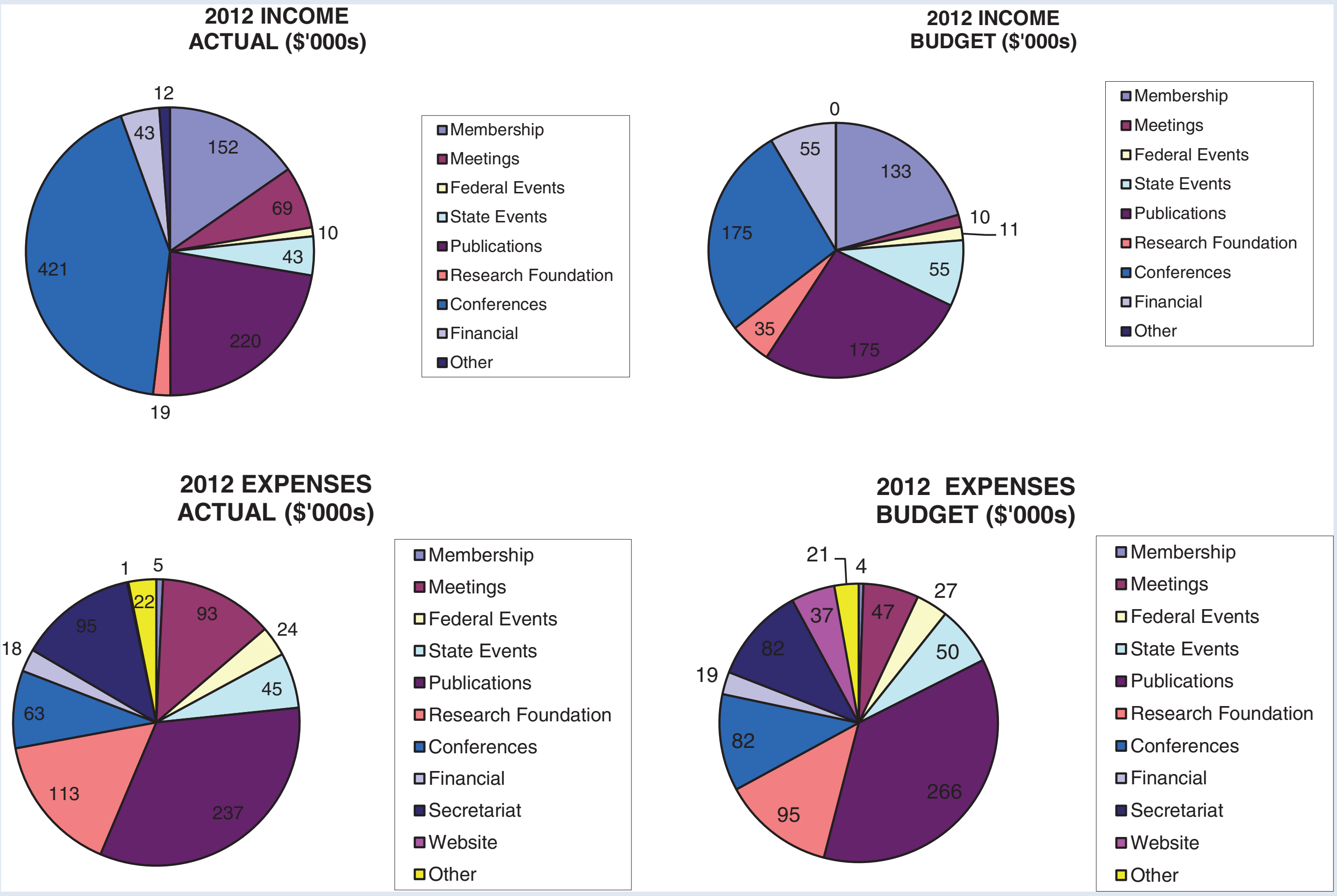
The Society's revenue source continues to be derived from:

- publications advertising: $220 000 (125% of budget item);
- membership subscriptions: $152 000 (114% of budget item);
- events and sponsorship: $134 000 (177% of budget item);
- conferences: $421 000 (241% of budget item);
- interest from accumulated investments: $43 000 (78% of budget item); and
- donations to the Research Foundation: $19 000 (55% of budget item).

The actual income for the year was 152% of the budgeted income. The most significant increase was income from Conferences (ASEG ($270 667), IGC ($103 000) and WAGES ($43 000)), and Publications advertising increased by $68 000 from the previous year. Approximately 88% of the society's funds are held in term deposits to take advantage of the best interest rates.

The major expenses for the Society include:

- publications: $237 000 (89% of budget item);
- events: $184 000 (128% of budget item);
- research Foundation support: $113 000 (119% of budget item);
- secretariat fees: $95 000 (117% of budget item);
- conferences: $63 000 (77% of budget item);
- financial: $18 000 (97% of budget item); and
- all other expenses: $6000 (16% of budget item).



Charts of income and expense items.

Expenditure was 98% of the budgeted expense. State Branch event costs were higher than budgeted, which reflects an increasing level of support for branches and members. The publication costs were less than expected and conference expenses were also down. There was also a contingency of $37 000 in the 2012 budget for website costs. However, while there was $34 000 expended on development of the website, this has been capitalised as an asset to the balance sheet.

Payments to the Research Foundation have 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 2013. The equity held will cover the uncertainty of income from future conferences.

I 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.

Reece Foster
Honorary Treasurer

ASEG Federal Executive 2013–14

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New members

The ASEG extends a warm welcome to 13 new individual members to the society approved in the Federal Executive Meeting held on 18 April 2013 (see table).

Name	Organisation	State/Country	Member grade
Beerworth Jacqueline	The University of Adelaide	SA	Student
Bell Miller	Geokinetics	USA	Active O/S
Clayfield Georgia	Monash University	VIC	Student
Davies Gareth	University of NSW	NSW	Student
Day Kiana	University of Adelaide	SA	Student
Finn Matthew	International Geoscience	WA	Active
Gomes Reynard	Monash University	VIC	Student
Grindey James	Bulletin Resources	QLD	Associate
Huang Guang	Monash University	VIC	Student
Kerr Tracey	Anglo American	UK	Active O/S
Potter Toby	International Centre for Radio Astronomy Research	WA	Student
Richards Lachlan	University of Adelaide	SA	Student
Smith Jeremy	Hiseis Pty Ltd	WA	Active

Service recognition award

President-Elect (Greg Street) presented former Editor of *Preview* magazine (Ann-Marie Anderson-Mayes) with a glass-mounted clock in recognition of her three years of service to *Preview*. Ann-Marie was thrilled to receive this gift from the ASEG. She continues to read every issue of *Preview* with much interest, especially as it is no longer her job to worry about whether there is too much or not enough content.

Australian Capital Territory

The ACT branch has had a busy past few months with lots of visiting academics and professionals to Canberra keeping our calendar very full.

We had a technical talk on 25 March by Niels Christensen, visiting from Denmark, on 'Using geophysical inversion results to extrapolate sparsely measured parameters of interest or How do we solve the problems of derived products: A theoretical, numerical and statistical analysis'. This really got us all thinking about whether we are actually trying to extrapolate more out of the data than what is really there.

We were lucky enough to get Des Fitzgerald of Intrepid Geophysics, who was visiting Geoscience Australia, to talk at a technical night on 16 April on 'Recent innovative geophysics techniques applied to defining geology under cover – a global perspective'.

David Isles, the SEG Pacific South Honorary Lecture spoke to us on 2 May on 'Aeromagnetics – a drive for discovery and developments of Earth resources'. Then a few ASEG members joined Dave for some Canberra night life.

Koya Suto, President of the ASEG Federal Executive, presented a talk to us on 14 May entitled 'Multichannel analysis of surface waves and its applications in Australia'. Koya also met with our Branch Committee to talk about the strategic plan and other initiatives of the Federal Executive.

Four of our members have received Silver Certificates in recognition of 25 years of membership: Peter Milligan, Murray Richardson, Richard Lane and Andrew Lewis.

Coming up we will have a technical meeting in June and a Joint Society Quiz night in July.

Carina Kemp

New South Wales

In March, John Peacock from CGG Veritas gave a presentation on the 'Development of a national standard for ground electrical surveys'. John outlined what was happening and where it was all at. Much discussion followed.

In April, Dave Robson from the Geological Survey of NSW gave a presentation on what was happening with the New Frontiers Program in 2013. Dave gave an overview about the New Frontiers Initiative and outlined what is planned for 2013 including the impact of the new Exploration Licence Rent. Dave also discussed the proposed new gravity survey in the greater Wagga Wagga region and a planned 250 km of reflection seismic survey in the Yathong Trough in central NSW.

Also at the April meeting we presented Scholarships to our 2013 ASEG NSW Student Scholarships recipients. The recipients are Cameron Perks and Morgan Evans from Macquarie University and Gareth Davies from UNSW. The Scholarships are to assist the students with their geophysics research topics.

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 ASEG Treasurer Roger Henderson (centre) with two of the Scholarship recipients: Morgan Evans (left) and Cameron Perks (right).

Queensland

The Federal AGM was held in Brisbane on 17 April. Congratulations to Koya Suto, our new elected President. Upcoming branch meetings in Brisbane include Kendall Lemke presenting 'Depth imaging for time processors' in May and David Isles presenting 'Aeromagnetics – a driver for discovery and development of Earth resources' in June as part of his 2013 SEG Pacific South Honorary Lecture Tour. The Brisbane branch is currently on the lookout for presenters to fill the 2013 program. We invite anybody willing to present to please contact Fiona Duncan (fiona.duncan@bg-group.com) and extend this invitation to those passing through Brisbane.

Fiona Duncan

South Australia/Northern Territory

Well isn't this year flying by quickly? On 26 March the SA branch of ASEG together with Adelaide University Geological Society (AUGS) hosted a barbeque for students to introduce them to the society. The event also offered a valuable opportunity for students to network with professional geophysicists. The large contingent of students that attended were very interested in learning more about the career options and opportunities available within geophysics once they have completed their studies.

On 26 April Dave Isles presented his talk 'Aeromagnetics – a driver for discovery and development of Earth resources', reminding everyone of the value of aeromagnetics in various applications, including mapping features in sedimentary basins. On the night successful applicants Dennis Conway and Joshua Sage were awarded student honours scholarships. Dennis' project explores regolith heterogeneity on MT surveys and Josh is assessing the risk of fault reactivation in the Collie/Perth basins. Congratulations again to Dennis and Josh and we wish you both the best in your honours year.

In May we welcomed the incoming ASEG president Koya Suto for our technical meeting to discuss 'Multichannel analysis of surface waves'. While in the state, he also met state branch committee members and presented a talk to students at the University of Adelaide.

On the 4 June we will have another technical meeting to be presented by Tim Munday about the paucity of outcrop and if regional scale AEM surveys may be beneficial.

As always please come and join us for our upcoming events. Please feel free to contact me for more information or if you have a presentation that you would be interested in giving to the SA branch.

Erin Shirley

Victoria

On Wednesday 17 April we welcomed the 2013 SEG Honorary Lecturer Dave Isles presenting 'Aeromagnetics – a

ASEG News

driver for discovery and development of Earth resources' at the Kelvin Club. Prior to the presentation the 2013 Annual General Meeting for the ASEG Victorian Branch was conducted in record time. Asbjorn Norlund Christensen and John Theodoridis were re-elected as President and Secretary, respectively, and Theo Aravanis was elected Treasurer (in absentia). By the time of publication Federal ASEG President Koya Suto will have presented 'Multichannel analysis of surface waves and its applications in Australia' on Thursday 16 May at RMIT, Melbourne City Campus.

We look forward to seeing many ASEG Victorian Branch members at the upcoming meetings of the 2013 winter season.

Asbjorn Norlund Christensen

Western Australia

Since the last edition of *Preview*, WA has been busy getting organised for hosting the ASEG Conference and Exhibition in early 2015. Chris Wijns and Andrew Long will be chairing the organising committee, which has already been established. Look out for a regular column on the conference news in upcoming editions of *Preview*.

We've also had time to hold four well-attended Tech Nights including two special events to accommodate renowned geophysicists Tariq Alkhalifah and Yaoguo Li who were travelling through Perth and kindly made time to present to WA branch members.

In early April, Tariq Alkhalifah from the King Abdullah University for Science and Technology in Thuwal, Saudi Arabia presented to over 60 attendees on 'Unravelling waveform inversion with an eye on the near surface'. Thank you to Andrew Long for organising Tariq to speak and to PGS (www.pgs.com) for sponsoring this event.

The following week Dr Peter Kovac from Fugro Airborne gave a talk on 'Mapping subsurface geological structure using TEMPEST data, McArthur Basin, Northern Territory'. Thank you to Fugro Airborne (www.fugroairborne.com) for sponsoring that night.

Yaoguo Li from the Colorado School of Mines was in Perth in late April and gave a talk on the Interpretation of magnetic data affected by remnant magnetisation: An effective approach via amplitude inversion and recent case studies. Thanks to Jamin Cristall (Vale Australia) for organising Yaoguo to speak and to Mira Geoscience (www.MiraGeoscience.com) for their sponsorship of that event.

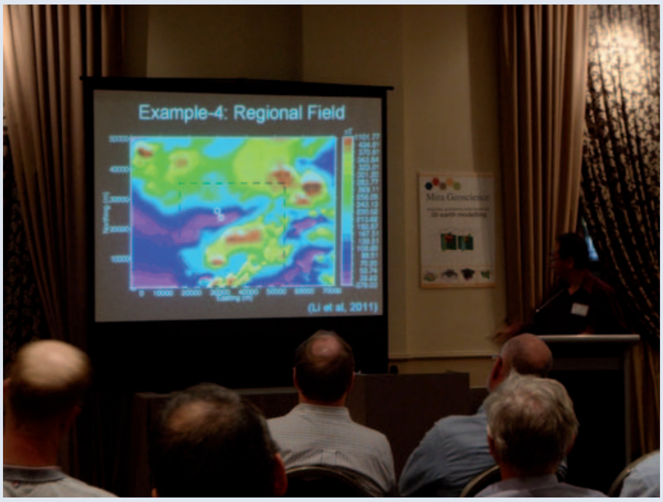
Last, our new federal President Koya Suto presented a talk on 'Multichannel analysis of surface waves (MASW): a tool for the investigation of ground competence' on 8 May. Thank you to GroundProbe for sponsoring the evening's drinks and nibbles. We also took this opportunity to present Silver Certificates to 14 WA members who celebrated 25 years of ASEG membership. Congratulations to David Abbott, Mark Anderson, Richard Brescianini, Nick Fitzgerald, Stephen Ingarfield, Paul

Jelley, Peter McPherson, Keith Mayes, Allan Perry, Greg Reudavey, Laurence Roe, Denny Rompotes, Mike Szczepaniak and Keith Woollard.

For our upcoming talks and events, check out the calendar here. Events are also posted on the ASEG website. And to make sure you never miss out, sign up to the WA mailing at http://eepurl.com/nleOD or follow the QR link below to receive notifications and online registration details for WA events and news.

Anne Tomlinson

WA: Tariq Alkhalifah, King Abdullah University for Science and Technology.



WA: Yaoguo Li, Colorado School of Mines.

Calendar of events for Western Australia

Date	Event	Presenter	Time	Venue
10 July	Tech Night: Seismic illumination on tight reservoir fractures and faults	Vincent Kong, WesternGeco, Perth	1730 – 1930	City West, West Perth
8 August	Tech Night: 4D seismics	David Johnston, ExxonMobil, Houston	1730 – 1930	Technology Park, Bentley
9 August	SEG DISC: Making a difference with 4D: Practical applications of time-lapse seismic data	David Johnston, ExxonMobil, Houston	0800 – 1700	Technology Park, Bentley
19 August	SEG DL 2013: Acquisition modeling: Expect the unexpected	Carl Regone, Houston	1730 – 1930	TBC
26 August	WA Geoscience Careers Night		1630 – 1800 (high school) 1800 – 1930 (university)	Technology Park, Bentley
11 September	Tech Night: Seismics for mineral exploration	Dr Milovan Urosevic, Curtin University, Perth	1730 – 1930	City West, West Perth
9 October	Tech Night: Rock physics / Pore elasticity	Dr Tobias Muller, CSIRO, Perth	1730 – 1930	City West, West Perth
13 November	Student Presentation and ASEG WA Awards Night		1730 – 1930	City West, West Perth
11 December	AGM and Christmas Party		1730 – 2100	TBC

News

Conference update

ASEG-PESA 2013

'THE EUREKA MOMENT'

11-14 AUGUST 2013 • MELBOURNE, AUSTRALIA

Technical program

The Technical Program committee, led by Michael Asten, has reviewed over 300 submissions and is extremely pleased to announce the preliminary program for ASEG-PESA 2013. Thank you to the reviewers who assisted with this massive task. The program runs over three full days with up to six concurrent sessions. The program is supported by more than 20 internationally recognised invited speakers who will speak on a variety of topics including:

- Unconventionals
- Seismic acquisition case histories
- Seismic processing
- CSEM
- Microseismic
- EM innovations
- Minerals exploration strategy
- Land seismic
- Seismic acquisition technologies
- Advanced seismic interpretation
- Minerals case histories
- Reservoir characterisation
- Seismic anisotropy
- Geophysics in hydrology
- Advances in data visualisation
- Minerals – potential fields – constrained geological inversion
- Seismic velocities and applications
- Environmental and engineering
- 4D monitoring

The preliminary program is now available (http://www.aseg-pesa2013.com.au/program) and covers a wide range of geophysical topics with plenty of well-known presenters and a pleasing number of new authors. In addition to the standard oral paper format, the program includes in-depth keynote sessions and a set of rapid-fire presentations intended to energise the late afternoon. Posters will also be on display, allowing you to peruse the subject matter at your convenience, with authors available during dedicated poster sessions at lunch.

Workshops

Review your own and your colleagues' training needs for 2013, whether it be seeking a new skill or extending current knowledge, and book one or more workshops at ASEG-PESA 2013. A wide variety of practical workshops are available canvassing topics such as GPR, MT and microseismic, and geohazards.

Please also make the most of this opportunity to hear SEG Distinguished Instructor for 2013, David Johnston, presenting the practical applications of time-lapse (4D) seismic technology.

Review the full list of workshops at www.aseg-pesa2013.com.au/workshops. For those already registered, additional workshops can still be selected by logging in at the website using your private access key.

Social program

In addition to the social functions included in your registration, we invite you to attend the conference dinner at the National Gallery of Victoria with the highly regarded Professor Geoffrey Blainey AC as dinner speaker. Book tickets for yourself and your guests when you register for the conference at www.aseg-pesa2013.com.au/registration.

Sponsorship and exhibition

The organising committee would like to thank our generous sponsors and exhibitors for supporting ASEG-PESA 2013. Sponsorship and exhibition opportunities are still available, so if you would like to be involved please contact Kirsty O'Brien on (02) 9265 0700 or email sponsorship@arinex.com.au.

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Bronze Sponsors

Velseis Integrated Seismic Technologies · bp · AngloGold Ashanti · Government of South Australia, Department for Manufacturing, Innovation, Trade, Resources and Energy

Update on UNCOVER – May 2013

This article follows previous updates on UNCOVER, the last of which was in Issue 162 of *Preview*.

Recapping: UNCOVER is an initiative of the Australian Academy of Sciences that sets out a new vision for exploration geoscience in Australia. UNCOVER grew out of earlier initiatives of the Academy, recognising that much of Australia's wealth is derived from mining ore bodies that were discovered decades ago. As those deposits are mined out, Australia faces a serious decline in its mineral sector, and therefore its economy, if new deposits are not found. Yet much of Australia remains underexplored because it lies under cover.

UNCOVER has identified four science themes that would help focus the effort to stimulate new exploration in areas under cover. These four science themes would be bound together by a network involving the exploration industry, service providers, researchers, and Federal and State/Territory government geoscience agencies:

- Characterising Australia's cover: new knowledge to confidently explore beneath the cover.
- Investigating Australia's lithospheric architecture: a whole-of-lithosphere architectural framework for mineral systems exploration.
- Resolving the 4D geodynamic and metallogenic evolution of Australia: understanding ore deposit origins for better prediction.
- Characterising and detecting the distal footprints of ore deposits: towards a toolkit for minerals exploration.
- Establishing a research network that encourages collaboration across sectors.

Until now, UNCOVER has been working in a development mode, with people from all sectors participating in a working group. They have now set up the process to shift UNCOVER to a more operational mode. In May, the first step was taken, with the Academy agreeing to a new management structure led by an Executive Committee. The Executive Committee will comprise representatives from the major stakeholders:

- The exploration industry
- Universities
- CSIRO
- The Geological Surveys
- The Geoscience Societies
- The Academy as the initiator of UNCOVER.

The Academy will announce the names of the people appointed to the UNCOVER Executive Committee on the UNCOVER website (http://www.science.org.au/policy/uncover.html) when appointments are complete.

The four science themes provide a skeleton of what has to be done. One of the next steps is to fill in the details of the four science themes. The strategy has two stages.

First, although the UNCOVER themes were defined by working groups of people from all sectors, a larger stakeholder group will be consulted. This will take two forms: a formal survey will be done by a consultant engaged for the purpose, who will target specific groups in all sectors, and members of the geoscience community can take part by filling in a questionnaire that will be posted soon on the Academy website.

Second, the results of the survey will be used to tease out the nature of discussions of the four science themes at the UNCOVER Conference later in the year.

The conference was originally planned for November 2013, but November is fairly booked up with conferences. The UNCOVER community considers the conference sufficiently important that it has decided to bring it forward to October rather than push it out to 2014.

Details of the Conference will be advertised widely, as well as on the UNCOVER website. In summary, it will be held at a residential venue near a capital city for easy access, and will take the form of a by-invitation workshop (people can submit a case to receive an invitation). Themes will be examined first by presentations to get attendees' thoughts focussed, and will be followed by structured and unstructured break-out and discussion sessions. Rapporteurs will be appointed to summarise the results of the conference, and the conference results will form the basis of a strategic approach to the first years of UNCOVER's operational life.

For more information, contact uncover@science.org.au or the author of this article.

Barry Drummond
Secretary of the ASEG and member of the UNCOVER Steering Committee
barrydrummond@bigpond.com

News

Update on Geophysical Survey Progress from the Geological Surveys of Western Australia, South Australia and WA Department of Water (information current at 8 May 2013)

Tables 1–3 show the continuing acquisition of the airborne magnetic, radiometric, gravity and AEM data of the Australian continent. Accompanying locality maps for Tables 1 and 2 can be found in Figures 1 and 2 respectively. All surveys are being managed by Geoscience Australia (GA).

Further information on these surveys is available from Murray Richardson at GA via email at Murray.Richardson@ga.gov.au or telephone on (02) 6249 9229.

Entries for Mole Creek and Northwest Tasmania submitted by Dr Mark Duffett, Senior Geophysicist, Mineral Resources Tasmania, Department of Infrastructure Energy and Resources (DIER).

Table 1. Airborne magnetic and radiometric surveys (also see Figures 1 and 2)

Survey name	Client	Contractor	Start flying	Line (km)	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
South Pilbara	GSWA	GPX	14 May 12	136 000	400 m 60 m N–S	42 500	100% complete @ 22 Jan 13	10 Apr 13	150 – Feb 11 p21	2 May 2013
Mt Barker (South West 4)	GSWA	GPX	24 Apr 11	120 000	200 m 50 m N–S	20 000	100% complete @ 27 Jan 13	10 Apr 13	150 – Feb 11 p22	24 April 2013
Marree	GSSA	UTS	29 Oct 12	130 473	400 m 80 m N–S	46 169	95.5% complete @ 3 May 13	TBA	160 – Oct 12 p16	TBA
Widgiemooltha – Norseman	GSWA	Thomson	15 Nov 12	131 900	100 m 50 m E–W	11 520	100% complete @ 4 Apr 13	TBA	161 – Dec 12 p16	TBA
Browse Basin	GA	TBA	TBA	184 547	800 m 80 m asl N–S	123 187	TBA	TBA	This issue	TBA
Mole Creek	MRT	Aerosystems	27 Apr 13	1900	200 m 80 m N–S	333	2 May 13	Jun 13 (expected)	This issue	TBA

TBA, to be advised.

Table 2. Gravity surveys (also see Figure 2)

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
Esperance	GSWA	TBA	TBA	TBA	2.5 km and 1 km along roads/tracks	TBA	TBA	TBA	158 – Jun 12 p23	Quotation request closes on 30 May 2013
Woomera Prohibited Area	DMITRE	TBA	TBA	34 500	1 km/2 km regular grid	TBA	TBA	TBA	163 – Apr 13 p17	Quotation request closed on 4 March 2013
North Perth – Gingin Brook	WA Dept of Water	Atlas Geophysics	9 Apr 13	1230	1.5 km regular grid	TBA	40% complete @ 4 May 13	TBA	163 – Apr 13 p17	TBA
Northwest Tasmania	MRT	Atlas Geophysics	25 Jan 13	1200	0.5 km and 1 km along roads/tracks	3862	26 Feb 13	Apr 13 (expected)	This issue	TBA

TBA, to be advised.

Table 3. AEM surveys

Survey name	Client	Contractor	Start flying	Line (km)	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Swan/Scott Coastal Plain and Albany/ Esperance	WA Dept of Water	Fugro Airborne Surveys	25 Mar 13	8607	300/600 m	TBA	40% complete @ 3 May 13	TBA	163 – Apr 13 p17	Esperance and Albany completed

TBA, to be advised.

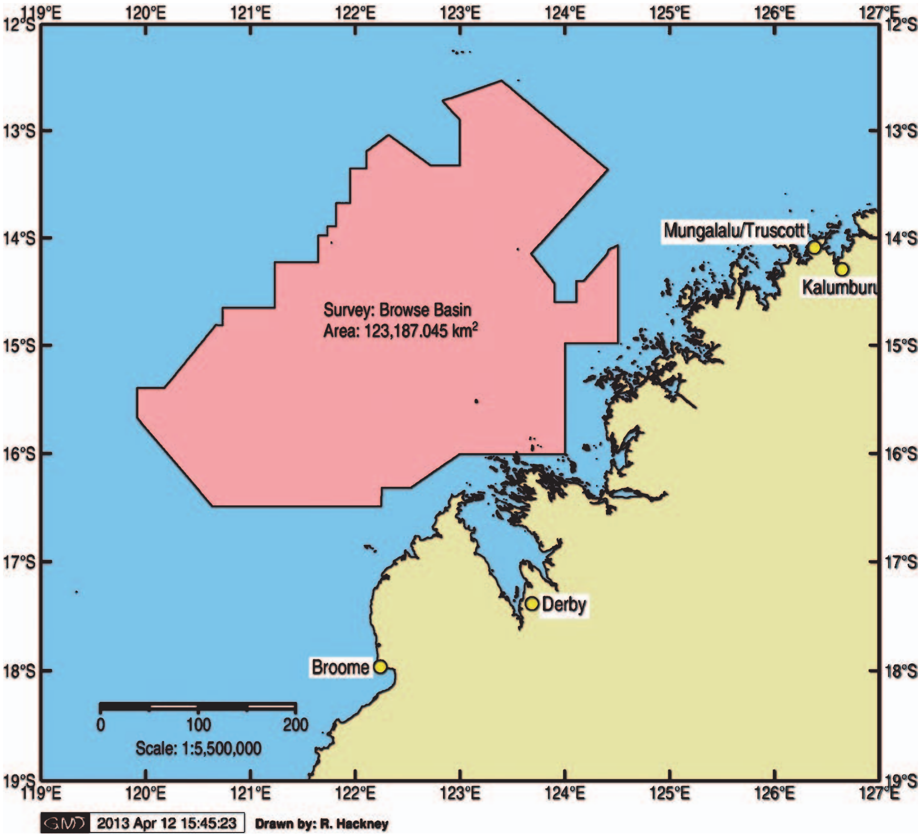

Fig. 1. *General locality diagram for the Browse Basin Survey Area (also see Table 1).*

Fig. 2. *General locality diagram for the Mole Creek magnetic and radiometric (red) and Northwest Tasmania gravity (green) survey areas (also see Tables 1 and 2 respectively).*

News from the surveys: SA – airborne EM data delivery via SARIG

Subsurface resistivity is a key component of many mineralisation models including unconformity-related uranium, palaeochannel-hosted uranium and nickel sulphides. Groundwater detection is a further application of this technique. Electromagnetic data complements more traditional magnetic and gravity data for a range of deposit styles, as well as enabling the search for other deposit styles, not detected by other techniques. This adds new dimensions to exploration targeting methodologies.

Surveys in the Cariewerloo Basin and Fowler Domain have been used to model uranium prospectivity and help define uranium and nickel targets. The Frome regional Airborne Electromagnetic (AEM) survey provided datasets that enabled the visualisation of subsurface conductivity contrasts that have driven new interpretations of palaeochannels and subsurface structures important for sandstone-hosted uranium targeting.

AEM surveys are now being delivered online, utilising SARIG (https://sarig.pir.sa.gov.au/Map) and are available via the visual search interface displayed in Figure 1. Figure 2 shows a map of currently available AEM survey data in South Australia. Data are available as ASCII ASEG-GDF2 format and ER Mapper grid files (.ers). For help with SARIG please contact DMITRE customer services on +61 8 8463 3000 or resources.customerservices@sa.gov.au.

Philip Heath, Tim Keeping, Gary Reed and Laszlo Katona
Geological Survey of South Australia

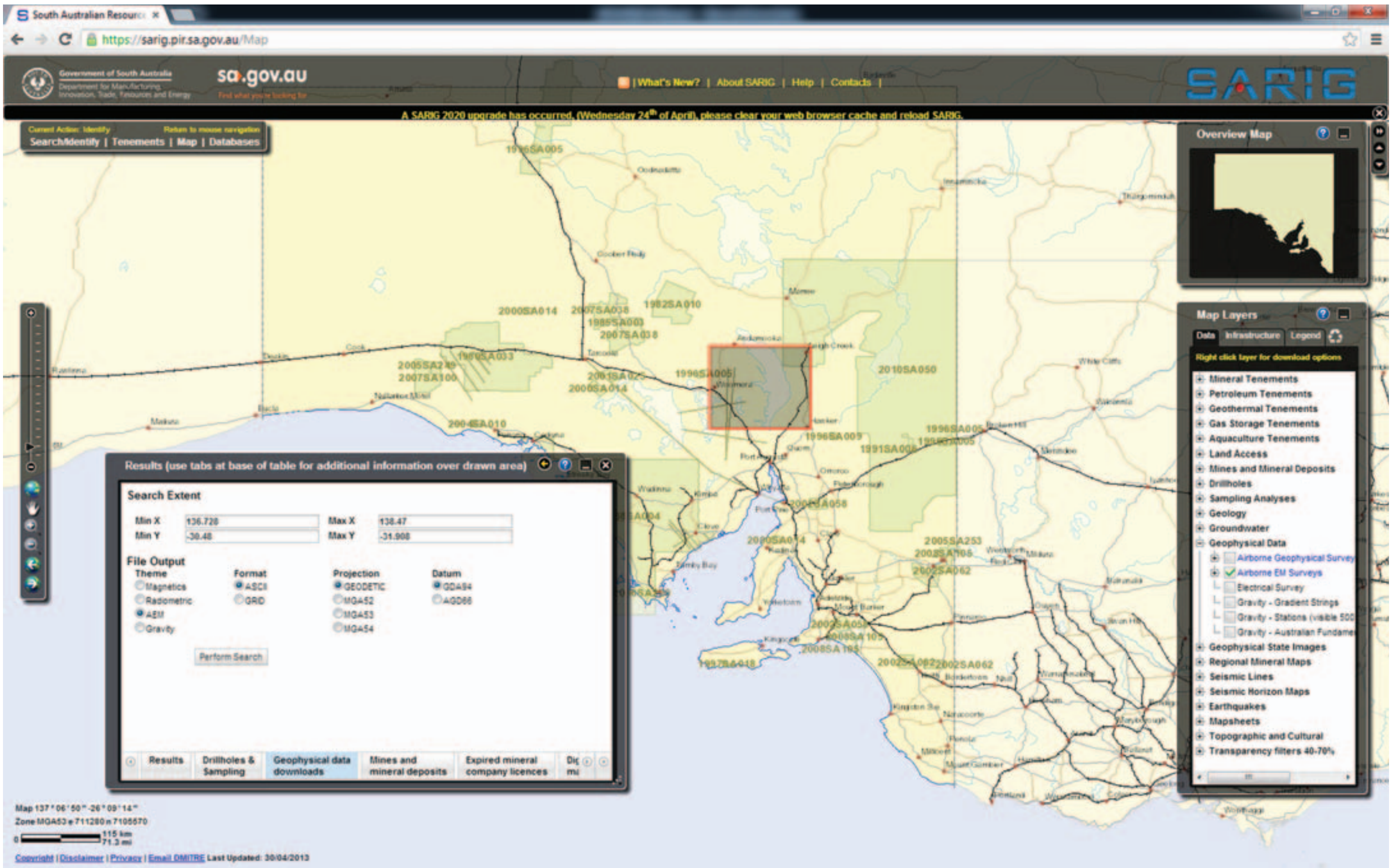

Fig. 1. *An example of a spatial search of AEM surveys in SARIG.*

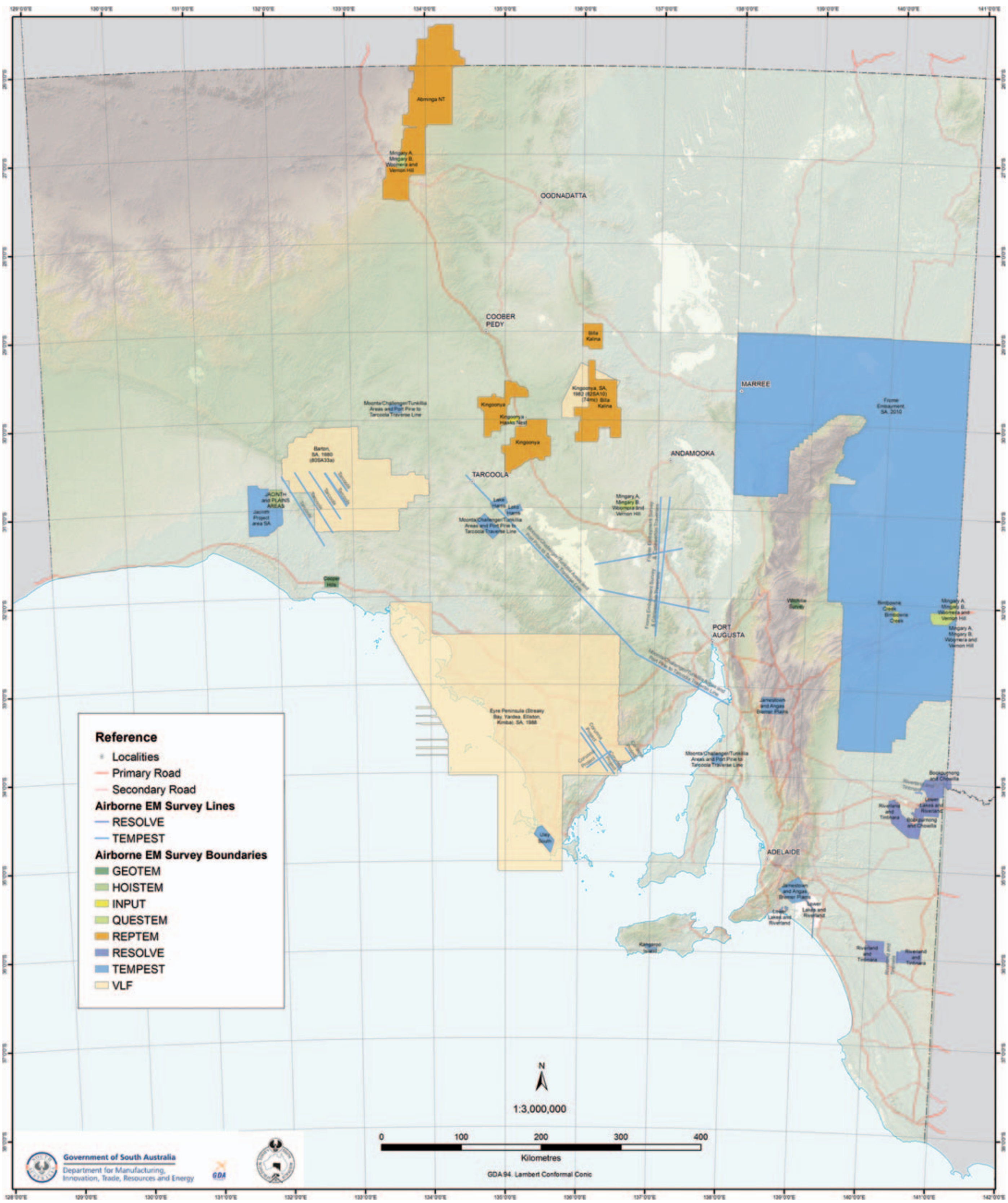

Fig. 2. *Map of Airborne EM surveys in South Australia, now being delivered via SARIG.*

Three magnetometers from Australia's National Historical Collection

Denis Shephard

Email: narioka@grapevine.com.au

This article significantly updates information first included in papers presented to the Scientific Instrument Symposium at Lisbon in 2008 and to a meeting of the Australian Society of Exploration Geophysicists at Canberra in 2009.

There are approximately 750 pieces of geophysical equipment in Australia's National Historical Collection (NHC) (Shephard 2013). The geomagnetic equipment in the collection includes variometers, aeromagnetic equipment and magnetometers.

This article will follow the working life of three Carnegie Institution of Washington (CIW) theodolite-magnetometers – CIW-7, CIW-16 and CIW-18 – from the collection. These were used in various places around the world before becoming part of the equipment of the Bureau of Mineral Resources, Geology and Geophysics (BMR). Together they illustrate the story of the four-decade 'magnetic crusade' of the Department of Terrestrial Magnetism (DTM) as well as subsequent geomagnetic research by the BMR and some of its predecessors. They were transferred to the National Museum of Australia for inclusion in the NHC in 1986, as part of a large collection of geophysical equipment covering the full range of BMR's activities.

They were associated with the work of several geomagneticians but this article will concentrate on only four: William Sligh in Central America, the Middle East and Africa; Earl Hanson in Africa; Robert Mansfield in Africa; and, Lew Richardson in Australia.

The Department of Terrestrial Magnetism

The task

The Carnegie Institution of Washington established DTM in April 1904 to investigate 'the magnetic and electric condition of the Earth and its atmosphere' on a worldwide scale (Fleming 1947, p. iii). Thus began a four-decade 'crusade' to extend the haphazard knowledge of Earth's magnetic field gathered by previous investigators. From its headquarters in Washington the DTM sent two vessels – the *Galilee* and the *Carnegie* – around the world's oceans, sponsored hundreds of land expeditions in some of the world's most remote places and established and operated two geophysical observatories at Watheroo (Western Australia) in 1919 and at Huancayo (Peru) in 1922 (Brown 2004).

Fig. 1. *Department of Terrestrial Magnetism's instrument workshop, 190?. Established in 1908 the workshop was under control of chief instrument maker Adolf Widmer. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

The land expeditions followed carefully selected routes through Africa, Asia, South America, China and Australia, establishing a co-ordinated system of stations at which the three elements of the magnetic field – declination, inclination and intensity – were determined and then regularly re-observed by subsequent expeditions. The expeditions of Sligh, Hanson and Mansfield, for example, all built on the work of previous magnetic observers. The purpose of this work was to establish a spatially and temporally co-ordinated set of data that could be used to mathematically analyse Earth's magnetic field to bring a greater understanding of it (Good 1994).

As well as conducting its own expeditions the DTM also provided training and equipment for others. Lew Richardson, for example, underwent training in DTM methods at Watheroo Magnetic Observatory before commencing his magnetic work for the Aerial, Geological and Geophysical Survey of Northern Australia.

The Equipment

The DTM's magnetic work in remote regions demanded a compact and portable instrument that could be quickly set up and read while maintaining the required level of accuracy. In the beginning the department purchased its magnetometers from established instrument makers, but from 1908-09 began constructing their own (Figure 1) (Carnegie Institution of Washington Year Book 1910).

The 'light portable type' of magnetometer they developed was enclosed in a timber case measuring 620 mm × 410 mm × 210 mm high that, when fully packed, weighed approximately 13 kg. Each individual component had its specific place in the case (Figure 2) and could quickly be assembled into an

Fig. 2. *Theodolite-magnetometer CIW-7. Image: National Museum of Australia, 2013.*

instrument that measured the three magnetic elements as well as astronomical elements. All this was achieved without any significant loss of accuracy. The instrument was improved on over time (Fleming 1911; Fleming and Widmer 1913).

The stories of CIW-7, CIW-16 and CIW-18 illustrate the usefulness of the DTM's instrument as well as the hardships and challenges faced by the magnetic observers who used them.

Theodolite-magnetometer no. 7 (CIW-7)

Theodolite-magnetometer CIW-7 (Figure 2), one of nine DTM-designed instruments assembled in the workshop of Bausch, Lomb and Saegmuller in New York, was acquired by the department in 1908 (Bauer *et al*. 1921). It was used briefly in Canada before being assigned to William Sligh who departed Washington in November 1908 on a three-year expedition that took him to Cuba, Central America, the Middle East, northwest Africa and Sierra Leone. Shortly after Sligh's return to Washington, the CIW-7 was sent to Watheroo Magnetic Observatory (Inventory Card for Magnetometer CIW-7).

William Sligh

Equipped with the CIW-7, a dip circle, pocket chronometer, watch and an observing tent, Sligh observed in Cuba, British Honduras (now Belize), Guatemala, Nicaragua, Honduras and El Salvador before returning to Washington in mid-1909, having occupied 45 stations. He had travelled by motor launch up the Belize River and by mule through the dense Guatemalan forest where progress was hampered by a lack of roads, swampy country, a scarcity of drinking water and inadequate shelter at night (Sligh 1912).

On Sligh's return to Washington, the CIW-7 underwent minor repairs to ready it for further field work. Sligh sailed from New York in December 1909 and arrived at Constantinople the following month. His equipment was the same as before but with the addition of a second watch. In the following six months he travelled a total of 22 300 miles by steamship, rail and pack animal through the Taurus Mountains and by raft down the Tigris River (Sligh 1915*a*, 1915*b*).

Fig. 3. *William Sligh at Malatia magnetic station, Anatolia, August 1910. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

Eighty-four observing stations were occupied, including Beirut, Damascus, Madain-Saleh (the farthest point south Christians were allowed to travel), Kharput, Malatia (Figure 3), Baghdad, Basra, Muscat, Bombay (where the CIW-7 was compared to the Alibag Observatory's standard instrument), Aden, Port Sudan and Suez. Sligh suffered illness, including a bout of malaria at Damascus, and was placed in quarantine on three occasions – at Tebbok, Mush and Ramadieh.

The second stage of Sligh's work began in Cairo in the second half of 1911. Between June and November he travelled 13 600 miles by steamship, rail and sloop, observing at 46 stations in North Africa, the Canary Islands and along the west coast of Africa (Sligh 1915*c*). This stage of his work brought problems with climatic conditions, particularly with the wind, and with personal security.

At Algiers the observing tent was ripped to pieces by strong wind and had to be replaced by a locally made one. Wind was also an issue at Fuerteventura Island (Canary Islands) where, shortly before completing his work, the tent, equipment and observer were blown over by a violent gust. Fortunately no damage was done. More serious, however, was the threat of attack from local gangs along the West African coast. At Melilla, for example, a guard of four gendarmes and six soldiers was posted while observations were being made. In the event the party was not molested at any stage but the threat of civil unrest was always in the back of Sligh's mind – a concern shared by other DTM observers working in remote areas (see Hanson below).

Sligh returned to Algiers in early September and, after comparing CIW-7 at the observatory, he sailed for home reaching Washington in January 1913.

The CIW-7 now remained in store for six years, after which it was transferred to Watheroo Magnetic Observatory where it was installed as a standard instrument.

Watheroo Magnetic Observatory

The Watheroo Observatory was commissioned on 1 January 1919 (Fleming 1947). At the time it comprised two buildings for magnetic work – an absolute observatory and a variometer observatory – a hut for atmospheric, electric and earth-current apparatus plus ancillary buildings (Fleming and Wallis 1920). The absolute hut measured 5 m x 10 m with three piers at each end of the observatory for mounting a magnetometer, earth inductor and galvanometer (Figure 4). The installed equipment comprised the CIW-7, an earth-inductor 2 (Figure 5) and a galvanometer 2 (Figure 6), both manufactured by Otto Toepfer and Son of Potsdam in Germany.

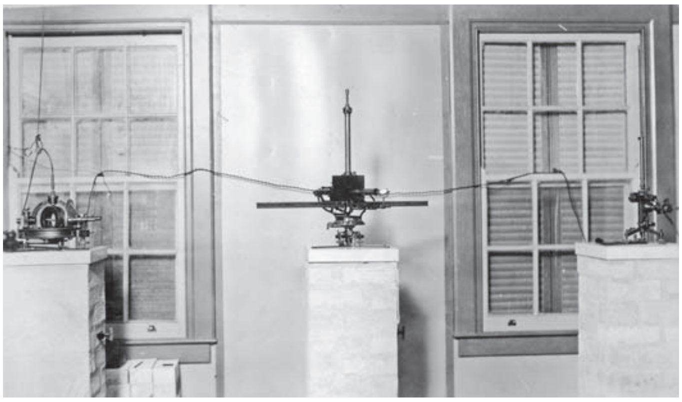

Fig. 4. *Watheroo Magnetic Observatory showing Toepfer earth-inductor no. 2, magnetometer CIW-7 and Toepfer mirror galvanometer no. 2, 25 May 1926. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

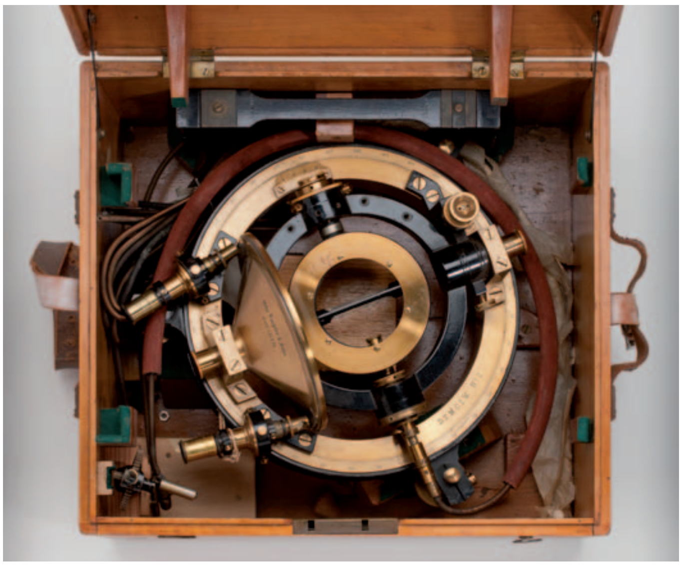

Fig. 5. *Toepfer earth-inductor no. 2. Image: National Museum of Australia, 2013.*

Fig. 6. *Toepfer mirror galvanometer no. 2. Image: National Museum of Australia, 2013.*

The fixed instruments were used to make absolute determinations of magnetic declination, inclination and intensity. At different times they were also used for comparison with field instruments, including the *Carnegie's* magnetometer in 1920 (Bauer *et al*. 1921) and the CIW-18 in 1935 (see below).

In July 1947, CIW gifted Watheroo Magnetic Observatory to the Australian Government and its operation was taken over by the BMR. It was closed in March 1959 and replaced by a new establishment at Mundaring, also close to Perth (McGregor 1979).

Unlike the CIW-7, the CIW-16 and CIW-18 remained field instruments for their whole working lives.

Theodolite-magnetometer no. 16 (CIW-16)

Theodolite-magnetometer CIW-16 (Figure 7) was assembled in the DTM workshop in May 1911 at a cost of US$650. It was used in Central America (1912 and 1940), South America (1912), Canada (1913), West Africa (1914–15 and 1922–27), South America (1919 and by Earl Hanson in 1931–33), on the Donald MacMillan Baffin Island Expedition (1921–22) (Figure 8), East Africa (by Robert Mansfield in 1934), on the Louise Boyd Arctic Expedition (1941), North America (1943) and at Huancayo Magnetic Observatory (1929–31 and 1946–48) before being written off the books in May 1949 (Inventory Card for Magnetometer CIW-16). When, how and why it came to Australia and where it was used here is still being investigated.

The Hanson and Mansfield expeditions shared experiences similar to those of Hanson but also illustrate some of the other field challenges faced by DTM's magnetic observers.

Earl Hanson

Earl Hanson departed New York in August 1931 and after some training in Cuba by J. W. Green moved to Venezuela in late

Fig. 7. *Theodolite-magnetometer CIW-16. Image: National Museum of Australia, 2013.*

September. From Caracas he travelled up the Orinoco River, crossed from its headwaters to the Rio Negro in the Amazon Basin and then, after observing at stations along the Amazon, moved to Bolivia and finally to Peru. He had travelled over 20 000 miles using a great variety of conveyances including steamers, launches, canoes, mules, horses, railroads, automobiles and trucks by the time he returned to Washington, via Ecuador and Colombia, in January 1932. Eighty-six field stations had been occupied and the CIW-16 compared with the standard instrument at Huancayo Magnetic Observatory (Hanson 1947).

Fig. 8. *Took-a-key viewing the azimuth mark with theodolite-magnetometer CIW-16 at Cape Dorset, Baffin Land, August 1922. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

Fig. 9. *Earl Hanson at Valera magnetic station, Venezuela, 31 October 1931. Note canvas observing tent. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

Hanson is unique in that he published a popular account of part of his South American expedition (Hanson 1938) in which he described the challenges and hardships of travelling and observing in the jungle regions of South America. Summarising his experiences he wrote 'I thought that a magnetic expedition would have been a lot of fun but for the need for observing the Earth's magnetism' (Hanson 1938, p. 301). More than a simple account of his geomagnetic work, however, his book commented on developmental issues in the countries he visited, thus anticipating his future career in regional development work in Latin America.

Hanson's task was to observe at monuments that had been established by previous observers as well as to establish new ones where necessary. Each provided its own difficulties. Many of the original monuments had been overgrown by vigorous jungle growth, villages had been abandoned and some had been deliberately destroyed by locals. At Guajara Mirim (Brazil), for example, the station site had been turned into a park. The president of the municipality assured Hanson that the replacement would not only be left alone, but would be considered as one of the features of the park (Hanson 1947).

Many of the sites originally proposed for new monuments proved unsuitable when examined in the field. At La Ceiba (Venezuela), for example, the proposed site was found to be a deep jungle-covered swamp. The station was eventually established at Valera (Figure 9), an overnight stopping place for buses and trucks on the main trans-Andean highway (Hanson 1947).

Illness and weather conditions also combined to hamper Hanson's work. At Caracas he suffered from a combination of a bad cold, indigestion and inflamed eyes, malarial attacks were frequent and at Porto Velho (Brazil) and Tres Unidos (Peru) his feet and legs were so infected from insect bites that he was unable to observe in the hot sun. The rugged country, heavy rain and flooded rives made travel difficult and on occasions damaged his instruments. Finally, like Sligh, he was concerned about civil unrest, including 'a bit of a revolution' in Cuba and the presence of a 200-strong gang of river pirates in Brazil (Hanson 1947, p. 27).

Following its return to Washington, the CIW-16 was in store or at Huancayo Observatory CIW-16 before being issued to Robert Mansfield for work in East Africa.

Robert Mansfield

Robert Mansfield was working at Huancayo Magnetic Observatory when commissioned to carry out work in southern and eastern Africa. He left Peru in April with equipment comprising the CIW-16, two pocket chronometers, two watches and an observation tent to begin work in Cape Town. Over the next 15 months he travelled 33 000 miles by ship, rail and motor vehicle to make observations at 60 stations in the Union of South Africa, Portuguese East Africa, Southern Rhodesia, Northern Rhodesia, Zanzibar, Tanganyika, Uganda, Kenya, Aden, Anglo-Egyptian Sudan, Egypt, Libya, Tunisia and Algeria. With his African work completed Mansfield travelled to Niemegk in Germany and Abinger in England before returning to Washington in August 1935 (Mansfield 1947). Many years later he reminisced about his experiences in an undated typescript that is now held in the DTM archives (Mansfield n.d.).

At first, Mansfield's work proceeded well but in July, at Pessene (Mozambique), disaster struck when the CIW-16 was badly damaged. He recorded the incident in his report

> *The shelter over the observing pillar, an arrangement with four large cement columns topped by canvas, collapsed for no obvious reason just as the magnetic instruments were being set up under it. The central base of the magnetometer was caught in the fall and thereby was damaged to such an extent that it could not again be used.* (Mansfield 1947, p. 50)

Fortunately he was able obtain a replacement – the CIW-18 – at Tabora Meteorological Station in Western Tanganyika (now Tanzania), after a 10-day trip by boat and rail. Thus, the rest of Mansfield's work is discussed below.

Theodolite-magnetometer no. 18 (CIW-18)

The CIW-18 (Figure 10) was assembled in DTM's workshop in 1916 and used in China (1916–17), East Africa (1930–34) and

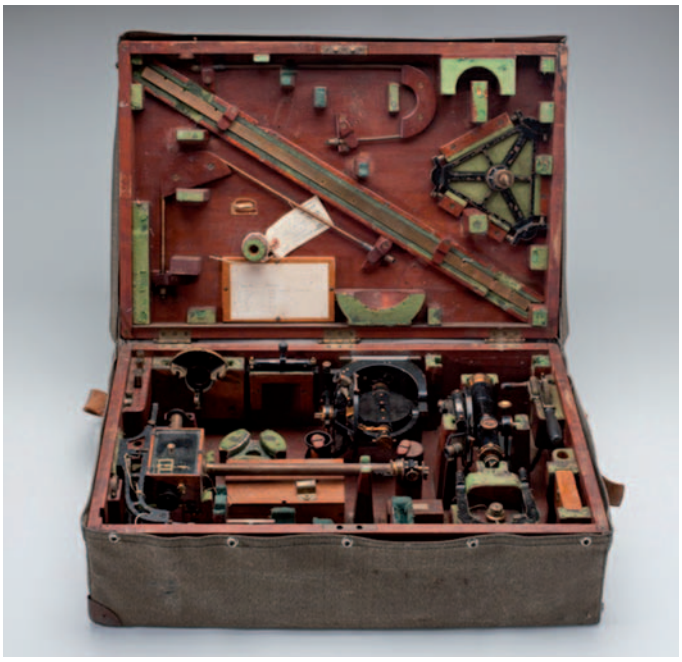

Fig. 10. *Theodolite-magnetometer CIW-18. Image: National Museum of Australia, 2013.*

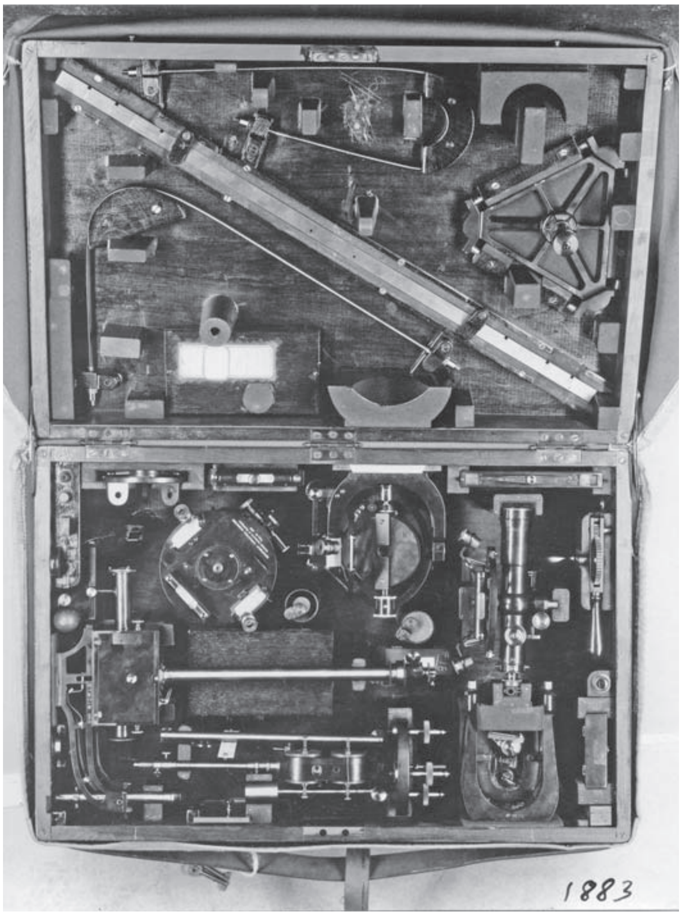

Fig. 11. *Theodolite-magnetometer CIW-18, as sent to British East African Meteorological Service at Nairobi in May 1930. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

Australia (from 1935). Its use between 1917 and 1930 is not clear at the moment (Inventory Card for Magnetometer CIW-18).

Early in May 1930, the CIW-18 was issued to the British East African Meteorological Service (Figure 11) at Nairobi (Kenya) for use in a planned extensive observing program in East Africa. Some problems were experienced with the standard observation tent – observing was never done without a sun helmet and in the old tent it was difficult to get around the instrument – so that it was replaced by a locally made one (Walter 1947). Subsequently it was loaned to 'Teddy' (later Sir Edward) Bullard who, together with his wife, made magnetic observations with the CIW-18 while carrying out a gravity survey in the Rift Valley (Bullard 1947). Subsequently it was transferred to Robert Mansfield in September 1934 to continue his African work.

Robert Mansfield (continued)

Having obtained the CIW-18 as a replacement instrument, Mansfield re-commenced his work, at Nairobi. The remainder of his expedition proved largely uneventful. On Zanzibar (Unguja) Island a contingent of police was needed to control curious onlookers while he established a new station behind the old Sultan's Palace at Chukwani (Figure 12). The African work was finished by the end of March 1935 and although he experienced some bureaucratic difficulties when landing his instruments in Egypt Mitchell was able to return to Washington by August 1935 (Mansfield 1947).

Fig. 12. *Chukwani magnetic station, Zanzibar, 2 October 1934. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

The CIW-18 story now shifts to Australia and to Lew Richardson and the Aerial, Geological and Geophysical Survey of Northern Australia.

Lew Richardson

The Aerial, Geological, and Geophysical Survey of Northern Australia (AGGSNA) was established in 1935 to 'investigate the mineral possibilities of the less known and less accessible parts' of Western Australia, the Northern Territory and Queensland (Report...30 June 1935, p. 13). It combined geological, geophysical and aerial survey work and operated from 1935 to 1940, although work in Western Australia ceased in 1938. The geophysical work included electrical, electromagnetic, gravimetric and seismic work, as well as a magnetic survey party, under leadership of Lew Richardson, which operated from 1935 until the end of 1937 (Report...31 December 1938, p. 71). Richardson was issued with the CIW-18 after receiving instruction on its use and DTM methods at Watheroo. His other equipment included two Watts vertical force variometers – 15887 (Figure 13) and 15977 – and one Watts horizontal force variometer – 16165.

Richardson's work is detailed in the six-monthly reports of the AGGSNA, while John Rayner has written about the work of the survey (Rayner 2007), particularly concentrating on the role played by Jack Rayner, chief geophysical consultant to the

Fig. 14. *Dent chronometer no. 53862. Image: National Museum of Australia, 2008.*

survey. Richardson worked mostly at Tennant Creek but also at Wiluna in Western Australia and at Herberton, Croydon and Blair Atholl in Queensland. He also re-occupied several DTM magnetic stations.

Richardson continued using the CIW-18 after the end of AGGSNA, including investigations for the Royal Australian Air Force and Royal Australian Navy at Sydney (1943), Brisbane (1944), Fremantle (1944) and Darwin (1944). In 1944 he left Canberra on a 4½-month field trip that took him overland to Perth and by plane to the north-west coast. His equipment included the CIW-18, Watts vertical and horizontal variometers and a chronometer. A total of 33 magnetic stations were occupied with new ones being marked with a concrete block 300 mm long with a diameter of 115 mm, sunk flush with the surface of the ground. At each station, variometer observations were made at surrounding points to investigate the uniformity or otherwise of the magnetic field. The CIW-18 was compared with the standard instrument – the CIW-7 – at Watheroo before the party returned to Canberra, observing at stations on the way (Richardson 1947).

Fig. 13. *Watts variometer no. 15887. Image: National Museum of Australia, 2007.*

Fig. 15. *Brockbank & Atkins marine chronometer no. 1437. Image: National Museum of Australia, 2008.*

Fig. 16. *Canvas cover to CIW-18. Stickers include 'QANTAS/AIR/CARGO/PORT MORESBY', indicating that it was used in Papua New Guinea toward the end of its working life. Image: National Museum of Australia, 2013.*

Richardson experienced problems with his Roskell chronometer – on loan from the University of Adelaide – which was replaced by the DTM's Dent No. 53862 (Figure 14) from Watheroo. This chronometer had previously been on the *Galilee* (1906–08) and the *Carnegie* (1909–21), after which it was transferred to Watheroo in May 1925 (Inventory Card for Dent Chronometer 53862). The Dent was used from September to November on the return trip from Perth to Canberra.

The CIW-18 was subsequently used by Noel Chamberlain on the Cocos-Keeling Islands together with Watts vertical force variometer 15887 and Brockbank and Atkins chronometer 1437 (Figure 15) in 1946 (Chamberlain 1960), on Heard and Macquarie islands and on Iles de Kerguelen, again with Brockbank and Atkins chronometer 1437 in 1948 and 1950 (Jacka 1953) and in Papua New Guinea (Figure 16).

Conclusion

These three DTM magnetometers have been joined in Australia's National Historical Collection by other instruments they were associated with during their working lives – Dent chronometer 53862, Brockbank and Atkins chronometer 1437, Watts variometers 15887 and 16165 plus Toepfer earth inductor and galvanometer 2. Both individually and collectively, these instruments provide a significant representation of Australia's and the world's geoscientific heritage.

Acknowledgements

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References

Bauer, L. A., Fleming, J. A., Fisk, H. W., and Peters, W. J. 1921, Land Magnetic Observations 1914–1920, Carnegie Institution of Washington, Washington.

Brown, L. 2004, Centennial History of the Carnegie Institution of Washington. Volume II. The Department of Terrestrial Magnetism, Cambridge University Press, Cambridge (UK).

Bullard, E. C. 1947, 'On Magnetic Work in Africa, November 1933 to February 1934', in W. F. Wallis and J, W Green, Land and Ocean Magnetic Observations, 1927–1944, Carnegie Institution of Washington, Washington, pp. 20-21.

Carnegie Institution of Washington Year Book, 1910.

Chamberlain, N. G. 1960, Cocos Island Magnetic Survey, 1946, Bureau of Mineral Resources, Geology and Geophysics Records 1960 Number 124, Bureau of Mineral Resources, Geology and Geophysics Records, Canberra.

Fleming, J. A. 1911, Two new types of magnetometers made by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. *Terrestrial Magnetism and Atmospheric Electricity* **16**(1), 1–12. doi:10.1029/TE016i001p00001

Fleming, J. A. 1947, 'Preface' to J. A. Fleming, H. F. Johnston, A. G. McNish, S. E. Forbush, A. G. McNish, and W. E. Scott, W. E., Magnetic Results from Watheroo Observatory, Western Australia, 1919–1935. Researches of the Department of Terrestrial Magnetism Volume VII-A, Carnegie Institution of Washington, Washington, pp. iii-iv.

Fleming, J. A., and Wallis, W. F. 1920, The construction and equipment of Watheroo Magnetic Observatory in Western Australia. *Terrestrial Magnetism and Atmospheric Electricity* **25**(1), 1–6. doi:10.1029/TE025i001p00001

Fleming, J. A., and Widmer, J. A. 1913, Description of the CIW Combined Magnetometer and Earth-Inductor. *Terrestrial Magnetism and Atmospheric Electricity* **18**(3), 105–110. doi:10.1029/TE018i003p00105

Good, G. A. 1994, 'Visions of Global Physics. The Carnegie Institution and the First World Magnetic Survey', in Gregory Good (ed), The Earth, the Heaven and the Carnegie Institution of Washington, Carnegie Institution of Washington, Washington, pp. 29-36.

Hanson, E. P. 1938, Journey to Manaus, Reynal & Hitchcock, New York.

Hanson, E. 1947, 'On Magnetic Work in West Indies and South America, August 1931 to January 1933', in W. F. Wallis and J, W Green, Land and Ocean Magnetic Observations, 1927–1944, Carnegie Institution of Washington, Washington, pp. 38-44.

Inventory Card for Dent Chronometer 53862, in Instrument and Equipment Records Series Three, SubSeries 1: General Technical Documentation and Correspondence, 1892–1970. Carnegie Institution of Washington, Department of Terrestrial Magnetism Archives, Washington.

Inventory Card for Magnetometer CIW-16, in Instrument and Equipment Records Series Three, SubSeries 1: General Technical Documentation and Correspondence, 1892–1970. Carnegie Institution of Washington, Department of Terrestrial Magnetism Archives, Washington.

Inventory Card for Magnetometer CIW-18, in Instrument and Equipment Records Series Three, SubSeries 1: General Technical Documentation and Correspondence, 1892–1970. Carnegie Institution of Washington, Department of Terrestrial Magnetism Archives, Washington.

Inventory Card for Magnetometer CIW-7, in Instrument and Equipment Records Series Three, SubSeries 1: General Technical Documentation and Correspondence, 1892–1970. Carnegie Institution of Washington, Department of Terrestrial Magnetism Archives, Washington.

Jacka, F., 1953, 1953 Magnetic Observations at Heard, Kerguelen and Macquarie Islands, 1947–51, Bureau of Mineral Resources, Geology and Geophysics Records, Canberra.

Mansfield, R. H. 1947, 'On Magnetic Work in Africa, May 1934 to June 1936', in W. F. Wallis and J, W Green, Land and Ocean Magnetic Observations, 1927-1944, Carnegie Institution of Washington, Washington, pp. 48–52.

Mansfield, R. H., n.d., 'Notes', in Robert Hubbard Mansfield Papers, 1932-1988, Department of Terrestrial Magnetism Archives, Washington DC.

McGregor, P. 1979, Australian Magnetic Observatories. *BMR Journal of Australian Geology and Geophysics* **4**, 361–371.

Rayner, J., 2007, 'Jack Rayner and AGGSNA', Preview No 128, pp. 34-9.

Report of the Committee Appointed to Direct and Control the Aerial, Geological and Geophysical Survey of Northern Australia, for the Period Ended 30 June 1935, Commonwealth of Australia, Canberra.

Report of the Committee Appointed to Direct and Control the Aerial, Geological and Geophysical Survey of Northern Australia, for the Period Ended 31 December 1938, Commonwealth of Australia, Canberra.

Richardson, L. A. 1947, 'On Magnetic Work in Australia, April 1936 to December 1944', W. F. Wallis and J, W Green, Land and Ocean Magnetic Observations, 1927–1944, Carnegie Institution of Washington, Washington, pp. 61–66.

Shephard, D., April 2013, 'Geophysical Instruments in the National Historical Collection', Preview No 163, pp. 21–27.

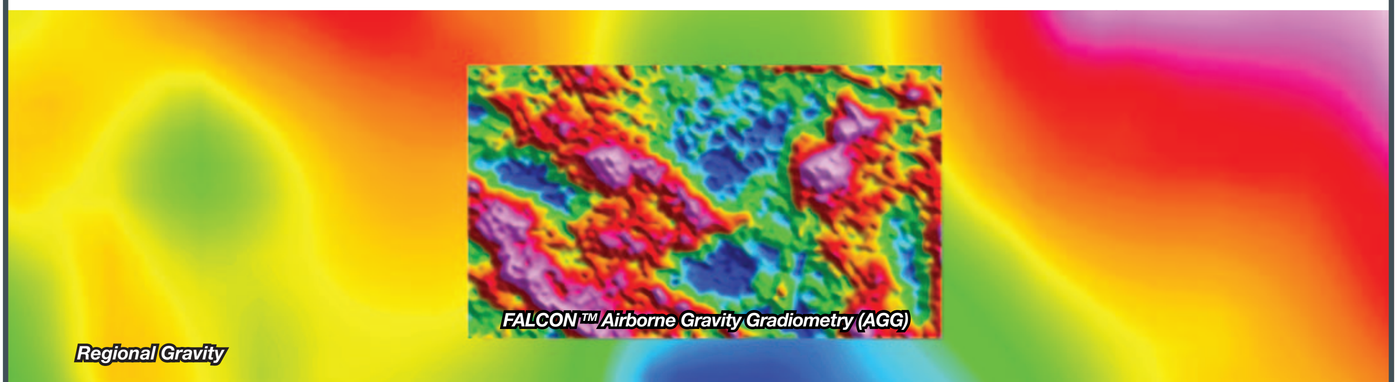
Sligh, W. H. 1912, 'On Magnetic Work in Cuba and Central America, November 1908 to July 1909', in L. A. Bauer, Land Magnetic Observations 1905–1910. *Carnegie Institution of Washington, Washington D.* **C**, 115–116.

Sligh, W. H. 1915*a*, 'On Magnetic Work in Asia Minor, India, Egypt and Sudan, January 1910 to June 1911', in L. A. Bauer and J. A. Fleming, Land Magnetic Observations 1911-1913 and Reports on Special Researches. *Carnegie Institution of Washington, Washington D.* **C**, 119–121.

Sligh, W. H. 1915*b*, 'On Magnetic Work in the Balkan States, Turkey and Italy, June to November 1911', in L. A. Bauer and J. A. Fleming, Land Magnetic Observations 1911-1913 and Reports on Special Researches. *Carnegie Institution of Washington, Washington D.* **C**, 122.

Sligh, W. H. 1915*c*, 'On Magnetic Work in Northwestern Africa, Tunis to Sierra Leone, November 1911 to December 1912', in L. A. Bauer and J. A. Fleming, Land Magnetic Observations 1911-1913 and Reports on Special Researches. *Carnegie Institution of Washington, Washington D.* **C**, 122–125.

Walter, A. 1947, 'On Magnetic Work in Africa', October 1930 to August 1934', in W. F. Wallis and J, W Green, Land and Ocean Magnetic Observations, 1927–1944, Carnegie Institution of Washington, Washington, p. 71.



From apples to atoms: measuring gravity with ultra cold atomic test masses

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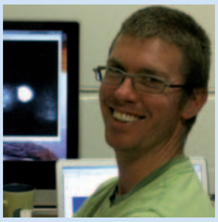

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Over 250 years ago Sir Isaac Newton, inspired by an apple falling from a tree in his orchard (Stuckeley 1752), made the mental leap to conjecture that the same force that caused this apple to fall also held the Moon to the Earth. This stimulated him to develop his Law of Gravitation, and led to the principle that all objects fall with the same acceleration irrespective of their mass, as observed by Galileo Galilei. Over 250 years ago, these scientists understood gravity as well as many people do today. In reality, we still measure gravity by dropping a proverbial apple – a falling test mass whose trajectory we measure through space–time. However, developments over the past two centuries have led to a vast improvement in our measurement precision. With the advent of the optical laser and atom interferometers over the past 50 years, we have far superior rulers, and far superior clocks with which to make such a measurement.

Mankind's most precise instruments are those that measure space and time. At the heart of these measurement devices is the phenomenon of wave interference. For example, the most precise rulers to date are optical interferometers, built for the detection of gravitational waves using very long baseline interferometers such as the Laser Interferometer Gravitational Wave Observatory (LIGO). This device measures distance with a sensitivity up to 1 part in 10^{24} (The LIGO Scientific Collaboration and The Virgo Collaboration 2012). On the other hand, the most precise keeper of time is an atomic clock. With its ceaseless ringing, a caesium atom is an oscillator that defines the International System of Units (SI) second at the level of 1 part in 10^{16} (Heavner *et al*. 2005). Precise measurement of the absorption of radiation at 9 192 631 770 Hz by caesium again relies on interference, in this case the interference of matter-waves in an *atom interferometer*.

More recently, atom interferometers have been used to measure inertial forces, such as the acceleration due to gravity. Indeed, state-of-the-art absolute gravimeters now include those that use free falling atomic ensembles (Altin *et al*. 2013, Peters *et al*. 2001). The measurement of gravity and its gradients has wide spread applications in the Earth sciences and the geophysics community. Such measurements give valuable information about density structure and changes to the geoid due to tectonic plate movement, magma flows, volcanic activity, and tidal forces. One notable recent example of gravity measurement is the data taken from the GRACE (Gravity Recovery and Climate Experiment) satellite mission (Leblanc *et al*. 2009), which has allowed monitoring of groundwater variation in the Murray-Darling tidal basin. Such measurements have a direct impact on Australian government policy.

In geophysical exploration, gravity and its gradients are a key metric for performing broad surveys of potential resource sites. For example, gravity gradients have become commercial ventures for Fugro, using its Falcon device, and Bell Aerospace with the Lockheed-Martin Full Tensor Gravity Gradiometer (FTG). These devices operate on mature, mechanical technology dating as far back as the 1970s. The University of Western Australia, in collaboration with Rio Tinto, has also been developing a competing aircraft-based gradient system (Anstie *et al*. 2010). More recently, time-resolved gravity data have been used to monitor oil and gas reservoirs, including the movement of fluid fronts (Zumberge *et al*. 2008).

Atomic gravimeters

As we move into the 21st century, atomic devices are not only becoming viable technology for the next generation devices, they also offer generous potential increases in precision. With increased precision, comes increased vision into the Earth's surface. In part, this is the result of developments in technology, which has seen our ability to control the motion of atoms using lasers reach exquisite levels. Combined with their universal properties (all atoms of a given element are equivalent), and their non-mechanical nature, atoms offer potentially fewer systematics, and more robust, reproducible, and configurable systems.

In an atomic based gravimeter, atoms are allowed to fall freely in vacuum, and their position is tracked precisely with an optical laser beam, while an atomic clock is used to time their motion. The laser, aligned vertically, effectively forms a ruler, encoding the number of wavelengths the atoms have fallen through onto the quantum state of the atoms. Interference of the atomic matter waves then allows precise counting of the number of traversed wavelengths, just as interference in an optical interferometer allows precise measurement of, for example, a

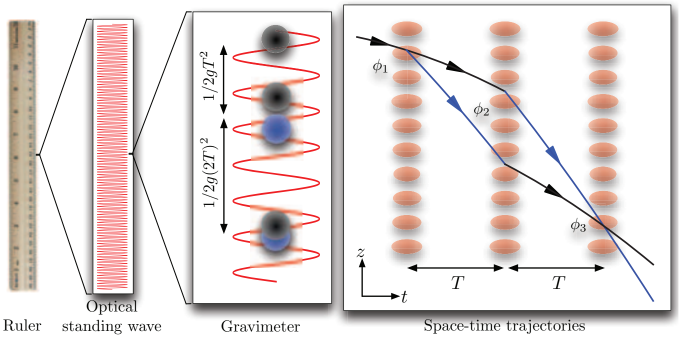

Fig. 1. *Basic operation of an atomic gravimeter. An atomic cloud falls freely under gravity through an optical standing wave, which forms an 'optical ruler' with a precision proportional to its wavelength. Three pulses of the standing wave are applied, separated equally in time and with appropriate durations to beam split, reflect, and recombine the atomic wave packets as shown in the space-time diagram on the right. The phase of the laser at each pulse is written onto the atomic state, encoding distance and time information onto the atomic state.*

mirror displacement. We extract this information by detecting and counting the number of atoms in each of two quantum states – equivalent to measuring an interference pattern in an optical interferometer. This idea is illustrated in Figure 1.

A gravimeter at the Australian National University

At the Australian National University, we have developed a state-of-the-art gravimeter, based on ultra-cold atoms and atom interferometry (Altin *et al*. 2013). A photograph of our laboratory and the device can be seen in Figure 2. Rubidium-87 atoms are laser cooled in a glass vacuum cell, and are dropped over a distance of ~20 cm. The cell can be seen in Figure 3, as well as an example of an example of a laser cooled atomic cloud. Laser cooling is important not only to localise the cloud, but to reduce its expansion during the drop due to thermal motion. This is equivalent to using collimated light in an optical interferometer. During the drop, the vertical reference laser – our ruler – is pulsed on in order to measure the position of the cloud. We use three pulses separated equally by a time T to build the atomic equivalent of a Mach-Zehnder interferometer.

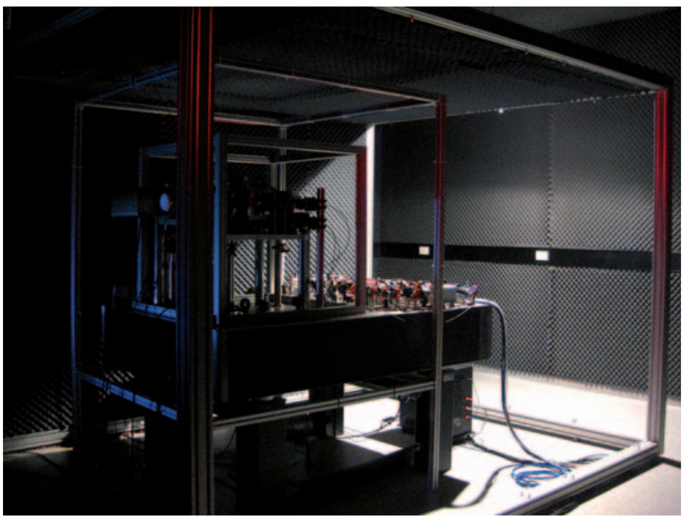

Fig. 2. *A photograph of our laboratory and the high precision atomic gravimeter.*

Typically, T is on the order of 100 ms. The resulting signal from the atom interferometer (or more precisely, the interferometer phase shift) is given by $\frac{4n\pi}{\lambda} gT^2$, where g is the acceleration due to gravity, λ is the wavelength of the vertical laser beam (~780 nm in our case), and n is an integer, which we choose experimentally, and determines how strongly the laser interacts with the atoms at each pulse. The colder the atoms, the more readily n can be increased (Debs 2012, Szigeti *et al*. 2012). For typical parameters, the signal is on the order of 10^7 radians, whereas noise in a quiet environment is typically on the order of 10^{-2} radians.

We have achieved state-of-the-art sensitivity to gravity of up to 2.7×10^{-8} ms^{-2} (equivalent to 2.7 µGal). To confirm operation and stability of the gravimeter, Figure 4 shows data monitoring the deviation of gravitational acceleration from its mean over a 36 hour period during 19–21 May 2012. Data points show a clear signature of the solid-Earth tide, with the solid line a tidal model calculated using the Tsoft software package of Van Camp and Vauterin (2005). No modification of the raw data logged from the gravimeter is performed in comparing the data to the model.

Measuring gravitational gradients

One of the fundamental principles of Einstein's theory of relativity is that it is not possible to distinguish between acceleration and a gravitational field. Thus, any vibrations of the reference laser used to measure the atomic trajectories, introduces parasitic noise into the gravitational signal. Every effort has therefore been taken to reduce environmental noise in out laboratory. In particular, no electronics are kept near the device, and the room has been acoustically damped (see Figure 2). Furthermore, the device sits on a vibration isolation system. This is indeed required of any absolute gravimeter, in order to reach state-of-the-art precision. Such a device is potentially suited to a ground station, where long-term data is required, and it can be setup in a purpose-engineered environment.

An alternative for noisy environments, such as a mobile device mounted in a vehicle or aircraft, is the measurements of gravity gradients. By using two spatially separated gravimeters, referenced to a common laser, vibrations become common to both sensors and can be subtracted, leaving only the gradient signal – the difference in gravity between the two gravimeters. Although devices such as Falcon and the Lockheed-Martin FTG system operate as excellent gradiometers, these devices are mechanical and specifically built for only this purpose. The ability to exquisitely control atoms using light allows us to split the atomic ensemble into two spatially separated ensembles, before releasing them into free fall. We may then perform the same measurement of their trajectories, and subtract the two signals giving the gravitational gradient. This whole process requires no hardware modification, only a minor variation to the control software of the system. In Figure 5(a), we show interference fringes from such a configuration. It is reasonably clear that the fringes are correlated (one is the negative of the other), and a correlation plot in (b) confirms this. Each data point in (b) is the signal of one sensor plotted against the other sensor for a given measurement. The correlation is evident as they both lie on a 45° line. Residual spread in the data is the result of atom-detection noise. Laboratory-based gravity gradiometers have already demonstrated sensitivities on the order of 10^{-9} s^{-2} (equivalent to 1 Eö) (McGuirk *et al*. 2002).

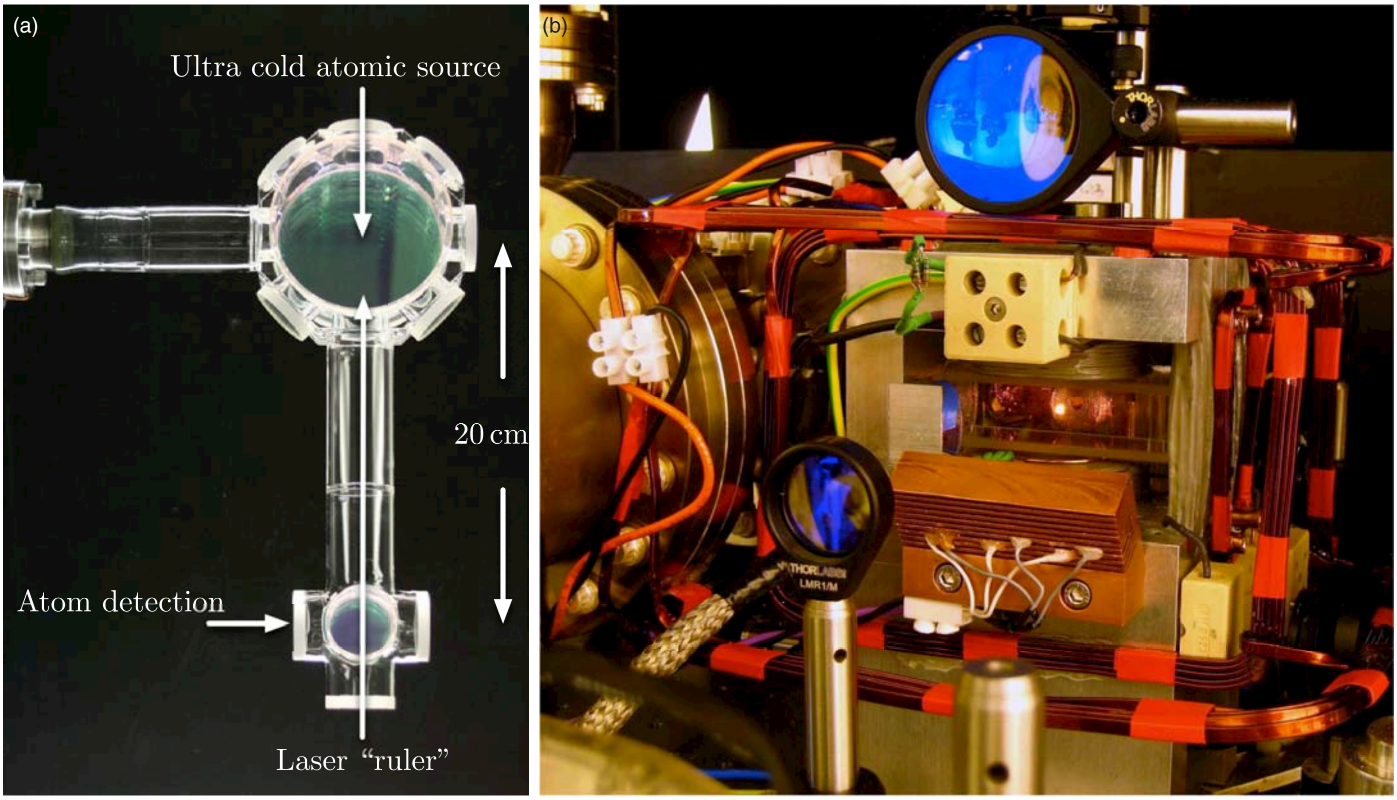

Fig. 3. *(a) Photograph of the glass vacuum cell in which atoms are dropped to measure gravity. (b) An example of a laser cooled cloud in one of our other experiments. The glowing ball in the centre of the glass cell can be seen as it scatters photons while being laser cooled.*

The future and miniaturisation

One key question for our team at ANU is whether such a device could ever be field deployable? The answer is a confident 'yes', provided there is a reasonable effort and investment in engineering. There is already work internationally, which has demonstrated the ability to miniaturise and cut power requirements of such atomic systems. For example, in Germany, the QUANTUS project has managed to reduce a system of similar complexity to that of Figure 1, to a volume on the order of 1 m^3 (Müntinga *et al*. 2013). The purpose of the project is to perform experiments under micro-gravity in a 110 m drop tower in Bremen. The entire device, including vacuum system, laser systems, electronics, and battery power, is placed inside a drop capsule. This is then loaded into the tower and dropped, experiencing 4.5 s of free-fall during which experiments are performed. The entire unit is not only compact, but robust enough to survive the 'catch' stage where it experiences 50*g* of deceleration, in order to be reloaded for the next experimental run. The long-term goal of such research aims to put these devices in satellite orbit, in order to make space-based measurement of, for example, gravity, as well as other tests of fundamental physics. There is also work in the USA, which has seen relatively high bandwidth (up to 330 Hz), high precision atomic inertial sensors reduced in size to approximately 0.2 m^3, operating under the same principles discussed above (McGuinness *et al*. 2012).

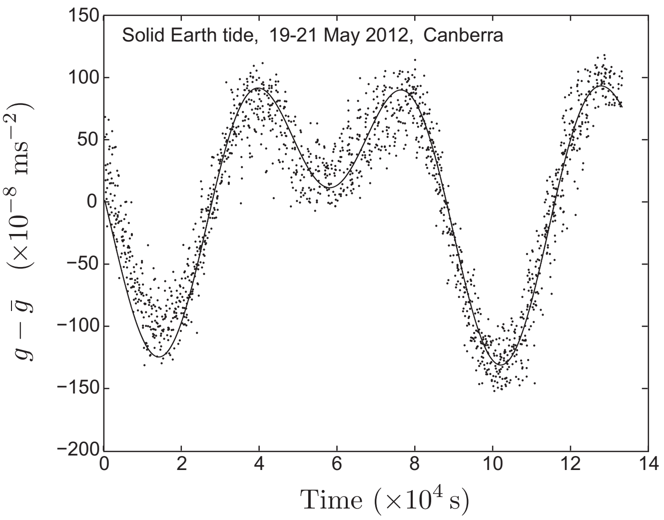

Fig. 4. *Gravity data taken over a 36 h period compared with a solid Earth tide model. Each data point represents the average of 38 individual measurements.*

Our current work is centred around improving the sensitivity and stability of our sensor. In particular, the Heisenberg uncertainty limit in quantum mechanics places a fundamental limit on the sensitivity of such a device. This limit depends on the number of atoms detected in the sensor (10^6 atoms in a typical device). Currently, our and other similar atomic devices are two orders of magnitude above this fundamental limit.

Our group has a history of working with atom-lasers. Compared with a thermal atomic gas, atom-lasers are the atomic analog of the optical laser, compared with light from an incandescent bulb. Given the immensely positive influence the optical laser had, and continues to have, on precision measurement, and particularly optical interferometers, it is reasonable to ask if the atom-laser can offer similar advantages for atom interferometers.

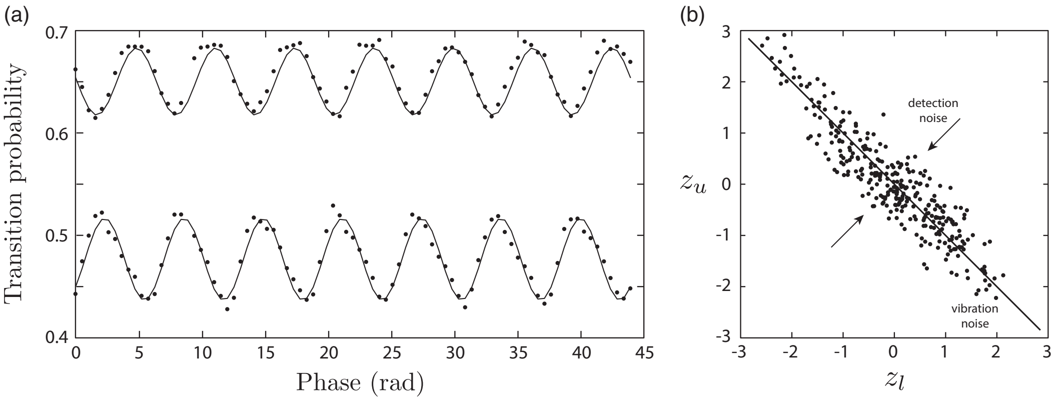

Fig. 5. *(a) Fringes from simultaneous gravimeters with T = 40 ms separated by a vertical distance of 2.4 cm and driven by the same Bragg laser beam. (b) Normalised (z-value) phase of the lower and upper interferometer plotted against each other, showing correlation. Vibration noise is common to both interferometers and does not affect the gradiometer signal. Residual uncorrelated fluctuations are caused by detection noise.*

We believe the answer to this question is yes, for similar reasons that the optical laser has been so successful, as outlined in the thesis of Debs (2012). We are currently implementing an atom laser into our existing gravimeter, and aim to soon answer this question. Such a device operating as a gradiometer has the potential to approach the fundamental limit sensitivity limit, opening access to a new regime of precision gravity measurements.

References

Altin, P. A., Johnsson, M. T., Negnevitsky, V., Dennis, G. R., Anderson, R. P., Debs, J. E., Szigeti, S. S., Hardman, K. S., Bennetts, S., McDonald, G. D., Turner, L. D., Close, J. D., and Robins, N. P. 2013, Precision atomic gravimeter based on Bragg diffraction. *New Journal of Physics* **15**, 023009. doi:10.1088/1367-2630/15/2/023009

Anstie, J., Aravanis, T., Johnston, P., Mann, A., Longman, M., Sergeant, A., Smith, R., Van Kann, F., Walker, G., Wells, G., and Winterflood, J. 2010, Preparation for flight testing the VK1 gravity gradiometer, Geoscience Australia airborne gravity 2010 workshop.

Debs, J. E. 2012, The application of Bose-Einstein condensates to inertial sensing, PhD Thesis, The Australian National University.

Heavner, T. P., Jefferts, S. R., Donley, E. A., Shirley, J. H., and Parker, T. E. 2005, NIST-F1: recent improvements and accuracy evaluations. *Metrologia* **42**, 411–422. doi:10.1088/0026-1394/42/5/012

Leblanc, M. J., Tregoning, P., Ramillien, G., Tweed, S. O., and Fakes, A. 2009, Basin-scale, integrated observations of the early 21st century multiyear drought in southeast Australia. *Water Resources Research* **45**, W04408. doi:10.1029/2008WR007333

McGuinness, H. J., Rakholia, A. V., and Biedermann, G. W. 2012, High data-rate atom interferometer for measuring acceleration. *Applied Physics Letters* **100**, 011106. doi:10.1063/1.3673845

McGuirk, J. M., Foster, G. T., Fixler, J. B., Snadden, M. J., and Kasevich, M. A. 2002, Sensitive absolute-gravity gradiometry using atom interferometry. *Physical Review A.* **65**, 033608. doi:10.1103/PhysRevA.65.033608

Müntinga, H., Ahlers, H., Krutzik, M., Wenzlawski, A., Arnold, S., Becker, D., Bongs, K., Dittus, H., Duncker, H., Gaaloul, N., Gherasim, C., Giese, E., Grzeschik, C., Hänsch, T. W., Hellmig, O., Herr, W., Herrmann, S., Kajari, E., Kleinert, S., Lämmerzahl, C., Lewoczko-Adamczyk, W., Malcolm, J., Meyer, N., Nolte, R., Peters, A., Popp, M., Reichel, J., Roura, A., Rudolph, J., Schiemangk, M., Schneider, M., Seidel, S. T., Sengstock, K., Tamma, V., Valenzuela, T., Vogel, A., Walser, R., Wendrich, T., Windpassinger, P., Zeller, W., van Zoest, T., Ertmer, W., Schleich, W. P., and Rasel, E. M. 2013, Interferometry with Bose–Einstein condensates in microgravity. *Physical Review Letters* **110**, 093602. doi:10.1103/PhysRevLett.110.093602

Peters, A., Chung, K. Y., and Chu, S. 2001, High-precision gravity measurements using atom interferometry. *Metrologia* **38**, 25–61. doi:10.1088/0026-1394/38/1/4

Stuckeley, W. 1752, Memoirs of Sir Isaac Newton's life, The Royal Society.

Szigeti, S. S., Debs, J. E., Hope, J. J., Robins, N. P., and Close, J. D. 2012, Why momentum width matters for atom interferometry with Bragg pulses. *New Journal of Physics* **14**, 023009. doi:10.1088/1367-2630/14/2/023009

The LIGO Scientific Collaboration, The Virgo Collaboration 2012, All-sky search for periodic gravitational waves in the full S5 LIGO data. *Physical Review D: Particles, Fields, Gravitation, and Cosmology* **85**, 022001. doi:10.1103/PhysRevD.85.022001

Van Camp, M., and Vauterin, P. 2005, Tsoft: graphical and interactive software for the analysis of time series and earth tides. *Computers & Geosciences* **31**, 631–640. doi:10.1016/j.cageo.2004.11.015

Zumberge, M., vard Alnes, H., Eiken, O., Sasagawa, G., and Stenvold, T. 2008, Precision of seafloor gravity and pressure measurements for reservoir monitoring. *Geophysics* **73**, WA133–WA141. doi:10.1190/1.2976777

A review of nodal land seismic acquisition systems

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As the pages of this magazine will attest there is currently much interest in nodal land seismic acquisition systems. The benefits claimed within the marketing materials of such systems are many but just how do they stack up? And with the number of different systems reaching double figures how do they compare? In this article we give a snapshot summary of the various systems available, their relative pros and cons, a comparison with cabled systems and look at the geophysical implications of acquisition system choice.

Acquisition systems

During the early 1970s land seismic acquisition was conducted using analogue cable telemetry systems with analogue-to-digital conversion and recording (to tape) both taking place in the recording truck (Figure 1a). The seismic signal from each receiver station, expressed as the output voltage of a wired array composed of multiple individual geophone sensors, had an analogue electrical connection to the recording truck through a line cable with one 'takeout' connection per receiver station interval. Each receiver station required its own conducting wires within the line cable. These systems often used 'CDP cables', which incorporated additional conductors so that multiple cables could be joined end-to-end (Crice 2004). The number of conductors that can be included in a single physical cable led to a total number of channels that could be recorded being limited to approximately 1000 (Khan *et al*. 1982).

One approach to overcoming the limitations of analogue telemetry, first introduced in the late 1970s, is to use a radio telemetry system where the seismic data is digitised and recorded by individual boxes or nodes located in the field adjacent to the seismic sensors (Figure 1b). Recording is triggered using a radio link with data being retrieved either via the radio link or, more commonly, collected later manually (Aldridge 1983). Whereas analogue telemetry systems had

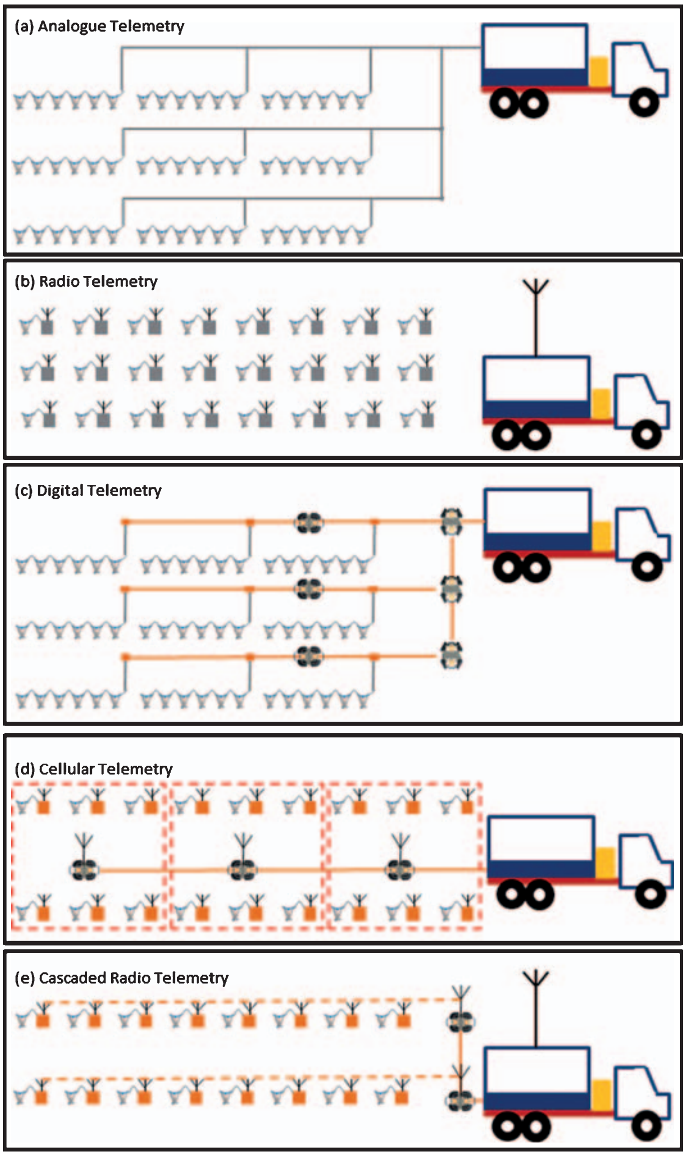

Fig. 1. *Diagrammatic representation of different types of land source telemetry. Grey boxes and links indicate analogue, while orange indicates digital.*

all the recording equipment located (and powered) in a central recording truck, the new system distributed the signal digitisation and recording functions out to equipment in the field. This avoided the limitations of analogue telemetry cables but brought new requirements to distribute power supply and sample time synchronisation to the separate field units. A distinction should be noted between 'data telemetry', where the full seismic data is transmitted (one-way) in near real-time to a central recording unit, and (two-way) 'command telemetry' where only time synchronisation between units, equipment status and parameter settings are managed by a central unit, the latter requiring considerably less bandwidth.

Another type of distributed system, introduced shortly after the introduction of radio systems, uses digital data and command telemetry over spread cables. This type of system has dominated the seismic market for the past 25 years. Seismic data is digitised in field units that handle the inputs from one or more receiver stations, before being passed back to the central recording system via a hierarchy of additional field units that concentrate the data telemetry from multiple receiver stations and multiple receiver lines. For example, in-line boxes can be placed at intermittent positions along the cable to buffer the data and send it further down the line; these boxes also provide power to other components, such as digitising takeouts, if required. At the end of each line a cross-line box takes the data from the line and passes it via another cable, often fibre-optic, to the recording truck. Where the lowest level field unit handles only one receiver station it can be either a digital sensor package (for point-receiver systems) or a 'takeout' connection to attach a geophone array (as shown in Figure 1c). On some systems the lowest level field unit handles seismic data from more than one receiver station, for example, from four, six or eight stations, with analogue telemetry of the seismic signals from geophone array takeouts at each receiver station to the field units, then or at in-line boxes placed at frequent intervals.

As will be discussed further in a later section, radio telemetry systems have a variety of drawbacks. To overcome these, a cellular telemetry system called the *Infinite Telemetry System* or *it System*, was launched by Vibtech (now part of Sercel) in 2002 (Park and Flavell 2006). Data from the sensors is digitised at each individual node and then communicated via radio to an intermediate node that then sends data to the recording system via a fibre-optic link (Figure 1d). A further development of this system, introduced in 2006, was Un*ite*, which allowed data, or a subset of the data, to be transmitted from the access nodes to the recording system directly via radio or collected ('harvested') later.

In recent years there has been a growing interest in 'cable-free' node technology. The definitions of these nodes are varied but can be broken into three groups:

- Blind nodes: nodes cannot communicate with the central recording system. Each node receives timing synchronisation via GPS. Data is saved locally and offloaded (harvested) when the node is picked up (similar to sub-sea nodes).
- Radio QC nodes: nodes send quality control information only to a central recording system via low speed radio infrastructure. Synchronisation is normally by GPS but can be distributed over radio. Data is saved locally and harvested when the nodes are picked up or periodically harvested via local radio or cable connections. Examples of the radio QC messages would be average RMS noise in the last 10 seconds, battery power remaining, memory capacity remaining, etc.
- Full radio nodes: nodes can send all seismic data in near real-time through high speed radio networks back to the central recording system. Synchronisation is normally by GPS but can be distributed over radio.

Blind systems

Blind systems have no data or command telemetry and record data onto local memory. GPS is used for timing and for synchronisation (although to reduce battery consumption they typically rely on an internal clock that is only periodically adjusted against GPS time). Data is recorded continuously over the period required and the shots are then extracted from the continuous data stream on download.

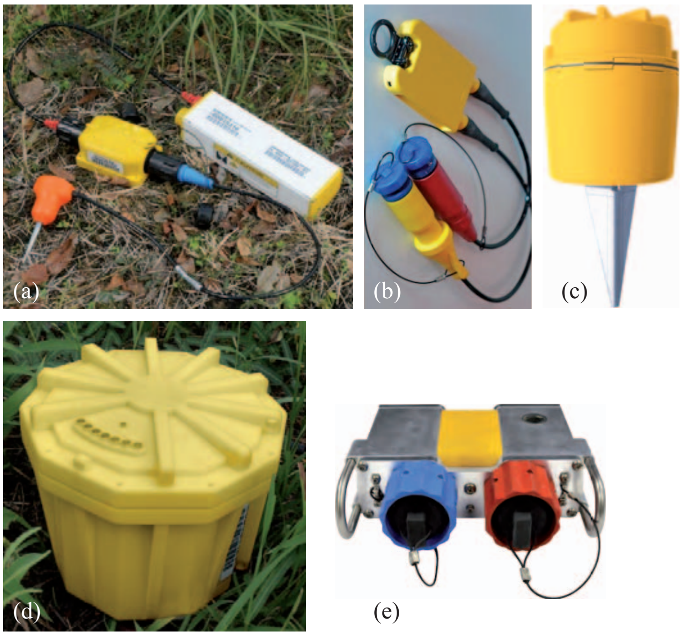

Fig. 2. *Examples of blind recording systems: (a) OYO Geospace GSR with separate geophone, recording unit, and battery (courtesy of OYO Geospace); (b) AutoSeis HDR; (c) ZLand with all components integrated, the unit is 15.9 cm high without the spike (courtesy of FairfieldNodal); (d) the OYO Geospace GCX with all components integrated (courtesy of OYO Geospace); and, (e) INOVA Hawk SN11, only the recording unit is shown (courtesy of INOVA).*

Blind systems give no real-time feedback as to their operation other than status lights on the units themselves. Data is usually downloaded manually from the unit when it is collected via a direct connection but the iSeis Sigma also has the option to use ruggedised memory sticks. These are the most common acquisition systems and include the OYO Geospace GSR (Figure 2a), the AutoSeis HDR (Figure 2b), ZLand (Figure 2c) and the OYO Geospace GCX (Figure 2d). The INOVA Hawk system (Figure 2e) also operates autonomously, but includes the ability to communicate locally with the line crew via Bluetooth and WiFi.

Typically most blind nodes are still operated with standard strings of geophones. In areas of high cable damage then many of the geophone may be cut or pulled out and this may go unnoticed for many days resulting in data degradation.

Radio QC nodes

Sitting between the real-time data systems and the completely blind systems are those that offer some form of real-time quality control. This category includes the Autonomous Recording Node (ARN) from Seismic Instruments (Figure 3a), which includes a radio to transmit a basic QC signal containing battery and memory status to the recording system. The INOVA FireFly system provides various trace attributes to QC the data as well as the sensor performance via a VHF or UHF radio link.

Full radio nodes

As mentioned above the first radio telemetry systems were developed in the 1970s, Shave (1982) stated that in the three years after its introduction in 1979 there were more than 20 crews each operating 200 *Opseis* 'seismic group recorder' units

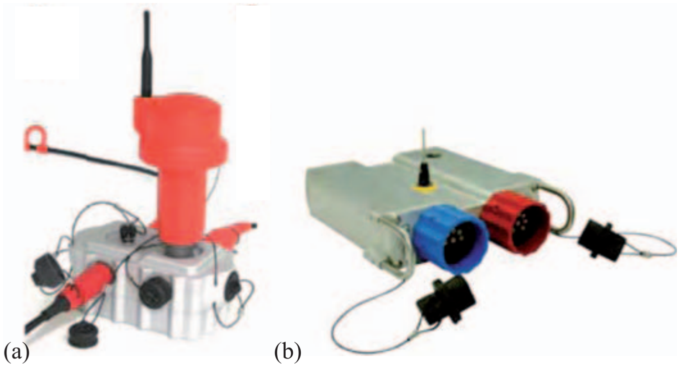

Fig. 3. *(a) The Seismic Instruments Autonomous Recording Node (ARN) in red, contains the memory, battery and an antenna and is connected to the silver recording box; and (b) INOVA FireFly.*

in the US. A survey of various people involved in Geophysics conducted in 1982 asked each respondent to predict when '25% of the seismic field systems in use will be dispersed, telemetry recording systems' the average answer was 1996 (Hewitt 1983), but by 2010 nodal system sales (including, but not limited to, systems using radio telemetry) were only 5% of channels sold (Mougenot 2010). The reasons for the failure of these early radio-frequency systems can be summarised as (Heath 2003; Mougenot 2010):

- Radio requirements, sending large amounts of data in real-time requires a large bandwidth, typically in the already well-used VHF band. This results in both licencing and interference issues.
- High power consumption.
- Data recovery problems, if receiving data in 'real-time' the system may be delayed waiting for all the data to be sent or, if storing the data on nodes, the data may not be recoverable.
- Missing records, as the recording is triggered by radio.
- Higher cost including specialised components such as large antennas (Figure 4).

In addition to these issues, one of their initial motivations, that of being able to overcome the channel limits associated with analogue cables, was overcome by the introduction of the aforementioned digital telemetry systems. Although radio systems continued to be used through the 1990s (e.g. Sixma and van Der Schans 1994) they were limited to specialist applications such as mountainous terrains.

The more recent systems that utilise radio communications make use of the 2.4 GHz Wi-Fi radio band. This band is licence free and although power is limited, it is enough to communicate between closely spaced units. The RT system from Wireless Seismic (Figure 5) overcomes the limited range by sending data ('bucket passing') along a line of field units (Figure 1e). At the end of each receiver line the data is received by a line box that then transmits the data via a cable, or a radio operating on either 900 MHz or 5.8 GHz, to the recording truck.

The SERCEL Unite system (Figure 6) also uses the 2.4 GHz frequency band but each unit transmits data individually. Data can either be transmitted in real-time to an antenna (Figure 6b, maximum line-of-sight-range of 1000 m) or harvested periodically.

Units that include the ability to harvest or provide real-time data often also have the ability to record blind if the radio network

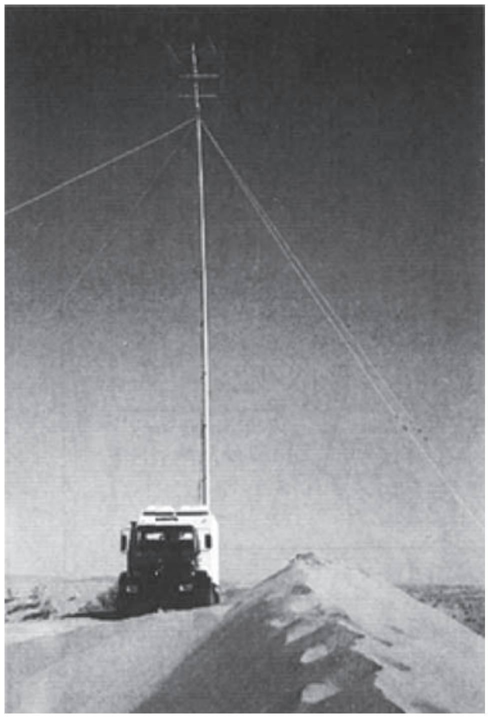

Fig. 4. *The central recording system of an Opseis acquisition system acquiring data in China in 1994 (photo courtesy of the SEG). Note the large radio antenna.*

Fig. 5. *Wireless Seismic Wireless Remote Unit the yellow batteries are attached to the outside of the unit for easy replacement (photo courtesy of Wireless Seismic).*

is disrupted. Not using functionality that has been paid for, both in cost and weight, is clearly undesirable, and the iSeis Sigma system overcomes this by allowing additional components to be

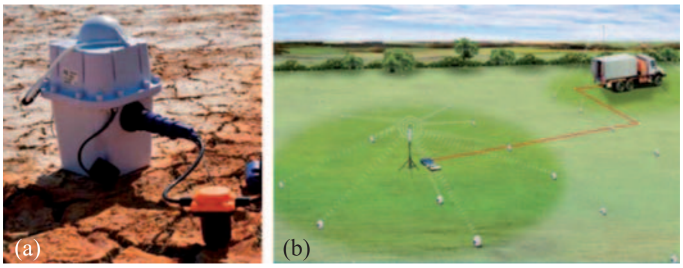

Fig. 6. *(a) Sercel UNITE node with an internal battery and separate geophone string; and (b) diagram showing UNITE nodes sending data to a central node for transmission via a cable to the recording truck (images courtesy of Sercel).*

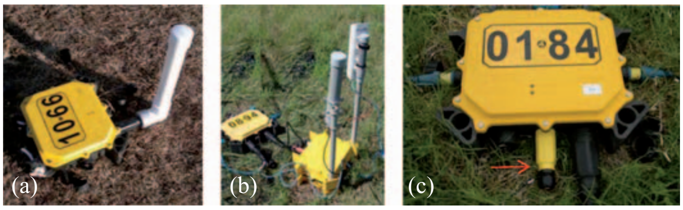

Fig. 7. *Different configurations of the iSeis Sigma system: (a) with WIFI antenna; (b) with high speed backbone link; and (c) with external USB storage (all images courtesy of iSeis).*

added to the basic node. For example, Figure 7a shows the unit with a WiFi antenna, Figure 7b shows the unit connected by cable and with a high speed backbone link and Figure 7c shows the unit with an external USB storage device.

Hardware configurations

All nodal systems consist of three basic components: the seismic sensor or takeout connection, a recording unit and a battery. Systems using some form of wireless telemetry also include an antenna. These three main components are variously combined into one, two or three separate packages. The most common configuration is to keep all three components separate, as in the OYO Geospace GSR (Figure 2a), INOVA Hawk (Figure 2e), iSeis Sigma (Figure 7), AutoSeis HDR (Figure 2b) and INOVA FireFly (Figure 3b). The Sercel UNITE system (Figure 6) incorporates the recording unit, antenna and battery (although an external battery can also be added). The Wireless Seismic RT1000 unit (Figure 5a) is slightly different in that although it too incorporates the batteries they are placed on the outside of the unit and can thus be easily replaced. The FairfieldNodal ZLand system (Figure 2c) and the Geospace GCX (Figure 2d) have all three basic components combined in a single package, which makes them the only truly cable-less system. The Autonomous Recording Node (ARN) from Seismic Instruments (Figure 3a) is unique in that the battery, data storage (but not recording) and antenna are combined in a single unit that attaches to the recording box, which can also be used as part of a cabled system.

A summary of the attributes of each system is included in Table 1. There is wide variation in the weight of the systems (including the weight of the batteries) ranging from 1.6 to 17.2 kg. Generally speaking the blind systems are generally the lightest as they do not require additional radio infrastructure.

Batteries and system weight

The downside of nodal acquisition systems are requirements for GPS time sample synchronisation and batteries. To use GPS it is imperative that the units have good sky visibility and are not underwater or under wet soil or snow. As the sensitivity of GPS receivers improves and more satellite constellations are deployed then this problem should diminish and reliability should be acceptable for most field conditions apart from full water submersion. It is difficult to obtain power consumption figures for nodal systems but from what is available the consumption of simple autonomous systems is about twice that of the latest cabled systems (120 mW/channel for the UniQ system). Systems that use some form of communication have consumption values around four times that of the best cabled systems.

All the systems currently available use Li-Ion batteries whose performance is heavily dependent on temperature. Operating at extreme temperatures (<10°C or >50°C, a temperature easily achieved when batteries are left out in the sun) reduced not only battery voltages and capacity but also the life of the battery (Bloom *et al*. 2001; Zhang *et al*. 2003). Reductions in battery performance not only result in the need for more frequent charging but also add to the cost of the survey if their useable

Table 1. Operating mode: B, blind; RT, real-time data; WH, wireless harvesting; QC, quality control

Name	Manufacturer	Operating mode	Number of channels	Incorporates		Weight[1] (kg)		
				Sensor	Battery	Unit	Battery	Combined
Z-Land	Fairfield Nodal	B	1	X[5]	X	2.17	N/A	2.17
GCX	Geospace	B	1 or 3	X	X	2.72	N/A	2.72
RT Sys. 2	Wireless Seismic	RT	1 or 4		X	1.83	1.12	2.95
UNITE	Sercel	B/WH/RT	1,2,3		X	1.6/1.95[2]	N/A	1.6/1.95
GSR	Geospace	B	1,2,3,4			0.91	1.5	2.41
Hawk	INOVA	B	1,2,3			1.72	2.49/3.45[3]	4.2/5.2
Sigma	iSeis	B/QC/RT	1,2,3			3.20	2.1	5.3
HDR	AutoSeis	B	1 or 3			0.32	2.1	2.42
ARN	Seismic Instruments	B/QC/RT[4]	max 72			2.2	15	17.2
FireFly	INOVA	QC	1,2,3			2.36	2.6	4.96

[1]Excluding sensors. [2]1-channel/3-channel versions. [3]192 and 288 WHr batteries. [4]Battery and memory QC only. [5]This is the standard unit, an external sensor can be added if required.

life is shortened and battery lifetime uncertainty adds a large data loss risk especially when number of nodes increase per crew.

As can be seen from Table 1 the weight of the battery is between 40 and 90% of the total weight of the node (excluding the weight of the sensors). Using a 10 000 channel crew recording for 12 hours/day as a benchmark the battery requirements for a nodal and a cabled system can be summarised as:

- Nodal system:
  - Battery duration: 14 days
  - Battery changes/day: 700
  - Battery charge time: 4–8 hours
  - Battery charging stations: 350 (based on 2 batteries/charger/day)
  - Total number of batteries: 15 000 (+50%, Lansley *et al.* (2008))
  - Total battery weight: 30 000 kg (2 kg/battery)
- Cabled system:
  - Battery duration: 12 hours (utilising solar panels)
  - Battery changes/day: 40
  - Battery charge time: 12 hours
  - Battery charging stations: 20
  - Total number of batteries: 80
  - Total battery weight: 2320 kg (29 kg/battery)

Comparisons of the weight of cabled and nodal systems vary in their conclusions. For example, Heath (2010) concluded that cabled acquisition systems are 'under almost all conceivable circumstances' always heavier whereas Lansley *et al.* (2008) considers that the weight of cabled systems is lower when the group interval is less than 50 m. For intervals of ~10 m, which are common for point receivers, his results show that the weight of a cabled system is only around 40% of that of a nodal system. Our own analysis shows that the weight of cabled systems when compared with blind (i.e. the lightest nodal) systems is lower at receiver intervals of less than 40 m, while for a receiver interval of 10 m the cabled system is only 24% of the weight of the blind node system.

Logistics

Since the majority of nodal systems still utilise geophone strings the day-to-day logistic effort of moving the spread is generally related to the crew's channel count. With cabled systems there are fewer batteries to change but a larger number of telemetry cables to move; with nodal systems there is the addition of data harvesting. As the number of channels increases then the battery charging and harvesting effort of the nodes becomes larger than the logistics required on cabled systems. The majority of nodal systems require the unit to be retrieved and manually downloaded while systems that use wireless harvesting (e.g. UNITE) or USB drives (e.g. iSeis, Figure 7c) must still be physically visited. If units must be downloaded in camp then the unit is clearly unavailable for use in the field, requiring the purchase of additional units to enable the full channel count to be maintained. Downloading data is usually relatively quick (~5 minutes) but those units that have an integrated battery (Unite, GCX, ZLand) are unavailable until the battery is fully charged (typically between 4 and 8 hours).

In desert or snow-bound terrains equipment often gets buried; finding buried cabled equipment is quite straight forward, you simply follow the cables and recover it. Nodal systems are not so simple; those systems that are capable of communicating can 'tell' you where they are but those that are not can be difficult to find, putting both the unit and the valuable data it contains at risk. Although theft can still affect both cabled and nodal systems, with cabled systems at least the data has been recorded by the central recording system and is not lost as well. With cabled systems theft is observed in real-time by the observers when the system is operating. With blind node systems the risk is high as it may not be noticed for several days or even weeks that the nodes have been stolen. The UNITE system has a sophisticated tracking system (Lansley 2012) that enables stolen equipment, or at least the data, to be recovered but for the other systems there is no simple way of recovering them.

Geophysical considerations

When discussing seismic acquisition systems it must not be forgotten that the primary objective of a seismic survey is to sample the seismic wavefield. The choice of acquisition system, in particular the type of telemetry, is an operational matter not a geophysical matter unless it restricts sampling of the wavefield, i.e. the type of telemetry does not affect the seismic data if it has been acquired using the same acquisition parameters.

Previously, arrays of geophones were used to ensure adequate sampling of the wavefield while still working within the constraints of acquisition systems that could only record a limited number (<4000) of channels. The introduction of high-channel count (>100 000) systems has allowed the arrays to be replaced by individually recorded sensors ('point-receivers') without spatially under-sampling the wavefield. Experience has shown that adequate spatial sampling often requires point-receivers to be around 10 m apart; at this spacing point-receiver nodal systems are an inefficient way to record such surveys. The receiver spacing at which the weight of nodal systems (as a proxy variable for efficiency) becomes less than cabled systems is ~40 m, a separation at which the data is unlikely to be sufficiently sampled. We could overcome this by using a closer source spacing but this would likely have serious operational implications, particularly if an explosive source is being used.

Discussion

The lack of success of early radio-telemetry systems can be attributed to their own technical limitations and the introduction of digital telemetry cables that removed one of their major motivations. Cable-less systems are often promoted as a light-weight, logistically simple, alternative to cabled systems but as discussed above they are only an advantage when the receiver interval is large. The logistics burden of maintaining cabled systems is replaced by the logistic burden of replacing batteries (although the impact of this burden is heavily dependent on terrain and temperature).

Cable-less systems are particularly advantageous when used in difficult terrain such as mountainous areas or cities. In areas where cable damage is an issue, for example from livestock, the use of cable-less systems only offers an advantage if point receiver data is acceptable (the use of arrays of geophones obviously providing plenty of geophone wire to be damaged).

Similarly many systems still include cables, for example between the recording system and the sensor and/or the recording system and the battery, which still require protection.

A move towards cable-less systems is also seemingly at odds with a move towards high-channel count dense point-receiver sampling (e.g. Pecholcs *et al*. 2012 and Lansley 2013). The logistics involved in downloading data and changing 10s of thousands of batteries a day is likely to be prohibitive. The future therefore, as suggested by Lansley (2012), is that there will continue to be surveys where the choice between cabled or cable-less systems is obvious, with some surveys benefiting from a combination of the two.

References

Aldridge, D. 1983, Opseis 5500: *53rd Annual Meeting of the SEG*, 409–412.
Bloom, I., Cole, B. W., Sohn, J. J., Jones, S. A., Polzin, E. G., Battaglia, V. S., Henriksen, G. L., Motloch, C., Richardson, E., Unkelhaeuser, T., Ingersoll, D., and Case, H. L. 2001. An accelerated calendar and cycle life study of Li-ion cells. *Journal of Power Sources* **101**, 238–247.
Crice, D. 2004. What is a CDP cable? *The Leading Edge* **23**, 830–832.
Heath, B. 2003. Hybrid cellular seismic telemetry system = a solution to the industry's profit and data quality problems? *The Leading Edge* **22**, 962–968.
Heath, B. 2010. Weighing the role of cableless and cable-based systems in the future of land seismic acquisition. *First Break* **28**, 69–77.
Hewitt, M. R. 1983. Delphi survey. *The Leading Edge* **2**, 18–31.
Khan, T. A., Fehrenkamp, W., and Pater, A. 1982, Evaluation of telemetry methods for a state-of-the-art geophysical field recording system: *52nd Annual Meeting of the SEG*, 48–50.
Lansley, M. 2012. Cabled versus cable-less acquisition: making the best of both worlds in difficult operational environments. *First Break* **30**, 97–102.
Lansley, M. 2013. Shifting paradigms in land seismic acquisition. *First Break* **31**, 73–77.
Lansley, M., Laurin, M., and Ronen, S. 2008. Modern land recording systems: how do they weigh up? *The Leading Edge* **27**, 888–894.
Mougenot, D. 2010. Land cableless systems: use and misuse. *First Break* **28**, 55–58.
Park, B., and Flavell, J. 2006. How a new cable-less land seismic survey. *First Break* **24**, 79–82.
Pecholcs, P. I., Al-saad, R., Al-sannaa, M., Quigley, J., Bagaini, C., Zarkhidze, A., May, R., Guellili, M., Sinanaj, S., and Membrouk, M. 2012, A broadband full azimuth land seismic case study from Saudi Arabia using a 100,000 channel recording system at 6 terabytes per day: acquisition and processing lessons learned: *82nd Annual Meeting of the SEG*.
Shave, D. G. 1982, Seismic group recorder survey: *52nd Annual Meeting of the SEG*, 45–46.
Sixma, E., and van Der Schans, C. 1994, 3-D seismic in mountainous terrain: *64th Annual Meeting of the SEG*, 1633–1636.
Zhang, S. S., Xu, K., and Jow, T. R. 2003. The low temperature performance of Li-ion batteries. *Journal of Power Sources* **115**, 137–140.

The Continental Drift Controversy

By Henry R. Frankel
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The Continental Drift Controversy by Henry R. Frankel is a tetralogy beginning with Vol. I *Wegener and the Early Debate*, followed by Vol. II *Paleomagnetism and Confirmation of Drift*, Vol. III *Introduction of Seafloor Spreading* and concluding with Vol. IV *Evolution into Plate Tectonics*. In an earlier review I summarised Vols. I and II (*Preview*, 10.1071/PVv2013n163, pp. 28–30) and here I summarise Vols III and IV to give readers an idea of the vast breadth of content.

Vol. III is divided into six chapters covering (1) *Extension and reception of paleomagnetism/paleoclimatic support for mobilism: 1960–1966*, (2) *Reception of the paleomagnetism case for mobilism by several notable: 1957–1965*, (3) *Harry Hess develops seafloor spreading*, (4) *Another version of seafloor spreading: Robert Dietz*, (5) *The Pacific as seen from San Diego and Menard's changing views about the origin and evolution of the ocean floor*, and (6) *Fixism and Earth expansion at Lamont Geological Observatory.*

Vol. III begins by revisiting the Squantum Tillite anomaly. This Permian unit possessed low inclination palaeomagnetic directions, and without raising the spectre of low-latitude glaciation now confirmed for most of Precambrian time, back in the 1906s a 'tillite' with equatorial palaeomagnetic inclinations was seen as a glaring inconsistency in the palaeoclimate/palaeomagnetic consilience. Two advances changed this. Radiometric dating pushed the Squantum's age back to the early Carboniferous/Devonian and new sedimentological evidence from Bob Dott showed that its origin was more plausibly by gravity movement of rapidly deposited, volcanic-rich sediments and periodic resedimentation by turbidity currents, thus nothing to do with glacial deposition. The anomaly disappeared. Interestingly, Edward 'Teddy' Bullard, the British geophysicist, cast aspersions on the veracity of a number of 'tillites', but also had little regard for palaeoclimatology. Dott may have agreed with Bullard's first misgivings but would have told Bullard to stick to geophysics regarding the second.

The increasing acceptance of Continental Drift in the early 1960s renewed efforts to seek mechanisms bearing in mind that Wegener had emphasised the significance of isostatic equilibrium of continents decades earlier. Mass movement in the upper mantle must be a possibility for isostacy to be maintained. Mantle convection had been proposed by Arthur Holmes, and worked on further by Vening Meinesz and Harold Urey. Keith Runcorn took up the cudgels incorporating emerging information about ocean features. Runcorn took on Harold Jefferys, who steadfastly denied mobilism, by pointing out that elastic behaviour that describes seismic and nutation events of the Earth is incomplete when considering the long term behaviour of solids at high temperature exposed to shear stress, which allows steady creep (irreversible flow) to occur (p. 19). Some discussion follows on whether seismic discontinuities in the Mantle represented chemical changes (disallowing Mantle wide convection) or phase changes (allowing Mantle wide convection), the latter leading to convection of the scale thought to be required for Continental Drift. Keith Runcorn and Ron Girdler were the first to (independently) posit that the central magnetic anomaly over the Mid-Atlantic Ridge was caused by thermoremanent magnetisation rather than induced magnetisation (p. 25), implying rapid cooling of magma.

The 1962 anthology *Continental Drift*, which appeared 50 years after Wegener's theory appeared, and Gordon MacDonald's acerbic dissection is examined ('Continental drift has many appealing features…a favourite topic of pundits condescending to the lay public; it is a grandiose theory involving great changes…eminently suitable for a 'Wonders of Nature' series' (Vol. III, pp. 25,26). Also, under the spotlight is the 1963 Newcastle NATO conference organised by Runcorn (pp. 37–47). Harland's contributions linking mobilism, the Great Infra-Cambrian Ice Age and the Cambrian diaspora of life are discussed on pp. 47–52. New palaeomagnetic laboratories sprang up in Africa, with Ken Graham and Anton Hales at BPI, Johannesburg, and Ian Gough, Mike McElhinny, Dai Jones and Andrew Brock in Salisbury (now Harare), Rhodesia (now Zimbabwe). Neil Opdyke also joined Salisbury (after a post-doc at ANU) on an NSF research fellowship, the first awarded outside the USA. The plethora of new African results is discussed on pp. 85–92.

Ted Irving continued amassing palaeoclimate/palaeomagnetic evidence working with his PhD student, Jim Briden, and David Brown at ANU (Vol. III, pp. 92–109). In 1964 Irving published the first text on palaeomagnetism, *Palaeomagnetism and its Application to Geological and Geophysical* Problems (John Wiley & Sons, New York). Several other influential volumes came from UK symposia around this time. Neil Opdyke and Keith Runcorn continued working on palaeowind directions showing that mid-latitude 'trade winds' were the same back in the Palaeozoic as they are today, when dune fields were re-positioned according to palaeomagnetic declination and inclination.

Chapter 2 moves onto the conversion to mobilism of several 'notables' beginning with Beno Gutenburg (renown for making the first accurate estimate of the depth to the core-mantle boundary, and maybe also for the first military use of seismology detecting gun positions in the Great War). Actually Gutenburg was an early mobilist from the 1930s and embraced the new palaeomagnetic evidence wholeheartedly (p. 115). Vening Meinesz was a fixist but converted to mobilism in the 1960s. Meinesz believed mid-oceanic ridges were remnants of continents and rejected seafloor spreading before being persuaded by palaeomagnetic data of mobilism (p. 123). Gordon MacDonald continued to deny mantle convection (p. 129). The satellite gravity geoid was seen as evidence by MacDonald (and

Munk) as evidence for 'finite strength' (*sic*., do they mean effectively infinite strength?) of the mantle, while Runcorn sees it as evidence for convection (finite, yielding strength?), which is the current interpretation I believe (pp. 131–133). Jeffreys' incessant objections are comprehensively covered complete with the amusing exchange in Canberra where Jeffreys repeated his claim of a 15° gaping bight between Africa and South America after closing the South Atlantic. David Brown, who was then Chair of the Geology Department at Canberra University College, asked had Jeffreys read Carey's work which shows that the 3D fit, using the continental shelves (as per Wegener), was nearly perfect. Jeffreys replied 'I have never read Carey's papers, and I have no intention of doing so' (p. 141). Teddy Bullard pioneered work on heat flow that led him inexorably to convection, but strangely does not acknowledge Arthur Holmes's work in this area decades earlier. Bullard 'comes out' in 1963 as a mobilist. The similarity of continental and oceanic heat flow led to many red-herrings which confused Bullard earlier and had been seen as an argument against mobilism (of course it is now known oceanic heat flow is higher, especially at mid-oceanic ridges). Arthur Holmes's attitude to palaeomagnetism is detailed beginning p. 173; '…has brought about a major revolution in attitude… toward…continental drift'. 'Soviet paleomagnetists, notably Khramov and colleagues who in the 1950s, despite the predominance of fixism among Soviet geologists, made an important contribution to the paleomagnetic drift case based on their own observations and their knowledge of work internationally' (p. 179). Chapter 2 finishes with a 14-page tract on who believed what, when and the many false leads down dead ends.

Harry Hess (Princeton University) is generally recognised as the 'father' of seafloor spreading. His story from fixist to mobilist to proposing the mechanism which worked reads like a science fiction plot (Chapter 3). Hess's research began aboard submarines making gravity and bathymetry observations with Meinesz. Later Hess left observations to others (submarine, ship borne, airborne and satellite) and became a synthesiser. However, the seafloor spreading 'working model' he finally proposed was not handed to him on a plate, it was not joining the dots. Hess earlier rejected mantle convection because of the close correlation between gravity anomalies and topography, and he could not envisage how convection could be maintained for the lengths of time (100 – 200 My) predicated by the geology. There were many blind alleys before he found his way out of the maze, exhaustively recounted in a long tract on pp. 198–275. The clash between the Princeton/Scripps schools (Hess/Bob Fisher), which believed trenches to be convergent features, and the Lamont school (Maurice Ewing, Bruce Heezen and others), which interpreted trenches to be tensional features, is examined on pp. 254–271. Some evidence is presented (p. 236) that Sam Carey converted Hess to accepting palaeomagnetic data and mobilism, although it also seems plausible Hess was sufficiently resilient to fixist dogma that he came to his own conclusions.

The US took its time to turn on to mobilism but by the 1960s many US geologists were converting in droves. Chapter 4 is a longish (pp. 280–319) discourse on Robert Dietz, who was trained in photo interpretation and geomorphology, only ever wanted to study the lunar surface. Dietz worked for the US Navy Electronic Laboratory (NEL) and later the US Coastal & Geodetic Survey (USCGS). In 1946 Dietz went out on a limb proposing a meteoritic origin of the lunar craters. Dietz provided evidence from shatter cones (his specialty) that both the Vredefort Dome and the Sudbury Igneous Complex were of impact origin. He even suggested the Sudbury nickel was cosmogenic. Dietz coined the term 'astrobleme' and proposed that they caused ocean basins on Earth and were related to continental drift (1958, p. 288).

Later Dietz also coined the term 'seafloor spreading'. Dietz's ideas on seafloor spreading were published in the popular press October, 1961, while Hess (November, 1961) had been induced to switch from publishing in *The Sea* to Runcorn's forthcoming book on *Continental Drift*. Dietz never claimed priority over Hess although the order of publishing may seem he had a right, notwithstanding he by-passed peer review. Dietz graciously added a note in proof clearing the air (p. 312).

Chapter 5 (pp. 320–357) documents a productive period in the development of seafloor spreading as a self-consistent hypothesis. Henry Menard went to work with Dietz at NEL as a photo interpreter and later joined Scripps, San Diego. Menard discovered seafloor fracture zones in 1953 and later showed that they were nearly parallel, and almost great circles, in the western Pacific. In 1958 Menard is so close yet so far from putting it all together. Instead he opts to accept convection and a mobile seafloor, but remains a continental fixist (p. 337). Menard took the retrograde step of proposing that mid-oceanic ridges were sunken isthmuses that once provided corridors for flora and fauna to pass along. I often think had I worked harder during my PhD years my thesis could have been so much better, but spare a thought for 'Bill' (Menard), if only he had been more open to mobilism. Menard had witnessed a fellow young scientist being torn apart by a crusty old fixist who had had the temerity to ask after a talk how his ideas fitted in with continental drift (p. 322). The event might have left an indelible scar on Menard but for his collaboration with Dietz. When magnetic anomalies in the north-eastern Pacific were shown to be offset parallel to Menard's fracture zones, he gave up his fixist notions (pp. 338–346). Other workers thought the magnetic anomalies showed the seafloor to be rigid, or blocky, and the congruent continents reflected this rigidity, so there was no way that continents had ploughed through the seafloor. The solution to this impasse would be an important advance in geophysics (p. 342).

The final chapter (Chapter 6, pp. 358–434) revolves around the ideas of Maurice Ewing and Bruce Heezen at the Lamont Geological Observatory. These include Ewing's fixist stance, until everyone else converted so he followed in 1967, and Heezen's support for, and later retraction of, Earth expansion. Ironically, or tellingly, it was under Ewing's stewardship that Lamont workers amassed the data that brought an end to fixism. I say tellingly, because a great research director does not micro-manage and gives researcher the freedom to either 'hang' or 'glorify' themselves. Despite Ewing's leanings he did not try to intervene at the individual level.

Moving onto Vol. IV, this is divided into seven chapters covering (1) *Reception of competing views of seafloor evolution, 1961–1962*, (2) *The origin of marine magnetic anomalies, 1958–1963*, (3) *Disagreements over continental drift, ocean floor evolution, and mantle convection continue, 1963–1965*, (4) *Further work on the Vine-Matthew hypothesis, transform faults, and seafloor evolution, 1965*, (5) *Continuing disagreement over the Vine-Matthew* *hypothesis, transform faults, and seafloor evolution, 1965*, (6) *Resolution of the continental drift controversy, and (7) The birth of plate tectonics.*

While by 1960 the palaeomagnetic evidence that continents had drifted was undeniable, there was such a gap in knowledge of the seafloor that it was not possible to construct a robust model that included the role of the seafloor. The scene was set for some momentous discoveries of the secrets of the oceanic realms. Throughout these volumes some characters are the stars (Irving, Creer, Opdyke and belatedly, Runcorn, etc.) fixed in the firmament, unchanging, their stories reappear in almost every chapter, so interrelated were their activities, while other are like planets and their stories wander, but at crucial stages they align with brilliance and add an important element to the development of ideas. Tuzo Wilson was a bit like a planet. Wilson was the giant of Canadian geophysics who nevertheless held onto fixism until 1961 (p. 37). Earlier, Wilson championed contractionism, continental growth by accretion, as could be interpreted from photo interpretation of Precambrian cratons of Canada, Australia and Africa, and geosynclinal theories with island arcs evolving into mountain belts. The contraction idea held that the outer 70 km 'skin' of Earth had finished cooling and contracting, but from 70 km to 700 km the 'husk' was still contracting and the 'kernel' below 700 km was yet to begin cooling and contracting. Thus, the 'skin' was in compression and the 'husk' in tension. The compressed 'skin' accommodated the growing space problem by up-down displacement along arcuate normal faults, explaining trenches. These ideas must have been elegant, if not compelling in their day, although I cannot see how the still cooling 'husk' can contract more that the already cool 'skin'. Once a mobilist, Wilson was joining up features across the Atlantic like the Great Glen Fault in Scotland with the Cabot Fault in Canada, and making spectacular prognostications faster than anyone. Wilson, of course, is remembered for his idea of transform faults which is fully covered in Chapter 4. This was one of the keys to understanding seafloor spreading as a kinematic model.

Another key to understanding seafloor spreading was the origin of marine magnetic anomalies (Chapter 2, pp. 62–147). In 1962 the Cambridge University marine geophysics group, headed by Drummond Matthews, acquired data from a new marine magnetic survey over the Carlsberg Ridge in the Indian Ocean. Frederick Vine, Matthew's student, suggested a way to simultaneously explain the pronounced magnetic anomaly over the axis of the ridges, and the symmetrical magnetic stripes of highs and lows either side. Spreading from the mid-ocean ridges, while the geomagnetic field polarity irregularly flipped, is obvious in hindsight. This scheme became famously known as the Vine-Matthews hypothesis. However, we humans cannot do things simply as the intriguing tale of Lawrence Morley's shows. (p. 124). Morley, Geological Survey of Canada, had arrived at similar conclusions as the Vine-Matthews hypothesis in 1962, but in 1963 had two papers rejected, one by *Nature* and the second by *JGR*. One *JGR* reviewer wrote, 'This is the sort of thing you would talk about at a cocktail party' (p. 137). Frankel devotes some space (p. 139–141) to why Vine's and Matthews' manuscript was accepted by *Nature* while Morley's was not, but does not descend to the level to suggest the former were from Cambridge while the latter from the colonies. I will not stoop to such temptation either. Vine's and Matthews' paper includes original data and computer modelling that most probably gave it the edge if an editor was weighing up between the two. One possibility Frankel does not discuss is that an editor's decision to accept at least one of them would be enhanced if two papers turned up with the same solution to such a controversial topic of the day. This may be especially so with *Nature* continually on the lookout for papers at the forefront. If the Vine-Matthews paper was submitted alone perhaps it would have been rejected out of hand. But, imagine the CI for the Vine-Matthews paper. John Sclater, then a geophysics PhD student at Cambridge, said the 'tea room' was 'surprised that *Nature* published what we considered idle speculation' (p. 140), not far from the *JGR* comment on Morley's manuscript.

Like Einstein's Special Relativity, if he had not published when he did, there were others with manuscripts ready. The palaeomagnetic group at Salisbury in Rhodesia (Gough, McElhinny and Opdyke) immediately thought of reversals on viewing the seafloor striped anomalies albeit after Gough returned from Scripps late 1962 (pp. 141, 142). Another was PhD student Geoff Dickson at Lamont (MSc Sydney University 1962, p. 144), who was familiar with reverse polarity remanence having worked on Tertiary igneous rocks in the Sydney Basin. Chapters 3 (p. 202) records Manic Talwani's assessment of the Vine-Matthew's hypothesis stating that 'less startling' explanations are possible, so not everyone at Lamont was predisposed to new ideas. Apart from Heezen, no one at Lamont was a mobilist until Neil Opdyke arrived 1963 (p. 440). Generally, the Vine-Matthews hypothesis was accepted rapidly by marine geologists and geophysicists (p. 431).

Chapter 3 to 6 continue in this vein documenting every thrust and parry between the heavy lifters and bickering amongst lesser mortals, until we arrive at Chapter 7, 'The Birth of Plate Tectonics' (pp. 437–616). For the remainder of my space I will attempt to succinctly summarise how the hypotheses of continental drift and seafloor spreading were fused into The Plate Tectonic Theory. In the 1960s, one by one, all the major Earth science schools became mobilists.

The serendipitous discovery of subducting slabs by Jack Oliver and Bryan Isacks at Lamont (pp. 438–456), and their conversion to mobilism, is well worth reading. Oliver was a fixist and sent his PhD student, Isacks, to Fiji in 1964 with some seismometers to see what deep earthquakes were all about; no hypothesis testing, just pure curiosity. There are amusing asides like the British colonials in Fiji attempting to thwart the 'Yank' from receiving any 'freebie' logistical support. This was circumvented by a 'Kiwi' in the met office who apparently had reason ('Pommy b…d') and so Isacks got the assistance he needed and collected some excellent data. After analysing the data, it was clear that a high Q rigid oceanic crust-like layer (at least like what was known about the North Atlantic then) was diving westward into the mantle between Tonga and Fiji. Seismic waves from deep earthquakes beneath Fiji arrived at Tonga with low loss of amplitude. Lamont seismologists were sold on subduction and seafloor spreading.

The next triumph was Dan McKenzie's (Cambridge/Scripps) who by 1967 had solved his perceived problems with mid-ocean ridges (p. 456–469). One problem was the heat flow was too low for the ridges to be sites of upwardly convecting limbs, as per Hess's seafloor spreading model. The second problem was Antarctica and Africa are essentially surrounded by ridges and McKenzie reasoned that seafloor spreading and stable convection in such a scheme were inconsistent. Thus McKenzie challenged Hess's model and proposed passive fracturing at mid-ocean ridges without any mantle root, a lower geothermal gradient and consequently normal thickness crust at ridges. I do not think this is current thinking but there are a lot more data now. Again there are amusing asides whereby McKenzie, who liked the company of geologists who were the reason for him becoming an earth scientist, states geophysicists are 'like geologists, but more intelligent' (p. 458). Perhaps I meant bemusing.

Once the scales fell from Lamont's eyes they worked furiously to catch up (pp. 469–474). Lamont completely redeemed itself in 1967 with four astonishing paper in *JGR* on seafloor spreading in the major oceans. Everyone should read this remarkable set of papers. Jim Heirtzler divided his team into four groups who digitised all the data they had (way ahead of Scripps and Woods Hole), which meant each team could access all date easily and quickly. One of the enduring outcomes of this was the extension of the polarity reversal time scale back to nearly 80 Ma based on the steady spreading in the South Atlantic.

Jason Morgan (Princeton with Hess) made the next splash, and it was the big one – Plate Tectonics (p. 474–494). In early 1967 Morgan worked on cartographically mapping fracture zones, starting in the eastern Pacific. His naval navigation skills on spherical surfaces had alerted him to the fact that Menard's 'almost great circle' fracture zones were actually small circles (the central fracture is very close to a great circle but those either side depart in the opposite sense from each other). By determining the intersection of great circles (perpendicular) to the small circles fractures Morgan defined Euler poles for each oceanic plate. In April 1967 Morgan presented plate tectonic replete with Euler poles and the three classes of boundaries between plates, trenches, transforms and triple-junctions at the Spring AGU meeting, and later submitted a paper to *JGR*. Next Dan McKenzie, who was unaware of Morgan's work, and Bob Parker both now at Scripps, independently discovered their version of plate tectonics (p. 499) using slip vectors along transforms and Euler poles determined by the intersection of great circles perpendicular to these vectors. McKenzie and Parker's paper was submitted to *Nature* in November 1967 just before Morgan was notified his paper was accepted by *JGR* for publication March 1968, pending minor revisions. McKenzie finally finds out about Morgan's paper via Menard and Morgan's much earlier AGU presentation. McKenzie did not know about Morgan's AGU talk because Morgan substituted his plate tectonic talk, understandably, instead of the one described in his abstract and McKenzie had left AGU beforehand. In an act of gallantry McKenzie and Parker make an effort to delay their publication in *Nature*. In late December *Nature* replies to McKenzie 'We must regret… already appeared…December 30th… one of the penalties of dealing with a really rapid journal'! Later McKenzie and Morgan meet and while some might think Morgan would have a right to be annoyed, they decide to write a joint paper on the evolution of triple-junctions (p. 505). The last 100 pages or so is filled with detailing the differences between McKenzie's and Morgan's versions of Plate Tectonic, Isacks discovery of the cause of deep earthquakes, Le Pichon closing the loop showing relative motions of plates to be consistent with their Euler rotations around the globe, the integration of seismology with plate tectonics and details of the evolution of triple junctions among other things.

Common throughout this series is the conflict and disagreement over many aspects of Continental Drift, Seafloor Spreading and the Plate Tectonic model. The reconciliation between Dietz and Hess, and later between McKenzie and Morgan stand out as beacons of integrity. We see that once unshackled from the conventions of the day, and free of the stigma of heresy, the combined intelligence of a community quickly sorts the gems from the dross. It is one of the triumphs of humanity, afflicted with the human condition that it is, that it has nevertheless developed the enterprise called the scientific method to guide us as a community like a pathfinder to overcome the entanglement of the many falsehoods and misleading notions held by individuals, to arrive at a closer and closer approach to the truth, satisfying an increasing number of observations as it does, until predictions can be made at which point hypotheses graduate to theories.

As for Vols I and II there is a profusion of quotes, citations and notes at the end of each chapter packed with extras for specialists and non-specialists alike. The occurrence of only a few blemishes throughout demonstrates, in general, excellent proofreading. The exceptions include: in the *Introduction* to Vol. I (p. xxi) fracture zones 'were found to be not small, but great circles' should be 'were found to be small, not great circles'; did Opdyke go to Lamont early (Vol. II, p. 92) or late 1963 (Vol. IV, p. 441)?; the indexing in Vol. III is sometimes inaccurate, e.g., Vine-Matthews is actually p. 428 not 431; Vol. IV, p. 465 should read anomalously 'low heat flow', rather than 'high heat flow'. There is also a quote of Munk's and MacDonald's that appears twice within a few pages in Vol. II, on pp. 394 and 398, but overall these volumes are high quality.

These volumes should be read by all geoscientists serious about understanding how we have come to learn the inner workings of our planet. Maybe many cannot afford to furnish their own libraries with them but institutional and university libraries should all acquire copies. Hopefully in time they will be available online or as CDs at reasonable prices for all.

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Recording noise

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I recently unearthed a report prepared for Delhi Petroleum in 1982 that documented a seismic experiment designed to obtain information about source generated linear noise. In 1982 we spent considerable effort testing various acquisition parameters so we could minimise noise before it was recorded. The purpose of these 'noise tests', commonly recorded when a crew moved into a new area, was to determine noise characteristics such as frequency and wavelength so that acquisition parameters could be selected. Parameters were selected that maximised the signal while minimising the strength of the unwanted linear noise. In contrast, my most recent experience with onshore acquisition involved recording everything – noise and data – with enough sampling to allow the noise to be removed in the processing sequence.

Figure 1 shows a typical noise analysis display. In this case 24 channels were laid out in a closely spaced receiver spread (3.125 m spacing) and a number of source positions were used in a walk away fashion to simulate a single 312 channel spread. The close spacing of each receiver allowed the noise to be recorded without spatial aliasing so that the wavelength and frequency could be determined and acquisition parameters designed that would attenuate the coherent noise. The main attack on noise was the receiver group array, which summed the output of each element (geophone) of the array so that horizontally propagating noise was attenuated while the vertical propagating reflections were not affected. Other parameters that could be altered to minimise noise were the low cut filter and the near and far trace offset.

Figure 2 is a shot record from a 1982 survey in the Eromanga Basin. The coherent noise is apparent but aliased, as a result processing options to remove it were limited. Often it was simply excised along with any useful data by applying an inner and outer trace mute. In contrast however, the 2006 record (Figure 3) has finely sampled the noise to avoid spatial aliasing and the processing algorithms can successfully reduce it (Shiju *et al*. 2008). Table 1 compares some of the acquisition parameters used in 1982 with those of the 2006 survey.

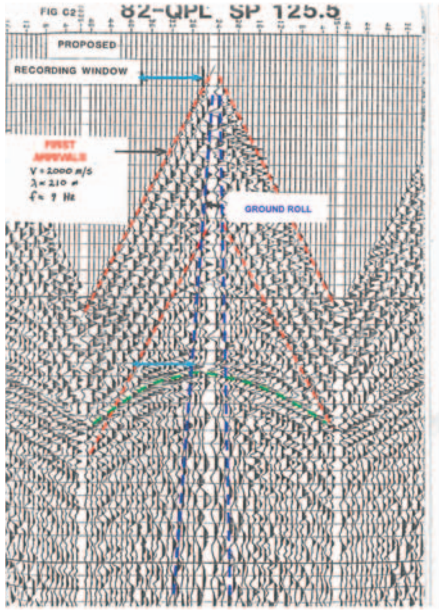

Fig. 2. *Shot record: 1982. Annotations (light blue) indicate the survey parameters were selected to avoid recording the high amplitude noise. Reflections at the target are shown in green.*

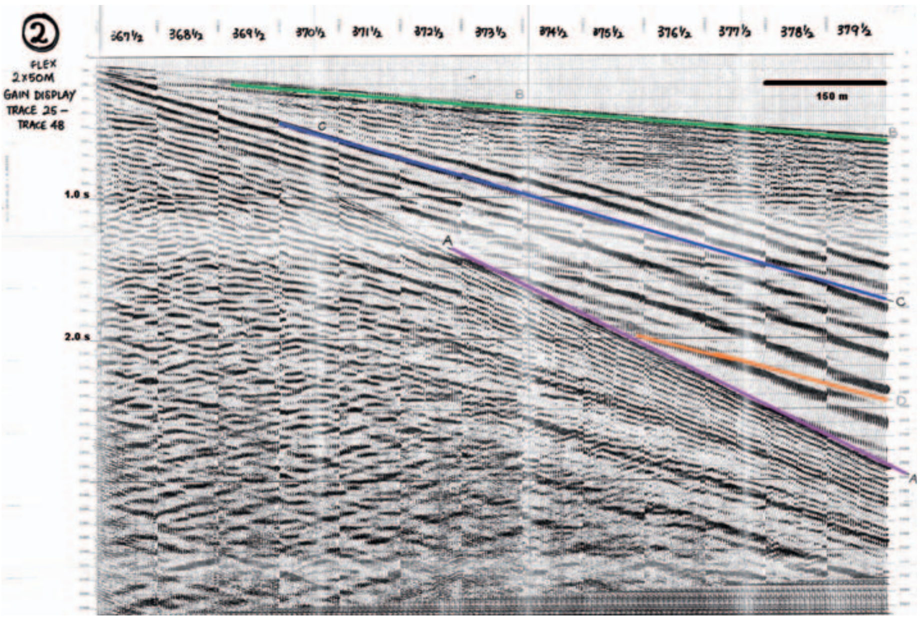

Fig. 1. *Noise test: one of the composite records from the 1982 Breakfast Creek–NAC seismic survey. On this panel four separate noise trains have been identified: (A) airblast; (B) first arrivals/refractions; (C,D) labelled ground roll in the past.*

When did this change to recording noise rather than signal occur and what has changed to drive this move?

I suspect the change occurred when enough channels were available to adequately sample and record the noise trains so that they could be filtered. My guess is that in Australia this occurred in the late 1990s.

Channel count. The major difference is channel count. In 1982 a good seismic crew had 48 channels (24 either side of the source point) so a wide group interval was used to obtain sufficiently long far offsets. In 2006 the onshore crew I used had thousands of channels, which enabled the receiver interval to be reduced and still retain the long maximum offset (Note: the 2006 survey was initially designed with an 8 m group interval but this was revised to 10 m for operational reasons). The channel count has increased almost 100 times and allowed a closer receiver group interval. This close receiver spacing in turn leads to the use of single elements or bunched groups rather than long arrays with the benefit that distortion of the wavelet is minimised. Figure 4 is a graph that shows the channel count

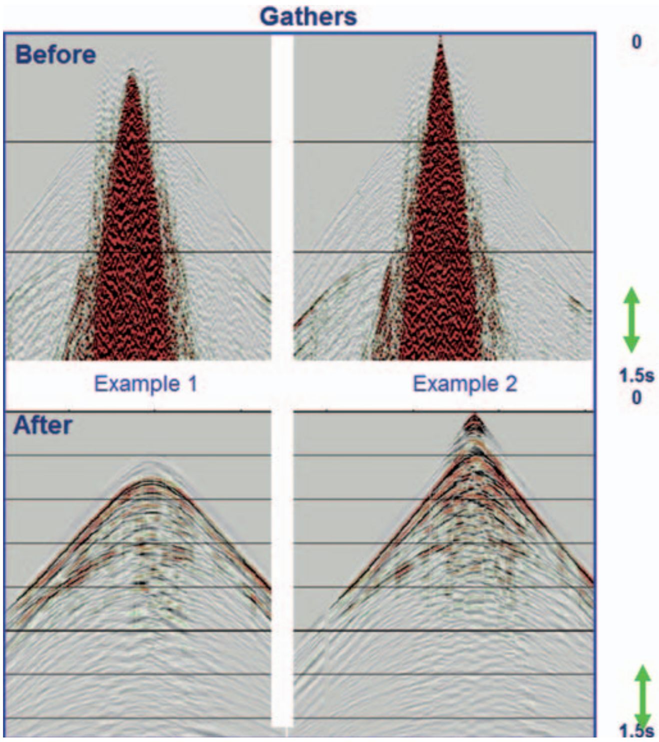

Fig. 3. *Noise attenuation using modern processing on the 2006 survey (from Shiju* et al. *2008).*

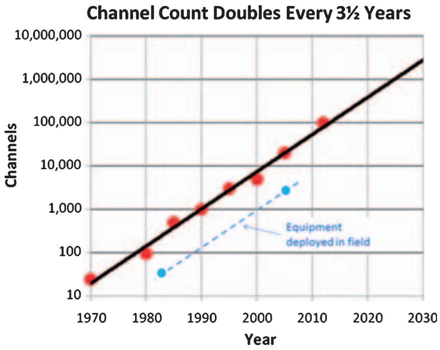

Fig. 4. *Channel count doubles every 3.5 years. Field equipment lags the curve as illustrated by the two blue points.*

Table 1. Acquisition parameters comparison (major differences shown in italics)

	1982 (2D)	2006 (3D)
Recording		
No. of data channels	*48*	*4320*
Sample rate	2 ms	2 ms
Record length	4 s	4 s
Acquisition filter	8–125 Hz	OUT-OUT (+ antialias filter)
Source	Single hole – 2.5kg Anzite@12.5m	1 vibrator 8–110 Hz 1 x 8 s sweep
Source spacing	*150 m*	*10 m*
Source line spacing	–	180 m
Receiver		
Group interval	*75 m*	*10 m*
Receiver line spacing	–	150 m, 10 line swath
Geophones/group	12	12
Group array	*Linear 12 @ 6 m spacing*	*12 in 2 m circle*
Near trace offset	*188 m*	*~5 m*
Far trace offset	1988	–
Nominal fold	12	60

increasing with time in a seismic version of Moore's Law. (The new generation Schlumberger recording system has a channel count of 150 000.) Practically the number of channels has now increased to a level where management of all the cabling is becoming an imposition and wireless technology is providing a viable alternative.

Dynamic Range has also improved. The 1980s instruments incorporated a 14 bit analogue to digital converter, which was adequate but there were substantial benefits in using receiver arrays to attenuate the high amplitude noise such as ground roll. Recording instruments now use 24 bit sampling, which enables the full waveform to be recorded without losing the subtle amplitude variations of weak reflections.

Processing algorithms have developed and can now remove noise (Figure 3) if it is adequately sampled. This requires closely spaced, effectively point receivers to ensure noise trains are not aliased or distorted. The noise-reducing algorithms are applied pre-stack so improvements in computing performance have also been a benefit. When properly sampled it is apparent that rather than being purely noise the unwanted energy is contained in a number of noise cones or diffractions, which propagate from scattering points in the near surface and can be effectively predicted and removed.

Compare the 2006 shot records (Figure 3) with those from the 1982 survey (Figure 2). The processing filters applied to the modern records have removed most of the noise and reflections are apparent across the gather. In contrast, the old record has significant noise that was best removed by muting or selecting an offset range between the noise trains, i.e. the noise affected areas were avoided but the offset range was limited.

Is there a practical limit to the number of channels?

Maybe the seismic acquisition contractors can answer this, but if there is a limit then this limit is also increasing. With wireless technology replacing cables and new designs reducing weight and power consumption per channel a million channels is a distinct possibility.

Reference

Shiju, J., Bowyer, G., and Micenko, M. 2008. *Mangala Field High Density 3D*. Proceedings SPG 7th International Conference and Exposition, Hyderabad 2008

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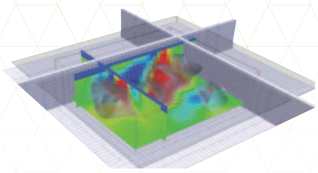

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21–26 Jul	IEEE GRSS International Geoscience and Remote Sensing Symposium (IGARSS) http://www.igarss2013.org	Melbourne	Australia
August			**2013**
9 Aug 11 Aug 16 Aug	SEG Distinguished Instructor Short Course 2013 David H. Johnston, ExxonMobil: Making a difference with 4D: practical applications of time-lapse seismic data http://www.seg.org/disc	Perth Melbourne Brisbane	Australia Australia Australia
11–14 Aug	ASEG-PESA 2013: 23rd International Geophysical Conference and Exhibition http://www.aseg-pesa2013.com.au/	Melbourne	Australia
September			**2013**
8–11 Sep	Near Surface Geoscience 2013 http://www.eage.org	Bochum	Germany
30 Sep–4 Oct	Sustainable Earth Sciences 2013: Technologies for Sustainable Use of the Deep Sub-surface http://www.eage.org/events/index.php?eventid=960&Opendivs=s3	Pau	France
October			**2013**
6–11 Oct	SAGA 13th Biennial Conference and 6th international AEM 2013 http://www.saga-aem2013.co.za/	Mpumalanga	South Africa
7–10 Oct	7th Congress of the Balkan Geophysical Society http://www.eage.org	Tirana	Albania
November			**2013**
18–20 Nov	The 11th SEGJ International Symposium: Geophysics for establishing a sustainable secure society http://www.segj.org/is/11th/	Yokohama	Japan
24–27 Nov	Second International Conference on Engineering Geophysics http://www.eage.org	Al Ain	UAE
January			**2014**
20–22 Jan	The 7th International Petroleum Technology Conference (IPTC) http://www.iptcnet.org/2014/doha/	Doha	Qatar
February			**2014**
25–27 Feb	SPE/EAGE European Unconventional Resources Conference and Exhibition http://www.eage.org/index.php?evp=1979	Vienna	Austria
March			**2014**
9–12 Mar	GEO 2014: 11th Middle East Geosciences Conference and Exhibition http://www.geo2014.com/	Manama	Kingdom of Bahrain
April			**2014**
7–10 Apr	The 6th Saint Petersburg International Conference & Exhibition http://www.eage.org/index.php?evp=1979	Saint Petersburg	Russia
June			**2014**
16–19 Jun	76th EAGE Conference and Exhibition incorporating SPE EUROPEC 2014 http://www.eage.org	Amsterdam	The Netherlands

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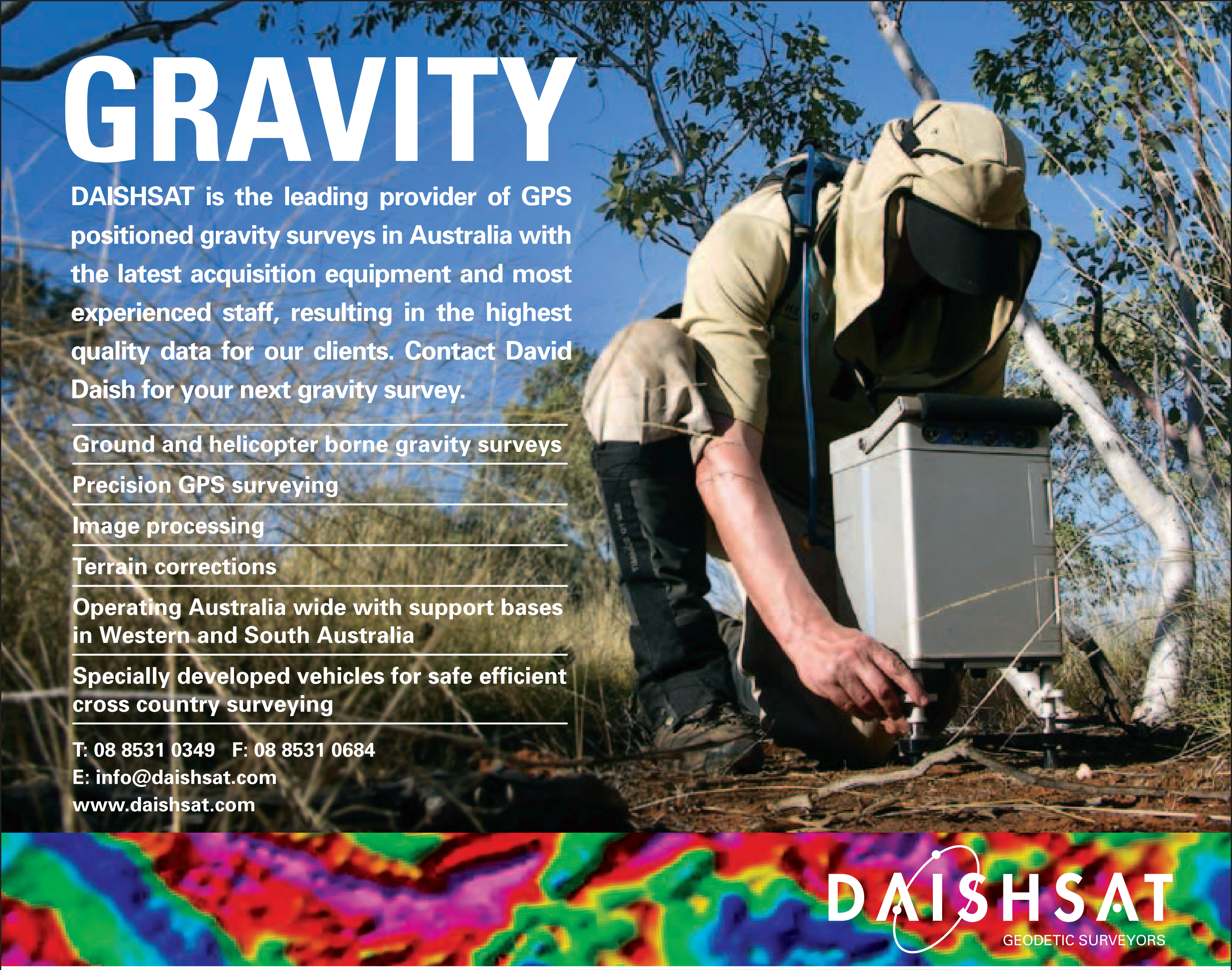
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